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A Comparison of Marine Productivity Among Outer Continental Shelf Planning Areas

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A COMPARISON OF MARINE PRODUCTIVITY AMONG OUTER CONTINENTAL SHELF PLANNING AREAS

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LIST OF ABBREVIATIONS

a - relative quantum efficiency or photosynthetic efficiency
at - atmosphere(s)
ATP - adenosine triphosphate

B - biomass

C - elemental carbon
chl a - chlorophyll a
chl-a - chlorophyll a
Chl a - chlorophyll a
cm - centimeter(s)
CO_2 - carbon dioxide

d - day(s)
d^{-1} - per day

Fe - elemental iron
ft - foot or feet

g - gram(s)
GDH - glutamate dehydrogenase
Gt - gross ton(s)

h or hr - hour(s)
h^{-1} or hr^{-1} - per hour
H - elemental hydrogen
ha - hectare(s)

I_b - light intensity beyond which photoinhibition occurs
I_k - saturated irradiance
I_o - surface irradiance

k - extinction coefficient
kcal - kilocalorie(s)
km - kilometer(s)
km^2 - square kilometer(s)
km^{-2} - per square kilometer

l - liter(s)
ly - langley(s)

m - meter(s)
m^2 - square meter(s)
m^{-2} - per square meter
m^3 - cubic meter(s)
mg - milligram(s)
mi - mile(s)
min - minute(s)
ml - milliliter(s)
mmol - millimole(s)
Mn - elemental manganese
mo - month(s)
mol - mole(s)

n - number
N - elemental nitrogen
nmi - nautical mile(s)
nmol - nanomole(s)
NO_3 - nitrate

O - elemental oxygen
O_2 - oxygen

P - production or elemental phosphorous
P_a - integrated photosynthetic rate
P_{max} - photosynthetic rate or photosynthetic capacity
POC - particulate organic carbon
PON - particulate organic nitrogen
POS - particulate organic sulfur
PC - particulate carbon
PN - particulate nitrogen
PP - primary production
ppt - part(s) per thousand

s - second(s)
S - elemental sulfur
Sv - svedburg
S.D. - standard deviation

Th - elemental thorium

U - elemental uranium

W - watt(s)

yr - year(s)
yr^{-1} - per year

z - water depth
Z_p - photic depth

μE - microeinstein(s)
μg - microgram(s)
μm - micrometer(s)
μmol or μM - micromole(s)

LIST OF ABBREVIATIONS (Continued)

°C - degrees Centigrade
°E - degrees East (longitude)
°N - degrees North (latitude)
°S - degrees South (latitude)
°W - degrees West (longitude)
′N - minutes North (latitude)
′W - minutes West (longitude)

ACRONYMS:

ACW - Alaska Coastal Water
AVHRR - advanced very high resolution radiometer
BCF - Bureau of Commercial Fisheries
BLM - Bureau of Land Management
BOPS - Bio-Optical Profiling System
BSAW - Bering Shelf-Anadyr Water
CalCOFI - California Cooperative Fisheries Investigations
CCORS - California Comprehensive Offshore Resource Study
CCS - California Current System
CDFG - California Department of Fish and Game
CDS - Coastal and Geodetic Survey
CODE - Coastal Ocean Dynamics Experiment
COPO - Coastal Physical Oceanography
CTD - conductivity-temperature-depth
CTZ - Coastal Transition Zone
CZCS - Coastal Zone Color Scanner
EIS - environmental impact statement
GLOBEC - Global Ecosystem Dynamics
GOFS - Global Ocean Flux Study
HPLC - high-performance liquid chromatography
INPFC - International North Pacific Fisheries Commission
ISHTAR - Inner Shelf Transfer and Recycling
MARMAP - Marine Resource Monitoring, Assessment and Prediction
MMS - Minerals Management Service
NASA - National Aeronautics and Space Administration
NCCCS - Northern California Coastal Circulation Study
NOAA - National Oceanic and Atmospheric Administration
NOS - National Ocean Service or National Ocean Survey
NPDES - National Pollution Discharge Elimination System
NSF - National Science Foundation
NWI - National Wetlands Inventory
OCS - outer continental shelf
OCSEAP - Outer Continental Shelf Environmental Assessment Program
OPTOMA - Ocean Prediction Through Observations, Modeling and Analysis
PROBES - Processes and Resources of the Bering Sea Shelf
PRPOOS - Plankton Rate Processes in Oligotrophic Oceans Study
RU - Research Unit (OCSEAP)

LIST OF ABBREVIATIONS (Continued)

ACRONYMS (Continued):

SCBS - Southern California Bight Study
SEEP - Shelf Edge Exchange Processes
SST - sea surface temperature
STD - salinity-temperature-depth
STOCS - South Texas Outer Continental Shelf
UNESCO - United Nations Educational, Scientific, and Cultural Organization
USDOC - U.S. Department of Commerce
USDOI - U.S. Department of the Interior
USFWS - U.S. Fish and Wildlife Service
USGS - U.S. Geological Survey
UMES - University of Maryland Eastern Shore
VERTEX - Vertical Transport and Exchange

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1.0 INTRODUCTION

1.1 HISTORICAL PERSPECTIVE

The U.S. Department of the Interior (USDOI), Minerals Management Service (MMS) has jurisdiction over leasing and development of outer continental shelf (OCS) submerged Federal lands for minerals development. Submerged OCS Federal lands are organized into 26 separate Planning Areas, as reflected in Figures 1 and 2. In Section 18(a)(2) of the OCS Lands Act Amendments, eight factors are detailed for consideration in the timing and location of exploration, development, and production of oil and gas resources on the OCS. By law, these factors must be considered in the preparation and development of various decision documents (e.g., the Secretarial Issue Document [SID]) pertaining to the 5-Year Oil and Gas OCS Leasing Program. These factors include "the relative environmental sensitivity and marine productivity of different areas of the OCS." In addition, Section 18(a)(3) of the OCS Lands Act Amendments provides that: "The Secretary shall select the timing and location of leasing, to the maximum extent practicable, so as to obtain a proper balance between the potential for environmental damage, the potential for discovery of oil and gas, and potential for adverse impact on the coastal zone."

Prior to the development of the SID for the Mid-1987 to Mid-1992 5-Year Leasing Program, analytical approaches to marine productivity and environmental sensitivity were discussed with the OCS Advisory Board Policy Committee and Scientific Committee. All parties agreed that the analyses were complex and difficult. In the SID for the Mid-1987 to Mid-1992 5-Year Leasing Program, the estimates of Smith and Kalber (1974) were compared with the estimates of primary production shown in Table 1. This comparison produced the rankings by planning area as shown in Table 2.

The analysis of environmental sensitivity for the Mid-1987 to Mid-1992 5-Year Leasing Program concentrated on the effects of spilled oil, as well as: 1) operational discharges from OCS activities; 2) noise generated by OCS activities; 3) habitat alteration from the installation of OCS facilities; and 4) air emissions from OCS operations. The analysis for the Mid-1987 to Mid-1992 5-Year Leasing Program considered the effects of these activities on coastal habitats, marine habitats, and biota. Table 3 from the Proposed Final Environmental Impact Statement (EIS) for the Mid-1987 to Mid-1992 5-Year Leasing Program is an example of the calculations performed for each of the components.

In 1983, the MMS contracted with the University of Maryland Eastern Shore (UMES) for a study entitled "Federal OCS Oil and Gas Activities: A Relative Comparison of the Marine Productivity Among the OCS Planning Areas." The study was designed to support the MMS analyses of relative marine productivity and environmental sensitivity. Significant problems associated with the interpretation of marine primary productivity data were encountered in the study. Although UMES researchers identified a significant amount of productivity data which might be applicable to various OCS Planning Areas, questions pertaining

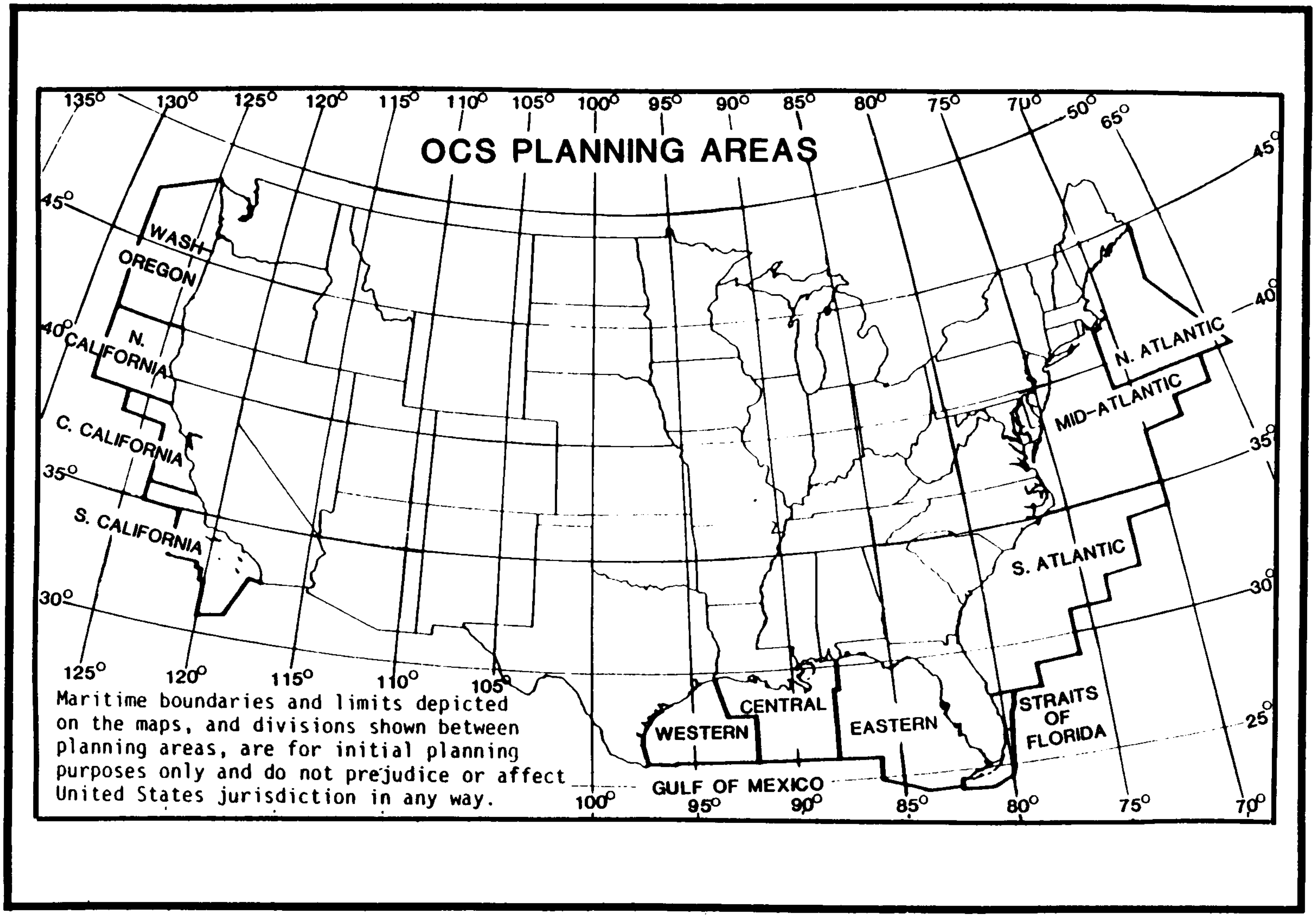
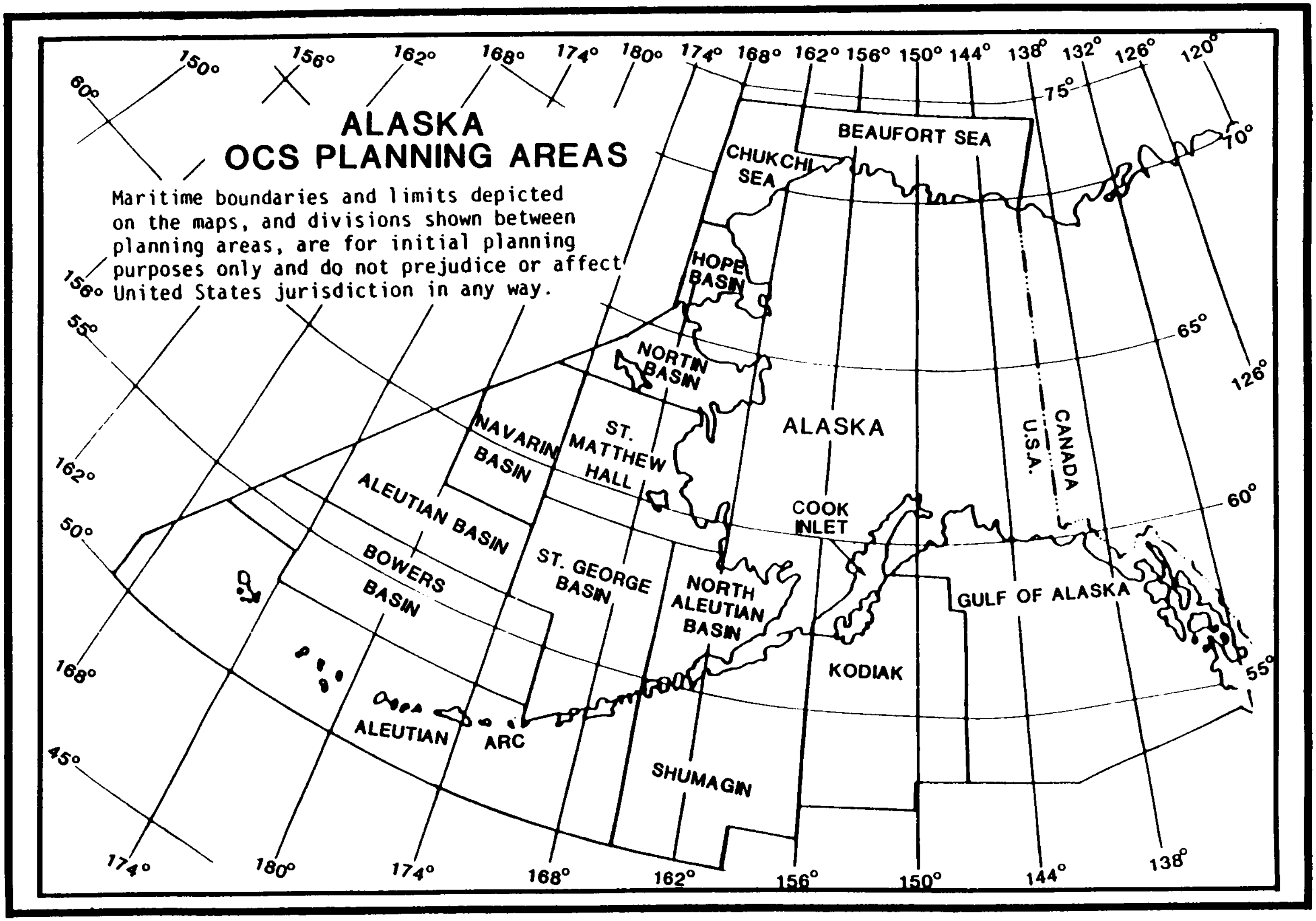


Figure 1. Outer Continental Shelf Planning Areas for the contiguous U.S. (From: USDOI, MMS, 1987a).


ALASKA
OCS PLANNING AREAS

Maritime boundaries and limits depicted on the maps, and divisions shown between planning areas, are for initial planning purposes only and do not prejudice or affect United States jurisdiction in any way.

Figure 2. Outer Continental Shelf Planning Areas for Alaska (From: USDOI, MMS, 1987a).

Table 1. Marine phytoplankton productivity by OCS Planning Area expressed as grams of carbon fixed per square meter per year (From: USDOI, MMS, 1987a).

Planning Area	Range of Values Used in the 1982 Analysis (g C•m^{-2}•yr^{-1})*	More Recent Observations	
		(g C•m^{-2}•yr^{-1})	Reference
North Atlantic	200 - 400	230 - 470	O'Reilly and Busch, 1984
Mid-Atlantic	200 - 400	260 - 370	O'Reilly and Busch, 1984
South Atlantic	50 - 200	130 - 360	Haines and Dunstan, 1975 Yoder *et al.*, 1983
Straits of Florida	50 - 100		
Eastern Gulf of Mexico	50 - 100	10 - 110	University of Maryland Eastern Shore, 1985
Central Gulf of Mexico	50 - 100	10 - 220	El-Sayed and Turner, 1977
Western Gulf of Mexico	50 - 100	15 - 70	El-Sayed and Turner, 1977
Southern California	200 - 400	180 - 360	Eppley *et al.*, 1979
Central California	200 - 400	10 - 470	Riznyk, 1977
Northern California	200 - 400	10 - 470	Riznyk, 1977
Washington/Oregon	200 - 400	35 - 350	Small *et al.*, 1972
Gulf of Alaska	200 - 400		
Cook Inlet	200 - 400		Griffiths *et al.*, 1982
Kodiak	200 - 400		
Shumagin	200 - 400		
North Aleutian Basin	400 - 7,300	120 - 400	Goering and McRoy, 1981
St. George Basin	400 - 7,300		
Navarin Basin	50 - 200		
Norton Basin	50 - 100		
Hope Basin	<50		
Chukchi Sea	<50	18 - 28	Carey, 1978
Beaufort Sea	<50	10 - 20	Schell and Horner, 1981

*Data from Smith and Kalber, 1974.

Table 2. Relative phytoplankton productivity of the OCS Planning Areas expressed as grams of carbon fixed per square meter per year (From: USDOI, MMS, 1987a).

High Productivity (200 to 500 g $C \cdot m^{-2} \cdot yr^{-1}$)

- North Atlantic
- Mid-Atlantic
- North Aleutian Basin
- St. George Basin
- Southern California
- Central California
- Northern California
- Washington/Oregon
- Gulf of Alaska
- Cook Inlet
- Kodiak
- Shumagin

Moderate Productivity (50 to 200 g $C \cdot m^{-2} \cdot yr^{-1}$)

- South Atlantic
- Straits of Florida
- Eastern Gulf of Mexico
- Central Gulf of Mexico
- Western Gulf of Mexico
- Navarin Basin
- Norton Basin

Low Productivity (<50 g $C \cdot m^{-2} \cdot yr^{-1}$)

- Hope Basin
- Chukchi Sea
- Beaufort Sea

Table 3. Relative marine productivity/environmental sensitivity analysis for a hypothetical planning area (From: USDOI, MMS, 1987a).

	Distribution of Resource	Relative Abundance of Biota	Sensitivity Coefficient (Spilled Oil and Recovery)		
			Adjective	Numerical Value*	Score†
Coastal Habitats	Miles				
Estuaries/Wetlands	200	33	High	225	74.25
Sandy Beaches	300	50	Low	45	22.50
Rocky Beaches	100	17	Moderate	135	22.95
TOTAL	600				119.70
Marine Habitats	Acres				
Submerged Vegetation	1,200,000	5.3	Moderate	135	7.16
Submarine Canyons	None	0.0	Low	45	0.00
Coral Reefs	5,000	0.02	High	225	0.05
Hard Bottoms	600,000	2.6	Low	45	1.17
Shelf Break Zone	850,000	3.7	Low	45	1.67
Mud/Sand Bottom	20,000,000	88.2	Low	45	39.69
TOTAL	22,655,000				49.74
Biota					
Phytoplankton	High	5	Low	1	5
Juvenile Fish/Shellfish	High	5	High	5	25
Adult Fish/Shellfish	Moderate	3	Moderate	3	15
Mud/Sand Benthos	Low	1	Low	1	1
Coastal Birds	Moderate	3	High	5	15
Marine Birds	High	5	High	5	25
Marine Turtles	None	0	Low	1	0
Marine Mammals	High	5	High	5	25
Whales	Moderate	3	High	5	15
TOTAL					126

*Numerical values assigned for coastal and marine habitats (high - 225, moderate - 135, and low - 45) and biota (high - 5, moderate - 3, and low - 1).

†Product of relative abundance of biota and numerical value (divided by 100 for coastal and marine

to methodology (e.g., incubation period, *in situ* or artificial light), regional or subregional variability (e.g., bloom vs. non-bloom productivity), and area-specific forcing mechanisms, limited the development of daily or annual production values which were consistently and directly comparable. In September 1989, the MMS contracted with Continental Shelf Associates, Inc. (CSA) to update the available primary productivity data base and to review and tabularize recent coastal and marine habitat information.

1.2 STUDY OBJECTIVES

The primary goal of this study effort has been to provide the MMS with the most current and complete data set for marine water column primary productivity for use in establishing the relative rankings of the 26 OCS Planning Areas. Specific objectives of the project were to:

1) provide estimates of the relative primary productivity of each of the OCS Planning Areas and to furnish information on potential biases in the analysis, such as ice-edge algal blooms and highly seasonal productivity which may not be accounted for in annualized values;

2) update the UMES report to the present state of knowledge on water column primary productivity and include any pertinent information that may be missing; and

3) provide estimates of numerical data, including linear measures of coastline and areal extent of offshore habitats.

One additional study objective (i.e., evaluating the potential for using measures of marine secondary productivity in determining relative rankings of the OCS Planning Areas) is to be completed and summarized within a separate final report.

1.3 REPORT FORMAT

Section 2.0 outlines the methodologies employed to identify, review, and summarize primary productivity information, followed by individual discussions of water column primary productivity for each of the 26 OCS Planning Areas. Section 3.0 presents summary discussions and tabular data pertinent to coastline measurements and the areal extent of marine habitats found within or adjacent to each of the 26 OCS Planning Areas. The initial discussion of Section 3.0 outlines the various techniques utilized to determine both linear and areal estimates presented, as well as identifying primary and secondary sources of information. Section 4.0 provides general comparisons between OCS Planning Areas, summarizes the problems and limitations with available data, and identifies the data gaps evident for both primary productivity and coastal and marine habitats. Section 5.0 contains the references cited within the first four sections of the report.

Appendices A and B contain comprehensive annotated bibliographies for primary productivity and coastal and marine habitats, respectively. A separate Map Series (Appendix C) has also been prepared as accompanying documentation to the Planning Area-specific discussions found in Section 2.2.

2.0 PRIMARY PRODUCTIVITY DATA

2.1 METHODS

The following sections outline the methods employed to identify, review, summarize, and annotate the available primary productivity information for Federal waters of the OCS. To assist in completion of the primary productivity component of this project, CSA assembled a team of recognized productivity experts who authored one or more of the following sections:

- Theodore J. Smayda, Ph.D., University of Rhode Island, Narragansett, RI
    - Section 2.2.1, North Atlantic Planning Area
    - Section 2.2.2, Mid-Atlantic Planning Area
    - Section 2.2.3, South Atlantic Planning Area
- Gabriel A. Vargo, Ph.D., University of South Florida, St. Petersburg, FL
    - Section 2.2.4, Straits of Florida Planning Area
    - Section 2.2.5, Eastern Gulf of Mexico Planning Area
    - Section 2.2.6, Central Gulf of Mexico Planning Area
    - Section 2.2.7, Western Gulf of Mexico Planning Area
- Thomas L. Hayward, Ph.D., Scripps Institution of Oceanography, San Diego, CA
    - Section 2.2.8, Southern California Planning Area
    - Section 2.2.9, Central California Planning Area
    - Section 2.2.10, Northern California Planning Area
- Thomas H. Sibley, Ph.D., University of Washington, Seattle, WA
    - Section 2.2.11, Washington-Oregon Planning Area
- C. Peter McRoy, Ph.D., and Donald M. Schell, Ph.D., University of Alaska, Fairbanks, Fairbanks, AK
    - Section 2.2.12, Gulf of Alaska Planning Area
    - Section 2.2.13, Cook Inlet, Kodiak, and Shumagin Planning Areas
    - Section 2.2.14, Aleutian Arc Planning Area
    - Section 2.2.15, North Aleutian Basin Planning Area
    - Section 2.2.16, St. George Basin Planning Area
    - Section 2.2.17, St. Matthew Hall Planning Area
    - Section 2.2.18, Bowers Basin and Aleutian Basin Planning Areas
    - Section 2.2.19, Navarin Basin Planning Area
    - Section 2.2.20, Norton Basin Planning Area
    - Section 2.2.21, Hope Basin Planning Area
    - Section 2.2.22, Chukchi Sea Planning Area
    - Section 2.2.23, Beaufort Sea Planning Area

These experts, with an intense familiarity of regional and world trends in primary production, provided a thorough and expert evaluation and summary of the current primary productivity data bases for OCS waters.

2.1.1 Data Identification, Collection, Evaluation, and Review

A multi-step data identification and collection plan was implemented, the goal of which was to recognize and supply published and unpublished literature and data sources pertinent to primary production. For the present analysis, it was recognized that an extensive, but dated, data base already existed (i.e., the UMES (1985) report, coupled with the UMES annotated bibliography containing 1,114 entries relevant to primary productivity, coastal and marine habitats, commercial finfish and shellfish species, ichthyoplankton, and benthos). The existing UMES data base was supplemented with current (i.e., post-1985) citations of direct relevance. The present analysis was also intended to supplement those sources of information that may have been overlooked or were unavailable within the data bases searched previously by UMES (1985).

Data Base Search

Following an initial meeting between CSA staff and the primary productivity authors, CSA conducted a computerized search of online data bases using the Lockheed DIALOG Information Retrieval Service. Access was gained under the direction of Ms. Kristen Metzger, Head Librarian, Harbor Branch Oceanographic Institution, Fort Pierce, FL. A listing of the various data bases contacted included the following:

- Aquatic Science and Fisheries Abstracts*
- Biosis Previews (Biological Abstracts)*
- CA Search (Chemical Abstracts)*
- Conference Papers Index
- Dissertation Abstracts*
- DOE Energy
- GEOREF*
- Life Sciences Collection*
- Meteorological/Geoastrophysical Abstracts
- NTIS (National Technical Information Service)*
- Oceanic Abstracts*
- Pollution Abstracts*
- SCISEARCH (Science Citation Index)*
- Zoological Record*

The search criteria employed in evaluating the 14 online data bases included the following key words:

- Primary
- Producti?
- Primary()Producti?

- Atlantic
- Pacific
- Ocean
- (Atlantic or Pacific)()Ocean
- Gulf
- Mexico
- Gulf(1N)Mexico
- Alaska(F)Marine
- (Atlantic or Pacific)()Ocean or Gulf(1N)Mexico or Alaska(F)Marine
- Alaska
- Ocean
- Alaska(F)Ocean
- (Atlantic or Pacific)()Ocean or Gulf(1N)Mexico or Alaska(F)Marine or Alaska(F)Ocean
- (Atlantic or Pacific)()Ocean or Gulf(1N)Mexico or Alaska(F)Marine or Alaska(F)Ocean and Primary()Producti?

In addition, when the option was available to enter the year of publication as a key word, the time period of interest included individual years from 1985 to 1989. Of the 14 online data bases searched cited above, a total of 11 data bases (noted by an asterisk) identified citations of potential interest.

It was recognized that the search parameters of the literature search were conservative. A total of 274 total citations, including several duplicate entries, were identified. Such a conservative approach also resulted in the identification of numerous citations which had no direct applicability to primary productivity measurements.

Results of the computer searches were obtained both as hard copy printout and as ASCII text files on floppy disk. Unedited citation entries were printed as part of a master listing on standard 8½ x 11" paper. This master listing was subsequently reviewed and coded for regional applicability. Individual copies of the bibliographic listing were then issued to authors for their review and evaluation.

At this point in the data identification process, the authors reviewed the listing and made a determination as to how complete the literature search had been. Based on the working expertise of each author, additional miscellaneous, yet significant, sources of data were subsequently identified, reviewed, annotated, and summarized.

Data Review and Evaluation

Individual authors reviewed all potentially pertinent data sources previously identified through computer literature search, miscellaneous data sources, and those cited within UMES (1985). Each data set was evaluated on the basis of a series of criteria (e.g., geographic location of sampling; analytical techniques employed; time of sampling; vertical extent of sampling, etc.), with particular emphasis placed on data which were useful in establishing relative estimates of primary productivity for one or more Planning Areas.

2.1.2 Update of the UMES Report

Once each productivity author reviewed available documents (i.e., published and unpublished papers, unpublished data report or data sets), a review of UMES (1985) followed. Each author either updated or rewrote primary productivity text by providing a synthesis and interpretation of the primary productivity data available for each of the 26 Planning Areas, current through late 1989. Depending upon the nature of primary productivity information identified for each region, the attributes and limitations of those data sources were discussed.

2.1.3 Annotated Bibliography

Concurrent with review, evaluation, and selection of the primary productivity data sources, each of the selected citations was annotated. The annotated bibliography for primary productivity (Appendix A) contains sources of primary productivity data which met the objectives of the study, being drawn from the recent literature, miscellaneous data sources (e.g., unpublished cruise or data reports), and prior synthesis efforts (e.g., UMES, 1985). The citations and accompanying annotations in Appendix A were organized by region to facilitate reader access to the data sources employed in the Planning Area-specific discussions presented in Section 2.2. Annotations were developed to provide: 1) a complete citation of the primary data sources; and 2) a summary (or abstract) of the major findings evident from a particular research effort.

The inclusion of citations within Appendix A was based solely on author selection and represents the best data sources currently available to characterize primary productivity in the 26 Planning Areas. Citations which provided direct measurements of water column primary productivity using acceptable methodology and were applicable to one or more of the 26 Planning Areas were of primary interest and have been incorporated into Appendix A; sources which allowed an author to summarize the physical processes which affect primary production have also been included. Under certain limited circumstances (i.e., in the absence of any source of direct measurement(s) of primary production), authors selected, annotated, and incorporated into Appendix A any secondary or corollary sources of information which were deemed adequate to establish relative levels of water column primary productivity.

2.1.4 Mapping

During the process of primary productivity data review and evaluation, a Planning Area-specific map series was provided to each author. Maps previously prepared by UMES were used as templates. The objective of the mapping component was to graphically depict the spatial extent of primary productivity sampling within each OCS Planning Area.

Individual maps for each of the 26 OCS Planning Areas have been provided in Appendix C. Mapped data points included: 1) a variable percentage of those locations previously mapped by UMES, having been deemed as quality sources of primary productivity data; and 2) additional sampling sites not previously identified (e.g., recently sampled sites). One of the functions of the Map Series is to provide a graphic indication of the spatial extent and frequency of sampling for primary production within a given Planning Area. More importantly, each author has estimated the variability evident in productivity measures within a given Planning Area. This variability in production was determined by each author based on his review of available direct measurements, and was often supplemented by comparisons to similar regions and/or proxy indicators.

Variability in productivity measurements has been defined as either: 1) **high**, where measurements in enriched patches on individual surveys are frequently greater than five times "background" or non-patch values in the survey area; or 2) **low-moderate**, where measurements in patches are typically less than five times background or non-patch values in the survey area.

Variability in primary productivity, whether geographic, seasonal, annual, or episodic in nature, has been illustrated, when appropriate, through the use of histograms located on maps contained within the Map Series (Appendix C).

2.1.5 Normalizing Primary Productivity Data

With the advent of the Winkler oxygen technique and the availability of ^{14}C-labeled bicarbonate, quantitative determination of carbon fixation in marine systems became a routine measurement in marine ecosystem studies. Similarly, as knowledge of nutrient cycling and the processes supplying nutrients to the euphotic zone improved, the prediction of regional productivity also improved.

The ^{14}C - CO_2 uptake method is one of the primary means available to directly measure oceanic primary production. Oceanic primary production can also be estimated from remote sensing of ocean color, bio-optical modelling, other biological models, and combinations of these techniques. The ^{14}C - CO_2 technique has undergone continuous modification since its introduction in 1953 (Peterson, 1980). Although it has become the "standard" method, in reality it is not a standardized technique, and has not been inter-calibrated. It is, in fact, a mosaic of different methodologies. There is disagreement amongst primary productivity experts as to what this technique actually measures and, in some instances, it may underestimate the true carbon uptake. It has been suggested by various researchers that measurements made with this technique lie between estimates of net and gross primary productivity.

Variations in several methodological procedures are commonplace and require, under the most rigorous analysis, "normalization" procedures. These variations include, but may not be limited to, the following: 1) incubation bottle and type; 2) incubation time; 3) secretion of photosynthate; 4) toxicity and stimulation;

5) incomplete euphotic zone coverage; and 6) changes in enclosed populations. Appropriate correction factors could not be determined for all these potential variations within the current study effort. Therefore, production values were normalized as described below.

Based on the results of two coordination meetings amongst the primary productivity authors, the following normalization approach was employed by each author during their review and summarization of primary productivity data:

Standard: 24-h, dawn to dawn, with no corrections (UNESCO standard)
Units: g $C \cdot m^{-2} \cdot d^{-1}$ (normalization of data within a Planning Area)
g $C \cdot m^{-2} \cdot yr^{-1}$ (for comparative purposes between Planning Areas)

Data analysis was directed primarily at the establishment of a daily value for primary production, to be followed by a conversion to an annual value. For data derived from 24-h dawn to dawn incubations, no corrections were required. Data derived from incubations of less than 24 h were scaled to daily (24-h) uptake by normalizing to the fraction of the daylight period during which the incubation took place, with no other correction applied. Such manipulations were conducted to make the comparisons between regions directly comparable, even though more detailed information for a specific region may have suggested a slightly different approach. Recognized or potential biases in this approach are discussed, when applicable, in individual Planning Area-specific discussions (Section 2.2).

2.2 PLANNING AREA-SPECIFIC DISCUSSIONS

The following discussions present summary information which has been based upon a review and interpretation of available primary productivity data for each of the 26 Planning Areas. The authors have attempted to briefly identify and discuss the oceanographic characteristics or forcing mechanisms which influence productivity within each Planning Area. In two instances (i.e., Alaska OCS), because of a paucity of information and/or similarities relating to oceanographic parameters, analyses of two or three Planning Areas have been combined under a single discussion.

As outlined previously (Section 2.1.4), a map for each of the 26 Planning Areas has been included in the Map Series (Appendix C). Because authors have directly or indirectly referred to these maps in the following text, it is suggested that individual maps from this series be consulted during text review.

2.2.1 North Atlantic Planning Area

The North Atlantic Planning Area is characterized by considerable habitat diversity which markedly influences the magnitude and regional variations in primary productivity. The principal sub-regional units are: Gulf of Maine, Scotian Shelf, Georges Bank, Nantucket Shoals, New York Bight and Hudson River discharge, and Atlantic continental shelf off Long Island and New Jersey. Each of these productivity sub-regions has a pronounced onshore-offshore component, along which primary productivity varies with the depth gradient. These physiographic features determine seasonal water column mixing characteristics, nutrient inputs, and transparency, factors which are important determinants of primary production.

More than 5,000 primary productivity measurements have been made within the North and Mid-Atlantic Planning Areas, an area of 260,000 km^2 (161,564 mi^2). Most of these quantitative measurements were made during the 11-yr survey carried out between 1977-1987 by the Marine Resource Monitoring, Assessment and Prediction Program (MARMAP) (Sibunka and Silverman, 1989). The MARMAP surveys, comprising the longest, continuously running monitoring program of its kind conducted to date in the western North Atlantic, were based on completion of 9 to 10 regional surveys per year. Thus, the high quality MARMAP primary productivity data, coupled with productivity data from other investigations in the North Atlantic and Mid-Atlantic regions, provide excellent regional and seasonal coverage of the variations in and magnitude of primary production rates. This overview of primary production characteristics was based on a literature review of publications available through 1989, and annotated in the accompanying bibliography (Appendix A).

The regional hydrographic diversity of the North Atlantic Planning Area is accompanied by a similar diversity in the importance of the various regional nutrient enrichment patterns which determine the primary productivity characteristics (Figure 3). Estuarine discharge from the Hudson River and numerous riverine inputs along the coast of Maine supply nutrients nearshore in the shallowest regions. Tidal mixing is an important nutrient supply mechanism on Georges Bank and other offshore shoals. At the edge of the continental shelf throughout the region, nutrients are supplied as slope inputs (= cross-shelf exchange) through physical fluxes. About 50 percent of the nitrogen demand of primary production in the shelf waters off New York and New Jersey and Georges Bank is supplied by the latter mechanism (Walsh *et al.*, 1987). Continued onshore transport onto Georges Bank, coupled with tidal mixing characteristics, is the primary nutrient supply mechanism on this productive fishing ground. Recycling of nutrients contributes from 28 to 60 percent on a seasonal basis on Georges Bank (Walsh *et al.*, 1987). As the following productivity analysis will show, the highest annual primary production evident in the North Atlantic Planning Area occurs on Georges Bank. This elevated fertility and sub-regional differences in primary production levels occur even though the seasonal nutrient cycles within the North Atlantic Planning Area exhibit little regional difference. This higher annual production on Georges Bank has been attributed to the more efficient vertical resupply of recycled nutrient by tidal mixing and a greater cross-shelf nutrient supply (= "new" nutrient) from slope water. Regional differences in the seasonal mixing characteristics and supply of "new" nutrient primarily account for the regional productivity patterns of the North Atlantic Planning Area and their variations described below. It has been estimated that "new" production resulting from "new" nutrient inputs ranges from about 29 to 49 percent of the total annual production along

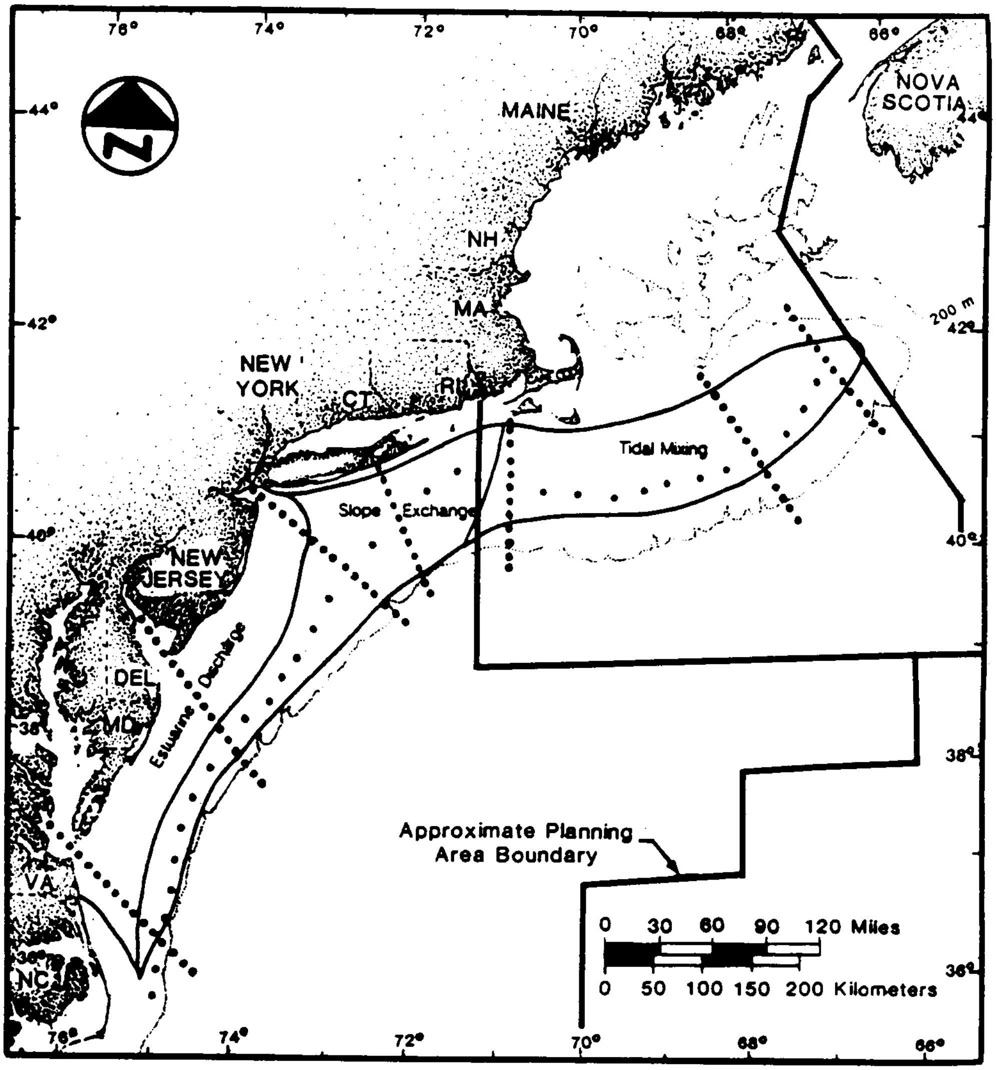


Figure 3. Regional occurrence of principal "new" nutrient supply mechanisms exclusive of recycling process, within the waters of the North and Mid-Atlantic Planning Areas (Adapted from: Walsh *et al.*, 1987).

the onshore-offshore gradient over Georges Bank (O'Reilly *et al.*, 1987). Aside from the shallowest nearshore regions subjected to elevated riverine nutrient loadings (Malone, 1982), the regional productivity patterns, magnitude, and their variability in the North Atlantic Planning Area are fundamentally determined by the hydrographic conditions and associated nutrient supply mechanisms. Anthropogenic activities leading to modified primary production probably would be of second- or third-order consequence. Upper trophic level consequences of such activities, however, can not be excluded.

Based on primary production measurements during the MARMAP surveys and by other investigators, 14 sub-areas within the North and Mid-Atlantic Planning Areas can be established (Figure 4, Table 4). Eight of these sub-areas occur within the North Atlantic Planning Area. Mean daily production rates varied by about two-fold, from about 0.71 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ in the inshore waters of the Gulf of Maine (GM1, Figure 4) and in the continental shelf waters between the 60- and 80-m (197- and 262-ft) isobaths (MAS4, Figure 4) to 1.38 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ in the shallow (<20 m [66 ft]) nearshore waters along the New Jersey coast and inner New York Bight. Mean daily production rates on Georges Bank in waters <60 m (197 ft) depth (GB1) were 1.25 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ (Table 4). Several regional patterns are evident. Mean daily production rates were generally lowest, approximately 0.74 g $C{\bullet}m^{-2}{\bullet}d^{-1}$, in the Gulf of Maine and in the contiguous Scotian Shelf (GM1, GM2, SS in Figure 4, Table 4). The significant 1.8-fold increase in mean daily rate (1.25 g $C{\bullet}m^{-2}{\bullet}d^{-1}$) on the shallowest (<60 m [197 ft], GB1) reaches of Georges Bank shows the remarkable augmentation of production in these shallow, tidally well-mixed, nutrient-enriched waters. Production rates decrease at depths >60 m (197 ft) to about 0.85 g $C{\bullet}m^{-2}{\bullet}d^{-1}$, both seaward out to the continental slope (GB2, GB3, GB4) and southward to Nantucket (NT). This mean daily rate of 0.85 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ generally persists south of Nantucket within the Mid-Atlantic Planning Area over the continental shelf off New York and New Jersey (regions MAS1 to MAS6 in Figure 4, Table 4). Within this latter region, mean daily production tends to decrease from the shallow, <20 m (66 ft) nearshore waters (MAS1) out to the 80-m (262-ft) isobath (MAS4), from 1.38 to 0.71 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ (Table 4). This pattern is similar to that along the offshore gradient from Georges Bank. At the outer portion of the continental shelf (MAS5, MAS6), mean daily production is elevated (0.85 to 0.96 g $C{\bullet}m^{-2}{\bullet}d^{-1}$), apparently in response to cross-shelf nutrient influxes from slope water (Walsh *et al.*, 1987).

Excluding the narrow coastal band along the New York and New Jersey coasts (MAS1), annual production (455 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$) over the shallow (<60 m [197 ft]) water of Georges Bank exceeds by 30 percent the next highest annual level (350 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$) found near the outer slope in region MAS5 (Figure 5, Table 4). Annual production rates in the North Atlantic Planning Area, exclusive of the Gulf of Maine (including Scotian Shelf), are generally about 300 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$, whereas production in the Gulf of Maine is about 265 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$. These annual rates correspond to mean daily production rates of 1.25, 0.82, and 0.73 g $C{\bullet}m^{-2}{\bullet}d^{-1}$, respectively. This produces the following productivity rank order in the North Atlantic Planning Area of: Georges Bank (<60 m [197 ft]) > "North Atlantic Region" > Gulf of Maine (i.e., equivalent to 450:300:265 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$, or a ratio of 1.7:1.13:1).

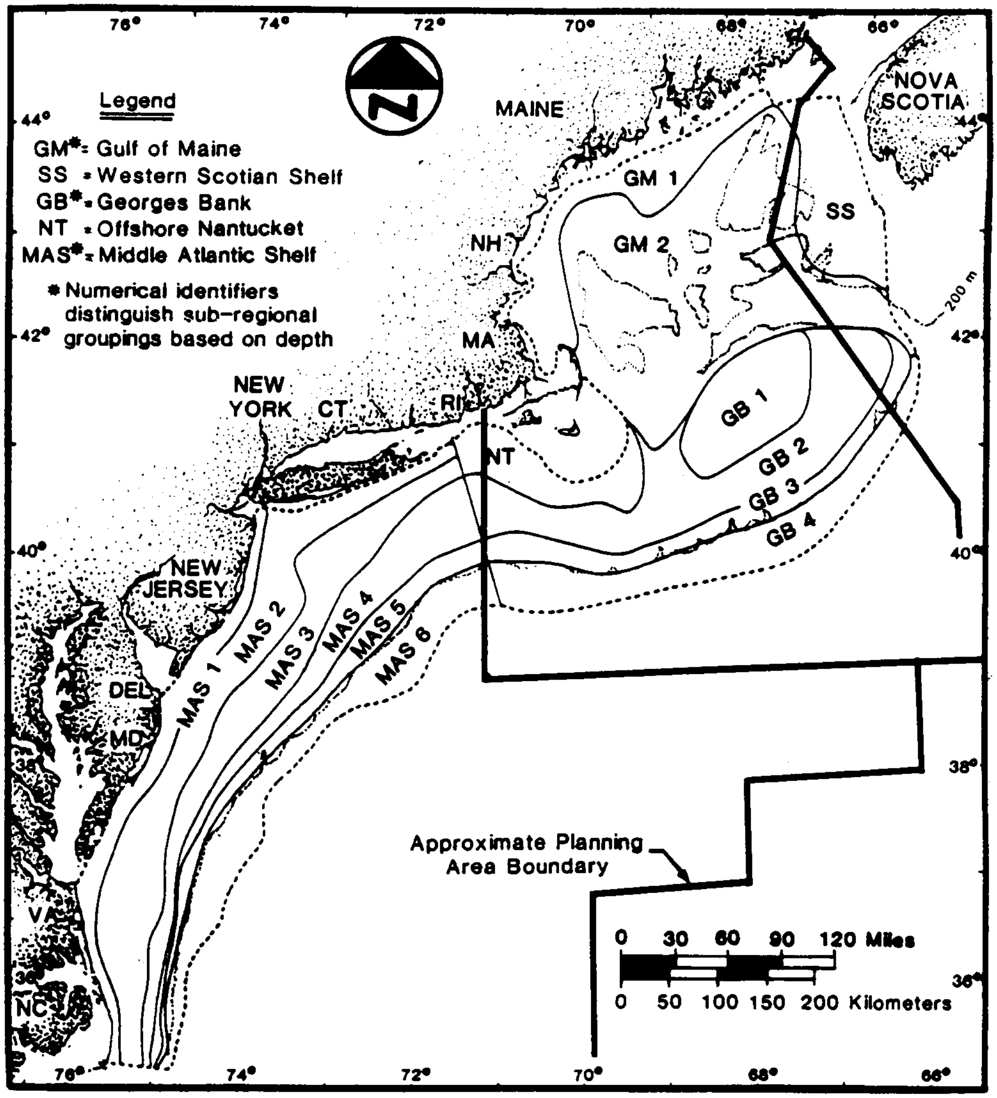


Figure 4. Sub-areas of regional primary production patterns evident within the waters of the North and Mid-Atlantic Planning Areas (Adapted from: O'Reilly *et al.*, 1987).

Table 4. Mean daily primary production and total annual primary production in 14 sub-areas within the North Atlantic and Mid-Atlantic Planning Areas (From: O'Reilly *et al.*, 1987).

Sub-area	Depth (m)	Mean Daily Production (g C•m^{-2}•d^{-1})	Annual Production (g C•m^{-2}•yr^{-1})
Georges Bank			
GB1*	< 60	1.25	455
GB2	60 - 100	0.85	310
GB3	100 - 200	0.73	265
GB4	> 200 (Slope)	0.84	305
Gulf of Maine			
GM1	Inshore	0.71	260
GM2	Offshore	0.74	270
Scotian Shelf			
SS	> 60	0.73	265
Offshore Nantucket			
NT	40 - 60	0.85	310
Middle Atlantic Shelf			
MAS1	< 20	1.38	505
MAS2	20 - 40	0.85	310
MAS3	40 - 60	0.82	300
MAS4	60 - 80	0.71	260
MAS5	80 - 200	0.96	350
MAS6	> 200 (Slope)	0.85	310

*Sub-areal designations conform to those shown in Figures 4 and 5.

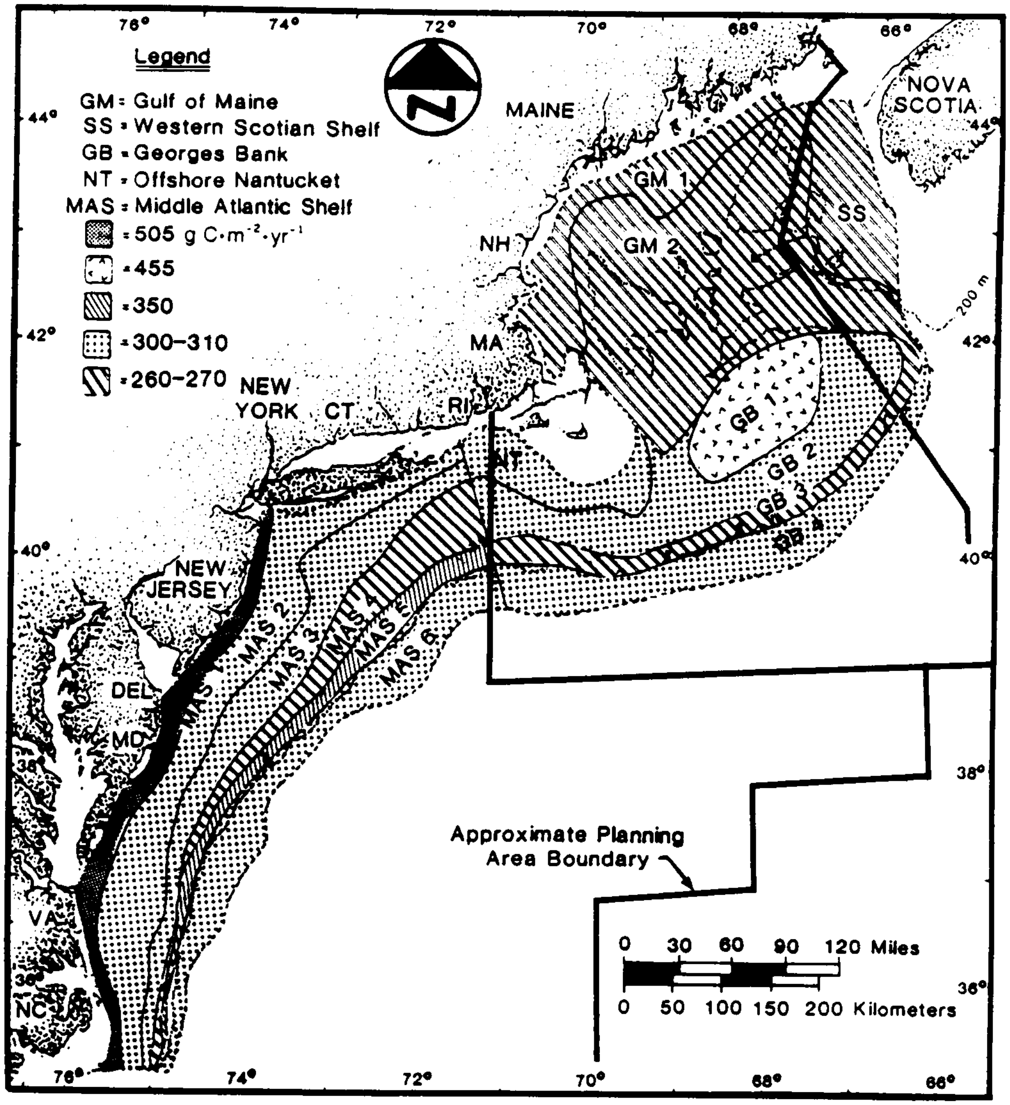


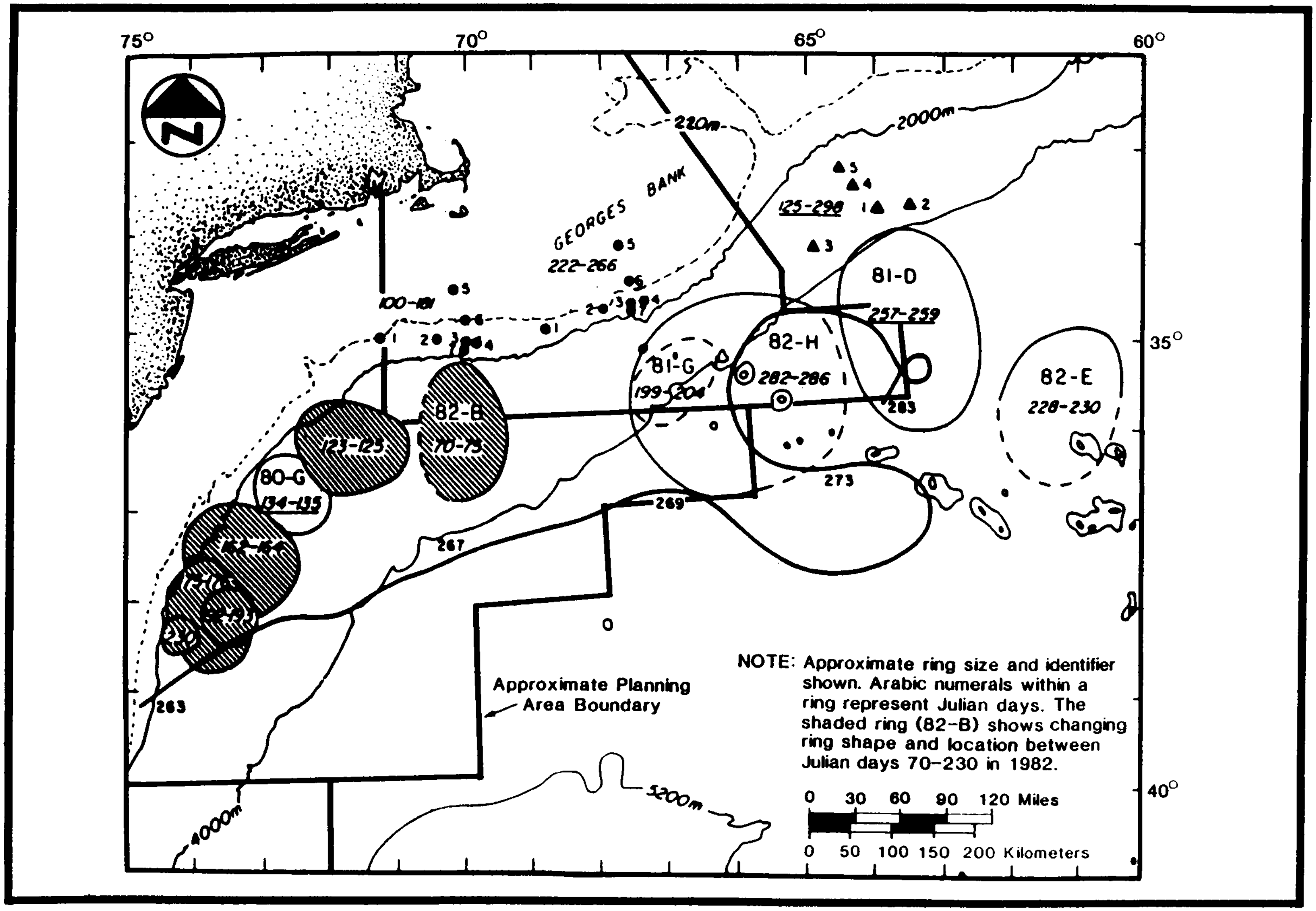
Figure 5. Annual gross primary production rates (g C·m^{-2}·y^{-1}) in 14 continental shelf sub-areas of the North and Mid-Atlantic Planning Areas (Adapted from: O'Reilly *et al.*, 1987).

A regional primary production comparison reveals Georges Bank to be among the most productive continental shelf ecosystems globally (Table 5). The area-weighted mean annual primary production for Georges Bank (335 g C/m^2) is nearly twice the mean for world continental shelves (O'Reilly *et al.*, 1987). O'Reilly *et al.* (1987) concluded that the annual primary production in the shallowest regions of the area (GB1) is about three-fold greater than the mean for continental shelves globally.

Primary production varies seasonally throughout the North Atlantic Planning Area. Daily rates vary from <0.25 g C$\cdot$m$^{-2}\cdot$d^{-1} in all 14 sub-areas to about 2.5 g C$\cdot$m$^{-2}\cdot$d^{-1} in the Gulf of Maine and to about 3 g C$\cdot$m$^{-2}\cdot$d^{-1} elsewhere (O'Reilly *et al.*, 1987). This 10- to 12-fold variation in daily primary production rates reveals the North Atlantic Planning Area to be highly variable irrespective of depth or location. Within this variability, however, rates exceeding 1 g C$\cdot$m$^{-2}\cdot$d^{-1} occur on Georges Bank during most months. Frequency (%) histograms of daily production rates reveal the mode is 1.38 g C$\cdot$m$^{-2}\cdot$d^{-1} for the shallowest regions of Georges Bank (GB1), 0.88 g C$\cdot$m$^{-2}\cdot$d^{-1} for the deeper Georges Bank area (GB2), and 0.63 g C$\cdot$m$^{-2}\cdot$d^{-1} for the Gulf of Maine (GM2) (Figure 5; O'Reilly and Busch, 1984). While high daily rates (up to 3 g C$\cdot$m$^{-2}\cdot$d^{-1}) can also occur during the spring bloom period throughout the North Atlantic Planning Area, very high rates (2 g C$\cdot$m$^{-2}\cdot$d^{-1}) can occur during the September - October (= "fall") bloom. The annual nadir in daily primary production rates (<0.25 g C$\cdot$m$^{-2}\cdot$d^{-1}) appears to occur during December - January.

The generation of warm core rings along the northern edge of the Gulf Stream near the continental slope and their subsequent southwesterly drift through the North Atlantic Planning Area significantly influence primary production within this region (Hitchcock *et al.*, 1985; 1987). As many as six warm core rings have been observed concurrently within this region (Figure 6, Joyce and Wiebe, 1983). These rings have a mean lifetime of about 4.5 mo before resorption by the Gulf Stream or disintegration within slope water. Rings can penetrate as far south as Cape Hatteras, within the southern portion of the Mid-Atlantic Planning Area. Primary production levels within the rings can exceed those in surrounding slope water. Daily primary production rates increased 17-fold, from 0.14 to 2.4 g C$\cdot$m$^{-2}\cdot$d^{-1}, within a warm core ring shortly after formation (Hitchcock *et al.*, 1987). During a six month life span of another warm core ring, total primary production rates of 126 g C/m^2 were observed in the approximately 200-km (108-nmi) diameter ring in contrast to parent Gulf Stream water production rates of about 25 g C/m^2 for this same period (i.e., six months). The formation, passage, and elevated primary production rates of warm core rings in the North Atlantic Planning Area (relative to Sargasso Sea source water) represent a significant source of regional variability, alters the baseline primary production, and decrease the overall fertility of the North Atlantic Planning Area which generally exhibits high rates of primary production relative to continental shelf waters globally (Table 5).

In both the North and Mid-Atlantic Planning Areas, the seasonal trends and overall contribution of the different phytoplankton size



NOTE: Approximate ring size and identifier shown. Arabic numerals within a ring represent Julian days. The shaded ring (82-B) shows changing ring shape and location between Julian days 70–230 in 1982.

Figure 6. Distribution patterns of warm core rings in continental shelf waters of the North Atlantic during 1981 and 1982 (Adapted from: Joyce and Wiebe, 1983).

Table 5. Annual primary production rates in North Atlantic, Mid-Atlantic, and South Atlantic Planning Areas compared to other ecosystems.

Area	Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Source
Georges Bank	455	O'Reilly *et al.*, 1987
Gulf of Maine	260 - 270	O'Reilly *et al.*, 1987
Mid-Atlantic Region	260 - 505	O'Reilly *et al.*, 1987
Georgia Coast (Altamaha R.)	585	Thomas, 1966
Inner Georgia Bight	285	Haines and Dunstan, 1975
Outer Georgia Shelf	180*	Yoder *et al.*, 1983
North Sea Coastal Zone	160 - 240	Cloern, 1987
English Channel	78 - 202	Jones, 1984
Fladen Ground	54 - 127	Jones, 1984
Northern Baltic	127	O'Reilly *et al.*, 1987

*Six months only, November - April.

fractions to total community primary production vary regionally. A general trend of increasing nanophytoplankton (<20 μm) contribution to total community primary production is evident along an onshore-offshore gradient in the North Atlantic Planning Area; similar trends evident in the Mid-Atlantic Planning Area are discussed further in Section 2.2.2. Within the North Atlantic Planning Area, a fundamental difference from this pattern of nanophytoplankton predominance is evident for the shallowest region of Georges Bank, where nanophytoplankton dominated the total community production rate in only 38 percent of the observations, in contrast to 87 percent in deeper Georges Bank waters (i.e., GB2 of Figure 4) and 81 percent in the Gulf of Maine (O'Reilly and Busch, 1984). This anomalous characteristic of this shallow sub-region of Georges Bank reflects the persistent year-round predominance of diatoms growing in response to cross-shelf nutrient fluxes which are then mixed vertically within the water column through tidal mixing. Such turbulence is generally detrimental to nanophytoplankton, among which flagellates predominate. Thus, Georges Bank is a unique ecosystem amongst all Atlantic Planning Areas (North, Mid- and South Atlantic) with regard to highly elevated mean daily primary production rates, annual production rate, the year-round predominance of netphytoplankton (>20 μm), principally diatoms, and its fisheries yield. The primary similarity of Georges Bank to all other regions is the considerable variability in daily production rates. Primary production within all shelf regions of the U.S. Atlantic coast is highly variable, with daily rates varying by at least 10-fold during the course of the annual primary production cycle.

2.2.2 Mid-Atlantic Planning Area

The Mid-Atlantic Planning Area is a simpler ecosystem than the North Atlantic Planning Area with regard to habitat diversity. Shallow areas similar to Georges Bank are absent. Tidal mixing as a physical and nutrient pumping mechanism which stimulates primary production, consequently, is relatively insignificant in the Mid-Atlantic Planning Area (Figure 3). A conspicuous hydrographic feature of the Mid-Atlantic Planning Area is the significant estuarine discharge and associated nutrient accretion detectable over a significant section of the continental shelf beginning with Delaware Bay and extending beyond the entrance to Chesapeake Bay southward to Cape Hatteras. The importance of estuarine discharge, in contrast to tidal mixing processes, is a major regional difference between the Mid- and North Atlantic Planning Areas. Cross-shelf nutrient exchange (= slope exchange) in both regions is important, although its importance appears to be restricted to a narrower offshore band in the Mid-Atlantic Planning Area (Figure 3). Thus, the onshore-offshore primary production gradient on the continental shelf in the Mid-Atlantic Planning Area reflects the dual gradients of 1) a progressive offshore decrease in estuarine nutrient discharge effects, and 2) progressively increasing offshore nutrient fluxes from slope water advected from cross-shelf physical exchange processes.

Similar to the North Atlantic Planning Area, the MARMAP and other data sets provide detailed regional, seasonal, and interannual coverage of the Mid-Atlantic Planning Area suitable to quantify the primary production characteristics of this region based on direct measurement. Five sub-areas are evident (Figure 4, Table 4). The mean daily carbon production rates vary by about two-fold, from 0.71 (60 to 80 m [197 to 262 ft]) to 1.38 g $C \cdot m^{-2} \cdot d^{-1}$ in the coastal band <20 m (66 ft) depth. Thus, daily primary production rates decrease by about 50 percent along the offshore gradient of decreasing estuarine discharge effects out to the 80-m (262-ft) isobath. At depths >80 m (262 ft), the effect of nutrient inputs resulting from cross-shelf exchange processes with slope water on primary production is evident from the increase in mean daily production rates (0.85 to 0.96 g $C \cdot m^{-2} \cdot d^{-1}$) out to the edge of the continental shelf.

A north-south gradient in primary production rates is not evident within the Mid-Atlantic Planning Area. The primary gradient is the onshore-offshore gradient along which total annual primary production decreases from 505 to 310 g $C \cdot m^{-2} \cdot yr^{-1}$ (Figure 5, Table 5). Although the annual rate of 505 g $C \cdot m^{-2} \cdot yr^{-1}$ in the narrow coastal band exceeds annual rates (455 g $C \cdot m^{-2} \cdot yr^{-1}$) on Georges Bank (Table 5), this elevated primary production is not accompanied by a similar increase in fishery yields (Jones, 1984). The mid-shelf region off the Delaware-Maryland-Virginia coasts is a contiguous primary production unit with that off New Jersey and Long Island, with similar annual production rates (Figure 5).

Productivity within the Mid-Atlantic Planning Area is highly variable. Mean daily rates range 11- to 13-fold, from <0.25 to 3.25 g $C \cdot m^{-2} \cdot d^{-1}$ in inshore and mid-shelf waters, and from <0.25 to 2.75 g $C \cdot m^{-2} \cdot d^{-1}$ in outer shelf and slope waters (O'Reilly *et al.*, 1987). The greatest frequency (25 to 30 percent) of occurrence in daily production rates ranges from 0.50 to 0.75 g $C \cdot m^{-2} \cdot d^{-1}$, in contrast to a range of 1.25 to 1.50 g $C \cdot m^{-2} \cdot d^{-1}$ in the shallowest regions (i.e., GB1 of Figure 5) of Georges Bank (O'Reilly *et al.*, 1987). The passage of warm core rings through the Mid-Atlantic Planning Area (Figure 6) also contributes to regional variations in primary production. However, relatively little is known about the production characteristics of warm core rings in this region, including whether the magnitude of elevated production approaches the high rates noted previously for the North Atlantic Planning Area. Warm core rings tend to break up within the Mid-Atlantic Planning Area, which suggests that they may not be as important to overall primary production in this region as in the North Atlantic.

As noted previously, the seasonal trends and overall contribution of the different phytoplankton size fractions to total community primary production vary regionally in both the North and Mid-Atlantic Planning Areas. The percentage of total measurements in which the nanophytoplankton (<20 μm) contributed >50 percent of the daily total community primary production rates increased from 50 percent in the shallow mid-shelf regions (MAS1 and MAS2 of Figure 4) to 90 percent in the outer shelf and slope regions (MAS5 and MAS6 of Figure 4) (O'Reilly and Busch, 1984). This general trend of an increased nanophytoplankton contribution to total community primary production along the onshore-offshore gradient also characterizes the North Atlantic Planning Area, as discussed in Section 2.2.1.

2.2.3 South Atlantic Planning Area

The continental shelf in the South Atlantic Planning Area varies in width from less than 30 km (16 nmi) off Cape Hatteras to a maximum of 120 km (65 nmi) off Savannah, GA (Figure 7; Atkinson *et al.*, 1984). The shelf break is at 55 m (180 ft). Depths over the shelf are uniform (the typical relief is 2 m [7 ft]) and, in marked contrast to the North Atlantic Planning Area, there are no basins or sills. The proximity of the Gulf Stream to the continental shelf is a conspicuous feature of the U.S. South Atlantic. The western edge of the Gulf Stream lies within ±15 km (8 nmi) of the shelf break south of 32°N latitude and closely follows the shelf break over a distance of >1,000 km (540 nmi) from Miami, FL to Cape Hatteras, NC. This northerly flow along the shelf break propagates a series of frontal disturbances such as meanders and eddies every several days to two weeks (Yoder *et al.*, 1983). These Gulf Stream frontal disturbances cause shelf break upwelling and associated intrusions on nutrient-rich watermasses onto the continental shelf. Such nutrient enrichment effects on productivity are sometimes detectable shoreward of the 40-m (131-ft) isobath (Yoder *et al.*, 1985). In nearshore waters <20 m (66 ft), significant riverine inputs deliver nutrients in certain regions. Biological processes within the large, inshore embayments (e.g., Pamlico Sound, Core Sound, Bogue Sound) of North Carolina, however, reduce the levels of nutrients reaching the continental shelf in that region. To the south, riverine flow directly onto the shelf, such as from the Altamaha River into the Georgia Bight, delivers nutrients which are available for primary production. With the exception of the Florida coast south of Jacksonville (approximately 30°20'N latitude), upwelled nutrients do not intrude into the turbid, inner shelf waters (0 to 20 m [0 to 66 ft]), a region which accounts for approximately 30 percent of the total shelf width (Yoder, 1985). "New" nutrients enter the inner-shelf zone from the numerous salt marshes along the Georgia-South Carolina coast. Thus, in addition to *in situ* remineralization, nutrients derived from shelf-break upwelling and intrusions of nutrient-rich Gulf Stream water occur throughout the South Atlantic Planning Area. Together with localized riverine discharge, these processes are important enrichment mechanisms which stimulate and regulate primary production within the South Atlantic Planning Area.

The frequency and regional, seasonal, and interannual coverage of primary production measurements in the South Atlantic Bight are significantly less than for the North and Mid-Atlantic Planning Areas. The most recent and most comprehensive data sets exist for the South Atlantic Bight between 29°N to 32°N latitude (Atkinson *et al.*, 1984; Yoder, 1985; Yoder and Ishimaru, 1989; Yoder *et al.*, 1983; 1985). The limited data set available for the South Atlantic region is partly vitiated by the apparent, more or less regionally uniform hydrographic conditions associated with Gulf Stream dynamics and associated advection and upwelling of nutrient-rich water stimulatory to primary production. Productivity events and levels determined for the South Atlantic Bight may be reasonable analogues for much of the South Atlantic Planning Area. Yoder (1985) concluded, however, from a consideration of continental shelf width and degree to which nutrient-rich watermasses intrude onshore, that primary production on the middle shelf south of

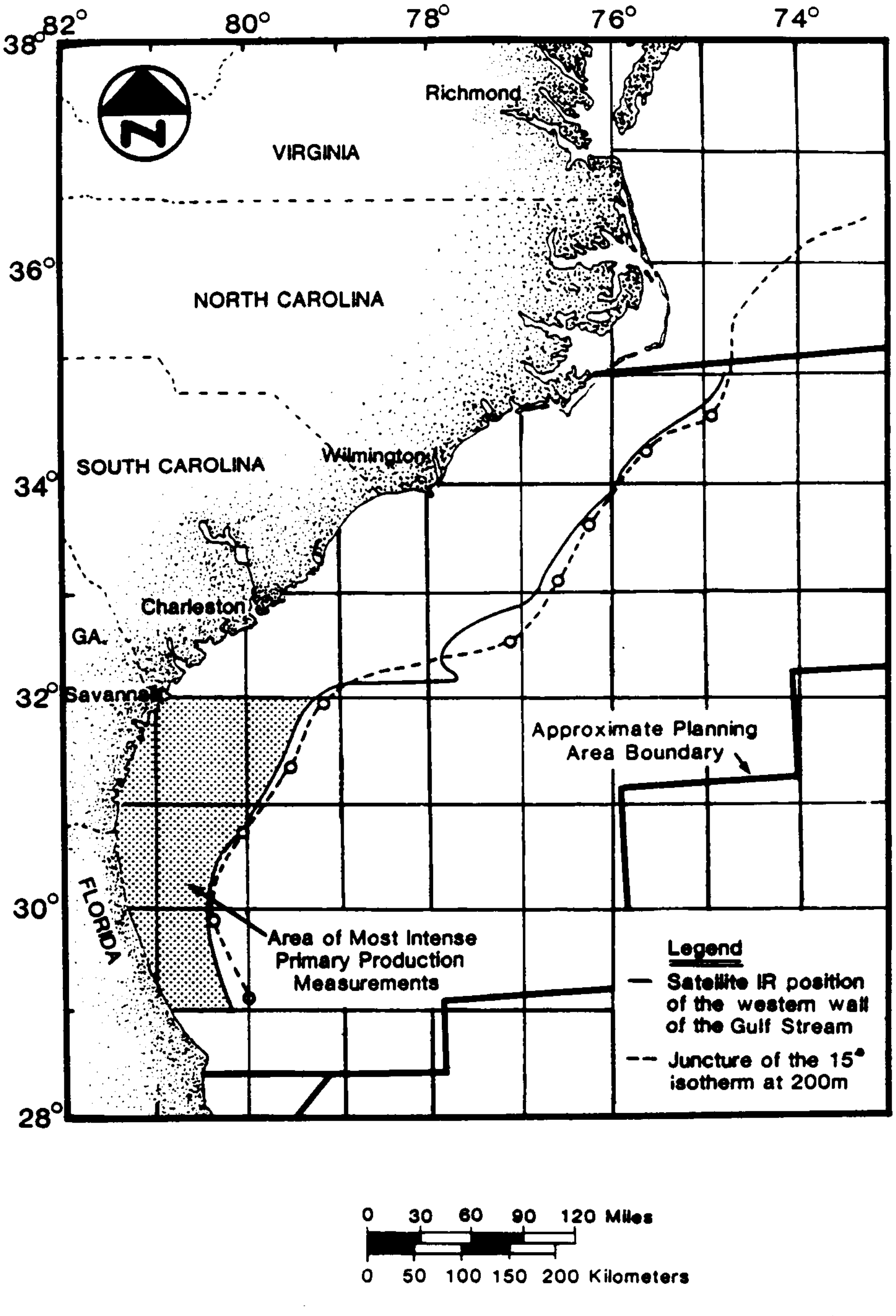


Figure 7. The western wall of the Gulf Stream as it appears in the waters of the South Atlantic Planning Area.

Jacksonville, FL (approximately 30°33'N latitude) and in the cape region north of 33°N latitude should be considerably higher than it is off Georgia. This regional variation remains to be established, and should be borne in mind in the following overview of primary production.

The results of recent studies clearly show that shelf-break upwelling at the outer southeastern shelf and intrusions of Gulf Stream water onto the shelf stimulate moderately high rates of primary production (>1 g $C \cdot m^{-2} \cdot d^{-1}$). Daily rates as high as 6 g $C \cdot m^{-2} \cdot d^{-1}$ have been measured during such upwelling events (Yoder *et al.*, 1983). In contrast, average daily rates between the 20- to 200-m (66- to 656-ft) isobaths apparently measured during non-upwelling events (Haines and Dunstan, 1975) were only 0.05 g $C \cdot m^{-2} \cdot d^{-1}$ (i.e., a 120-fold difference). Thus, a significant characteristic of the South Atlantic Bight is the extremely high variability in daily production rates. The range of variability may be 10-fold greater than the range of variability characterizing the North Atlantic and Mid-Atlantic Planning Areas. Given the great importance of Gulf Stream dynamics in regulating primary production in this region, there is significant cross-shelf, daily, seasonal, and interannual variability associated with this frontal system, and in response to the vagaries of such hydrographic disturbances. As a consequence, it is difficult to estimate the seasonal or annual magnitude of primary production in the South Atlantic Bight, since the level of production is related to the frequency of upwelling events, their duration, and the area influenced. Paffenhöfer and Lee (1987), for example concluded that the average longevity of a summer upwelling event probably exceeds 25 d, based on a study of three upwelling-induced intrusions over a two-month period. Width of the intrusions varied from 35 to 63 km (19 to 34 nmi) and the length from about 100 to >155 km (54 to >84 nmi). The maximum potential width is 75 km (40 nmi), a scale restricted by width of the continental shelf. Lengths can exceed 180 km (97 nmi) if onshore flow persists for more than two weeks (Paffenhöfer and Lee, 1987). Thus, episodic occurrences of mesoscale hydrographic events influencing production over wide areas are a fundamental habitat feature of the South Atlantic Bight. Variations in irradiance levels associated with the degree of vertical mixing also determine the magnitude and variability of primary production. Mean daily primary production during a 1979 upwelling event was about four-fold greater (2.7 g $C \cdot m^{-2} \cdot d^{-1}$) than during a 1980 event, a difference associated with differences in mixed-layer phytoplankton distributions and light availability (Yoder *et al.*, 1983).

Yoder *et al.* (1983), based on an average primary production rate of 1.8 g $C \cdot m^{-2} \cdot d^{-1}$ (n = 23) in upwelled waters on the outer shelf during November - April and the occurrence of upwelling during 53 percent of the six-month period, estimated a production magnitude of 175 g C/m^2 during this period. When non-upwelling rates were included, this six-month primary production was increased slightly to 180 g C/m^2. This rate applies to the outer 40 km (22 nmi) of the continental shelf (i.e., about 33 percent of the shelf width off the Georgia coast). In contrast, this six-month rate was 40 percent higher than the annual rate of 130 g $C \cdot m^{-2} \cdot yr^{-1}$ reported previously by Haines and Dunstan (1975). The basis of this significant discrepancy is that the latter investigators completed their investigation prior to the recognition of the local importance of upwelling to primary production. This is evident in the estimation of Haines and Dunstan (1975) that recycled nitrogen provided 95 percent of the nitrogenous nutrient required to support this production rate. Yoder *et al.* (1983), in contrast, estimated that upwelled nutrients account for about 50 percent (85 g C/m^2 per 6 mo) of the total primary production, or 10-fold greater contribution than the "new" production estimate of 5 percent cited by Haines and Dunstan (1975).

For the inner third of the shelf between the 0- to 20-m (0- to 66-ft) isobaths, Haines and Dunstan (1975) estimated an annual production rate of 285 g C•m^{-2}•yr^{-1}. Near the mouth of the Altamaha River on the Georgia coast (approximately 31°20'N latitude), an annual primary production rate of 585 g C•m^{-2}•yr^{-1} was estimated (Thomas, 1966). Primary production rates measured in the mid-shelf region during July - August 1981 suggest a total primary production of 150 g C/m^2 during this two-month period (Yoder *et al.*, 1985). This rate is about 15 percent higher than the annual rate of 130 g C•m^{-2}•yr^{-1} estimated by Haines and Dunstan (1975) for the shelf area between the 20- and 200-m (66- and 656-ft) isobaths.

Table 6 summarizes key aspects of the primary production rate characteristics in the South Atlantic Bight. The data are obviously too limited to arrive at overall regional and annual conclusions for the South Atlantic Planning Area. However, the most recent quantitative data available suggest that annual primary production rates in the mid and outer shelf regions (at least in the South Atlantic Planning Area between 29°N and 32°N latitude) are considerably higher than earlier estimates. The six-month estimate for the outer shelf is at least 50 percent greater than the annual rate previously estimated, and the two-month mid-shelf rate (i.e., 150 g C/m^2) is about 20 percent greater than the annual rate previously estimated for this region. Moreover, the six-month outer shelf rate (i.e., 180 g C/m^2) may exceed the average annual inner-shelf rate of 285 g C•m^{-2}•yr^{-1} and may be as much as 60 percent of the annual rate (i.e., 580 g C•m^{-2}•yr^{-1}) near the mouth of the Altamaha River, a major southeastern river (Yoder *et al.*, 1983). It would appear, therefore, that primary production over the continental shelf of the South Atlantic Planning Area is significantly higher than previously suggested. In fact, the annual rates may prove to be similar to those characterizing the North and Mid-Atlantic Planning Areas, exclusive of Georges Bank (Figure 5, Table 4).

The warm, oligotrophic continental shelf waters of the South Atlantic Planning Area have traditionally been considered to be relatively unproductive. However, this notion must now be abandoned, given the demonstrated effects of frequent, episodic upwelling events at the shelf break of this region and associated onshore intrusions of nutrient-rich Gulf Stream water highly stimulatory to primary production.

Results of regional surveys conducted in the North, Mid-, and South Atlantic, collectively, clearly indicate that while the onshore-offshore gradients and annual magnitude of primary production (exclusive of Georges Bank) may be similar along the entire U.S.

Table 6. Comparison of mean daily, seasonal, and annual production rates in the South Atlantic Bight off Georgia.

Area	Daily Production Rate ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Seasonal Production Rate ($g\ C/m^2$)	Annual Production Rate ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Source
Inner Shelf:				
Altamaha River	1.6	--	580	Thomas, 1966
0 - 20 m	0.76	--	285	Haines and Dunstan, 1975
Mid Shelf:				
July - August 1981	1.9	150*	130	Yoder *et al.*, 1985; Haines and Dunstan, 1975
Outer Shelf:				
November - April	--	180†	130	Yoder *et al.*, 1983; Haines and Dunstan, 1975
Upwelling	0.7 - 2.7	--	--	Yoder *et al.*, 1983; Haines and Dunstan, 1975
Non-upwelling	0.05	--	--	Yoder *et al.*, 1983; Haines and Dunstan, 1975

*July - August total.
†Six-month total.

Atlantic continental shelf, the predominant physical-chemical nutrient enrichment mechanisms responsible for much of the primary production output vary regionally within, and between Atlantic OCS Planning Areas. This requires the development of regionally specific models to evaluate the potential modification of the intrinsic primary production patterns accompanying any proposed anthropogenic activities and associated environmental changes. There is also need for additional measurements of primary production, particularly within the South Atlantic Planning Area. A thorough discussion of identified data gaps and recommendations for future research, as they pertain to the Atlantic Planning Areas, have been presented in Section 4.1.3.

2.2.4 Straits of Florida Planning Area

Information on water column primary production in the Straits of Florida Planning Area is extremely limited (Figure 8). Most of the recent data sources provided information on Biscayne Bay, the coastal waters off the Bay, and the Straits offshore of the Bay. Additional data pertain to the Dry Tortugas, located on the border between the Straits of Florida and Eastern Gulf of Mexico Planning Areas. Therefore, areal coverage for this Planning Area is extremely limited.

Riley (1938) reported a single primary production value based on changes in oxygen concentration. This citation has been plotted (see Figure 8 or the Straits of Florida map, Map Series), however this data source was not used to estimate regional variability or annual production. Work by Jones (1963) was also based on changes in oxygen concentration during six-hour incubations (0600 to 1200 h). Six-hour values were subsequently doubled to obtain a daily rate. Recalculation of these data, employing the appropriate photoperiod for those months in which observations were reported, yielded essentially the same results. Four months of observations were reported by Jones (1963) which were used to obtain seasonal averages. These averages display a 50-fold variation ranging from non-detectable net production to 560 mg $C \cdot m^{-2} \cdot d^{-1}$. The high degree of variation in the Jones (1963) data set precluded its use in estimating daily variation and an annual average. Values from a later study by Roman *et al.* (1983), which included monthly measurements over an annual cycle in a comparable area, was used to obtain an estimate of seasonal variability for the Straits of Florida Planning Area.

Corcoran and Alexander (1963) provided the only seasonal information available for the offshore waters of the Straits of Florida. Their values, covering a five-month sampling period, were based on ^{14}C uptake over six-hour *in situ* incubations (0600 to 1200 h). Data were presented graphically in units of mg $C \cdot m^{-3} \cdot d^{-1}$. For the present analyses, graphic values were taken from Corcoran and Alexander (1963) and integrated with depth using the trapezoidal rule. These calculated values were comparable to two integrated values (g $C \cdot m^{-2} \cdot d^{-1}$) provided by Corcoran and Alexander (1963) in the text (April: calc. = 0.46, text = 0.5; May: calc. = 0.2, text = 0.2). Seasonal averages were calculated as appropriate and the five-month average was used to estimate annual production.

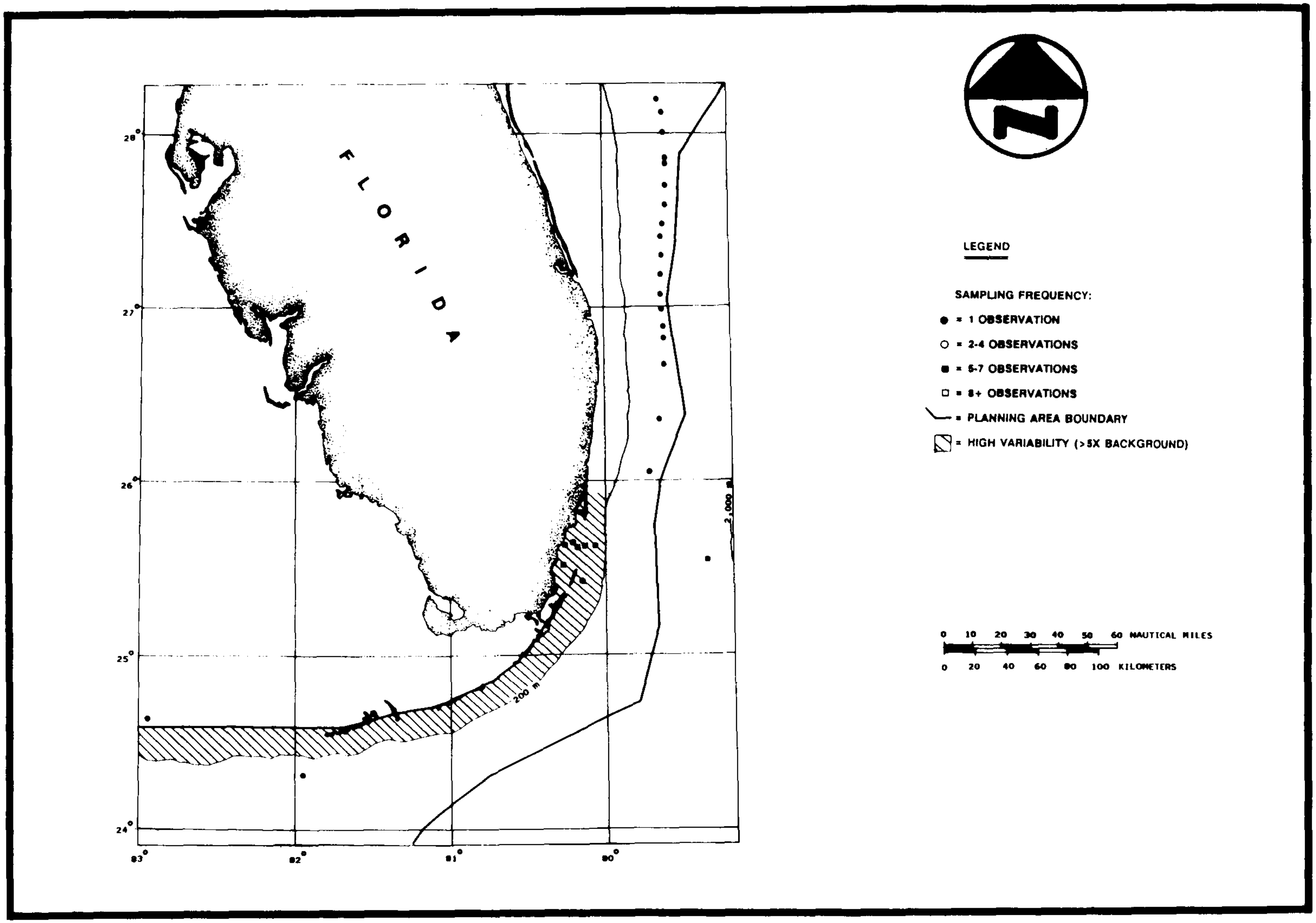


Figure 8. Sampling frequency in the Straits of Florida Planning Area with an indication of variability in primary production.

El-Sayed and Trees (1980) reported production measurements for one station in the Florida Current (24.3°N latitude, 81.9°W longitude). Volumetric rates for five depths (i.e., surface to 90 m [295 ft]) were integrated to yield an areal rate of 2,952 mg $C \cdot m^{-2} \cdot d^{-1}$. This value was five-fold higher than rates measured by Corcoran and Alexander (1963) and greater than any Loop Current values for the Eastern Gulf of Mexico Planning Area. Since this value was intuitively high for the region, and represented a single location and time, it was not included in the calculations for seasonal or annual averages.

The following discussion has been divided into separate subsections, including embayments, coastal waters, and offshore waters.

Embayments

Both Roman *et al.* (1983) and Brand (1988) reported annual cycles of primary production in Biscayne Bay, FL. Roman *et al.* (1983) calculated annual integrated totals for each of three areas of the Bay. Seasonal variability, however, required estimating values from figures (reported as mg $C \cdot m^{-3} \cdot d^{-1}$), multiplying by the reported depth of the water column, and averaging over the required months. Annual averages based on these estimated areal rates were comparable to the annual integrated values reported in the text (Table 7). Brand (1988) measured production under artificial light at three light levels in the laboratory. He did not report water column depth or an extinction coefficient for the 12 stations where samples were collected for productivity measurements. Therefore, the average production rate for the three light levels was assumed to represent the rate for a square meter of water column. Since the average depth in most areas of Biscayne Bay is two meters or less, the value can be considered as representative of the water column. The hourly rates reported by Brand (1988) were multiplied by the appropriate photoperiod (i.e., for the six months of observations) and a monthly average was computed. The grand mean (expressed as mg $C \cdot m^{-2} \cdot d^{-1}$) for all stations and months was used to estimate the annual production. This value of 58.8 mg $C \cdot m^{-2} \cdot d^{-1}$ is higher than the estimate of 40 mg $C \cdot m^{-2} \cdot d^{-1}$ given by Brand (1988) in the text. No calculations were provided as to how Brand derived this estimate. A comparison of data calculated from Brand (1988) and Roman *et al.* (1983) in Table 8 indicates there are seasonal differences in the daily areal rates but the annual totals are comparable.

Lack of sufficient areal and seasonal data precluded a rigorous assessment of variability in this region. Variation between North and South Bay is approximately five-fold (Table 8) which Brand (1988) suggested was the result of increased pollution in the heavily populated North Bay area. Seasonal averages calculated from Brand's data indicated an approximately four-fold variation, whereas estimates from Roman *et al.* (1983) were more consistent (Table 8). The differences between the two data sets reflects the difference in sampling strategy. Brand (1988) sampled 12 locations throughout the entire Bay, whereas Roman *et al.* (1983) confined their observations to three locations along a single east-west transect of the mid-Bay axis. The latter investigators therefore did not include the nutrient enriched North Bay region in their program.

Table 7. Annual production (g C•m^{-2}•yr^{-1}) at three locations in Biscayne Bay (Stations 1 through 3) and coastal waters (Station 4) based on calculated values derived from Roman *et al.* (1983) and values reported in the text of that publication.

Station	Calculated	Text
1	51.0	46.0
2	20.2	27.0
3	12.2	13.0
4	18.4	16.0

Table 8. Seasonal, annual, and areal variation in primary production in Biscayne Bay based on data derived from Brand (1988) and Roman *et al.* (1983).

		Daily Production (mg C•m^{-2}•d^{-1})		Annual Production (g C•m^{-2}•yr^{-1})	
Season	Location	Brand (1988)	Roman *et al.* (1983)	Brand (1988)	Roman *et al.* (1983)
Winter	Entire Bay	35.0	65.0	--*	--
Spring	"	127.5	75.0	--	--
Summer	"	74.9	79.0	--	--
Fall	"	58.2	95.0	--	--
Annual	"	58.8	55.0	21.5	27.0
Annual	North Bay	97.0	--	35.4	--
Annual	South Bay	20.8	--	7.6	--

*No values reported.

Florida Straits may be expected to show a high degree of consistency in primary production in a latitudinal extent, a complete seasonal description is needed and a cross-current survey is required. Western Boundary Current upwelling and its effect on primary production have been described for the West Florida Shelf (Yoder and Mahood, 1983) and the outer southeastern U.S. Shelf (Yoder *et al.*, 1981). Lee *et al.* (1981) described similar upwelling in the northern Florida Straits and along the southeastern shelf of the U.S. Similar situations should also occur along the Florida Keys northward to the boundary of the Straits of Florida Planning Area. There are no primary production measurements available for the shelf regions where upwelling would be expected nor is the extent or duration of upwelling known. Such information is required for an accurate assessment of water column primary production in this region.

Values used to characterize primary production in the Straits of Florida Plannng Area and presented in the Map Series must be viewed with caution. The lack of information available for this region, particularly the coastal and offshore areas precludes an accurate assessment of water column primary production. Although data for Biscayne Bay are reasonably consistent, direct comparisons between the two data sets could not be made because incubation methods varied considerably. The degree to which the data for Biscayne Bay reflects production in other Florida east coast embayments and the embayments of the Florida Keys cannot be assessed. An accurate description of the annual primary production for this region cannot be made until additional information becomes available.

2.2.5 Eastern Gulf of Mexico Planning Area

Embayments

The largest embayments in the Eastern Gulf of Mexico Planning Area are Tampa Bay and Charlotte Harbor on the west coast of Florida (Figure 9). Information on Tampa Bay dates from a study by Pomeroy (1960) in Boca Ciega Bay, a shallow tributary of Tampa Bay. Primary production of phytoplankton and seagrasses was determined by changes in oxygen concentration. In shallow areas of Boca Ciega Bay (<2 m [7 ft]), water column and seagrass production was equivalent (approximately 500 $g\ C{\bullet}m^{-2}{\bullet}yr^{-1}$). Phytoplankton production dominated deeper regions of the Bay.

Johansson *et al.* (1985), Lewis and Estevez (1988), and Lewis (1989) summarized all existing production data from Tampa Bay from 1965 to 1982. Johansson (1985) compiled a series of measurements made by the U.S. Fish and Wildlife Service from 1965 through 1972. Most of the productivity estimates were based on relationships between chlorophyll concentration and light, with values that ranged from 120 to 580 $g\ C{\bullet}m^{-2}{\bullet}yr^{-1}$. However, measurements of oxygen in light and dark bottles was used in a variety of locations throughout Tampa Bay for several years (i.e., 1965-1969). Daily, areal rates from these studies and from measurements made using the ^{14}C method by the City of Tampa (Johansson *et al.*, 1985) were used to estimate seasonal and yearly total production for Tampa Bay. Although sufficient information was available

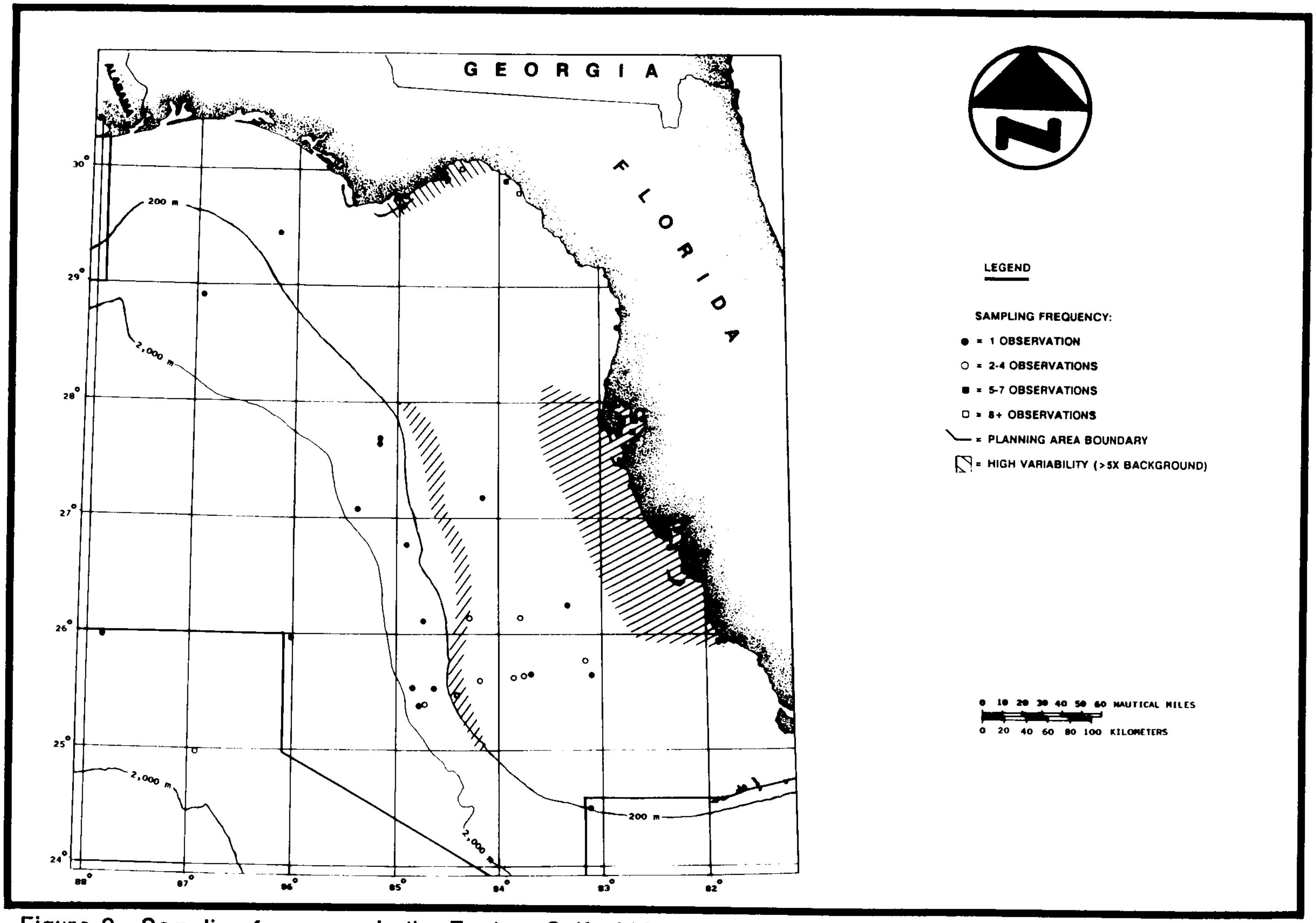


Figure 9. Sampling frequency in the Eastern Gulf of Mexico Planning Area with an indication of variability in primary production.

to calculate seasonal averages, there is a pronounced wet and dry season in this area of central Florida. All available data indicated a significant increase in production during the wet season (defined here as June, July, August, and September) as a result of increased runoff and concomitant nitrogen loading (Johansson *et al.*, 1985). Therefore, seasonal variability was expressed as wet vs. dry season averages. Production increased more than two-fold during the wet season (1.4 to 3.7 g $C \cdot m^{-2} \cdot d^{-1}$; Johansson *et al.*, 1985) for some sections of Tampa Bay. This is of the same order as spatial variability within the Bay. Highest production rates occur in the Hillsborough Bay section, an arm of Tampa Bay surrounded by industrial and urban areas, with rates exceeding 4 g $C \cdot m^{-2} \cdot d^{-1}$ during the wet season. Maximum rates in lower Tampa Bay, at the mouth, generally do not exceed 1 g $C \cdot m^{-2} \cdot d^{-1}$.

Annual production based on the U.S. Fish and Wildlife Service data set, as reported by Johansson *et al.* (1985), ranged from 220 g $C \cdot m^{-2} \cdot yr^{-1}$ at the mouth to 610 g $C \cdot m^{-2} \cdot yr^{-1}$ in polluted Hillsborough Bay. Johansson *et al.*, (1985) reported values of 620 g $C \cdot m^{-2} \cdot yr^{-1}$ for Hillsborough Bay and Middle Tampa Bay but suggested that a rate of 340 g $C \cdot m^{-2} \cdot yr^{-1}$ would be more representative of the annual production throughout the Bay in areas >2 m (7 ft) depth. A rate of 50 g $C \cdot m^{-2} \cdot yr^{-1}$ was also proposed for areas <2 m (7 ft) depth. In the present analysis, time weighted averages for the wet vs. dry season in Hillsborough and Middle Tampa Bays were calculated from Johansson's data, yielding values of 3.7 and 1.4 g $C \cdot m^{-2} \cdot d^{-1}$, respectively. Based on these values, annual production was 787 g $C \cdot m^{-2} \cdot yr^{-1}$, a value considerably greater than Johansson *et al.* (1985) measured or their "representative" rate. A similar calculation using data from McNulty (1969) yielded wet vs. dry season rates of 1.8 and 0.97 g $C \cdot m^{-2} \cdot d^{-1}$, respectively. Annual production based on this estimate was 455 g $C \cdot m^{-2} \cdot yr^{-1}$. McNulty (1969) suggested that a Bay-wide integrated value for 1968 was approximately 400 g $C \cdot m^{-2} \cdot yr^{-1}$. The difference between the rates calculated from either data set underscores the variability found in the eutrophic and relatively pristine sections of Tampa Bay.

Squires (1984), Fraser and Wilcox (1981), and Montgomery (1988) provide primary production rates for Charlotte Harbor. Measurements by Froelich *et al.* (1985) and Carder *et al.* (1986) included chlorophyll a and b but no production values. All of the production rates presented by Squires (1984) and Montgomery (1988) were hourly volumetric rates (mg $C \cdot m^{-3} \cdot h^{-1}$) incubated at one isolume (50 percent) for an unspecified (Montgomery, 1988) duration around local apparent noon. No extinction coefficients or water depths were available for calculation of an integrated daily rate. Therefore, data from these sources were not used in estimating annual or seasonal totals. Fraser and Wilcox (1981) measured surface and near bottom production rates (g $C \cdot m^{-3} \cdot d^{-1}$) for three stations along a transect of the Harbor. Maximum rates were presented in tabular form and extinction coefficients were available. Areal production was estimated using the equation suggested by Rodhe *et al.* (1958) and Steeman-Nielsen (1954):

$$g\ C \cdot m^{-2} \cdot d^{-1} = (2.5) \times (P_{max}/k)$$

where P_{max} is the production rate at light saturation ($g\ C{\cdot}m^{-2}{\cdot}d^{-1}$), k is the extinction coefficient (1/m) and 2.5 is a constant. Volumetric rates from each station were converted to areal rates and the three stations averaged to provide a value for the entire Harbor and for the year. Areal rates ranged from 0.4 $g\ C{\cdot}m^{-2}{\cdot}d^{-1}$ for a station near the mouth to 5.4 $g\ C{\cdot}m^{-2}{\cdot}d^{-1}$ for a station located at the head of the Harbor. Volumetric rates show a similar >5-fold variation (Montgomery, 1988), while data from Squires (1984) shows a 23-fold areal and seasonal variation. Annual production based on the Fraser and Wilcox (1981) data was calculated as 809 $g\ C{\cdot}m^{-2}{\cdot}yr^{-1}$. Wet and dry season values did not show the same increase as in Tampa Bay; wet-dry season rates were 2 and 2.3 $g\ C{\cdot}m^{-2}{\cdot}d^{-1}$, respectively.

The range of daily, areal production rates illustrated for embayments in the Eastern Gulf of Mexico Planning Area were based on the values reported by McNulty (1969), coupled with values calculated from Johansson *et al.* (1985) and Fraser and Wilcox (1981). A reasonable estimate of annual production in this section of the Eastern Gulf of Mexico Planning Area is on the order of 400 to 800 $g\ C{\cdot}m^{-2}{\cdot}yr^{-1}$. As noted above, spatial and temporal variability within coastal embayments is high (>5-fold).

Myers and Iverson (1981) provide limited information on primary production, chlorophyll a, and nutrients for several estuaries in the northeastern Gulf of Mexico. Average volumetric ($mg\ C{\cdot}m^{-3}{\cdot}h^{-1}$) production rates for six locations sampled over a period from May to September, 1974 to 1976 were presented. Insufficient information on incubation time, water depth, or clarity was provided; therefore, calculation of areal rates was not possible, nor was it possible to use this data set for estimates of annual production or variability for embayments adjacent to the Eastern Gulf of Mexico Planning Area.

Average volumetric production rates presented by Myers and Iverson (1981) ranged from 6 to 40.3 $mg\ C{\cdot}m^{-3}{\cdot}h^{-1}$. Values for Apalachicola Bay were 36.7 and 40.3 $mg\ C{\cdot}m^{-3}{\cdot}h^{-1}$ for two locations. Lowest values were on the order of 6 and 9.2 $mg\ C{\cdot}m^{-3}{\cdot}h^{-1}$ for the Ecofina estuary and a location between the Ecofina and Apalachicola Bay, respectively. Two locations in the Ochlockonee estuary had rates of 30.8 and 26.4 $mg\ C{\cdot}m^{-3}{\cdot}h^{-1}$. Correlations between productivity and phosphorus were greater than with all forms of soluble inorganic nitrogen. A step-wise multiple regression technique indicated that salinity and phosphorus concentrations were the only variables which yielded a significant relationship ($p = 0.001$). However, neither nutrient availability, nutrient limitation, nor the N/P ratio could explain the approximately 7-fold variation in volumetric production rates between locations.

Coastal Waters

Representative values for primary production in coastal waters of the eastern Gulf of Mexico were limited (i.e., data from Bittaker [1975] as cited in Iverson and Hopkins [1981] and one measurement from Vargo *et al.* [1987]). Nine data points were available from Bittaker (1975) that covered six months at a location five miles off the mouth of the Fenholloway River in Apalachee Bay. Values ranged from 125 to 400 mg $C\cdot m^{-2}\cdot d^{-1}$, an average of 246 mg $C\cdot m^{-2}\cdot d^{-1}$. The range for the month of July was 125 to 250 mg $C\cdot m^{-2}\cdot d^{-1}$. Vargo *et al.* (1987) reported a rate of 300 mg $C\cdot m^{-2}\cdot d^{-1}$ for waters less than three meters deep off the Chassahowitzka and Homosassa Rivers.

Blooms of the red-tide dinoflagellate, *Gymnodinium breve*, occur over a wide area on the West Florida Shelf of the eastern Gulf of Mexico. These blooms are both spatially and temporally heterogeneous, occurring during any month of the year with longitudinal transport (normally southward) along the entire west coast of Florida. Vargo *et al.* (1987) estimated productivity within blooms from direct measurements and Coastal Zone Color Scanner (CZCS) derived pigment values. Daily production rates ranged from 0.5 to 3.8 g $C\cdot m^{-2}\cdot d^{-1}$ with an average of 1.9 g $C\cdot m^{-2}\cdot d^{-1}$. Such values are five to six times greater than the averages calculated for non-bloom periods by Bittaker (1975) and Vargo *et al.* (1987). Blooms commonly last one to two months. Based on the average daily rate within a bloom, production by red-tides would range from approximately 60 to 120 g C/m^2 for a one- to two-month bloom. These rates are greater than the historical estimate of 30 g $C\cdot m^{-2}\cdot yr^{-1}$ (El-Sayed, 1972) for the West Florida Shelf. Vargo *et al.* (1987) estimated that these blooms could contribute an average of 40 percent of the annual shelf production. However, the frequency, duration, and areal extent of these blooms is poorly documented. Therefore, productivity estimates from red-tide blooms were not included in the present calculations for annual production and variability of coastal waters in the Eastern Gulf of Mexico Planning Area. The potential for annual re-occurrences of these blooms, however, can be used as an indication of high seasonal and areal variation of production in coastal regions.

Averages for winter/spring (November, December, and April) and summer/fall (May, June, and July) were calculated from Bittaker (1975) and Vargo *et al.* (1987) for non-red-tide bloom periods and were used to illustrate spatially averaged production (see the Eastern Gulf of Mexico map, Map Series). The average of all values suggested that an annual coastal waters production rate is approximately 89 g C/m^2. The information available indicated that there is little spatial variability, at least for a given month of the year, with approximately a three-fold temporal variation. Chlorophyll a values from Froelich *et al.* (1985) were insufficient to use for estimates of variability. Although Carder *et al.* (1986) measured chlorophyll concentrations at several nearshore locations, the data were not reported in a format that allowed for estimates at specific locations. Therefore, given the potential for episodic red-tides within the region and the paucity of data available for non-bloom periods in this section of the eastern Gulf of Mexico, any estimates of annual production or variability would be purely speculative.

Offshore Waters

Primary production data for the offshore waters of the Eastern Gulf of Mexico Planning Area span the years from 1964 to 1987. El-Sayed and Turner (1977) provided data for three locations within the region for June 1972. Several additional values were available from Ortner *et al.* (1984), Vargo *et al.* (1987), and El-Sayed and Trees (1980). The most comprehensive data set is based on the Yoder and Mahood (1983) study. Daily integrated ^{14}C-based production rates were determined at 29 locations in April and September 1982. Three additional sources of primary production values were found but were not used in the present analysis. Steele (1964) presents data from three stations at three depths along a transect that crossed the Loop Current at approximately 25°N latitude. Volumetric rates ranged from 0.3 to 1.08 mg $C \cdot m^{-3} \cdot h^{-1}$. However, since his samples were incubated under artificial light, these data were not included in the present analysis. Data from Trees (1985) encompasses two years of historical observations for 1964 and 1965 that cover most of the entire Gulf of Mexico. Values for 6 mo in 1964 and 12 mo in 1965 averaged 41.2 and 16.6 mg $C \cdot m^{-2} \cdot d^{-1}$, respectively. Annual production based on these values would range from 6.1 to 15 (mean = 7.6) g $C \cdot m^{-2} \cdot yr^{-1}$. All of the other available information indicated that daily and annual production rates are at least an order of magnitude higher. In light of this fact, it was decided not to include the information from Trees (1985) in the present estimates of spatially-averaged production or annual production.

With one exception, all the productivity values reported in the literature pertinent to this section of the Gulf were given as daily, areal rates. Data from El-Sayed and Trees (1980), reported as mg $C \cdot m^{-3} \cdot d^{-1}$ for given depths, were integrated using the trapezoidal rule to estimate daily areal rates. Two of their eight stations fell within the boundaries for the Eastern Gulf of Mexico Planning Area (approximately 25.9°N latitude, 86°W longitide and 28.9°N latitude 86.9°W longitude) with daily rates of 813 and 943 mg C/m^2, respectively.

Monthly averages were calculated from all usable sources. Values for seven months ranged from 150 to 878 mg $C \cdot m^{-2} \cdot d^{-1}$. This represents an approximately six-fold variation, however, the data span a time period of 10 yr. Nevertheless, seasonal averages were estimated from this information to depict the areal/seasonal variation for the eastern Gulf of Mexico. The seasonal rates included winter/spring (495 mg $C \cdot m^{-2} \cdot d^{-1}$; December through April) and summer/fall (410 mg $C \cdot m^{-2} \cdot d^{-1}$; May through November), although data from August, and October through December were not available. Information for August was available for a region in the eastern Gulf below 26°N latitude from El-Sayed and Turner (1977). Daily, areal rates for August 1973 showed a five-fold spatial variation ranging from approximately 190 to 1,570 mg $C \cdot m^{-2} \cdot d^{-1}$ with an average for the month of 402 mg $C \cdot m^{-2} \cdot d^{-1}$. This value was essentially the same as the seasonal averages for the entire region.

All of the existing usable data were combined to estimate annual production for the region (see Eastern Gulf of Mexico map, Map Series). A grand mean of 452 mg $C \cdot m^{-2} \cdot d^{-1}$ yields an annual production of 165 g $C \cdot m^{-2} \cdot yr^{-1}$. This value is considerably higher than the original estimate of 29 g $C \cdot m^{-2} \cdot yr^{-1}$ for coastal and oceanic waters in the Gulf by El-Sayed (1972). Later, El-Sayed and Turner (1977) increased this mean production value to 105 g $C \cdot m^{-2} \cdot yr^{-1}$. Vargo *et al.* (1987), using information from Yoder and Mahood (1983) and Yoder (1989, Skidaway

Institute of Oceanography, pers. comm.) estimated annual production rates for waters >100 m (328 ft) as 150 to 180 g $C \cdot m^{-2} \cdot yr^{-1}$. Although there was insufficient seasonal data to provide a reliable estimate of the differences in annual production between northern and southern sections of the Eastern Gulf of Mexico Planning Area, an indication of the potential variation can be made by assuming that the June 1972 rates of 326 mg $C \cdot m^{-2} \cdot d^{-1}$ from El-Sayed and Turner (1977) are representative of the southern section and rates of 942 mg $C \cdot m^{-2} \cdot d^{-1}$ measured in March 1980 by El-Sayed and Trees (1980) are representative of the northern section. Annual production based on these values ranged from 119 to 344 g $C \cdot m^{-2} \cdot yr^{-1}$, approximately a three-fold variation. Since the offshore waters of this region are considered to be oligotrophic, an average annual mean on the low side of this north-south range would be expected. Therefore, the calculated value of 165 g $C \cdot m^{-2} \cdot yr^{-1}$ derived during the present analysis appears to be a reasonable estimate.

Data from Yoder and Mahood (1983) and Ortner *et al.* (1984) provided information on spatial and temporal variation within the region. Ortner *et al.* (1984) measured a 4-fold increase in production over a five-day period at the same location (154 to 682 mg $C \cdot m^{-2} \cdot d^{-1}$). They suggested that increased mixing and an uncoupling between phytoplankton production and grazing losses was responsible for the increase. Data from Yoder and Mahood (1983) can be partitioned in three depth categories for their April and September 1982 cruises (<100 m [328 ft], 100 to 500 m [328 to 1,641 ft], and >1,000 m [3,281 ft]). During the April cruise, the average values for each depth range were 500 mg $C \cdot m^{-2} \cdot d^{-1}$. For waters <100 m (328 ft), a 1.5-fold variation was noted; a 3.5-fold variation was evident for the 100 to 500 m (328 to 1,641 ft) region and a 7-fold variation was noted in waters >1,000 m (3,281 ft). Variability increased in the offshore direction due to variation in the position of the Loop Current. Similar spatial variability was found during September. Intrusion of Loop Current eddies with a corresponding increase in nitrate along the shelf break (depths >100 m [328 ft]) allowed development of subsurface chlorophyll maxima. Total water column production was linearly related to the amount of chlorophyll a in the subsurface maximum (Yoder, 1989, pers. comm.). Therefore, the frequency, duration, and latitudinal extent of these eddies will ultimately determine the annual productivity of shelf waters in the Eastern Gulf of Mexico Planning Area. Additional studies which relate total water column production to subsurface maxima will be required if biomass and productivity estimates based on CZCS or other remotely-sensed data are used for this region since these chlorophyll maxima occur between 40 and 80 m (131 and 262 ft); these depths are below one optical depth (i.e., the depth over which remote ocean color scanners can receive a signal) for these waters.

Information for this Planning Area was based on relatively few studies. This is particularly true for coastal waters where no seasonal information was available. The occurrence of red-tides within coastal waters yields additional problems for estimating production. The West Florida Shelf is one of the widest shelf areas in the world and supports both commercial and tourist fishing industries. Until a comprehensive, area wide, long-term program to assess production within this region is instituted, the assessment of water column primary productivity within the region must be viewed with caution.

2.2.6 Central Gulf of Mexico Planning Area

Coastal Waters

Relevant information on water column primary productivity in coastal waters of the Central Gulf of Mexico Planning Area (Figure 10) was available from three sources; Sklar and Turner (1981), Fucik (1974), and three locations cited by Trees (1985). Of the three references, only one was listed by UMES (1985). Although Fucik and El-Sayed (1979) was identified and contains some of the information found in Fucik (1974), it has not been plotted (see Figure 10 or the Central Gulf of Mexico map, Map Series). Fucik (1974) was employed in the current analysis since it contained dates and station location information for the associated production data. Data from Ferguson and Sunda (1984) were limited to a single volumetric production rate which could not be converted to an areal rate. This latter volumetric production rate was not used in the present analysis of seasonal or areal production.

Of the 34 references mapped by UMES (1985) for the Central Gulf of Mexico Planning Area, data from Sklar and Turner (1981) represents the only information available for water column production. Sklar and Turner (1981) measured production at monthly intervals along a six-station transect from the mouth of Barataria Bay to a location 40 km (22 nmi) northwest of the Mississippi River delta in 10 m (33 ft) of water. Production was estimated using two methods. At Stations A to E, water samples were incubated for 2 to 4 h in a light box with fluorescent lights. These values were used as an indication of potential production and were not used in the present analysis. *In situ* production measurements were conducted at Station F. Water samples were incubated for 4 to 6 h at five depths that corresponded to sampling depth. Areal production was calculated by integrating over depth and assuming a 12-h photoperiod. The areal rates were recalculated during the present analysis using a photoperiod based on mid-month at 30°N latitude. Sklar and Turner (1981) calculated an annual value of 290 g $C \cdot m^{-2} \cdot yr^{-1}$, while the photoperiod-corrected value was 339 g $C \cdot m^{-2} \cdot yr^{-1}$. The difference is well within the 25 percent coefficient of variation estimated by Sklar and Turner (1981) for the temporal and spatial variability of their data set.

Fucik (1974) measured production at two locations in 20 m (66 ft) of water approximately 50 mi off the Southwest Pass of the Mississippi River. The program was designed to assess effects of drilling activity on phytoplankton populations. One station, termed Platform, was located at an active drilling site. The second station was located 6 mi upstream from the platform and termed Control. Both locations were sampled 12 times from June 1972 to January 1974. All samples were incubated *in situ* at five depths for six hours between noon and sunset. Values were reported as hourly volumetric and integrated rates. Hourly rates of Fucik (1974) were converted to daily rates using the appropriate photoperiod as described above. Although 12 cruises were made to both locations, only eight months of data were available.

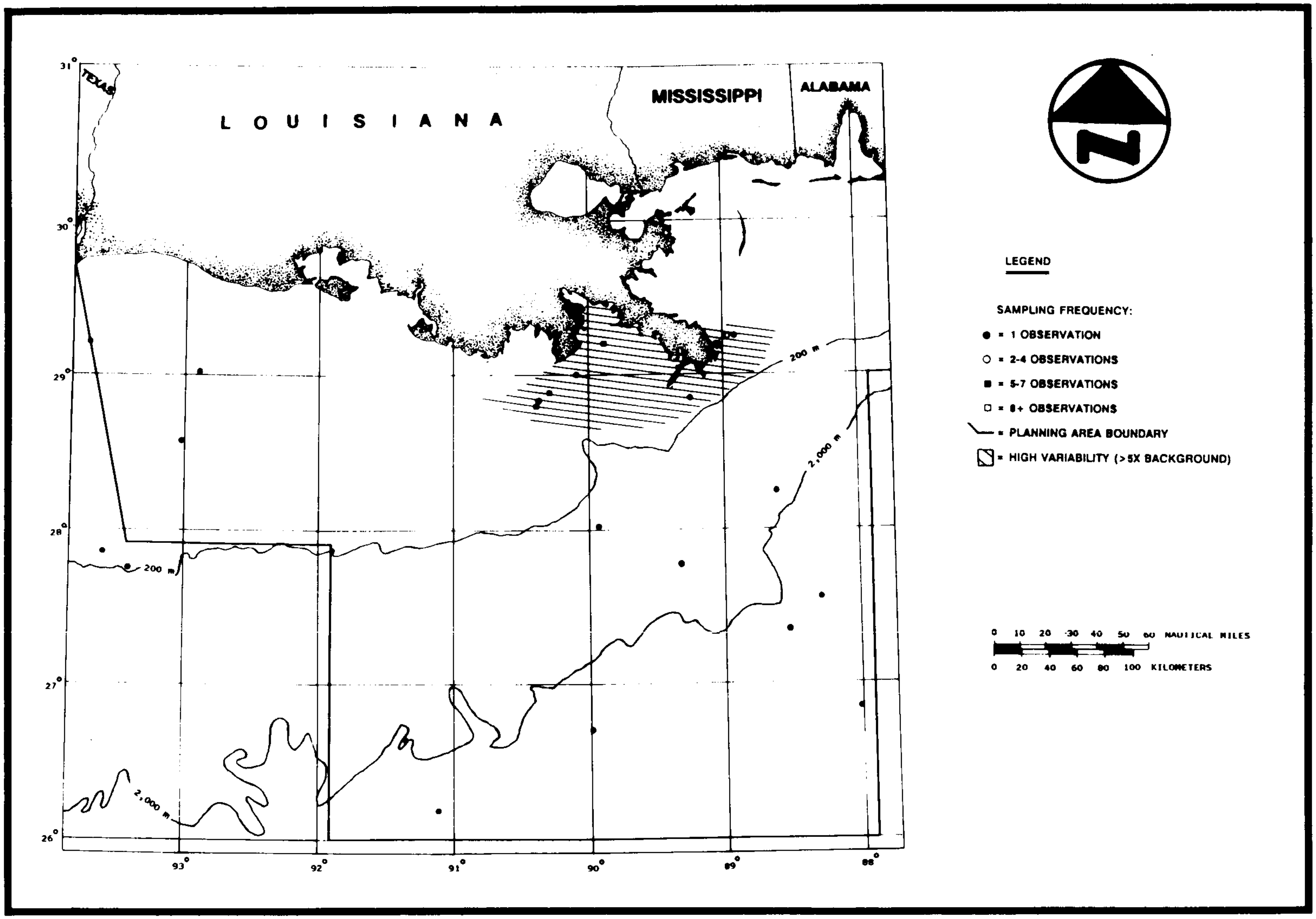


Figure 10. Sampling frequency in the Central Gulf of Mexico Planning Area with an indication of variability in primary production.

Average daily rates for the Platform and Control stations were approximately 1.3 and 1.1 g C/m^2. The range of monthly variation at both locations suggested that there was no significant difference in average annual production. Therefore, data from the Platform and Control stations were averaged to estimate an annual production rate of 473 g C/m^2. The annual production rate depicted in the Central Gulf of Mexico map (see Map Series) represents the average of the estimates based on the values of Fucik (1974) and Sklar and Turner (1981).

A comparison between the data from Fucik (1974) and Sklar and Turner (1981) suggests considerable temporal variability (Table 9). A five-fold difference is noted for January with a nine-fold variation in October. A similar interannual variation was noted in the Fucik (1974) data for his Platform location. Production in January 1973 and 1974 varied 17-fold, from 157 to 2,725 mg $C \cdot m^{-2} \cdot d^{-1}$, respectively. Monthly values, based on the average of the two data sets, vary by more than an order of magnitude (Table 9). The average, monthly value from both data sets was used to estimate seasonal variability (see Central Gulf of Mexico Map, Map Series). A two- to three-fold variation between winter/fall and spring is indicative of the seasonality in river flow, as noted below.

Data from Trees (1985) provided an indication of spatial variation. Integrated production rates at two locations approximately 60 mi apart and measured on consecutive days varied from 0.59 to 2.52 g $C \cdot m^{-2} \cdot d^{-1}$. Historical data from Thomas and Simmons (1960) indicated a similar spatial variation. Areal production for two locations off Pass a Loutre varied from 161 to 1,495 mg $C \cdot m^{-2} \cdot d^{-1}$. No information regarding the location of these stations with respect to the edge of the river plume was given. However, based on other information in Thomas and Simmons (1960), reduced production was associated with the high sediment load, and hence reduced light levels, in the river plume. Thomas and Simmons (1960) also assessed daily variability at one location within the plume over a three-day period. Hourly production rates were 0.82, 5.7, and 0.96 mg $C \cdot m^{-3} \cdot h^{-1}$. They associated the increased production with an increase in chlorinity. Neither temperature nor phosphate concentrations varied over the three-day period although high phytoplankton cell counts corresponded with the maximum production rate.

The estimates of annual production derived under the present study for coastal waters of the Central Gulf of Mexico Planning Area must be viewed with caution since they are based on limited data (i.e., two data sets). However, annual rates of approximately 300 to 400 g $C \cdot m^{-2} \cdot yr^{-1}$ are not unreasonable for this region. Koblents-Mishke *et al.* (1970) suggested a value of 500 mg $C \cdot m^{-2} \cdot d^{-1}$ for phytoplankton production around the Mississippi River delta which is intuitively low for coastal waters but may be representative of offshore regions. There are sufficient measurements of production rates in the range of 1 to 2 g $C \cdot m^{-2} \cdot d^{-1}$ from all of the sources noted above to suggest that the estimated annual production rate derived during the present analysis is reasonable.

Table 9. Average daily integrated primary productivity ($mg\ C \cdot m^{-2} \cdot d^{-1}$) (From: Fucik, 1974; Sklar and Turner, 1981).

Month	Fucik (1974)	Sklar and Turner (1981)	Average
Jan	2,045	390	1,159
Feb	--	450	450
Mar	--	765*	765
Apr	3,348	1,200*	3,348
May	--	2,400	2,400
Jun	558	417	489
Jul	745	1,510*	745
Aug	1,406	2,620	2,013
Sep	538	1,160	663
Oct	1,297	136	910
Nov	417	100	258
Dec	--	100	100

*Values were linearly interpolated from Figure 6B in Sklar and Turner (1981) but were not used in calculating the average.

Offshore Waters

Observations in offshore waters of the Central Gulf of Mexico Planning Area are also limited (Figure 10). Six usable records containing direct measurements of primary production were found (i.e., four records from El-Sayed and Turner (1977) for 1969 to 1972; two records from El-Sayed and Trees (1980) for 1980). Four additional values were found in Trees (1985) from 1965, however, as in the Eastern Gulf of Mexico Planning Area, they were unaccountably low for the reported chlorophyll concentrations. For example, Trees (1985) reported a production rate of 16.12 mg $C \cdot m^{-2} \cdot d^{-1}$ at a chlorophyll level of 0.18 mg/m^3, whereas the rate of El-Sayed and Turner (1977) was 402 mg $C \cdot m^{-2} \cdot d^{-1}$ at a chlorophyll level of 0.2 mg/m^3. Consequently, data from Trees (1985) were not used in the present analysis to determine estimates of variability or annual production.

Areal rates from El-Sayed and Turner (1977) ranged from 18.4 to 605 mg $C \cdot m^{-2} \cdot d^{-1}$ (1969-1972) for areas in the central Gulf between 26 to 29°N latitude and 88 to 91°W longitude. The two values from El-Sayed and Trees (1980) were 387 and 446 mg $C \cdot m^{-2} \cdot d^{-1}$ for 26°N latitude, 88°W longitude and 28°N latitude, 90°W longitude, respectively. These values represent information for June, October, and February. For measurements made within the same month and year, the variation is less than two-fold. Minimum and maximum rates were 18.4 and 605 mg $C \cdot m^{-2} \cdot d^{-1}$ (El-Sayed and Turner, 1977) based on measurements made in 1969 and 1972, respectively, at approximately 27°N latitude and 29°N latitude along 90°W longitude. The areal average, irrespective of time, was 317 mg $C \cdot m^{-2} \cdot d^{-1}$.

An assessment of chlorophyll concentrations from the same data sources showed a similar range of variation. Values ranged from 0.07 to 0.82 mg/m^3 which suggests high variability. However, a five-fold range of chlorophyll concentration can be found in vertical profiles at one location.

It is not possible to characterize the areal or seasonal variability in primary production within the offshore waters of this region with the available data. The graphic depiction of areal variation for this region contains all the data identified (i.e., average values for 1972 and 1980). The range of annual production, 115 to 184 g $C \cdot m^{-2} \cdot yr^{-1}$, was based on the grand average of all data and the average of two 1972 measurements from El-Sayed and Turner (1977), respectively. Although only limited confidence can be placed in these estimates, they are within the range calculated for offshore waters in the Eastern Gulf of Mexico Planning Area.

2.2.7 Western Gulf of Mexico Planning Area

Embayments

Primary production in the Corpus Christi estuary, which includes Corpus Christi and Nueces Bays, has been summarized by Flint (1984). The information contained in this publication was also used by Flint and Kalke (1985; 1986) for ecological studies of benthic structure and function which were summarized by UMES (1985). Flint (1984) was used in the present analysis for assessment of phytoplankton primary production in the embayments of the Western Gulf of Mexico Planning Area. Primary production measurements for other Texas coastal embayments (e.g., Galveston Bay, San Antonio Bay, Laguna Madre), were not found nor were there any useful references listed by UMES (1985). However, Flint (1984) does list annual production rates for all of the above embayments.

Primary productivity was measured at two locations in Nueces Bay and at six additional locations in Corpus Christi Bay (Figure 11). Samples were taken in June and July 1981 and at quarterly intervals thereafter from October 1981 to October 1983. Water was obtained from 0.5 and 1.0 m (1.6 to 3 ft) depth, partitioned into two light and one dark incubation bottle, and incubated *in situ* at two locations which were representative of water column conditions in Nueces and Corpus Christi Bays. Four-hour incubations, from 1000 to 1400 h, were carried out with parallel irradiance measurements. Flint (1984) converted volumetric rates (mg C/m^3 per 4-h period) to areal rates (mg $C{\bullet}m^{-2}{\bullet}d^{-1}$) using the ratio of incubation period light intensity to daily light intensity and the depth of the euphotic zone based on Secchi disc disappearance depths (or water column depth, whichever was less). Ancillary measurements included river flow, rainfall, temperature, salinity, and ammonia-nitrogen.

Four-hour volumetric production rates for the Nueces Bay stations were higher than middle-bay Corpus Christi sites and showed the greatest variability over the total area under study. Flint (1984) reported coefficients of variation of 100 and 93 percent for the Nueces Bay stations, whereas all the other stations had variations in the range of 65 to 79 percent. However, when areal rates were calculated (mg $C{\bullet}m^{-2}{\bullet}d^{-1}$), a different trend was observed. Daily areal production rates in Corpus Christi Bay were two to three times greater than Nueces Bay due to the shallow depth of this region. Production in Corpus Christi Bay increased toward the mouth of the bay. One exception to this generalization occurred at Station 5, at the mouth of Oso Bay, where a sewage outfall was located. Ammonia concentrations in this area were three times higher than at any other location.

Mean daily production rates were calculated for each season over the three years of the program. In Corpus Christi Bay, lowest production rates (approximately 0.2 to 0.4 g $C{\bullet}m^{-2}{\bullet}d^{-1}$) occurred in winter with highest rates in spring and summer (0.4 to 0.9 g $C{\bullet}m^{-2}{\bullet}d^{-1}$). In Nueces Bay, the seasonal picture was more variable with highest rates during Summer 1981, Spring 1982, and Fall 1983. Values ranged from 0.1 to 0.6 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ during the three-year period. Lower areal production in Nueces Bay corresponded to shallow Secchi depths (0.2 m) [0.66 ft], indicative of high turbidity. Multiple regression analyses of production in Nueces Bay indicated that river flow from the Nueces River explained 47 percent of the variation in productivity while Secchi depth contributed an additional 19 percent. Monthly rainfall was strongly correlated with variation in production in Corpus Christi Bay (78 percent of the total variability explained), while total sunlight and Secchi depth explained an additional 17 percent. Ammonia

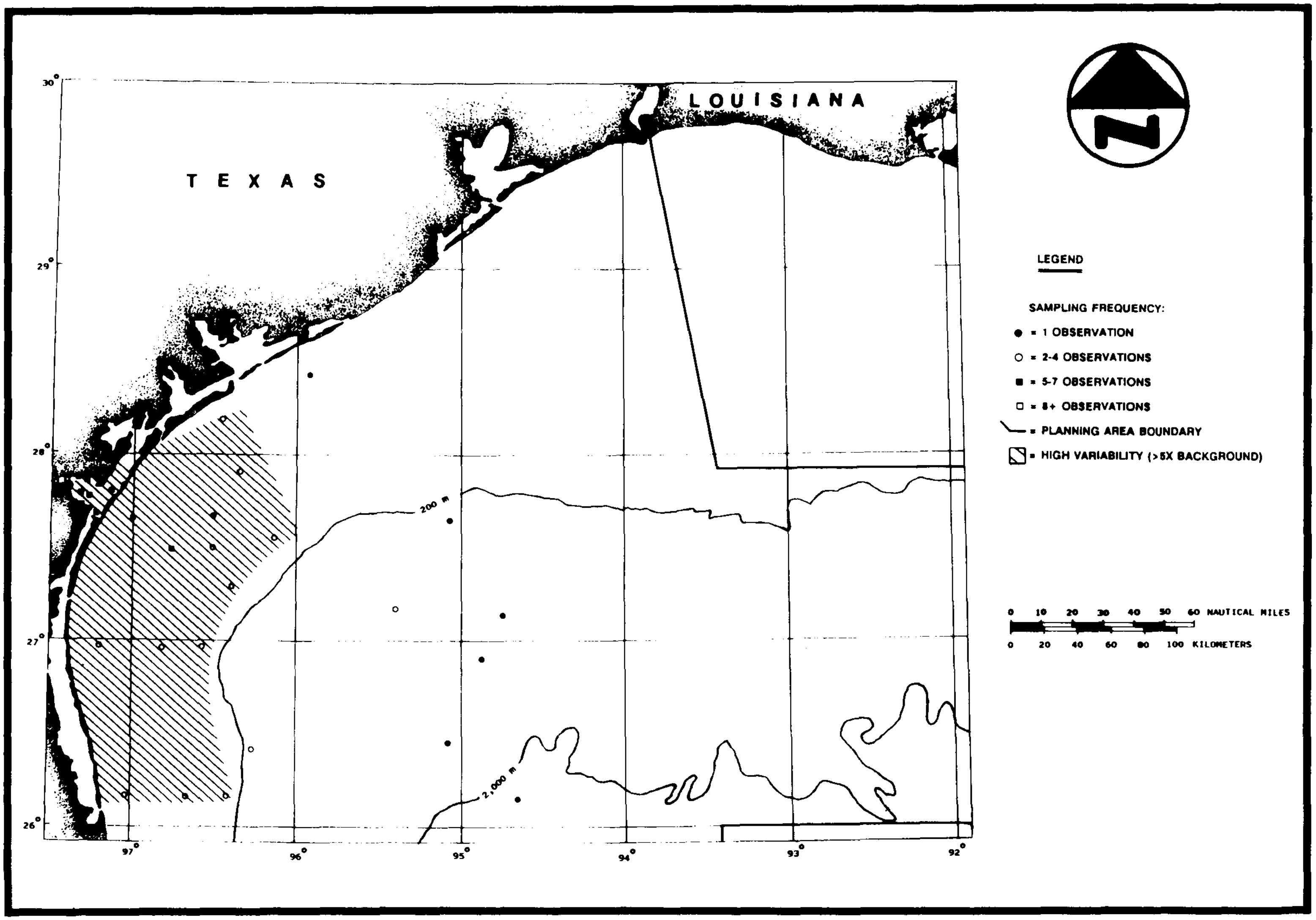


Figure 11. Sampling frequency in the Western Gulf of Mexico Planning Area with an indication of variability in primary production.

concentration was significantly related to variation in production in Corpus Christi Bay and explained an additional 1 percent of the total variability in the multiple regression analysis.

The average annual production rate for the entire estuary in 1981 was 717 mg $C{\bullet}m^{-2}{\bullet}d^{-1}$. However, Flint (1984) noted that winter rates were not measured for this year. He speculated that if the mean winter rates for 1982 and 1983 were included in the calculation for 1981, the average rate would have been reduced to 546 mg $C{\bullet}m^{-2}{\bullet}d^{-1}$. Annual averages for 1982 and 1983 were 347 and 422 mg $C{\bullet}m^{-2}{\bullet}d^{-1}$. These areally-averaged rates were cited as an indication of the variability found within coastal embayments for this region. The lack of information for other bays precluded a more detailed assessment. Since annual averages were available, it was determined that annual values gave a better indication of variability than the seasonal averages used for other regions.

The grand mean for the entire estuary over the three-year period was 480 mg $C{\bullet}m^{-2}{\bullet}d^{-1}$ or 174 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$. Annual averages of Flint (1984) were used to estimate annual production values of approximately 200, 127, and 154 g C/m^2 for 1981, 1982, and 1983, respectively. Daily areal rates for other estuaries in Texas ranged from 0.7 to 4.78 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ (Table 10). Most of the studies upon which these data are based were done with the oxygen method. Therefore, Flint (1984) assumed that the ^{14}C method he used measured only 70 percent of the production measured by the oxygen method. He subsequently reduced the values from the earlier studies by 30 percent for comparison with his values. Flint (1984) noted that an earlier study in Corpus Christi Bay yielded considerably higher daily rates. Annual production of 642 and 1,744 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$ can be calculated for Corpus Christi Bay and lower Laguna Madre, respectively, from these daily rates. Such values would be three-fold higher than reports for any other estuary (Flint, 1984) and are probably not representative of true annual production rates.

Tidal exchange and river inflow are small relative to the volume of the Corpus Christi estuary which, therefore, produces a long turnover time. Input of "new" nitrogen to sustain the high rates of phytoplankton production, and total production by macrophytes, and tidal-flat algae, is concomitantly low. Flint (1984) estimated that "new" nitrogen sources contributed only 3.3 percent of the annual nitrogen required for phytoplankton production. Earlier work on benthic nutrient regeneration indicated that the sediment can supply 23.9 g $N{\bullet}m^{2}{\bullet}yr$ as ammonia, which could potentially supply 90 percent of the nitrogen required for water column production. Consequently, recycling appears to be the major pathway for maintenance of primary production in this estuary.

Stockwell and Busky (1990) presented measurements of primary production at monthly intervals for four locations in Upper Laguna Madre. Production rates varied from 0.2 to 1.0 g $C{\bullet}m^{-2}{\bullet}d^{-1}$ over seagrass beds and from 0.5 to 3 g $C{\bullet}m\text{-}^{2}{\bullet}d^{-1}$ over muddy sediments. Nanoplankton, the 5 to 20 μm size fraction, accounted for 95 percent of the biomass and primary production in this area. Production rates at the lower end of the range reported by Stockwell and Busky (1990) were within the

Table 10. Comparison of phytoplankton primary production* rates for various Texas estuaries (From: Flint, 1984).

Estuary	Primary Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)
Galveston Bay†	4.11
San Antonio Bay§	0.70
Corpus Christi Bay (1960-1962)¶	1.76
Corpus Christi Bay (this study)	0.48
Upper Laguna Madre¶	2.68
Lower Laguna Madre¶	4.78

*Where photosynthesis was initially measured by oxygen production, oxygen production was converted to carbon fixation based upon ratio of 3:1 (Findko and Zaika, 1970). Oxygen production measures gross production; to convert to net production, which is more closely estimated by ^{14}C method, it was assumed net production was 70 percent of gross production (Riley and Chester, 1971).

†Armstrong and Hinson (1973).

§Davis (1971).

¶Odum and Wilson (1962); Odum *et al.* (1963).

range given by Flint (1984) for Corpus Christi Bay. The estimates presented in the current analysis, although based on one three-year data set, appear to be reasonable. Additional information on other embayments is certainly required for an adequate assessment of variability or site specificity.

Coastal Waters

Essentially all of the information relative to primary production in coastal waters in the Western Gulf of Mexico Planning Area comes from the Bureau of Land Management-funded Marine Environmental Study Program for the South Texas Outer Continental Shelf (STOCS). Four cross-shelf transects were established with field sampling commencing in December 1974 and ending in November 1978 (Figure 11). During the first year (1975), a total of 12 sites (i.e., Stations 1 through 3 on each transect) were sampled. Thirteen additional locations on all transects were added during the second and third year of the project. Phytoplankton cell counts, chlorophyll in two size fractions, particulate ATP, nutrients, and light transmission data were measured for all three years with surface primary production measurements using the ^{14}C method added in 1977. Net and nanoplankton chlorophyll were calculated by the difference between values determined before and after the water sample was filtered through a 20 μm Nitex mesh and collected on a 0.4 μm filter. The nanoplankton size-fraction was the difference between the total and net-plankton values. Initially, seasonal samples corresponding to winter, spring, and fall were taken at Stations 1, 2, and 3 on each transect. In 1976 and 1977, monthly sampling was done at selected locations (i.e., Stations 1, 2, and 3 along Transect II), which represented nearshore, mid, and outer shelf locations. Data from these locations have been used by Flint and Rabalais (1981a) to summarize the annual phytoplankton dynamics. Since the data set used by Flint and Rabalais (1981b) and Flint and Kamykowski (1984) for their publications is based on the reports by Kamykowski *et al.* (1977), Kamykowski and Van Baalen (1979), and Kamykowski *et al.* (1980), the information from Flint and Rabalais (1981a) and Kamykowski *et al.* (1979) from 1976 and 1977 was used for this summary.

Chlorophyll a concentrations displayed a pronounced seasonal and cross-shelf variability. Surface values for Station 1 (nearshore) ranged from approximately 0.2 $\mu g/l$ to greater than 3 $\mu g/l$ with maximum concentrations in the spring and minimum levels in late summer (July/August). Chlorophyll a at Station 2 ranged from approximately 0.1 $\mu g/l$ to 1 $\mu g/l$ in January. Values at Station 3, located at the seaward end of the transect, displayed a similar range and seasonal distribution as at Station 2, although lower concentrations were found during spring and fall. The nanoplankton size fraction showed lower seasonal variation than the net plankton (i.e., the "net" size fraction) but contributed a greater percentage of the total biomass. Average surface values for 1976-1977 presented by Flint and Rabalais (1981a) were 0.64 $\mu g/l$ for total, 0.45 $\mu g/l$ for the nanoplankton size-fraction, and 0.19 $\mu g/l$ for the net plankton size-fraction. An approximately two-fold seasonal variation occurred in the mean total chlorophyll concentration with highest values in winter (0.8 $\mu g/l$) and lowest in spring (0.43 $\mu g/l$). Flint and Rabalais (1981a) noted a north-south gradient in chlorophyll on the shelf with lowest values along the southern transect. They suggested that the Mississippi River had a greater influence in surface waters of the northern transects to account for the north-south gradient.

Surface, volumetric primary production rates (mg $C \cdot m^{-3} \cdot h^{-1}$) for two size-fractions at the three shelf locations were presented by Kamykowski *et al.* (1979). Total carbon uptake was highest at the inshore station with maximum rates of approximately 24 mg $C \cdot m^{-3} \cdot h^{-1}$ during April. Summer minima in total production occurred in July/August with rates of 2 to 3.5 mg $C \cdot m^{-3} \cdot h^{-1}$. Uptake rates declined 2- to 20-fold in a seaward direction depending upon the season.

Flint and Rabalais (1981a) also presented a seasonal picture of surface, volumetric production for the same year. Their values differed from those given by Kamykowski *et al.* (1979) with maximum rates of 2 mg $C \cdot m^{-3} \cdot h^{-1}$ for Station 1 in April. It is possible that a scale error occurred. However, annual mean values for this same year were presented in their Appendix Table A-5, wherein the mean of total carbon uptake was 4.99 mg $C \cdot m^{-3} \cdot h^{-1}$ with the nanoplankton and net plankton size-fractions contributing 3.2 and 2.38 mg $C \cdot m^{-3} \cdot h^{-1}$. Standard deviations for these three rates were 5.37, 3.33, and 3.52 mg $C \cdot m^{-3} \cdot h^{-1}$, respectively. These averages and standard deviations reflect the Kamykowski *et al.* (1979) rates to a greater extent than the rates of Flint and Rabalais (1981a).

Flint and Rabalais (1981b) used this same data set to estimate areal and total annual production. An equation developed by Ryther and Yentsch (1957) which incorporated chlorophyll a measurements, an extinction coefficient, an average assimilation number, and a variable determined from total daily irradiance, was used to convert the volumetric rates to areal values for inner shelf waters. Production ranged from approximately 2 to 24.7 mg $C \cdot m^{-2} \cdot d^{-1}$. Annual production based on these calculated values was estimated at 103 g $C \cdot m^{-2} \cdot yr^{-1}$ which Flint and Rabalais (1981b) suggested was somewhat low since the spring peak in biomass for 1977 was not sampled. Later, Flint and Kamykowski (1984) used this data set plus additional information from measurements obtained from July 1981 to January 1983 (these data were not referenced or presented in their paper) to modify the Flint and Rabalais (1981a,b) estimate to 176.5 g $C \cdot m^{-2} \cdot yr^{-1}$.

Trees (1985) provided areal production rates for two locations within this study area from November 1978. One station was located very close to the mid-shelf STOCS site (i.e., Station 2, Transect II; 27.66°N latitude, 96.49°W longitude), and had a production rate of 116 mg $C \cdot m^{-2} \cdot d^{-1}$. The rate at the second location, northwest of the STOCS region at 28.42°N latitude, 95.93°W longitude, was 83.8 mg $C \cdot m^{-2} \cdot d^{-1}$. Both values are considerably higher than the daily areal rates presented by Flint and Rabalais (1981a,b). Extrapolating Trees (1985) daily integrated rates over a year yields values of 42.3 and 30.6 g $C \cdot m^{-2} \cdot yr^{-1}$, respectively, which are lower than the annual rates given by Flint and Rabalais (1981a,b) and Flint and Kamykowski (1984).

The formula of Rodhe *et al.* (1958) was used in the present analysis to estimate areal production from the monthly volumetric rates given by Kamykowski *et al*. (1979). These calculated areal rates range from 0.5 to 1.3 g $C \cdot m^{-2} \cdot d^{-1}$ for the inner-shelf station, 1.2 to 4.6 g $C \cdot m^{-2} \cdot d^{-1}$ for the mid-shelf station, and 0.37 to 3.3 g $C \cdot m^{-2} \cdot d^{-1}$ for the outer-shelf station. All of the calculated rates are one to three orders of magnitude higher than those estimated by Flint and Rabalais (1981a,b) and would yield annual rates of 300 to 800 g $C \cdot m^{-2} \cdot yr^{-1}$ for the three shelf locations. The rates calculated under the present analysis (i.e., areal rates) are erroneous since the reported chlorophyll concentrations would not support this magnitude of production. At chlorophyll concentrations similar to those reported by Kamykowski *et al*. (1979), volumetric rates in other areas are comparable to their values. Areal rates based on these chlorophyll concentrations in the Eastern and Central Gulf of Mexico Planning Areas are on the order of 300 to 500 mg $C \cdot m^{-2} \cdot d^{-1}$, although a direct areal comparison is difficult since the depth ranges in other regions were not comparable. However, there is an inexplicable difference in the volumetric rates presented by Kamykowski *et al*. (1979) and Flint and Rabalais (1981a,b) that can not be resolved. Also, the annual production rate of 103 (or 176) g $C \cdot m^{-2} \cdot yr^{-1}$ appears to be low for this region. This rate is in the range of current estimates for offshore waters of the Straits of Florida, coastal and offshore waters of the eastern Gulf of Mexico which were historically characterized by low production, and offshore waters of the central Gulf of Mexico.

The differences between the volumetric production rates presented by Kamykowski *et al*. (1979) and Flint and Rabalais (1981a) is puzzling. Further, the differences between the volumetric rates presented by Flint and Rabalais (1981a) (i.e., in their figure and Appendix Table A-5) and what appeared as low annual production values precluded an assessment of annual production for this region. An annual production of 103 g $C \cdot m^{-2} \cdot yr^{-1}$ would yield an average daily rate of approximately 300 mg $C \cdot m^{-2} \cdot d^{-1}$ which is considerably higher than the rates noted by Flint and Rabalais (1981a,b). This problem requires resolution since the values estimated by Flint and Rabalais (1981a,b) have been perpetuated through the literature.

Offshore Waters

Production measurements in the offshore waters of the Western Gulf of Mexico Planning Area are limited (i.e., three values from El-Sayed and Turner [1977]; two values in December, 1987 from a large-scale ring [Biggs, 1989, Texas A & M University, pers. comm.], and a series of rates from 1982, 1983, and 1984 listed by Trees [1985]), as depicted in Figure 11. All measurements were made using the ^{14}C method and were reported as daily areal rates; no recalculations were necessary.

Values from El-Sayed and Turner (1977) were from an area from 26.1°N to 27.6°N latitude along the 95°W longitude line. Rates in October 1969 were 157.7 and 172.6 mg $C \cdot m^{-2} \cdot d^{-1}$, whereas a value of 42.9 mg $C \cdot m^{-2} \cdot d^{-1}$ was recorded in June 1971. Data from Biggs (1989, pers. comm.) were measured at approximately 27°N latitude, 94.8°W longitude on successive days with rates of 290 and 360 mg $C \cdot m^{-2} \cdot d^{-1}$. Such values are similar to rates measured in offshore waters of the central and eastern Gulf regions. Annual production based on these rates would be in the range of 60 to 118 g $C \cdot m^{-2} \cdot yr^{-1}$ for El-Sayed and Turner (1977) and Biggs (1989, pers. comm.), respectively, however, annual values calculated from two months of data collected eight years apart must be used and viewed with caution.

Areal rates reported by Trees (1985) ranged from 24.7 to 63.7 mg $C \cdot m^{-2} \cdot d^{-1}$ for four months in 1982 to 1984. Measurements made at the same location (27.17°N latitude, 95.4°W longitude) in August 1982, June 1983, and February 1984 were 44, 29, and 50 mg $C \cdot m^{-2} \cdot d^{-1}$, respectively. Similarly, production at 27.5°N latitude, 96.5°W longitude on 29 June and 1 July 1984 had a range of 64 and 75 mg $C \cdot m^{-2} \cdot d^{-1}$. Rates at another location (26.4°N latitude, 96.3°W longitude) on two successive days in July 1984 were 24.7 and 27.6 mg $C \cdot m^{-2} \cdot d^{-1}$. Although these production rates are in the low range relative to those reported by Biggs (1989, pers. comm.) and El-Sayed and Turner (1977), they suggest that spatial and temporal variation for this region is low.

There is a general lack of information that can be used to estimate production or variability in the Western Gulf of Mexico Planning Area and adjacent waters. Proxy variables for production in offshore waters of this region were not found. It was noted in the present analysis that insufficient information is available to estimate annual production or to estimate variability with any degree of confidence. It is suggested, however, that production in the offshore waters of this region is similar to the central Gulf. However, the occasional presence of rings (i.e., eddies) shed by the Loop Current may induce upwelling at the Texas-Mexico shelf break (Walsh *et al.*, 1990). They estimated that nutrient input associated with the edge of these eddies could only support a "new" production of 15.6 g $C \cdot m^{-2} \cdot yr^{-1}$. This value is only 10 percent of the annual production noted above. Biggs *et al.* (1990) also suggested that cyclonic gyres in the western Gulf may be responsible for literature reports of elevated (i.e., two to five times other oceanic regions of the Gulf of Mexico) primary production in this region. Therefore, additional data are required for an accurate assessment of production in offshore waters of the Western Gulf of Mexico Planning Area.

2.2.8 Southern California Planning Area

The Southern California Planning Area includes the area between the U.S.-Mexico border and Cape San Martin. The physical and biological structure of this region is strongly influenced by the circulation of the California Current System (Hickey, 1979). The California Current System is composed of the low-salinity, southward flow of the core of the California Current and the northward flow of the California Undercurrent which is found inshore of this. The California Undercurrent may surface as the Davidson Current during winter months. The Southern California Bight is the area south of Pt. Conception where the California Current is separated from the coast by the Southern California Eddy, the counterclockwise circulation formed by the California Current and the northward flow inshore of this of the Southern California Counter Current. Jackson (1986) has recently reviewed the relation between the circulation and the epipelagic community in the Southern California Bight region. The biological structure of the Southern California Bight appears to differ from the areas offshore and to the north due to the presence of the Southern California Eddy. The coastal area near Pt. Conception and to the north of it is more strongly affected by wind-driven coastal upwelling and the associated filaments and eddies. The circulation offshore of the Southern California Bight is affected by the eddies and fronts associated with the main flow of the California Current.

The environmental structure of the Southern California Bight region, including the patterns of primary production, has recently been reviewed and synthesized (Eppley, 1986). There are active research programs in several aspects of the structure of this region. The extensive data sets collected by these programs make the Southern California Planning Area a valuable example which is useful for comparison and for extending the conclusions reached for this Planning Area to other areas.

The Southern California Planning Area is one of the best sampled areas of the ocean for primary production. There are large data sets of direct measurements of water column primary production made by ^{14}C uptake. Production has been surveyed by: 1) the California Cooperative Fisheries Investigations (CalCOFI) (Hewitt, 1988); and 2) the Southern California Bight Study (SCBS) (Eppley, 1986) programs. Additional direct measurements have also been made by other programs. The large suite of additional oceanographic properties that have been measured by these programs allows the direct measurements of primary production to be put into a larger context. The present analysis focuses upon water column phytoplankton primary production. In some shallow nearshore areas of this Planning Area, production by macroalgae may also be locally important.

The ^{14}C uptake measurements employed by the SCBS program used a 24-h simulated *in situ* technique (Balch *et al.*, 1989). This yields a direct estimate of daily production. The ^{14}C uptake measurements determined during the CalCOFI program used a simulated *in situ* incubation done from local apparent noon until sunset yielding half-day production values (Scripps Institution of Oceanography, 1989). Both programs sampled the entire euphotic zone typically using six depth intervals. The data are considered here in terms of daily carbon uptake which is vertically integrated through the water column. The CalCOFI values have been normalized to daily (24-h uptake) values by multiplying them by two. This was done in order to allow direct comparison with the results of other Planning Areas. This may result in a small overestimate, since direct comparisons with the SCBS 24-h incubations yielded a conversion factor of about 1.8 (Balch *et al.*, 1989). The CalCOFI and SCBS measurements comprise more than 90 percent of the direct measurements of primary production in the Southern California Planning Area.

Primary production has also been measured by other programs using techniques that differed in some aspects from those used by the CalCOFI and SCBS programs. Values reported in the literature as daily or yearly estimated primary production have been used for comparison with the CalCOFI and SCBS data. Other research projects were directed at specific "process" questions, and used techniques which generated data that can not be directly converted to either daily or yearly production integrated through the euphotic zone. For example, in some cases only a single depth was sampled or in other cases the incubations were not made at *in situ* light levels. These latter measurements are useful for putting the observations made with standard techniques in a larger context and for comparison with other areas where similar techniques may have been used. A total of 642 directly comparable measurements of primary production have been identified for this Planning Area (see Southern California map, Map Series).

The analysis of primary production in this Planning Area should also consider how the measured primary production is separated into patterns of new and regenerated production. New primary production is the production supported by new nutrients (e.g., NO_3) that are mixed or advected into the system from outside or below (Dugdale and Goering, 1967). This is also referred to as export production (Eppley and Peterson, 1979), since, at steady state, this is also the amount of production that is available for utilization by upper trophic levels or export from the system. Regenerated primary production is that sustained by nutrients regenerated by excretion by heterotrophic organisms within the system (e.g., NH_4). Total production is the sum of new and regenerated production. The fraction of total production that is new production is referred to as the f-ratio (Eppley and Peterson, 1979; Harrison *et al.*, 1987). New and regenerated production are measured with isotope uptake techniques, and they can also be estimated from biogeochemical models and from sediment trap data.

The f-ratio is observed to be positively correlated with both total production and with the ambient nutrient concentration (Eppley and Peterson, 1979; Harrison *et al.*, 1987). Since both the f-ratio and total production appear to be higher in coastal areas where production is high, the new production will be disproportionately higher in these areas. The yield from higher trophic levels and the patterns in biogenic properties affected by primary production, such as the flux of materials from the euphotic zone or the carbon system, may be more directly affected by new production than the total production.

In addition to the direct measurements of ^{14}C uptake, there are also indirect proxy indicators that can be used to extend conclusions to spatial and temporal scales which have not been directly sampled. Useful proxy variables include: nearsurface and integrated chlorophyll, nearsurface temperature, the nearsurface concentration of nutrients and dissolved oxygen, and macrozooplankton biomass. The surface and integrated chlorophyll concentration has been measured extensively from shipboard sampling. The nearsurface chlorophyll distribution can also be estimated from remote sensing of ocean color. The chlorophyll concentration is correlated with primary production in many cases (Hayward and Venrick, 1982; Smith and Baker, 1982; Eppley *et al.*, 1985), thus providing more detailed information about spatial and temporal pattern. Interannual variations in primary production and macrozooplankton biomass have also been observed to be related to interannual sea surface temperature anomalies. Nearsurface nutrients tend to be inversely correlated with sea surface temperature in areas where sea surface temperature corresponds to temperatures in the thermocline below the depth of the nutricline (Dugdale *et al.*, 1989). Sea surface temperature patterns can thus be used to infer the location of areas of strong forcing where nutrients have recently been brought to the euphotic zone. An ongoing program of measuring temperature, salinity, chlorophyll, and nutrients at the Scripps Institution of Oceanography pier twice weekly also provides information about high-frequency variations about physical structure and phytoplankton abundance in the coastal margins of this region. The long time series of macrozooplankton biomass measurements collected by the CalCOFI program provides an indication about seasonal and interannual variations in secondary production and, by inference, primary production.

Spatial patchiness and temporal variability in primary production makes it impossible to infer its patterns on all scales based only upon direct measurements, even with the extensive data sets available for the Southern California Planning Area. Production varies seasonally and between years. Patches of high production tend to obscure the mean patterns. However, in spite of this, some patterns are evident in the direct measurements. There tends to be a north to south decrease in production. Production is generally higher near the coast, but there is also frequently an offshore maximum in chlorophyll and primary production. The area near Pt. Conception often has patches of very high values of chlorophyll and primary production, due to coastal upwelling. Observations from individual cruises suggest that the areas within a few kilometers of the coastal margin and the islands and offshore banks tend to have higher production than the surrounding waters. Production tends to be highest in the spring and early summer. The variability in production means that these patterns may differ significantly on any individual cruise or during a particular seasonal cycle. In addition to making sampling more difficult, this type of patchiness is an important aspect of planktonic community structure (Hayward, 1986) and it may affect the higher trophic levels of the system (Wroblewski and Richman, 1987).

The combination of strong local forcing and advection from areas of high production results in great spatial patchiness in the region. Observations of primary production in a coastal front off Santa Barbara (Smith *et al.*, 1987; Prézelin *et al.*, 1987) showed a spatial gradient of more than a factor of 10 over a spatial scale of a few tens of kilometers. Observations of an offshore front off southern California taken in 1985 and 1988 (Haury *et al.*, 1985) revealed spatial gradients in primary production of two and more than a factor of 10 in chlorophyll over a spatial scale of 50 to 100 km (27 to 54 nmi). The proxy indicators discussed below provide much additional information about spatial patchiness and its causes.

At least some of the causes of the spatial patterns in primary production are evident. Primary production is affected by phytoplankton biomass, nutrients, light, temperature, and other properties. The effects of these factors on primary production in the Southern California Bight have recently been reviewed (Eppley and Holm-Hansen, 1986). Phytoplankton biomass is largely determined by the level of primary production. The nutrient distribution is probably the most important environmental determinant of primary production in this region. Eppley *et al.* (1978) synthesized the relation between the NO_3 distribution and primary production. Nitrate appears to be the most strongly limiting nutrient, since PO_4 may be found in the surface waters after NO_3 has been depleted (Eppley and Holm-Hansen, 1986). The large-scale seasonal integral primary production is limited by the nutrient input to the upper layers (Hayward, in review). The nutrient input is, in turn, determined largely by physical structure. Instantaneous production may or may not be nutrient limited, depending upon whether or not there has been a recent nutrient input. Patchiness in primary production is caused mainly by physical processes which affect phytoplankton abundance and the supply of nutrients to the euphotic zone. Strong nutrient inputs affect not only the primary production but the f-ratio. Anthropogenic nutrient inputs are small. The largest anthropogenic source is the treated effluent discharged from metropolitan sewage treatment plants. Detectable effects upon primary production from this source are limited to localized areas within a few kilometers of the discharge from treatment plants (Eppley, 1986).

The north-south gradient in primary production may result from the occurrence of stronger coastal upwelling in the northern part of the Planning Area, especially near upwelling centers such as Pt. Conception. The offshore maximum in production may be caused by a combination of advection of nutrients and biomass from the north, and by *in situ* nutrient inputs associated with wind forcing and the mesoscale circulation patterns. The spatial patchiness results from advection of phytoplankton and nutrients, and from strong physical forcing which alters the nutrient distribution. The coupling between the circulation and primary production can be seen in the similarity of spatial patterns of the circulation, nutrient distribution, chlorophyll, and primary production.

Wind-driven coastal upwelling increases the nutrient input and stimulates primary production near the coast. This process is episodic and tightly coupled to the local wind field. Coastal filaments, eddies, and jets may transport rich coastal water away from the nutrient input area, and themselves may act as a nutrient source in a mechanism that is not yet fully understood (The Coastal Transition Zone Group, 1988). Wind-driven coastal upwelling appears to be most pronounced during spring and summer months. Wind-driven stirring of the mixed layer and erosion of the pycnocline, and nutricline, can also inject nutrients to the euphotic zone and stimulate production (Wroblewski and Richman, 1987). This process is also episodic and it affects the offshore regime as well as the coastal area. The nutrient input from wind-driven stirring is coupled to the local wind field, but on time and space scales that are different than for coastal upwelling. Vertical mixing and associated upward vertical diffusion through the nutricline and pycnocline is likely to be an important nutrient source in the oligotrophic offshore areas. This process has also been argued to be episodic, and it may also be a source of spatial and temporal patchiness in primary production (Eppley and Renger, 1989). Eddies and fronts have been shown to affect the nutrient distribution and primary production in both the coastal and offshore regions (Simpson *et al.*, 1984; 1986;

Pelaez and McGowan, 1986; Hayward, 1990). The spatial pattern of primary production in the Southern California Planning Area at any given time is due to the sum of these forcing processes. The relative importance of any individual process varies in space and time. Physical processes also act on different space and time scales. This makes it difficult to predict patterns of primary production and determine the causes of its variations.

Primary production in this region may also at times be strongly affected by nutrients and phytoplankton populations advected into the region from outside. Some of the primary production of this region is, in turn, advected to other regions. Thus the pattern of primary production has causes and consequences that extend well beyond the area.

Seasonal and interannual cycles can be seen in the direct measurements (Figure 12). Each plotted point in Figure 12(a) represents the spatial mean of approximately 13 primary productivity measurements from a single CalCOFI cruise; Figure 12(b) plots represent the spatial mean of approximately 65 chlorophyll measurements, also from a single CalCOFI cruise. The seasonal cycle in the spatial average primary production ranges to a factor of about three to five. The maximum occurs in spring or early summer, but the timing is not well resolved by the data. No seasonal cycle can be detected in some years. The spatial mean production ranges from about 300 to 800 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$ in winter to maximum values of 1,000 to 3,000 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$. Smith and Eppley (1982) show an estimated long-term mean seasonal increase of about a factor of two in their time series of spatial average primary production measured from 1974 to 1979 in the Southern California Bight region.

The seasonal cycle in primary production appears to be due to the annual cycle in nutrient availability and light. Interannual variability is caused by a combination of large-scale, or ocean basin wide, forcing processes and local physical processes. The extreme example of the large-scale processes is the El Niño phenomenon (McGowan, 1984; Fiedler, 1984) which has been shown to strongly affect this region. Lesser changes in production on an interannual time scale are also caused by large-scale forcing processes, as is indicated by the correlation between variations in primary production (Smith and Eppley, 1982) and macrozooplankton biomass (Chelton *et al.*, 1982) with interannual variations in sea surface temperature anomalies and transport of the California Current.

The pattern of primary production inferred from the proxy indicators is consistent with the patterns discussed above. The seasonal cycle in vertically integrated chlorophyll measured from shipboard surveys has a pattern similar to that of primary production (Figure 12). Great spatial patchiness is evident in shipboard surveys of nearsurface and integral chlorophyll. Nearsurface chlorophyll estimated from remote sensing of ocean color also shows great spatial patchiness (Pelaez and McGowan, 1986). The remote sensing of sea surface temperature and pigments and the estimates of chlorophyll and primary production derived from it (Smith and Baker, 1978; 1982; Eppley *et al.*, 1985; Balch *et al.*, 1989) show strong mesoscale variability. Shipboard surveys of physical structure and the nutrient distribution

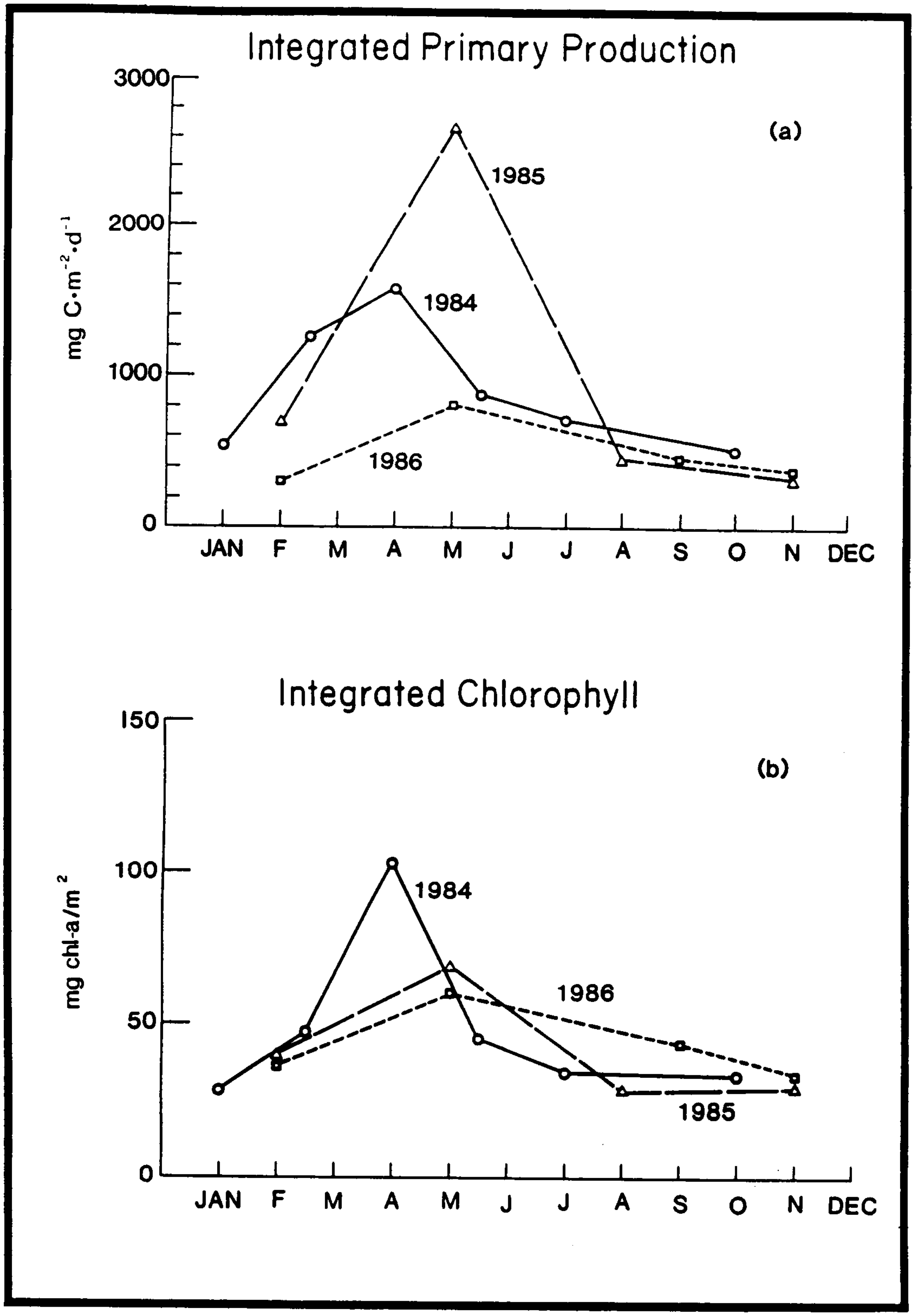


Figure 12. Seasonal and interannual variations in spatial average for: (a) primary production, and (b) vertically integrated chlorophyll in the Southern California Bight Region (From: Hayward, in review).

near Pt. Conception show great patchiness (Simpson, 1985). The long-term counts of diatom abundance at the Scripps Institution of Oceanography pier (Tont, 1976; 1981) and the more recent twice-weekly observations of temperature, salinity, chlorophyll, and nutrients show the highly variable structure of the coastal environment. This latter unpublished data source represents physical and chemical measurements made by the Marine Life Research Group, Scripps Institution of Oceanography. High diatom counts and high chlorophyll (greater than 10 times the background) are found in short-term events lasting days to a few weeks. The strong currents in the coastal region make it difficult to separate the effects of *in situ* growth from advection in causing these short-term events. The interannual variability is consistent with the large observed interannual variations in macrozooplankton biomass in the California Current (Chelton *et al.*, 1982).

The use of proxy variables to infer the pattern of primary production is illustrated with scatter plots of the relation between properties from an individual CalCOFI cruise (Figures 13, 14, and 15). These data are from CalCOFI Cruise 8404, which was conducted in April-May 1984 (Scripps Institution of Oceanography, 1984). The cruise covered the region from north of San Francisco to Baja California. Sea surface temperature is correlated with sea surface NO_3 in the range of temperatures corresponding to thermocline values below the nutricline (Figure 13). Areas of low sea surface temperature measured from shipboard surveys or satellite remote sensing can be used to identify areas of strong forcing or nutrient inputs, and to make inferences about the circulation of the region. Sea surface temperature is also correlated with surface chlorophyll (Figure 14). It can be seen that high chlorophyll is found only at temperatures where NO_3 can be found at the sea surface. The scatter in this relation is likely due to the time lag required for phytoplankton growth. The correlation between surface chlorophyll and primary production (Figure 15) shows that nearsurface chlorophyll measured from shipboard surveys or by the satellite remote sensing of ocean color can be used to infer the spatial pattern of primary production. The correlation between nearsurface chlorophyll and primary production is much weaker in offshore waters where there is a well-developed deep chlorophyll maximum layer (Hayward and Venrick, 1982; Michaelsen *et al.*, 1988).

The estimated annual mean in the spatial average primary production in the Southern California Planning Area is about 275 g $C \cdot m^{-2} \cdot yr^{-1}$, a relatively high level of production. This estimate was derived by assuming an average primary production of 500 mg $C \cdot m^{-2} \cdot d^{-1}$ for nine months a year and 1,500 mg $C \cdot m^{-2} \cdot d^{-1}$ for the three months during the spring increase. This seasonal cycle is also illustrated in the accompanying Map Series for southern California.

This estimate and the patterns described above are consistent with estimates derived by other investigators. The above estimate is about 50 percent greater than the yearly values derived for the SCBS survey region by Smith and Eppley (1982). The difference may be due to including the higher production region near Pt. Conception in the Planning Area estimate. Smith *et al.* (1987) measured primary production in a frontal region off Santa Barbara. A combination of incubations and

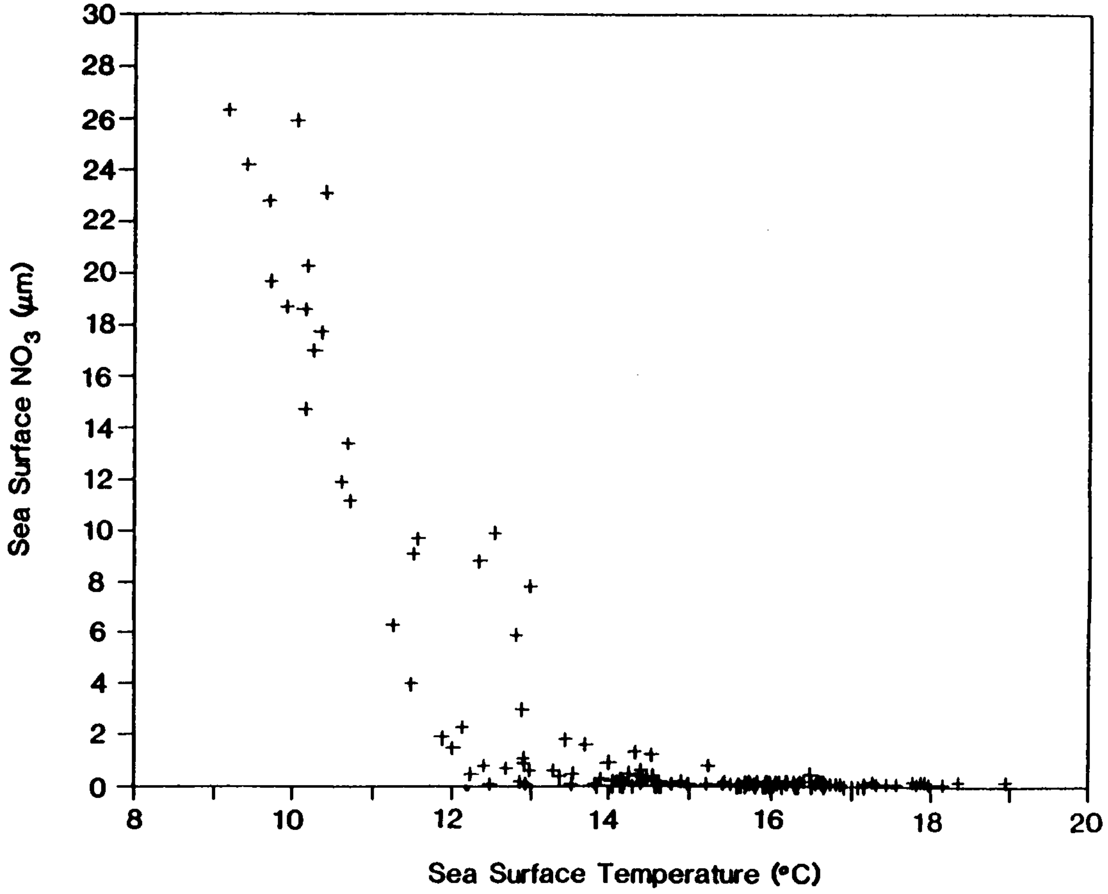


Figure 13. Scatter plot of sea surface temperature versus NO_3 for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April–May 1984. Data derived from Scripps Institution of Oceanography (1984).

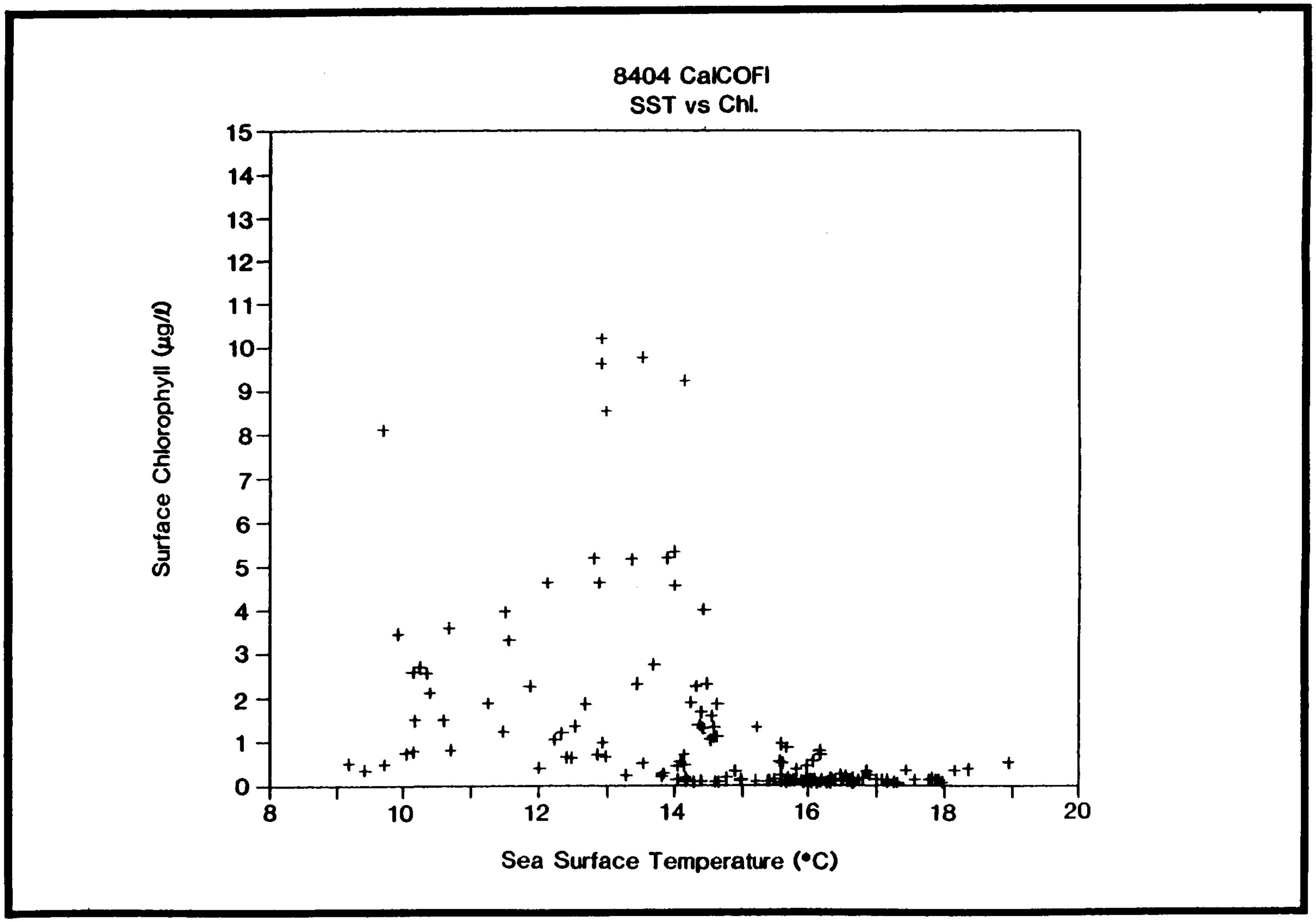


Figure 14. Scatter plot of sea surface temperature versus chlorphyll for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April-May 1984. Data derived from Scripps Institution of Oceanography (1984).

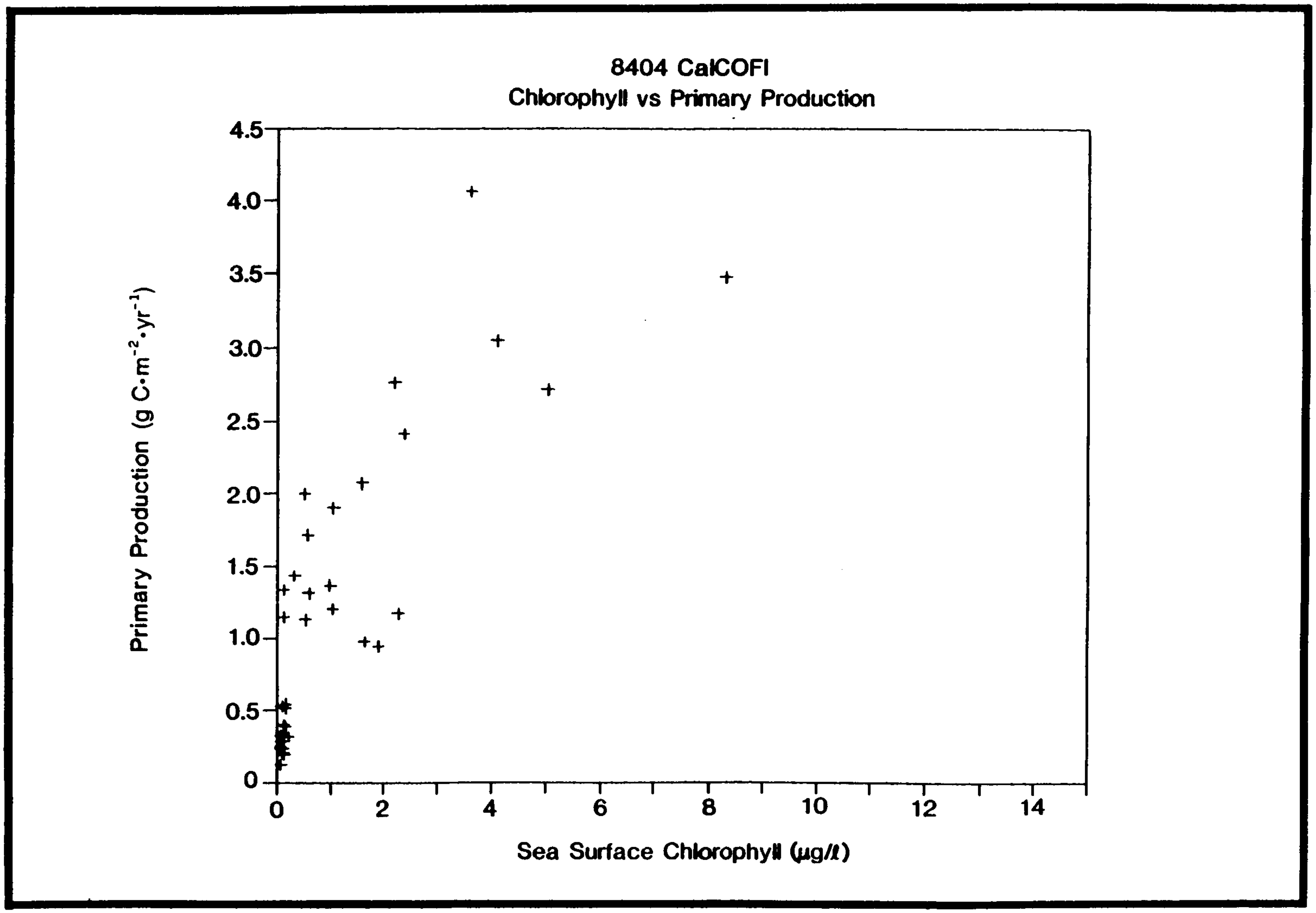


Figure 15. Scatter plot of sea surface chlorophyll versus integrated primary production for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April-May 1984. Data derived from Scripps Institution of Oceanography (1984).

models were used to estimate daily production. There was a strong spatial gradient in estimated primary production across the front from values of 227 mg $C \cdot m^{-2} \cdot d^{-1}$ on the warm side of the front to 3,323 mg $C \cdot m^{-2} \cdot d^{-1}$ on the cold side of the front. The above values are also consistent with the limited number of measurements presented by Owen (1974). The entire coastal region of California has been put in the 200 to 500 g $C \cdot m^{-2} \cdot yr^{-1}$ contour in the Berger *et al.* (1987) global synthesis of primary production. A mass balance budget of nutrients in the southern California region yielded an estimated annual average production of 600 mg $C \cdot m^{-2} \cdot d^{-1}$ (Roemmich, 1989). This general similarity in rates derived by different programs using somewhat differing methods indicates that large technique biases beyond those which may be common to the ^{14}C technique (Peterson, 1980) are unlikely. Primary production in the high production patches can be much higher than the annual mean or spatial averages. Production in the more oligotrophic offshore areas will be somewhat below the annual mean most of the time.

The entire Southern California Planning Area exhibits high variability in water column primary productivity (see Map Series). This means that patches with production values of greater than five times the background are likely to be common over the entire area. The great small and mesoscale variability make the concepts of average seasonal cycles or average spatial pattern of limited value. Any individual station is likely to have an annual signal that differs greatly from the average pattern. This makes detecting and documenting changes and the response, or lack of one, to an "event" or environmental perturbation much more difficult. Anthropogenic change is also made more difficult to separate from natural change as a result of this variability.

The large data set available for the Southern California Planning Area makes this area useful as a model for placing the more limited observations from other areas in a larger context. Patchiness is very important. The intense mesoscale patchiness in primary production is sufficient to obscure its patterns. Pattern on the mesoscale can only be inferred from indirect or proxy indicators. Interannual variability may be larger than the annual cycle, which means that measurements from different years should be interpreted as an annual cycle with caution. The mesoscale patchiness means that an observed annual cycle at a single location is unlikely to be a good representation of the annual cycle in the spatial mean. This variability also means that separating anthropogenic change from natural change or documenting a perturbation or event that has affected the primary production of the system will be difficult without a larger context in which to embed a set of measurements. The pattern of new primary production is much less well understood than the pattern of total production. New production will most directly affect upper trophic levels and biogeochemical cycling in the system (e.g., the carbon cycle). Study of the pattern of primary production in the continental margins of the ocean is an important aspect of large programs including Global Ocean Flux Study (GOFS), Global Ecosystem Dynamics (GLOBEC), and Coastal Physical Oceanography (COPO). Future evaluations of primary production should consider the results of these programs. Field programs should be coordinated if possible, since these observations have shown the tight coupling between primary production and the physical and chemical structure of the region. The patchiness in primary production may strongly affect the system and act in a different way than variability in the mean production. Thus both the mean and variability in production should be considered when evaluating the relation between primary production and upper trophic levels.

2.2.9 Central California Planning Area

The Central California Planning Area extends between Cape San Martin and Pt. Arena. This region includes the Monterey and San Francisco Bays, both of which are located within adjacent California State waters (i.e., within three miles of the outer coast). The biological structure of the area is strongly affected by the circulation of the California Current System (Hickey, 1979), with the southerly flow of the main body of the California Current offshore and the poleward flows of the California Undercurrent and Davidson Current closer to the coast. The circulation and biological structure in the coastal part of this Planning Area are strongly affected by wind-driven coastal upwelling and associated filaments and eddies.

The oceanographic structure of the Central California Planning Area has been examined by several programs including: 1) California Cooperative Oceanic Fisheries Investigations (CalCOFI) (Hewitt, 1988); 2) Coastal Ocean Dynamics Experiment (CODE) (CODE Group, 1983); 3) Coastal Transition Zone (CTZ) (The Coastal Transition Zone Group, 1988); 4) Northern California Coastal Circulation Study (NCCCS) (EG&G, 1989); 5) Ocean Prediction Through Observations, Modeling and Analysis (OPTOMA) (Rienecker *et al.*, 1987); and 6) Vertical Transport and Exchange (VERTEX) (Martin *et al.*, 1987) programs. Additional oceanographic measurements have been made on "process" cruises designed to study specific oceanographic processes such as offshore eddies (Simpson *et al.*, 1986) and nearsurface variability in the coastal region (Cox *et al.*, 1982; Simpson, 1985). These large programs and process studies provide a larger regional and oceanographic context in which to embed the direct measurements of primary production, and they provide a stronger basis for the use of proxy variables. Additional inferences about this region can also be drawn from comparison to the better sampled Southern California Planning Area.

The direct measurements of primary production in this region have been made primarily by the CalCOFI, CTZ, and VERTEX programs. Fifty-six direct measurements have been identified for the oceanic part of this Planning Area. Most of the measurements have been made with the CalCOFI technique, previously discussed in Section 2.2.8, Southern California Planning Area. Ninety-six additional direct measurements have been identified for San Francisco Bay. The locations of stations at which directly comparable sampling techniques have been employed is illustrated on the Central California map found in the Map Series.

In terms of primary productivity measurements, this region is much less well sampled than the Southern California Planning Area. Patterns of primary production are not well resolved based upon the direct measurements. This increases the need to rely upon proxy indicators. The focus of the following discussion is upon phytoplankton primary production in the coastal and offshore waters, although observations from San Francisco Bay are also available. The discussion is also limited to phytoplankton primary production, although production by macroalgae in the coastal kelp beds may be significant in the nearshore area.

The half-day (i.e., noon to sunset) simulated *in situ* incubations made by the CalCOFI and CTZ programs have been normalized to daily values by multiplying them by two (see also Section 2.2.8, Southern California Planning Area). Values from other programs have been reported as daily uptakes.

The spatial patterns can not be resolved from the limited direct measurements, but the strong coupling between physical structure and primary production is evident. Hayward and Mantyla (in review) measured primary production and other oceanographic properties in the region off Pt. Arena and Cape Mendocino in April-May 1987. The area of interest was separated into inshore and offshore sampling areas, with the boundary being the inshore edge of a coastal jet. The average primary production for the offshore waters was reported as 301 mg C/m^2 per half-day (i.e., ~600 mg C•m^{-2}•d^{-1}). The average for the inshore waters was 1,444 mg C/m^2 per half-day (i.e., ~3,000 mg C•m^{-2}•d^{-1}). These observations were based upon only seven stations in the offshore area and five stations in the inshore area. The inshore waters were more productive because the ambient nutrient concentration was much higher inshore of the coastal jet. The other properties measured in the area showed great patchiness, indicating that primary production in this area is also highly variable. Additional observations from this cruise are also discussed in Section 2.2.10, Northern California Planning Area.

Observations made in the VERTEX program (Fellows *et al.*, 1981) at a station located about 160 km (86 nmi) offshore from Pt. Sur gave an average daily production of 760 mg C•m^{-2}•d^{-1} or an estimated yearly production of 277 g C•m^{-2}•yr^{-1}. Observations by Karl and Knauer (1984) at a station about 100 km (54 nmi) northeast of Pt. Sur gave a mean daily integrated value of 564 mg C•m^{-2}•d^{-1} or 205 g C•m^{-2}•yr^{-1}. These measurements were made by ^{14}C uptake conducted over sequential 4-h incubations. The Central California Planning Area was contoured in the 200 to 500 g C•m^{-2}•yr^{-1} range by Berger *et al.* (1987) in their global summary of primary production. The annual primary production for stations in San Francisco Bay ranged from 93 to 150 g C•m^{-2}•yr^{-1} based upon measurements made at six sites from January 1980 to February 1981 (Cole *et al.*, 1986). Cloern (1984) estimated an annual production of 140 g C•m^{-2}•yr^{-1} in San Francisco Bay based upon sampling at four stations during 1982. Although conclusions must be limited by the great patchiness of the region, the general similarity in values of primary production taken by different groups and with somewhat different techniques indicates that large biases beyond those which are common to the ^{14}C uptake technique (Peterson, 1980) are unlikely.

The distribution of biological properties in the Central California region during a period of strong forcing is illustrated in Figures 16, 17, and 18. The data shown here were collected on CalCOFI Cruise 8404, conducted in April-May 1984 (Scripps Institution of

Oceanography, 1984). Sea surface temperatures were low in the central California coastal area north of Pt. Conception (Figure 16). The nutricline outcropped at the sea surface in a large coastal area north of Pt. Conception (Figure 17). The north-south and onshore-offshore gradient in nutricline depth is also evident. The chlorophyll distribution showed high values near the coast, but the highest values were found in an offshore tongue (Figure 18). The cause of the offshore maximum in chlorophyll on this cruise is not understood. It could be due to advection of phytoplankton biomass from the productive coastal region or due to an offshore, *in situ* nutrient source that is not evident in the nutrient distributions. Although the coastal region generally appears to be enriched with respect to the offshore region, an offshore maximum in chlorophyll is a common feature. Scatter plots of the relation between sea surface temperature, NO_3, chlorophyll, and primary production from this cruise have also been shown for the Southern California Planning Area in Figures 14 and 15.

The coastal region of the Central California Planning Area is generally enriched with respect to the offshore region. This enrichment is caused in part by coastal upwelling (Richards, 1981; Barber and Smith, 1981). More recent observations show that filaments, eddies, and fronts are also important features of the coastal region (Traganza *et al.*, 1981; Flament *et al.*, 1985; Hayward and Mantyla, in review) which act to enhance production. In addition to enriching the system, the high velocity flow associated with coastal filaments, meanders of the coastal jet, eddies, and fronts all may act to transport rich coastal water and its associated biota to the offshore parts of the California Current System. Offshore eddies and fronts (Simpson *et al.*, 1986) may also act themselves as an *in situ* enrichment mechanism and as a source of patchiness in this area.

The coastal region frequently has very high values of nutrients at the sea surface (Simpson, 1985). This results both in high total production and in high new production. The concept of new production has been discussed in more detail in Section 2.2.8. The high new production in the central California coastal region is likely an important resource for higher trophic levels. The phytoplankton populations formed in the production events may be advected for considerable distances if the loss terms (e.g., sinking and grazing, etc.) are low. This means that high production in this region could also serve as a food source to support production in higher trophic levels some distance away.

There appears to be a seasonal cycle in the direct measurements. The CalCOFI observations show primary production ranging from 400 to over 1,600 mg C/m^2 per half-day (800 to 3,200 mg $C \cdot m^{-2} \cdot d^{-1}$) in April-May 1984. Data taken in 1969 show daily values ranging from below 200 to over 1,100 mg $C \cdot m^{-2} \cdot d^{-1}$ (Owen, 1974). The cruise mean in the spatial average taken over the entire California coast from central Baja California to San Francisco (Hayward, in review) shows approximately a three-fold increase in spring, from 250 mg C/m^2 per half-day (500 mg $C \cdot m^{-2} \cdot d^{-1}$) to maximum values of about 750 mg C/m^2 per half-day (1,500 mg $C \cdot m^{-2} \cdot d^{-1}$).

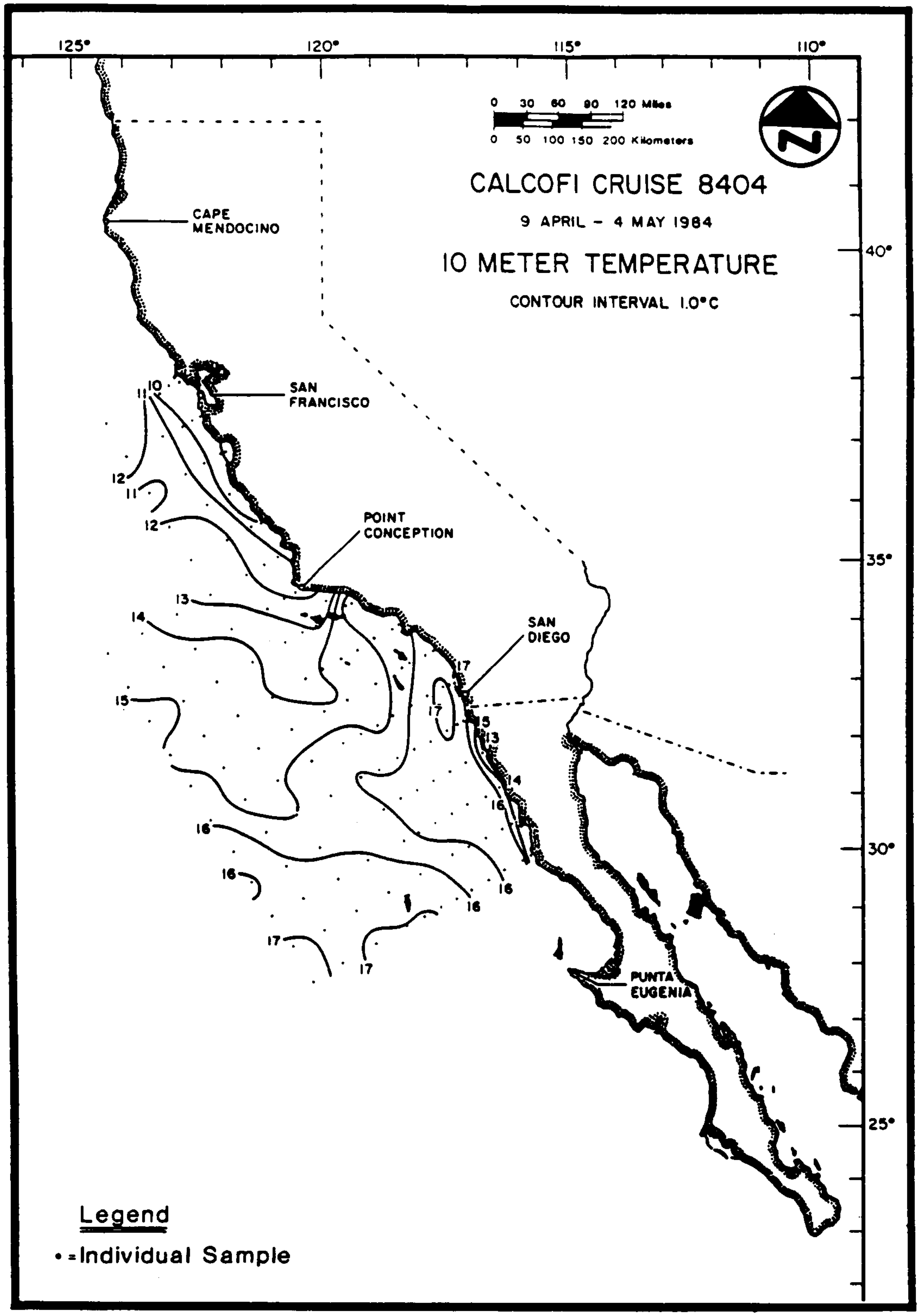


Figure 16. Spatial distribution of sea surface temperature for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April-May 1984 (From: Hayward, in review).

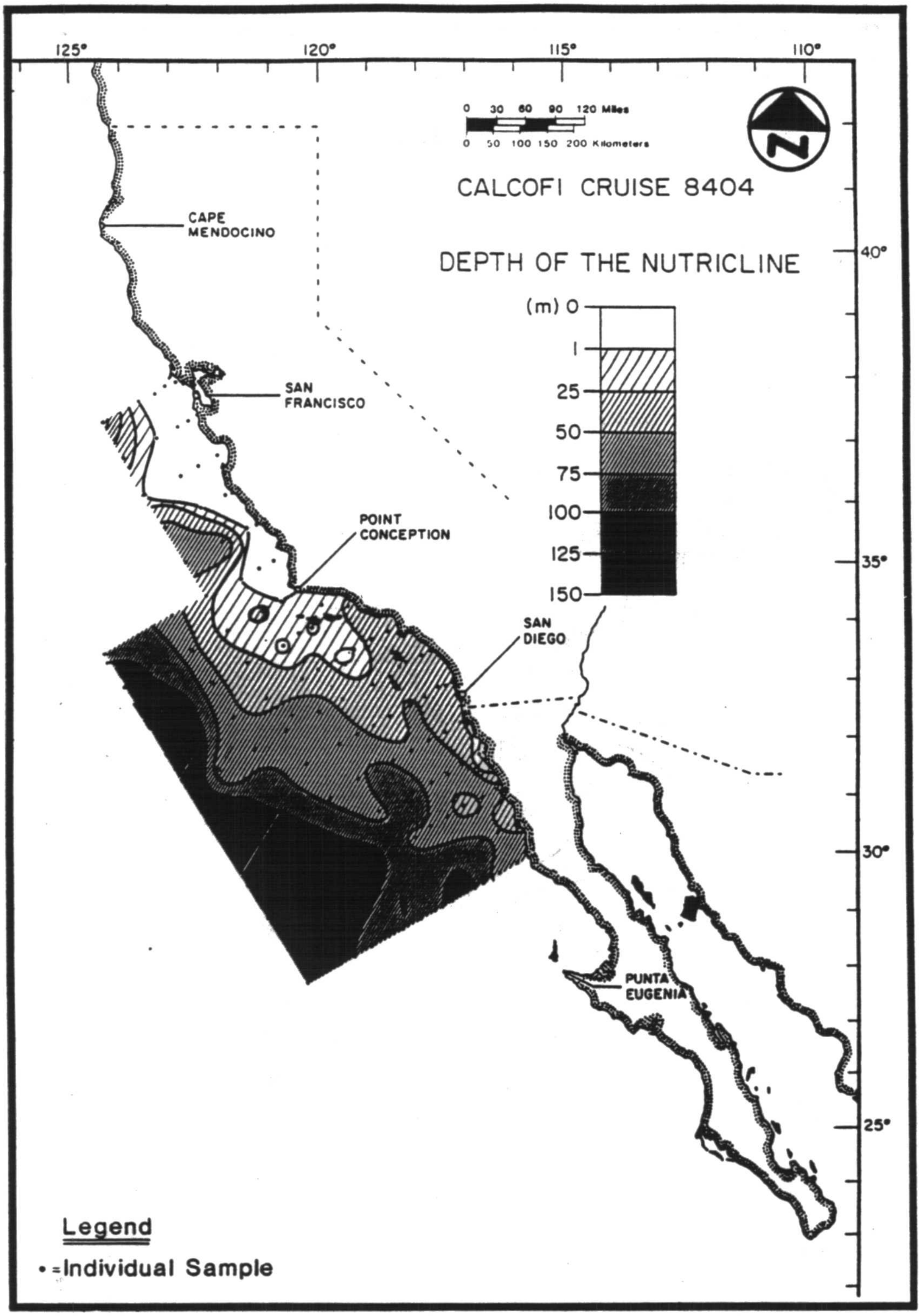


Figure 17. Spatial distribution of nutricline depth for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April–May 1984 (From: Hayward, in review).

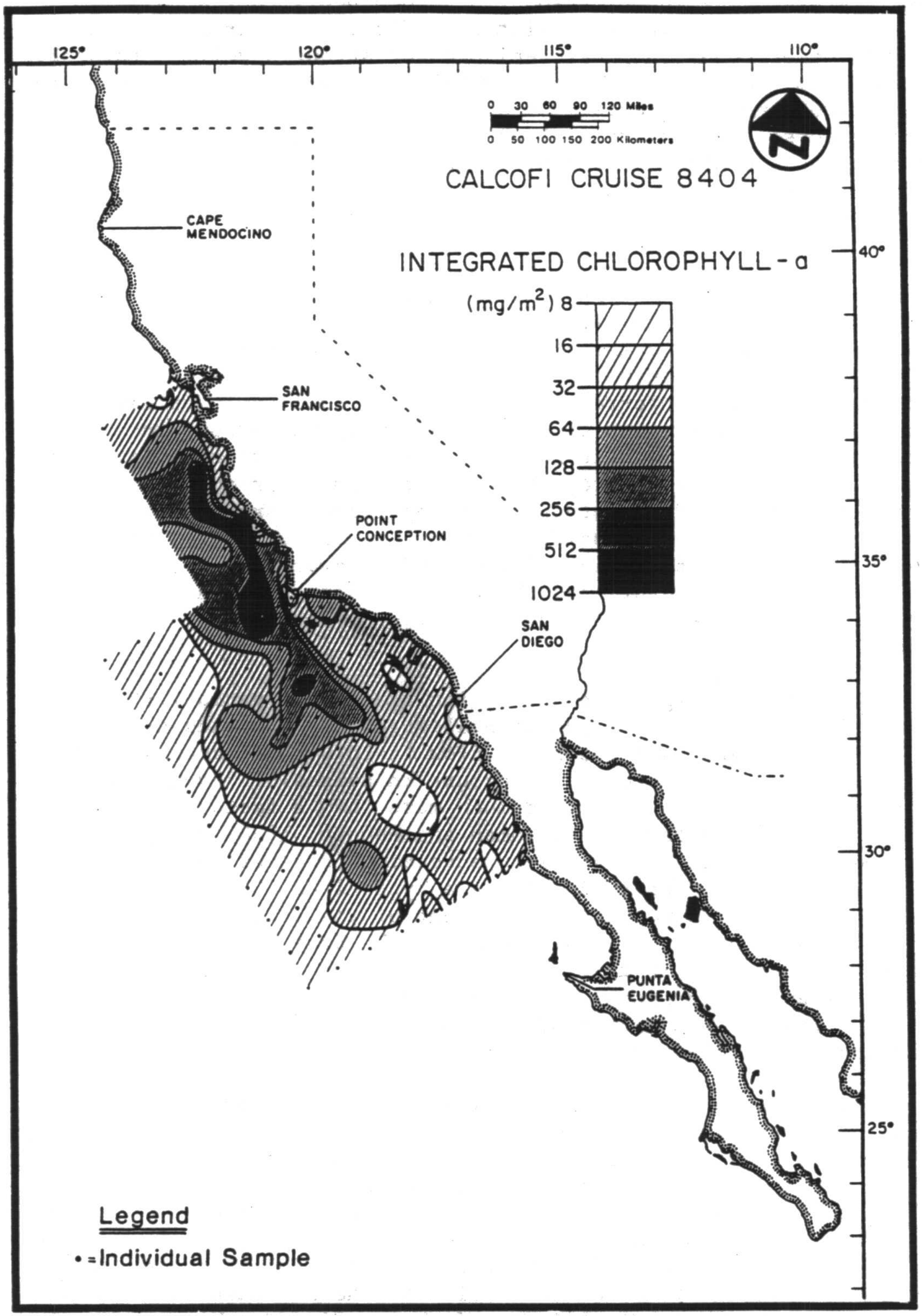


Figure 18. Spatial distribution of vertically integrated chlorophyll for the region from central Baja California to San Francisco from CalCOFI Cruise 8404, April–May 1984 (From: Hayward, in review).

There is also a strong seasonal cycle in physical structure. The spring transition (Strub *et al.*, 1987; Strub and James, 1988) is the dominant feature. The spring transition (combined with its fall counterpart) marks a change from winter conditions of strong storms to the spring-summer condition where episodes of strong upwelling-favorable winds blow from the north. The biological response to this has not been fully observed, and hypotheses must be made based upon models of the expected response. The macrozooplankton biomass time series shows stronger seasonal cycles and higher values in this region than in the southern California area. The higher values could be due to advection from a higher production source region to the north or to higher *in situ* production.

There is strong interannual variability in physical structure of which the El Niño phenomenon is a major example (Fiedler, 1984; McGowan, 1984). The mechanism of the biological response to interannual variability and the way in which primary production occurs is not well understood. The large inferred interannual variability in primary production is consistent with similar interannual variations in macrozooplankton biomass (Chelton *et al.*, 1982). The seasonal cycle in chlorophyll has a similar pattern to that of primary production (Hayward, in review). Nearsurface chlorophyll concentrations estimated from remote sensing of ocean color show intense spatial patchiness, especially in the coastal region (Pelaez and McGowan, 1986). Shipboard surveys of physical structure and the nutrient distribution show great patchiness in those factors believed to influence primary production (Simpson, 1985).

The dominant signal in the region is extreme variability or patchiness in space and time. Horizontal gradients are caused by the strong coastal currents and mesoscale flow field with filaments, eddies, and fronts. Much of the production occurs in pulses or "events" where the increase over background may be much more than a factor of 10. The events may last only a few days (Denman and Abbott, 1988) and patterns will be smeared on this same scale by advection (Breaker and Mooers, 1986). Hayward (1986) observed that on a typical CalCOFI cruise covering the California Current, 50 percent of the spatial integral of chlorophyll was found in only 20 percent of the area because it aggregated in patches. Primary production, because it is a rate, appears to be even more patchy. Breaker and Mooers (1986) and Denman and Abbott (1988) show the episodic variability in physical structure and chlorophyll in this region.

The annual spatial average primary production of the Central California Planning Area is estimated to be about 300 $g\ C{\cdot}m^{-2}{\cdot}yr^{-1}$. This estimate was made by dividing the Planning Area into two regimes consisting of an offshore and an inshore component (i.e., region or regime). Each regime is assumed to occupy about 50 percent of the area of the Planning Area and the Planning Area annual average is the mean of the annual average estimated for the two regimes. The offshore regime is assumed to have an annual cycle similar to the Southern California Planning Area with an annual estimate of about 275 $g\ C{\cdot}m^{-2}{\cdot}yr^{-1}$. The inshore regime is affected by coastal processes such as upwelling, filaments, and eddies. The annual cycle inshore is assumed to be an upwelling season of six months, with a spatial average production of 3,000 mg $C \cdot m^{-2} \cdot d^{-1}$, and a non-upwelling season, with a spatial average of 600 mg $C \cdot m^{-2} \cdot d^{-1}$. The annual average is estimated to be approximately 325 g $C \cdot m^{-2} \cdot yr^{-1}$. These estimated seasonal cycles are reflected in the Map Series, Central California map. The average for the two regimes is thus about 300 g $C \cdot m^{-2} \cdot yr^{-1}$, a relatively high level of production. Further, this entire region exhibits high variability (i.e., patches with primary productivity values greater than five times the background value are likely to be common).

2.2.10 Northern California Planning Area

The Northern California Planning Area extends from Pt. Arena to the California-Oregon border. This region can be characterized as having been poorly-sampled for oceanographic and, especially, biological properties. The southern section of the Northern California Planning Area, near Pt. Arena and Cape Mendocino, has been the object of the most intense study, and its oceanographic structure appears to be similar to the northern part of the Central California Planning Area. The remainder of the region is presumed to be similar to central California as well, but this conclusion is based upon inference and a limited suite of proxy variables, such as satellite remote sensing of temperature and chlorophyll.

Observations of physical, chemical, and biological structure in this Planning Area have been made by: 1) the Coastal Transition Zone (CTZ) (The Coastal Transition Zone Group, 1988); 2) Northern California Coastal Circulation Study (NCCCS) (EG&G, 1989); and 3) Ocean Prediction Through Observations, Modeling and Analysis (OPTOMA) (Rienecker *et al.*, 1987) programs. These observations, combined with the very limited direct measurements and the proxy indicators discussed below, allow some inferences to be made about the patterns of primary production. Additional inferences about the region can be made through comparison with the better sampled Southern and Central California Planning Areas.

This region is poorly sampled in terms of direct measurements of primary production. This area has not routinely been sampled for primary production by the California Cooperative Fisheries Investigations (CalCOFI) program or any other large program. A total of eight direct measurements of primary production have been identified for the region. The locations of these measurements have been illustrated in the Map Series, Northern California map. This section considers phytoplankton primary production, although production by macroalgae may be locally important in the nearshore kelp beds.

Measurements made with the CalCOFI primary production technique have been normalized to daily carbon uptake by multiplying the noon-to-sunset uptake by two. This may result in a slight overestimate since direct comparisons in the Southern California Planning Area yielded a conversion factor of about 1.8 (Balch *et al.*, 1989). See Section 2.2.8, Southern California Planning Area, for further discussion.

The direct measurements of primary production in this region are consistent with values observed in central California. The coastal region appears to be generally enriched with respect to areas further offshore. These limited observations can be put in a larger context by considering other oceanographic measurements made in the region. Observations of physical and biological structure made by the CTZ program show that wind-driven coastal upwelling and other forms of coastal forcing tend to be very strong near Pt. Arena and Cape Mendocino. Cold water is often found near the coast during shipboard surveys; this is also commonly seen in satellite images of sea surface temperature. This cold water is typically high in nutrients and is often high in chlorophyll. The relation between sea surface temperature and sea surface chlorophyll (and, by inference, primary production), however, is variable depending upon the residence time of water parcels in the coastal area and the response time scales of the phytoplankton (Abbott and Zion, 1985). The dominant pattern in the region is the high spatial or "event scale" variability. Much of the production appears to take place during these "events".

On one recent cruise which sampled chlorophyll and primary production in addition to other oceanographic properties near Pt. Arena and Cape Mendocino (SQ87; April-May 1987), the spatial average primary production in the coastal area (2,888 mg $C \cdot m^{-2} \cdot d^{-1}$) was about five times greater than in the offshore area (602 mg $C \cdot m^{-2} \cdot d^{-1}$; Hayward and Mantyla, in review). Additional observations from this cruise are illustrated in Figures 19, 20, and 21. The circulation in the study region was dominated by an equatorward flowing jet that was composed of low-salinity, low-nutrient water. The flow of this jet was also perturbed by a set of mesoscale eddies. The inshore edge of the coastal jet marked the boundary between rich coastal water and more oligotrophic offshore water. Sea surface nutrients were high inshore of the jet. Nutrients were depleted throughout the euphotic zone offshore of the jet. Primary production in the inshore region was variable depending upon the residence time and "age" of the water (i.e., time since this high nutrient water was brought to the euphotic zone).

A strong counterclockwise coastal eddy was observed near Cape Mendocino on Cruise SQ87 (Figure 19). The cyclonic flow of this eddy caused a doming of density surfaces. The circulation pattern in the eddy affected the distributions of chlorophyll and nutrients, and, through this, the pattern of primary production. The secondary circulation associated with the strong flow features in the region, such as the Cape Mendocino eddy, both affects the local nutrient distribution and advects water with differing characteristics from one locale to another. This is the only available data set which resolves both the mesoscale vertical and horizontal structure in biological properties in this region. However, the preliminary unpublished results of the 1988 observations of the CTZ program suggest that the 1987 structure was typical of at least one additional summer.

Simpson (1985) sampled the mesoscale nearsurface distributions of biological and chemical properties related to primary production in the Pt. Arena region. He observed very large gradients in temperature, nutrients, chlorophyll, and dissolved oxygen over a spatial scale of a

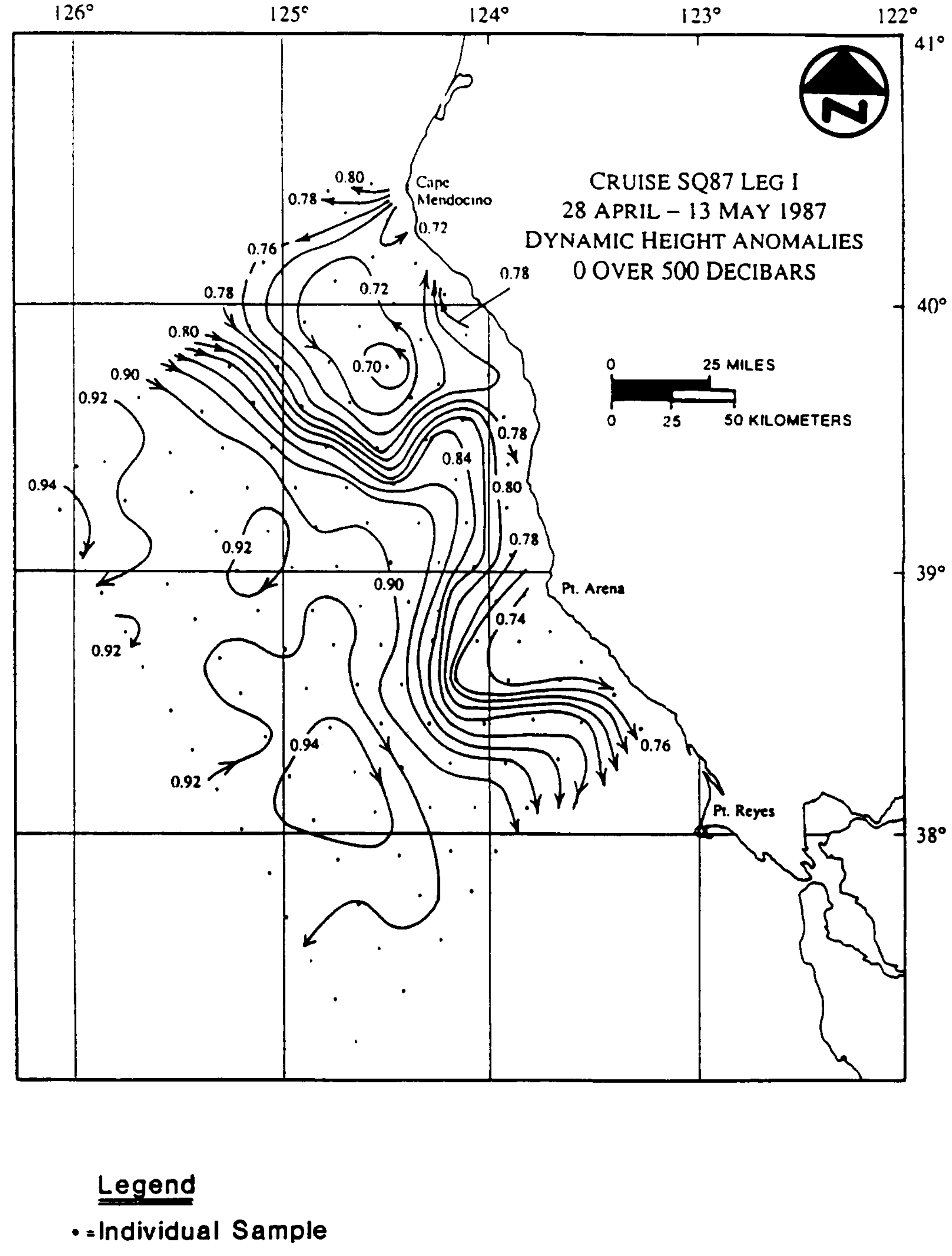


Figure 19. Spatial distribution of dynamic height anomalies for the Northern California Planning Area for Cruise SQ87, April-May 1987 (From: Hayward and Mantyla, in review).

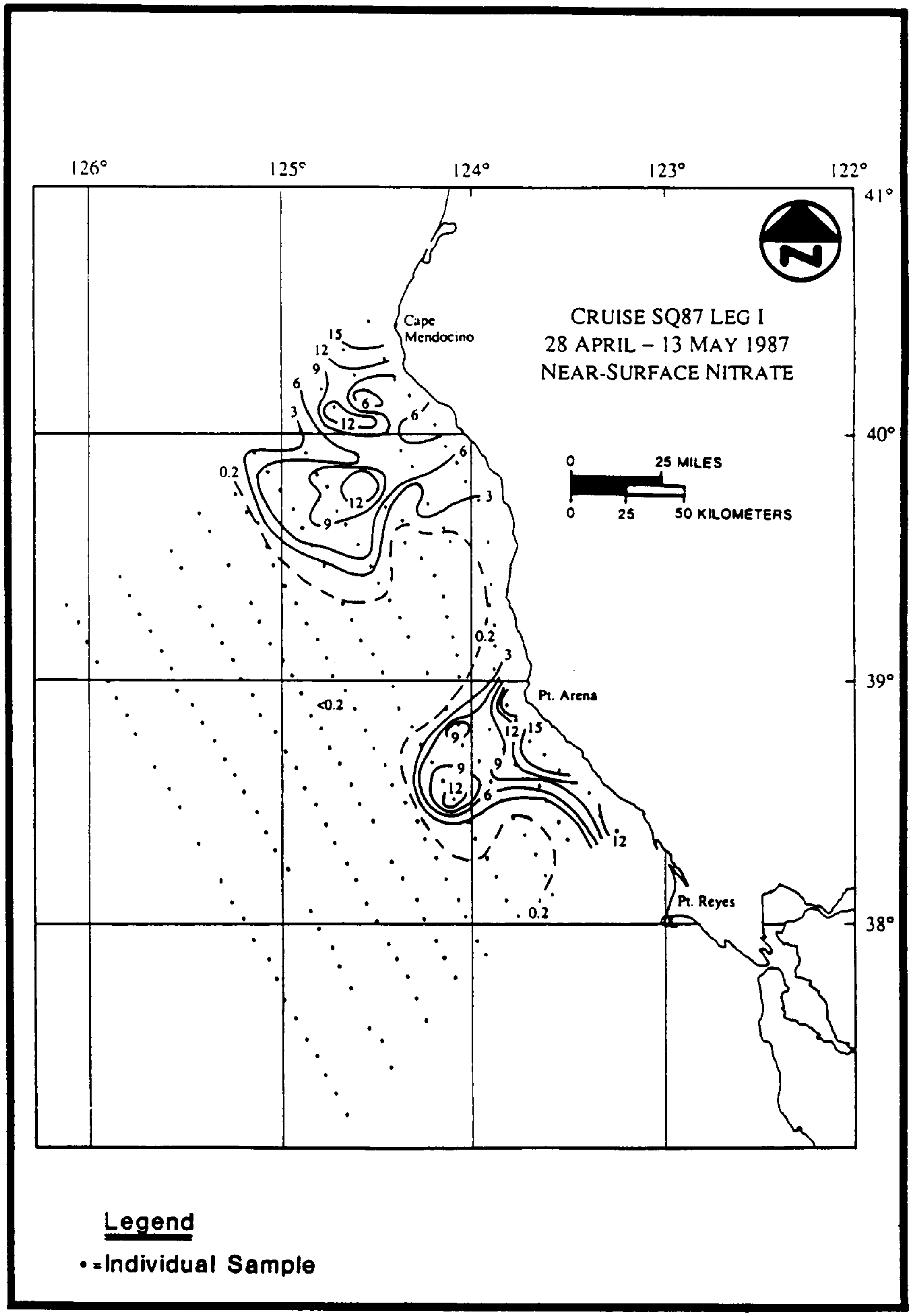


Figure 20. Spatial distribution of near surface nitrate for the Northern California Planning Area from Cruise SQ87, April–May 1987 (From: Hayward and Mantyla, in review).

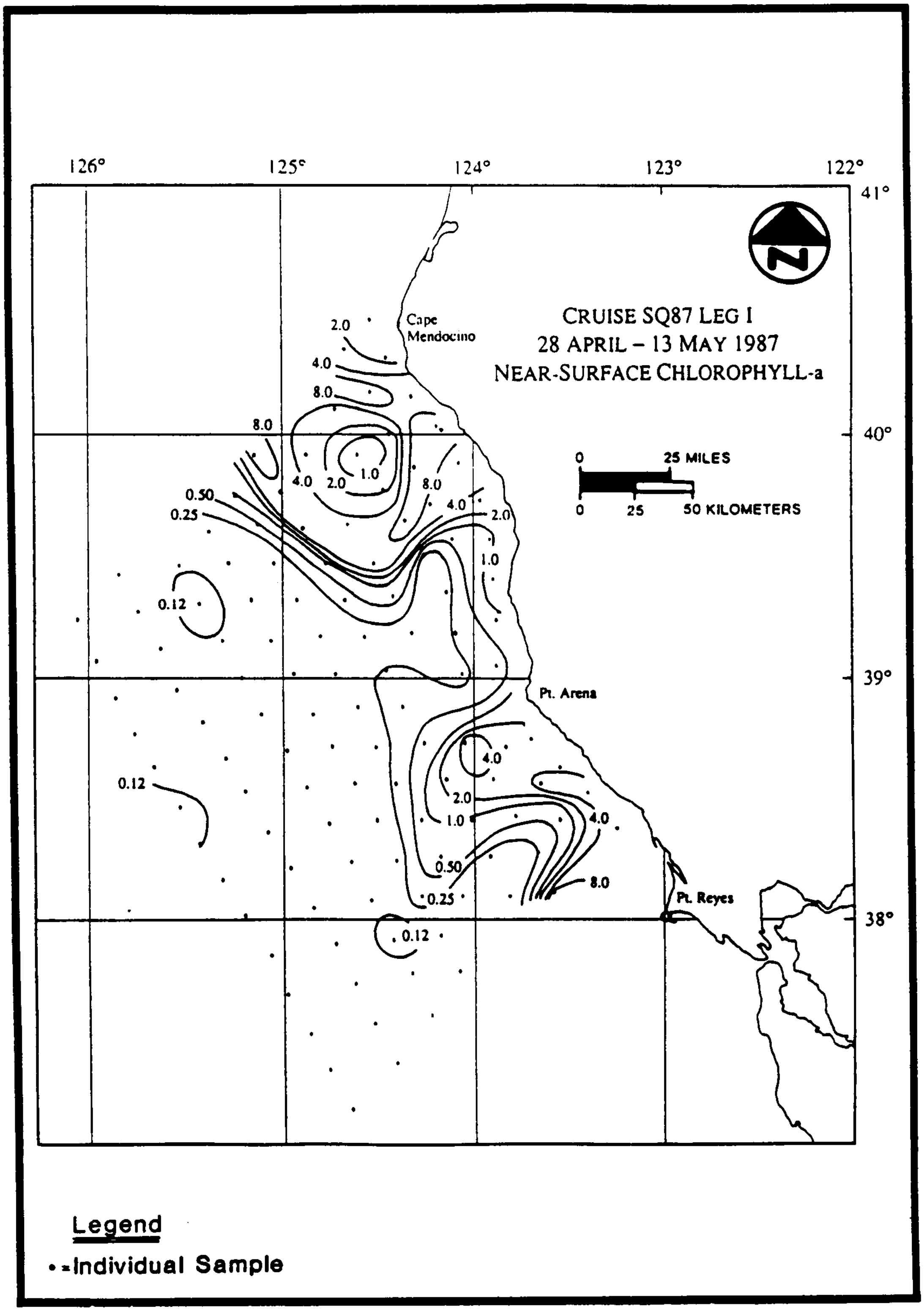


Figure 21. Spatial distribution of near surface chlorophyll-a for the Northern California Planning Area from Cruise SQ87, April-May 1987 (From: Hayward and Mantyla, in reveiw).

few kilometers. The strong gradients in dissolved oxygen and anomalies from saturation in oxygen indicate the effects of photosynthesis. The strong relation between the spatial patterns of temperature, nutrients, and chlorophyll shows that these gradients are caused by the physical structure. It is clear from this type of observation that patterns in primary production on this scale can not be resolved by sampling with direct measurements because the spatial structure changes on time scales which are shorter than the time needed for sampling.

Some general regional observations and recommendations can be made for this Planning Area. The coastal region frequently has very low sea surface temperatures and high nutrient concentrations. This should result in a relatively high f-ratio and, thus, high new production. New and total production have been defined in Section 2.2.8, Southern California Planning Area. This high inferred new production may be relatively more important to the system than is indicated by the values of total production which are estimated from the ^{14}C uptake technique. The large sea surface dissolved oxygen saturation anomalies (Simpson, 1985; Hayward and Mantyla, in review) are consistent with the inferred high new production. High new production in the coastal region may have an important role in the global cycling of carbon and other biogenic properties affected by photosynthesis. However, the small data set available from the region limits the conclusions that can be reached.

The high velocity flow in the coastal region means that advection is an important issue. The distribution of primary production and properties dependent upon it are determined by a combination of *in situ* change and advection. The great spatial patchiness and strong advection means that for long-lived plankton populations, such as macrozooplankton, the changes will be determined by both events within the region and by events which take place upstream. In turn, the production in this region may have important consequences for downstream regions.

The biogeochemical structure and circulation in coastal regions of eastern boundary current systems such as found in the Northern California Planning Area are the subject of continuing and planned programs. The examination of this region in the future should consider the results of these programs.

The annual spatial average primary production of the region is estimated to be about 300 g $C \cdot m^{-2} \cdot yr^{-1}$, a relatively high level of production. This estimate was made in the same manner and is subject to the same assumptions as for the Central California Planning Area. The limited suite of direct measurements and the great patchiness of the region make a statistical estimate based upon the direct measurements inappropriate. The oceanographic structure of the two Planning Areas is similar. There is insufficient data to determine whether there is a latitudinal gradient in production between the two Planning Areas. The seasonal cycle inferred for the inshore and offshore portions of the Planning Area is illustrated in the Map Series, Northern California map. This inferred cycle is based primarily upon proxy variables and the patterns inferred from other areas.

The entire Planning Area is estimated to be in the high variability category. This means that patches with production greater than five times the background are likely to be common in the region. This estimate was based upon the observed variability in sea surface temperature and chlorophyll, and the strong forcing and advection in the region. This variability complicates sampling and it may also be an important aspect of the structure of the epipelagic community (Hayward, 1986).

2.2.11 Washington-Oregon Planning Area

The Washington-Oregon Planning Area extends from the California-Oregon state boundary at 42°N latitude to the Canadian-United States border in the north and from the coastline to 128°W longitude. The international border is located at approximately 48.5°N latitude at the entrance to the Straits of Juan de Fuca and extends offshore in a southwesterly direction to 47.2°N latitude at the 128°W longitude meridian. Oregon and Washington have 480 and 258 km (298.3 and 160.3 mi) of coast, respectively, for a total of 738 km (458.6 mi).

The Washington-Oregon Planning Area coastal zone is a classical eastern boundary current region with extremely high production. The coastline is relatively straight compared to California or U.S. East Coast regions. A broad, deep shelf with a well defined transition to the continental slope at the shelf break simplifies the physical environment. As a consequence, major physical processes are easily identified. The principal physical processes affecting primary production in the region are coastal upwelling and discharge from the Columbia River (Small and Curl, 1968).

Studies of phytoplankton distribution and primary production along the Washington and Oregon coasts began in 1961 as part of a larger program investigating the effects of the Columbia River on the northeast Pacific Ocean, sponsored by the U.S. Atomic Energy Commission. Initially, the principal objective of the program was to relate the seasonal and areal distribution of phytoplankton concentrations and primary production to the hydrography of the region. Later studies conducted extensive sampling during the spring blooms, investigated small scale spatial and temporal variations inside and outside of the bloom, and compared nearshore and oceanic stations. The program eventually focused on the mechanisms responsible for nutrient regeneration and depletion and the formation of the subsurface chlorophyll maximum. Research from that program pertaining to phytoplankton production was summarized by Anderson (1964; 1972), Small and Curl (1968; 1972), and Small and Menzies (1981). The overall results of the research program on Columbia River impacts to the northeast Pacific was presented in Pruter and Alverson (1972).

A total of 278 productivity measurements were made at sea between 1961 and 1973 (Figure 22). Most productivity measurements were made using the Steeman-Nielsen (1952) ^{14}C method for a period of 3 to 6 h at constant temperature and illumination in a deck-mounted incubator. Simulated *in situ* measurements were obtained by incubating samples on deck and varying the illumination with neutral density

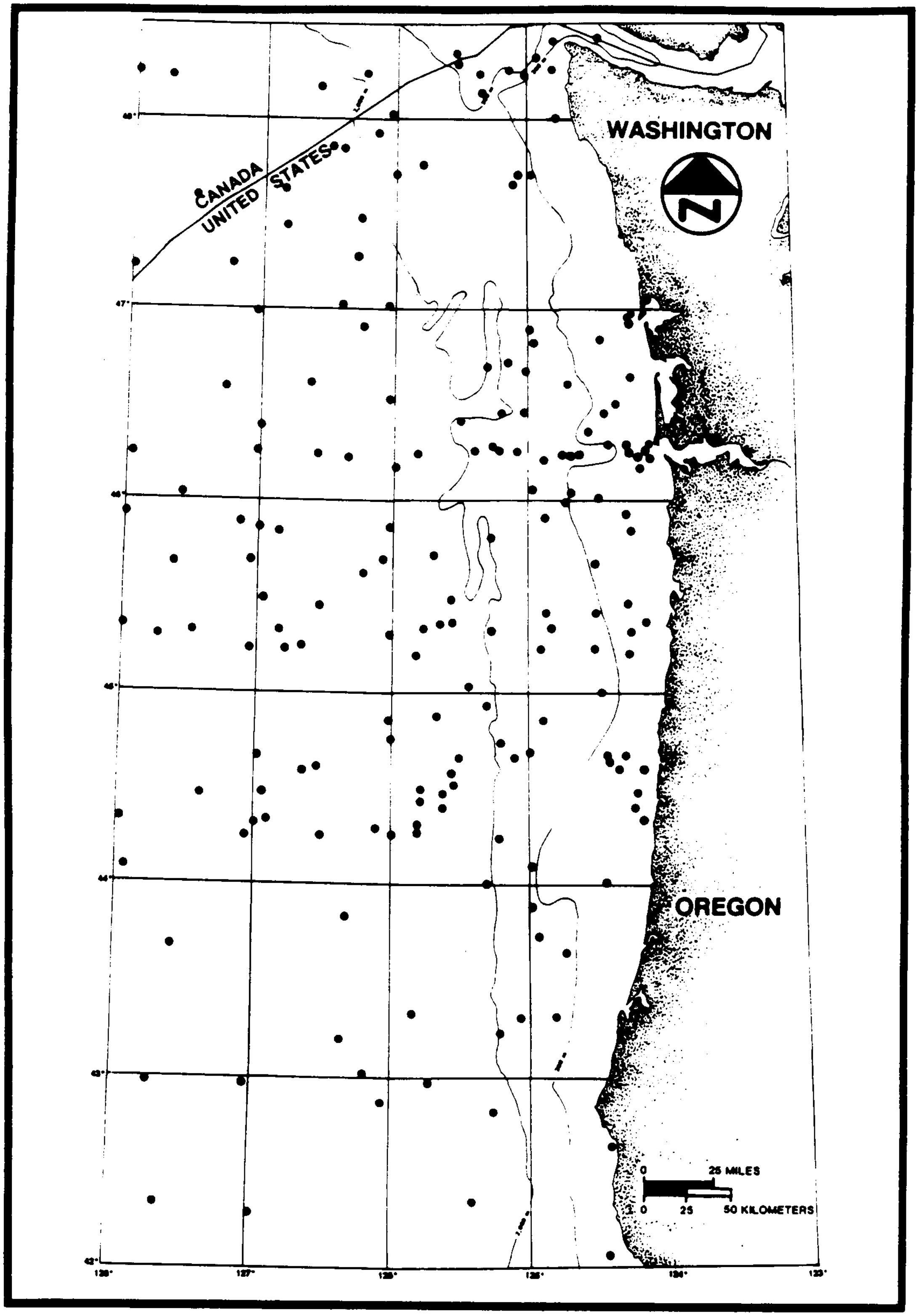


Figure 22. Stations sampled within the Washington–Oregon Planning Area between 1961–1973 under a Federally-funded study of the Columbia River estuary and adjacent waters.

filters. Incubation periods either extended from sunrise to noon or from noon to sunset. Reported production rates were corrected for dark-bottle uptake but not for nighttime respiration. Since these data were not compiled previously, the present analysis relied upon a review of original cruise reports (see Appendix A). Only simulated *in situ* values, corrected to 24-h production values have been considered in this evaluation.

In 1974, the emphasis of the research program (under the purview of the U.S. Department of Energy) changed to better understand the interactions between physical, chemical, and biological processes that occur simultaneously in the continental shelf ecosystem. From 1974 until 1982, 17 cruises were conducted across the Washington shelf with collection of a total of 153 productivity measurements (Figure 23). Stations were generally located between 46°N and 48°N latitude and between the coastline and 127°W longitude. Thus, the area covered was considerably smaller than the previous (1961 - 1973) program, as is evident in a comparison of Figures 22 and 23. Production was measured with the Steeman-Nielsen method (1952) using water from six depths and neutral density filters to simulate *in situ* irradiance from the surface to the compensation depth (i.e., 1 percent of surface irradiance). Incubation period during this program was generally 24 h, although a few samples were incubated from sunrise to sunset, sunrise to noon, or noon to sunset. To standardize the results to daily net production values, sunrise to sunset samples had 20 percent of the production value subtracted to account for nighttime respiration (Perry *et al.*, 1989; Vezina and Platt, 1988). Values for sunrise to noon and noon to sunset were doubled before subtracting 20 percent of the total value.

Virtually all primary production measurements that have been made in the Washington-Oregon Planning Area region were collected during the research program discussed above. These are the only data considered in this review. Table 11 lists the available samples according to season and oceanographic regime.

There are obvious differences between the data sets collected prior to and following 1974. The earlier program emphasized oceanic stations while the latter program concentrated on shelf and slope locations. Since 1974, spring and summer sampling periods have been emphasized while the earlier (pre-1974) samples were more uniformly distributed among seasons. The most significant differences, however, were obtained for productivity estimates. Bolger and Perry (1987) showed that the productivity measurements obtained between 1961 and 1973 were significantly lower than the measurements obtained after 1974. Differences in the mean, and median, values occur for all oceanographic regimes and seasons and sometimes exceed an order of magnitude. Analytical methods changed substantially in the early 1970s and other researchers have reported systematically higher productivity estimates during the 1980s (Eppley, 1982; Chavez and Barber, 1987). In the Washington-Oregon research program, a different incubation system was used after 1974 (J. Postel, 1989, School of Oceanography, University of Washington, pers. comm.). It has been suggested that total illumination to the sample containers was substantially lower prior to 1974.

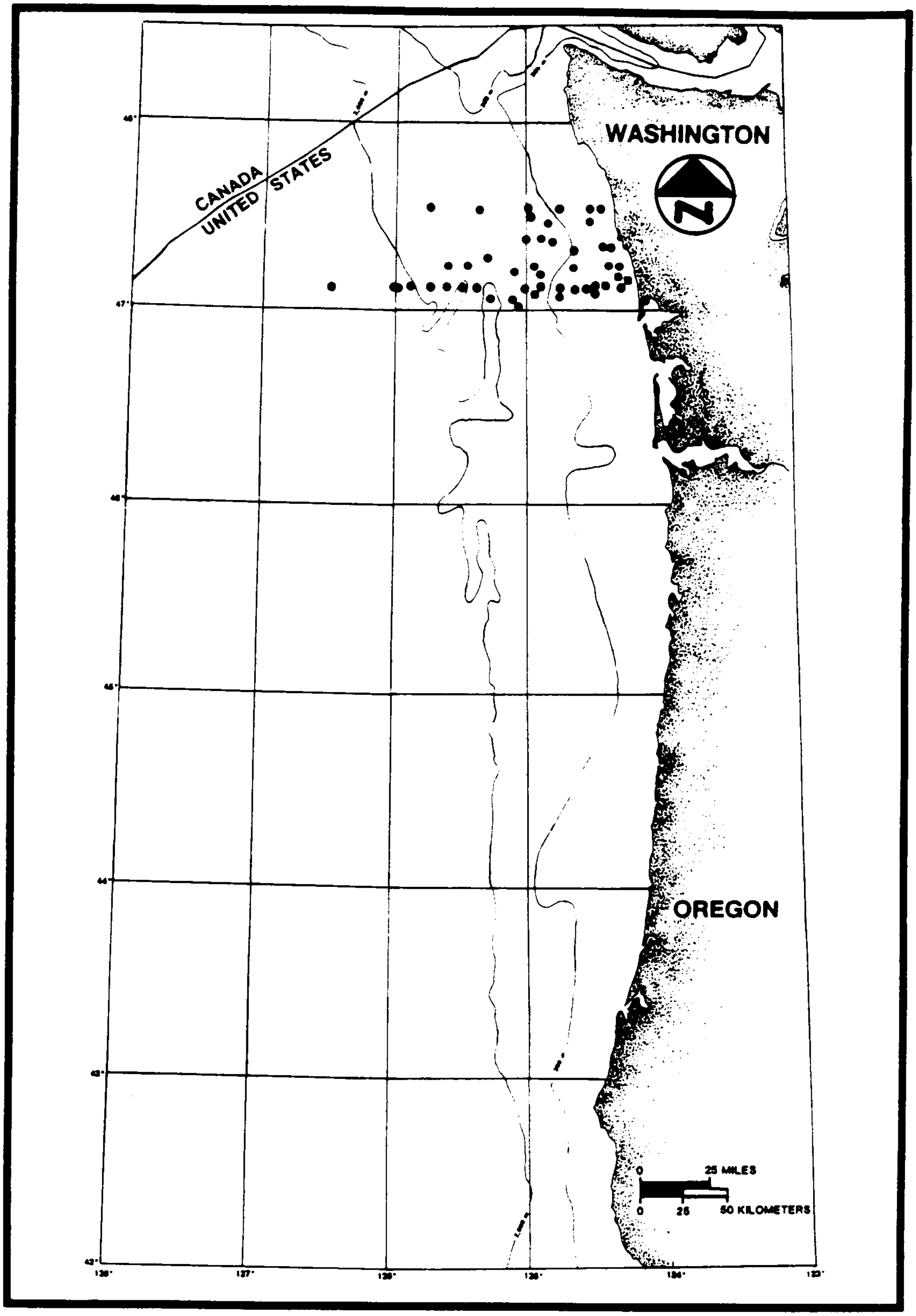


Figure 23. Stations sampled within the Washington–Oregon Planning Area between 1974–1982 under a Federally–funded study of the Columbia River estuary and adjacent waters.

Table 11. Number of productivity samples by year, season, and regime within the Washington-Oregon Planning Area.

Season	Shelf	Slope	Oceanic	Total
Period 1961-1973:				
Spring	11	16	59	86 (30.9%)
Summer	16	8	52	76 (27.3%)
Autumn	19	23	41	83 (29.9%)
Winter	9	7	17	33 (11.9%)
Total	55	54	169	278
%	19.8	19.4	60.8	
Period 1974-1982:				
Spring	31	5	2	38 (24.8%)
Summer	61	23	2	86 (56.2%)
Autumn	16	10	0	26 (17.0%)
Winter	2	0	1	3 (2.0%)
Total	110	39	4	153
%	71.9	25.5	2.6	

Unfortunately, this factor cannot be evaluated because the old incubator has been destroyed.

Sampling locations for each time period have been plotted separately in Figures 22 and 23. Combined collections for 1961-1984 are graphically presented in the Map Series. The earlier data may be valuable for observing seasonal and areal trends although the absolute production values are considerably too low. The best estimate of average annual production presented below is based upon post-1974 daily production estimates. It must be remembered, however, that these data represent a limited area and there are significant biases in this data set.

The first discussion of temporal and spatial variation in primary production along the Washington and Oregon coasts was provided by Anderson (1964). Small and Menzies (1981) discussed patterns of productivity in upwelling regions off Oregon, describing variation on scales of kilometers and days. Phytoplankton production on the Washington coast has been reviewed recently by Hermann *et al.* (1989), Dortch and Postel (1989), and Perry *et al.* (1989) as part of an overall review of the coastal oceanography of Washington and Oregon (Landry and Hickey, 1989). Productivity varies on different spatial and temporal scales that can not be resolved from shipboard sampling (Anderson, 1964; Small and Menzies, 1981; Perry *et al.*, 1989), although general patterns of production and variability are apparent.

Productivity is highest in spring and progressively declines in summer and autumn with the lowest daily production values in winter. In all seasons, production is highest on the shelf, decreases over the slope, and is lowest in oceanic regimes (Perry *et al.*, 1989). Although the data collected prior to 1974 generally support these trends, there are two differences of note evident in that data set. Lowest production estimates were obtained in autumn when there were no significant differences among the different oceanographic regimes. Secondly, estimates of production during the winter were higher on the slope than either the shelf or oceanic regimes.

Variability in production within a region and specific oceanographic regime is estimated by the coefficient of variation (i.e., standard deviation of the data set divided by the mean expressed as a percent). The coefficient of variation for daily production estimates is greatest in summer (generally exceeding 100 percent), is slightly lower in spring, and declines in autumn to values of 40 to 60 percent. There are too few recent values to calculate a reliable coefficient of variation for winter, however values from 1961 to 1973 indicated that variation within a particular regime is lowest during winter. The high variability during summer probably results from periodic (Hermann *et al.*, 1989) and spatially confined upwelling events. Production is considerably higher in upwelling versus downwelling areas. The location of sampling sites relative to local hydrographic conditions can significantly bias the results of a particular cruise or the overall seasonal average for particular seasons and regions (Perry *et al.*, 1989; Dortch and Postel, 1989).

Several estimates of annual production have been made for particular regions of the Washington-Oregon coasts. Anderson (1964) identified four areas; ocean, river plume, river mouth, and upwelling areas; and estimated annual production to be 61 g C/m^2, 60 g C/m^2, 88 g C/m^2 and 152 g C/m^2, respectively. These values have been used and repeated by other researchers (Hameedi, 1974; Jawed, 1973; Gross *et al.*, 1972) although they are clearly too low because of very low production estimates obtained during 1961 (Anderson, 1972). Several methodological reasons for low values obtained prior to 1965 are discussed by Anderson (1972), who revised his earlier estimates to exceed 126 g C/m^2 in the plume and oceanic regions and to exceed 300 g C/m^2 in upwelling regions. Perry *et al.* (1989) used data collected from 1974 to 1982 to estimate annual production of 229 g C/m^2 in oceanic regimes, 294 g C/m^2 over the slope, and 646 g C/m^2 on the shelf. These estimates are based on sunrise to sunset values of production that were obtained by adding 20 percent to the daily production estimates. Table 12 contains daily net production estimates from the same data set, expressed as mg $C \cdot m^{-2} \cdot d^{-1}$. It should be noted that the winter (1974-1982) oceanic production value (385 mg $C \cdot m^{-2} \cdot d^{-1}$) was derived from a single sample; no explanation is offered regarding this anomalously high value.

Approximately two thirds of the total Washington-Oregon Planning Area is oceanic with the remainder being equally divided between slope and shelf regimes. This factor must be considered when evaluating primary production estimates for the entire Washington-Oregon Planning Area.

Seasonal and spatial patterns of production in the Washington-Oregon Planning Area are driven by the annual pattern of solar radiation and the availability of nutrients. During the winter when nutrients are available, radiation is limiting and low production occurs throughout the region (Anderson, 1964; Perry *et al.*, 1989). Maximum production occurs over the shelf in spring and summer when wind-driven upwelling events bring nutrient-rich water to the surface (Landry *et al.*, 1989) during periods of high solar radiation. Bakun wind indices (Bakun 1973; 1975), which are used to predict the strength of upwelling, are highest along both the Washington and Oregon coasts from June to August and predict that upwelling will occur from April to October. Small and Menzies (1981) report that upwelling activity is greatest from May through August. Upwelling events are episodic during this period, producing spatial and temporal variability in production. The shelf overall, however, has a nearly continual supply of nutrients to maintain large standing stocks of phytoplankton and high rates of production (Perry *et al.*, 1989).

The Columbia River provides a massive amount of freshwater into the waters adjacent to and contained within the Washington-Oregon Planning Area, accounting for 60 to 90 percent (winter and summer, respectively) of the total freshwater input to the Pacific Ocean between San Francisco, CA and Vancouver, BC (Strickland and Chasen, 1989). Small and Curl (1968) reported that production in the plume is reduced because of low nutrient concentrations, high water column stability that restricts upwelling, and high turbidity from suspended particulate matter.

Table 12. Median daily production values for the Washington-Oregon Planning Area. Values are given as mg $C \cdot m^{-2} \cdot d^{-1}$.

Season/Period	Shelf	Slope	Oceanic
Spring			
1961-1973	166	97	85
1974-1982	2,400	1,360	960
Summer			
1961-1973	337	140	66
1974-1982	1,760	1,040	319
Autumn			
1961-1973	36	35	38
1974-1982	680	319	---
Winter			
1961-1973	57	110	64
1974-1982	70	---	385*

*Production value derived from a single sample.

On the outer shelf and over large regions of the North Pacific Ocean, a deep chlorophyll maximum occurs near the pycnocline (Anderson 1964; 1969). Both phytoplankton biomass and production are typically greatest at the chlorophyll maximum due to nutrient depletion in the surface waters. However, samples from this depth are not usually collected for measurements of production. Thus, the estimates of daily production for the oceanic region may be significantly lower than the actual production in this region.

2.2.12 Gulf of Alaska Planning Area

From an oceanographic perspective, the Gulf of Alaska region has been designated as that area lying north of 52°N latitude and between about 127°30'W longitude on the east, where it meets British Columbia, and 176°W longitude on the west, near Great Sitkin Island in the Aleutian Arc. Within this vast region, there exist several distinct water masses and productivity regimes, as well as several OCS Planning Areas (i.e., all or part of the Gulf of Alaska, Cook Inlet, Kodiak, Shumagin, and Aleutian Arc Planning Areas), as shown in Figure 24. The following discussion pertaining to primary production within the Gulf of Alaska Planning Area must necessarily consider the mesoscale patterns of oceanography evident within the Gulf of Alaska region. This is also the case with subsequent sections pertaining to primary production within the Cook Inlet, Shumagin, Kodiak, and Aleutian Arc Planning Areas (Sections 2.2.13 and 2.2.14).

The Gulf of Alaska region is bounded by an extremely irregular coastline and steep coastal mountains associated with high inputs of freshwater. Precipitation inputs to the Gulf of Alaska region exceed evaporation and keep surface salinities to less than 34 ppt. The deep North Pacific Ocean contains the highest nutrient concentrations of the world oceans and the upwelling and deep-mixing processes along the continental shelves and through the Aleutian passes support areas of extremely high primary productivity. Reed and Schumacher (1986) describe the circulation of the Gulf of Alaska and its physical oceanography. The surface water domains have been delineated by Dodimead *et al.* (1963) and include three main water types. The coastal waters are part of a large counterclockwise circulation of low salinity designated as the Alaska Stream. Further offshore are the main Alaska Gyre and the Central Subarctic Domain. Virtually all of the continental shelf is overlain by the Alaska Stream.

Oceanic Environments

Most of the phytoplankton production measurements in the oceanic waters of the Gulf of Alaska Planning Area have focused on two goals: 1) determining the carrying capacity of fishery stocks and; 2) determining the fluxes of particulate carbon to the deep ocean. Sambrotto and Lorenzen (1986) reviewed the various physical chemical and biological controls on phytoplankton abundance and productivity over most of this region. Their listings of past work are comprehensive and will not be repeated here other than to note that the work of Larrance

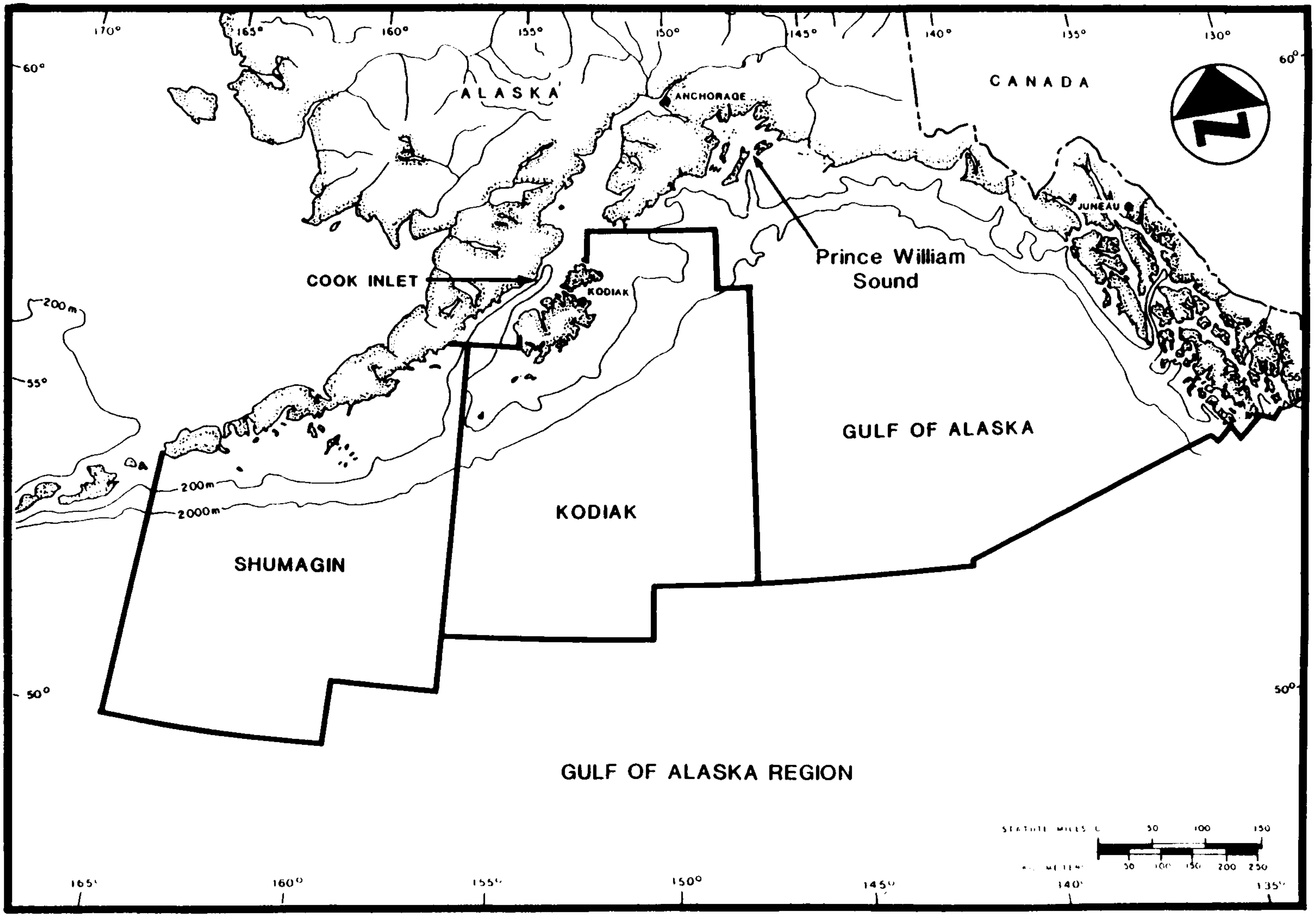


Figure 24. Map of the Gulf of Alaska region indicating the location of its four Planning Areas.

et al. (1977) is the most comprehensive study using well defined protocols for ^{14}C productivity measurements.

A time series of measurements have been made at Ocean Station P, located just south of the Gulf of Alaska Planning Area boundary (McGowan and Hayward, 1978; Parsons and Lalli, 1988; Stephens, 1964, 1966, 1968). These data have been included on the Gulf of Alaska map (see Map Series) since Sambrotto and Lorenzen (1986) argue that the circulation patterns result in much of this productivity being transported into northern latitudes.

Summer primary productivity rates in the Gulf of Alaska are low (~0.5 g $C \cdot m^{-2} \cdot d^{-1}$) in offshore waters and increase approaching the coast. Winter ^{14}C uptake rates are much lower and are estimated at near 0.05 g $C \cdot m^{-2} \cdot d^{-1}$ (Sambrotto and Lorenzen, 1986). Sambrotto and Lorenzen (1986) give an annual estimate for the central Gulf of Alaska in the range of 48 to 100 g $C \cdot m^{-2} \cdot yr^{-1}$.

Coastal Waters

The coastal waters of the Gulf of Alaska contain a wide variety of habitats ranging from the complex fjord systems of southeast Alaska and Prince William Sound to the exposed, relatively straight coastlines near Yakutat. Many of the more protected waters produce a strong spring bloom followed by secondary production peaks in late summer and fall. Wind-mixing events can also cause blooms at intervals throughout the summer season. As a result of the EXXON VALDEZ oil spill in March 1989, a flurry of activity has occurred in Prince William Sound with some slated to continue into 1990. These data are mostly proprietary pending litigation over the oil spill and are not available at this time.

The coastal waters, unlike the open areas of the Gulf of Alaska, become nutrient depleted during the summer months. As nutrients become limiting to production, chlorophyll maxima tend to be found deeper and deeper in the water column. Sambrotto and Lorenzen (1986) suggest that yearly production in these coastal habitats can exceed 200 g $C \cdot m^{-2} \cdot yr^{-1}$.

2.2.13 Cook Inlet, Kodiak, and Shumagin Planning Areas

Primary production in the coastal environment of the Gulf of Alaska region, including the Cook Inlet, Kodiak, and Shumagin Planning Areas, has a pronounced seasonality imparted by the temperature extremes and the large swings in light energy between winter and summer. The breakdown in water structure over the shelves during the winter months provides a renewal of nutrients in the surface waters. Periods of high production follow mixing events when relatively calm weather and warmer temperatures prevail. Often as much as 25 percent of the annual primary productivity occurs over the course of the spring bloom. Even in summer, the high energy environments of the coastal Gulf of Alaska waters result in deep mixing and the advection of large quantities of nutrient-laden water onto the continental shelves and into the euphotic zone. The Aleutian passes, lower Cook Inlet, the Shumagin Islands, the Kodiak Shelf, and much of Prince William Sound have extremely high rates of primary productivity which Sambrotto and Lorenzen (1986) estimated may average >2 g $C \cdot m^{-2} \cdot d^{-1}$ and the annual production may reach in excess of 300 g $C \cdot m^{-2} \cdot yr^{-1}$. Larrance and Chester (1979) reported daily rates of 31 to 391 mg C/m^2 for March, 86 to 7,185 mg C/m^2 for May, 641 to 6,877 mg C/m^2 for June, 788 to 5,089 mg C/m^2 for July, and 785 to 7,690 mg C/m^2 for August from two stations in lower Cook Inlet. These estimates reflect elevated planktonic primary production for the late spring-summer period from May through August (e.g., maximum production ranging from 5,089 to 7,690 mg $C \cdot m^{-2} \cdot d^{-1}$). Extreme variability in primary production is also suggested for the lower Cook Inlet area (e.g., 6- to 83-fold increases during May through August), based on a limited data base.

Larrance and Chester (1979; Table 9-4) identified the studies that provide biological and oceanographic data related to productivity of the coastal waters adjacent to the Gulf of Alaska. These high rates of productivity support the zooplankton stocks necessary for the recruitment of the vast pollock fisheries and also supply sufficient food for the invertebrates and other demersal fishes among the rich benthos.

The Alaska Current and the Alaska Coastal Current cause appreciable advection of primary production along the Gulf of Alaska and the Aleutian Peninsula. The Coastal Current is a prominent feature within 35 km (19 nmi) of the coast with a mean velocity of about 0.5 m/s. Part of this current flows through Unimak Pass and the turbulence and entrainment of underlying nutrient-rich water supports very high primary productivity on the North Aleutian Shelf. Upwelling associated with intrusion of Alaska Coastal Current water into lower Cook Inlet causes advection of nutrients into the shallow waters and enhances primary production throughout the summer months. The strong tides of Cook Inlet also cause formation of strong frontal systems with enhanced production in the vicinity of the fronts (Iverson *et al.*, 1974).

The large river run-off volumes entering Prince William Sound and Cook Inlet contain extensive amounts of suspended glacial silts and clay which severely attenuate light in the water column wherever the river influence is evident. In upper Cook Inlet and in the vicinity of the mouth of the Copper River near Cordova, the euphotic zone is 50 percent or less than in adjacent waters unaffected by the runoff (Larrance, 1977).

2.2.14 Aleutian Arc Planning Area

The Aleutian Arc Planning Area extends from the eastern Aleutian Islands westward to the International Date Line at about 170°E longitude (Figure 25). This is a complex region since it includes the North Pacific Ocean south of the Aleutian Islands and the Bering Sea to the north. The Aleutians are a classic volcanic island arc system with numerous passes that connect the Bering Sea to the North Pacific and little or no shelf area. Most passes are shallow and narrow enough to restrict circulation with deep basin waters (Sayles *et al.*, 1979); the deepest connections are the far west Near Strait (2,000 m [6,562 ft])

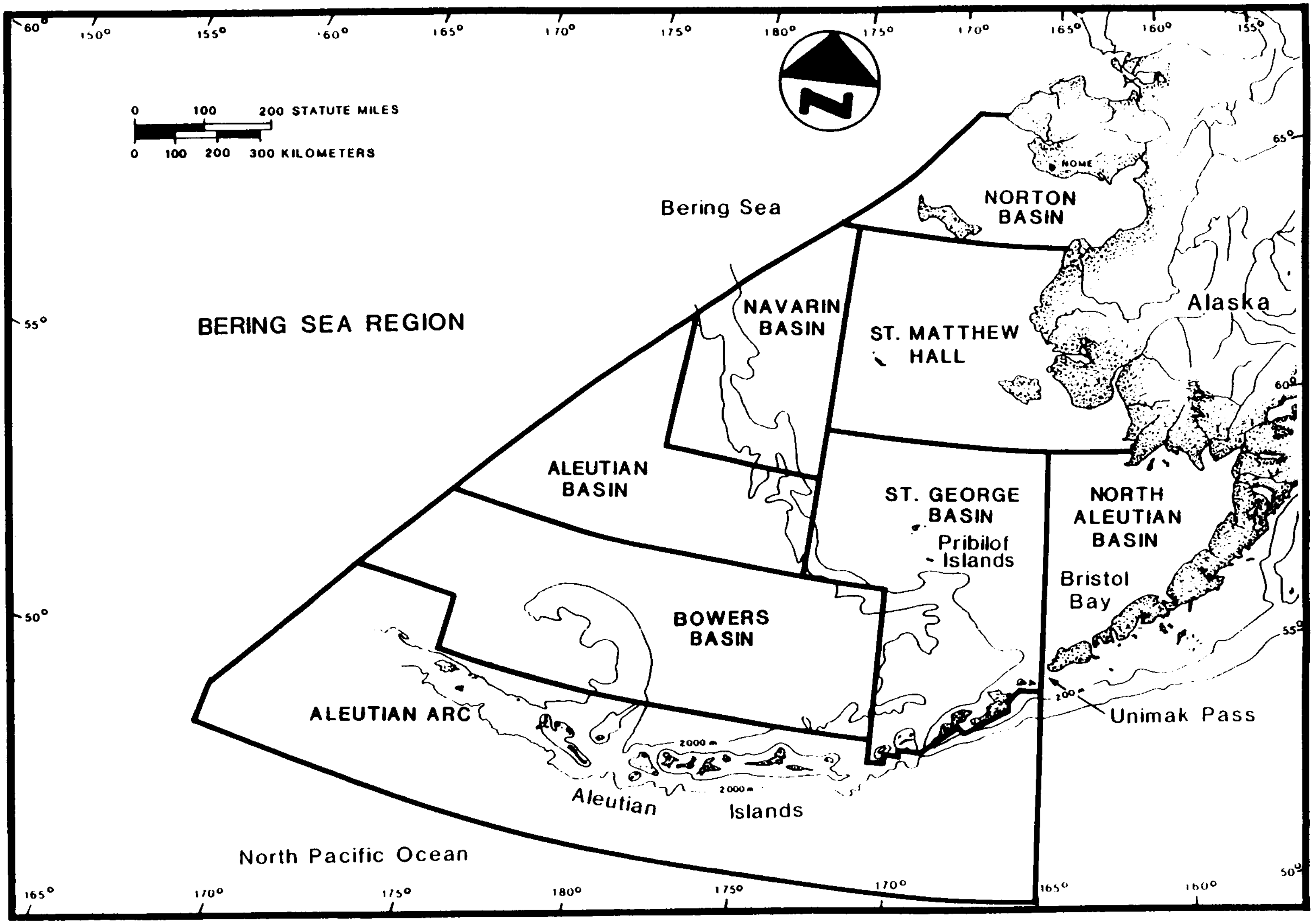


Figure 25. Map of the Bering Sea region indicating the location of its eight Planning Areas

and Kamchatka Strait (over 4,000 m [13,124 ft]). Within the central Aleutian Islands are three other deep connections, Buldir Pass (640 m [2,100 ft]), Amchitka Strait (1,155 m [3,790 ft]) and Amukta Pass (430 m [1,411 ft]), that allow waters below the pycnocline to exchange between these seas. Transport into the Bering Sea through these passes has been estimated as 25 Sv in summer and 35 Sv in winter with a net flow in of about 1 Sv (Hood, 1983). With the exception of Amukta, the major eastern passes are in the depth range of 200 to 275 m (656 to 902 ft) and hence are not significant contributors to the volume transport.

The source of the surface waters is the western extension of the Alaska Stream (Reed and Schumacher, 1986). Although there are few studies, exchange and tidal mixing through the numerous passes can cause local upwelling and hence the potential for high primary production. Upwelling has been documented on the north side of Samalga Pass in the eastern islands (Kelley *et al.*, 1971; Swift and Aagaard, 1976). The latter authors estimate the vertical transport to be 0.007 cm/s.

Direct measurements of primary production in this region are scarce. South of the Aleutian Islands, away from the areas of turbulent mixing, the productivity is likely to be similar to that of the waters of the central northern North Pacific Ocean. These are deep basin, oligotrophic waters where productivity is expected to be seasonal and determined by episodes of nitrate supply as in other oceanic areas (Platt *et al.*, 1989). Data for waters south of 50°N latitude indicate rates of about 100 mg $C \cdot m^{-2} \cdot d^{-1}$ for the growing season which are consistent with the earlier estimates of 100 to 150 mg $C \cdot m^{-2} \cdot d^{-1}$, based on oxygen methods, by Koblents-Mishke (1965). Taniguchi (1972) estimated the integrated daily production of 160 mg $C \cdot m^{-2} \cdot d^{-1}$ from limited data.

Annual production in these waters is estimated to be similar to the central Gulf of Alaska gyre (i.e., in the range of 30 to 50 g $C \cdot m^{-2} \cdot yr^{-1}$). Koblents-Mishke (1965) estimated the annual production to be 73 g $C \cdot m^{-2} \cdot yr^{-1}$ while Sanger (1972) estimated the rate at 82 g $C \cdot m^{-2} \cdot yr^{-1}$. Peak rates occur in May through July with lowest values occurring in November through March (McAllister, 1969). Martin *et al.* (1989) made a case for iron limitation of phytoplankton production in the oceanic waters of the North Pacific.

Productivity around the Aleutian Islands is complicated by turbulence and upwelling events related to storms and tidal mixing. Sanger (1972) calculated annual primary production, from carbon uptake data, in Adak Bay as 332 g $C \cdot m^{-2} \cdot yr^{-1}$ and considered this indicative of waters in immediate proximity to the islands. McRoy *et al.* (1972) measured productivity in the vicinity of Unimak Pass in June which averaged 243 mg $C \cdot m^{-2} \cdot d^{-1}$ and ranged from 18 to 867 mg $C \cdot m^{-2} \cdot d^{-1}$, reflecting the complex effect of mixing around the islands. Productivity in these areas must be locally highly variable when sufficient light is available (May through August) due to island induced upwelling; high carbon fixation rates are possible when new nutrients are available for growth. Fall and winter productivity rates are uniformly low in spite of nutrient availability (McRoy *et al.*, 1972).

The Aleutian Arc Planning Area also includes waters of the Bering Sea north of the Aleutian Islands that must be considered somewhat separately from the other contiguous areas, especially waters away from the immediate effect of the islands. Taniguchi (1972) estimated daily rates in these waters to be 490 mg $C \cdot m^{-2} \cdot d^{-1}$ (range 340 to 630), more than three times those south of the islands. By extrapolation, this suggests an annual primary production of 200 g $C \cdot m^{-2} \cdot yr^{-1}$, but Sanger (1972) estimated the rate at 100 g $C \cdot m^{-2} \cdot yr^{-1}$. With no direct evidence, or at least very few direct observations, the actual rate is probably between these two; this estimate is also supported by the three-fold increase evident in counts of phytoplankton cells from north of the Aleutians versus collections made south of the islands and within the influence of the Gulf of Alaska (Karohji, 1972).

2.2.15 North Aleutian Basin Planning Area

The North Aleutian Basin Planning Area extends from Unimak Pass to the north shores of Bristol Bay; its southern and eastern boundaries are formed by the Alaska Peninsula (Figure 25). The area includes a large portion of the southeastern continental shelf of the Bering Sea that was extensively studied through NSF-funded research, including Processes and Resources of the Bering Sea Shelf (PROBES) and Outer Continental Shelf Environmental Assessment Program (OCSEAP) study efforts.

Circulation and mixing of these waters have been well described by Coachman (1986). The physical regime of this broad (i.e., >500 km [270 nmi]) shelf has a distinct zonation that divides the region into three depth domains that have a fundamental influence on biological processes, including: 1) Coastal Domain, inside of the 50-m (164-ft) isobath; 2) Central Domain, between 50 and 100 m (164 to 328 ft); and 3) Outer Domain, from 100 m (328 ft) to the shelf break, located at about 170 m (558 ft). These domains are divided by oceanographic fronts, or quasi-permanent transition zones, over the 50-, 100-, and 170-m (164-, 328-, and 558-ft) isobaths, respectively. These fronts form two water masses (i.e., coastal and central) on the shelf bounded by a third oceanic water mass over the deep basin seaward of the shelf break. These domains are dynamic and exist because of the proportional distribution of kinetic energy with depth. Since the shelf is broad and has a low slope gradient, the manifestation of this energy distribution is expressed; these energy sources and their distribution determine the primary production of the shelf waters of the North Aleutian Basin Planning Area, with further influence over the entire shelf of the Bering Sea.

The primary energy on the shelf is that of tidal action. While the sources of vertical energy are the same for all areas of the shelf, it is the depth of the water column which leads to layering and vertical property flux. With respect to primary productivity, such phenomena are crucial to determining nutrient supply and stratification necessary for phytoplankton growth.

The Coastal Domain is characterized by an advective-diffusive physical regime with a flushing time of about six months (Coachman, 1986). Although tidal mixing accounts for 90 percent of the energy within the Coastal Domain, there is also general advection to the north along the Alaska Peninsula and around inner Bristol Bay. In this domain, wind mixing and tidal action overlap resulting in a well-mixed water column (i.e., from sea surface to the sea floor). Under such conditions, the associated primary production cycle would be expected to be a spring bloom whose magnitude should be largely determined by the concentration of nitrate at the end of winter (i.e., approximately 15 micromolar; Whitledge *et al.*, 1986), plus that from any regenerated nitrogen available during summer. The annual integrated amount of carbon fixed should be low, in the vicinity of 50 to 60 g $C \cdot m^{-2} \cdot yr^{-1}$. However, data from the inner shelf area north of the Alaska Peninsula indicate much higher production (Schell and Saupe, 1989) which the authors attributed to an advective nutrient supply supported by upwelling around Unimak Island. These investigators reported a maximum carbon fixation rate of 6.7 g $C \cdot m^{-2} \cdot d^{-1}$ during the spring bloom. Advective nitrate sustains production so that even in July, rates are as high as 2.6 g $C \cdot m^{-2} \cdot d^{-1}$. The production cycle is seasonal extending from April through September; the long season is a consequence of the shallow depth of these waters inside the inner front, and the advective nutrient supply downstream of Unimak Pass. There is a long-shore gradient in production since, the greater the distance from the nutrient source (Unimak Pass), the more depletion will occur and, thus, lower production. The result is lower nearshore production in inner Bristol Bay than further down the Alaska Peninsula (e.g., off Izembek Lagoon). Schell and Saupe (1989) estimate the annual phytoplankton production to be 220 to 240 g $C \cdot m^{-2} \cdot yr^{-1}$.

The inner shelf along the Alaska Peninsula also receives a measurable particulate carbon subsidy in the form of eelgrass detritus which Schell and Saupe (1989) estimate to be on the order of 62 g $C \cdot m^{-2} \cdot yr^{-1}$ (equal to 28 percent of phytoplankton production) for the area immediately adjacent to the coastal lagoons out to the 50-m (164-ft) isobath. Based on evidence from stable carbon isotopes, the authors conclude that this energy source is rapidly diluted by phytoplankton carbon outside the lagoons.

The Central Domain is an area of extremely slow flushing, physically characterized by tidally-driven diffusive processes and wind-induced Ekman transport, the latter of which is only applicable to surface waters. Residence time for water in this domain can be more than one year (Coachman, 1986). During winter, the water column mixes vertically; in spring and summer, a surface layer forms (10 to 40 m [33 to 131 ft] thick), both from heating and ice melting, which results in a two-layered water column. The surface layer is relatively warm, low salinity water, while the deep layer is slightly higher in salt content and much colder. Since this water retains the temperature signature of winter, it is often termed the "cold pool" and it is a recognizable feature of the entire central shelf of the Bering Sea.

The cycle of primary production in the Central Domain begins in late April with a distinct spring bloom that lasts until late May. This bloom is apparently determined by light conditions since there was almost no interannual variability from 1978 to 1981 in spite of large differences in winter ice conditions in those years (Whitledge *et al.*, 1986). Exhaustion of the surface layer nitrate leads to the end of bloom conditions. Sambrotto (1983) estimates the annual production to be 188 g $C\cdot m^{-2}\cdot yr^{-1}$, somewhat greater than the 166 g $C\cdot m^{-2}\cdot yr^{-1}$ used by Walsh and McRoy (1986) in their carbon budget of the region.

The Outer Domain is a region of lateral water mass interaction between Central Shelf and Bering Sea Basin Waters (Coachman, 1986). This is a zone of layering and interleaving of water masses characterized by advective-diffusive energies. Flushing in this domain is on the order of two to three months which is accomplished by a general northwest advection paralleling the shelf break.

The annual cycle of primary production in the Outer Domain begins with a spring bloom fueled by nitrate from winter resupply, as is the case in the other domains. Nitrate concentrations below the mixed layer can be greater than 25 or 30 micromolar (Whitledge *et al.*, 1986). High primary production is sustained in the shelf break front by the availability of nutrients from basin waters; nitrate isopleths of 10 to 15 micromolar intersect the surface in this area even in June, well after the maximum bloom. In addition, the fine structure layering that occurs over the outer shelf leads to some cross-isopycnal mixing that could supply nutrients to the euphotic zone (Coachman, 1986). Daily rates in this domain range from 0.1 to 5 g $C\cdot m^{-2}\cdot d^{-1}$ (Niebauer *et al.*, 1981). The integrated production is estimated to be 162 g $C\cdot m^{-2}\cdot yr^{-1}$. This value is essentially the same as that for the Central Domain, however, the Central Domain production value must be considered an underestimate since the authors only considered production during the spring bloom (Walsh and McRoy, 1986).

In both domains, away from the shelf break front where the water column stratifies, Sambrotto *et al.* (1986) found that post-bloom storms could inject nitrate into the euphotic zone to increase production. The bloom also depends on the mixed layer depth and only begins once the mixed layer depth is less than the 0.1 percent light level. The interannual difference in wind events and storm tracks results in measurable interannual variations in integrated primary production.

In some years, production by microalgae associated with sea ice can provide a measurable contribution to the total annual production in the middle and inner shelf. Since this is a regular feature of the St. Matthew Hall Planning Area, this topic is discussed in greater detail in Section 2.2.17. Within the North Aleutian Basin Planning Area, such production is considered part of the interannual variability. It is estimated that sea ice-associated microalgae production might contribute 10 percent to the total annual production during cold years when ice is present.

2.2.16 St. George Basin Planning Area

The St. George Basin Planning Area includes the central and outer shelf and adjacent basin waters from the Aleutian Islands to about 60°N latitude, including the Pribilof Islands (Figure 25). The oceanographic processes for this Planning Area have been described previously (see Section 2.2.15, North Aleutian Basin Planning Area). Data do not allow distinction between the production in this area and that in the North Aleutian Basin. With the exception of the immediate vicinity of the Pribilof Islands, where some island effect mixing could enhance productivity, primary production within the St. George Basin Planning Area should be comparable to the North Aleutian Basin region.

The estimates for the Outer and Central Domains in this area are 162 and 166 g $C{\cdot}m^{-2}{\cdot}yr^{-1}$, respectively (Walsh and McRoy, 1986). Both estimates are considered low since they are primarily based on the spring bloom and should be revised upwards to account for summer production from regenerated nutrients. A revised estimate is projected to be approximately 200 g $C{\cdot}m^{-2}{\cdot}yr^{-1}$.

2.2.17 St. Matthew Hall Planning Area

The St. Matthew Hall Planning Area extends from the Yukon-Kuskokwim Delta region out to St. Matthew and St. Lawrence Islands and includes Nunivak Island (Figure 25). These are primarily inner and central shelf waters located away from the shelf break. A major feature of the Coastal Domain is dilution by the freshwater plume from the Kuskokwim and Yukon Rivers. Although the waters mix vertically in winter, in spring as runoff begins they become strongly two layered as the flow increases (Muench *et al.*, 1981). Maximum river flow occurs from mid-May to July; the mean discharge for the Yukon River is 6,220 m^3/s. The rivers are a source of nutrients and particulate organic matter to ambient shelf waters. Nitrate in the Yukon River (i.e., at Pilot Station) has been measured at about 10 micromolar, a level which is considered typical of pristine rivers (Walsh *et al.*, 1989). In most years, this region is ice-covered out to about the 150-m (492-ft) isobath, or wherever the thermodynamic limit of sea ice is established.

The only direct measurements of primary production for this area are from February, when productivity rates are near zero (McRoy *et al.*, 1972). Production estimates for the St. Matthew Hall Planning Area were, therefore, determined from measurements in adjacent areas and ancillary data. The inner shelf waters have been estimated to exhibit an integrated annual production of 50 to 70 g $C{\cdot}m^{-2}{\cdot}yr^{-1}$, which is based on the nitrate concentration of 10 micromolar at the end of winter and an additional 70 percent of carbon fixed by recycled nitrogen (Walsh *et al.*, 1989). This would give average daily rates of 300 to 500 mg C/m^2. Although expected, no production from riverine nutrients was detected.

The middle shelf is an extension of the Central (shelf) Domain. By extension, the annual production should be in the range of 160 to 200 g $C{\cdot}m^{-2}{\cdot}yr^{-1}$, as discussed previously for the North Aleutian Basin and St. George Basin Planning Areas (see Sections 2.2.15 and 2.2.16). McRoy and Goering (1974) and Alexander and Niebauer (1989) suggest that the timing of the spring bloom in this area can be promoted by water column stability associated with receding ice.

Beginning in late February, the undersurface of sea ice in this area can have a dense population of epontic microalgae. This community has measured carbon fixation rates of 2 to 5 mg $C \cdot m^{-2} \cdot d^{-1}$ (McRoy and Goering, 1974) which are about 10 to 15 percent of water column productivity under the ice during this pre-bloom season.

2.2.18 Bowers Basin and Aleutian Basin Planning Areas

Bowers Basin and Aleutian Basin Planning Areas have been considered together as they include the waters over the central Bering Sea (Figure 25). There is a general counterclockwise circulation in the basin of the Bering Sea (Takenouti and Ohtani, 1974). Current speeds are on the order of a few centimeters per second. The waters have their origin in the Alaska Stream that enters through the numerous passes in the Aleutian Islands; residence time is on the order of years, thus the water develops a distinct Bering Sea water mass signature before it flows back into the Pacific Ocean along its western boundary as the East Kamchatka Current. These waters have a strong seasonal thermocline and a permanent halocline near 100 m (328 ft). The seasonal vertical mixing is the major event in nutrient supply and determines primary productivity within the waters of these two Planning Areas.

Koblents-Mishke (1965) estimated the average production for this region as 100 to 150 mg $C \cdot m^{-2} \cdot d^{-1}$. Additional observations by Taniguchi (1969) resulted in rates of 160 to 630 mg $C \cdot m^{-2} \cdot d^{-1}$ with an average of 490 mg $C \cdot m^{-2} \cdot d^{-1}$ for May to September. Taguchi (1972) calculated average summer production as 330 mg $C \cdot m^{-2} \cdot d^{-1}$. Whitledge *et al.* (1988) reported productivities ranging from 299 to 1,007 mg $C \cdot m^{-2} \cdot d^{-1}$ from five stations in this area in July, although the data were from carbon uptake experiments using artificial lights. Highest values were recorded in the vicinity of Bowers Bank.

Data for this region are scarce and no direct measurements exist for the bloom period. Consequently, estimates of annual production are based on inferences from other oceanic regions and basic knowledge of Bering Sea oceanography. Using oxygen methods, Ivanenkov (1961) estimated annual production for the oceanic area of the Bering Sea to be 230 g $C \cdot m^{-2} \cdot yr^{-1}$. While Taguchi (1972) reported a value of 71 g $C \cdot m^{-2} \cdot yr^{-1}$ for "Central Water", Taniguchi (1972) estimated annual production at 89 g $C \cdot m^{-2} \cdot yr^{-1}$ for the oceanic Bering Sea. Under the present analysis, the annual production rate for this region is estimated to be in the range of 150 to 200 g $C \cdot m^{-2} \cdot yr^{-1}$. Interannual variations will depend on the frequence and magnitude of storm events in any given year.

2.2.19 Navarin Basin Planning Area

The Navarin Basin Planning Area includes the waters over the outer shelf and slope west of St. Matthew Island (Figure 25). The region is influenced by the Bering Slope Current (Kinder *et al.*, 1975). It has a recognizable water mass that is distinct from the waters of the central gyre (Takenouti and Ohtani, 1974). The region has broken sea ice evident in some winters.

The only direct productivity measurements for this area are from Whitledge *et al.* (1988) who reported daily rates ranging from 109 to 534 mg C/m^2. With this lack of detail, it is only possible to estimate the productivity of the region by inference for other outer shelf areas. In the southeastern Bering Sea, the estimated annual production for the Outer (shelf) Domain is 166 to 220 g $C \cdot m^{-2} \cdot yr^{-1}$, a reasonable projection for the Navarin Basin Planning Area.

2.2.20 Norton Basin Planning Area

The Norton Basin Planning Area includes Norton Sound and the adjacent shelf waters around St. Lawrence Island north to Bering Strait. The shelf outside of Norton Sound is dominated by a strong advective field created by Bering Strait, which functions as a leak in the Bering Sea. Flow over the shelf is predominantly to the north into the Chukchi Sea and the Arctic, although occasional short-term reversals do occur (Coachman *et al.*, 1975). On an annual basis, transport is about 1 Sv which is composed of three identifiable water masses: 1) Anadyr Water in the west, 2) Bering Shelf Water in the center, and 3) Alaska Coastal Water in the east. This latter water mass also fills Norton Sound. Norton Sound becomes strongly two-layered in summer due to the freshwater from the Yukon River and solar heating (Muench *et al.*, 1981). In winter, Norton Sound approaches vertical homogeneity due to cooling. In terms of primary production, the layering means that the nutrient supply at the end of winter, plus any from regenerative processes, will drive carbon fixation.

While there are no direct measurements of primary production for Norton Sound, there are data for the nearby inner shelf waters available from a multi-year NSF-funded program (i.e., Inner Shelf Transfer and Recycling in the North Bering/Chukchi Seas, or ISHTAR), as summarized by McRoy *et al.* (1987). These data were collected in the ice free months of July, August, and September and are only indicative of post-bloom conditions. Springer (1988) reported a bloom in mid-June, well before the time of ice departure, for Alaska Coastal Water off Cape Lisburne in the Chukchi Sea. It is likely that such a bloom also occurs within Norton Basin (Norton Sound) since nutrient concentrations in July are well below one micromolar. Post-bloom carbon uptake rates for Alaska Coastal Water, including Norton Sound, range from 0.2 to 2.6 g $C \cdot m^{-2} \cdot d^{-1}$ for July and August and 50 to 400 mg $C \cdot m^{-2} \cdot d^{-1}$ for September. The higher rates were measured in waters close to Bering Strait where turbulent mixing occurs. A rate of 1.7 g $C \cdot m^{-2} \cdot d^{-1}$ was measured at a single station just off the Yukon Delta suggesting some riverine influence. The annual integrated production is estimated to be 50 to 70 g $C \cdot m^{-2} \cdot yr^{-1}$ for an average daily rate of 330 to 470 mg $C \cdot m^{-2} \cdot d^{-1}$ over the estimated 150-d growth season. Production was calculated from a pre-bloom nitrate concentration of 10 micromolar and a measured 70 percent regenerated production (Walsh *et al.*, 1989).

A well-defined frontal zone, distinguished by salinities greater than 31.8 ppt, separates the Bering Shelf and Anadyr Water masses from Alaska Coastal Water. The two former waters are treated as a single unit in the present analysis since their density differences are more subtle and more mixing occurs between them. Productivity in these waters is initiated in the water column and in the sea ice long before the waters are ice-free. Alexander and Chapman (1981) report carbon uptake rates for phytoplankton communities in "brash ice" in early April of 200 to 400 mg $C \cdot m^{-3} \cdot d^{-1}$; while only surface values were reported, clearly the annual increase in productivity had begun.

Integrated water column data are also available for this area for July, August, and September from McRoy *et al.* (in prep.). During the summer season, rates can be very high as a result of a high concentration of nutrients supplied with the Anadyr Water as it passes through Anadyr Strait (Walsh *et al.*, 1989). Even in summer, these waters can have nitrate concentrations in excess of 20 micromolar, a level which can support very high rates of carbon uptake by phytoplankton. This system is analogous to those typical of upwelling regions of the world's oceans (Sambrotto *et al.*, 1984). In the very high turbulence areas in summer, productivity is low in spite of high nutrients and continuous daylight; rates are 200 to 700 mg $C \cdot m^{-2} \cdot d^{-1}$. Away from the high turbulence, wherever some degree of layering occurs, productivity becomes very high; measured rates range from 2 to 12 g $C \cdot m^{-2} \cdot d^{-1}$ depending on the availability of nutrients. Because of the persistent, strong flow to the north and the confined area of the basin, storms affect the transport of Anadyr Water through the system and hence the supply of nitrate. Coachman (unpublished data) calculated 30 percent less Anadyr Water flowed through Bering Strait in 1986 than in either 1985 or 1987. The annual production for these waters was estimated to be 324 g $C \cdot m^{-2} \cdot yr^{-1}$ by Sambrotto *et al.* (1984); this estimate has since been revised to 285 g $C \cdot m^{-2} \cdot yr^{-1}$ by Walsh *et al.* (1989).

2.2.21 Hope Basin Planning Area

The Hope Basin Planning Area includes the shelf waters from Bering Strait to Pt. Hope and those of Kotzebue Sound out to the International Date Line (Figure 26). Kotzebue is a large, very shallow (10 to 18 m [33 to 59 ft]) embayment of Alaska Coastal Water that is ice covered for a minimum of 239 d of the year (Hameedi, 1988). Tides in Kotzebue Sound and on the shelf are small, within the range of 30 cm (12 in.) or less. Storm surges have a greater effect on sea level and on circulation (Johnson, 1988).

The Chukchi Plain is a broad shallow shelf with depths generally less than 50 m (164 ft) in the Hope Basin Planning Area; an important feature is the relict Hope Sea Valley that dips a few tens of meters below the surrounding plain. This feature is apparently important in the circulation regime since it seems to be an area of concentrated biological activity. Water masses on this shelf are determined by advection with some local effects. The water masses entering from Bering Strait are the primary source waters for the region. North of the Strait, Anadyr and Bering Shelf water masses mix to form the Bering Sea Water which is separated from the Alaska Coastal Water by a distinct front. To the west, on the Siberian side of the shelf, Siberian Coastal Water and Chukchi Water can be found (Johnson, 1988). Currents in Bering Strait can be very strong (i.e., >100 cm/s) but as the flow proceeds northward on the plain it slows to less than

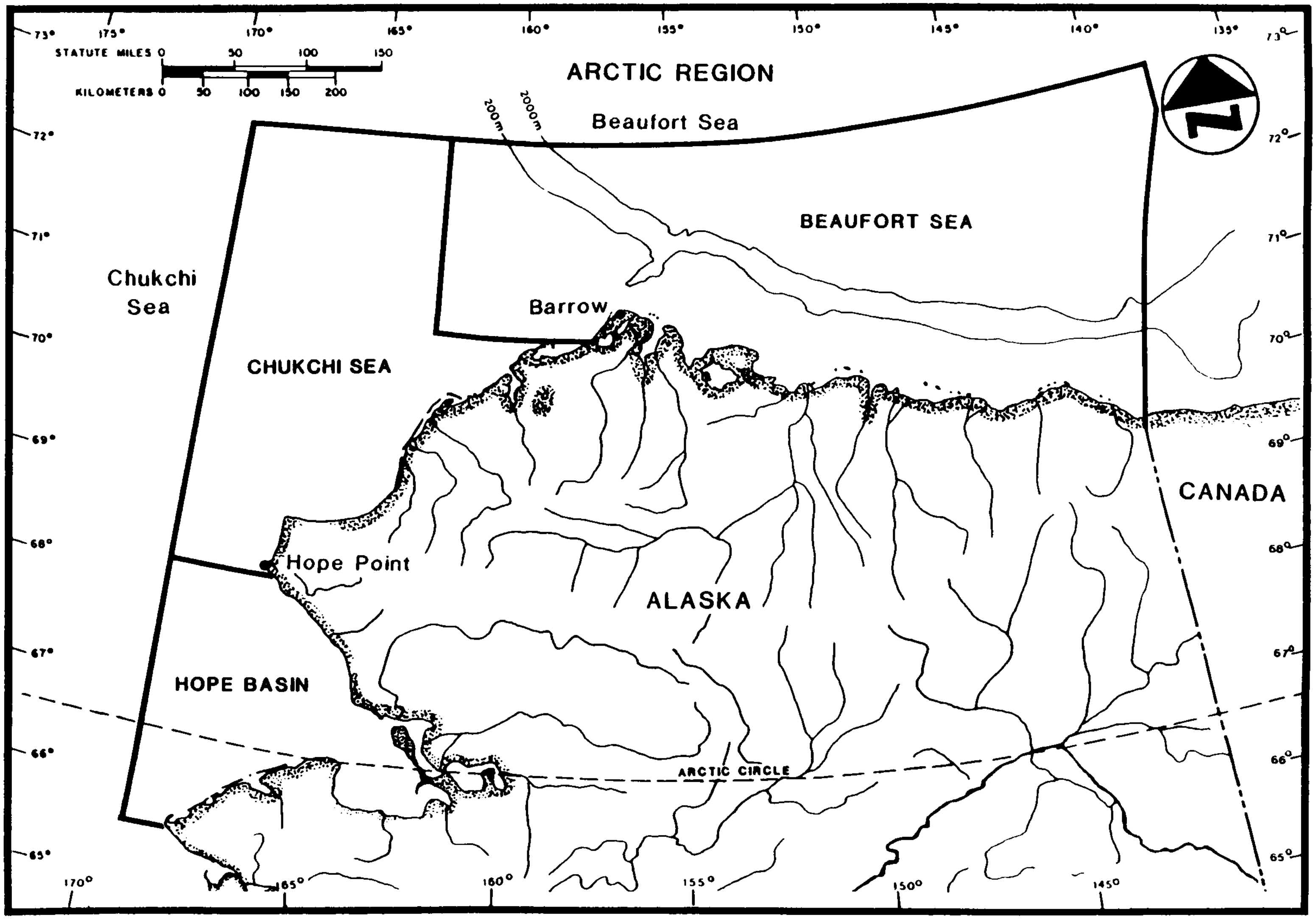


Figure 26. Map of the Arctic region indicating the location of its Planning Areas.

50 cm/s. Flow over the Hope Sea Valley has been measured at 15 cm/s (Coachman *et al.*, 1975). The flow of Anadyr/Bering Shelf Water that becomes Bering Sea Water after mixing has a high concentration of nutrients even in summer (Springer, 1988).

The primary productivity for this region has been reviewed by Schell *et al.* (1988) who note that here, as in other Arctic seas, the total production has two components, including 1) the epontic algae associated with sea ice, and 2) the phytoplankton. The growth season for ice algae extends from March until mid-June. Parrish (1986) calculated the contribution of this community to be 13 g $C \cdot m^{-2} \cdot yr^{-1}$.

Water column productivity depends on the water mass in question. In Alaska Coastal Water on the eastern border of the Chukchi Sea (including Kotzebue Sound), productivity is nutrient limited after the spring bloom, which occurs in late May or early June. Productivity in these waters is similar to that south of Bering Strait along the Alaska coast (see Section 2.2.20, Norton Basin Planning Area). Primary production is initially driven by the nitrate present at the end of winter (about 10 micromolar) and then by regenerated nitrogen. Carbon uptake rates during the summer, ice free season range from 0.5 to 1.57 g $C \cdot m^{-2} \cdot d^{-1}$ (Hameedi, 1978; Springer, 1988). Annual production is estimated to be 50 to 70 g $C \cdot m^{-2} \cdot yr^{-1}$ as in Norton Sound. This estimate is lower than the 75 to 100 g $C \cdot m^{-2} \cdot yr^{-1}$ given by Schell *et al.* (1988). The estimate of Schell *et al.* (1988) for the Hope Basin area is higher because they did not distinguish between water masses.

Bering Sea Water covers the western portion of this shelf and the flow is apparently bathemetrically driven since it follows the contours of the Hope Sea Valley. Productivity over the western portion of the shelf is high throughout the summer because it is driven by nutrients originating in the Anadyr Water from the Bering Sea. Although phytoplankton reduce the nitrate content of this water as it flows north, as much as 8 to 10 micromoles remain as it enters the Chukchi Sea (Walsh *et al.*, 1989). Daily rates are from 1 to 16 g $C \cdot m^{-2} \cdot d^{-1}$ (McRoy *et al.*, in prep.) At one station in July, a rate of 16.14 g $C \cdot m^{-2} \cdot d^{-1}$ was measured which is as high as any value reported for the world's oceans. The annual production for these waters is estimated to be 250 to 300 g $C \cdot m^{-2} \cdot yr^{-1}$.

2.2.22 Chukchi Sea Planning Area

The Chukchi Sea Planning Area encompasses the eastern shelf waters of the Chukchi Sea from Pt. Hope to Pt. Barrow and out to the International Date Line (Figure 26). The 25 to 30 cm/s current flow along this portion of the Alaska coast is deflected by Pt. Hope. As a result, the waters in this Planning Area are primarily Alaska Coastal Water (Coachman *et al.*, 1975). As with the Hope Basin, the region is ice covered most of the year. The waters near Pt. Barrow can be partially ice covered in summer.

Productivity in these waters is low due to nutrient and light limitation. Parrish (1986) measured daily rates ranging from 0.10 to 0.32 g $C \cdot m^{-2} \cdot d^{-1}$ in August and 0.66 to 1.51 g $C \cdot m^{-2} \cdot d^{-1}$ in September.

Annual production is estimated to be 50 to 100 g $C \cdot m^{-2} \cdot yr^{-1}$ near Cape Lisburne. Production levels decrease to 25 to 50 g $C \cdot m^{-2} \cdot yr^{-1}$ near Pt. Barrow. The upper range of these estimates appear to be high.

Sea ice algae are also a potentially significant contributor to the primary production in this region. The annual contribution by this community from measurements near Pt. Barrow has been estimated to be 5 g $C \cdot m^{-2} \cdot yr^{-1}$ (Schell *et al.*, 1988).

2.2.23 Beaufort Sea Planning Area

The Arctic Ocean, in contrast to the Antarctic Ocean, exhibits a relatively small change in annual ice cover and the seasonal open water occurs at the periphery of a permanent ice sheet. The stability of the water column is enhanced by meltwater, river runoff and limited fetches for wind mixing. The region north of Alaska, including the Beaufort Sea Planning Area (Figure 26), is typical in that it is influenced by northward draining rivers. The ice retreat varies from only broken pack ice in heavy ice years to over 300 km (162 nmi) of open water during summers with a maximum ice retreat. The limited mixing and extreme stability of the Arctic Surface Water prevents appreciable quantities of nutrients from reaching the surface and sets the upper bounds on annual primary production. Only in areas where limited upwelling occurs (e.g., north of Barter Island and in the Bathurst Polynya area of the eastern Beaufort Sea) are there zones of relatively high primary production. Even here, low nutrient concentrations in the underlying waters (typically <10 micromolar nitrate) keep phytoplankton concentrations from ever approaching the magnitude of blooms in more temperate waters.

In comparison to the waters along the more southern Alaska coastlines, the Beaufort Sea Planning Area (i.e., the Western Beaufort Sea) supports a relatively sparse biota. No appreciable harvests of marine resources are made except for limited bowhead whaling, seal and polar bear hunting, and a small commercial fishery operated in the Colville River delta. Small subsistence fisheries are also operated in the estuaries along the coast by Inupiat families. Subsistence catch fish, taken by Natives most frequently in Admiralty Bay, the Colville River delta, Simpson Lagoon, and at Barter Island, are sold or bartered. The zone of maximum biological productivity is confined to a relatively narrow strip along the coast wherein the interaction of terrestrially derived nutrients somewhat enhances the nutrient-sparse offshore regime.

Primary production in the Beaufort Sea occurs in two distinct phases. With the onset of increased daylight in April and May, a population of ice algae begins to grow on the underside of the ice cover. Distribution of the algae is believed to be heterogeneous because the nearly 2-m (7-ft) thick ice severely attenuates the light and the presence of snow cover on top of the ice further diminishes the light energy available. Only in optimum sites do the ice algae thrive to constitute a significant fraction of the annual productivity. This epontic algae layer provides a localized source of food for grazers and an inverted benthic community results. The algal populations thrive until the onset of melt in the first weeks of June. As the ice warms, the algae act as localized absorbers of radiant energy and melt off from the bottom of the ice. Estimated rates of carbon fixation during the ice algae bloom range from about 1 g $C \cdot m^{-2} \cdot d^{-1}$ (Horner *et al.*, 1974) to near 5 g $C \cdot m^{-2} \cdot d^{-1}$ (Alexander *et al.*, 1974). Schell *et al.* (1984) emphasize, however, that the heterogeneity of the ice cover and the pronounced rafting of ice floes offshore make the estimation of ice algal productivity very uncertain over any large spatial scale.

Ice algal production has been assumed to be largely a spring phenomenon in the Beaufort Sea. This is in contrast to the Antarctic Ocean, wherein freezeup occurs a full month earlier in the solar year with consequent higher light levels available beneath the ice. The conditions of the fall ice algae bloom in the Antarctic are well documented (Hoshiai, 1969), but no similar blooms have been reported in the Arctic. In November 1980, Schell *et al.* (1984) found sea ice north of Prudhoe Bay with a layer of ice algae in densities similar to the concentrations found in spring. No recent information has emerged as to either the extent or occurence of annual fall ice algae blooms.

Estimation of ice algae productivity in the nearshore Beaufort Sea is further complicated by the phenomenon of turbid ice. If fall, storms occur during the onset of freeze-up, wherein large amounts of sediment are suspended in the water column and are incorporated into the sea ice. Sediment-laden ice is widespread in some years and, since the ice cover persists well into the following summer, there may be very little or no light penetrating the ice until it melts. Complete melting of the ice typically occurs in mid-July in the nearshore lagoons. Offshore of the barrier islands, ice melting occurs at the beginning of August. Since the absence of light prevents the growth of both ice algae and phytoplankton, the primary productivity season may not begin until two or more weeks following the summer solstice in some years (Schell *et al.*, 1984).

As the ice cover melts following the spring ice algal bloom, phytoplankton production becomes predominant. As noted previously, the instability of the water column hinders the advection of nutrients to the photic zone. As a result, phytoplankton productivity estimates are low, ranging from less than 1 g $C \cdot m^{-2} \cdot yr^{-1}$ in the central Arctic Ocean (Appolonio, 1959; English, 1959; Melnikov, 1980) to about 20 g $C \cdot m^{-2} \cdot yr^{-1}$ in the coastal Beaufort Sea (Alexander *et al.*, 1974). More recent estimates place the continental shelf production at near 40 g $C \cdot m^{-2} \cdot yr^{-1}$.

Site-specific data on the Beaufort Sea coastline are limited to OCSEAP-sponsored studies at Prudhoe Bay, the Simpson Lagoon area, and at Barter Island. NSF-supported work at Barrow was accomplished primarily on the Chukchi Sea side of the point, although the data are useful in area-wide estimations (Horner, 1981; Schell *et al.*, 1984). In the eastern Alaskan Beaufort Sea, the only productivity studies completed to date were also OCSEAP-supported and were conducted in the shallow lagoons (Schell *et al.*, 1984) with a few comparative stations immediately offshore.

Schell *et al.* (1984) attempted to estimate the annual primary production in the Beaufort and Chukchi Seas by a combination of methods.

Initially, the available ^{14}C uptake data were integrated for monthly intervals with corrections for the presence or absence of ice cover. Secondly, Schell *et al.* (1984) attempted to calculate the plant biomass that could be supported by the uptake of the available inorganic nitrogen. Although the authors acknowledged that there was evidence for considerable year-to-year variability in the maximum winter concentrations of nitrate and ammonia, the concentrations were sufficiently uniform spatially and with depth to allow area-wide extrapolation of uptake rates.

Schell *et al.* (1984) used satellite data on ice cover extent to determine "average" retreat rates of the pack ice and to contour the position of the ice cover along the coast. The ice-free areas were assigned euphotic zone depths based on field measurements and the ubiquitous cloudy weather and low solar angles. From the data and the projected productivities, Schell *et al.* (1984) constructed a contour map for Alaskan Beaufort Sea productivity that contained many untested assumptions. Nevertheless, this estimate has proved useful as a qualitative guide to regional productivity.

Most of the shallow continental shelf north of Alaska is composed of fine-grained silts and muds which offer very poor substrate for macrophytes. The intertidal region freezes to over 1.5 m (5 ft) each winter and the extreme hypersalinity and cold temperatures pose a severe environmental stress on the biota. Further offshore, where under-ice waters offer more benign temperatures, the presence of moving ice and plowing of the bottom by ice keels again restricts the habitats available for infaunal and epibenthic organisms.

One exception to the severe benthic environments along the coast is found in the waters of Stefansson Sound north of Prudhoe Bay. Here, a unique combination (for the Alaskan Beaufort Sea) of water depths near 5 m (16 ft), protective barrier islands which restrict ice movements, and a bottom strewn with boulders and cobbles provides a habitat for epilithic algae and associated hard-bottom fauna. The richness and variety within this community which is dominated by the macroalga *Laminaria solidungula* contrasts markedly with the rest of the coast. Dunton (1985) describes this epilithic community in detail. The macroalgal abundance and density is more remarkable in that the primary productivity rates are among the lowest described on earth. The presence of sediment-laden ice and the seasonal extremes of daylight and temperature require that the alga complete its annual photosynthesis over time periods as short as two to three months per year. During this brief period when light energy is available, *L. solidungula* fixes and stores carbohydrates required to complete its annual growth and reproduction during the remaining nine to ten months of often complete darkness (Dunton and Schell, 1986). The proximity of this community to areas of offshore oil and gas development has led to continuing studies regarding its sensitivity to increased sedimentation and changes in water chemistry.

3.0 ESTIMATES OF COASTAL AND MARINE HABITATS

3.1 METHODS

The following sections outline the methods employed to identify, collect, evaluate, and annotate the available graphic and literature information pertaining to the coastal and marine habitats located adjacent to and within the 26 OCS Planning Areas. Section 3.0 was prepared by M. John Thompson of Continental Shelf Associates, Inc.

3.1.1 Objectives and Definitions

The primary objective of the coastal and marine habitats component of this project, as outlined in Section 1.2, was to revise and update quantitative habitat estimates used in formulating the individual OCS Planning Area environmental sensitivity analysis required under Section 18(a)(2)(g) of the OCS Lands Act. Specific directives were to develop the methodology for measuring habitat extent and to provide quantitative estimates for shoreline, coastal, and benthic habitats within each of the 26 OCS Planning Areas.

Table 13 presents the general habitat classification utilized in developing the Environmental Sensitivity Analysis tables presented in Appendix I of the 1987 5-Year Leasing Program document (Detailed Decision Documents, Proposed Final 5-Year Leasing Program: Mid-1987 to Mid-1992; USDOI, MMS, 1987a). These general habitat classifications have been redefined and two additional categories have been added for the present analysis. The new categories include:

1) General Coastline; and

2) the ratio of Estuary Mouth to General Coastline.

Definitions for each of the habitat classifications discussed, measurement parameters utilized, and units of measurement employed in the present analysis are as follows:

- General Coastline has been defined according to the National Oceanographic and Atmospheric Administration (NOAA) standard used in their publication entitled "The Coastline of the United States" (U.S. Department of Commerce [USDOC], NOAA, 1975). This category includes bays and sounds as part of the coastline to that point where they narrow to below the resolution limits of the chart utilized (i.e., narrow to unit measurement). The distance across the mouths of inlets, estuaries, and lagoon openings is also included in the measurement of General Coastline. For those individual Planning Areas which include large islands, the mainland and island coastlines have been measured separately and included as "Mainland" and "Island" coastline estimates, respectively. General Coastline represents a linear measurement expressed in kilometers.

Table 13. Designated coastal and marine habitat types, as outlined in Appendix I, Proposed Final 5-Year Leasing Program: Mid-1987 to Mid-1992 (USDOI, MMS, 1987a).

Habitat	Unit
Coastal Habitats	
Estuaries	Miles
Wetlands	Miles
Sandy Beaches	Miles
Rocky Beaches	Miles
Marine Habitats	
Submerged Vegetation	Acres
Submarine Canyons	Acres
Coral Reefs	Acres
Hard Bottoms	Acres
Shelf Break Zone	Acres
Mud/Sand Bottom	Acres

- Estuary/Wetland has been defined as the seaward boundary of coastal swamps, marshes, or wetland areas fronting coastal (i.e., State) waters located immediately adjacent to an individual Planning Area. Estuary mouths and wetlands fronting on estuaries or lagoons have not been included in these estimates. Estuaries/Wetland estimates represent a linear measurement expressed in kilometers.

- Sand/Gravel Beach has been defined to include both sand and gravel beach areas. This habitat classification represents a linear measurement expressed in kilometers.

- Rocky Beach has been defined to include beaches composed of rubble, boulders, or solid rock. This habitat classification represents a linear measurement expressed in kilometers.

- Estuary Mouth/General Coastline is a calculated, unitless ratio of the extent of estuarine egress to the General Coastline for a given Planning Area. The purpose of such a ratio is to allow comparison of Planning Areas based on their estuarine access. In most cases, only the Mainland General Coastline estimate is used for this calculation, however exceptions occur in those Planning Areas which are composed entirely of islands, or when large estuaries or fjords are present on islands. Such exceptions have been noted in the text, accompanying the habitat tables presented for each Planning Area.

- Submerged Vegetation has been defined to include all species of vascular plants (seagrasses) and all major, bed-forming species of macroalgae found within individual Planning Areas. The types of species comprising coverage estimates of Submerged Vegetation are listed in the accompanying Planning Area-specific text. Estimates of the areal extent of Submerged Vegetation include only those areas of vegetation actually found within or fronting individual Planning Areas. No attempts have been made in the present analysis to include Submerged Vegetation found within estuaries or lagoons which open into waters adjacent to individual Planning Areas; the sole exception rests with those major beds which are found directly at the mouths of such estuaries or lagoons. Such inshore beds are not considered part of the OCS for planning purposes. Submerged Vegetation represents an areal estimate expressed in hectares.

- Submarine Canyons represent the summation of the areas covered by canyons and valleys within each Planning Area. There is some ambiguity in the terms "canyon" and "valley" as applied to submarine features located in various OCS

Planning Areas. For example, the valleys present in deeper portions of the continental slope of the Mid-Atlantic Planning Area appear geologically distinct from true canyons, while features designated as valleys in the South Atlantic, Western Gulf of Mexico, and Southern California Planning Areas appear identical to other features designated as canyons. Throughout this analysis, the similarities of habitat provided by both canyons and valleys were deemed more important than differences in the geologic origin of such features. As such, features designated as valleys have been included in the Submarine Canyons habitat estimate. This habitat classification represents an areal measurement expressed in hectares. The areal extent of submarine canyons and valleys have been measured by drawing a line across the apparent mouth of the canyon or valley, delineating a line up the axis, and developing a polygon from this axial line to the shoulders of the canyon. Canyons and valleys have been measured from their mouths shoreward to a point where they no longer depress the bathymetric contours. In many instances throughout the OCS, submarine canyons run together into areas of extremely complex bottom topography. In these instances, the entire area is designated as a "submarine canyon complex" and the measured polygon encompasses all of the recent canyon features.

- <u>Coral Reefs</u> have been defined as reefs formed by living coral species that show a vertical relief of ≥1 m (3 ft). This habitat classification represents an areal measurement expressed in hectares. There are several regions within U.S. OCS waters where deepwater and ahermatypic corals, as well as various gorgonian species, form habitat features which are locally referred to as "reefs" or "patches". These habitats have been grouped with the Hard Bottom classification defined below. The Coral Reef habitat classification, as employed here, has been restricted to coral communities in the process of developing reefs. This definition has been restricted because true coral reefs are very rare within the continental U.S. and, since they are particularly sensitive habitats, their coverage should not be exaggerated by inclusion with other coral habitats.

- <u>Hard Bottom</u> has been defined as rock outcrops which may support biologically significant stands of ahermatypic corals, hermatypic corals, gorgonids, or macroalgae. This definition closely parallels the "live bottom" definition as seen in various MMS lease stipulations. This habitat classification represents an aerial measurement expressed in hectares.

- Shelf Slope Zone represents a redefinition of the "Shelf Break" category presented in 1987. This redefinition represents an attempt to quantify the more productive shelf break zone and upper slope portions of the continental margins in a consistent manner that will allow comparisons between Planning Areas. The Shelf Slope Zone, as defined here, included the OCS area between the 200 and 2,000 m (656 and 6,562 ft) bathymetric contours. This habitat classification represents an areal measurement expressed in hectares.

- Mud/Sand Bottom has been defined as the open or sediment-covered bottom area within a Planning Area. These estimates usually encompass portions of Planning Areas where no specific information is available, and have been derived by subtracting known bottom types from the total area present within a given Planning Area. This habitat classification represents areal estimates expressed in hectares.

Each Planning Area-specific summary table also provides areal estimates for State Waters, OCS Area, and Total Area. The State Waters estimate is based on the areal extent of waters located inshore of the Planning Area of interest, encompassing those waters which lie either 3 or 12 mi from shore. A majority of the Planning Areas that border State waters have been established using the 3-mi demarcation line, separating State and Federal (OCS) waters. The exceptions lie with the Eastern and Western Gulf of Mexico Planning Areas, both of which border states which historically established the 12-mi demarcation line. The OCS Area estimate is based on the areal extent of OCS waters lying within a given Planning Area. The Total Area figure represents the summation of the two previous areal estimates (i.e., State Waters and OCS Area).

Within the present analysis, there are four marine habitats that are mutually exclusive, including Submerged Vegetation, Coral Reefs, Hard Bottom, and Mud/Sand Bottom. In several instances, when the areal extent of three of these mutually exclusive marine habitats is known, the areal extent of the fourth habitat can be determined. For example, the sum of Submerged Vegetation, Coral Reefs, and Hard Bottom areal estimates can be subtracted from a Planning Area's Total Area to determine a Mud/Sand Bottom estimate. By definition, the Submarine Canyons and Shelf Slope Zone marine habitat categories are not mutually exclusive.

3.1.2 Data Identification and Collection

Data identification and collection for the Coastal and Marine Habitats component of the present analysis consisted of the following phases:

1) computerized searches of online data bases (as discussed in Section 2.1.1) and map sets accessible through government agencies;

2) search of the in-house map and document files;

3) acquisition of maps and documents identified as critical for this study effort;

4) telephone contacts with MMS regional offices to identify any studies in progress which might provide additional data for this effort; and

5) telephone contacts with State and Federal regulatory personnel (i.e., non-MMS personnel) to identify any additional regional-specific data sources not previously identified.

Identified data sets were collected and divided according to their applicability to individual Planning Areas. From these data sets, Planning Area-specific estimates of habitat type were derived.

3.1.3 Habitat Estimation Procedure

Throughout the present analysis, first priority was given to mapped information. Coastal habitats, expressed in terms of linear extent (i.e., kilometers, miles) of interface with individual Planning Areas, were measured directly from coastal and habitat maps. All linear measurements found in the present analysis were made with a Kartenmesser Curvimetre Map Measurer which reads in inches. Initially, a scale conversion of miles per inch was calculated based on the stated scale of each map utilized. A verification was then completed using the calculated scale conversion factor to measure a known distance on the map. This verification step was necessary because maps are frequently distorted slightly when reproduced, thus introducing discrepancies between stated and actual scale. If such distortions were encountered, a correction factor was calculated for that specific map. Accuracy of measurements ranged from ± 0.15 to 0.30%, depending on the complexity of coastline or habitat feature being measured. Through the entire study, all coastal measurements were checked against NOAA measurements of General Coastline for all coastal states (USDOC, NOAA, 1975).

The areal extent of marine habitats was measured in units of acres using a Model L-30 Lasico Compensating Polar Planimeter. Accuracy tests were performed using the known area of a standard lease block as a calibration standard. Table 14 presents the size ranges tested and percent error encountered with this instrument. These tests were performed repeatedly throughout this survey as a quality assurance procedure.

All marine habitat estimates (other than the Submerged Vegetation estimates) were rounded to the nearest 1,000 acres (405 ha) when presented in the tables which accompany each Planning Area discussion. An exception was made in the case of the Submerged Vegetation estimate because of the extreme vulnerability of this habitat to OCS events. In compliance with MMS contractual requirements, linear and area measurements have been presented in both metric and U.S.

Table 14. Accuracy test parameters employed during use of the Model L-30 Lasico Compensating Polar Planimeter, set and calibrated for maximum areal coverage. These settings were maintained for all measurements derived during the present analysis.

Test Area*	Hectares	(Acres)	Measurement Error
3 Lease Blocks	6,993	(17,280)	± 0.051
25 Lease Blocks	58,277	(144,000)	± 0.021
391 Lease Blocks	911,449	(2,252,160)	± 0.015

*1 Lease Block = 2,331 ha (5,760 acres).

equivalent units, although all original measurements were made using units of either miles or acres.

3.1.4 Data Base and Presentational Format

No single map or literature data set contained all of the data necessary for the present analysis. The wide range of habitat types being reviewed and large geographical area covered necessitated the use of a variety of map products and literature sources to derive the estimates presented in the following text. All map and literature data sources have different scales and levels of internal accuracy. Since the eventual goal of this study effort was to allow sensitivity comparisons between Planning Areas, primary consideration was given to insuring consistency and reproducibility between Planning Areas.

Calculations of the General Coastline of the U.S. have been based on NOAA 1:1,200,000 coastal charts (USDOC, NOAA, 1975). For the present analysis, MMS Planning Area Protraction Diagrams were selected as the most consistent map base from which to measure the General Coastline and Estuary Mouth in each Planning Area. With the exception of the Gulf of Mexico Region, Protraction Diagram charts have a consistent scale of 1:750,000. The Gulf of Mexico Planning Area Protraction Diagrams have a scale of 1:840,000.

Physical features within individual Planning Areas (e.g., Submarine Canyons, Shelf Slope Zone) were measured directly from NOAA-National Ocean Survey or National Ocean Service (NOS) topographic/bathymetric charts prepared at a 1:1,000,000 scale. A variety of charts and maps have been utilized for the other coastal and marine habitat classifications summarized under the present analysis. Table 15 lists the four primary map data sets used in the characterization of a majority of the Planning Areas. These broad, but incomplete, data sources have been supplemented by numerous region- or area-specific charts prepared at various scales. Where no mapped habitat data exist, estimates have been drawn from the literature. Such cases are clearly indicated on the Planning Area-specific summary tables. Table 16 is an example of the summary table presentational format used throughout the Planning Area summaries presented in Section 3.2. Every estimate presented has a specific reference or set of references from which tabular data were taken. In those cases where no specific data exist, or where certain habitats are known to occur but no estimates of their coverage or extent are available, this fact has been noted in both the accompanying text and tabular summary for that Planning Area. Other topics discussed in the Planning Area-specific text include an evaluation of the accuracy of the information available and identified data gaps. References cited in the following text and tables have been annotated in Appendix B.

Table 15. Primary mapped data sources (i.e., large-scale uniform map sets) employed in the present analysis.

Map Set	Scale	Mapped Data Availability	Comments
U.S. Department of the Interior, Minerals Management Service (MMS) Planning Area Protraction Diagrams	1:750,000, except Gulf of Mexico Planning Areas at 1:840,000	Available for all 26 Planning Areas	These are the only official maps which currently reflect the boundaries of all designated OCS Planning Areas. Maps within this set are developed from NOS base maps and are updated periodically. Dates of the recent versions vary by Planning Area. (Note: there were several of the newest Planning Areas in Alaska for which official Protraction Diagrams were not available.)
U.S. Department of Commerce, National Oceanic and Atmospheric Admistration (NOAA) - National Ocean Survey or Service (NOS) Topographic/Bathymetric Charts	1:1,000,000	Available for the entire contiguous U.S. and most of Alaska. Coverage lacking for the western Aleutian Islands and several northern Alaskan basins.	The base maps and bathymetric information on these charts is compiled from NOS coastal and hydrographic surveys augmented by bathymetric information provided by the U.S. Naval Oceanographic Office. These maps are presently being updated and expanded. Dates of publication and specific chart numbers are referenced for each measurement presented.
U.S. Fish and Wildlife Service (USFWS), National Wetland Inventory (NWI) Wetlands Classification Maps	1:100,000, except for Alaska Planning Areas at 1:63,360	Available for the majority of the coastline of the contiguous U.S. There are noticable gaps in the North Carolina area, portions of the Gulf of Mexico, and several locations in California and Oregon. NWI information for Alaska is available only for the Cook Inlet and Beaufort Sea Planning Areas.	When available, these maps represent the most consistent, uniform data source for the coastal habitat features reviewed in this study. The base map employed for each of these charts is a photographic enlargement of a 1:250,000 scale U.S. Geological Survey quadrangle. Wetlands classifications are based on black and white, color IR, and color transparency imagery. NWI imagery covers the period from 1971 through the present and covers a range of scales from 1:80,000 to 1:40,000, which are subsequently standardized to either 1:100,000 (contiguous U.S.) or 1:63,360 (Alaska). These charts are constantly being updated. Dates of publication are listed for individual maps referenced.
U.S. Fish and Wildlife Service, Ecological Inventory Maps	1:250,000	Available for the entire contiguous U.S.	The base maps employed for these charts are the U.S. 1:250,000 scale Geological Survey quadrangles published in 1969. Although excellent for their intended purpose, these maps are of limited utility in assessing coastal and marine habitats. This map set, published in 1980, has been used primarily as a supplemental data source to bridge coverage gaps evident in the NWI map set.

Table 16. Presentation format employed for Planning Area-specific summary tables. The example shown has been taken from the Straits of Florida Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	531 (330)	MMS Straits of Florida Planning Area Protraction Diagram (USDOI, MMS, 1987e).
Estuary/Wetland	129 (80)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Sand/Gravel Beach	402 (250)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Rocky Beach	Negligible	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Estuary Mouth/ General Coastline	58/531 = 0.109	MMS Straits of Florida Planning Area Protraction Diagram (USDOI, MMS, 1987e).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	160,261 (396,000)	Continental Shelf Associates, 1990; MMS Report 89-80 (USDOI, MMS, 1990b); BLM Fort Jefferson National Monument Map (USDOI, BLM, 1979a); MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979).
Submarine Canyons	46,945 (116,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Coral Reefs	23,068 (57,000)	BLM Fort Jefferson National Monument Map (USDOI, BLM, 1979a); MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979); Reed *et al.*, 1980.
Hard Bottom	62,729 (156,000)	MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979); Duane and Meisburger, 1969; Thompson and Gilliland, 1976; Reed *et al.*, 1980.
Shelf Slope Zone	2,573,487 (6,359,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Mud/Sand Bottom	4,300,349 (10,625,000)	Estimated by subtracting the Hard Bottom, Submerged Vegetation, and Coral Reefs estimates from the Total Area.
State Waters	256,580 (634,000)	Calculated based on 3-mi limit.
OCS Area	4,289,820 (10,600,000)	USDOI, MMS, 1990a.
Total Area	4,546,400 (11,234,000)	

*Insufficient data.

3.2 Planning Area Summaries

3.2.1 North Atlantic Planning Area

Coastal Habitats

The general coastline lying shoreward of the North Atlantic Planning Area extends from the U.S.-Canada border southward around Cape Cod to Buzzards Bay, MA. This Planning Area also includes the two large islands of Nantucket and Martha's Vineyard, located off the southern shore of Cape Cod.

The northernmost portion of this coastline, extending from the U.S.-Canada border to Cape Elizabeth, ME, represents a glacially gouged shoreline with steep rocky beaches, deep narrow inlets and fjords, and innumerable rocky islands. Many streams and rivers flow into these bays and fjords, creating a variety of small, isolated wetland habitat pockets (NWI Wetlands Classification Maps [USDOI, USFWS, 1979-1982a]).

The total surface area of the estuaries and fjords fronting waters adjacent to the North Atlantic Planning Area has been estimated at 15,500,773 ha (38,301,887 acres) by Lynch *et al.* (1976), and the total tidal shoreline throughout this area is given as 8,249 km (5,127 mi) (USDOC, NOAA, 1975). Most of the wetland areas within these narrow fjords and bays are located some distance inshore of their mouths and, as such, are not directly in contact with the OCS waters of the North Atlantic Planning Area. The wetland areas that comprise the estimate presented in Table 17 are salt marshes dominated by *Juncus geradi* and *Spartina alterniflora*.

The coastline inshore of the North Atlantic Planning Area from Cape Elizabeth, ME to Cape Cod, MA remains a high-energy coastline, however this area is not as gouged (or dissected) and rocky as the northern zone noted previously. The linear extent of sand/gravel beaches south of Cape Elizabeth increases. These beaches are referred to as "pocket" beaches bracketed by rocky outcrops.

Along the eastern and southern shoreline of Cape Cod, sandy beaches predominate. These beaches are generally low and narrow, but are characterized by the upland presence of well-developed dune systems. Near the base of Cape Cod and throughout Buzzards Bay, there are low, rocky outcrops interspersed with beaches; in protected areas, marshes are evident (UMES, 1985; NWI Wetlands Classification Maps [USDOI, USFWS, 1979-1982a]).

Only the mainland General Coastline estimate has been used in calculating the Estuary Mouth to General Coastline ratio presented in Table 17. The Estuary Mouth to General Coastline ratio calculated for this Planning Area is particularly high due to the large number of bays and fjords present north of Cape Elizabeth. A total of 153 km (95 mi) of estuary mouth occurs north of Cape Elizabeth; this represents 70% of the entire 219 km (136 mi) of estuary mouth noted for this Planning Area. In terms of the numbers of fjords and bays, the only areas

Table 17. Summary table for the North Atlantic Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline		MMS North Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987b).
Mainland	685 (426)	
Island	143 (89)	
Estuary/Wetland	66 (41)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982a).
Sand/Gravel Beach	475 (295)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982a); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Rocky Beach	288 (179)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982a); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Estuary Mouth/ General Coastline	219/685 = 0.320 (mainland only)	MMS North Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987b).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	1,708 (4,220)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982a).
Submarine Canyons	481,188 (1,189,000)	NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).
Coral Reefs	Negligible	
Hard Bottom	1,133,565 (2,801,000)	MMS, Visual No. 3, North Atlantic Region (USDOI, MMS, 1984a); NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).
Shelf Slope Zone	1,045,745 (2,584,000)	NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).
Mud/Sand Bottom	19,986,110 (49,385,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	643,473 (1,590,000)	Calculated based on 3-mi limit.
OCS Area	20,477,820 (50,600,000)	USDOI, MMS, 1990a.
Total Area	21,121,293 (52,190,000)	

comparable to the North Atlantic Planning Area amongst all Planning Areas reviewed are some of the rocky coastlines present in Alaska.

Marine Habitats

Submerged vegetation within the North Atlantic Planning Area consists almost entirely of eel grass (*Zostera marina*) beds. A limited amount of widgeon grass (*Ruppia maritima*) can also be found growing further upstream within rivers which empty along this coastline, however this species generally occurs too far up-river to be affected by OCS activities. The Submerged Vegetation estimates presented in Table 17 do not account for the important intertidal algal community present along the rocky coast of the northern segment of this Planning Area. Algal species, represented by *Chondrus crispis* (Irish moss) and *Ascophyllum nodosum* (rockweed), as well as several species of *Fucus* (kelp), are particularly important along the coast of Maine (UMES, 1985). Although they do not form submerged vegetative beds in the classical sense, these communities do form thick mats overlying the intertidal rock. Unfortunately, quantitative estimates on the coastline-wide aerial extent of this community are not available.

Eleven submarine canyons disect the Shelf Slope Zone in this Planning Area (Table 18). Substantial areas of hard bottom have been mapped in association with the head of Oceanographer Canyon (MMS OCS North Atlantic Region, Visual No. 3, Bottom Sediments, [USDOI, MMS, 1984a]) and reported from the walls and floor of Lydonia Canyon (Maciolek *et al.*, 1987). Extensive areas of hard-bottom habitat occur across all of Georges Bank and in the nearshore area from Cape Cod to Maine (MMS OCS North Atlantic Region, Visual No. 3, Bottom Sediments, [USDOI, MMS, 1984a]). In addition to containing large areas of bedrock outcropping, the North Atlantic Planning Area also has a number of seamounts within its boundaries (Table 19). These seamounts lie beyond the bounds of the continental slope, in 2,500 to 5,000 m (8,203 to 16,405 ft) of water (MMS OCS North Atlantic Region, Visual No. 3, Bottom Sediments, [USDOI, MMS, 1984a]; NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States [USDOC, NOAA-NOS, 1985a]). The crest area for these seamounts has been assumed to represent bedrock outcrop and has been incorporated into the Hard Bottom habitat estimate presented in Table 17.

Considering the well-documented nature of rock outcroppings across Georges Bank and along the New England coast, a limited amount of confidence can be placed in the Mud/Sand Bottom estimate generated for this Planning Area (Table 17). Undoubtedly, there are several thousand acres of rock outcroppings in and around various submarine canyons which have not been accounted for in this estimate. Despite this omission, the estimate of Hard Bottom Habitat provided in Table 17 can be considered an approximation and should be useful for comparisons with other Planning Areas.

Table 18. Submarine canyons present within the North Atlantic Planning Area. Data derived from NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).

Canyon	Hectares	(Acres)
Nygren Canyon	44,438	(109,806)
Munson Canyon	78,433	(193,806)
Powell Canyon	49,666	(122,724)
Lydonia Canyon	61,429	(151,790)
Gilbert Canyon	36,596	(90,428)
Oceanographer Canyon	52,280	(129,183)
Welker Canyon	26,140	(64,592)
Hydrographer Canyon	43,131	(106,576)
Veatch Canyon	32,675	(80,740)
Atlantis Canyon	28,754	(71,051)
Alvin Canyon	27,447	(67,821)
Total	480,989	(1,188,517)*

*Acreage total rounded to 1,189,000 acres (or 481,188 ha) for inclusion in Tables 17 and 61.

Table 19. Seamounts located within the North Atlantic Planning Area. Data derived from NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a) and MMS OCS North Atlantic Region, Visual No. 3, Bottom Sediments (USDOI, MMS, 1984a).

	Crest Depth		Crest Area	
Seamount	Meters	(Feet)	Hectares	(Acres)
Bean	1,102	(3,616)	14,377	(35,525)
Physalia	1,881	(6,172)	11,763	(29,066)
Mytilus	2,269	(7,445)	11,655	(28,800)
Retriever	1,843	(6,047)	20,912	(51,673)
Picket	1,693	(5,555)	30,061	(74,280)
Balanus	1,466	(4,810)	33,982	(83,969)
Asterias*	3,720	(12,205)	3,921	(9,689)
Total Crest Area			126,671	(313,002)

*Asterias Seamount is only partially located within the boundaries of the North Atlantic Planning Area. Only the seamount area found within existing Planning Area bounds is provided.

3.2.2 Mid-Atlantic Planning Area

Coastal Habitats

The General Coastline lying shoreward of the Mid-Atlantic Planning Area extends from south of Buzzards Bay, MA to the Pamlico Sound barrier island-sound complex of North Carolina. This region contains some of the largest and best studied estuaries in the United States. Long Island Sound, Hudson River, Raritan Bay, Delaware Bay, and Chesapeake Bay all open into the coastal waters adjacent to this Planning Area.

Wetlands fronting directly onto coastal waters adjacent to this Planning Area consist primarily of salt marshes dominated by *Spartina alterniflora* and *S. patens* in the northern portion of the Planning Area and by *S. alterniflora* and *Juncus romerianus* in the southern portion (Sugihara *et al.*, 1979; UMES, 1985).

Sand and gravel beaches are predominant along the coastline south of Buzzards Bay and along the barrier islands inshore of the Mid-Atlantic Planning Area. The rocky beaches present within this region represent isolated outcrops seen primarily around the headland of capes and bays in estuary mouths.

Marine Habitats

The Submerged Vegetation evident in the Mid-Atlantic Planning Area consists of seagrass beds dominated by *Zostera marina* (Table 20). A limited amount of widgeon grass (*Ruppia maritima*) is present within this area, however this species normally grows too far upstream within estuaries or rivers to be considered in the estimates developed in the present analysis.

There are a total of 15 submarine canyons or canyon complexes located within this Planning Area (Table 21). Thirteen of these submarine features have official names as listed on the NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a). In addition to these named features, Table 21 lists data from two unnamed canyons (designated Canyon #1 and Canyon #2) located between Block Canyon and Jones Canyon, at the northern edge of the Planning Area. Canyon #1 is the more northerly of these features and extends from a depth of 200 m (656 ft) down to the 2,400 m (7,874 ft) depth contour. Canyon #2, the smaller unnamed feature, extends from the 200 m (656 ft) depth contour to 2,000 m (6,562 ft).

Hard Bottom outcrops have been reported from the head and walls of Baltimore Canyon (Lamont-Doherty Geological Observatory of Columbia University, 1983). These researchers also reported the presence of massive limestone outcrops along the axis and walls of Hudson Canyon and extensive hard bottom exposure below 1,400 m (4,593 ft) along the entire Shelf Slope Zone. Due to the considerable, but unknown, extent of rock outcropping seen within the Shelf Slope Zone of this Planning Area, no estimate of the total Hard Bottom or Mud/Sand Bottom coverage was justified in the present analysis.

Table 20. Summary table for the Mid-Atlantic Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	1,007 (626)	MMS Mid-Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987c).
Estuary/Wetland	101 (63)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1987); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Sand/Gravel Beach	851 (529)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1987); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Rocky Beach	55 (34)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1987); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Estuary Mouth/ General Coastline	132/1,007 = 0.131	MMS Mid-Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987c).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	5,882 (14,533)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1987); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Submarine Canyons	1,679,505 (4,150,000)	NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).
Coral Reefs	Negligible	
Hard Bottom	*	No estimate given based on data acquired during the Canyon and Slope Processes Study (Lamont-Doherty Geological Observatory of Columbia University, 1983).
Shelf Slope Zone	2,193,069 (5,419,000)	NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).
Mud/Sand Bottom	*	No estimate given based on data acquired during the Canyon and Slope Processes Study (Lamont-Doherty Geological Observatory of Columbia University, 1983).
State Waters	486,449 (1,202,000)	Calculated based on 3-mi limit.
OCS Area	33,266,340 (82,200,000)	USDOI, MMS, 1990a.
Total Area	33,752,789 (83,402,000)	

*Insufficient data.

Table 21. Submarine canyons present within the Mid-Atlantic Planning Area. Data derived from NOAA-NOS Topographic/Bathymetric Chart, Northeastern United States (USDOC, NOAA-NOS, 1985a).

Canyon	Hectares	(Acres)
Block Canyon	35,289	(87,199)
Canyon #1	60,123	(148,561)
Canyon #2	39,206	(96,877)
Jones Canyon	40,517	(100,117)
Hudson Canyon	94,105	(232,530)
Tom's Canyon Complex	230,034	(568,406)
Lindenoehl Canyon	90,184	(222,841)
Spencer Canyon	33,982	(83,969)
Wilmington Canyon	92,798	(229,300)
Baltimore Canyon	87,570	(216,382)
Accomac/Leonard Canyon Complex	126,780	(313,269)
Washington Canyon Complex	105,868	(261,596)
Norfolk Canyon	52,280	(129,183)
Washington Valley	244,411	(603,932)
Arstens Valley/Hudson Valley Complex*	346,358	(855,839)
Total	1,679,505	(4,150,001)†

*This measurement also encompasses the narrow Heezen Plateau area. It was recognized that this plateau was extremely narrow, placing virtually all of it within the topographic province of either Arstens Valley or Hudson Valley.

†Acreage total rounded to 4,150,000 acres (1,679,505 ha) for inclusion in Tables 20 and 61.

3.2.3 South Atlantic Planning Area

Three major coastal morphologies are present adjacent to the South Atlantic Planning Area, including:

1) long barrier islands characterized by the presence of wide sand beaches and large sounds located landward, as represented by the Cove, Block, and Bogue Sound areas (inshore of the northern reaches of the Planning Area);

2) short barrier islands exhibiting numerous inlets and extensive tidal marshes evident from Onslow Bay, NC southward to the St. Johns River area of Florida; and

3) long narrow barrier islands characterized by relatively narrow sand beaches and widely spaced inlets opening into narrow coastal lagoons or inland waters. These types of barrier islands are present from the St. Johns River area southward to the southern limit of this Planning Area.

Estuary and wetland areas fronting directly onto coastal waters adjacent to the OCS are evident primarily in the middle portion of this Planning Area (i.e., Onslow Bay, NC to St. Johns River, FL). There are no rocky beaches of significance within this Planning Area, but a large number of both wide and narrow openings to lagoons or estuaries are evident.

Marine Habitats

A majority of the submerged vegetation present in waters adjacent to or within the South Atlantic Planning Area consist of eel and shoal grass beds (*Zostera marina* and *Halodule wrightii*, respectively) grown in association with the tidal marshes. While seagrass growth is extensive in the bays and lagoons present adjacent to OCS Planning Area waters, most of this growth occurs behind the barrier islands along the coast. Estimates presented in Table 22 include only those seagrass beds potentially exposed to OCS activities.

Six submarine canyons indent the Shelf Slope Zone within this Planning Area (Table 23). Of these, the Hatteras Transverse Canyon, which lies offshore of the Pamlico and Hatteras Canyons and runs almost parallel with the Cape Hatteras shoreline, is the most extensive.

Hard Bottom areas lying within continental shelf depths of the South Atlantic Planning Area are extensive (Continental Shelf Associates, Inc., 1979; 1983). A nearly continuous line of carbonate reef outcropping is evident along the 100-m (328-ft) isobath. Shoreward of this outcropping are large areas where Hard Bottom habitats are either reported or expected (Visual No. 1; Continental Shelf Associates, Inc., 1983). A considerable amount of hard coral is found growing along many of these outcrops (Reed, 1980; Parker and Ross, 1984). Many researchers have referred to specific features in this hard bottom complex as "coral" reefs over the years. Using the definition applied

Table 22. Summary table for the South Atlantic Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	1,035 (643)	MMS South Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987d).
Estuary/Wetland	352 (219)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980a-1983); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Sand/Gravel Beach	682 (424)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980a-1983); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Rocky Beach	Negligible	
Estuary Mouth/ General Coastline	103/1,035 - 0.100	MMS South Atlantic Planning Area Protraction Diagram (USDOI, MMS, 1987d).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	7,389 (18,259)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980a-1983); USFWS Atlantic Coast Ecological Inventory Maps (USDOI, USFWS, 1980a).
Submarine Canyons	1,189,413 (2,939,000)	NOAA-NOS Topographic/Bathymetric Chart, Southeastern United States (USDOC, NOAA-NOS, 1986a).
Coral Reefs	Negligible	
Hard Bottom	944,165 (2,333,000)	BLM South Atlantic Hard Bottom Study (Continental Shelf Associates, Inc., 1979); MMS North Carolina Fisheries and Environmental Data Search and Synthesis Study, Visual No. 1, Bottom Types (Continental Shelf Associates, Inc., 1983).
Shelf Slope Zone	14,552,607 (35,959,000)	NOAA-NOS Topographic/Bathymetric Chart, Southeastern United States (USDOC, NOAA-NOS, 1986a).
Mud/Sand Bottom	42,365,511 (104,685,000)	Estimated by subtracting the Hard Bottom and Submerged Vegetation estimates from the Total Area.
State Waters	449,805 (1,235,000)	Calculated based on 3-mi limit.
OCS Area	42,817,260 (105,800,000)	USDOI, MMS, 1990a.
Total Area	43,317,065 (107,035,000)	

Table 23. Submarine canyons present within the South Atlantic Planning Area. Data from NOAA-NOS Topographic/Bathymetric Chart, Southeastern United States (USDOC, NOAA-NOS, 1986a).

Canyon	Hectares	(Acres)
Blake Canyon	152,920	(377,861)
Beaufort Valley	35,289	(87,199)
Charleston Valley	43,131	(106,576)
Pamlico Canyon	163,377	(403,698)
Hatteras Canyon	252,253	(623,309)
Hatteras Transverse Canyon	542,410	(1,340,276)
Total	1,189,380	(2,938,919)*

*Acreage total rounded to 2,939,000 acres (or 1,189,413 ha) for inclusion in Tables 22 and 61.

in the present analysis, these coral growth areas are classified under the Hard Bottom category rather than the Coral Reef habitat classification. Blake *et al.* (1986) reported rock outcropping continuing below the 100-m (328-ft) isobath. These researchers also reported a considerable amount of hard-bottom habitat in the 450- to 700-m (1,476- to 2,297-ft) depth range around the Charleston Bump. Considering the extent of topographic variation present along the continental shelf and slope of this Planning Area, it is likely that the Hard Bottom estimate given in Table 22 underestimates the extent of this habitat. It is recognized that this Planning Area is large and encompasses a sizeable area where depths are greater than 3,000 m (9,843 ft), where soft sediments are expected to predominate. The Mud/Sand Bottom estimate provided in Table 22 is deemed to be adequate for comparative purposes.

3.2.4 Straits of Florida Planning Area

Coastal Habitats

Two types of coastline are present adjacent to the Straits of Florida Planning Area. From Melbourne southward to Biscayne Bay, the coastline is characterized by the presence of barrier islands and sandy beaches. While there are some intermittent outcrops of lithofied beach rock along this portion of the Florida coastline, none of it can truly be considered a rocky beach. South of Biscayne Bay, the coastline fronting coastal waters adjacent to this Planning Area consists of the south-facing shore of the Florida Keys.

Most of the wetland areas present within this region consist of the mangrove swamps fringing the Florida Keys. Other extensive wetland areas are found at the north end of Jupiter Island, along Hutchinson Island south of the Ft. Pierce Inlet, and in the Sebastian Inlet area (NWI Wetlands Classification Maps [USDOI, USFWS, 1979]).

In order to calculate the Estuary Mouth to General Coastline ratio for this Planning Area, all of the channels north of Big Pine Key (i.e., interkey channels) in the Florida Keys have been considered as openings into the Florida Bay estuary.

Marine Habitats

In 1979, the U.S. Department of the Interior, Bureau of Land Management (BLM), in cooperation with the Florida Department of Natural Resources, published a detailed, 10-map series termed the Florida Reef Tract Marine Habitats and Ecosystems Maps (USDOI, BLM and Florida Department of Natural Resources, 1979). Submerged Vegetation estimates presented in Table 24 have been taken primarily from these habitat maps. Supplementary data were derived from the 1979 OCS Resource Management Map, Coral Distribution for Jefferson National Monument, The Dry Tortugas (USDOI, BLM, 1979a), and the maps produced in association with the South Florida Nearshore Benthic Habitat Study (Continental Shelf Associates, Inc., 1990; USDOI, MMS, 1990b). Submerged Vegetation estimates taken from these sources were considered highly accurate, particulary for the seagrasses growing in areas directly exposed to

Table 24. Summary table for the Straits of Florida Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	531 (330)	MMS Straits of Florida Planning Area Protraction Diagram (USDOI, MMS, 1987e).
Estuary/Wetland	129 (80)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Sand/Gravel Beach	402 (250)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Rocky Beach	Negligible	NWI Wetlands Classification Maps (USDOI, USFWS, 1979).
Estuary Mouth/ General Coastline	58/531 = 0.109	MMS Straits of Florida Planning Area Protraction Diagram (USDOI, MMS, 1987e).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	160,261 (396,000)	Continental Shelf Associates, Inc., 1990; MMS Report 89-80 (USDOI, MMS, 1990b); BLM Fort Jefferson National Monument Map (USDOI, BLM, 1979a); MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979).
Submarine Canyons	46,945 (116,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Coral Reefs	23,068 (57,000)	BLM Fort Jefferson National Monument Map (USDOI, BLM, 1979a); MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979); Reed *et al.*, 1980.
Hard Bottom	62,729 (156,000)	MMS Florida Reef Tract Maps (USDOI, BLM and Florida Department of Natural Resources, 1979); Duane and Meisburger, 1969; Thompson and Gilliland, 1976; Reed *et al.*, 1980.
Shelf Slope Zone	2,573,487 (6,359,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Mud/Sand Bottom	4,300,349 (10,625,000)	Estimated by subtracting the Hard Bottom, Submerged Vegetation, and Coral Reefs estimates from the Total Area.
State Waters	256,580 (634,000)	Calculated based on 3-mi limit.
OCS Area	4,289,820 (10,600,000)	USDOI, MMS, 1990a.
Total Area	4,546,400 (11,234,000)	

*Insufficient data.

waters of the OCS. There are additional seagrass beds present within Biscayne Bay, however these beds are within the Bay proper and have not been included in the estimate provided in Table 24.

The dominant seagrass species found within coastal waters adjacent to the Straits of Florida Planning Area consist of turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*). In addition to fringing seagrass species, *Halophila decipiens* and *H. englemanii* make a slight contribution to submerged vegetation throughout this area (Zieman, 1982; Continental Shelf Associates, 1990).

Only one submarine canyon, the Tortugas Valley, is partially contained within the Straits of Florida Planning Area. This feature is located on the western boundary of the Planning Area. Slightly more than half of the areal extent of this submarine feature lies within the Eastern Gulf of Mexico Planning Area.

Nearshore coral reef estimates provided in Table 24 were derived from the same map sets used to determine the Submerged Vegetation estimates. In both instances, the mapped information and the tabular estimates derived were considered to be highly accurate. It should also be noted that there is an extensive, deep water (37 to 40 m; 121 to 131 ft) coral reef extending virtually the entire length of the Florida Keys (USDOC, NOAA, 1981). This reef has been partially mapped in the area of the Key Largo Marine Sanctuary, but its overall extent remains unknown. The Coral Reef estimate presented in Table 24 should, therefore, be considered an underestimate of total coral reef coverage in this Planning Area.

All reefs located north of Biscayne Bay have been delineated under the Hard Bottom category. While many species of reef building corals are found along these hard ground areas, it is generally believed that actual reef growth ends between 25°N and 26°N latitude (Smith, 1972). Hard-bottom areas along this shelf area were first mapped by Duane and Meisburger (1969) and have been further delineated by several other authors (Thompson and Gilliland, 1979; Reed, 1980). Despite the data derived during these studies, it is felt that the Hard Bottom habitat estimates presented in Table 24 still underestimate the total hard ground present in this Planning Area, particularly for the deeper water portions of this region. The Mud/Sand Bottom estimate presented in Table 24 has been extrapolated by subtracting Hard Bottom, Submerged Vegetation, and Coral Reefs estimates from the Total Area. In light of the projected underestimation of Hard Bottom noted previously, the Mud/Sand Bottom estimate should be viewed as a potential overestimation.

3.2.5 Eastern Gulf of Mexico Planning Area

Coastal Habitats

There are extensive tracts of coastal wetlands located along the western shore of Florida which front the coastal waters adjacent to this Planning Area. From Ocklockonee Bay to Tarpon Springs, FL (i.e., the Florida Big Bend area), and from Charlotte Harbor through Florida

Bay, the coastline is comprised almost entirely of wetlands (NWI Wetlands Classification Maps, [USDOI, USFWS, 1979-1981]). From Ocklockonee Bay westward to the Planning Area boundary, a series of barrier islands separates large and productive sounds and bays from the open OCS waters of the Gulf of Mexico. Beaches along these islands are formed from fine- and medium-grained siliceous sand, while those seen farther south (along the barrier islands between Clearwater and Charlotte Harbor) are formed of carbonate sands and shell hash. There are virtually no rocky beaches adjacent to this Planning Area, although the shoreline along the northern side of the Florida Keys exhibits many areas where a very thin sand veneer covers the rocky, carbonate platform from which the Keys are formed.

The mouth of Florida Bay (51 km; 32 mi) has been included in the calculation of the Estuary Mouth to General Coastline ratio (Table 25). Florida Bay represents a triangular-shaped body of water with its southwest side completely open to the Gulf of Mexico. This configuration renders it extremely vulnerable to OCS activities.

Marine Habitats

There are six species of seagrass which grow abundantly within the Eastern Gulf of Mexico, including turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), widgeon grass (*Ruppia maritima*), and two species which have no universally recognized common name, *Halophila decipieus* and *H. englemanni* (Zieman, 1989). Recent studies (Continental Shelf Associates, Inc., 1985a; 1990) have shown that the two *Halophila* species cover substantially more submerged area on the continental shelf than was previously imagined. In addition to the *Halophila* species which grow to a depth of 37 m (121 ft) in certain portions of this Planning Area, the dense *Thalassia* and *Syringodium* seagrass beds present within the Florida Big Bend area and in Florida Bay form the most significant stands of submerged vascular plant vegetation seen in any of the 26 Planning Areas.

There are two significant submarine canyons within the Eastern Gulf of Mexico Planning Area, including:

1) DeSoto Canyon, which lies in the northwest corner of this Planning Area near its border with the Central Gulf of Mexico Planning Area; and

2) Tortugas Valley, which lies at the southeast margin of the Planning Area along its border with the Straits of Florida Planning Area.

Coral reef concentrations located within the boundaries of the Eastern Gulf of Mexico Planning Area are comprised of: 1) the Florida Middle Grounds, located off the Big Bend region of Florida; 2) the reefs on the northern side of the Tortugas Bank formations (those on the southern side fall into the Straits of Florida Planning Area); and 3) the reefs on the northern side of the Florida Keys. In addition, the west Florida shelf is covered with extensive Hard Bottom habitat in

Table 25. Summary table for the Eastern Gulf of Mexico Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	1,358 (844)	MMS Eastern Gulf of Mexico Planning Area Protraction Diagram (USDOI, MMS, 1987f).
Estuary/Wetland	629 (391)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1981).
Sand/Gravel Beach	729 (453)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1981); MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b).
Rocky Beach	Negligible	
Estuary Mouth/ General Coastline	228/1,358 = 0.168	MMS Eastern Gulf of Mexico Planning Area Protraction Diagram (USDOI, MMS, 1987f).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	2,932,081 (7,245,074)	MMS Report 85-0088 (USDOI, MMS, 1985a); MMS Report 89-0080 (USDOI, MMS, 1990b).
Submarine Canyons	961,972 (2,377,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Coral Reefs	65,289 (161,327)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); MMS Report 89-0080 (USDOI, MMS, 1990b).
Hard Bottom	427,134 (1,055,443)	MMS, Bottom Sediments and Selected Endangered and Threatened Species, Visual No. 3 (USDOI, MMS, 1983a); MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b; MMS Report 85-0088 (USDOI, MMS, 1985a); MMS Report 89-0080 (USDOI, MMS, 1990b).
Shelf Slope Zone	4,751,178 (11,749,000)	NOAA-NOS Topographic/Bathymetric Chart, Eastern Gulf of Mexico (USDOC, NOAA-NOS, 1986b).
Mud/Sand Bottom	*	
State Waters	2,623,265 (6,482,000)	Calculated based on 12-mi limit.
OCS Area	30,595,320 (75,600,000)	USDOI, MMS, 1990a.
Total Area	33,218,585 (82,082,000)	

*Insufficient data.

which reef-forming hard corals play an important role. Parker *et al.* (1983) estimated that 38.2% of the continental shelf between Pensacola and Key West, FL in depths less than 180 m (591 ft) was covered with reef or hard bottom habitat. This represents a total of 4,494,662 ha (11,106,157 acres). The actual extent of mapped Hard Bottom habitat, as estimated in Table 25, is considerably less than this figure, but many surveys (Continental Shelf Associates, Inc., 1985a; 1985b; 1990) conducted across the west Florida shelf support the original estimates of Parker *et al.* (1983). The mapped Hard Bottom habitat estimate presented in Table 25 is provided for comparative purposes; insufficient data are currently available to estimate total Mud/Sand Bottom coverage within this Planning Area.

3.2.6 Central Gulf of Mexico Planning Area

Coastal Habitats

There is an interesting and important discrepancy evident between the General Coastline estimate presented in Table 26 when compared to two other sources. These sources include the General Coastline estimates developed for the United States by the U.S. Department of Commerce (USDOC, NOAA, 1975) and estimates derived for the Central Gulf of Mexico Planning Area, the latter of which was drawn from the tabular analysis of relative marine productivity/environmental sensitivity (Appendix I, 1987-1992 Five Year Leasing Plan) prepared by the MMS (1987a). Both these documents present a General Coastline estimate of 795 km (494 mi) for this area. It is suggested that the MMS (1987a) estimate was taken directly from the earlier U.S. Department of Commerce (USDOC, NOAA, 1975) document. Realizing this substantial discrepancy (795 km vs. 1,308 km; 494 mi vs. 813 mi), these calculations were checked several times during the present analysis. Under those conditions where measurements are made exactly along the 5 km (3 mi) line marking the border between State waters and the waters of the OCS, a figure of 795 km (494 mi) can be obtained. Such a procedure would, however, exclude the coastlines of a number of bays and lakes which are open to OCS waters. Important coastal areas which would be omitted under a cursory approach include Lake Borgne, Breton Sound, Barataria Bay, Timbalier Bay, Atchafalaya Bay, and Vermilion Bay. All of these lakes and bays include extensive coastal wetlands, and all are sufficiently exposed to the waters of the northern Gulf of Mexico that they could be affected by OCS activities. For these reasons, the 1,308 km (813 mi) General Coastline estimate developed under the present analysis has been retained. This is the only case of all Planning Areas reviewed where such a wide discrepancy was encountered.

Three distinct environments are evident along the coastline adjacent to the Central Gulf of Mexico Planning Area, including:

1) a barrier island complex, located adjacent to the eastern third of the Planning Area and extending from Mobile Bay, AL to Gulf Point, MS;

Table 26. Summary table for the Central Gulf of Mexico Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	1,308 (813)	MMS Central Gulf of Mexico Planning Area Protraction Diagram (USDOI, MMS, 1987g).
Estuary/Wetland	1,046 (650)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); NWI Wetlands Classification Maps (USDOI, USFWS, 1980b).
Sand/Gravel Beach	262 (163)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); NWI Wetlands Classification Maps (USDOI, USFWS, 1980b).
Rocky Beach	Negligible	
Estuary Mouth/ General Coastline	118/1,308 = 0.090	MMS Central Gulf of Mexico Planning Area Protraction Diagram, 1987g.

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	106,064 (262,080)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); NWI Wetlands Classification Maps (USDOI, USFWS, 1980b).
Submarine Canyons	575,079 (1,421,000)	NOAA-NOS Topographic/Bathymetric Chart, Western Gulf of Mexico (USDOC, NOAA-NOS, 1986c).
Coral Reefs	Negligible	
Hard Bottom	83,368 (206,000)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b).
Shelf Slope Zone	3,863,671 (9,547,000)	NOAA-NOS Topographic/Bathymetric Charts, Eastern and Western Gulf of Mexico (USDOC, NOAA-NOS, 1986b; USDOC, NOAA-NOS, 1986c).
Mud/Sand Bottom	19,114,790 (47,232,000)	MMS, Bottom Sediments and Vegetation, Visual No. 4 (USDOI, MMS, 1986a).
State Waters	631,737 (1,561,000)	Calculated based on 3-mi limit.
OCS Area	19,304,190 (47,700,000)	USDOI, MMS, 1990a.
Total Area	19,935,927 (49,261,000)	

2) the Mississippi/Atchafalaya Delta area, located adjacent to the central third of the Planning Area and composed mostly of coastal swamps and marshes; and

3) the Blanche Bay, LA to Subine Lake, TX area, located adjacent to the western third of the Planning Area and characterized by low sand beaches with extensive upland marsh and lake systems.

In terms of linear extent, the coastal region adjacent to the Central Gulf of Mexico Planning Area exhibits more Estuary/Wetland Habitat (opening directly to the coastal waters adjacent to the Planning Area) than any other Planning Area. Sandy beaches of this region are characteristically low and narrow, most of which occur along the barrier islands. There are no significant rocky beaches present within this region.

Marine Habitats

Submerged Vegetation within or adjacent to the Central Gulf of Mexico Planning Area is limited primarily to lakes and bays, although substantial growth does occur along the inshore margins of many of the barrier islands. Shoal grass (*Halodule wrightii*) is the dominant species currently found adjacent to this Planning Area, although turtle grass (*Thalassia testudinum*) and manatee grass (*Syringodium filiforme*) are also reported from that area (Zieman, 1989). Historical evidence indicates that the seagrass bed acreage seen throughout the north-central Gulf of Mexico has been diminishing over the years (Eleuterius, 1989).

The only submarine canyon present within this Planning Area is the Mississippi Canyon, located directly off the southern prong of the Mississippi River's "Bird's foot" delta. Farther offshore, two other depressional features indent the Mississippi Fan (i.e., Lural Valley, Atwa Valley), but these features are not sufficiently distinct bathymetrically to be included in the estimates given in Table 26.

A series of hard-bottom banks protrude into the Central Gulf of Mexico Planning Area from the west. In general, these banks run along the 100- to 120-m (328- to 394-ft) depth contours and are considerably more developed in the adjacent Western Gulf of Mexico Planning Area. Originally, the crests of these banks were classified as coral reefs, but a review of earlier studies and subsequent classifications by Bright *et al.* (1982) suggest that the banks seen in the Central Gulf of Mexico Planning Area represent Hard Bottom rather than true Coral Reef habitats.

The Shelf Slope Zone in the Central Gulf of Mexico Planning Area is narrowest at its eastern margin, where the DeSoto Canyon (in the Eastern Gulf of Mexico Planning Area) indents the continental shelf. From this point westward, the Shelf Slope Zone widens considerably to the western boundary of the Planning Area. A majority of the Planning Area is covered by a sandy silt sediment, reflecting the influence of current and prehistoric river drainage patterns.

3.2.7 Western Gulf of Mexico Planning Area

Coastal Habitats

Two geomorphically distinct elements form the General Coastline adjacent to the Western Gulf of Mexico Planning Area. From Lake Sabine, TX to Galveston Bay, TX, the coastline is characterized by narrow, high energy sand beaches and extensive brackish and freshwater marshes (USDOI, MMS, 1986a; UMES, 1985). From Galveston Bay southward to the U.S.-Mexico border, the coastline consists of a series of narrow barrier islands seaward of a large system of warm, shallow estuaries and lagoons. The General Coastline throughout this area is comprised of a fine, unconsolidated sand. There are virtually no rock outcroppings evident along the coastline adjacent to this Planning Area.

Marine Habitats

For a variety of reasons, including turbidity and unstable bottom sediments within the nearshore area (Zieman, 1982), very little Submerged Vegetation is present in coastal waters adjacent to this Planning Area. The estimates presented in Table 27 were derived from portions of the extreme lower Laguna Madre, TX and seaward edge of Matagorda Bay, where seagrass are openly exposed to the Gulf of Mexico.

Two submarine canyons, (i.e., Alaminos Canyon, Keathley Canyon) are present in this Planning Area. Both canyons are located far offshore, along the Sigsbee Escarpment in the northern Gulf of Mexico.

The Hard Bottom and Coral Reef estimates presented in Table 27 were derived primarily from a series of banks and topographic prominences found between the 40- and 600-m (131- and 1,969-ft) depth contours in the northwestern Gulf of Mexico. These bank and reef features have been studied extensively (Bright and Rezak, 1981). The Coral Reef estimate provided in Table 27 was taken directly from detailed community maps of the East and West Flower Garden Banks (Bright *et al.*, 1982; USDOI, MMS, 1982a; 1982b).

The Shelf Slope Zone located within the northwestern portion of the Gulf of Mexico is extremely wide. The Sigsbee Escarpment virtually parallels the southern edge of this Planning Area and marks the seaward extent of the very broad continental shelf and shelf slope zone evident within this offshore portion of the Planning Area. Sediments along this gently sloping continental margin, strongly influenced by current and prehistoric river discharge patterns, consist primarily of muddy sands, as reflected in MMS Visual No. 10 (USDOI, MMS, 1983b) and MMS Visual No. 4 (USDOI, MMS, 1986a).

3.2.8 Southern California Planning Area

Coastal Habitats

The southern California coastline is geologically recent and seismically active. No large rivers enter the coastal waters adjacent

Table 27. Summary table for the Western Gulf of Mexico Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	560 (348)	MMS Western Gulf of Mexico Planning Area Protraction Diagram (USDOI, MMS, 1987h).
Estuary/Wetland	64 (40)	MMS, Bottom Sediments and Vegetation, Visual No. 4 (USDOI, MMS, 1986a).
Sand/Gravel Beach	496 (308)	MMS, Bottom Sediments and Vegetation, Visual No. 4 (USDOI, MMS, 1986a).
Rocky Beach	Negligible	
Estuary Mouth/ General Coastline	30/560 = 0.054	MMS Western Gulf of Mexico Planning Area Protraction Diagram (USDOI, MMS, 1987h).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	4,662 (11,520)	MMS, Bottom Sediments and Vegetation, Visual No. 4 (USDOI, MMS, 1986a).
Submarine Canyons	405,105 (1,001,000)	NOAA-NOS Topographic/Bathymetric Chart, Western Gulf of Mexico (USDOC, NOAA-NOS, 1986c).
Coral Reefs	4,414 (10,907)	MMS, East Flower Garden Bank Biotic Zonation (USDOI, MMS, 1982a); MMS, West Flower Garden Bank Biotic Zonation (USDOI, MMS, 1982b).
Hard Bottom	59,896 (148,000)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); USDOI, MMS, 1982a; USDOI, MMS, 1982b).
Shelf Slope Zone	7,691,728 (19,006,000)	NOAA-NOS Topographic/Bathymetric Chart, Western Gulf of Mexico (USDOC, NOAA-NOS, 1986c).
Mud/Sand Bottom	14,459,931 (35,730,000)	MMS, Selected Areas of Environmental Importance, Visual No. 10 (USDOI, MMS, 1983b); MMS, Bottom Sediments and Vegetation, Visual No. 4 (USDOI, MMS, 1986a).
State Waters	1,081,763 (2,673,000)	Calculated based on 12-mi limit.
OCS Area	14,528,730 (35,900,000)	USDOI, MMS, 1990a.
Total Area	15,610,493 (38,573,000)	

to this Planning Area and those few embayments which are present are small. The region has experienced considerable development and urbanization. As a result of these factors, there are very few wetland areas present.

Along the mainland coast, sandy beaches comprise approximately 89% of the General Coastline. For the offshore islands present in this region, sandy beaches make up approximately 20% of the General Coastline (NWI Wetlands Classification Maps [USDOI, USFWS, 1979-1982b]; USGS Topographic/Bathymetric Maps [USDOI, USGS, NOS, 1978]).

Marine Habitats

On the Pacific coast of the United States, seaweed (brown algae) of the kelp group replace the seagrasses (vascular plants) as the most important biogenic habitat in coastal waters. The term kelp or kelp bed is applied to several algal species and the habitats they dominate. Off southern and central California, the giant kelp (*Macrocystis pyrifera*) occurs from the U.S.-Mexico border to just south of San Francisco. The bull kelp (*Nereocystis luetkeana*) is seen all the way from San Luis Obispo County northward through the Aleutian Islands (Ambrose *et al.*, 1989).

Ambrose *et al.* (1989) provide an estimate of 14,999 ha (37,062 acres) of kelp within coastal waters adjacent to the Southern California Planning Area. Their estimates are based on data from a 1968 California Department of Fish and Game (CDFG) survey. The NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b), developed on the basis of interpretation of aerial images collected at various scales between 1975 and 1977, show only 8,274 ha (20,445 acres) of submerged vegetation in this region. Locations where kelp beds appear are remarkably consistent between these two data sets, however the mainland beds appear to be reduced in coverage. NWI imagery is produced primarily for the mapping of terrestrial wetland communities and typically tends to underestimate the amount of Submerged Vegetation present within a given area. Recent studies using comparative aerial imagery (Neushul, 1981; Harger, 1983) showed continuing declines in coverage within kelp bed areas of southern California. Several of the major kelp beds located off the coasts of Orange and Santa Barbara Counties have failed to recover from the 1982-1983 El Niño, an anomalous phenomenon which introduced warm, nutrient-deficient water into the region. The Submerged Vegetation estimate presented in Table 28 represents a mean estimate based on the CDFG estimate of 1968 (Ambrose *et al.*, 1989) and kelp beds mapped from the NWI imaging (NWI Wetlands Classification Maps, [USDOI, USFWS, 1979-1982b]).

Fifteen submarine canyons or canyon complexes are present in the OCS waters off southern California (Table 29). The most extensive of these features is a vast complex of canyon, fan, and slump features present offshore extending from Point Arguello southward to beyond Point Conception.

The topography found within this Planning Area is the most complex of all Planning Areas reviewed. The complex geology and

Table 28. Summary table for the Southern California Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline Mainland	555 (345)	MMS Southern California Planning Area Protraction Diagram (USDOI, MMS, 1987i).
Island	408 (250)	
Estuary/Wetland	6 (4)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b).
Sand/Gravel Beach	619 (385)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b); USGS Topographic/Bathymetric Charts (USDOI, USGS, NOS, 1978).
Rocky Beach	338 (210)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b); USGS Topographic/Bathymetric Charts (USDOI, USGS, NOS, 1978).
Estuary Mouth/ General Coastline	8/555 - 0.014 (mainland only)	MMS Southern California Planning Area Protraction Diagram (USDOI, USFWS, 1979-1982b).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	11,636 (28,753)	Ambrose *et al.*, 1989; NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b).
Submarine Canyons	483,212 (1,194,000)	NOAA-NOS OCS Resource Management Map, Southwestern United States (USDOC, NOAA-NOS, 1983); USGS Topographic/ Bathymetric Charts (USDOI, USGS, NOS, 1978).
Coral Reefs	Negligible	
Hard Bottom	278,029 (687,000)	NOAA Chart 18740 (USDOC, NOAA-NOS, 1984a); NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1982b); Richmond and Burdick, 1981.
Shelf Slope Zone	4,862,066 (12,014,000)	NOAA-NOS OCS Resource Management Map, Southwestern United States (USDOC, NOAA-NOS, 1983).
Mud/Sand Bottom	12,802,280 (31,634,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	748,290 (1,849,000)	Calculated based on 3-mi limit.
OCS Area	12,343,350 (30,500,000)	USDOI, MMS, 1990a.
Total Area	13,091,640 (32,349,000)	

Table 29. Submarine canyons present within the Southern California Planning Area. Data derived from NOAA-NOS OCS Resource Management Map, Southwestern United States (USDOC, NOAA-NOS, 1983) and USGS Topographic/Bathymetric Charts (USDOI, USGS, NOS, 1978).

Canyon	Hectares	(Acres)
Point Arguello-Point Conception Canyon Complex	377,726	(933,348)
Hueneme-Mugu Canyon Complex	23,608	(58,334)
Dume Canyon	2,287	(5,652)
Santa Cruz Canyon	4,329	(10,698)
Santa Monica Canyon	4,820	(11,910)
Redondo Canyon	2,859	(7,065)
San Pedro Valley	4,575	(11,304)
San Gabriel Canyon Complex	6,862	(16,955)
San Clemente Canyon	7,189	(17,763)
Catalina Canyon	4,820	(11,909)
Newport Canyon Complex	10,047	(24,827)
Dana Point Canyon Complex	2,696	(6,661)
Carlsbad Canyon	5,146	(12,716)
La Jolla Canyon	12,171	(30,075)
Loma Canyon	13,969	(34,516)
Total	483,104	(1,193,733)*

*Acreage total rounded to 1,194,000 acres (or 483,212 ha) for inclusion in Tables 28 and 61.

presence of various submarine features and offshore islands has led researchers to name this region the Southern California Bight or Southern California Borderland. There are 10 major basins present within this region, ranging in depths from 627 to 2,107 m (2,057 to 6,913 ft) and interspersed with a series of banks, escarpments, and islands (Jones, 1969). Hard Bottom areas are extensive along the coastline and around the islands. For the purpose of developing the Hard Bottom estimates provided in Table 28, only the crest of the observed bank features were assumed to represent rock outcropping.

The plethora of basins interspersed with banks, ridges, and islands evident in the Southern California Bight renders the concept of the Shelf Slope Zone as defined here difficult to compare with other Planning Areas. Basins range from 627 to 2,107 m (2,057 to 6,913 ft) in depth. This is well above the 4,000-m (13,124-ft) depth range considered the upper depth limit of the abyssal plain, but still considerably deeper than 200 m (656 ft), the lower limit of the continental shelf. The nearshore basins (i.e., Santa Barbara, Santa Monica, and San Pedro) receive most of the mainland runoff materials such as terrigenous silts and clays, as well as coarser materials slumping down from the continental shelf. The deeper offshore basins accumulate primarily non-terrigenous materials, including open ocean planktonic tests and fecal pellets which form the deep ocean basin planktonic ooze (Littler, 1978). The majority of this Planning Area falls into the Mud/Sand Bottom classification (Table 28).

3.2.9 Central California Planning Area

Coastal Habitats

Beaches adjacent to the Central California Planning Area consist primarily of relatively short, linear stretches of sand between rocky outcrops (Woodward-Clyde Consultants, 1982). These "pocket" beaches make up approximately 40% of the shoreline fronting coastal waters adjacent to this Planning Area. The remainder of the coastline consists of rock outcrops and approximately 19 km (12 mi) of estuary mouth. Very little coastal wetlands that front on the ocean remain (NWI Wetlands Classification Maps [USDOI, USFWS, 1980-1981]), as evident in the estimates provided in Table 30.

Marine Habitats

Ambrose *et al.* (1989) provide an estimate of approximately 3,341 ha (8,256 acres) of kelp present along the California coast between the Mendocino and San Luis Obispo County lines. These data were derived from a study completed by the CDFG in 1968. Data available from NWI Wetlands Classification Maps (USDOI, USFWS, 1980-1981) is of little utility for this region because most of the kelp beds in question are beyond the resolution of the imagery employed to generate these maps. Areal estimates of kelp bed extent presented by Ambrose *et al.* (1989) remain the best currently available (Table 30).

Two major submarine canyon complexes are present within the Central California Planning Area. These include the Monterey Canyon

Table 30. Summary table for the Central California Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	397 (247)	MMS Central California Planning Area Protraction Diagram (USDOI, MMS, 1987j).
Estuary/Wetland	8 (5)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980-1981).
Sand/Gravel Beach	156 (97)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980-1981).
Rocky Beach	233 (145)	NWI Wetlands Classification Maps (USDOI, USFWS, 1980-1981).
Estuary Mouth/ General Coastline	19/397 = 0.048	MMS Central California Planning Area Protraction Diagram (USDOI, MMS, 1987j).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	3,341 (8,256)	Ambrose *et al.*, 1989.
Submarine Canyons	755,575 (1,867,000)	NOAA-NOS OCS Resource Management Map, Western United States (USDOC, NOAA-NOS, 1982a).
Coral Reefs	Negligible	
Hard Bottom	213,019 (526,362)	Richmond and Burdick, 1981.
Shelf Slope Zone	906,528 (2,240,000)	NOAA-NOS OCS Resource Management Map, Western United States (USDOC, NOAA-NOS, 1982a).
Mud/Sand Bottom	6,045,813 (14,939,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	191,828 (474,000)	Calculated based on 3-mi limit.
OCS Area	6,070,500 (15,000,000)	USDOI, MMS, 1990a.
Total Area	6,262,328 (15,474,000)	

Complex, which extends up the continental shelf into Monterey Bay, and the Carmel Canyon Complex, which consists of Carmel Canyon and a series of smaller "finger" canyons which almost reach shore along the Carmel to Big Sur coastline.

Numerous reefs, banks, and pinnacles are located adjacent to the central California coastline (Ambrose *et al.*, 1989). Most of these areas are located relatively near to shore in shelf-depth waters (i.e., <200 m; 656 ft deep). Richmond and Burdick (1981) have mapped extensive hard-bottom areas which occur further offshore at depths greater than 250 m (820 ft). The results of this latter study were used as a primary data source for the development of the EIS and associated graphics prepared for Lease Sale No. 73 (USDOI, MMS, 1983c; Graphic No. 2). Hard corals of several non-reef building, cold water species are present within the Central California Planning Area, however these species do not form true coral reefs as in tropical and subtropical latitudes. As a result, these areas have been grouped within the Hard Bottom rather than Coral Reef habitat classification.

The continental shelf off the central California coast is narrow, dropping off rapidly into the Shelf Slope Zone and beyond. Sediments on the shelf proper consist of well-sorted sand. At depths greater than 100 m (328 ft), these sediments grade into muds and silts, finer sediments which are typical across the Shelf Slope Zone. The majority of the bottom contained with this Planning Area is a sand/mud substrate (Richmond and Burdick, 1981).

3.2.10 Northern California Planning Area

Coastal Habitats

The coastline adjacent to the waters of the Northern California Planning Area consists of alternating stretches of exposed rock face and sand or "pocket" beaches. Very little estuarine area is present north of San Francisco Bay. The only major estuary fronting the coastal waters adjacent to the Northern California Planning Area is the Humboldt Bay/Arcata Bay complex, located in Humboldt County.

Marine Habitats

Kelp beds are found on almost all hard-bottom substrates shallower than 100 m (328 ft) off the coast of northern and central California. For coastal waters adjacent to the Northern California Planning Area, bull kelp (*Nereocystis luetkeana*) is the primary species contributing to the Submerged Vegetation estimate presented in Table 31 (Ambrose *et al.*, 1989).

Six submarine canyons indent the Shelf Slope Zone of the Northern California Planning Area (Table 32). Of these, the Mendocino and Mattole Canyons run together and have been considered as one canyon complex.

Coral "beds" are present off the coast of California. These features may occur in some of the Hard Bottom habitats seen within or

Table 31. Summary table for the Northern California Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	446 (277)	MMS Northern California Planning Area Protraction Diagram (USDOI, MMS, 1987k).
Estuary/Wetland	45 (28)	USGS Charts NJ10-5 and NJ10-10 (USDOI, USGS, NOS, 1977-1979); NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1980).
Sand/Gravel Beach	185 (115)	USGS Charts NJ10-5 and NJ10-10 (USDOI, USGS, NOS, 1977-1979).
Rocky Beach	216 (134)	USGS Charts NJ10-5 and NJ10-10 (USDOI, USGS, NOS, 1977-1979).
Estuary Mouth/ General Coastline	2/446 = 0.005	MMS Northern California Planning Area Protraction Diagram (USDOI, MMS, 1987k).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	35,863 (88,617)	NWI Wetlands Classification Maps USDOI, USFWS, 1979-1980); USDOI, BLM, 1980a; Ambrose *et al.*, 1989.
Submarine Canyons	75,679 (187,000)	NOAA-NOS OCS Resource Management Map, Western United States (USDOC, NOAA-NOS, 1982a).
Coral Reefs	Negligible	
Hard Bottom	98,342 (243,000)	USDOI, BLM, 1980a.
Shelf Slope Zone	1,271,567 (3,142,000)	NOAA-NOS OCS Resource Management Map, Western United States (USDOC, NOAA-NOS, 1982a).
Mud/Sand Bottom	11,614,890 (28,700,000)	Estimated by subtracting the Hard Bottom and Submerged Vegetation estimates from the Total Area.
State Waters	215,000 (532,000)	Calculated based on 3-mi limit.
OCS Area	11,533,950 (28,500,000)	USDOI, MMS, 1990a.
Total Area	11,748,950 (29,032,000)	

Table 32. Submarine canyons present within the Northern California Planning Area. Data derived from NOAA-NOS OCS Resource Management Map, Western United States (USDOC, NOAA-NOS, 1982a).

Canyon	Hectares	(Acres)
Trinity Canyon Complex	12,988	(32,094)
Eel Canyon	27,611	(68,225)
Mendocino-Mattole Canyon Complex	21,647	(53,490)
Spanish Canyon	2,941	(7,267)
Delgada Canyon	5,310	(13,120)
Nogo Canyon	4,983	(12,313)
Total	75,480	(186,509)*

*Acreage total rounded to 187,000 acres (or 75,679 ha) for inclusion in Tables 31 and 61.

adjacent to the Northern California Planning Area. Coral species forming these "beds" are not the reef-building type normally present in tropical latitudes. Species present within the California communities include hydrocorals (e.g., *Allopora californica*), the gorgonian corals *Lepidisis* and *Paragorgia*, and the non-reef building (ahermatypic) hard corals *Paracyathus* and *Balanophyllia* (USDOI, BLM, 1980a; Foster *et al.*, 1986; Foster *et al.*, 1988).

Richmond and Burdick (1981) have mapped extensive nearshore rock outcroppings around Crescent City, Cape Mendocino, Fort Bragg, Mendocino, and Point Arena. Many of these same banks and rocky outcrops are indicated on both the USGS Topographic/Bathymetric Charts (NJ series [USDOI, USGS, NOS, 1977-1979]) for the western United States, and the NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1980) for the California coast. In the Shelf Slope Zone, extensive rock outcroppings are shown off Cape Mendocino and in a line north-northwest from Point Arena (Richmond and Burdick, 1981; USDOI, MMS, 1983c [Graphic No. 2, Geologic Structures, Lease Sale No. 73]). It is probable that there are extensive rock outcroppings along the Gorda Escarpment and Mendocino Ridge, as well as with the various canyons seen along this coast, but such areas remain unmapped.

The Mud/Sand Bottom estimate presented in Table 31 has been extrapolated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area. It is expected that this figure for the areal extent of Mud/Sand Bottom will be revised downward as more detailed seafloor maps become available. At the present time, estimates for the various habitat categories outlined in Table 31 are suitable for comparisons between Planning Areas.

3.2.11 Washington-Oregon Planning Area

Coastal Habitats

The General Coastline lying shoreward of the Washington-Oregon Planning Area is characterized by rocky, mountainous terrain. Two major estuaries open into the coastal waters adjacent to this Planning Area: Puget Sound and the Columbia River estuary. A complete set of NWI Wetlands Classification Maps exist for this region and both the Estuary/Wetland and Submerged Vegetation estimates presented in Table 33 have been developed from this map set (USDOI, USFWS, 1979-1983).

Marine Habitats

Including Puget Sound and the Columbia River estuary, there are 26 bays, sounds, or river mouths located adjacent to this Planning Area in which eel grass (*Zostera marina*) beds have been reported (Phillips, 1984). Only those major seagrass beds located within the mouths of these bays and estuaries (i.e., which might be affected by activities in the OCS) have been included in the Submerged Vegetation estimates presented in Table 33. Mapped kelp beds indicated on the NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983) have also been included in this estimate.

Table 33. Summary table for the Washington-Oregon Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	729 (453)	MMS Washington-Oregon Planning Area Protraction Diagram (USDOI, MMS, 19871).
Estuary/Wetland	73 (45)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983).
Sand/Gravel Beach	139 (86)	Lynch *et al.*, 1976; NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983).
Rocky Beach	518 (322)	Lynch *et al.*, 1976; NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983).
Estuary Mouth/ General Coastline	53/729 = 0.073	MMS Washington-Oregon Planning Area Protraction Diagram (USDOI, MMS, 19871).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	20,271 (50,090)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983); Phillips, 1984.
Submarine Canyons	364,635 (901,000)	NOAA-NOS Seamap Series Chart 12042-12B (USDOC, NOAA-NOS, 1974).
Coral Reefs	Negligible	
Hard Bottom	217,324 (537,000)	NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983); NOAA-NOS Seamap Series Chart 12042-12B (USDOC, NOAA-NOS, 1974).
Shelf Slope Zone	4,037,287 (9,976,000)	NOAA-NOS Seamap Series Chart 12042-12B (USDOC, NOAA-NOS, 1974).
Mud/Sand Bottom	19,499,660 (48,183,000)	Estimated by subtracting the Hard Bottom and Submerged Vegetation estimates from the Total Area.
State Waters	352,089 (870,000)	Calculated based on 3-mi limit.
OCS Area	19,385,130 (47,900,000)	USDOI, MMS, 1990a.
Total Area	19,737,219 (48,770,000)	

There are seven submarine canyons which indent the Shelf Slope Zone of the Washington-Oregon Planning Area. Three of these canyons (i.e., Guide Canyon, Willapa Canyon, Willapa Channel) run together into a canyon system complex designated as the Willapa Canyon Complex (Table 34).

Table 35 lists the major offshore hard bottom banks and seamount crests (the latter of which has been assumed to be bedrock outcroppings) present in this Planning Area. The Washington-Oregon Planning Area can be divided into a relatively narrow shelf, upper and lower slope, and a series of deeper basins, channels, and trenches. The Cascadia Plain covers almost two thirds of the northern portion of the Planning Area. This feature is bounded on the west by the Cobb Fracture Zone which appears at the western edge of the Planning Area, and by the Blanco Fracture Zone which runs northwest to southeast across the lower third of the Planning Area (NOAA-NOS Chart 12042-12B [USDOC, NOAA-NOS, 1974]).

The Hard Bottom estimate presented in Table 33 incorporates the seamount crest areas shown in Table 35 with the nearshore Hard Bottom habitats (i.e., approximately 16,678 ha, [41,210 acres]) measured from the NWI Wetlands Classification Maps (USDOI, USFWS, 1979-1983). It is suggested that a considerable amount of bedrock outcropping remains undetected and undocumented within this Planning Area. For the purposes of this analysis, it is projected that the vast majority of the 19,385,130 ha (47,900,000 acres) present within this Planning Area are covered by marine sediments (Proctor *et al.*, 1980; USDOI, MMS, 1986b).

3.2.12 Gulf of Alaska Planning Area

Coastal Habitats

Coastal morphology for the shoreline area located adjacent to the Gulf of Alaska Planning Area is extremely complex. The shoreline area which extends from the Dixon Entrance (U.S.-Canada border) northward to Cross Sound is considered to be one of the most complex coastlines present in the United States. Major islands include Dall, Prince of Wales, Kuiu, Kupreanof, Petersburg, Admiralty, Baranof, and Chichagof Islands, with countless smaller islands, straits, and peninsulas interspersed between them.

The total General Coastline for Alaska has previously been estimated at 10,684 km (6,640 mi) by Pederson (1965). The tidal shoreline, which includes islands, inlets, and all shorelines to the head of tidewater is estimated at 76,106 km (47,300 mi) in Alaska. Of this latter estimate, the area between the U.S.-Canada border and Cross Sound represents 47,947 km (29,799 mi) or 63% of the total tidal shoreline present in Alaska (McRoy and Goering, 1974).

This uniquely complex coastline posed several problems in attempts to develop coastal habitat estimates which would be considered comparable to the other 25 Planning Areas surveyed. Utilizing the normal (standard) approach of General Coastline computation applied in the present analysis, the General Coastline estimate for the shoreline

Table 34. Submarine canyons present within the Washington-Oregon Planning Area. Data derived from NOAA-NOS Seamap Series Chart 12042-12B (USDOC, NOAA-NOS, 1974).

Canyon	Hectares	(Acres)
Juan DeFuca Canyon	56,201	(138,872)
Quinault Canyon	74,500	(184,086)
Grass Canyon	23,526	(58,132)
Willapa Canyon Complex*	159,455	(394,009)
Astoria Canyon	50,974	(125,954)
Total	364,656	(901,053)†

*Willapa Canyon Complex includes Guide Canyon, Willapa Canyon, and Willapa Channel.

†Acreage total rounded to 901,000 acres (or 364,635 ha) for inclusion in Tables 33 and 61.

Table 35. Major hard bottom banks and seamounts located within the Washington-Oregon Planning Area. Data derived from NOAA-NOS Seamap Series Chart 12042-12B (USDOC, NOAA-NOS, 1974) and USDOI, MMS (1986b).

Feature	Crest Depth		Crest Area	
	Meters	(Feet)	Hectares	(Acres)
Dasy Bank	100	(328)	22,219	(54,903)
Stonewall Bank	50	(164)	40,517	(100,117)
Perpetua Bank	50	(164)	50,974	(125,954)
Heceta Bank	100	(328)	23,526	(58,132)
Siltcoos Bank	100	(328)	771	(1,905)
Coquille Bank	75-100	(246-325)	1,307	(3,230)
Thompson Seamount (twin banks)	600	(1,969)	22,219	(54,903)
Parks Seamount (lies on western boundary)	1,400	(4,593)	23,526	(58,132)
President Jackson Seamount	600	(1,969)	15,684	(38,755)
Total Crest Area			200,743	(496,031)

adjacent to the Gulf of Alaska Planning Area would exceed 58,729 km (36,500 mi). Such a high estimate for General Coastline was felt to skew the resulting comparisons of the Gulf of Alaska Planning Area with other Planning Areas, and yielded a biased coastline estimate for developing relationships between Planning Areas. For this reason, the General Coastline estimate presented in Table 36 was calculated based on the linear extent of the 5-km (3-mi) line (separating State and Federal OCS waters) rather than actual coastline. Admittedly, this procedure reduced the accuracy of the estimate in terms of true coastline, however, for the overall purposes of allowing comparisons of OCS lease frontage in each Planning Area, this approach was determined to be the preferable method for General Coastline estimation.

Aside from being geomorphically complex, the coastal and shoreline area between the U.S.-Canada border and Cross Sound is also extremely environmentally sensitive, with extensive areas of wetland and submarine vegetation. The entire measured General Coastline extending from Portland Canal (at the U.S.-Canada border) to Cape Spencer (on the north side of Cross Sound) has been designated as Estuary/Wetland in the estimates presented in Table 36.

Sand and gravel beaches dominate the coastline north and west of Cross Sound, but there are large, notable wetland areas between Yakutat Bay, the Copper and Bering River deltas, and in the Orca Inlet (Alaska Department of Fish and Game, 1984).

The coast adjacent to the westernmost portion of the Gulf of Alaska Planning Area, from Hinchinbrook Island to the western reaches of Prince William Sound, is generally steep and rocky (UMES, 1985).

Marine Habitats

Marine habitats within the Gulf of Alaska Planning Area are equally as complex as those present along the adjacent coastline. The Submerged Vegetation estimate presented in Table 36 has been based on descriptions contained in Calvin and Ellis (1981) and includes only those kelp beds expected to occur in Pacific waters fronting the OCS. The submerged vegetation within the sounds and inlets south of Cross Sound has not been included in this estimate even though vast amounts of both kelp and *Zostera marina* are reported for these areas (Calvin and Ellis, 1981; UMES, 1985).

Seven submarine canyons indent the Shelf Slope Zone of the Gulf of Alaska Planning Area (Table 37). These submarine canyons are generally associated with coastal features such as major glaciers, river discharges, bays, and sounds (Feder and Jewett, 1986). As relatively shallow features, these submarine canyons rarely influence bathymetry below the 900-m (2,953-ft) contour.

The vast majority of the 53,582,280 ha (132,400,000 acres) found within the Gulf of Alaska Planning Area lie below the 2,000-m (6,562-ft) depth contour. Within this area, however, are a number of seamounts which reach above this depth range (Table 38). There are two parallel chains of submerged mountains which bisect the North Pacific

Table 36. Summary table for the Gulf of Alaska Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	2,545 (1,582)	MMS Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram (USDOI, MMS, 1988).
Estuary/Wetland	1,179 (733)	McRoy and Goering, 1974; Alaska Department of Fish and Game, 1984; UMES, 1985.
Sand/Gravel Beach	774 (481)	UMES, 1985.
Rocky Beach	592 (368)	Sears and Zimmerman, 1977.
Estuary Mouth/ General Coastline	575/2,545 = 0.226	NOAA Charts 16013 (USDOC, NOAA-NOS, 1989a) and 16016 (USDOC, NOAA-NOS, 1989b); MMS Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram (USDOI, MMS, 1988).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	180,270 (445,440)	Calvin and Ellis, 1981.
Submarine Canyons	660,470 (1,632,000)	Feder and Jewett, 1986; MMS Gulf of Alaska Planning Area Protraction Diagram (USDOI, MMS, 1985b).
Coral Reefs	Negligible	
Hard Bottom	1,533,408 (3,789,000)	BLM, Eastern Gulf of Alaska, Environmental Geology, Graphic No. 1 (USDOI, BLM, 1979b); NOAA Chart #530 (USDOC, NOAA-NOS, 1980).
Shelf Slope Zone	3,881,478 (9,591,000)	MMS Gulf of Alaska Planning Area Protraction Diagram (USDOI, MMS, 1985b).
Mud/Sand Bottom	52,950,543 (130,839,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	1,081,763 (2,673,000)	Calculated based on 3-mi limit.
OCS Area	53,582,280 (132,400,000)	USDOI, MMS, 1990a.
Total Area	54,664,043 (135,073,000)	

Table 37. Submarine canyons present within the Gulf of Alaska Planning Area. Data derived from MMS Gulf of Alaska Planning Area Protraction Diagram (USDOI, MMS, 1985b).

Canyon	Hectares	(Acres)
Bering Canyon	104,774	(258,894)
Ice Canyon Complex	62,134	(153,530)
Yakutat Canyon	180,310	(445,539)
Alsek Canyon	60,915	(150,520)
Cross Sound Canyon	159,598	(394,362)
Iphigenia Canyon	30,458	(75,260)
Bartolome Canyon	62,134	(153,530)
Total	660,323	(1,631,635)*

*Acreage total rounded to 1,632,000 acres (or 660,470 ha) for inclusion in Tables 36 and 61.

Table 38. Seamounts located within the Gulf of Alaska Planning Area. Data derived from NOAA Chart #530 (USDOC, NOAA-NOS, 1980), NOAA Chart #50 (USDOC, NOAA-NOS, 1979), and NOAA-NOS OCS Resource Management Maps NOS No. 6-4 (USDOC, NOAA-NOS, 1988c) and NOS No. 6-8 (USDOC, NOAA-NOS, 1988b).

	Crest Depth		Crest Area	
Seamount	Meters	(Feet)	Hectares	(Acres)
Dall	2,579	(8,462)	15,031	(37,140)
Ely	2,200	(7,218)	36,188	(89,419)
Giacomini	640	(2,100)	92,640	(228,910)
Quinn	658	(2,160)	123,520	(305,214)
Surveyor	444	(1,458)	185,280	(457,820)
Pratt	710	(2,328)	277,920	(686,731)
Applequist	1,214	(3,984)	154,400	(381,517)
Durgin	739	(2,424)	138,960	(343,365)
Welker	710	(2,328)	77,200	(190,758)
Brown	1,390	(4,560)	61,760	(152,607)
Dickius	428	(1,404)	148,224	(366,256)
Denson	927	(3,042)	111,168	(274,692)
Miller	1,002	(3,288)	92,640	(228,910)
Total Crest Area			1,514,931	(3,743,339)

between northern California and the Alaska Peninsula. The most northerly range lies in an approximate line from Afognak Island and Cape Douglas southeastward to Graham Island. This range passes directly through the Gulf of Alaska Planning Area and is comprised primarily of the seamounts listed in Table 38. The more southerly range lies in a broad band which extends from slightly southwest of Kodiak Island east-southeastward to just north of the California-Oregon border. This range lies primarily west and south of the Gulf of Alaska Planning Area. Miller and White Marsh Seamounts are both part of this southern band of submerged mountains (NOAA Chart #530 [USDOC, NOAA-NOS, 1980]). Miller Seamount has been listed in Table 38 while White Marsh Seamount has not because it lies just beyond the southern boundary of the Gulf of Alaska Planning Area.

For the purpose of deriving the Hard Bottom estimate presented in Table 36 the crest of these seamounts has been assumed to represent bedrock upthrust. In addition to the seamount areas summarized in Table 38, there are scattered bedrock outcroppings present in the nearshore (<200 m; 656 ft) zone. Some of these outcroppings are evident on the graphics developed in association with the Lease Sale No. 55 EIS (USDOI, BLM, 1979b). These areas have also been incorporated into the estimate presented in Table 38. It is suggested that there are other unreported outcroppings of bedrock in the nearshore waters of the Gulf of Alaska Planning Area, however, such features are expected to contribute an extremely small percentage of Hard Bottom to the Total Area.

3.2.13 Cook Inlet Planning Area

Coastal Habitats

The Cook Inlet Planning Area is bounded on the east by 151°55'W longitude. On the western side, this Planning Area extends down the Shelikof Strait to 57°N latitude, encompassing this portion of the Alaska Peninsula and the western side of Shuyak, Afognak, and Kodiak Island. Rocky beaches dominate the lower portion of the Cook Inlet and the various islands present in and adjacent to this Planning Area. Beginning at Tuxedui Bay and continuing into Cook Inlet and through the northern shore of Kachemak Bay, bedrock outcrops give way to sand and mud shoreline typical of alluvial, glacial, lacustrine, and swamp deposits. The majority of the wetlands actually fronting on Cook Inlet are present on its northwestern shoreline. Smaller areas of wetland are also seen along the eastern shoreline of Cook Inlet, around the mouths of the various rivers entering there, and along the northern shoreline of Kachemak Bay (USDOI, MMS, 1984b; NWI Wetlands Classification Maps [USDOI, USFWS, 1989b]). For the Cook Inlet Planning Area, both the Mainland General Coastline and the Island General Coastline have been used to calculate the Estuary Mouth to General Coastline ratio presented in Table 39. In the case of Cook Inlet, the MMS Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram (USDOI, MMS, 1988) was not used to measure the General Coastline because this map ends at 61°N latitude. Although not leaseable, Cook Inlet extends considerably farther. For the present analysis, the coastline has been measured into Cook Inlet as far as 61°25'N latitude.

Table 39. Summary table for the Cook Inlet Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline		
Mainland	1,678 (1,043)	MMS Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram (USDOI, MMS, 1988); MMS Kodiak Planning Area Protraction Diagram (USDOI, MMS, 1987m).
Island	278 (173)	
Estuary/Wetland	246 (153)	NWI Wetlands Classification Maps (USDOI, USFWS, 1989b); BLM, Graphic Nos. 2 and 9 (USDOI, BLM, 1976).
Sand/Gravel Beach	730 (454)	NWI Wetlands Classification Maps (USDOI, USFWS, 1989b); BLM, Graphic Nos. 2 and 9 (USDOI, BLM, 1976).
Rocky Beach	980 (609)	NWI Wetlands Classification Maps (USDOI, USFWS, 1989b); BLM, Graphic Nos. 2 and 9 (USDOI, BLM, 1976).
Estuary Mouth/ General Coastline	217/1,957 = 0.111	MMS Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram (USDOI, MMS, 1988); MMS Kodiak Planning Area Protraction Diagram (USDOI, MMS, 1987m).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	42,583 (105,220)	BLM, Graphic No. 9 (USDOI, BLM, 1976); NWI Wetlands Classification Maps (USDOI, USFWS, 1989b).
Submarine Canyons	Negligible	
Coral Reefs	Negligible	
Hard Bottom	204,147 (504,440)	BLM, Graphic No. 2 (USDOI, BLM, 1976).
Shelf Slope Zone	Negligible	
Mud/Sand Bottom	2,990,733 (7,390,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	1,092,690 (2,700,000)	Calculated based on 3-mi limit and the non-OCS waters of upper Cook Inlet.
OCS Area	2,144,910 (5,300,000)	USDOI, MMS, 1990a.
Total Area	3,237,600 (8,000,000)	

Marine Habitats

Kelp beds and stands of eel grass (*Zostera marina*) are prominent habitats throughout the nearshore waters of lower Cook Inlet. Kelp covers the rocky subtidal zones around the Kenai Peninsula and mouth of Kachemak Bay almost as far as Ninilchik. Eel grass (*Z. marina*) occurs in well developed areas within the more protected bays and fjords along the eastern shore of lower Cook Inlet (Lees and Rosenthal, 1977; Lees *et al.*, 1980; USDOI, MMS, 1984b; NWI Wetlands Classification Maps [USDOI, USFWS, 1989b]). On the western side of lower Cook Inlet, kelp beds are still prominent, although their coverage is reduced from that evident on the eastern shore. No major concentrations of *Z. marina* are reported from this area (USDOI, MMS, 1984b). North of Tuxena Bay on the western shore and Ninilchik on the eastern side, the sediments of Cook Inlet are not conducive to kelp growth (MMS, Graphic No. 2 [USDOI, MMS, 1984b]).

The geology and geobathymetry map (Graphic No. 2) produced by the BLM Alaska OCS Office (USDOI, BLM, 1976) indicates a considerable amount of Hard Bottom or rock outcropping throughout the Cook Inlet Planning Area. These acreages have been combined with the shallow subtidal kelp bed estimates to develop the Hard Bottom estimate given in Table 39. The remaining marine habitat throughout Cook Inlet is a course gravel to fine mud mosaic which has been well delineated in Graphic No. 2 (USDOI, BLM, 1976).

3.2.14 Kodiak Planning Area

Coastal Habitats

The general coastline located shoreward of the Kodiak Planning Area is comprised of offshore islands of the Barren, Kodiak, Chirikof, and Semidi groups. A majority of the exposed shoreline present within this region is steep and rocky, with numerous fjords, estuaries, and bays evident along the mainland coast and throughout the island groups (Sears and Zimmerman, 1977). Many important bays, estuaries, and fjords are present on the island groups found within nearshore coastal waters adjacent to this Planning Area. For this reason, both Island and Mainland General Coastline estimates have been developed in the present analysis; further, the sum total of these coastline estimates have been used to compute the Estuary Mouth to General Coastline ratio presented in Table 40.

Marine Habitats

Intertidal and shallow subtidal zones from 0 to 20 m (0 to 66 ft) found adjacent to or within the Kodiak Planning Area are dominated by macroalgae and kelp (Strauch, 1980). Kelp beds are reported to extend 400 m to 10 km (1,312 ft to 6 mi) from shore throughout most of this region. Small beds of eel grass (*Zostera marina*) have also been reported from within some of the protected bays and estuaries (Zimmerman *et al.*, 1978; Strauch, 1980; McRoy, 1970), but their occurrences within this area are relatively rare.

Table 40. Summary table for the Kodiak Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	746 (475)	MMS Kodiak Planning Area Protraction Diagram (USDOI, MMS, 1987m).
Estuary/Wetland	Negligible	UMES, 1985.
Sand/Gravel Beach	287 (190)	Sears and Zimmerman, 1977; Arneson, 1980.
Rocky Beach	459 (285)	Sears and Zimmerman, 1977; Arneson, 1980.
Estuary Mouth/ General Coastline	134/746 = 0.180	MMS Kodiak Planning Area Protraction Diagram (USDOI, MMS, 1987m).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	669,961 (1,655,450)	Science Applications Inc., 1980; BLM, Location of Marine Macrophytes and Major Shellfishing Areas, Graphic No. 7 (USDOI, BLM, 1980d).
Submarine Canyons	Negligible	
Coral Reefs	Negligible	
Hard Bottom	169,165 (418,000)	BLM, Environmental Geology, Graphic No. 1 (USDOI, BLM, 1980d); NOAA-NOS Chart #530 (USDOC, NOAA-NOS, 1980).
Shelf Slope Zone	3,219,389 (7,955,000)	MMS Kodiak Planning Area Protraction Diagram (USDOI, MMS, 1987m).
Mud/Sand Bottom	35,548,443 (87,839,000)	Estimated by subtracting the Submerged Vegetation and Hard Bottom estimates from the Total Area.
State Waters	369,086 (912,000)	Calculated based on 3-mi limit.
OCS Area	36,018,300 (89,000,000)	USDOI, MMS, 1990a.
Total Area	36,387,386 (89,912,000)	

There are no designated Submarine Canyons within the Kodiak Planning Area despite the fact that the continental shelf in this region drops rapidly to abyssal depths. Further offshore, a number of seamounts have been charted (Table 41). The most prominent of these is the Patton Seamount, followed by the Cowie, Odessey, Chirikof, and Kodiak Seamounts in decreasing order of prominence (NOAA-NOS Chart #530 [USDOC, NOAA-NOS, 1980]). The crests of these seamounts have been assumed to be exposed bedrock upthrust; their areal contributions have been included in the Hard Bottom estimate presented in Table 40. Additional areal measurements have been included for those hard-bottom areas identified in Graphic No. 1 (USDOI, BLM, 1980d), prepared as part of a recent lease sale (Lease Sale No. 46) EIS covering the Kodiak region. The Shelf Slope Zone estimate for the Kodiak Planning Area is extremely small (negligible) due to the rapid descent from shelf to abyssal depths. Most of this Planning Area has been assumed to contain Mud/Sand Bottom habitat.

3.2.15 Shumagin Planning Area

Coastal Habitats

The coastline lying shoreward of the Shumagin Planning Area includes the southern shore of the Alaska Peninsula extending from 156°40'W longitude westward to Unimak Island (within the Aleutian Islands). There are 31 major islands, including those in the Shumagin and Sanak Island groups, and countless smaller islands within this region. Most of the coastline is steep and rocky, however there are numerous bays and fjords in which protected shallow water habitats and occasional wetland marshes are present (UMES, 1985). The General Coastline encompassing the Alaska Peninsula and Unimak Island measures 1,018 km (633 mi), while that of the major islands measures 853 km (530 mi). For purposes of calculating the Estuary Mouth to General Coastline ratio presented in Table 42, only the General Coastline estimate for the Alaska Peninsula and Unimak Island have been used.

Marine Habitats

McRoy (1970) provided the only quantitative estimates for the areal extent of eel grass (*Zostera marina*) beds in waters adjacent to the Shumagin Planning Area (i.e., 87 ha (215 acres) of *Z. marina* in Kinzarof Lagoon, at the mouth of Cold Bay). This species is known to be present in the other bays and lagoons within coastal waters adjacent to the Shumagin Planning Area (McRoy *et al.* 1971; Sears and Zimmerman, 1977), however no quantitative estimates of the areal extent of these beds are available (UMES, 1985). Similarly, kelp beds are known to be nearly ubiquitous throughout the shallow subtidal portion of this region (Sears and Zimmerman, 1977). The submerged vegetation estimates presented in Table 42 include the estimates of McRoy (1970) for known *Z. marina* coverage and an extrapolated kelp bed estimate based on continuous kelp coverage in the 0- to 20-m (0- to 66-ft) depth ranges.

The Aleutian Trench, which runs parallel to the Aleutian Arc, extends into this Planning Area from the west, separating a narrow

Table 41. Seamounts located within the Kodiak Planning Area. Data derived from NOAA-NOS Chart #530 (USDOC, NOAA-NOS, 1980).

Seamount	Crest Depth		Crest Area	
	Meters	(Feet)	Hectares	(Acres)
Kodiak	3,000	(9,843)	32,349	(79,932)
Chirikof	2,524	(8,280)	57,345	(141,698)
Patton	168	(552)	28,673	(70,849)
Odessey	1,657	(5,436)	15,439	(38,149)
Cowie	527	(1,728)	18,380	(45,416)
Total Crest Area			152,186	(376,044)

Table 42. Summary table for the Shumagin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline		
Mainland	1,018 (633)	MMS Shumagin Planning Area Protraction Diagram (USDOI, MMS, 1987n).
Island	853 (530)	
Estuary/Wetland	10 (6)	Sears and Zimmerman, 1977.
Sand/Gravel Beach	357 (228)	Sears and Zimmerman, 1977.
Rocky Beach	1,504 (935)	Sears and Zimmerman, 1977.
Estuary Mouth/ General Coastline	142/1,018 = 0.139 (mainland only)	MMS Shumagin Planning Area Protraction Diagram (USDOI, MMS, 1987n).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	936,881 (2,315,000)	*Zostera marina* in Cold Bay (McRoy, 1970) and assumed ubiquitous kelp and macroalgae coverage in water depths of 0-20 m (0-66 ft), as suggested in Sears and Zimmerman, 1977.
Submarine Canyons	None	
Coral Reefs	None	
Hard Bottom	1,658,865 (4,099,000)	Estimated by extrapolating rocky shoreline and kelp distribution estimates of Zimmerman *et al.* (1978), and McBride *et al.* (1982); NOAA-NOS Charts #50 (USDOC, NOAA-NOS, 1979) and #530 (USDOC, NOAA-NOS, 1980).
Shelf Slope Zone	366,127 (904,687)	MMS Shumagin Planning Area Protraction Diagram (USDOI, MMS, 1987n).
Mud/Sand Bottom	31,978,989 (79,019,000)	Estimated by subtracting the Hard Bottom estimate from the Total Area.
State Waters	903,695 (2,233,000)	Calculated based on 3-mi limit.
OCS Area	33,671,040 (83,200,000)	USDOI, MMS, 1990a.
Total Area	34,574,735 (85,433,000)	

continental shelf from the abyssal plain which covers most of this Planning Area. No true submarine canyons are delineated along the Shumagin Planning Area shelf. The Shelf Slope Zone, defined as that area found between the 200- and 2,000-m (656- to 6,562-ft) depth contours, is relatively small within this region. Many reefs and banks are designated in the nearshore zone and the coastlines of the Alaska Peninsula and islands adjacent to this Planning Area are extremely rocky. A number of seamounts are seen further offshore (Table 43) and the crest of these features is assumed to be formed of bedrock outcropping. The estimated Hard Bottom area shown in Table 42 represents a summation of the areal extent of kelp bed, reef, and bank top habitat distributions mentioned by Zimmerman *et al.* (1979), and McBride *et al.* (1982), coupled with an evaluation of the map reports of Sears and Zimmerman (1977) and the total area of seamount crest present within this region (Table 43). The estimate of Mud/Sand Bottom provided in Table 42 has been derived by subtracting this Hard Bottom estimate from the Total Area.

3.2.16 Aleutian Arc Planning Area

Coastal Habitats

The Aleutian Arc Planning Area extends westward from 171°W longitude, in the straight between Yunaska and Amukta Islands, and lies adjacent to all of the Aleutian Islands westward to the U.S.-U.S.S.R. Convention Line of 1867. The Aleutian Arc Planning Area also lies adjacent to the southern coastlines of Yunaska, Herbert, Chuginadak, Samalga, Umnak, and Unalaska Islands; the northern coastlines of these islands front the St. George Basin Planning Area (Section 3.2.18). This latter segment of the Aleutian Arc Planning Area runs from 171°W longitude eastward to 165°W longitude. There are 47 islands ranging in circumference from 0.53 km (0.33 mi) to 274 km (170 mi) which are located in waters adjacent to the Aleutian Arc Planning Area. These islands are steep and rocky with many fjords and bays. The extent of true estuary/wetland areas is negligible along these rocky islands, however the many productive bays and fjords present in this region provide significant wildlife habitat to numerous species of birds and marine mammals.

Marine Habitats

Extensive stands of kelp grow throughout rocky marine substrates with the nearshore waters of the Aleutian Islands (Sears and Zimmerman, 1977), and it is likely that eel grass (*Zostera marina*) appears in some of the sheltered bays and fjords of this region. The Submerged Vegetation estimates presented in Table 44 are based on an assumption of nearly continuous kelp and macroalgae coverage inshore of the 20-m (66-ft) depth contour around the Aleutian Islands. The Aleutian Arc shows a rugged subsurface terrain and water depths drop off rapidly around the islands.

There are 31 submarine canyons or canyon complexes in the Aleutian Arc Planning Area (Table 45). In addition to the complex canyon features present in this region, there are a variety of ridges,

Table 43. Seamounts located within the Shumagin Planning Area. Data derived from NOAA-NOS Charts #50 (USDOC, NOAA-NOS, 1979) and #530 (USDOC, NOAA-NOS, 1980).

Seamount	Crest Depth		Crest Area	
	Meters	(Feet)	Hectares	(Acres)
Unimak	3,973	(13,035)	70,688	(174,669)
Derickson	2,890	(9,482)	196,357	(485,190)
Sirius	1,930	(6,332)	125,668	(310,522)
Putnam	3,383	(11,100)	119,463	(295,190)
Pritchett	3,608	(11,838)	159,049	(393,004)
Walls Knoll	3,768	(12,363)	237,591	(587,080)
Total Crest Area			908,816	(2,245,655)

Table 44. Summary table for the Aleutian Arc Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	2,471 (1,536)	NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966); Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966).
Estuary/Wetland	Negligible	
Sand/Gravel Beach	370 (230)	Estimate based on measurements of pocket beach formation using NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); and Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).
Rocky Beach	2,101 (1,306)	Estimate based on coastal topography as seen on NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); and Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).
Estuary Mouth/ General Coastline	222/2,471 = 0.090	NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	12,363 (30,547)	Estimated based on continuous kelp and macroalgae cover within the 20-m depth contour.
Submarine Canyons	2,102,804 (5,196,000)	Measured from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).
Coral Reefs	Negligible	
Hard Bottom	2,661,807 (6,577,000)	Measured from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).
Shelf Slope Zone	16,536,851 (40,862,000)	Measured from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a); Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).
Mud/Sand Bottom	63,724,467 (157,461,000)	Estimated by subtracting the Hard Bottom and Submerged Vegetation estimates from the Total Area.
State Waters	1,193,460 (2,949,000)	Calculated based on 3-mi limit.
OCS Area	65,278,110 (161,300,000)	USDOI, MMS, 1990a.
Total Area	66,471,570 (164,249,000)	

Table 45. Submarine canyons present within the Aleutian Arc Planning Area. Data derived from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973), Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a), and Attu Bathymetric Chart 1910N-2 (USDOC, CGS, 1966b).

Canyon	Hectares	(Acres)
Amukta Canyon*	39,210	(96,887)
Sequam Canyon*	61,429	(151,790)
Amlia Canyon and Basin*	154,228	(381,091)
Atka Canyon	48,360	(119,495)
Korovian Canyon	58,815	(145,331)
Kouiuji Canyon	35,289	(87,199)
Aganah Canyon	27,447	(67,821)
Bobrof Canyon	22,219	(54,903)
Tanaga Canyon	108,482	(268,055)
Pochnoi Canyon	288,849	(713,737)
Bowers Canyon*	135,929	(335,876)
Rude Canyon	134,465	(332,259)
Bowie Canyon	119,409	(295,055)
Sitkin Canyon	25,513	(63,041)
Segala Canyon	16,102	(39,788)
Stalemate Canyon	134,884	(333,293)
Etienne Canyon	35,342	(87,328)
Abraham Canyon	75,702	(187,057)
Agattu Canyon	54,372	(134,351)
Tahoma Canyon	9,620	(23,770)
Coulee Canyon	35,969	(88,878)
Murray Canyon	124,637	(307,973)
Rat Island Canyon Complex	54,999	(135,901)
Bird Canyon	7,110	(17,569)
Thurmond Canyon	14,011	(34,621)
Seymour Canyon	12,338	(30,487)
Karius Canyon	6,901	(17,052)
Amchitka Canyon	36,387	(89,912)
Kanaga Canyon	73,193	(180,857)
Adah Canyon	109,789	(271,285)
Usof Canyon	41,825	(103,347)
Total	2,102,825	(5,196,009)†

*Upper portion only.
†Acreage total rounded to 5,196,000 acres (or 2,102,804 ha) for inclusion in Tables 44 and 61.

spurs, reefs, banks, and plateaus scattered along the Aleutian Arc. These upthrust features are bounded by the Aleutian Trench on the south side of the Arc, and by the Aleutian Basin to the north. A variety of smaller basins exist along the Aleutian Arc in conjunction with the canyons noted previously.

For the purpose of developing the Hard Bottom estimate presented in Table 44, virtually all upthrust features reaching a depth of less than 100 m (328 ft) were assumed to be hard bottom or seafloor covered by a very thin layer of sediment. As a consequence, the Hard Bottom estimate should be viewed as conservative. It is suggested that bedrock outcrops are present along the canyon and trench sides and atop many of the seamount crests present within this Planning Area. A similar assumption has been applied to define the Mud/Sand Bottom estimate presented in Table 44. It is suggested that the deep basins, *in toto* which comprise the major portion of the seafloor of the Aleutian Arc Planning Area, are sediment covered. The exact proportions of Mud/Sand Bottom and Hard Bottom habitats, however, remain to be determined.

3.2.17 North Aleutian Basin Planning Area

Coastal Habitats

The major portion of the General Coastline lying shoreward of the North Aleutian Basin Planning Area, from Izembek Lagoon to Kulukah Bay, is low-lying with long stretches of sand and gravel beach broken by large bays and lagoons. The rivers and coastal waters of Bristol Bay support one of the world's largest salmon fisheries (Schell and Saupe, 1989). The General Coastline of this region encompasses 1,319 km (820 mi) of mainland and 151 km (94 mi) of island shoreline. Large areas of Estuary/Wetland habitat are seen continuously along the coastline in this region, particularly in and around the mouths of rivers and bays (Pace, 1984). Only the Mainland General Coastline estimate has been utilized in calculating the Estuary Mouth to General Coastline ratio presented in Table 46.

Marine Habitats

Extensive areas of eel grass (*Zostera marina*) are seen in Izembek Lagoon (Pace, 1984; Cimberg *et al.*, 1986) and it is likely that this seagrass appears in the other bays and estuaries along the coast adjacent to this Planning Area (UMES, 1985; Armstrong *et al.*, 1984). Pace (1984), based on personal communication with McRoy, indicated the presence of an extensive kelp bed along the southwestern shore of Unimak Island and in one major concentration off Aurak Island. After reviewing the available data, the Submerged Vegetation estimate provided in Table 46 is considered conservative. This estimate is expected to increase as a result of future surveys.

The North Aleutian Basin Planning Area lies entirely within the broad, shallow shelf areas of Bristol and Kuskokwim Bays. Water depths throughout the entire Planning Area rarely exceed 100 m (328 ft); as a

Table 46. Summary table for the North Aleutian Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline		
Mainland	1,319 (820)	MMS North Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1987o).
Island	151 (94)	
Estuary/Wetland	584 (363)	Pace, 1984.
Sand/Gravel Beach	405 (252)	UMES, 1985; Cimberg *et al.*, 1986; Pace, 1984; Thomson, 1989.
Rocky Beach	330 (205)	UMES, 1985; Cimberg *et al.*, 1986; Thomson, 1989.
Estuary Mouth/ General Coastline	86/1,319 = 0.065 (mainland only)	MMS North Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1987o).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	18,923 (46,759)	Pace, 1984; Schell and Saupe, 1989.
Submarine Canyons	Negligible	NOAA-NOS OCS Resource Management Map, North Aleutian Basin Regional Map (USDOC, NOAA-NOS, 1984b).
Coral Reefs	Negligible	
Hard Bottom	15,094 (37,296)	Pace, 1984; Thomson, 1989.
Shelf Slope Zone	Negligible	NOAA-NOS OCS Resource Management Map, North Aleutian Basin Regional Map (USDOC, NOAA-NOS, 1984b).
Mud/Sand Bottom	13,137,776 (32,463,000)	Extrapolated from Pace, 1984 and Thomson, 1989.
State Waters	710,249 (1,755,000)	Calculated based on 3-mi limit.
OCS Area	13,152,750 (32,500,000)	USDOI, MMS, 1990a.
Total Area	13,862,999 (34,255,000)	

consequence, no Submarine Canyons or Shelf Slope Zone features are present.

The presence of boulder zones and bedrock outcrops within this Planning Area are rare and the majority of the marine substrate is covered with a mud/sand/gravel sediment mix (Thomson, 1989; Cimberg *et al.*, 1986).

3.2.18 St. George Basin Planning Area

Coastal Habitats

Coastal habitats present within or adjacent to the St. George Basin Planning Area consist of the northern shorelines of Tigaida, Avatanah, Rootak, Unalga, Unalaska, Umnak, Chuginadak, Herbert, and Yanaska Islands; the southern coastlines of several of these islands front the Shumagin and Aleutian Arc Planning Areas. In addition, the islands of Akun, Akutan, Fire, Bogosiof, Uliaga, Kagamil, Carlisle, St. George, Walrus, Otter, and St. Paul are located completely within the boundaries of the St. George Basin Planning Area. The individual measured coastlines from all these islands have been totalled to provide the General Coastline estimate presented in Table 47. The shores of a majority of these islands are rocky and steep. A few long stretches of sand and gravel pocket beaches are reported from the north side of Umnak and Unimak Islands (Sears and Zimmerman, 1977). The Estuary Mouth/General Coastline ratio presented in Table 47 includes measurements of the mouths of the major fjords and bays present primarily on Unalaska Island. These are not true estuaries in the classical sense, but they are extremely productive in terms of kelp beds and, in some instances, eel grass (*Zostera marina*) stands (Sears and Zimmerman, 1977). As such, these areas represent sensitive habitat and have been incorporated into this ratio.

Marine Habitats

The results of aerial surveys of the Aleutian Islands report the presence of dense kelp beds along nearly the entire coastline where rocky substrates are present (Sears and Zimmerman, 1977; Calvin, 1979). No detailed mapping of these beds is currently available, however, in the Aleutian Islands, kelp beds are reported from the intertidal zone to a depth of approximately 20 m (66 ft). The estimate provided for Submerged Vegetation in Table 47 has been developed under the assumption of uniform kelp distribution within these bathymetric contours (Calvin and Ellis, 1981).

The northwestern half of the St. George Basin Planning Area lies upon the broad, flat extension of the Bering Sea shelf. South of the Pribilof Islands, a steep and extremely rugged shelf slope is evident. Beyond this shelf slope, the adjacent continental rise drops briefly into the Aleutian Basin before rising again at the Umnak Plateau and Aleutian Arc (Cooper *et al.*, 1982). A total of 15 submarine canyons or canyon systems dissect the shelf slope and continental rise within this Planning Area (Table 48). The largest of these include the vast Zhemchug and Pribilof Canyon System located in the north central portion

Table 47. Summary table for the St. George Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	991 (616)	MMS St. George Basin Planning Area Protraction Diagram (USDOI, MMS, 1987p).
Estuary/Wetland	Negligible	UMES, 1985; MMS St. George Basin Planning Area Protraction Diagram (USDOI, MMS, 1987p).
Sand/Gravel Beach	105 (65)	UMES, 1985; MMS St. George Basin Planning Area Protraction Diagram (USDOI, MMS, 1987p).
Rocky Beach	887 (551)	UMES, 1985; MMS St. George Basin Planning Area Protraction Diagram (USDOI, MMS, 1987p).
Estuary Mouth/ General Coastline	66/991 = 0.067	MMS St. George Basin Planning Area Protraction Diagram (USDOI, MMS, 1987p).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	83,773 (207,000)	Estimate based on the amount of substrate in <20 m (66 ft) water depths and the findings of Sears and Zimmerman, 1977; Calvin, 1979; and Calvin and Ellis, 1981.
Submarine Canyons	3,594,141 (8,881,000)	NOAA-NOS OCS Resource Management Map, St. George Basin Regional Map (USDOC, NOAA-NOS, 1984c); NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973).
Coral Reefs	Negligible	
Hard Bottom	*	
Shelf Slope Zone	5,810,683 (14,358,000)	NOAA-NOS OCS Resource Management Map, St. George Basin Regional Map (USDOC, NOAA-NOS, 1984c).
Mud/Sand Bottom	*	
State Waters	478,760 (1,183,000)	Calculated based on 3-mi limit.
OCS Area	28,409,940 (70,200,000)	USDOI, MMS, 1990a.
Total Area	28,888,700 (71,383,000)	

*Insufficient data.

Table 48. Submarine canyons present within the St. George Basin Planning Area. Data derived from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973) and NOAA-NOS OCS Resource Management Map, St. George Basin Regional Map (USDOC, NOAA-NOS, 1984c).

Canyon	Hectares	(Acres)
Zhemchug and Pribilof Canyon Complex*	1,851,758	(4,575,631)
Bristol Canyon	267,884	(661,932)
Bering Canyon	314,985	(778,317)
St. George Canyon	24,869	(61,450)
Umnak Canyon System†	908,439	(2,244,721)
Inanudah Canyon	98,098	(242,397)
Ohmuh Canyon	49,907	(123,319)
Bagoslof Canyon	78,214	(193,265)
Total	3,594,154	(8,881,032)§

*Upper portion only.

†Includes Chagulak Canyon, Aimukta Canyon, Uliaga Canyon, Carlisle Canyon, Herbert Canyon, and the eastern portion of Yunasha Canyon.

§Acreage total rounded to 8,881,000 acres (or 3,594,141 ha) for inclusion in Tables 47 and 61.

of the Planning Area and the Umnak Canyon System found in the southwest corner of this Planning Area. Neither of these two complex canyon systems are located entirely within the St. George Basin Planning Area, but they both represent major submarine features within this region.

No definitive data are available pertaining to the extent of bedrock or hard bottom outcrops within the St. George Basin Planning Area. Sediments can be expected to cover the majority of the Bering Sea shelf and the Aleutian Basin. It is suggested that a considerable amount of hard bottom outcropping lies along the Umnak Plateau and within the canyons of this Planning Area. Biologically productive hard-bottom areas are known to surround the islands of this region, but no data are available as to how far these areas extend offshore.

3.2.19 St. Matthew Hall Planning Area

Coastal Habitats

The mainland coast lying shoreward of the St. Matthew Hall Planning Area is predominantly low-lying and marshy. A large portion of the shoreline of this region comprises the coastal component of the Yukon-Kushokwim River Delta system, estimated to cover over 1,236,490 ha (3,055,325 acres) (King and Dau, 1981). Rocky shores present along the mainland coast are seen at Cape Romanzof, while sand and gravel beaches are seen primarily along the long narrow barrier islands which fringe the mainland coast off Cape Avinot, the mouth of the Kashunuh River, and off Cape Romanzof (UMES, 1985; NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map [USDOC, NOAA-NOS, 1984d]). The major islands of this region (i.e., Nunivak, Nelson, St. Matthew Hall and Pinnacle Islands) exhibit primarily rocky beaches interspersed with occasional pocket beaches of sand and gravel (UMES, 1985). Only the Mainland General Coastline estimate derived during the present analysis has been used to develop the Estuary Mouth to General Coastline ratio presented in Table 49.

Marine Habitats

Kelp beds are either known or expected to occur on the rocky substrates present around Cape Romanzof and Nunivak, St. Matthew Hall, Nelson Island, and the Pinnacle Islands (Healey, 1972). However, there are no quantitative estimates available as to how much area these habitats occupy. Along the mainland coast, within the Yukon River Delta, and in the numerous lagoons of the region, eel grass (*Zostera marina*) is present (King and Dau, 1981), however there are no published estimates of its coverage available.

The continental shelf of the Bering Sea is one of the widest and flattest in the world (Carlson *et al.*, 1983). Within the St. Matthew Hall Planning Area, bathymetry never exceeds 150 m (492 ft). The entire Planning Area is located inshore of the shelf slope and continental rise features which are present further to the west (i.e., in the Navarin Basin Planning Area) (NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map [USDOC, NOAA-NOS, 1984d]). As a consequence of this bathymetric characteristic, no Submarine Canyons or

Table 49. Summary table for the St. Matthew Hall Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline		
Mainland	711 (442)	NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map (USDOC, NOAA-NOS, 1984d).
Island	442 (275)	
Estuary/Wetland	494 (307)	Zimmerman, 1982.
Sand/Gravel Beach	179 (111)	UMES, 1985.
Rocky Beach	481 (299)	UMES, 1985.
Estuary Mouth/ General Coastline	64/711 = 0.090 (mainland only)	NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map (USDOC, NOAA-NOS, 1984d).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	*	Kelp and other macroalgae are known to occur on rocky substrates around islands of this Planning Area (Healey, 1972), but no quantitative estimates are available.
Submarine Canyons	Negligible	NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map (USDOC, NOAA-NOS, 1984d).
Coral Reefs	Negligible	
Hard Bottom	*	No quantitative estimates available.
Shelf Slope Zone	Negligible	NOAA-NOS OCS Resource Management Map, Navarin Basin Regional Map (USDOC, NOAA-NOS, 1984d).
Mud/Sand Bottom	*	Assumed to predominate throughout this Planning Area based on studies in neighboring basins.
State Waters	557,272 (1,377,000)	Calculated based on 3-mi limit.
OCS Area	21,934,740 (54,200,000)	USDOI, MMS, 1990a.
Total Area	22,492,012 (55,577,000)	

*Insufficient data.

Shelf Slope Zone areas are present within the St. Matthew Hall Planning Area.

The seafloor sediments of the St. Matthew Hall Planning Area are considered to be primarily sand/mud due to the flat topography and large amount of riverine sediment drainage and deposition into this region. Johnson and Nelson (1984) have reported that benthic feeding by marine mammals typically stirs up large amounts of sediment which are suspended in the water column. The lack of reliable data regarding the extent of hard bottom features within this Planning Area also prevented an estimation of Mud/Sand Bottom areal extent (Table 49).

3.2.20 Bowers Basin Planning Area

Coastal Habitats

There are no land areas located adjacent to or in close proximity to the Bowers Basin Planning Area (Table 50).

Marine Habitats

A majority of the Bowers Basin Planning Area lies below the 3,600-m (11,812-ft) isobath, within the abyssal plain as defined by Carlson *et al.* (1983). The exceptions to abyssal depths include: 1) the extreme southeast corner of the Planning Area, where the seafloor rises to meet the Umnak Plateau, the majority of which lies within the St. George Basin Planning Area; and 2) the south central portion of the Planning Area along 180°W longitude, where Bowers Ridge partially bisects the region along a curved arc stretching from north to west (NOAA-NOS Seamap Series, North Pacific Ocean, Chart 16648-14B [USDOC, NOAA-NOS, 1973]). No submerged vegetation is expected within this Planning Area since the shallowest indicated depth is 500 m (1,641 ft). Several submarine canyons and canyon complexes open into the southern and west-central boundaries of the Bowers Basin Planning Area (Table 51). The only known sites for potential hard bottom outcrops located within the Bowers Basin Planning Area boundaries are: 1) Amilia Knoll, located near the central southern boundary; and 2) the shallowest portions of Bowers Ridge along the western boundary of the Planning Area. The Shelf Slope Zone, as defined in the present analysis, is evident only in the southeast corner and along the eastern side of Bowers Ridge. The seafloor within these portions of the Planning Area is convoluted and indented by canyons and canyon complexes.

3.2.21 Aleutian Basin Planning Area

Coastal Habitats

There are no land areas located adjacent to or in close proximity to the Aleutian Basin Planning Area (Table 52).

Marine Habitats

The shallowest depths evident within the Aleutian Basin Planning Area are approximately 200 m (656 ft), found in the northeast

Table 50. Summary table for the Bowers Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).
Estuary/Wetland	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).
Sand/Gravel Beach	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).
Rocky Beach	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).
Estuary Mouth/ General Coastline	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	None	MMS Bowers Basin Planning Area Map (USDOI, MMS, 1985c).
Submarine Canyons	461,358 (1,140,000)	NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973).
Coral Reefs	None	
Hard Bottom	15,783 (39,000)	NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973).
Shelf Slope Zone	784,713 (1,939,000)	NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973); Kiska Bathymetric Chart 1910N-1 (USDOC, CGS, 1966a).
Mud/Sand Bottom	36,528,627 (90,261,000)	Estimated based on the high percentage of seafloor lying below the 3,600-m isobath (abyssal plain).
State Waters	None	
OCS Area	36,544,410 (90,300,000)	USDOI, MMS, 1990a.
Total Area	36,544,410 (90,300,000)	

Table 51. Submarine canyons present within the Bowers Basin Planning Area. Data derived from NOAA-NOS Seamap Series Chart 16648-14B (USDOC, NOAA-NOS, 1973).

Canyon	Hectares	(Acres)
Umnak, Chagulak, and Amuhta Canyon Complex*	416,742	(1,029,756)
Amlia Canyon†	27,656	(68,337)
Bowers Canyon†	17,157	(42,395)
Total	461,555	(1,140,488)§

*Middle and lower portion.
†Lower portion only.
§Acreage total rounded to 1,140,000 acres (or 461,358 ha) for inclusion in Tables 50 and 61.

Table 52. Summary table for the Aleutian Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d).
Estuary/Wetland	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d).
Sand/Gravel Beach	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d).
Rocky Beach	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d).
Estuary Mouth/ General Coastline	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	None	MMS Aleutian Basin Planning Area Protraction Diagram (USDOI, MMS, 1985d); NOAA-NOS OCS Resource Management Map, Navarin Basin Map (USDOC, NOAA-NOS, 1984d).
Submarine Canyons	1,973,317 (4,876,000)	Fischer *et al.*, 1982.
Coral Reefs	None	
Hard Bottom	None	Fischer *et al.*, 1982; Carlson *et al.*, 1983.
Shelf Slope Zone	338,329 (836,000)	Fischer *et al.*, 1982.
Mud/Sand Bottom	19,182,780 (47,400,000)	Extrapolated from Fischer *et al.*, 1982 and Carlson *et al.*, 1983, coupled with the assumption that bottom conditions are similar to those evident in Navarin Basin.
State Waters	None	
OCS Area	19,182,780 (47,400,000)	USDOI, MMS, 1990a.
Total Area	19,182,780 (47,400,000)	

corner of the Planning Area near its boundary with the Navarin Basin and St. George Basin Planning Areas. No submerged vegetation is expected at these depths (Table 52). A number of submarine canyons (i.e., with their lower and lower-middle portions extending into the northeastern segment of the Aleutian Basin Planning Area) are evident (Table 53). The upper and upper-middle portions of these canyons extend into the Navarin Basin Planning Area to the north and St. George Basin Planning Area to the east (Fischer *et al.*, 1982; Carlson *et al.*, 1983).

No hard bottom areas have been reported from the Aleutian Basin Planning Area. The nearest mapped upthrust of basement rock, where rocky knobs have been noted, is that portion of the Pribilof Ridge lying in less than 130 m (427 ft) of water. This portion of the Pribilof Ridge is located within the adjacent St. George Basin Planning Area (Fischer *et al.*, 1982).

The Shelf Slope Zone, as defined in the present analysis, comprises a very narrow and rugged band of limited areal extent located within the northeast corner of the Aleutian Basin Planning Area. The majority of this Planning Area lies in water depths greater than 3,600 m (11,812 ft), defined by Carlson *et al.* (1983) as being part of the abyssal plain.

3.2.22 Navarin Basin Planning Area

Coastal Habitats

There are no land areas located adjacent to or in close proximity to the Navarin Basin Planning Area (Table 54).

Marine Habitats

The Navarin Basin Planning Area is a region of pronounced geomorphological contrast. The continental shelf, extending from water depths of >60 to 200 m (>197 to 656 ft), has been characterized as being remarkably flat and covered with a thick sediment layer. The shallowest depths evident within this Planning Area are >60 m (>197 ft) and no submerged vegetation is expected to occur within this region (Table 54). The Shelf Slope Zone is extremely steep and narrow and is indented by five major submarine canyons or canyon complexes (Table 55). Transverse ridges are located parallel to the shelf break, some of which reveal knobs where basement rock outcrops are exposed through the surrounding sediments. The prominent transverse ridges include Prevenets Ridge, located just north of Prevenets Canyon, and two areas of the Navarin Ridge, located just north of St. Matthew and Middle Canyon. In those areas where water depths are >2,000 m (6,562 ft), the continental rise exhibits a gentle slope which is criss-crossed by turbidity current channels and buried deep sea fan channels (Fischer *et al.*, 1982).

Table 53. Submarine canyons present within the Aleutian Basin Planning Area. Data derived from Fischer *et al.* (1982).

Canyon	Hectares	(Acres)
St. Matthew Canyon*	840,266	(2,076,270)
Middle Canyon†	167,012	(412,681)
Zhemchug and Pribilof† Canyon Complex	966,189	(2,387,420)
Total	1,973,467	(4,876,371)§

*Lower portion only.
†Middle and lower portions.
§Acreage total rounded to 4,876,000 acres (or 1,973,317 ha) for inclusion in Tables 52 and 61.

Table 54. Summary table for the Navarin Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	None	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Estuary/Wetland	None	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Sand/Gravel Beach	None	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Rocky Beach	None	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Estuary Mouth/ General Coastline	None	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	None	Fischer *et al.*, 1982; MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Submarine Canyons	2,619,623 (6,473,000)	Fischer *et al.*, 1982; Carlson *et al.*, 1983.
Coral Reefs	Negligible	
Hard Bottom	212,872 (526,000)	Potential areas of bedrock outcropping as defined by Fischer *et al.*, 1982.
Shelf Slope Zone	2,056,281 (5,081,000)	MMS Navarin Basin Planning Area Protraction Diagram (USDOI, MMS, 1987q).
Mud/Sand Bottom	12,958,089 (32,019,000)	Based on sediment description data from Fischer *et al.*, 1982 and Carlson *et al.*, 1983.
State Waters	None	
OCS Area	15,014,370 (37,100,000)	USDOI, MMS, 1990a.
Total Area	15,014,370 (37,100,000)	

Table 55. Submarine canyons present within the Navarin Basin Planning Area. Data derived from Fischer *et al.* (1982) and Carlson *et al.* (1983), coupled with a review of bathymetric charts of the Navarin Basin Province, St. Matthew and Middle Canyons, and Fan-Valley Systems (USDOI, MMS, 1987q).

Canyon	Hectares	(Acres)
Navarinsky Canyon Complex	687,596	(1,699,027)
Prevenets Canyon Complex	1,176,410	(2,906,870)
St. Matthew Canyon*	243,166	(600,854)
Middle Canyon†	44,630	(110,279)
Zhemchung Canyon†	467,961	(1,156,315)
Total	2,619,763	(6,473,345)§

*Middle and upper portion.
†Upper portion only.
§Acreage total rounded to 6,473,000 acres (or 2,619,623 ha) for inclusion in Tables 54 and 61.

3.2.23 Norton Basin Planning Area

Coastal Habitats

The Yukon River Delta coastline, located inshore of the southern edge of this Planning Area, consists of marshes, wetlands, and intertidal mud flats. The remainder of the mainland coast and most of the island coastline comprising the General Coastline estimate presented in Table 56 is characterized by alternating bedrock, boulder, gravel, and sand beaches. The Yukon River Delta comprises approximately 199,922 ha (494,000 acres) of intertidal wetland along this coastline (Zimmerman, 1982). The total General Coastline, representing contributions from both mainland and island shores, has been used to calculate the Estuary Mouth to General Coastline ratio given in Table 56. The linear extent of insular estuary mouths has been included in the derivation of this ratio because of the major lagoons present on St. Lawrence Island.

Marine Habitats

There are 16 lagoon or bay-like features found in coastal waters adjacent to this Planning Area, most of which are expected to have large standing stocks of eel grass (*Zostera marina*) and kelp (Zimmerman, 1982). Many of the features designated as lagoons by previous researchers (e.g., UMES, 1985) actually have wide mouths which open directly onto coastal waters, and are thus considered vulnerable to activities on the OCS. These areas also lack the barrier islands which are characteristic of true lagoon features. For these reasons, the areal extent of submerged vegetation estimated to occur within their bounds (i.e., within nearshore waters) has been included in the Planning Area-specific estimates of Submerged Vegetation (Table 56).

The Norton Basin Planning Area covers a broad, shallow shelf with depths ranging from <10 m (<33 ft) to slightly more than 70 m (230 ft). There are no submarine canyons or shelf slope zones present in this Planning Area (NOAA, OCS Resource Management Map, Norton Sound Regional Map, [USDOC, NOAA-NOS, 1982b]). The majority of the seafloor located outside Norton Sound is a mosaic of medium to fine-grained sand and gravel. Within Norton Sound, the seafloor is covered primarily by a thin layer of sandy silt deposited from modern river drainages. There are several large areas near the coastline (e.g., from Nome to Wales, and off St. Lawrence Island) where bedrock outcroppings may be seen (USDOI, MMS, 1985e).

3.2.24 Hope Basin Planning Area

Coastal Habitats

Coastal habitats located shoreward of the Hope Basin Planning Area are diverse, ranging from salt marshes and protected coastal lagoons to seacliffs and rocky offshore islands (UMES, 1985). The description of the coastal habitats of this region presented by UMES (1985) were derived mainly from the studies of coastal bird habitat by

Table 56. Summary table for the Norton Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline Mainland	1,059 (658)	MMS Norton Basin Planning Area Protraction Diagram (USDOI, MMS, 1987r).
Island	537 (334)	
Estuary/Wetland	129 (80)	Estimated based on measurements of mud and tidal flats and wetland areas of the Yukon River Delta (UMES, 1985); MMS Norton Basin Planning Area Protraction Diagram (USDOI, MMS, 1987r).
Sand/Gravel Beach	951 (591)	UMES, 1985.
Rocky Beach	516 (21)	UMES, 1985.
Estuary Mouth/ General Coastline	50/1,596 = 0.031	Measured and calculated from MMS Norton Basin Planning Area Protraction Diagram (USDOI, MMS, 1987r). Estimate includes measurements of estuary mouth derived from the islands.

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	88,105 (218,000)	Estimated based on the suspected presence of *Zostera marina* and kelp beds in bays and lagoons (UMES, 1985).
Submarine Canyons	Negligible	NOAA-NOS OCS Resource Management Map, Norton Sound Regional Map (USDOC, NOAA-NOS, 1982b).
Coral Reefs	Negligible	
Hard Bottom	448,408 (1,108,000)	Estimated from Hess and Nelson, 1982, as shown in the Norton Basin Lease Sale No. 100 Final EIS (USDOI, MMS, 1985e).
Shelf Slope Zone	None	NOAA-NOS OCS Resource Management Map, Norton Sound Regional Map (USDOC, NOAA-NOS, 1982b).
Mud/Sand Bottom	9,669,092 (23,892,000)	Hess and Nelson, 1982, as shown in the Norton Basin Lease Sale No. 100 Final EIS (USDOI, MMS, 1985e).
State Waters	770,954 (1,905,000)	Calculated based on 3-mi limit.
OCS Area	10,117,500 (25,000,000)	USDOI, MMS, 1990a.
Total Area	10,888,454 (26,905,000)	

Drury *et al.* (1981). The majority of the coastal habitat data presented in Table 57 has been based on estimates derived from earlier studies.

Rocky shores are present in several areas, including Cape Lisburne, Cape Thompson, the southern shore of Kotzebue Sound, and on the Diomede, Puffin, and Chamissol Islands. The remainder of the shoreline of this region consists of sand and gravel barrier islands backed by lagoons and large wetland areas. For the Estuary/Wetland estimate presented in Table 57, only the river deltas and lagoon mouths fronting directly onto coastal waters were measured. If the protected lagoonal shorelines were to be included, the Estuary/Wetland linear shoreline estimate would increase by 50 to 70% from that provided in Table 57.

Marine Habitats

There are no data available pertaining to kelp or other macrophytic algal distributions within the Hope Basin Planning Area. Stands of eel grass (*Zostera marina*) may occur in the lagoons along the Hope Basin coast but no distributional or areal estimates are presently available. Kelp is expected to be present along the rocky coastline and at other locations where suitable substrate occurs, however, there are no estimates of aerial coverage presently available.

The continental shelf of the Hope Basin Planning Area is broad and shallow, with water depths ranging from 13 to 55 m (43 to 180 ft) between Kotzebue Sound and 169°W longitude, the U.S.-U.S.S.R. border. Based on the work of Phillips (1983) within the Chukchi Sea, it has been assumed that the seafloor within the Hope Basin Planning Area is predominantly a mixture of sand, mud, and gravel.

3.2.25 Chukchi Sea Planning Area

Coastal Habitats

Approximately one third of the coastline located shoreward of the Chukchi Sea Planning Area is composed of long, low-lying barrier islands. Of particular significance is the Kasegaluk Lagoon into which the Utukoh, Kikolih, and Kukpowruh Rivers empty. Within the Kasegaluk Lagoon are located large areas of intertidal mud flats and salt marshes, however, these areas have yet to be reliably mapped. A majority of the shoreline is backed by a series of tundra cliffs which range from 3 to 14 m (10 to 46 ft) in height. Sand and gravel beaches predominate throughout this region (Phillips, 1983; Lewbel, 1984). Wetland areas fronting directly onto coastal waters of this region are estimated to represent 10% of the General Coastline; wetlands are typically present in association with various river deltas and mud flats (UMES, 1985).

Marine Habitats

The Chukchi Sea Planning Area is characterized by the presence of a flat, shallow shelf. There is neither a Submarine Canyon or Shelf Slope Zone present within the bounds of this Planning Area (Table 58). These are several nearshore locations adjacent to or within this

Table 57. Summary table for the Hope Basin Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	999* (621)	NOAA-NOS OCS Resource Management Map, Norton Sound Regional Map (USDOC, NOAA-NOS, 1982b).
Estuary/Wetland	100 (62)	UMES, 1985; MMS Hope Basin Planning Area Protraction Diagram (USDOI, MMS, 1985f); NOAA-NOS OCS Resource Management Map, Norton Sound Regional Map (USDOC, NOAA-NOS, 1982b).
Sand/Gravel Beach	700 (435)	Drury *et al.*, 1981.
Rocky Beach	200 (124)	Drury *et al.*, 1981.
Estuary Mouth/ General Coastline	83/999 = 0.083	NOAA-NOS OCS Resource Management Map, Norton Sound Regional Map (USDOC, NOAA-NOS, 1982b).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	†	
Submarine Canyons	Negligible	NOAA-NOS Chart 16033 (USDOC, NOAA-NOS, 1978).
Coral Reefs	None	
Hard Bottom	†	
Shelf Slope Zone	None	NOAA-NOS Chart 16033 (USDOC, NOAA-NOS, 1978).
Mud/Sand Bottom	4,700,000 (11,613,000)	Estimate based on assumed similarities with the Chukchi Sea Planning Area.
State Waters	482,402 (1,192,000)	Calculated based on 3-mi limit.
OCS Area	4,775,460 (11,800,000)	USDOI, MMS, 1990a.
Total Area	5,257,862 (12,992,000)	

*Measurement includes the Baldwin Peninsula.
†Insufficient data.

Table 58. Summary table for the Chukchi Sea Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	543 (337)	MMS Chukchi Sea Planning Area Protraction Diagram (USDOI, MMS, 1987t).
Estuary/Wetland	55 (34)	McRoy and Goering, 1974; UMES, 1985.
Sand/Gravel Beach	282 (175)	UMES, 1985; USDOI, MMS, 1987s.
Rocky Beach	206 (128)	USDOI, MMS, 1987s.
Estuary Mouth/ General Coastline	20/543 = 0.037	MMS Chukchi Sea Planning Area Protraction Diagram (USDOI, MMS, 1987t).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	*	USDOI, MMS, 1987s; Phillips, 1990, pers. comm., USGS.
Submarine Canyons	Negligible	NOAA-NOS OCS Resource Management Map, Barrow Arch/Diapir Field Regional Map (USDOC, NOAA-NOS, 1984e).
Coral Reefs	Negligible	
Hard Bottom	*	USDOI, MMS, 1987s; Phillips, 1983.
Shelf Slope Zone	Negligible	NOAA-NOS Bathymetric Chart 16003 (USDOC, NOAA-NOS, 1978).
Mud/Sand Bottom	11,736,300 (29,000,000)	Estimated from data contained in Phillips, 1983 and USDOI, MMS, 1987s.
State Waters	261,841 (647,000)	Calculated based on 3-mi limit.
OCS Area	11,938,650 (29,500,000)	USDOI, MMS, 1990a.
Total Area	12,200,491 (30,147,000)	

*Insufficient data.

Planning Area where extensive kelp beds have been reported. These include:

1) east of Point Franklin in water depths <15 m (<49 ft) as noted in the Chukchi Sea Lease Sale No. 109 Draft EIS (USDOI, MMS, 1987s);
2) 25 km (16 mi) southwest of Wainwright in water depths of 11 to 13 m (36 to 43 ft) (USDOI, MMS, 1987s);
3) 20 km (12 mi) northeast of Peard Bay, near Skull Cliff (USDOI, MMS, 1987s); and
4) off Cape Lisburne and Cape Beaufort in water depths of 8 to 13 m (26 to 43 ft) (Phillips, 1990, pers. comm., USGS, Menlo Park, CA).

At present, there is insufficient data on existing kelp beds upon which to develop an areal estimate of their extent (Table 58).

Throughout much of the Chukchi Sea Planning Area, there is a 2- to 5-m thick (7- to 16-ft) layer of sediment present over the bedrock of the continental shelf. Areas of exposed bedrock are found frequently in water depths greater than 30 m (98 ft). No data were available regarding the areal extent of these outcroppings (Phillips and Reiss, 1984a,b; Phillips *et al.*, 1984; 1988; Phillips, 1990, pers. comm.). Mud is the predominant substrate present in the deeper portions of the continental shelf, while gravel predominates along the shoreline and sand is evident most frequently within mid-depth ranges (20 to 40 m [66 to 131 ft]) (Phillips *et al.*, 1988).

3.2.26 Beaufort Sea Planning Area

Coastal Habitats

Beaches located shoreward of the Beaufort Sea Planning Area are primarily narrow bands of sand and gravel overlying peat and mud permafrost. Discontinuous, but extensive, chains of small barrier islands partially enclose a number of productive bays, sounds, and estuaries. Boulder beaches occur on the western side of the Sagavanirktok River Delta, at Point Barrow, on Tigvauiah Island, and in the Niakuh Islands, but rocky shores are otherwise absent along this coastline (Hopkins and Hartz, 1978; NWI Wetlands Classification Maps [USDOI, USFWS, 1987-1989]).

Several large river delta systems are present along the coastline of this region. These rivers generally discharge into the lagoons, bays, and estuaries where they form large areas of salt marshes, sand islands, and tidal flats. A review of the NWI Wetlands Classification Maps, wherein habitat classifications were depicted, indicated that virtually the entire coastal area of this region is "wetland". The extent of actual, or perennial wetland habitat fronting coastal waters of the region, however, is much smaller, estimated at only 8 to 10% of the linear shoreline (UMES, 1985; NWI Wetlands Classification Maps [USDOI, USFWS, 1987-1989]).

Marine Habitats

The continental shelf of the Beaufort Sea Planning Area is narrow (55 to 80 km; 34 to 50 mi) and relatively shallow (64 m; 210 ft), (Feder *et al.*, 1976). The seafloor of the shelf is primarily soft mud, however, boulder fields have been reported near Hurlak, Flaxman, and adjacent to the Narwhal Islands (Dunton *et al.*, 1982). There are isolated kelp beds found in association with these boulder fields (Broad *et al.*, 1979; Dunton *et al.*, 1982), the best studied of which are those in Stefannson Sound off the Narwhal Islands and in Camden Bay (Dunton *et al.*, 1982). Boulder patches and kelp beds must necessarily be discussed together because there is a lack of suitable substrate within this region for the attachment of kelp or other macroalgae. Where boulder fields occur, kelp can routinely be expected. Such boulder field-associated kelp beds support a unique epifaunal community otherwise rare in the Beaufort Sea Planning Area (Broad *et al.*, 1979). In addition to the kelp beds growing in association with these boulder fields, there are significant quantities of other algal species found growing across the nearshore shelf (Miley and Barnes, 1986).

In view of the results of these studies, it is suspected that the Submerged Vegetation estimate provided in Table 59 represents an underestimate of the actual submerged vegetation present within or adjacent to this Planning Area. The estimate provided in Table 59 includes only those kelp beds studied to date and should be expanded (when additional data become available) to include all mapped boulder fields. There is a lack of basic information regarding shelf break and Shelf Slope Zone features in the Beaufort Sea Planning Area. This lack of available data precludes a proper assessment of other potentially significant marine habitats.

Table 59. Summary table for the Beaufort Sea Planning Area.

Coastal Habitats: Category	Linear Extent km (mi)	Reference
General Coastline	706 (439)	MMS Beaufort Sea Planning Area Protraction Diagram (USDOI, MMS, 1987u).
Estuary/Wetland	80 (50)	Estimated at 10% of the General Coastline, based on UMES, 1985.
Sand/Gravel Beach	618 (384)	NWI Wetlands Classification Maps (USDOI, USFWS, 1987-1989).
Rocky Beach	8 (5)	NWI Wetlands Classification Maps (USDOI, USFWS, 1987-1989).
Estuary Mouth/ General Coastline	60/706 = 0.085	MMS Beaufort Sea Planning Area Protraction Diagram (USDOI, MMS, 1987u).

Marine Habitats: Category	Areal Extent ha (acres)	Reference
Submerged Vegetation	3,268 (8,074)	Broad *et al.*, 1979; 1981; Dunton *et al.*, 1982; BLM, Land Status, Graphic No. 8 (USDOI, BLM, 1979c).
Submarine Canyons	*	NOAA-NOS OCS Resource Management Map, Barrow Arch/Diapir Field Regional Map (USDOC, NOAA-NOS, 1984e).
Coral Reefs	Negligible	
Hard Bottom	41,959 (103,680)	BLM, Land Status, Graphic No. 8 and Cultural Resources, Graphic No. 10 (USDOI, BLM, 1979c).
Shelf Slope Zone	3,142,496 (7,765,000)	NOAA-NOS Chart 16004 (USDOC, NOAA-NOS, 1986d).
Mud/Sand Bottom	19,946,854 (49,288,000)	Estimate based on mapped boulder fields (Dunton *et al.*, 1982; BLM, Land Status, Graphic No. 8 (USDOI, BLM, 1979c).
State Waters	341,162 (843,000)	Calculated based on 3-mi limit.
OCS Area	19,992,180 (49,400,000)	USDOI, MMS, 1990a.
Total Area	20,333,342 (50,243,000)	

*Insufficient data.

4.0 SUMMARY

4.1 PRIMARY PRODUCTIVITY

4.1.1 General Comparisons

Table 60 outlines the estimated variability in daily and annual production (i.e., g $C \cdot m^{-2} \cdot d^{-1}$ and g $C \cdot m^{-2} \cdot yr^{-1}$, respectively) identified for each of the 26 OCS Planning Areas. In terms of both daily and annual primary production, the variability characteristic of select spatial or temporal regimes present within a given Planning Area (e.g., coastal versus offshore; bloom versus non-bloom; winter versus summer) have been provided. The comments section of Table 60 also discusses 1) tabular comparisons of the Planning Area-specific levels of sampling frequency (i.e., high, moderate, or poor sampling via direct or indirect measures) upon which the daily and annual estimates have been based, and 2) a description of the variability evident within a Planning Area (e.g., high [>5-fold variation] or low-moderate [<5-fold variation]) based on the definitions provided in Section 2.1.4. The major oceanographic characteristics which influence primary production within each Planning Area have also been identified within the comments section of Table 60.

Table 61 summarizes the relative annual water column primary productivity, variability in production, and confidence in the available data for the 26 OCS Planning Areas, paralleling a previous analysis conducted by the U.S. Department of the Interior, Minerals Management Service (1987a). As is evident from a review of Table 61, there remain a significant number of Planning Areas for which direct primary productivity measurements are either extremely limited or completely lacking (e.g., Straits of Florida, Central Gulf of Mexico, Northern California, most of the Alaska Planning Areas). In contrast, several Planning Areas have been well sampled (e.g., North Atlantic, Mid-Atlantic, Southern California, Washington-Oregon), as reflected in the high or moderate-to-high confidence levels noted in Table 61.

4.1.2 Problems and Limitations

The major problem encountered in establishing relative estimates of water column primary productivity for the 26 OCS Planning Areas rested with the lack of a consistent and uniform data base. The problem with data availability prompted additional concerns regarding the inability to determine estimates of variability in daily and annual production, as evidenced in the number of "Unknown" entries found within Table 61. Any evaluation or utilization of the daily or annual primary production levels established in this analysis must necessarily take two factors into consideration: 1) the spatial and temporal extent of direct primary productivity measurements (expressed as "Confidence", Table 61); and 2) the variability evident in the available primary productivity data base (expressed as "Variability", Table 61).

Table 60. Summary of water column primary productivity by Planning Area.

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
North Atlantic	<0.25 - 3.0	260 - 455	Regional sampling for primary production: high. High (10- to 12-fold variation) evident on a seasonal basis (spring, fall blooms). Tidal mixing, estuarine input, and cross shelf exchange represent the major features influencing nutrient input and production; warm core rings exhibit elevated production levels compared to adjacent waters (2.4 $g\ C \cdot m^{-2} \cdot d^{-1}$ within vs. 0.14 $g\ C \cdot m^{-2} \cdot d^{-1}$ outside).
Mid-Atlantic	<0.25 - 3.25	260 - 505	Regional sampling for primary production: moderate to high. High (11- to 13-fold variation) evident. Estuarine input and cross shelf exchange represent the major features influencing nutrient input and production; warm core rings also contribute to regional variations in production values.
South Atlantic	0.05 - 2.70	130 - 580	Regional sampling for primary production: poor to moderate. Exceptionally high variability (120-fold differences) noted between upwelling and non-upwelling production; upwelling production measured as high as 6 $g\ C \cdot m^{-2} \cdot d^{-1}$. Gulf Stream dynamics (e.g., meanders, eddies) regulate production over the shelf and slope; riverine inputs influence nearshore waters, with additional mediation via inshore embayments (e.g., Pamlico Sound).

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production (g C•m^{-2}•d^{-1})	Estimated Annual Production (g C•m^{-2}•yr^{-1})	Comments
Straits of Florida	0.021 - 0.128 (embayments) 0.004 - 0.020 (coastal) 0.19 - 0.50 (offshore)	7.6 - 35.4 (embayments) 18.4 (coastal)	Regional sampling for primary production: very poor; data base restricted (Biscayne Bay and adjacent coastal waters, offshore Biscayne Bay, Dry Tortugas). High (>10-fold variation) to low-moderate (<3-fold variation) variability evident for daily and seasonal averages, respectively. Florida Current represents the major oceanographic feature influencing production; upwelling may also contribute, however data are unavailable.
Eastern Gulf of Mexico	1.0 - 4.0 (embayments) 0.125 - 0.400 (coastal; non-bloom) 0.50 - 3.80 (coastal; bloom) 0.15 - 0.94 (offshore)	50 - 800 (embayments) 89 (coastal; non-bloom) 165 (offshore)	Regional sampling for primary production: moderate (embayments and offshore) to poor (coastal waters). High (5- to 6-fold variation) variability in coastal waters attributed to red-tide dinoflagellates bloom; low-moderate to high variability was evident in offshore waters. The Loop Current and associated eddies represent the major oceanographic features influencing production.
Central Gulf of Mexico	1.1 - 1.3 (coastal) 0.018 - 0.605 (offshore)	300 - 400 (coastal) 115 - 184 (offshore)	Regional sampling for primary production: poor; data base very limited. High (5- to 17-fold variation) seasonal and interannual variability evident in coastal waters; high (≥5-fold variation) spatial variability also evident. Mississippi River discharges influence nearshore (coastal) production.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
Western Gulf of Mexico	0.10 - 3.00 (embayments) 0.002 - 0.025 (coastal) 0.29 - 0.36 (offshore)	127 - 200 (embayments) 103 - 176 (coastal) 60 - 118 (offshore)	Regional sampling for primary production: moderate (embayments and coastal) to poor (offshore). High variability evident for coastal waters; low-moderate variability suggested for offshore waters. Loop Current-associated rings may represent regions of limited elevations in production.
Southern California	0.30 - 0.80 (winter) 1.00 - 1.50 (summer) 0.50 - 1.50 (mean)	275	Regional sampling for primary production: high. High (>10-fold variation) variability evident on a seasonal and interannual basis; spatial variability (patchiness) also prominent. The California Current System represents the primary mediator of production; El Niño events and upwelling implicated in changes in interannual productivity.
Central California	0.80 - 3.20 (CalCOFI) 0.60 - 3.00 (offshore-inshore gradient)	275 - 325 (offshore-inshore gradient)	Regional sampling for primary production: moderate. High (>5- to 10-fold variation) variability evident on a seasonal and interannual basis; spatial variability (patchiness) also indicated. The California Current System represents the primary mediator of production; upwelling, eddies, and fronts implicated in increases in production in coastal waters; El Niño events also noted.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
Northern California	0.602 - 2.888 (offshore-inshore gradient)	300	Regional sampling for primary production: poor; data base limited. High (>5-fold variation) variability suggested on a seasonal and interannual basis; spatial variability (patchiness), prompted by oceanographic events, strongly suggested. Major oceanographic features include wind-driven coastal upwelling (particularly proximal to major promontories) and coastal forcing processes (eddies, coastal jets, advection).
Washington-Oregon	0.070 - 2.40 (shelf) 0.319 - 1.360 (slope) 0.385 - 0.960 (mean)	126 - >300 (river plume and oceanic to upwelling gradient)	Regional sampling for primary production: moderate (entire Planning Area) to high (coastal waters influenced by Columbia River). High variability evident. Major oceanographic features include coastal upwelling and discharges from the Columbia River.
Gulf of Alaska	0.05 - 0.50 (winter to summer, offshore) No daily production data available for coastal waters	48 - 100 (offshore) 200 (coastal)	Regional sampling for primary production: poor; extremely limited data base. Variability in production unknown. Coastal (shelf) waters influenced by the Alaska Stream; freshwater input evident nearshore. Offshore waters influenced by the Alaska Gyre and the Central Subarctic Domain.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
Cook Inlet, Kodiak, Shumagin	>2.0	>300	Regional sampling for primary production: poor to moderate. Extremely high variability evident in production, attributed to seasonality (temperature extremes, seasonal fluctuation in light intensity); Alaska Current and Alaska Coastal Current produce advection and upwelling, respectively; tidal influences in Cook Inlet result in both productivity enhancement (related to tidal fronts and associated increases in nutrients) and diminution (related to increased levels of glacial silt).
Aleutian Arc	0.10 - 0.15 (waters south of the Aleutians) 0.34 - 0.63 (waters north of the Aleutians)	30 - 82 (waters south of the Aleutians) 100 - 200 (waters north of the Aleutians)	Regional sampling for primary production: poor. Variability in production relatively unknown, although turbulence and upwelling proximal to islands and passes produces highly variable production measurements. Major oceanographic features include the Alaska Stream (south of the Aleutians) and Bering Sea waters (north of the Aleutians).
North Aleutian Basin	2.60 - 6.70 (Coastal Domain, upwelling) No daily production data available for the Central Domain 0.10 - 5.00 (Outer Domain)	50 - 60 (Coastal Domain, non-upwelling) 220 - 240 (Coastal Domain, advection and upwelling) 166 - 188 (Central Domain) No annual production data available for the Outer Domain 1 - 2 (sea ice microalgae, estimated)	Regional sampling for primary production: high (PROBES). High variability evident in all three domains. Major oceanographic features (including their prevalent action) include: Coastal Domain (tidal action, advection-diffusion); Central Domain (tidal-driven diffusion); and Outer Domain (advection-spring bloom); interannual variability attributed to storm and wind variation, particularly for the Outer Domain. Sea ice microalgae contributions to total water column production $\leq$10%.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g \; C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g \; C \cdot m^{-2} \cdot yr^{-1}$)	Comments
St. George Basin	No daily production data available	200 (Central and Outer Domains); estimate extrapolated from North Aleutian Basin data	Regional sampling for primary production: poor. Variability in production unknown. Major oceanographic features (including their prevalent action) include: Central Domain (tidal-driven diffusion); and Outer Domain (advection-diffusion); island effect (proximal to the Pribilof Islands) suggested as a mechanism which enhances productivity; interannual variability attributed to storm and wind variation, particularly for the Outer Domain. Characteristics have been extrapolated from North Aleutian Basin data.
St. Matthew Hall	0.30 - 0.50 (Coastal Domain) 0.002 - 0.005 (ice algae, Central Domain)	50 - 70 (Coastal Domain) 160 - 200 (Central Domain)	Regional sampling for primary production: poor. Variability in production unknown, although it is expected to be high. Major features affecting production include the freshwater input from Kuskokwim and Yukon Rivers. Central Domain features are expected in the distal waters of the St. Matthew Hall Planning Area. Characteristics have been extrapolated, in part, from the North Aleutian Basin.
Bowers Basin, Aleutian Basin	0.160 - 0.630 (May-September) 0.490 (mean, May-September) 0.330 (mean, summer) 0.299 - 1.007 (July)	150 - 200	Regional sampling for primary production: poor. High variability is suggested for these Planning Areas, based on inferences from other regions and knowledge regarding Bering Sea oceanography. Interannual variability is dependent upon the frequency and magnitude of storm events during any given year.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
Navarin Basin	0.109 - 0.534	166 - 220	Regional sampling for primary production: poor. Variability in production is unknown, although it is expected to be high. The region is influenced by the Bering Slope Current. Characteristics have been extrapolated from other Alaska outer shelf regions.
Norton Basin	0.330 - 0.470 (Alaska Coastal Water) No production data available for Anadyr/Bering Shelf Water	50 - 70 (Norton Sound, Alaska Coastal Water) 285 - 324 (Anadyr/Bering Shelf Water)	Regional sampling for primary production: poor (Norton Sound) to moderate (shelf waters). Variability in production is unknown, although is expected to be high. Region is influenced by Anadyr Water, Bering Shelf Water, and Alaska Coastal Water. Freshwater input from the Yukon River affects nearshore production. Some characteristics of this region have been extrapolated from the ISHTAR study effort.
Hope Basin	0.50 - 1.57 (summer, ice free, Alaska Coastal Water) 1.0 - 16.0 (Bering Sea Water [Anadyr + Bering Shelf Water])	50 - 70 (Alaska Coastal Water) 250 - 300 (Bering Sea Water) 13 (ice algae, March-June growth period)	Regional sampling for primary production: moderate. Variability in production is unknown, although is expected to be high. Most of Kotzebue Sound is ice covered 60-70% of the year; the contribution of ice algae to total water column production is potentially significant. Storm surges affect circulation and nutrient distribution.

Table 60. (Continued).

Planning Area	Estimated Variability in Daily Production ($g\ C \cdot m^{-2} \cdot d^{-1}$)	Estimated Annual Production ($g\ C \cdot m^{-2} \cdot yr^{-1}$)	Comments
Chukchi Sea	0.10 - 0.32 (August) 0.66 - 1.51 (September)	50 - 100 (Alaska Coastal Water, Cape Lisburne) 25 - 50 (Alaska Coastal Water, Pt. Barrow) 5 (ice algae, March-June growth period)	Regional sampling for primary production: poor to moderate. Variability in production is unknown. The major oceanographic feature of this region is Alaska Coastal Water, plus the presence of an ice cover during most of the year.
Beaufort Sea	1.0 - 5.0 (ice algae, bloom [April-June])	1 - 20 (phytoplankton) 40 (shelf waters)	Regional sampling for primary production: poor to moderate. High variability in production is evident. The presence of an ice cover during most of the year is the prevalent feature of this region.

Table 61. Relative annual water column primary productivity, variability, and confidence in available data for the OCS Planning Areas. Primary productivity expressed as grams of carbon fixed per square meter per year.

Planning Area	Productivity*			Variability†	Confidence¶
	High	Moderate	Low		
North Atlantic	+			High	High
Mid-Atlantic	+			High	Moderate to High
South Atlantic	+	+		High	Poor to Moderate
Straits of Florida:					
Embayments			+	Low-Moderate	Poor
Coastal			+	Low-Moderate	Poor
Eastern Gulf of Mexico:					
Embayments	+	+		Low-Moderate	Moderate
Coastal, non-bloom		+		High	Poor
Offshore		+		Low-Moderate to High	Moderate
Central Gulf of Mexico:					
Coastal	+			High	Poor
Offshore		+		High	Poor
Western Gulf of Mexico:					
Embayments		+		Unknown	Moderate
Coastal		+		High	Moderate
Offshore		+		Low	Poor
Southern California	+			High	High
Central California	+			High	Moderate
Northern California	+			High	Poor
Washington-Oregon	+	+		High	Moderate to High
Gulf of Alaska		+	+	Unknown	Poor
Cook Inlet	+			High	Poor to Moderate
Kodiak	+			High	Poor to Moderate
Shumagin	+			High	Poor to Moderate
Aleutian Arc:					
South of Aleutians		+	+	Unknown	Poor
North of Aleutians		+		Unknown	Poor

Table 61. (Continued).

Planning Area	Productivity[*] High	Productivity[*] Moderate	Productivity[*] Low	Variability[†]	Confidence[¶]
North Aleutian Basin					
Coastal Domain		+		High	High
Coastal Domain, advection/upwelling	+			High	High
Central Domain		+		High	High
Sea ice			+	High	Poor to Moderate
St. George Basin	+			Unknown	Poor
St. Matthew Hall:					
Coastal Domain		+		Unknown	Poor
Outer Domain		+		Unknown	Poor
Bowers Basin		+		Unknown	Poor
Aleutian Basin		+		Unknown	Poor
Navarin Basin	+	+		Unknown	Poor
Norton Basin:					
Coastal/Sound		+		Unknown	Poor
Anadyr/Shelf	+			Unknown	Moderate
Hope Basin:					
Coastal		+		Unknown	Moderate
Bering Sea	+			Unknown	Moderate
Chukchi Sea:					
Coastal (Lisburne)		+		Unknown	Poor to Moderate
Coastal (Barrow)			+	Unknown	Poor to Moderate
Ice algae			+	Unknown	Poor to Moderate
Beaufort Sea			+	High	Poor to Moderate

[*] Relative phytoplankton productivity categories include: High (200 to 500 g $C \cdot m^{-2} \cdot yr^{-1}$), Moderate (50 to 200 g $C \cdot m^{-2} \cdot yr^{-1}$) and Low (<50 g $C \cdot m^{-2} \cdot yr^{-1}$), corresponding to levels established by the U.S. Department of the Interior, Minerals Management Service (1987a).

[†] Variability categories, drawn from Table 60, include: High (>5-fold variation) and Low-Moderate (<5-fold variation), as defined in Section 2.1.4.

[¶] Confidence level represents an evaluation of the individual data bases available for each Planning Area and utilized to establish relative levels of primary productivity, as identified in Table 60.

4.1.3 Data Gaps and Suggestions for Future Research

Atlantic Planning Areas. Primary production within all three Atlantic OCS Planning Areas is very high relative to continental shelves globally. Georges Bank represents a particularly unique and highly productive marine ecosystem. Annual primary production rates there exceed global averages by two- to three-fold. The onshore-offshore gradients, annual magnitude and temporal variability in primary production are generally similar throughout U.S. Atlantic waters despite considerable regional diversity in environmental conditions. The predominant physical-chemical mechanisms regulating primary production through nutrient inputs are tidal mixing, cross-shelf transport, upwelling and estuarine discharge. The relative importance of these mechanisms varies regionally, both within and between the three OCS Atlantic sub-regions. Such intrinsic habitat variability requires the application of regionally specific primary production models rather than treatment of the OCS Atlantic region as a single marine ecosystem.

While primary production measurements in the North Atlantic Planning Area have provided excellent regional coverage, they have generally been carried out without concurrent measurement of environmental conditions (e.g., nutrient conditions, physical water column characteristics, herbivorous zooplankton stocks, etc.). Knowledge of the environmental processes regulating the regional and seasonal variations in primary production characteristics of this Planning Area are, therefore, generally obscure except for the region south of Long Island. Available primary production maps for this region are to be treated only as qualitative surveys which are compromised by suitable quantification of the mechanisms regulating observed production patterns. There is considerable need to quantify ecosystem processes regulating primary production and its interannual variability in this very fertile region.

Selected stations in the major environmental regions of the North Atlantic Planning Area for which good seasonal coverage of primary production exists should be selected for extensive follow-up study. A field program should be initiated at these sites to measure the appropriate physical, nutrient, and biological parameters, including upper trophic levels. This study should be designed to provide a quantitative understanding of the underlying mechanisms regulating primary production processes. Stations should be selected to be representative of the major environmental subregions characterizing this Planning Area to facilitate future forecasting. An adequate elucidation of primary production processes, including magnitude, variability, and regional patterns, requires knowledge of secondary production processes. There is evidence that grazing structure is a determinant of primary production levels, and that long-term trends in modified fish stock levels presently characterize this Planning Area. It is also recommended that these studies be carried out for a sufficient duration to establish interannual variability patterns. There is presently little information regarding this aspect. Arguments that "creeping eutrophication" is presently occurring in the continental shelf waters of the North Atlantic Planning Area require assessment. Historical primary production and associated nutrient and biomass data need to be reevaluated, where possible, together with initiating appropriate field studies to assess this hypothesis.

Data gaps for the Mid-Atlantic Planning Area are similar to those identified for the North Atlantic Planning Area. The contribution of Chesapeake Bay discharge to primary production processes in the Mid-Atlantic region needs assessment. Continental shelf dynamics in this region are coupled to the outflow from this complex and very large ecosystem, but the effects of this onshore-offshore coupling on continental shelf processes, including regional, seasonal, and interannual variations on primary production, are poorly understood. The large scale estuarine contribution from the Chesapeake Bay to offshore waters represents a major environmental characteristic of this Planning Area. The recommendations noted previously for the North Atlantic Planning Area are also applicable to the Mid-Atlantic region.

The frequency and regional, season, and interannual coverage of primary production measurements in the South Atlantic Planning Area are significantly less than those for the North Atlantic and Mid-Atlantic regions, particularly between Cape Hatteras and 32°N latitude. An adequate description of regional levels of (and variation in) primary production suitable to OCS planning needs to be established. Since meanders of the Gulf Stream and associated upwelling events are significant determinants of primary production processes in the South Atlantic Planning Area, primary production studies closely coupled with physical oceanographic measurements are particularly needed to quantify and describe production processes. The incorporation of measurements on nutrient levels and herbivorous zooplankton is also necessary.

Knowledge of primary production processes in this Planning Area is very poor relative to the other OCS Atlantic Planning Areas. An extensive series of surveys, particularly between Cape Hatteras south to 32°N latitude, is needed to establish baseline primary production levels, their annual magnitude, and variability. Such data collection is necessary prior to the initiation of the more quantitative, broader based ecosystem analyses and measurements (including upper trophic levels) recommended for the North and Mid-Atlantic Planning Areas. The available data evaluated for this region suggest that the South Atlantic Planning Area is not an oligotrophic, unproductive ecosystem, as commonly held, but equally productive to the North and Mid-Atlantic Planning Areas, generally because of upwelling processes. Future studies may further support this hypothesis; a major revision in contemporary views as to the fertility and primary and secondary production processes and dynamics in the continental shelf waters of the U.S. Atlantic coast may be forthcoming.

Straits of Florida and Gulf of Mexico Planning Areas. The Planning Area-specific discussions of productivity in the Florida Straits and Gulf of Mexico regions strongly suggest that well coordinated biological and physical studies which examine hydrographic and biological changes over time scales of days to a week for monthly or quarterly periods of an annual cycle are needed. Further, such studies should focus, at least initially, on the relationship between western boundary current upwelling and productivity. The extent and duration of shelf intrusions must be known in the Straits of Florida and eastern Gulf of Mexico before accurate estimates of areal and annual water column primary production can be made.

Similarly, in the Eastern and Western Gulf of Mexico Planning Areas, such work needs to be coordinated with information on the configuration of the Loop Current, its attendant eddies (i.e., in the Eastern Gulf of Mexico Planning Area), and the anticyclonic rings which spin off from it and traverse the Gulf with effects in the Western Gulf of Mexico Planning Area. Additionally, there is a serious lack of data available to resolve the vertical structure of production in the coastal regions of the Western Gulf of Mexico Planning Area.

The entire coastline of Florida is undersampled, particularly with respect to the variability induced by dinoflagellate blooms and the eddies of the Loop Current - Florida Current western boundary system. The population in the state of Florida is one of the most rapidly expanding in the continental United States. Eutrophication of bays and rivers is occurring at a rapid pace which will, in turn, have dramatic effects on coastal ecosystems. An assessment of potential effects on the variety of ecosystems that occur along Florida's coastline will be hindered by the current lack of information at all levels of ecosystem organization.

California Planning Areas. The pattern of production in the California Current region (encompassing Northern, Central, and Southern California Planning Areas) is observed to be highly variable and tightly coupled to the physical structure of the region. This variability makes it virtually impossible to directly sample productivity patterns on all scales. In particular, mesoscale and episodic events are both important and poorly sampled. Low-frequency (i.e., interannual and longer) changes dominate the pattern of temporal variability in both physical structure and macrozooplankton biomass. These patterns of variability make it difficult to assign cause and effect relationships to changes in production and to separate anthropogenic changes from natural variability. In addition, the effects of variability in production on the chemical and biological structure of the region are not well understood. However, the large oceanographic and fisheries data sets which are available for this region provide a strong context in which to base further studies of the causes and consequences of changes in primary production.

Specific recommendations regarding further study of production in the California region include: 1) additional sampling in the relatively poorly sampled Northern and Central California Planning Areas; 2) collection of continuing time series data at a limited suite of locations and analysis of existing data in order to provide a framework in which to evaluate low-frequency change and to separate anthropogenic change from natural variability; 3) increased use of remote sensing and proxy variables to evaluate patterns of production on scales which are difficult to sample directly; 4) increased study of the physical processes determining the patterns of primary production and the consequences of changes in production in higher trophic levels; 5) study of new production and the biogeochemical consequences of changes in production; and 6) additional study of the region should be carefully coordinated with ongoing studies of other aspects of the California Current system due to the interdisciplinary nature of the problem.

Washington-Oregon Planning Area. A considerable amount of primary productivity information was collected off the Washington and Oregon coasts between 1961 and 1973. As noted in Section 2.2.11, these earlier productivity estimates (i.e., obtained prior to 1973) could not be used in the present analysis to reliably evaluate spatial or temporal patterns of production. Between 1974 and 1982, primary productivity estimates were derived from stations sampled along selected transects located off the Washington coast. These efforts emphasized spring and summer sampling of shelf and slope locations. As a consequence, there are very few data pertinent to 1) oceanic stations during all seasons, and 2) shelf and slope stations during the winter season. None of the transects occupied between 1974 and 1982 were sampled with adequate frequency to evaluate site-specific temporal variation or to calculate annual production. Similarly, the areal coverage was not sufficient to map spatial patterns of production at any particular time. In terms of marine waters lying off the Oregon coast, no acceptable primary productivity data have been collected since 1973.

To remedy these data gaps, large sampling programs at different spatial and temporal scales are necessary. It is suggested that water column sampling be conducted on a quarterly basis over several years along designated transects extending from the shoreline to the western boundary of the Planning Area. It is also suggested that such an effort be combined with biological, chemical, and physical oceanographic data collection efforts (e.g., as part of a major oceanographic program). Selected nearshore areas should also be identified for intensive study (i.e., increased number of sampling sites and sampling frequency). Such intensive study efforts should also be coupled with efforts directed at determining the physical factors of the nearshore zone in order to understand the processes that drive primary production. Satellite imagery may also be useful in an evaluation of the spatial and temporal patterns of chlorophyll distribution, however, such a program would also require an extensive calibration effort.

The physical processes that play a major role in primary production within the Washington-Oregon Planning Area include coastal upwelling and discharge from the Columbia River, as noted previously. Process studies should concentrate on productivity within these regions. However, it should be noted that coastal upwelling may decrease in the future as a result of climatic change; further, the pattern of discharge from the Columbia River may change as result of efforts to enhance salmon runs in the river.

Gulf of Alaska Region: Gulf of Alaska, Cook Inlet, Kodiak, Shumagin and Aleutian Arc (southern portion) Planning Areas. The available data base used to estimate primary productivity within the Gulf of Alaska region is very limited. Data gathered under the Outer Continental Shelf Environmental Assessment Program (OCSEAP) remain the most comprehensive productivity measurements presently available for this region, however there are severe temporal limitations evident within the OCSEAP data set. More recent evaluations of primary production in the Prince William Sound area resulting from the EXXON VALDEZ oil spill have expanded and will, following pending litigation, update the current data base. In general, there are limited amounts of synoptic data available for areal comparisons. In many cases, no data are available for the spring bloom period. Since the spring bloom is typically a large (i.e., 25 to 40 percent) fraction of annual productivity, the estimates developed for the present analysis are approximations for nearly the entire Gulf of Alaska region. Annual estimates are actually seasonal estimates, since no winter data have been collected. It is suggested that future studies concentrate on seasonal measurements of primary production within both coastal and offshore regimes of the Gulf of Alaska region.

Bering Sea Region - Continental Shelf Waters: North Aleutian Basin, St. George Basin, St. Matthew Hall, Navarin Basin, and Norton Basin Planning Areas. As a result of recent OCSEAP- and National Science Foundation-sponsored research conducted predominantly within the North Aleutian Basin Planning Area, primary productivity data for continental shelf waters of the Bering Sea are deemed more complete than for any other Alaska region. Temporal coverage is good because previous studies were directed toward an assessment of primary and secondary production. Supporting physical and chemical data are also extensive and there exist integrated syntheses linking primary productivity to higher trophic levels. In addition, advected carbon produced in this region has been assessed as to its impacts within regions north of the Bering Sea (i.e., where *in situ* production is sharply reduced by ice cover). Recent cooperative efforts with Soviet investigators has allowed a region-wide integration of biological and physical efforts which has greatly expanded the understanding of this marine ecosystem. Future study efforts should be directed towards determining interannual variability in primary production for the St. George, Navarin, and Norton Basin Planning Areas.

Bering Sea Region - Offshore Waters: Aleutian Arc (northern portion), Bowers Basin, and Aleutian Basin Planning Areas. In marked contrast to continental shelf waters, the offshore waters of the Bering Sea have seen little effort directed toward an assessment of primary production. Annual estimates of production have been inferred from a very small and limited data base accumulated primarily from incidental studies associated with biological (e.g., fishery) or physical oceanography. As is evident from a review of Table 61, estimates of primary production range from approximately 150 to 200 g $C \cdot m^{-2} \cdot yr^{-1}$ in the central Bering Sea (i.e., Bowers Basin and Aleutian Basin Planning Areas) with high interannual variability anticipated due to the timing and frequency of severe storms which bring deepwater nutrients into the euphotic zone. Temporal coverage within the Bowers Basin and Aleutian Basin Planning Areas is poor. Future study efforts should be designed and implemented to delineate the temporal variability suggested by measurements made in adjacent regions and current knowledge of Bering Sea oceanography.

The northern waters of the Aleutian Arc Planning Area are subjected to intense vertical mixing due to the presence of strong currents and relatively shallow depths characterizing passes which separate the Aleutians. This mixing, in turn, results in locally high primary productivity in the vicinity of island passes. Annual production is anticipated at 200 g $C \cdot m^{-2} \cdot yr^{-1}$ in the waters north of the Aleutians, although temporal coverage within this portion of the Aleutian Arc Planning Area is very poor.

Coastal waters of the Bering Sea have realized significantly greater interest in terms of primary productivity measurements as compared to the offshore waters of the Bering Sea. Very little is known as to the magnitude of the spring bloom within offshore Bering Sea waters and no comparisons have been made regarding interannual variability. In light of the rich fisheries of the Bering Sea and their increased and rapid exploitation, this region warrants additional study efforts directed at determining 1) the spatial and temporal variability in primary production, and 2) the trophic relationship between primary production and higher trophic levels.

Arctic Region: Hope Basin, Chukchi Sea, and Beaufort Sea Planning Areas. Within these Planning Areas are found the extremes of primary production in Alaskan waters. Immediately north of the Bering Strait, the intense blooms resulting from the advection of nutrient-rich Anadyr Water leads to estimates of 300 g $C \cdot m^{-2} \cdot yr^{-1}$; several hundred miles to the north in the perennial pack ice, annual production ranges from 1 to 20 g $C \cdot m^{-2} \cdot yr^{-1}$ (Table 60). The presence of pack ice, coupled with the seasonal presence of ice algae, severely limits light penetration into the water column. The stability of the water masses of this region (e.g., the Arctic Surface Layer) also acts to reduce the supply of nutrients to a minimum. In spite of 24-h daylengths, the ice often does not melt in the Chukchi and coastal Beaufort Seas until July, effectively truncating the water column primary productivity season to a few weeks in late summer. Nutrient supplies are often not entirely consumed over the course of the season in the Chukchi Sea. In the coastal Beaufort Sea, low surface salinity levels and a broad continental shelf prevent nutrient re-supply, even in open water areas. Upwelling in the Barter Island area (near the U.S.-Canada border) and turbulent mixing by strong currents near Pt. Barrow contribute to localized increases in primary productivity (i.e., 50 to 100 g $C \cdot m^{-2} \cdot yr^{-1}$).

The difficulties associated with assessing the contribution of ice algae toward annual primary production and providing an appropriate platform from which to conduct oceanographic measurements of pack ice makes this the least studied of the Alaskan marine regions. The primary productivity data base is sparse, most often limited to the narrow band of open water along the coast. Although temporal coverage is adequate for interannual comparisons within the nearshore waters of the Beaufort Sea, similar comparisons cannot be made for the Hope Basin and Chukchi Sea Planning Areas. Future study efforts should be designed and implemented to delineate the temporal variability suggested for this region.

4.2 COASTAL AND MARINE HABITATS

4.2.1 General Comparisons

Table 62 summarizes coastal and marine habitat data from all 26 OCS Planning Areas and compares the estimates developed during the present analysis with those presented in the Proposed Final 5-Year Leasing Program: Mid-1987 to Mid-1992 (USDOI, MMS, 1987a). The information provided in Table 62, which summarizes the more detailed tabular presentations provided for each Planning Area in Sections 3.2.1 through 3.2.26, presents decisionmakers with an array of options for comparisons within and among Planning Areas. As examples, 1) Planning Areas may be ranked by their sensitive coastal habitats (e.g., exposed estuary/wetlands, Estuary Mouth to General Coastline ratios); 2) Planning Areas can be reviewed based on the amount of Coral Reef or Submerged Vegetation they contain; or 3) Planning Areas can be evaluated in terms of Shelf Slope Zone to Total Area.

The marine habitat data developed during the present analysis may also be useful in developing a more comprehensive characterization of productivity within the 26 Planning Areas. This linkage may represent an important next step in the evaluation and ultimate ranking of Planning Areas in terms of relative environmental sensitivity and marine productivity.

It should be recognized that any sensitivity indexing system based on the designated habitats summarized in Table 62 will be biased toward Planning Areas located in the southern latitudes. As an example, it is obvious that more Coral Reefs habitat is present in the Straits of Florida than in the Chukchi Sea. The fact that a specific habitat is limited within a given Planning Area does not render that habitat (or the entire Planning Area) less sensitive to OCS-related events. In fact, the opposite may be true; the limited habitats present in more northerly Planning Areas may assume greater sensitivity simply because of their scarcity or limited latitudinal distribution.

4.2.2 Problems and Limitations

A number of problems and limitations have been encountered in compiling the coastal and marine habitat data presented in Section 3.2 and summarized in Table 62. Technically, there have been problems associated with utilizing data extracted from a variety of map data sets of differing scales and levels of accuracy. All data presented in this study should therefore be treated as estimates which have been based on summaries of research completed to date and existing data.

In evaluating the information presented in Table 62, it is noteworthy that the habitats found along the continental margins of the contiguous U.S. have been documented more thoroughly than those of Alaska; this trend is evident for both 1987 and 1990 analyses. While the results of the present analysis have greatly expanded the coastal and marine habitat estimations for the 15 Alaska Planning Areas, those areas remain less well documented than the 11 Planning Areas of the contiguous U.S.

Table 62. Estimates of linear and areal extent for Coastal and Marine Habitats, respectively. Data for 1987 (standard print) derived from Appendix I (Relative Marine Productivity and Environmental Sensitivity), Proposed Final 5-Year Leasing Program: Mid-1987 to Mid-1992 (USDOI, MMS, 1987a). Data for **1990 (bold print)** derived during the present analysis. Coastal habitat estimates are in kilometers; marine habitat estimates are in hectares.

	Coastal Habitats					Marine Habitats							
	General Coastline 1987 **1990**	Estuary/ Wetland 1987 **1990**	Sand/Gravel Beach 1987 **1990**	Rocky Beach 1987 **1990**	Estuary Mouth to General Coastline **1990 only**	Submerged Vegetation 1987 **1990**	Submarine Canyons 1987 **1990**	Coral Reefs 1987 **1990**	Hard Bottom 1987 **1990**	Shelf Break Zone 1987 only	Shelf Slope Zone **1990 only**	Mud/Sand Bottom 1987 **1990**	Total Area **1990 only**
North Atlantic	697	40	442	214	---	Negligible	522,063	Negligible	*	2,628,931	---	*	---
	685 Mainland **143 Island**	**66**	**475**	**288**	0.320†	**1,708**	**481,188**	**Negligible**	**1,133,565**	---	**1,045,745**	**19,986,110**	**21,121,293**
Mid-Atlantic	994	126	845	24	---	Negligible	242,820	Negligible	Negligible	316,880	---	32,706,640	---
	1,007	**101**	**851**	**55**	**0.131**	**5,882**	**1,679,505**	**Negligible**	*	---	**2,193,069**	*	**33,752,789**
South Atlantic	1,170	516	653	Negligible	---	8,499	30,353	194,661	749,504	1,548,382	---	40,285,862	---
	1,035	**352**	**682**	**Negligible**	**0.100**	**7,389**	**1,189,413**	**Negligible**	**944,165**	---	**14,552,607**	**42,365,511**	**43,317,065**
Straits of Florida	716	434	282	Negligible	---	49,778	Negligible	179,484	*	*	---	*	---
	531	**129**	**402**	**Negligible**	**0.109**	**160,261**	**46,945**	**23,068**	**62,729**	---	**2,573,487**	**4,300,349**	**4,546,400**
Eastern Gulf of Mexico	1,043	557	544	Negligible	---	821,541	Negligible	94,093	4,400,708	*	---	*	---
	1,358	**629**	**729**	**Negligible**	**0.168**	**2,932,081**	**961,972**	**65,289**	**427,134**	---	**4,751,178**	*	**33,218,585**
Central Gulf of Mexico	795	753	42	Negligible	---	28,734	Negligible	Negligible	8,499	694,465	---	17,520,272	---
	1,308	**1,046**	**262**	**Negligible**	**0.090**	**106,064**	**575,079**	**Negligible**	**83,368**	---	**3,863,671**	**19,114,790**	**19,935,927**
Western Gulf of Mexico	591	60	531	Negligible	---	Negligible	Negligible	2,266	21,044	650,353	---	13,612,246	---
	560	**64**	**496**	**Negligible**	**0.054**	**4,662**	**405,105**	**4,414**	**59,896**	---	**7,691,728**	**14,459,931**	**15,610,493**
Southern California	1,144	6	682	455	---	51,968	*	Negligible	*	*	---	*	---
	555 Mainland **408 Island**	**6**	**619**	**338**	0.014†	**11,636**	**483,212**	**Negligible**	**278,029**	---	**4,862,066**	**12,802,280**	**13,091,640**
Central California	500	8	175	317	---	8,499	100,366	34,400	*	*	---	*	---
	397	**8**	**156**	**233**	**0.048**	**3,341**	**755,575**	**Negligible**	**213,019**	---	**906,528**	**6,045,813**	**6,262,328**
Northern California	394	14	203	177	---	2,833	123,434	Negligible	*	*	---	*	---
	446	**45**	**185**	**216**	**0.005**	**35,863**	**75,679**	**Negligible**	**98,342**	---	**1,271,567**	**11,614,890**	**11,748,950**
Washington-Oregon	729	72	138	518	---	*	*	*	*	*	---	*	---
	729	**73**	**139**	**518**	**0.073**	**20,271**	**364,635**	**Negligible**	**217,324**	---	**4,037,287**	**19,499,660**	**19,737,219**
Gulf of Alaska	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	2,545	**1,179**	**774**	**592**	**0.226**	**180,270**	**660,470**	**Negligible**	**1,533,408**	---	**3,881,478**	**52,950,543**	**54,664,043**
Cook Inlet	2,452	346	637	1,469	---	*	Negligible	Negligible	*	*	---	*	---
	1,678 Mainland **278 Island**	**246**	**730**	**980**	**0.111**	**42,583**	**Negligible**	**Negligible**	**204,147**	---	**Negligible**	**2,990,733**	**3,237,600**
Kodiak	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	746	**Negligible**	**287**	**459**	**0.180**	**669,961**	**Negligible**	**Negligible**	**169,165**	---	**3,219,389**	**35,548,443**	**36,387,386**

Table 62. (Continued).

	Coastal Habitats					Marine Habitats							
	General Coastline 1987 1990	Estuary/ Wetland 1987 1990	Sand/Gravel Beach 1987 1990	Rocky Beach 1987 1990	Estuary Mouth to General Coastline 1990 only	Submerged Vegetation 1987 1990	Submarine Canyons 1987 1990	Coral Reefs 1987 1990	Hard Bottom 1987 1990	Shelf Break Zone 1987 only	Shelf Slope Zone 1990 only	Mud/Sand Bottom 1987 1990	Total Area 1990 only
Shumagin	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	1,018 Mainland 853 Island	10	357	1,504	0.139†	936,881	None	None	1,658,865	---	366,127	31,978,989	34,574,735
Aleutian Arc§	2,471 (all Island)	Negligible	370	2,101	0.090	12,363	2,102,804	Negligible	2,661,807	---	16,536,851	63,724,467	66,471,570
North Aleutian Basin	*	*	*	*	---	*	Negligible	Negligible	*	Negligible	---	*	---
	1,319 Mainland 151 Island	584	405	330	0.065†	18,923	Negligible	Negligible	15,094	---	Negligible	13,137,776	13,862,999
St. George Basin	*	*	*	*	---	*	*	None	*	*	---	*	---
	991	Negligible	105	887	0.067	83,773	3,594,141	Negligible	*	---	5,810,683	*	28,888,700
St. Matthew Hall§	711 Mainland 442 Island	494	179	481	0.090†	*	Negligible	Negligible	*	---	Negligible	*	22,492,012
Bowers Basin§	None	None	None	None	None	None	461,358	None	15,783	---	784,713	36,528,627	36,544,410
Aleutian Basin§	None	None	None	None	None	None	1,973,317	None	None	---	338,329	19,182,780	19,182,780
Navarin Basin	None	None	None	None	---	Negligible	*	Negligible	*	*	---	*	---
	None	None	None	None	None	None	2,619,623	Negligible	212,872	---	2,056,281	12,958,089	15,014,370
Norton Basin	2,999	1,002	615	1,382	---	*	Negligible	Negligible	*	*	---	*	---
	1,059 Mainland 537 Island	129	951	516	0.031	88,105	Negligible	Negligible	448,408	---	None	9,669,092	10,888,454
Hope Basin	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	999	100	700	200	0.083	*	Negligible	None	*	---	None	4,700,000	5,257,862
Chukchi Sea	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	543	55	282	206	0.037	*	Negligible	Negligible	*	---	Negligible	11,736,300	12,200,491
Beaufort Sea	*	*	*	*	---	*	*	Negligible	*	*	---	*	---
	706	80	618	8	0.085	3,268	*	Negligible	41,959	---	3,142,496	19,946,854	20,333,342

* Indicates no estimate given.

† Mainland coastline estimate only used to compute Estuary Mouth to General Coastline ratio.

§ Planning Areas not covered under the 1987 document.

Throughout the 11 Planning Areas of the contiguous U.S., the habitat estimates presented in 1987 and 1990 are generally comparable. The minor discrepancies evident in a direct comparison of 1987 versus 1990 data can be attributed to the redrawing of specific Planning Area boundaries, or to the use of slightly different measurement techniques during the present analysis. Where major discrepancies are evident, they have been attributed to the integration of recently acquired data (e.g., new seagrass distribution data from the eastern Gulf of Mexico) or to the redefinition of the specific habitats being estimated. For a number of Planning Areas, the more restrictive definition of Coral Reefs habitat applied in this review has resulted in significant reductions in the estimated areal extent of this habitat, accompanied by an increase in the amount of Hard Bottom habitat present.

For all of the Planning Areas evaluated, the habitats which were the most difficult to estimate were the Hard Bottom and Mud/Sand Bottom categories. It was expected that the majority of each Planning Area would be comprised of a Mud/Sand Bottom habitat. The relative contribution of Hard Bottom estimates (i.e., the extent of rock outcroppings) to Total Area or OCS Area is poorly documented, particularly in submarine canyons and within the Shelf Slope Zone of the various Planning Areas. As indicated in the Planning Area-specific text and tabular summaries presented in Section 3.2, estimates have been provided with caveats, whenever sufficient data were available. In some instances, such estimates could not be justified and the "insufficient data" footnote was employed.

4.2.3 Data Gaps and Suggestions for Future Research

With the onset of modern Geographic Information Systems (GIS) mapping capabilities, mapped data and the ability to manipulate and model data via overlays placed on map bases has become an increasingly important tool in all forms of resource management. One of the major problems encountered during the present analysis was the lack of a specific set of mapping conventions, and mapped data bases, between the various MMS regions. Every attempt has been made in the present analysis to utilize mapped data bases that are both current and consistent across all Planning Areas. Those maps or map sets utilized in the development of specific estimates have been carefully documented, along with the exact measurement techniques used to generate the estimate. One recommendation for future research encompasses the development of a digitized GIS mapping system that would allow overlaying of all of the habitat data compiled during the present analysis on maps of uniform scale. Such a system could easily be updated as new studies are completed and new information becomes available. Even more important than the ease with which updating could be completed using this approach, this uniform mapped habitat data system would allow real time prediction and estimation of environmental impacts from specific OCS incidents or accidents.

The question of primary and secondary productivity within the coastal and marine habitats (as delineated in the present analysis), while beyond the scope of the present study, remains a critical one. It is suggested that the next logical step is to utilize the same procedures applied to standardize primary productivity (i.e., within the water column) of the various Planning Areas to the designated coastal and marine communities evaluated in the present analysis.

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Wroblewski, J. S. and J. G. Richman. 1987. The non-linear response of plankton to wind mixing events - implications for survival of larval northern anchovy. J. Plank. Res. 9(1):103-123.

Yoder, J. A. 1985. Environmental control of phytoplankton production on the southeastern U.S. continental shelf, Chap. 7, pp. 93-103. In L. P. Atkinson, D. W. Menzel, and K. A. Bush (eds.), Oceanography of the Southeastern United States Continental Shelf, Coastal and Estuarine Sciences 2, Am. Geophys. Union, Washington, DC.

Yoder, J. A. and T. Ishimaru. 1989. Phytoplankton advection off the southeastern United States continental shelf. Cont. Shelf Res. 9:547-553.

Yoder, J. A. and A. Mahood. 1983. Primary production in Loop Current upwelling. In Woodward Clyde Consultants/Skidaway Institute of Oceanography Southwest Florida Shelf Ecosystem Study, Year 2 Modification, 219-278. A final report for the U.S. Department of the Interior, Minerals Management Service, OCS Study MMS Contract No. 14-12-0001-29144. New Orleans, LA.

Yoder, J. A., L. P. Atkinson, T. N. Lee, H. H. Kim, and C. R. McClain. 1981. Role of Gulf Stream frontal eddies in forming phytoplankton patches on the outer southeastern shelf. Limnol. Oceanogr. 26:1103-1110.

Yoder, J. A., L. P. Atkinson, S. S. Bishop, E. E. Hofmann, and T. N. Lee. 1983. Effect of upwelling on phytoplankton productivity of the outer southeastern United States continental shelf. Cont. Shelf Res. 1:385-404.

Yoder, J. A., L. P. Atkinson, S. S. Bishop, J. O. Blanton, T. N. Lee, and L. J. Pietrafesa. 1985. Phytoplankton dynamics within Gulf Stream intrusions on the southeastern United States continental shelf during summer 1981. Cont. Shelf Res. 4:611-635.

Zieman, J. C. 1982. The ecology of seagrasses of south Florida: A community profile. National Coastal Ecosystem Team, U.S. Department of the Interior, Washington, DC. FWS/OBS-82/85. 123 pp.

Zieman, J. C. 1989. The ecology of the seagrass meadows of the west coast of Florida: A community profile. U.S. Fish and Wildlife Service, National Wetlands Research Center, Slidell, LA. Biological Rept. 85 (7.25). 156 pp.

Zimmerman, S. T., J. L. Hanson, J. T. Fujioka, N. I. Calvin, J. A. Gharrett and J. S. MacKinnon. 1978. Intertidal biota and subtidal kelp communities of the Kodiak Island area. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Biological Studies 4:316-508.

Zimmerman, S. T. (ed.). 1982. The Norton Sound environment and possible consequences of planned offshore oil and gas development. Proceedings of a synthesis meeting, 28-30 Oct, Anchorage, AK. 55 pp.

APPENDICES

APPENDIX A
ANNOTATED BIBLIOGRAPHY:
PRIMARY PRODUCTIVITY

APPENDIX A
ANNOTATED BIBLIOGRAPHY: PRIMARY PRODUCTIVITY

The citations and accompanying annotations found within the following annotated bibliography have been organized by region to facilitate reader access to the primary data sources employed in the Planning Area-specific primary productivity analyses presented in Section 2.2. The five subsections include 1) Atlantic; 2) Straits of Florida and Gulf of Mexico; 3) California; 4) Washington-Oregon; and 5) Alaska.

The inclusion of citations within this annotated bibliography was based solely on author selection. As outlined in Section 2.1, all potentially applicable sources of water column primary productivity data were initially identified and reviewed, being drawn from 1) a computerized search of peer-reviewed journals, dissertations, and government publications identified using the Lockheed DIALOG Information Retrieval Service; 2) a review of unpublished data sources (e.g., unpublished cruise reports and/or data reports) conducted by each author, including academic and personal libraries; and 3) a review of the annotated bibliography compiled by UMES (1985). This appendix contains citations drawn from all three sources and, based on the evaluations of the primary productivity authors, represents the best data sources currently available to characterize primary productivity in the 26 OCS Planning Areas. Citations which provided direct measurements of water column primary productivity using acceptable methodology and applicable to one or more of the 26 OCS Planning Areas were of primary interest and have been incorporated into Appendix A; sources which allowed an author to summarize the physical processes which affect primary production have also been included. Under certain limited circumstances (i.e., in the absence of any source of direct measurement(s) of primary production), authors selected, annotated, and incorporated into Appendix A any secondary or corollary sources of information which were deemed adequate to establish relative levels of water column primary productivity.

The annotations contained within Appendix A have been developed to provide the reader with 1) a complete citation of the primary data sources used in this analysis; and 2) a summary (or abstract) of the major findings evident from a particular research effort. Individual annotations of newly identified data sources [i.e., post-1985 citations; citations not identified by UMES (1985)] present a summary of the major findings contained within that data source. In the case of salient citations previously identified within the UMES (1985) annotated bibliography, the annotations contained within this appendix (Appendix A) have been rewritten yet still reflect the study's major findings. In the case of unpublished cruise or data reports, the annotation has been prepared to identify the scope and duration of survey efforts and to summarize the nature of the survey data. In an extremely limited number of cases, author review of a complete document was not possible; the citation (without an accompanying annotation) has been included, however, because the data source was deemed significant based on recommendations from the author.

ATLANTIC REGION

Atkinson, L. P., T. N. Lee, J. O. Blanton, and G. A. Paffenhöfer. 1987. Summer upwelling on the southeastern continental shelf of the U.S.A. during 1981. Hydrographic observations. Prog. Oceanogr. 19:231-266.

Based on nitrogen advected onshore during upwelling intrusions, seasonal carbon production of 16-20 g C/m^2 is estimated on southeastern continental shelf. Direct measurements of primary production yield a seasonal level of 150 g C/m^2. Authors state that discrepancy of low calculated production resulted from their assumption that nitrogen fluxes evenly introduced over 12,500 km^2 area and they estimated "new production" only. The direct measurement of 150 g C/m^2 includes all primary production.

Atkinson, L. P., L. J. Pietrafesa, and E. E. Hofmann. 1982. An evaluation of nutrient sources to Onslow Bay, North Carolina. J. Mar. Res. 40:679-699.

Upwelled Gulf Stream water is a major source of nutrients for primary production, while rivers are a minor, if not insignificant nutrient source. The 1971 summer NO_3 flux of 2.0 $\mu M \cdot m^{-2} \cdot s^{-1}$ is considerably less than that estimated for the Georgia shelf or Scotia shelf.

Atkinson, L. P., J. A. Yoder, and T. N. Lee. 1984. Review of upwelling off the southeastern United States and its effect on continental-shelf nutrient concentrations and primary productivity. Rapp. P.-v. Réun. Cons. Int. Explor. Mer. 183:70-78.

Gulf Stream induced upwelling occurs along the length of the southeastern United States continental shelf break. Upwelling events are produced by northward propagating Gulf Stream frontal meanders and eddies and travel northwards with these features. Meanders and eddies occur throughout the year in a period band of 2-14 d; however, resultant upwellings can affect the shelf quite differently. During fall, winter, and spring, upwelling is restricted to the outer shelf by cross-shelf density distributions, but in the summer upwelled water may penetrate across as a subsurface intrusion if aided by upwelling-favorable winds. If water does penetrate across the shelf, it may become stranded, detached from its deep-water Gulf Stream source, and may reside on the shelf for many weeks. The mass of nitrate within stranded water masses has been observed to be over 2,500 metric tonnes nitrate-nitrogen covering an area of 2,500 km^2. Gulf Stream upwelling-induced nutrient inputs dominate all other sources to the South Atlantic Bight and have a profound effect on phytoplankton production. During the fall, winter, and spring, high phytoplankton coincides with outer shelf upwelling, while in the summer production also occurs in the lower layer over the inner and middle shelf. Upwelling in the Gulf Stream frontal disturbances occurs roughly 50% of the time on the outer shelf during November - April (shelf not stratified), leading to the

estimate that seasonal primary production in these upwelled waters is 175 g C/m^2 per 6 mo, of which at least 50% is "new" production. More than 90% of production occurs during upwelling at the outer shelf. Thus Gulf Stream induced upwelling is the dominant process affecting primary productivity of the outer shelf. Our seasonal estimates of outer shelf plant production are, respectively, two and ten times higher than previous estimates that did not account for upwelling by Gulf Stream disturbances.

Bishop, J. K. B., M. H. Conte, P. H. Wiebe, M. R. Roman, and C. Langdon. 1986. Particulate matter production and consumption in deep mixed layers: Observations in a warm-core ring. Deep-Sea Res. 33:1813-1841.

Particulate matter variability in the core waters of WCR 82B between February and late June, 1982 is described. Observations demonstrate that the coupling of physical, biological and chemical processes in the upper ocean occurs on time scales as short as 10 d, and that particulate matter is a sensitive indicator of the balance between production and removal processes in the upper 1,000 m. The data suggest that zooplankton consumption is the dominant loss mechanism for phytoplankton C, and the imbalance between production and removal in the euphotic zone during stratification leads to development of the spring phytoplankton bloom.

Bourne, D. W. and C. S. Yentsch. 1987. Phytoplankton, primary production, and microbiology, pp. 210-212. In R. H. Backus and D. W. Bourne (eds.), Georges Bank. MIT Press, Cambridge, MA.

Annual cycle of primary production over deepest parts of Georges Bank differs markedly from chlorophyll biomass cycle. Although chlorophyll levels are lowest during summer, about 30 to 50% of spring and autumn levels, production rates are comparable to the latter seasons. This may reflect a higher production per unit chlorophyll due to increased solar irradiance or higher physiological efficiency of the summer nanophytoplankton communities. Annual nitrogen requirements are about 80 g/m^2 on Georges Bank and 60 g/m^2 in New York Bight, with zooplankton excretion contributing about 10% of the annual N requirement in both regions; the bottom fauna 7 and 14%, and microbial remineralization 9 and 3%, respectively. Greater annual primary production on Georges Bank shoals partly attributed to inputs from summer, slope-water nitrate intrusions and year-round vertical mixing of recycled ammonium in contrast to intense summer and autumn stratification within New York Bight.

Brown, O. B., R. H. Evans, J. W. Brown, H. R. Gordon, R. C. Smith, and K. S. Baker. 1985. Phytoplankton blooming off the U.S. East Coast: A satellite description. Science 229:163-167.

A "bloom" of near-surface phytoplankton occurs in the Atlantic Slope region of the western Atlantic Ocean off the U.S. East Coast in the spring. Satellite time series of sea-surface temperature and phytoplankton pigment concentrations were derived from NOAA-7 Advanced Very-High-Resolution Radiometer and NASA Nimbus-7 Coastal Zone Color Scanner, respectively, during a 28-d period in April through May, 1982. The phytoplankton concentration of the slope water was comparable to that of the Atlantic Shelf. Total primary productivity of the slope during this period was equivalent to that of the shelf. The primary productivity within a warm-core ring and in the Gulf Stream system is less by a factor of two.

Brzezinski, M. A. and D. M. Nelson. 1989. Seasonal changes in the silicon cycle within a Gulf Stream warm core ring. Deep-Sea Res. 36:1009-1030.

The silicon cycle within Gulf Stream warm-core ring 82-B was examined before and after spring stratification using silicon isotope tracers. In April, prior to stratification, the ring was isothermal and isohaline to 400 m. Ambient silicic acid concentrations were approximately 3 μmol/l and biogenic silica concentrations ranged from 80 to 100 μmol/l throughout this depth range. Specific production rates tended to be greatest at the surface and were vertically uniform below 20 m. Net silica production occurred from the surface to 300 m on 25 April, about three times deeper than has been observed before in the sea. The zone of net production shoaled to <150 m by 4 May. These depths were 2 to >4 times the 1% light depth, indicating that the diatom assemblage was producing substantial amounts of silica at depths where little or no photosynthesis was taking place. By June, a seasonal pycnocline had developed; silicic acid concentrations were depleted to <0.2 μmol/l in the upper 20-30 m and vertically integrated particulate silica concentrations in the upper 80 m had increased four-fold compared to those for the upper 110 m in April/May. The upper 80 m was a zone of net silica production, but net dissolution occurred at all depths >100 m. The average specific production rate of biogenic silica was five times less than observed during April/May. The percentage of silica production that could be supported by *in situ* dissolution increased from <30% for the upper 110 m during April/May to 68% for the upper 80 m in June. This transition from a "new production" cycle to a "regenerated production" cycle is the first observation of a seasonal trend in the silicon cycle in the surface ocean.

Cohen, E. B. and M. D. Grosslein. 1987. Production on Georges Bank compared with other shelf ecosystems, pp. 383-391. In R. H. Backus and D. W. Bourne (eds.), Georges Bank. MIT Press, Cambridge, MA.

The authors revised their previous annual total primary production estimate, (based on ^{14}C technique) for Georges Bank downwards from 400 to 500 g $C \cdot m^{-2} \cdot yr^{-1}$ to about 350 g $C \cdot m^{-2} \cdot yr^{-1}$. This annual rate includes dissolved organic production, estimated to be about 16% of total. The annual rate is comparable to Riley's (1941) estimate of 200-300 g $C \cdot m^{-2} \cdot yr^{-1}$ based on oxygen technique. Expressed as kcal/m^2, where 1 gm C = 11.4 kcal, Georges Bank annual production of 3,342 kcal/m^2 slightly exceeds that (3,103 $kcal \cdot m^{-2} \cdot yr^{-1}$) for Middle Atlantic Bight and is about 30 to 40% greater than Gulf of Maine and Scotian Shelf annual rates. Macrozooplankton:phytoplankton production ratios show Georges Bank to be intermediate (6%) between the Middle Atlantic Bight (4%) and Gulf of Maine/Scotian Shelf (8%). The estimated production potential (MSY) of fish and squid relative to phytoplankton production (0.28%) shows Georges Bank to be twice as efficient as the Middle Atlantic Bight and Gulf of Maine and similar to the North Sea (0.24%) transfer efficiency.

Cohen, E. B., M. D. Grosslein, M. P. Sissenwine, F. Steimle, and W. R. Wright. 1982. An energy budget for Georges Bank. Can. Spec. Publ. Fish. Aquat. Sci. 59:95-107.

From ^{14}C measurements made on 11 cruises during 1975-1978, authors concluded that Georges Bank annual primary production is higher than previously believed: 400-500 g $C \cdot m^{-2} \cdot yr^{-1}$. Data indicated a consistent annual cycle beginning with the spring bloom, with production peaking in late summer or early autumn before declining to a winter low. This cycle is a distinct departure from a classic spring bloom - autumn bloom with low productivity during both summer and winter. High summer productivity is probably due to a continuous supply of nutrient with water available from the Gulf of Maine and slope water that is advected onto Georges Bank by tidal mixing. The shallowness of Georges Bank, coupled with wind and tidal mixing, also allows a constant supply of regenerated nutrients from the water column and the benthos to reach phytoplankton in the euphotic zone.

Colton, Jr., J. B., J. L. Anderson, J. E. O'Reilly, C. A. Evans-Zetlin, and H. G. Marshall. 1985. The shelf/slope front south of Nantucket Shoals and Georges Bank as delineated by satellite infrared imagery and shipboard hydrographic and plankton observations. NOAA Tech. Mem. NMFS-F/NEC-38. NTIS Access. No. PB85-221083/AS.

No annotation. Document unavailable.

Cowles, T. J., M. R. Roman, A. L. Gauzens, and N. J. Copley. 1987. Short-term changes in the biology of a zooplankton biomass grazing. Limnol. Oceanogr. 32:653-664.

Gale force winds in September 1981 deepened the mixed layer and introduced nutrients to the surface waters of Gulf Stream warm-core ring 81D. Phytoplankton nitrate uptake rates, primary productivity, and chlorophyll a in the mixed layer of ring 81D increased after the mixing event. Data on zooplankton biomass, numbers of naupliar and copepodite stages of copepods, zooplankton grazing rates inside the ring, and measurements of high egg production rates by ring copepod species suggest that enhanced phytoplankton production and biomass in ring 81D were utilized by the ring zooplankton.

Cox, J. L., P. H. Wiebe, P. Ortner, and S. Boyd. 1982. Seasonal development of subsurface chlorophyll maxima in slope water and northern Sargasso Sea of the northwestern Atlantic Ocean. Biol. Oceanogr. 1:271-285.

Seasonal trends in the vertical distribution of chlorophyll a in slope water west of 60°N longitude and seaward of the 200-m isobath off the shelf of the Middle Atlantic Bight were analyzed from published and unpublished sources. A seasonal submergence of the chlorophyll maximum and the formation of a summer to early fall deep chlorophyll maximum (DCM) are evident. Mechanisms of formation of the DCM appear to differ from those in the Sargasso Sea, as evidenced by differences in the degree of light penetration at the maximum, timing of DCM formation, abundance of chlorophyll, temperature at the chlorophyll maximum, and relationships between DCM parameters. Correlations between these parameters (DCM depth, DCM chlorophyll concentration, integral chlorophyll, nitracline depth, nitrite maximum depth, pycnocline depth) are generally high for data from both regions combined and in slope water alone.

Emerson, C. W., J. C. Roff, and D. J. Wildish. 1986. Pelagic-benthic energy coupling at the mouth of the Bay of Fundy. Ophelia. 26:165-180.

Annual primary production rate was 130 g $C \cdot m^{-2} \cdot yr^{-1}$, which compares with the rate of about 300 g $C \cdot m^{-2} \cdot yr^{-1}$ in adjacent waters (= Gulf of Maine). Of this, about 60% was attributable to nanoplankton <20 µm.

Falkowski, P. G., T. S. Hopkins, and J. J. Walsh. 1980. An analysis of factors affecting oxygen depletion in the New York Bight. J. Mar. Res. 38:479-506.

A $60 million loss of shellfish resulting from anoxia along the New Jersey coast accompanying a bloom of the dinoflagellate *Ceratium tripos* could have occurred. Calculations suggest that this bloom occurred without any carbon loading from anthropogenic sources and resulted from natural physical forcing and biological response.

Fornshell, J. A., D. D. Frydenlund, and P. D. Christensen. 1984. Winter distribution of four species of the genus *Ceratium* from Cape Canaveral, Florida to Cape Henlopen, Delaware. J. Plankton Res. 6:15-27.

Based on a survey in February 1976, two distinct assemblages of the dinoflagellate genus *Ceratium* were found, with Cape Hatteras forming the boundary between the northern element (*Ceratium tripos* and *C. macroceros*) and southern element (*C. trichoceros* and *C. massiliense*). A toxic red-tide bloom of *C. tripos* was recorded in the New York in summer 1976. This survey greatly extends the southern limits of this species during 1976. The potential effect of nutrients and physical processes on the distribution of *Ceratium* is discussed. The distribution pattern was in good agreement with high resolution infrared satellite imagery of the Gulf Stream position off Cape Hatteras.

Fournier, R. O., J. Marra, R. Bohrer, and M. Van Det. 1977. Plankton dynamics and nutrient enrichment of the Scotian Shelf. J. Fish. Res. Bd. Canada 34:1004-1018.

Four cruises along a 270-km transect off Nova Scotia demonstrated a persistent oceanic front in which enhanced vertical transport of nutrients occurred. This advection of nutrient is estimated to provide 20% of that needed for primary production during spring and summer, with recycling accounting for the remaining 80%.

Franks, P. J. S., J.S. Wroblewski, and G. R. Flierl. 1986. Prediction of phytoplankton growth in response to frictional decay of a warm-core ring. J. Geophys. Res. 91:7603-7610.

A model was developed to quantify the processes governing phytoplankton production in a warm-core ring 82B. The model generated a lens of high phytoplankton biomass at ring center in response to advection of nutrients into the euphotic zone. This is consistent with field observations. The model predicts that this increased biomass and production takes place through relaxation of the ring's rate of rotation, which causes upward motion of nutrient-rich water at ring center.

Fryxell, G. A., R. W. J. Gould, E. R. Balmori, and E. C. Theriot. 1985. Gulf Stream warm core rings: Phytoplankton in two fall rings of different ages. J. Plankton Res. 7:339-364.

Warm core ring (WCR) 82-H sampled in September - October 1982 is compared with the 3-mo-old WCR 81-D visited in September - October 1981. Although the rings have different histories, their phytoplankton assemblages share some characteristics. Using cluster analyses, a station from one of the younger rings at the time of sampling, WCR 82-H, had lower diversity, fewer shelf species, and greater consistency between stations, except for a high level of the nitrogen-fixing Oscillatoria. Interaction with slope water was seen principally at the ring margin. WCR 81-D showed a great deal of structure, and immediate dilutions with slope water and the Gulf Stream were apparent, with higher diversity before and a week after such interactions. The upper water column of warm core rings, although showing evidence of physical mixing, can exhibit stratification of species, even after a storm.

Glover, H. E., A. E. Smith, and L. Shapiro. 1985. Diurnal variations in photosynthetic rates: Comparisons of ultraphytoplankton with a larger phytoplankton size fraction. J. Plank. Res. 7(4):519-535.

The composition and photosynthetic activity of two size fractions of phytoplankton was compared during a cruise from the Gulf of Maine to the Sargasso Sea in August 1983. At every station, and at every depth, ultraplankton (defined here as cells passing through 3 µm pores in filters) made a major contribution to both the standing crop of chlorophyll and the rate of primary production. Ultraphytoplankton assemblages were dominated by phycoerythrin-rich cyanobacteria. Overall, the ultraplankton contribution to total primary production was greatest at low photon fluxes. Surface (2 m) ultraphytoplankton assemblages were almost exclusively composed of phycoerythrin-rich cyanobacteria with smaller (0.2 to 0.8 µm) cyanobacteria predominating. Below the surface mixed-layer, the proportion of larger (0.8 to 3.0 µm) to smaller cyanobacteria increased, and the eukaryotic component of the ultraphytoplankton often became important. At two Sargasso Sea stations, the greatest numbers of cyanobacteria were below the mixed layer at the 1% light level, while the maximum numbers of eukaryotic ultraphytoplankters occurred deeper still, at the 0.5% light level, coincident with the chlorophyll maximum. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Glover, H. E., L. Campbell, and B. Prézelin. 1986. Contribution of *Synechococcus* spp. to size-fractioned primary productivity in three water masses in the Northwest Atlantic Ocean. Mar. Biol. 91(2):193-204.

At the neritic front, the larger photoautotrophs of the 1 to 5 µm and >5 µm fractions are the major contributors to chlorophyll concentrations and primary production. *Synechococcus* spp. accounted for only 6% of the dawn-to-dusk *in situ* primary production at the neritic front. In modified Sargasso water in the warm-core eddy, *Synechococcus* spp. contributed 25% of the *in situ* rate of integrated primary production, and the 0.2 to 0.6 µm fraction made a major contribution to the standing crop of chlorophyll and primary production that equalled or exceeded that of the large-size categories. At the bottom of the euphotic layer, eukaryotes numerically dominated the 0.2 to 0.6 μm fraction, which contributed 61% of the primary productivity. At Wilkinson's Basin, the *Synechococcus* spp.-dominated 0.6 to 1.0 μm fraction made the greatest contribution to the chlorophyll standing crop and primary production. Largest numbers (2.9 x 10^8 cells/l) occurred at the 18% isolume, the site of maximum *in situ* primary productivity. At Wilkinson's Basin, *Synechococcus* spp. contributed 46% to the *in situ* photosynthesis integrated over the water-column.

Goldman, J. G. and M. Dennett. 1985. Susceptibility of some marine phytoplankton species to cell breakage during filtration and post-filtration rinsing. J. Exp. Mar. Biol. Ecol. 86:47-58.

Several fragile phytoplankton species among a diverse group of 13 species were found to be very susceptible to cell breakage when exposed to the air under vacuum between the filtration and rinsing steps used to terminate ^{14}C fixation experiments and remove residual [^{14}C]HCO_3^-. Up to 60% of fixed carbon after 15-min incubation was in the rinse. Osmotic shock probably explains results, although unaccountable losses of ^{14}C occurred with polycarbonate filters resistant to glass-fiber filters. Vacuum pressure differentials >25-100 mg Hg across polycarbonate filters also caused cell breakage leading to accumulation of ^{14}C in the filtrate. Avoiding air exposure of the filter between filtration and rinsing steps or eliminating the rinsing step entirely and acid-soaking or fuming the filters led to virtually complete recovery of fixed carbon.

Gould, R. W. J. 1988. Net phytoplankton in a Gulf Stream warm-core ring: Species composition, relative abundance, and the chlorophyll maximum layer. Deep-Sea Res. 35:1595-1614.

Gulf Stream warm-core ring (WCR) 82B and surrounding waters (Sargasso Sea, Slope Water) sampled during three cruises from April to August 1982, assessed changes in the species composition and relative abundance of the large, rare net-phytoplankton. Analysis of net samples indicated that major changes in dinoflagellate species composition occurred between the April and June cruises. Centric diatom species composition and relative abundance were stable over cruise-length time periods (three weeks) in April and June but varied greatly in the 1.5-mo interval between cruises. Between April and June, the dominant centric diatom species changed dramatically, although the overall species assemblages remained similar. The opposite occurred between the June and August cruises: species assemblages showed large changes, unlike the abundant diatoms. Based on the species composition and relative abundance of centric diatoms, the chlorophyll maximum layers exhibited a greater similarity to surface layers at the same station than to chlorophyll maximum layers at other locations. This is consistent with the hypothesis that the chlorophyll maximum forms as a result of cells sinking from the surface, rather than each layer being composed of distinct, separate species assemblages.

Gould, R. W. J., E. R. Balmori, and G. A. Fryxell. 1986. Multivariate statistics applied to phytoplankton data from two Gulf Stream warm core rings. Limnol. Oceanogr. 31:951-968.

Multivariate statistical techniques were used on data from two cruises (1981, 1982) to Gulf Stream warm core rings to reveal patterns and relationships between phytoplankton species abundance and environmental parameters. Principal component analysis (PCA) performed for each cruise and on the combined data delineated groups of stations, depths, and species. A ring center station with high numbers of diatoms and a Slope Water station formed separate groups. Strong similarities characterized phytoplankton abundance and species composition between fall samples from the two rings. Simple correlations, multiple regressions, and canonical correlations performed with the phytoplankton log abundance data and the environmental data suggest that high numbers of dinoflagellates and other algae are associated with lower salinity in the Slope Water and at the ring edge, and that higher temperatures and low values of silica (dissolved) are reflected in higher numbers of diatoms and coccolithophorids at ring center.

Hanson, R. B. 1987. Nutrient recycling on the southeastern US continental shelf: Progress report 1 August 1987. Department of Energy. Rept. No. DOE/ER/60311-3. 44 pp.

A major conclusion from the SPREX nitrogen recycling experiments is that NH_4^+ regeneration could support 29 to 127% of the measured primary production; however, only 50% of the NH_4^+ was biologically and chemically accounted for and the remainder was lost ("vanishing nitrogen" paradox). NH_4^+ assimilation was 10 to 20% of measured photosynthesis. The results suggest alternative sources of nitrogen are required to meet the nitrogen demand of the coastal phytoplankton and sinks of nitrogen (NH_4^+) during SPREX.

Hargrave, B. T. 1984. Barrage effects on phytoplankton production and chemosynthesis in Cumberland Basin. Can. Tech. Rep. Fish. Aquat. Sci. No. 1256:439-448.

Tidal power development in the upper reaches of the Bay of Fundy requires holding water behind a tidal barrage. For the Cumberland Basin, the areal increase of water behind the barrier would be 30%. It is estimated that phytoplankton primary production would increase by about 50% from about 9 to 14 mg $C \cdot m^{-3} \cdot h^{-1}$, or from 708 to 1,098 tons/h for the entire basin.

Hitchcock, G. L. 1986. Methodological aspects of time-course measurements of ^{14}C fixation in marine phytoplankton. J. Exp. Mar. Biol. Ecol. 95:233-243.

Time course measurements of H^{14}CO fixation in three regions of the northwestern Atlantic (two warm core rings and the Sargasso Sea) indicated that carbon uptake was linear for at least 4-6 h. The distribution of ^{14}C among various soluble and particulate fractions of labelled natural phytoplankton populations showed that an "equilibrium" was achieved among the various fractions after 1 to 2 h of incubation.

Hitchcock, G. L., C. Langdon, and T. J. Smayda. 1985. Seasonal variations in the phytoplankton biomass and productivity of a warm-core Gulf Stream ring. Deep-Sea Res. 32:1287-1300.

Phytoplankton biomass, as chlorophyll a and ATP, and carbon productivity rates were determined in three cruises to a warm-core Gulf Stream ring. Ring 82B was formed in late February 1982; observations made in April to May showed little vertical structure during a period when the ring mixed layer extended from the surface to >350 m. Daily productivity rates, chlorophyll a, and ATP biomass estimates of the euphotic zone were similar to those in the source waters, the Sargasso Sea, but lower than those in contiguous Slope Waters. Despite the absence of a stratified surface layer in the ring, the phytoplankton productivity rates, assimilation numbers, and carbon-specific growth rates were relatively high. In June, a pycnocline existed at 25 m across the ring with biomass maxima of chlorophyll a, ATP, and POC occurring near the seasonal pycnocline. Although the range in productivity in June (0.26 to 0.98 g $C \cdot m^{-2} \cdot d^{-1}$) was similar to that in April, the carbon biomass estimated from ATP increased from 1.42 to 4.77 g C/m^2 between the two cruises. The increase was partially attributed to an increased heterotrophic biomass. Carbon-specific doubling times in June were, most likely, influenced by the presence of a large heterotrophic ATP component. In August, the surface layer of the ring was displaced by intrusions, or overwash, of Slope and Gulf Stream waters. During the 6-mo lifespan of 82B, total primary production was estimated at 126 g C/m^2, a value similar to productivity estimates for the contiguous Slope waters.

Hitchcock, G. L., C. Langdon, and T. J. Smayda. 1987. Short-term changes in the biology of a Gulf Stream warm-core ring: Phytoplankton biomass and productivity. Limnol. Oceanogr. 32:919-928.

Temporal changes in chlorophyll a and primary production were followed in a Gulf Stream warm-core ring as it underwent an interaction with the Gulf Stream and a subsequent wind event. As the physical events altered the structure of the mixed layer, chlorophyll a within the euphotic zone increased from about 10 to 42 mg/m^2 while productivity rates increased from 140 to

$>2,400$ mg $C \cdot m^{-2} \cdot d^{-1}$. Carbon-specific growth rates in Ring 81-D derived from ATP-C biomass and ^{14}C productivity rates increased five-fold. Nanoplankton (<20 μm) initially accounted for nearly 90% of the total chlorophyll a biomass in ring surface waters, although there was a subsurface maximum of net-plankton chlorophyll a near the base of the euphotic zone before the wind event. After the wind event, chlorophyll a was uniformly distributed throughout the mixed layer and net plankton accounted for an increased proportion of total chlorophyll a standing stock and productivity. In the peripheral high velocity region and the surrounding Slope Water, phytoplankton standing stocks and productivity rates were less than the maximum values found at ring center. Observations indicate that phytoplankton standing stock and productivity within a warm-core ring can increase rapidly in response to physical processes on the event time scale.

Hopkinson, C. S. J. 1987. Nutrient regeneration in shallow-water sediments of the estuarine plume region of the nearshore Georgia Bight, U.S.A. Mar. Biol. 94:127-142.

Benthic community respiration and cycling of N and P were investigated in the sandy sediments of the nearshore zone of the Georgia Bight during 1981-1982. Fluxes of N and P from the sediments ranged from 3 to 34% (mean = 11%) of the primary production needs for N and from 6 to 93% (mean = 40%) for the P needs. During the summer much of the phytoplankton P demand could be met by sediment PO_4^{3-} release; water column regeneration of P was more important during colder periods. Sedimentary flux of N as a source of phytoplankton requirements was generally low throughout the year.

Iselin, C. O. 1939. Some physical factors which may influence the productivity of New England's coastal waters. J. Mar. Res. 2:75-85.

The authors hypothesized that because of tidal stirring, nutrients in continuous supply to the euphotic zone are responsible for the great fertility of Georges Bank, and this physical mechanism must be considered along with purely biological factors regulating productivity.

Jones, R. 1984. Some observations on energy transfer through the North Sea and Georges Bank food webs. Rapp. P.-v. Réun. Cons. Int. Explor. Mer. 183:204-217.

The author concludes that there is insufficient primary production on Georges Bank, despite its high productivity, to satisfy fish food requirements if a 10% energy efficiency transfer coefficient between trophic levels is assumed. Analyses suggest that the problem may not lie with an underestimation of primary productivity levels. It is suggested that trophic transfer efficiency of 10% may be in error, and should be increased to 15 to 20%.

Joyce, T., R. Backus, K. Baker, P. Blackwelder, O. Brown, T. Cowles, R. Evans, G. Fryxell, D. Mountain, D. Olson, R. Schlitz, R. Schmitt, P. Smith, R. Smith, and P. Wiebe. 1983. Rapid evolution of a Gulf Stream warm core ring. Nature, London. 308:837-840.

The physical and biological features of warm core ring 81-D examined in the latter half of September 1981 reveal that major alterations to ring structure can occur during short periods (2-5 d) when interaction with the Gulf Stream is particularly intense. The initial physical, chemical, and biological properties of the core of the 100-200 km eddies are often similar to those of its parent watermass, the Sargasso Sea. The September time series of ring 81-D revealed that phytoplankton biomass (as chlorophyll) increased 10-fold over a 20-d period; coccolithophorid abundance increased 100-fold during the same period. Parallel increases were not found within the Gulf Stream, Sargasso Sea, or Slope Water.

Joyce, T. and P. Wiebe. 1983. Warm core rings in the Gulf Stream. Oceanus. 26:34-44.

A five-year summary of warm core rings progression in Slope Water during 1976-1980 is given. Rings are generated all along the northern edge of the Gulf Stream and drift slowly southwest at rates 3 to 5 km/d. Rings have a mean lifetime of 4.5 mo before being reabsorbed by the Gulf Stream. Chlorophyll and primary production levels within the rings' centers exceed those in the surrounding slope water.

King, F. D., T. L. Cucci, and D. W. Townsend. 1987. Microzooplankton and macrozooplankton glutamate dehydrogenase as indices of the relative contribution of these fractions to ammonium regeneration in the Gulf of Maine. J. Plank. Res. 9(2):277-289.

Ammonium regeneration by micro- (35 to 153 μm) and macrozooplankton (>153 μm) was determined in the Gulf of Maine by measuring the activity of the excretory enzyme glutamate dehydrogenase (GDH) in various size fractions. GDH maxima were generally observed to correspond to the depth of the chlorophyll maximum as previously reported in the Gulf of Mexico and in the vicinity of the Nantucket Shoals. GDH activity of the microzooplankton was considerably lower than the macrozooplankton, suggesting the microzooplankton made only a minor contribution (1 to 11%) to the total ammonium regenerated. Ammonium excretion by both zooplankton fractions was estimated to supply 5 to 31% of the nitrogen requirements for primary production. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Klein, P. 1986. Role of thermal fronts on Georges Bank primary production, pp. 141-152. In J. C. C. Nihoul (ed.), Marine Interfaces Ecohydrodynamics, Elsevier Oceanography Series, Amsterdam.

A physical-biological model was developed to simulate the seasonal cycle of the nitrogen budget and associated plankton dynamics. Thermal fronts developing around the bank during the spring and their disappearance during the fall initiate the transitions between the winter and summer growth periods. Two seasonally distinct nutrient input mechanisms are present: Georges Bank functions as a "chemostat" during winter, whereas nutrient recycling dominates the summer period.

Krupatkina, D. K., A. S. Lopukhin, and G. Yu. 1987. Size distribution of phytoplankton of the tropical Atlantic and its effect on evaluation of the primary production and chlorophyll a in waters of different trophicity. Okeanologiya 27(3):470-474.

This paper, in Russian, evaluates phytoplankton size distribution in the tropical Atlantic Ocean. The trophic status of various phytoplankton are determined.

Lewis, M. R. and J. C. Smith. 1983. A small volume, short-incubation-time method for measurement of photosynthesis as a function of incident irradiance. Mar. Ecol. Prog. Ser. 13:99-102.

A method is presented to allow determination of algal photosynthetic rate as a function of incident irradiance. The method uses small volumes (1 ml), short incubation times (20 min), and provides sufficient replication (n = 36) for objective analyses. This methodology can be used with natural populations, with more isotope provided when lower phytoplankton densities are present.

Malone, T. C. 1976. Phytoplankton productivity in the apex of the New York Bight, September 1973 - August 1974. NOAA Tech. Mem. ERL-MESA-5. Boulder, CO. 100 pp.

No annotation. Document unavailable.

Malone, T. C. 1982. Factors influencing the fate of sewage derived nutrients in the lower Hudson Estuary and New York Bight, pp. 389-400. In G. Mayer (ed.), Ecological Stress in the New York Bight: Science and Management. Estuarine Research Federation, Columbia, SC.

The lower Hudson River estuary receives large quantities of sewage wastes and associated plant nutrients. Most of the nutrient load is transported into adjacent coastal waters where it is taken up by phytoplankton within a relatively small area (<1,500 km^2). Geographically, productivity tends to be highest within 20 km of the mouth of the estuary and decreases with distance offshore as nutrient and chlorophyll a concentrations decrease and salinity increases. Nitrogen budget calculations indicate that the influence of sewage-derived N on phytoplankton productivity is limited to the area of the apex. Productivity in this region is projected to increase by about 15% in the next 20 yr as a consequence of increased delivery of secondary treated effluent accompanying urban development.

Malone, T. C., P. G. Falkowski, T. S. Hopkins, G. T. Rowe, and T. E. Whitledge. 1983. Mesoscale response of diatom populations to a wind event in the plume of the Hudson River. Deep-Sea Res. 30:149-170.

Effects of a southwest wind event on distributions of dissolved inorganic nitrogen and diatom biomass during March 1981 are described and evaluated in terms of interactions between circulation, static stability of the water column, and the suspension and growth of diatom populations. A diatom bloom, dominated by *Skeletonema costatum*, developed in response to upwelling as a consequence of the vertical transport of biomass from the aphotic zone (deduced from distributions and rate measurements), accompanied by a decrease in sinking rate from 1.0 to 0.3 m/d (from sediment trap collections), and lower dilution rates (from hydrography). Carbon-specific growth rate of diatoms showed little variability based on measurements made before and during the bloom (i.e., variations in diatom production were primarily due to variable loss rates rather than to growth). The influence of diatom production associated with the coastal plume of the Hudson River (areas <1,000 km^2) was observed to extend approximately 100 km seaward of the zone of most active production. Episodes of cross-shelf transport and onshore accumulation of phytoplankton biomass appear to alternate with periods of high surface production in the plume.

Marshall, H. G. 1984. Phytoplankton distribution along the eastern coast of the USA. Part V. Seasonal density and cell volume patterns for the northeastern continental shelf. J. Plankton Res. 6:169-193.

Seasonal phytoplankton distribution maps of phytoplankton numerical abundance and biomass as cell volume are presented for the region between Cape Hatteras and Nova Scotia sampled between 1978 - 1982. Highest cell concentrations and cell volumes were associated with large bay systems, southern coastal section in the Gulf of Maine, Georges Bank, and sites along the shelf margin. Diatom abundance levels exceeded those of dinoflagellates and coccolithophorids. Although the shelf populations are represented by a diverse group of species, the major species in terms of numerical abundance and biomass are a select, ubiquitous group found throughout the region.

Marshall, H. G. and M. S. Cohn. 1982. Seasonal phytoplankton assemblages in northeastern coastal waters of the United States. NOAA Tech. Mem. NMFS-F/NEC-15. 32 pp.

The composition, abundance, and distribution of phytoplankton within northeastern continental shelf waters, including Georges Bank, collected during eight cruises carried out between October 1978 and February 1980 are described. Phytoplankton was most abundant in nearshore waters adjacent to major estuarine systems, Georges Bank, various locations within the Gulf of Maine, and at scattered sites along the shelf break. The seasonality of 678 phytoplankton taxa is summarized.

Marshall, H. G. and J. A. Ranasinghe. 1989. Phytoplankton distribution along the eastern coast of the U.S.A. VII. Mean cell concentrations and standing crop. Cont. Shelf Res. 9:153-164.

This paper provides an analysis of a 10 yr data set (1969-1988) based on 188 surveys conducted at a total of 1,903 stations between Cape Cod and Cape Hatteras. Pico-nanoplankton (<10 μm), the diatom *Skeletonema costatum*, and a mixed centric diatom group (<20 μm) represented 75% of the cells over the shelf. In contrast, a large *Rhizosolenia* species (*R. calcar avis*) and a dinoflagellate assemblage contributed 42% of the mean annual cell volume. Species composition, occurrence, and abundance over the outer shelf regions were more closely related than among coastal regions. The highest values of mean annual cell number and biomass were associated with the New York coastal and outer shelf regions, including Georges Bank, the most productive sites in this region.

Matta, J. M. and H. G. Marshall. 1984. A multivariate analyses of phytoplankton assemblages in the western North Atlantic. J. Plankton Res. 6:663-675.

Principal component analysis of phytoplankton sampled at 1,111 stations over a nine-year period between 1965-1982 from Cape Hatteras to Nova Scotia was carried out. Year-to-year variation was the largest component of variation in abundance, occurrence and distribution patterns, and more important than seasonal variations. Geographical patterns showed distinct trends, with the southern estuaries and Mid-Atlantic Shelf, and offshore versus coastal zones having distinct species assemblages.

McCarthy, J. J. and J. L. Nevins. 1986. Utilization of nitrogen and phosphorus by primary producers in warm-core ring 82-B following deep convective mixing. Deep-Sea Res. 33:1773-1788.

Rates of utilization for NO_3^-, NH_4^+, urea, and PO_4^- by primary producers and the abundances of particulate C, N, and P were determined for the euphotic zone in April and early May 1982. During the study, NO_3^- decreased near the surface, allowing a NO_3^- gradient to develop, while particulate N (PN) and the rate of N uptake increased. Only 16% of the NO_3^--based production remained in the euphotic zone. The PN:chlorophyll a ratio was higher at the bottom of the euphotic zone than at the top, indicating that detrital PN was being formed faster than it was exported.

McLaughlin, J. J. A., G. S. Kleppel, M. P. Brown, R. J. Ingram, and W. B. Samuels. 1982. The importance of nutrients to phytoplankton production in New York Harbor, pp. 469-479. In G. Mayer (ed.), Ecological Stress in the New York Bight: Science and Management, Estuarine Research Federation, Columbia, SC.

Nitrogen (as NH_4) and phosphorus appear to be present in excess of concentrations capable of limiting phytoplankton growth. Silicon delivery to the New York Bight apex decreases sharply in May and June and the phytoplankton community changes from being diatom-dominated to chlorophyte- and dinoflagellate-dominated. Primary productivity reflects this change, initially decreasing between April and May, then increasing towards the summer as the chlorophytes become dominant. Enrichment experiments suggest that silicon and trace metals regulate this observed community successional pattern and productivity.

Nelson, D. M., H. W. Ducklow, G. L. Hitchcock, M. A. Brzezinski, T. J. Cowles, C. Garside, R. W. J. Gould, T. M. Joyce, C. Langdon, J. McCarthy, and C. S. Yentsch. 1985. Distribution and composition of biogenic particulate matter in a Gulf Stream warm-core ring. Deep-Sea Res. 32:1347-1369.

The biogenic particle field in Gulf Stream warm-core ring 82-B in June of 1982 was characterized. Observations include chlorophyll a and phaeopigments, ATP, particulate organic carbon and nitrogen, biogenic silica, total particle volume and size distribution, bacterial abundance and picoplankton biomass, and the abundances of diatoms, dinoflagellates and coccolithophorids in the upper 700 m along two transects of the ring. A distinct maximum in phytoplankton biomass occurred within the thermocline (20-40 m) at the ring's center of rotation. This maximum, not present in late April, apparently developed within 3-4 weeks after the ring stratified in May. Biomass decreased outward from ring center. A second biomass maximum associated with shelf surface water was entrained into the anticyclonic flow field of the ring 60-70 km from its center. Maximum chlorophyll a and ATP concentrations in the two biomass maxima were similar, but the ring-center maximum was 2-10 times richer in particulate carbon, biogenic silica, particles >5 μm in diameter, dinoflagellates, diatoms and estimated organic detritus, while the entrained shelf water had 2-5 times greater abundances of unicellular monads. Heterotrophic bacterial abundance and biomass, and the abundance of coccoid cyanobacteria were maximal in the region of highest rotational velocity 40-50 km from the ring center. In this region the abundances of bacteria and cyanobacteria were 2-5 times as great as at the center of the ring. Two possible mechanisms can explain the development of an axially symmetrical maximum in biogenic particulate matter in the center of a warm-core ring: concentration by the flow field and *in situ* growth. Our data indicate a greater likelihood that this particular ring-center maximum developed *in situ*.

Nelson, D. M., J. J. McCarthy, T. M. Joyce, and H. W. Ducklow. 1989. Enhanced near-surface nutrient availability and new production resulting from the frictional decay of a Gulf Stream warm-core ring. Deep-Sea Res. 36:705-714.

Warm-core eddies in at least three different current systems have been observed to evolve over a few weeks' time from local minima to local maxima in phytoplankton biomass and primary productivity. The causes of this biological enrichment have been uncertain. The authors report a possible explanation of this phenomenon, based on events observed in Gulf Stream warm-core ring 82-B. During the time when a phytoplankton biomass maximum was present in this ring, nutrient concentration gradients beneath a nutrient-depleted surface layer were consistently both greater in magnitude and closer to the sea surface in the interior of the ring than in the surrounding Slope Water. In addition, surface-layer densities were greater inside than outside the ring, resulting in much smaller density differences between the surface and the nitracline (shallowest depth at which nitrate was detectable by conventional methods). The cumulative result of these two factors was that, compared to the surrounding Slope Water, less than one fifth as much wind energy would have been needed near the center of the ring to mix the water column from the nitracline to the surface. The layered nutrient and density profiles within the ring were consistent with physical and biological models of eddy dynamics, which predict that the frictional decay of the rotational flow field should result in shoaling of the main thermocline, and thus upwelling, in the interior of a warm-core eddy. There is reasonably good quantitative agreement between calculated rates of vertical nutrient transport associated with upwelling in the interior of the ring and the measured net uptake rates of nitrate and silicic acid by the phytoplankton. It is suggested that ring-center biomass and production maxima, recognized as common features of warm-core ocean eddies, are generated and maintained by intensified new production that results from the general sequence of physical events described.

O'Reilly, J. E. and D. A. Busch. 1979. Summary of primary productivity made during MARMAP surveys (Belogorsk 78-01, 78-03, 78-04). NOAA, NMFS, NEFC Rept. SHL 79-09.

No annotation. Document unavailable.

O'Reilly, J. E. and D. A. Busch. 1984. Phytoplankton primary production on the northwestern Atlantic shelf. Rapp. P.-v. Réun. Cons. Int. Explor. Mer. 183:255-268.

Phytoplankton production of particulate and dissolved organic carbon was measured using the ^{14}C simulated *in situ* sunlight incubation method during 23 surveys of the Mid-Atlantic Bight, Georges Bank, and the Gulf of Maine. Annual phytoplankton production (particulate plus dissolved) ranged between 260 and 470 g C•m^{-2}•yr^{-1} in various regions, which places this continental shelf system among the most productive in the world. The highest rates of daily phytoplankton production were consistently found off the coast of New Jersey in the sewage-polluted apex of the New York Bight, followed by the shallow, well-mixed waters on Georges Bank. In general, high daily rates of primary production (1 g C•m^{-2}•d^{-1}) were observed during most of the months sampled and were not limited to the "spring bloom" period. Microheterotrophs above the thermocline (not the seabed) supply most of the mineralized nutrients required by the productive summer phytoplankton communities. Size-fractionation of the ^{14}C-labeled particulate organic carbon revealed that netplankton (>20 μm) are major primary producers during the spring and fall blooms in the Mid-Atlantic Bight, on Georges Bank, and in the Gulf of Maine; however, the nanoplankton (<20 μm) are responsible for most of the annual photosynthesis of organic carbon. On an annual basis, the percentage of particulate carbon productivity by nanoplankton increased from shallow to deep water. Euphotic percent extracellular release (PER) of dissolved organic carbon by phytoplankton ranged between 0 and 55%, averaging 15%, and increased from shallow to deep waters of the continental shelf. No well-defined seasonal cycle in euphotic PER was evident from our data.

O'Reilly, J. E., C. Evans-Zeitlin, and D. A. Busch. 1987. Primary Production, pp. 220-233. In R. H. Backus and D. W. Bourne (eds.), Georges Bank. MIT Press, Cambridge, MA.

The patterns of phytoplankton biomass as chlorophyll and primary production in the shelf waters between Cape Hatteras and Nova Scotia based on measurements at 4,467 stations between October 1977 - June 1982 are given. Relatively high chlorophyll concentrations occur over Georges Bank and in the coastal waters of the Middle Atlantic shelf between Long Island and Cape Hatteras; lowest chlorophyll levels are usually found in deep water in the Gulf of Maine and over the continental slope flanking Georges Bank and the Middle Atlantic shelf. Chlorophyll concentrations usually decrease progressively by about five-fold from the Shoal area (<60 m) on Georges Bank to the slope (200-2,000 m) flanking the bank. Nanophytoplankton predominate (80-95% of total chlorophyll) in the shelf/slope water interface. The continental shelf was partitioned into 14 subareas; the average water column chlorophyll level over a five-year period ranged about 10-fold from 4.38 mg/m^3 in the <20 m nearshore zone extending from Long Island to Cape Hatteras to 0.49 mg/m^3 in the slope water east of Georges Bank. The second highest average chlorophyll concentration was 2.58 mg/m^3 over Georges Bank of <60 m depth. The average of total chlorophyll concentrations present as nanophytoplankton ranged from 41 to 82%. Annual primary production rates for subareas of Georges Bank range between 265 and 455 g C/m^2, placing this region among the most productive shelf ecosystems in the world. The area-weighted annual mean of 333 g $C \cdot m^{-2} \cdot yr^{-1}$ is nearly twice the mean for world shelves. Production over the shallow portion of Georges Bank (455 g $C \cdot m^{-2} \cdot yr^{-1}$) is about three-times the world mean. Annual production in the Middle Atlantic coastal zone (<20 m) between Long Island and Cape Hatteras is 505 g $C \cdot m^{-2} \cdot yr^{-1}$; production between the 20-60 m isobath about 310 g $C \cdot m^{-2} \cdot yr^{-1}$; production between the 60-200 m isobath about 350 g $C \cdot m^{-2} \cdot yr^{-1}$, while levels of about 305 g $C \cdot m^{-2} \cdot yr^{-1}$ are evident over the slope (>200 m). The elevation in production over the outer Middle Atlantic shelf (60-200 m) relative to the 20-60 m zone differs from that over outer Georges Bank where primary production is lower than in shallower, bank waters. Observed regional differences in biomass and primary production may reflect the development and passage of warm core rings which generally are positioned closer to the 200-m isobath of the Middle Atlantic shelf than they are to Georges Bank.

O'Reilly, J. E., J. P. Thomas, and C. Evans. 1976. Annual primary production (nanoplankton, netplankton, dissolved organic matter) in the lower New York Bay. Paper No. 19, pp. 1-32. In W. H. McKeon and G. L. Lawer (eds.), Fourth Symposium on Hudson River Ecology. Hudson River Environmental Society, Inc., NY.

Netplankton-nanoplankton production rates were measured from November 1973 - March 1975 at a station located in lower New York Bay, below New York City. The annual primary production rate in this sewage polluted region was 817 g $C \cdot m^{-2} \cdot yr^{-1}$. This annual rate exceeds previously reported rates from estuarine and marine ecosystems dominated by phytoplankton. Light intensity, rather than nutrients, regulates phytoplankton productivity and growth rates at this location. Nanoplankton account for about 67% of the total annual production, netplankton 18%, and release of dissolved organic matter 15%. The annual production rate was approximately 2.2-fold greater than that (370 g $C \cdot m^{-2} \cdot yr^{-1}$) in adjacent coastal waters.

Paffenhöfer, G. A., L. P. Atkinson, J. O. Blanton, T. N. Lee, L. R. Pomeroy, and J. A. Yoder. 1987a. Summer upwelling on the southeastern continental shelf of the U.S.A. during 1981. Introduction. Prog. Oceanogr. 19:221-230.

This paper summarizes the primary productivity results of a study carried out between June - August 1981 on the southeastern continental shelf between 29°N and 32°N latitude.

Paffenhöfer, G. A., L. P. Atkinson, J. O. Blanton, T. N. Lee, L. R. Pomeroy, and J. A. Yoder. 1987b. Summer upwelling on the southeastern continental shelf of the U.S.A. during 1981. Summary and conclusions. Prog. Oceanogr. 19:437-441.

This paper summarizes the observed linkages between hydrography, upwelling events and intrusions, nutrient advection, primary production, and zooplankton dynamics during summer 1981 on the southeastern continental shelf between 29°N and 32°N latitude.

Paffenhöfer, G. A. and T. N. Lee. 1987. Summer upwelling on the southeastern continental shelf of the U.S.A. during 1981. Distribution and abundance of particulate matter. Prog. Oceanogr. 19:373-401.

This paper describes the size, shape, and longevity of phytoplankton patches accompanying Gulf Stream upwelling events and intrusions onto the southeastern continental shelf. Variability in distribution and co-occurrence of phytoplankton and zooplankton biomass were demonstrated. Study results showed the importance of physical circulation patterns on patch formation, size, and longevity on primary production.

Pomeroy, L. R., G. A. Paffenhöfer, and J. A. Yoder. 1987. Summer upwelling on the southeastern continental shelf of the U.S.A. during 1981. Interactions of phytoplankton, zooplankton and microorganisms. Prog. Oceanogr. 19:353-372.

A study was conducted to measure autotrophic and microheterotrophic production on the continental shelf off northeastern Florida. Autotrophic production was found to be twice that of microheterotrophs. Microheterotrophs were the dominant biomass source in the upper watermass layers because of differential distribution. They may also be keen competitors with autotrophs for nutrients.

Prêzelin, B., M. Putt, and H. E. Glover. 1986. Diurnal patterns in photosynthetic capacity and depth-dependent photosynthesis-irradiance relationships in *Synechococcus* spp. and larger phytoplankton in three water masses in the Northwest Atlantic Ocean. Mar. Biol. 91(2):205-217.

The photosynthetic characteristics of *Synechococcus* spp. and larger eukaryotic algae were compared at neritic frontal station, in a warm-core eddy, and at Wilkinson's Basin (P3) during a cruise in the Northwest Atlantic Ocean in the summer of 1984. *Synechococcus* spp. numerically dominated the 0.6-1 μm fraction, and to a lesser extent the 1-5 μm size fractions at the bottom of the euphotic zone. The highest photosynthetic capacity was observed at dawn. The size-specific contribution to potential primary production in surface waters did not vary appreciably over the day. Estimates of the contribution of *Synechococcus* spp. to total primary productivity in surface waters at the neritic front were significantly higher when derived from short-term incubator measurements of photosynthetic capacity than from dawn-to-dusk *in situ* measurements of carbon fixation. The discrepancy was not due to photoinhibitory effects on photosynthesis, but appeared to reflect increased selective grazing pressure on *Synechococcus* spp. in dawn-to-dusk samples.

Prouse, N. J., D. C. J. Gordon, B. T. Hargrave, C. J. Bird, J. McLachlan, J. S. S. Lakshminaiayana, J. Sita Diva, and M. L. H. Thomas. 1984. Primary production: Organic matter supply to ecosystems in the Bay of Fundy. Can. Tech. Rept. Fish. Aquat. Sci. No. 1256:65-95.

Studies from 1976 to 1982 of primary production by phytoplankton, seaweeds, benthic microalgae and salt marsh flora in the Bay of Fundy are reviewed. Phytoplankton primary production decreases from 133 g $C \cdot m^{-2} \cdot yr^{-1}$ at the entrance into the Bay of Fundy to 15 g $C \cdot m^{-2} \cdot yr^{-1}$ in the innermost basins. Annual net production of fucoid seaweeds in the outer Bay of Fundy is 845 g $C \cdot m^{-2} \cdot yr^{-1}$, about six-fold higher than for phytoplankton. Benthic microalgal production ranged from 27-73 g $C \cdot m^{-2} \cdot yr^{-1}$ and salt marsh primary productivity was 215 g $C \cdot m^{-2} \cdot yr^{-1}$.

Riley, G. A. 1941a. Plankton studies. IV. Georges Bank. Bull. Bingh. Oceanogr. Coll. 7:1-73.

On 6 cruises between September - June, production and utilization of dissolved oxygen by surface phytoplankton populations incubated on shipboard for 24 hr were determined. Daily gross production rates ranged from 0.11 (January) to 3.95 (April) g $C \cdot m^{-2} \cdot d^{-1}$, and daily net production rates from -0.05 (January) to 0.95 (April) g $C \cdot m^{-2} \cdot d^{-1}$.

Riley, G. A. 1941b. Plankton studies. V. Regional summary. J. Mar. Res. 4:162-171.

Phytoplankton biomass and primary production measured from January - September on Georges Bank are compared to predicted levels calculated from a series of equations. A fair degree of accuracy was evident when using seasonal averages, but the non-linear environmental - phytoplankton response relationships resulted in poor predictive capability prior to the spring bloom development.

Riley, G. A. 1942. The relationship of vertical turbulence and spring diatom flowerings. J. Mar. Res. 5:67-87.

Cruises to Georges Bank in the spring of 1941 showed that the relationship between plankton and stability was zero in March, positive in April, and negative in May. Theoretical considerations suggest that when the thickness of the euphotic zone and the rates of photosynthesis and respiration are constant, the rate of increase in the plankton population is a linear function of the reciprocal of the thickness of the zone of vertical turbulence. Data from the April cruise fit the theory.

Riley, G. A. 1946. Factors controlling phytoplankton populations on Georges Bank. J. Mar. Res. 6:54-73.

Variations in the phytoplankton population of the Georges Bank area were correlated with various environmental factors and equations developed statistically, by which the size of the population can be calculated on the basis of temperature, depth of water, and the quantities of nitrate, phosphate, and zooplankton. Calculated horizontal variations in the plankton crop at various times in the year differ from observed values by about 20-40%. Calculations of the seasonal variation of the average crop in the area were accurate within about 20%. The seasonal cycle of phytoplankton was also evaluated from a theoretical standpoint, based on the postulate that the rate of change of the phytoplankton population is equal to the photosynthetic rate of the zooplankton. Factors affecting these rates and considered particularly important are solar radiation, temperature, transparency of the water, depth of the isothermal surface layer, phosphate, and zooplankton. The observed variations of these factors were combined with appropriate constants derived from experimental data to develop an equation that expresses the seasonal rate of change of the phytoplankton population. Approximate integration of the equation yielded a population curve of the same order of accuracy as the statistical estimate.

Riley, G. A. 1955. Review of the oceanography of Long Island Sound. Deep-Sea Res. Suppl. 3:224-238.

Annual net phytoplankton production on Georges Bank estimated to be 150 g $C \cdot m^{-2} \cdot yr^{-1}$, with commercial fish catches ranging from 7-33 lb per acre. Total primary production is probably twice the commercial fish catch, so that the efficiency of conversion of phytoplankton production into fish production, as carbon, is about 0.5%, similar to Block Island Sound and the English Channel.

Riley, G. A. and D. F. Bumpus. 1946. Phytoplankton-zooplankton relationships on Georges Bank. J. Mar. Res. 6:33-47.

A significant inverse relationship occurred between the horizontal distribution of Georges Bank phytoplankton and zooplankton when the latter was increasing most rapidly. The evidence points to grazing as the cause of the inverse relationship. Theoretically, the maximum amount of grazing that could occur, based on the difference between the phytoplankton primary production rate and the rate of change of the standing crop, ranged from 17-25% of zooplankton wet weight during April - May.

Riley, G. A. and S. Gorgy. 1948. Quantitative studies of summer plankton populations of the western North Atlantic. J. Mar. Res. 7:100-121.

Some measurements of temperature, nutrient salts, phytoplankton pigments, zooplankton, wet weight and organic content, and experimental determinations of phytoplankton photosynthesis and zooplankton respiration were made at various positions in the western North Atlantic between New England and the Azores during the period of July to September 1947. The coastal and slope water data were incidental to a focus on quantifying phytoplankton processes in the Sargasso Sea.

Riley, G. A., H. Stommel, and D. F. Bumpus. 1949. Quantitative ecology of the plankton of the western North Atlantic. Bull. Bingh. Oceanogr. Coll. 12(3):1-169.

Data were evaluated from the Gulf of Maine, Georges Bank, and the coastal zone off southern New England; the so-called slope water, lying off the edge of the continental shelf south of Georges Bank and the New England Coast; the part of the Gulf Stream system extending from the Florida Straits to the New England offing; and the subtropical water mass of the central Atlantic, or Sargasso Sea. Data are used to test theories of distribution and production. The change in phytoplankton concentration with depth is quantitatively determined by the interrelation of five factors - vertical diffusion, the settling velocity of the phytoplankton, euphotic zone depth, primary production, respiration, and grazing.

Roman, M. R., C. S. Yentsch, A. L. Gauzens, and D. A. Phinney. 1986. Grazer control of the fine-scale distribution of phytoplankton in warm-core Gulf Stream rings. J. Mar. Res. 44:795-813.

In situ rates of primary production, zooplankton grazing and the fine-scale distribution of zooplankton abundance, along with continuous observations of salinity, temperature and fluorescence were measured in vertical profiles of two warm-core Gulf Stream rings and a station in the northern Sargasso Sea. A subsurface chlorophyll maximum was located within the pycnocline at the pump stations. In the majority of pump profiles, subsurface chlorophyll maxima coincided with maxima in particulate organic carbon and ATP. However, neither zooplankton biomass or numerical abundance were related to chlorophyll concentrations. Maxima in zooplankton biomass and grazing generally occurred at depths of highest primary production. Zooplankton grazing and biomass were more closely coupled to phytoplankton production per unit chlorophyll (P-chlorophyll) rather than production per unit volume (absolute production). Results suggest that after the seasonal thermocline is established, phytoplankton removal by zooplankton is greatest in the upper water column where P-chlorophyll is

higher. This phytoplankton removal by zooplankton limits the amount of absolute primary production in the upper water column and results in a subsurface maximum of absolute production at depths where grazing pressure is reduced. In contrast, the subsurface chlorophyll maximum, likely formed from both production at depth and sinking, does not appear to be a site of enhanced zooplankton grazing activity.

Rowe, G. T. 1986. Production and remineralization in continental shelf ecosystems: A test of the SEEP (Shelf Edge Exchange Processes) hypothesis. Dept. of Energy, Rept. No. BNL-38988; CONF-8609246-1. 39 pp.

The hypothesis that continental shelf ecosystems export a major fraction of the carbon produced by the phytoplankton during the spring bloom was tested during the Shelf Edge Exchange Processes (SEEP) experiment off the northeast United States coast in 1984. On average, about 25% of the primary production appeared to be utilized by the aerobic benthos on the continental shelf in the SEEP area.

Sherr, B., E. B. Sherr, and S. Y. Newell. 1984. Abundance and productivity of heterotrophic nanoplankton in Georgia coastal waters. J. Plankton Res. 6:195-202.

Population abundances and rates of biomass production of heterotrophic nanoplankton (mostly non-pigmented microflagellates <10 μm) were established. Abundance ranged about 20-fold from 300-6,300 cells/ml along a 15 km onshore-offshore gradient; production about 8-fold, and population generation times about 2.5-fold, from 9.7-26.5 h.

Sibunka, J. D. and M. J. Silverman. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977-1983). Atlas No. 1. Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-33. 360 pp.

This paper summarizes the sampling methods, station locations and activities, and geographic coverage of MARMAP surveys.

Sibunka, J. D. and M. J. Silverman. 1989. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1984-87). Atlas No. 3. Summary of operations. NOAA Tech. Mem. NMFS-F/NEC-68. 197 pp.

This paper summarizes the sampling methods, station locations and activities, and geographic coverage of MARMAP surveys.

Sissenwine, M. P., E. B. Cohen, and M. D. Grosslein. 1984. Structure of the Georges Bank ecosystem. Rapp. P-v. Réun. Cons. Int. Explor. Mer. 183:243-254.

Georges Bank is a highly productive fishing ground located off the northeast coast of the USA. Primary productivity is estimated as 6,320 kcal•m^{-2}•yr^{-1} (400 g C•m^{-2}•yr^{-1}). About 50% of primary productivity is necessary to support 350 kcal•m^{-2}•yr^{-1} of macrozooplankton production (with nanoplankton passing through a longer food chain including microzooplankton). The remaining primary productivity supports 200 kcal•m^{-2}•yr^{-1} of benthic production via a food chain including detritus and bacteria. Total fish production (all species and sizes together) was 68.9 and 41.7 kcal•m^{-2}•yr^{-1} during 1964-1966 and 1973-1975, respectively. Fish consumed 33% of the suitable food during the latter period of low abundance and 56% during the earlier period of high abundance. Approximately half of demersal fish consumption is of young fish too small to be vulnerable to exploitation. Gross estimates of early life-stage mortality, based on egg production, larval abundance, and subsequent recruitment, confirm that late-larval and post-larval mortality is extremely high. Year-class strength is probably determined during late-larval or post-larval stages when only a very small difference in mortality rate is necessary to account for the difference between strong and weak year classes.

Smayda, T. J. 1973. A survey of phytoplankton dynamics in the coastal waters from Cape Hatteras to Nantucket, pp. 3-1 to 3-100. In Coastal and Offshore Environmental Inventory Cape Hatteras to Nantucket Shoals, Publ. Ser. No. 2, Univ. Rhode Island.

Mean annual production rates for phytoplankton and macrophytes in coastal salt ponds in Massachusetts, Rhode Island, and Connecticut are listed and ranged from 80 to 1,400 g C•m^{-2}•yr^{-1} (gross production) and 15 to 500 g C•m^{-2}•yr^{-1} (net production) for phytoplankton. Annual gross and net production rates for Narragansett Bay were 840 and 220 g C•m^{-2}•yr^{-1}, respectively; for Chesapeake Bay, gross production rates ranged from 100 to 580 g C•m^{-2}•yr^{-1}; for North Carolina embayments, gross production rates ranged from 100 to 320 g C•m^{-2}•yr^{-1}. For open coastal waters in southern New England, gross production was about 400 g C•m^{-2}•yr^{-1} and net production ranged from 205 to 285 g C•m^{-2}•yr^{-1}.

Smith, R. C. and K. S. Baker. 1985. Spatial and temporal patterns in pigment biomass in Gulf Stream warm-core ring 82B and its environs. J. Geophys. Res. 90:8859-8870.

A chronology of the horizontal and vertical distribution of phytoplankton pigment biomass in Gulf Stream warm-core ring 82B through three distinct periods is given: a winter/early spring period of deep convective overturn, with uniform and relatively high pigment concentrations to depths of 400 m; a late spring stratification period with subsurface (20-30 m) pigment maxima and relatively high ring center values compared to surrounding waters, and a Gulf Stream interaction period when ring characteristics are dominated by intrusions of low pigment concentration waters. While the ring maintained a unique identity through these periods, prolonged deep vertical mixing as well as episodic interactions with its surroundings significantly influenced pigment distributions within the ring. These interactions generally enhanced pigment biomass compared to the water mass from which it is derived.

Stoecker, D. K., A. Taniguchi, and A. E. Michaels. 1989. Abundance of autotrophic, mixotrophic and heterotrophic planktonic ciliates in shelf and slope waters. Mar. Ecol. Prog. Ser. 50:241-254.

During early summer, the density of microplanktonic ciliates in the euphotic zone on Georges Bank (northwest Atlantic) ranged from 600-13,000 cells/l; in the slope waters to the southeast of the bank, densities ranged from 1,900-2,800 cells/l. *Myrionecta rubra*, a photosynthetic autotroph ciliate with a reduced algal endosymbiont, numerically comprised an average of 30% of the microplanktonic ciliate fauna at stations in <100-m depth, but 3% or less of the ciliate fauna at the deeper stations. Oligotrichous ciliates with chloroplasts are estimated to have contributed 34% of the ciliate fauna and were abundant at both shallow, unstratified stations on the bank and at deeper, stratified stations on the slope of the continental shelf and in the Gulf of Maine. Overall, about 50% of the ciliates in the euphotic zone contained chlorophyll. At the shallow water stations, *M. rubra* and *Laboea strobila* accounted for over 50% of the biomass of ciliates with chlorophyll. During summer, when phytoplankton biomass is low, autotrophic and mixotrophic ciliates may make an important contribution to photosynthesis in the larger size fractions and be an important source of food for larger organisms that rely on high quality, >15-20 μm food particles.

Subba Rao, D. V. 1975. Phytoplankton production, nutrients and density structure in the shelf area of Nova Scotia and Georges Bank during August 1974. Fish. Mar. Sew. Tech. Rept. 524:1-272.

This paper contains the data report of a cruise made in August 1974 to Georges Bank to measure phytoplankton cell numbers, biomass, and primary production at 5-m depth.

Subba Rao, D. V. and S. J. Smith. 1987. Temporal variation of size-fractionated primary production in Bedford Basin during the spring bloom. Oceanologica Acta. 10:101-109.

The 1974, 1976, and 1977 spring phytoplankton blooms in Bedford Basin, Nova Scotia and their variations in phytoplankton biomass and primary production are investigated. The 1977 bloom had a longer duration (64 d) than the others, characterized by a wide range (13-fold) in chlorophyll biomass, from 1.46-18.8 mg/m^3, and primary production (18-fold) rates, from 3.5-63.7 mg C$\cdot$m$^{-3}\cdot$h^{-1}. Nanoplankton (<20 µm) contributed a mean of 25% of biomass and production levels, but were likewise variable between sampling periods from about 8 to 60%.

Taguchi, S., G. R. DiTullio, and E. A. Laws. 1988. Physiological characteristics and production of mixed layer and chlorophyll maximum phytoplankton populations in the Caribbean Sea and western Atlantic Ocean. Deep-Sea Res. 35(8A):1363-1377.

Phytoplankton photosynthetic rates and relative and absolute growth rates were estimated using ^{14}C techniques at five stations in the Caribbean Sea and two stations in the western Atlantic. Integral photosynthetic rates at the Caribbean stations averaged (±1 S.D.) 633 ± 77 mg C$\cdot$m$^{-2}\cdot$d^{-1}. Light-saturated growth rates were about 0.6/d. Relative growth rates averaged 85% in the surface mixed layer and 93% in the lower euphotic zone. Estimated phytoplankton carbon concentrations were virtually identical in the mixed layers and chlorophyll maxima. The latter were therefore the result of adaptation of the phytoplankton to low irradiance levels and did not represent biomass maxima. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Thomas, J. P. 1966. Influence of the Altamaha River on primary production beyond the mouth of the river. M.S. thesis, Univ. of Georgia, Athens, GA. 88 pp.

The annual primary production rate along the Georgia coast off the Altamaha River was 547 g C$\cdot$m$^{-2}\cdot$yr^{-1}.

Thomas, J. P., J. E. O'Reilly, C. N. Robertson, and W. C. Phoel. 1978. Primary production and respiration over Georges Bank during March and July 1977. ICES CM 1978/L:37. 18 pp.

Oxygen consumption by the seabed during the summer was found to be less than 10% of the total oxygen consumption. If the ratio of nutrients released to oxygen consumed is similar at the seabed and in the water column, then the seabed is not an important source of nutrients required by summer phytoplankton stocks in New York Bight, and organic remineralization would represent the major source of recycled nutrients on Georges Bank.

Thomas, J. P., J. E. O'Reilly, A. F. J. Draxler, J. A. Babinchak, C. N. Robertson, W. C. Phoel, R. I. Waldhauer, C. A. Evans, A. Matte, M. S. Cohn, M. F. Nitkowski, and S. Dudley. 1979. Biological processes: Productivity and respiration, Chap. 10. In R. L. Swanson and C. J. Linderman (eds.), Oxygen depletion and associated benthic mortalities in New York Bight, 1976. NOAA Prof. Pap. 11, Washington, DC.

The seabed accounted for an average of 6% of the total (water column and seabed) aerobic respiration per m^2 during the summer in the New York Bight. Organic mineralization in the water column was determined to be a major source of recycled nutrients used in production.

Townsend, D. W. and J. P. Christensen. 1986. Summertime oceanographic conditions in the Gulf of Maine, 16-24 July, 1985; physical oceanographic, nutrient, and chlorophyll data. Bigelow Lab. for Ocean Sci. Tech. Rept. No. 61. 422 pp.

No annotation. Document unavailable.

Townsend, D. W. and R. W. Spinrad. 1986. Early spring phytoplankton blooms in the Gulf of Maine. Cont. Shelf Res. 6:515-529.

Early spring phytoplankton bloom development in late March - early April 1984 in Gulf of Maine is in agreement with previous findings in a variety of bodies of water, that bloom propagation begins when depth averaged *in situ* solar irradiance within the upper mixed layer is about 40 ly/d.

Townsend, D. W., J. P. Christensen, D. K. Stevenson, J. J. Graham, and S. B. Chenoweth. 1987. The importance of a plume of tidally-mixed water to the biological oceanography of the Gulf of Maine. J. Mar. Res. 45:699-728.

During the warmer months of the year, the eastern Gulf of Maine features a plume of cold water which extends from the tidally well-mixed area adjacent to Grand Manan Island at the mouth of the Bay of Fundy southwest along the Maine coast to well beyond Penobscot Bay. Near Grand Manan Island, the plume waters are cold (approximately 10°C), nearly vertically isothermal, and carry high concentrations of dissolved inorganic nutrients. The plume waters become increasingly stratified as they flow to the southwest which leads to a phytoplankton bloom downstream. Nitrate concentrations within the euphotic zone of the plume decrease approximately linearly (approximately 194 mg-at NO_3-N/m^2) along a distance of about 130 km travelled after its exit from the Grand Manan area (approximately 7.5 d transit time). Total chlorophyll concentrations increase nearly linearly with distance along the first 80 km and then decrease in the following 50 km. Over the distance of increasing chlorophyll concentrations (80 km), the nitrate decrease corrected for physical losses laterally would support a "new" primary production of 1.46 g $C \cdot m^{-2} \cdot d^{-1}$. As much as 44% of the new nitrate which enters the Gulf of Maine at depth through the Northeast Channel upwells in the eastern Gulf becoming part of the plume. This feature appears to be very important to the nutrient budget and general biological oceanography of the inner Gulf of Maine.

Townsend, D. W., C. M. Yentsch, C. E. Parker, W. M. Boalch, and E. D. True. 1983. An island mixing effect in the coastal Gulf of Maine. Helgolander Meeresunters 36:347-356.

Hydrographic stations around Monhegan Island were sampled periodically over a five-year period between April - October. A combination of upwelling and vertical mixing events enhanced phytoplankton production resulting in increased biomass as chlorophyll on the north and south flanks of the island (= "island mass" effect).

Turner, R. E. 1981. Plankton productivity and the distribution of fishes on the southeastern U.S. continental shelf. Science 214:353-354.

This paper refutes the claim of Yoder *et al.* (1981) that changes in plankton community dynamics offshore of the 20-m isobath are driven by shelf break upwelling events. It also argues that an onshore - offshore gradient occurs in which phytoplankton biomass as chlorophyll and primary production decrease. Findings demonstrate that average areal primary production rates between the 0-20 m and 20-200 m isobaths on the Georgia - South Carolina continental shelf are strongly correlated ($r = 0.97$).

Turner, R. E., S. W. Woo, and H. R. Jitts. 1979. Estuarine influences on a continental shelf community. Science 206:218-220.

Phytoplankton production was measured on four transects between Charleston, SC and Jacksonville, FL. Maximal production rates decreased significantly within 10 km of the shore, but primary production in the nearshore (<20 m) was closely coupled with that in deeper waters (20-200 m). The transition zone between these two areas is only 5 km wide. Seasonal production patterns in both regions followed each other closely, except for periodic increased winter production bursts offshore accompanying storms. The annual production maximum occurred in late summer/early fall, with maximal rates of about 1.5 g $C \cdot m^{-2} \cdot d^{-1}$ in the nearshore region (5-10 m) and about 0.3 g $C \cdot m^{-2} \cdot d^{-1}$ in deeper waters (20-200 m). The accompanying seasonal cycles in numerical abundance of copepods and fish eggs and larvae are also reported. Investigators conclude that shelf phytoplankton communities are dominated by couplings with the local estuaries and shallow nearshore zone.

Walsh, J. J., E. T. Premuzic, J. S. Gaffney, G. T. Rowe, G. Harbottle, R. W. Stoenner, W. L. Balsam, P. R. Betzer, and S. A. Macko. 1985. Organic storage of CO_2 on the continental slope off the mid-Atlantic Bight, the southeastern Bering Sea, and the Peru coast. Deep-Sea Res. 32:853-883.

As much as 50% of the annual primary production of the mid-Atlantic shelf is neither consumed by the pelagic and demersal food web, nor stored in shelf sediments. About 90% of the shelf phytoplankton biomass produced during the February - April diatom blooms and about 10% during the low May - October standing stocks of flagellates, dinoflagellates and coccolithophorids are transported seaward across shelf break.

Walsh, J. J., T. E. Whitledge, J. E. O'Reilly, W. C. Phoel, and A. F. Draxler. 1987. Nitrogen cycling on Georges Bank and the New York Shelf: A comparison between well-mixed and seasonally stratified waters, pp. 234-246. In R. H. Backus and D. W. Bourne (eds.), Georges Bank. MIT Press, Cambridge, MA.

Data are presented from 14 research cruises to Georges Bank carried out during 1977-1980 and 76 cruises on the New York shelf south of Long Island during 1957-1961 and 1974-1982. Annual primary production rates at the 60-m isobath are 301 and 380 g $C \cdot m^{-2} \cdot yr^{-1}$ for the New York Bight and Georges Bank, respectively. Analysis of data from 113 cruises in the Middle Atlantic Bight suggests that 40-50% of the nitrogen demand of primary production in shelf waters off New York and Georges Bight supplied by physical fluxes of NO_3 from slope water inputs at the outer shelf boundary.

Walsh, J. J., D. A. Dieterle, and M. B. Meyers. 1988. A simulation analysis of the fate of phytoplankton within the Mid-Atlantic Bight. Cont. Shelf Res. 8:757-787.

A time-dependent, three-dimensional simulation model of wind-induced changes of the circulation field, light and nutrient regulation of photosynthesis, vertical mixing, algal sinking, and of herbivore grazing stress, is used to analyze the seasonal production, consumption, and transport of the spring bloom within the mid-Atlantic Bight over a 58-d period in February-April 1979. Primary production was simulated based on both nitrate and recycled nitrogen. A mean of 0.62 g $C \cdot m^{-2} \cdot d^{-1}$ characterized the whole model domain, with export at the shelf-break off Long Island of 2.60 g $chlorophyll \cdot m^{-2} \cdot d^{-1}$. About 57% of the carbon fixation was removed by herbivores, with 21% lost as export, either downshelf or offshore to slope waters, after the first 58 d of the spring bloom. Extension of the model for another 22 d increased the mean export to 27%. Variation of the model's parameters in eight other cases led to a range in export from 8 to 38% of the average primary production.

Weinstein, M. P. 1981. Plankton productivity and the distribution of fishes on the southeastern U.S. continental shelf. Science 214:351-352.

Winter increase in primary productivity reported by Turner, Woo, and Jitts (1979) was argued to be an important component of nearshore coupling in the South Atlantic Bight with regard to spawning and dispersal of several marine fish species.

Williams, R. B. 1966. Annual phytoplanktonic production in a system of shallow temperate estuaries, pp. 699-716. In H. Barnes (ed.), Some contemporary studies in marine science. George Allen & Unwin, Ltd., London.

Primary production rates were measured between March 1964 - March 1965 in a system of estuaries near Beaufort, NC. Annual gross production rates were about 100 g $C \cdot m^{-2} \cdot yr^{-1}$ and 47 g $C \cdot m^{-2} \cdot yr^{-1}$ for phytoplankton respiration. These rates are considerably below those reported for Long Island Sound: 380 and 210 g $C \cdot m^{-2} \cdot yr^{-1}$, respectively.

Yentsch, C. S. 1977. Plankton production. MESA New York Bight Atlas Monograph, 12, New York Sea Grant Institute, Albany, NY. 25 pp.

No annotation. Document unavailable.

Yentsch, C. S. and N. Garfield. 1981. Principal areas of vertical mixing in the waters of the Gulf of Maine, with reference to the total productivity of the area, pp. 303-322. In R. Gower (ed.), Oceanography from space. Plenum, NY.

No annotation. Document unavailable.

Yentsch, C. S. and D. A. Phinney. 1985. Rotary motions and convection as a means of regulating primary production in warm core rings. J. Geophys. Res. 90:3237-3248.

The authors believe two mechanisms are important in regulating primary production and phytoplankton abundance in warm core rings. The first mechanism is anticyclogenesis associated with rotary motion of rings; the resultant geostrophic forces are believed to be the basis of nutrient enrichment in the high velocity region. Phytoplankton populations in this peripheral region experience a near steady state growth closely coupled with the rotational velocity of the ring. The second mechanism concerns the phytoplankton populations in the ring center which rely on seasonal changes in the depth of the mixed layer due to convection and stabilization. This process regulates both the mean light energy reaching phytoplankton and equalizes the nutrient distribution over the water column. Growth in populations at ring center occurs as pulses, responding to changes in the depth of the mixed layer.

Yoder, J. A. 1985. Environmental control of phytoplankton production on the southeastern U.S. continental shelf, Chap. 7, pp. 93-103. In L. P. Atkinson, D. W. Menzel, and K. A. Bush (eds.), Oceanography of the Southeastern United States Continental Shelf. Coastal and Estuarine Sciences 2, Am. Geophys. Union, Washington, DC.

Different processes affect the rate and dynamics of primary production across the southeastern U.S. continental shelf of the South Atlantic Bight. Within relatively low salinity waters near the coast, primary production is relatively constant throughout the year and is sustained by nutrients emanating from rivers and salt marshes that line the coast. High turbidity of coastal waters limits the amount of light available for photosynthesis. Gulf Stream-induced upwelling at the shelf break and intrusion of upwelled waters across the shelf are the dominant processes affecting the dynamics of phytoplankton production on the middle and outer shelf. During colder months of the year, upwelled waters generally do not penetrate far across the shelf, and thus phytoplankton blooms and high rates of production are restricted to the outer shelf. Subsurface intrusions of nutrient-rich water penetrate across the shelf during warmer months of the year when the shelf is stratified, particularly in the northernmost and southernmost regions of the South Atlantic Bight. Phytoplankton production and biomass are more than 10 times higher within intrusions than in surrounding resident shelf waters.

Yoder, J. A., L. P. Atkinson, S. S. Bishop, J. O. Blanton, T. N. Lee, and L. J. Pietrafesa. 1985. Phytoplankton dynamics within Gulf Stream intrusions on the southeastern United States continental shelf during summer 1981. Cont. Shelf Res. 4:611-635.

During July and August 1981 subsurface intrusion of upwelled nutrient-rich Gulf Stream water was the dominant process affecting temporal and spatial changes in phytoplankton biomass and productivity of the southeastern United States continental shelf between 29°N and 32°N latitude. Intruded waters in the study area covered as much as 10 km including virtually all of the middle and outer shelf and approximately 50% of the inner shelf area. Within two weeks following a large intrusion event in late July, middle shelf primary production and chlorophyll a reached 3 to 4 g $C \cdot m^{-2} \cdot d^{-1}$ and 75 mg/m^3, respectively. At the peak of the bloom, 80% of the water column primary production occurred below the surface mixed-layer, and new primary production (i.e., NO_3-supported) exceeded 90% of the total. Chlorophyll a-normalized photosynthetic rates were very high as evidenced by high mean assimilation number (15.5 mg C per mg chlorophyll a per h). The results imply a seasonal (June to August) middle shelf production of 150 g C/m^2, about 15% higher than previous estimates of annual production on the middle shelf. Intrusions of the scale we observed in 1981 may not occur every summer. However, when such events do occur, they are by far the most important processes controlling summer phytoplankton dynamics of the middle and outer shelf and of the inner shelf in the southern half of the study area.

Yoder, J. A. and T. Ishimaru. 1989. Phytoplankton advection off the southeastern United States continental shelf. Cont. Shelf Res. 9:547-553.

Preliminary calculations suggest that a significant level of enhanced production resulting from nutrient intrusion was advected off-shelf during a winter event.

STRAITS OF FLORIDA AND GULF OF MEXICO REGION

Brand, L. E. 1988. Assessment of plankton resources and their environmental interactions in Biscayne Bay, Florida. Dept. Environ. Res. Mgt. Tech. Rept. 88-1.

Plankton resources were assessed at 24 locations in Biscayne Bay and covered the entire range of environmental conditions found in the Bay. Monthly samples were collected over an annual cycle to determine the standing stock biomass of phytoplankton and zooplankton. Community composition was assessed using size fractionation and identification of the major phylogenetic groups. Phytoplankton biomass was size fractionated to include the >64 μm, the 5-64 μm and the <5 μm size categories. Photosynthetic capacity was assessed by measuring the fluorescence before and after the addition of dichlorophenyl-dimethylurea. Primary production was measured at 12 stations bimonthly at three light levels (0.3, 0.1, and 0.03 ly/min) and are reported as $\mu g\ C \cdot l^{-1} \cdot h^{-1}$ for each light level. Nutrient bioassays were conducted at every other station bimonthly to assess potential nutrient limitation by nitrogen, phosphorus, silicon, iron, zinc, and manganese. Zooplankton were collected monthly using a 280 μm net and a 64 μm net. Biomass in the 280 μm sample was determined as wet volume, dry weight, and ash free dry weight. Samples from both mesh sizes were used for taxonomic analyses of major groups.

Checkley, D. M. and L. C. Entzeroth. 1985. Elemental and isotopic fractionation of carbon and nitrogen by marine planktonic copepods and implications to the marine nitrogen cycle. J. Plank. Res. 7(4):553-568.

Particle-grazing copepods, primarily *Temora longicornis* and *T. stylifera*, and seawater with natural particles were collected from the northwest Gulf of Mexico. Control and ammonium-enriched aliquots of seawater were incubated in triplicate for two days; then copepods were added and the incubation continued for two days. Analyses were made of dissolved nutrients (i.e., nitrate, ammonium, and phosphate), suspended particles (chlorophyll a, phaeopigments, carbon [C], nitrogen [N], change in ^{13}C, change in ^{15}N), and copepod bodies and feces (C, N, change in ^{13}C, change in ^{15}N); and the rates of egg and feces production were estimated. Primary production (change in chlorophyll a, C, N) was enhanced by N enrichment, indicating its initial N limitation. The rates of egg and feces production were greater for copepods in N-enriched seawater, indicating food-limited ingestion and egg production. Elemental (C:N) and isotopic (change in ^{13}C, change in ^{15}N) fractionation by copepods occurred following ingestion of suspended particulate matter (spm) and during the production of tissue (b) and feces (f): C:Nf > C:Nspm > C:Nb, change in ^{13}Cb > change in ^{13}Cf > change in ^{13}Cspm, and change in ^{15}Nf > change in ^{15}Nb > change in ^{15}Nspm. In a second experiment, N-enriched and N-deficient phytoplankton were fed to *Acartia tonsa* and again C:Nf > C:Nspm > C:Nb. These data indicate that copepods in the present study (i) assimilated nitrogen more efficiently than carbon for tissue production and (ii) produced tissue and feces enriched and excreta depleted in ^{13}C and ^{15}N relative to the suspended particulate matter. The implications of these results to the marine nitrogen cycle are discussed. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Corcoran, E. F. and J. E. Alexander. 1963. Nutrient, chlorophyll and primary production studies in the Florida Current. Bull. Mar. Sci. Gulf and Carib. 13:527-541.

Inorganic and total phosphates, Kjeldahl nitrogen, ammonia, nitrite and nitrate nitrogen, iron, and silicate were measured monthly for 31 mo at a station in the Florida Current 40 mi east of Miami, FL (25°33'N latitude, 79°25'W longitude). Phytoplankton standing crop and primary production were measured for 9 mo. Nutrient concentrations were low with phosphates and nitrates on the order of 0.0 to 0.3 μg-at P/l and 0.0 to 10.0 μg-at N/l. Ammonia and Kjeldahl nitrogen ranged from 0.3 to 4.0 μg-at N/l. Silicate was generally not detectable and iron was principally present in particulate state with concentrations ranging up to 6 μg/l. The phytoplankton standing crop ranged from 0.05 to 0.5 mg chlorophyll/m^3 with net production rates of 0.2 to 0.5 g $C \cdot m^{-2} \cdot d^{-1}$.

Day, J. W., Jr., L. A. Deegan, J. G. Gosselink, Jr., A. Yanez-Arancibia, G. Soberon-Chavez, and P. Sanchez-Gil. 1985. Relationships among primary productivity, fisheries yield, and physical characteristics in Gulf of Mexico estuaries. (Abstr.) Estuaries 8(2B):3A.

The relationships of vegetation, primary production, and fisheries yield were investigated for a number of estuaries in the Gulf of Mexico. For 64 estuaries, total intertidal area was related to land slope, length along the coast, and open water area. Emergent vegetation area was related to rainfall and intertidal area. For 8 selected estuaries in the U.S. and Mexico, total production was related to total area. Average productivity increased with increasing wetland area and freshwater inflow. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

El-Sayed, E. S. and C. C. Trees. 1980. Ecological studies of phytoplankton in the Gulf of Mexico during NOAA/NMFS OREGON II cruise. Tech. Rept. 80-8-T, Texas A&M Research Foundation Project RF 4224. 53 pp.

Phytoplankton standing crop, primary production, gelbstoff, suspended solids and inorganic nutrients were determined during the February/March 1980 Ichthyoplankton Survey Cruise throughout the Gulf of Mexico. Chlorophyll a values averaged 0.172 mg/m^3 ($n = 247$) while integrated values at eight stations averaged 15.19 mg/m^2. Continuous *in vivo* fluorescence mapping was used to contour surface chlorophyll concentrations throughout the Gulf. Primary production averaged 34.41 mg $C \cdot m^{-3} \cdot d^{-1}$ for surface samples and 1.11 g $C \cdot m^{-2} \cdot d^{-1}$ (min = 0.446, max = 2.95 g $C \cdot m^{-2} \cdot d^{-1}$) for integrated values at the eight stations.

Feijtel, T. C., R. D., Delaune, and W. H. Patrick, Jr. 1985. Carbon flow in coastal Louisiana USA. Mar. Ecol. Prog. Ser. 24(3):255-260.

Carbon (C) flux data was synthesized to estimate C flow along a salinity gradient in Louisiana's Barataria Basin, a major U.S. Gulf Coast estuary. Using a mass balance approach, an estuarine C surplus of 150 to 250 $g \cdot m^{-2} \cdot yr^{-1}$ was found, which originated primarily in the tidal salt marsh. Carbon export from marshes to adjacent water bodies decreases with distance from the Gulf of Mexico. The Barataria Basin marshes function as important global C sinks within this export gradient. High community respiration, methane emission, and C accretion resulting from annual carbon fixation reduce carbon export from the northern part of the Basin. Higher primary production, low community respiration and low methane evolution make the southern part of the Basin a source of aquatic carbon. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Flint, R. W. 1984. Phytoplankton production in the Corpus Christi Bay estuary. Contrib. Mar. Sci. 27:65-83.

Primary production, ammonium concentration, salinity, temperature, pH, surface light intensity and light penetration were monitored at six stations in the Corpus Christi Bay estuary (including Nueces Bay) from June 1981 through October 1983. ^{14}C-labelled carbon uptake was performed using *in situ* incubations of samples taken from 0.5 and 1.0 m depths for four hours centered around local noon. Daily integrated primary production (mg $C \cdot m^{-2} \cdot d^{-1}$) was calculated for the photoperiod of the date of incubation and from the photic zone or water column depth, whichever was less. The grand mean (all stations, all years) was 479.9 mg $C \cdot m^{-2} \cdot d^{-1}$. The coefficient of variation was high, 93 to 100% for Nueces Bay stations, and 65 to 79% for Corpus Christi Bay stations. River flow (upper estuary), rainfall (lower estuary), incident irradiation and Secchi disk depth (turbidity index) accounted for approximately 67 and 95% of the variability in Nueces and Corpus Christi Bays, respectively. Comparisons with other sources of carbon for this ecosystem (marshes, seagrasses, benthic algae) and with the productivity of other estuaries are discussed.

Fucik, K. W. 1974. The effect of petroleum operations on the phytoplankton ecology of the Louisiana coastal waters. M.S. thesis, Texas A&M Univ. 82 pp.

Phytoplankton standing crop, primary production, nutrient concentrations, temperature and salinity were measured on 13 cruises between June 1972 and January 1974 at two locations designated as Platform and Control stations. Drilling operations at the Platform station had a negligible effect on the phytoplankton communities of this region. Surface chlorophyll a averaged 1.51 mg/m^3 at the Platform and 1.87 mg/m^3 at the Control station. Integrated chlorophyll averaged 22.85 and 21.64 mg/m^2 at the Platform and Control stations, respectively. The average daily production at the Platform and Control stations was greater than 1,000 mg C/m^2. Increased discharge of the Mississippi River in 1973 compared to 1972 resulted in a 3- to 18-fold increase in primary production.

Herbland, A., R. LeBorgne, A. LeBouteiller, and B. Voituriez. 1984. Hydrological structure and primary production in the oriental tropical Atlantic waters. Oceanogr. Trop. 18(2):249-294.

The tropical Atlantic Ocean shows a low primary biological production except in the areas where nutrients are brought to the surface. Seasonal variations of the primary production values are significant in the equatorial area, and previously reported values of the primary production measured by the ^{14}C method are disparate and variable. Three recent discoveries have changed some ideas on the primary production processes in the tropical Atlantic Ocean: 1) the amplitude of the hydrological seasonal variations are higher than previously believed; 2) a permanent deep chlorophyll maximum exists in the nitracline, when the mixed layer is nutrient depleted; and 3) the pelagic ecosystem in oligotrophic conditions has a structure (sizes of organisms) and growth rate different from the classical pyramid food chain concept. The unity of the productive systems in the eastern tropical Atlantic (thermal domes, equatorial upwelling, and ridging) and the respective importance of the two enrichment processes (i.e., upwelling and ridging) are mentioned. An example of seasonal co-variation of chlorophyll a and nitrate distribution on a transect (from 5°N to 10°S latitude at 4°W longitude) and the zonal decrease (from 6°E to 9°W longitude) of the integrated values of chlorophyll a in the water column are given. During the cold season (July-Sept), the equatorial area is also subjected to short-term variations (days) which have important influence on the chlorophyll a integrated values. The influence of the meanders of the Lomonosov Current were also observed during the warm season (February and November). The equatorial area is a productive zone (1 to 2 g C/m^2), year round. In spite of high variations of the physical and chemical properties of the euphotic layer from summer to winter, the global production is not increased during the upwelling season, and this area remains a Typical Tropical System from a biological view point. The Typical Tropical Structure is defined and described from statistical and ecological considerations: the depth of the nitracline would reflect the intensity of the new production, and that property and the permanence of the vertical stratification are used to map the total primary production from the O_2 and nitrate historical data. Absolute values of photosynthetic C fixation cannot be done since the ^{14}C method is challenged in the oligotrophic waters. High variations of chlorophyl a values were recently observed in the equatorial area (0° to 4°W longitude) during a 13-d station visit.

Schematically, chlorophyll changes would represent diel variations of the phytoplankton biomass itself, equilibrated by a continuous consumption by herbivorous zooplankton. The problem now is to know if the tropical Atlantic as a whole is a very dynamic ecosystem, and particularly if the exported production (fish and sedimentation) is larger than believed 10 yr ago. A new strategy is necessary to solve the problem. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Herbland, A. 1984. Chlorophyll maximum in the oriental tropical Atlantic Ocean: Description, ecology, and interpretation. Oceanogr. Trop. 18(2):295-318.

The deep chlorophyll maximum (MPC) in the eastern tropical Atlantic Ocean was studied from 487 profiles made between 1975 and 1979, in the 0 to 150 or 0 to 100 m layer. Some methodological observations were noted, including: the Whatman fiber filter does retain all the chlorophyll a containing particles; the *in vivo* fluorescence (F_v) maximum and the MPC are at the same depth; the use of DCMU does not improve the chlorophyll a-F_v relationship; and the thickness and depth of the observed MPC are closely dependent on the validity of the discrete sampling. The thickness of the MPC and the chlorophyll a value at the maximum level (C_m) are negatively correlated with depth in the Typical Tropical Structure (TTS). C_m changed from 2.5 μg near the surface to 0.12 μg at 120 m. The depth of the MPC follows the depth of the nitracline. Temperature (T), light, and nutrient conditions in the MPC are significantly different from those of the mixed layer. The MPC would be frequently a phytoplankton biomass maximum, a primary maximum in the 40 to 50 m layer of the TTS (only 20 m in the equatorial upwelling), and rarely a maximum growth rate of phytoplankton. The new production would be the main driving force in the formation and maintenance of the MPC in the eastern tropical Atlantic Ocean. The other possible causes (decrease in the ratio of C:chlorophyll a of phytoplankton, sedimentation, and grazing) would be of secondary importance. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Jones, J. A. 1963. Ecological studies of the southeastern Florida patch reefs. Part 1. Diurnal and seasonal changes in the environment. Bull. Mar. Sci. Gulf and Carib. 13:282-307.

Hourly sampling of several physical and chemical features at four locations were made during August and November 1961 and March and May 1962 to determine the characteristics of the shallow patch reef environment in southeastern Florida. Measurements included: temperature, salinity, pH, dissolved oxygen, illumination, sky clarity, wind speed and direction, current velocity, rainfall, inorganic phosphorus, and nitrogen. Water column primary production (gross and net) was determined by changes in oxygen concentration in 125-ml bottles incubated within the surface 1 m of the water column between 0600 and 1200 h daily. Total system production was determined by diel changes in water column oxygen levels. Water column gross production rates varied between 0.02 and 0.06 g $C \cdot m^{-2} \cdot d^{-1}$ in August, March, and May and between 0.42 and 0.84 g $C \cdot m^{-2} \cdot d^{-1}$ in November. Water column net production rates ranged from 0.01 to 0.04 g $C \cdot m^{-2} \cdot d^{-1}$ in August, March, and May with rates of 0.28 to 0.56 g $C \cdot m^{-2} \cdot d^{-1}$ in November. Total system production was on the order of 0.9 g $C \cdot m^{-2} \cdot d^{-1}$ in November and March and 1.9 g $C \cdot m^{-2} \cdot d^{-1}$ in May and August. Jones concluded that the benthic flora were the major contributors to primary production in the patch reef environment.

LeBouteiller, A. and A. Herbland. 1984. Carbon fixation and productivity index in relation to chlorophyll and light in the equatorial Atlantic Ocean. Oceanogr. Trop. 19(2):161-180.

During a 14-d study at a fixed position at the Equator (4°W longitude) in February 1979 (SOP cruise), concentrations of chlorophyll a measured in samples taken between 25 and 50 m depth showed marked changes from day to day. Similarly, the amounts of carbon fixed during *in situ* incubations also varied. Hence, highly significant regression lines can be calculated between production and chlorophyll for each sampling depth. These equations make it possible to calculate easily the primary production from the sole chlorophyll data, provided that the available light intensities are of the same order of magnitude. They are used to predict the production for 17 stations carried out during three other cruises in the same general area (0°N latitude, 4°W longitude): CIPREA 2 (3 stations, April 1979); CIPREA 4 (13 stations, October 1979); and CIPREA 5 (1 station, January 1980). A total of 72 values of production have been calculated in this fashion; they are not statistically different from the measured values of *in situ* carbon fixation. If the profile of chlorophyll is mainly regulated by the nitrate availability, in contrast the nitrate concentration has no direct effect upon the pattern of the vertical profile of the productivity index (mg C per mg Chl a per h) which typically presents a maximum between 5 and 15 m, and decreases regularly downwards. Consequently, for an incident radiation close to the average, the vertical distribution of production, and in particular the depth of production maximum, are entirely defined by the chlorophyll profile. The productivity index varies approximately two-fold at a given value of available radiation. Observations support the hypothesis that these variations would be related to the concentration of chlorophyll. The mean cell size would also vary as a function of the chlorophyll content; in chlorophyll-poor water, cells would be very small and the productivity index would then be very high. A good adaptation to the environment, added to a specially high photosynthetic efficiency, characterize the natural assemblages of phytoplankton in the deep-sea tropical Atlantic Ocean. Effectively, a single relationship between productivity index and depth or available light allows one to describe the primary production of the four cruises, even when two opposite situations are compared; the mixed layer is nitrate depleted in one case, not in the other, due to the input of nutrient-rich waters by the equatorial divergence. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Ortner, P. B., R. L. Ferguson, S. R. Piotrowicz, and L. Chesal. 1984. Biological consequences of hydrographic and atmospheric advection within the Gulf Loop Intrusion. Deep-Sea Res., Part A 31(9A):1101-1120.

This paper discussed copper toxicity to plankton, weather mixing layers, and Gulf of Mexico plankton productivity.

Ortner, P. B., R. L. Ferguson, S. R. Piotrowicz, L. Chesal, G. Berberian, and A. V. Palumbo. 1984. Biological consequences of hydrographic and atmospheric advection within the Gulf Loop Intrusion. Deep-Sea Res. 31:1101-1120.

A station in the Gulf Loop intrusion at 25°30'N latitude, 87°00'W longitude was sampled repeatedly for eight days in 1981 (30 January - 6 February). Chlorophyll, ATP, bacterial biomass, dissolved free amino acids, nutrients, primary production, zooplankton biomass, and sensitivity to copper additions were among the parameters measured. Passage of a front associated with a continental high temporarily deepened the mixed layer but did not necessarily increase nutrients. Primary productivity increased from 14 to 64 mg $C \cdot m^{-2} \cdot h^{-1}$ and bacterioplankton increased from 4.3 to 6.1 X 10^{13} cells/m^2. Passage of a low salinity lens with elevated temperature coincided with the mixing event. Phytoplankton populations within the low salinity lens were relatively insensitive to copper additions due to high sequestering of added copper by qualitatively distinct marine humus. The authors suggest that vertical redistribution of biomass may have decoupled zooplankton grazing from primary production contributing to increases in phytoplankton and bacterioplankton standing stocks.

Randall, J. M., J. W. Day, Jr., and K. G. Teague. 1985. Spatial and temporal variability of aquatic primary productivity in a highly turbid Louisiana estuary. (Abstr.) Estuaries 8(2B):22A.

Aquatic primary productivity was measured in Four League Bay, a shallow (2 m) bay adjacent to the Atchafalaya River delta. The upper bay site is dominated by very turbid, nutrient-rich river water (0 ppt salinity), while waters at the lower bay site, 4 km from the Gulf of Mexico, vary between 0 and 20 ppt, depending on river flow, winds, and tides. Light gradients at both stations are generally very steep and Secchi depths average 25 cm (range: 5 to 80 cm). Because high variability in rates of vertical mixing are expected due to variable winds and currents, comparisons of several rates of vertical motion were made. These comparisons enabled the authors to ascertain the effects of vertical mixing through the light gradient on net primary production and to make more realistic production estimates where mixing effects were significant. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Roman, M. R., M. R. Reeve, and J. L. Froggatt. 1983. Carbon production and export from Biscayne Bay, Florida. I. Temporal patterns in primary production, seston and zooplankton. Est. Cstl. Shelf Sci. 17:45-59.

Five stations along a transect from the western shore of Biscayne Bay, FL to the Florida Current were sampled monthly for one year. Variables measured included: seston particulate organic carbon, ATP, chlorophyll a in the water column and surface sediments, water column primary production, nitrate and nitrite, and zooplankton. Particulate carbon, ATP, water column chlorophyll, primary production and zooplankton decreased along the seaward transect. Annual primary production ranged from 13 to 46 g $C \cdot m^{-2} \cdot yr^{-1}$. Chlorophyll in the bay ranged from 1 to 3 mg/m^2, while chlorophyll in the surface centimeter of sediment ranged from 50 to 300 mg/m^2. Over 90% of the total primary production is by submerged macrophytes and benthic algae. The high zooplankton biomass in the bay is most likely sustained by macrophyte detritus and the resuspension of benthic diatoms.

Trees, C. C. 1985. Remote sensing of ocean color in the northern Gulf of Mexico. Ph.D. diss., Texas A&M Univ. 258 pp.

Coastal Zone Color Scanner (Nimbus-7) images during a 17-mo period (November 1978 - March 1980) showed large variability in the spatial and temporal distributions of pigment fronts. The mean pigment concentration during the 17-mo period was 3.30 ± 1.45 mg/m^3. A correction factor of 1.67 was applied to the pigment concentration to correct for the tendency of the standard fluorometric method to underestimate chlorophyll a concentrations. A primary productivity algorithm was investigated using historical ground truth data on primary productivity, chlorophyll a concentration, sea surface temperature, and day length. However, a multiple regressions model could only describe 15% of the variability in production. Therefore, conversion of the mean pigment concentration to production was calculated using two different regression equations with results that ranged from 237 to 663 g $C \cdot m^{-2} \cdot yr^{-1}$. Although a wide range of primary production values could be calculated from the CZCS pigment estimates, the author feels that they would probably fall within the range of 150 to 600 g $C \cdot m^{-2} \cdot yr^{-1}$.

Vargo, G. A., K. L. Carder, W. Gregg, E. Shanley, C. Heil, K. A. Steidinger, and K. D. Haddad. 1987. The potential contribution of primary production by red tides to the west Florida shelf ecosystem. Limnol. Oceanogr. 32:762-767.

Production rates and the potential annual carbon input for blooms of the red-tide dinoflagellate *Ptychodiscus brevis (Gymnodinium* *breve*) on the West Florida Shelf were estimated from several sources, including field and laboratory measurements, a published value, and Coastal Zone Color Scanner (CZCS) imagery. Daily production rates during blooms based on measured and calculated values ranged from 0.8 to 3.8 g $C \cdot m^{-2} \cdot d^{-1}$ and were 2 to 5 times higher than literature values or rates measured during nonbloom periods. Estimates of total production for blooms in 1978, 1979, and 1982 indicate that this toxic dinoflagellate can contribute a significant fraction of the total annual production to an extensive region of the West Florida Shelf.

CALIFORNIA REGION

Abbott, M. R. and P. M. Zion. 1985. Satellite observations of phytoplankton variability during an upwelling event. Cont. Shelf Res. 4:661-680.

During spring and summer of 1981 and 1982, Coastal Ocean Dynamics Experiment (CODE) studied the processes governing the wind-driven circulation over the continental shelf. Upwelling occurred within a 50-km wide band between Cape Mendocino and Pt. Reyes; upwelling was more complex than some upwelling systems. Within this region there were several upwelling centers, associated with features in the coastline topography, characterized by anomalously low sea surface temperature (SST) and low pigment water. A large offshore plume extending 200 km was observed at the southern Pt. Arena upwelling center. Estimates of phytoplankton growth rates from Coastal Zone Color Scanner (CZCS) and drifter data were about 0.8/d in the plume. The upwelling region was bounded by warmer, higher pigment water to the north and south. As winds decreased during the upwelling episode SST and pigment concentration increased, and warm high pigment water encroached in the upwelling region.

Abbott, M. R. and P. M. Zion. 1987. Spatial and temporal variability of phytoplankton pigment off northern California during Coastal Ocean Dynamics Experiment I. J. Geophys. Res. 92:1745-1756.

Coastal Zone Color Scanner (CZCS) imagery was used to examine the distribution of phytoplankton pigment during the Coastal Ocean Dynamics Experiment (CODE) in 1981. Of the available CZCS images, 25 of sufficient quality were selected for analysis of the four-month period (March - July). The patterns of wind forcing determined the distribution of the data, which were biased to those times and regions of strong equatorward winds. Three clearly defined regions were apparent from the weighted mean pigment image and the coefficient of variation image: a 100 km wide coastal region; a region offshore characterized by low variability and low pigment concentrations; two filaments with offshore extensions of several hundred kilometers. The dynamics of the coastal region are strongly affected by topography of the coastline and longshore variations in wind forcing. Patterns of windstress curl and offshore filaments appear to be related and may explain the nearshore large-scale patterns: a northern region off Cape Mendocino, a central region near the CODE Central line, and a southern area off San Francisco. A periodicity in the width of the coastal zone of 5-6 d was observed. Empirical orthogonal function (EOF) analysis of time series during two equatorward wind events showed consistency between the pigment variability and the patterns of wind forcing.

Alldredge, A. L. and J. L. Cox. 1982. Primary productivity and chemical composition of marine snow in surface waters of the Southern California Bight. J. Mar. Res. 40(2):517-528.

The primary productivity of flocculent marine snow (fragile and amorphous macroscopic particulates) was measured for the first time using samples collected quantitatively in surface waters of the Southern California Bight. ^{14}C production rates averaged 53 ± 12 times higher on macroscopic aggregates than in equal volumes of surrounding, aggregate-free seawater. Densities of marine snow were low, ranging from 0.1 to 1.1 aggregates per liter. Only 0.1 to 9.1% of total primary production at 10 m occurred on flocculent marine snow; average values of 0.24 ± 0.15 μg C fixed per aggregate per h. Comparisons of primary productivity were made between unfiltered seawater and samples enriched with 10 to 20 aggregates. The productivity of control bottles was subtracted from that of bottles containing marine snow. Aggregates were collected by syringe using SCUBA approximately 1 to 2 km east of Isthmus Cove, Santa Catalina Island during the spring of 1981. Primary productivity was measured using ^{14}C tracer techniques (Vollenweider, 1974); seven measurements of whole water (controls) primary productivity are given. A mean value of 6.5 ± 1.2 μg $C \cdot l^{-1} \cdot h^{-1}$ was obtained for the controls.

Balch, W. M., M. R. Abbott, and R. W. Eppley. 1989. Remote sensing of primary production. I. A comparison of empirical and semi-analytical algorithms. Deep-Sea Res. 36(2):281-295.

Several algorithms were evaluated based on the ability to predict integrated primary production using remotely-sensed data. Data from the Southern California Bight Study (SCBS) and the California Cooperative Fisheries Investigations (CalCOFI) were used for algorithm testing and development. The performance of algorithms was also examined using satellite-derived pigment concentrations. Empirical algorithm prediction improved with the use of satellite pigment data. Using inputs of Coastal Zone Color Scanner (CZCS) pigment, the algorithms accounted for between 28-42% of the variance. A semi-analytical algorithm based on pigments and temperature (PT) was derived. Over 70% of the variance in surface production, as determined on SCBS cruises, was explained by the PT algorithm; 24% of the variance was accounted for when the input data was CZCS. With input from shipboard measurements 38% of the variance in integral primary production was explained. *In situ* calibration of the algorithm could increase the explained variance to 44%. Calibration here refers to the use of calibration stations (an inshore and offshore station) for each cruise contributing a data set.

Berger, W. H., K. Fischer, C. Lai, and G. Wu. 1987. Ocean productivity and organic carbon flux. Part 1. Overview maps of primary production and export production. Scripps Institution of Oceanography Reference 87-30.

The present-day productivity and the carbon flux to the seafloor are mapped as a first step toward reconstruction of the productivity of past oceans. Two global maps of primary production are presented based on: 1) the compilation of 8,000 published productivity measurements (>90% by radio carbon methods); 2) an algorithm for conversion of phosphate concentrations to productivity. Of a global ocean productivity of 26.9 Gt C/yr, the Pacific, Atlantic, Indian, and Antarctic Oceans account for 44%, 22%, 17%, and 13% respectively. The following equation, modelled after Suess (1980) is used to convert primary production to export production for the upper 1,000 m: $J(z) = 0.2\ PP/z$ where z is a 100-m depth increment and PP is primary production. Twenty percent of the primary production in the upper 100 m is therefore considered export. This export, comparable to "new" production, is 5.4 Gt C/yr. Coastal and subpolar regions accounted for one half of the total global productivity and for >80% of the downward carbon flux.

Carlucci, A. F., R. W. Eppley, and J. R. Beers. 1986. Introduction to the Southern California Bight, pp. 1-12. In R. W. Eppley, ed., Plankton dynamics of the Southern California Bight. Springer-Verlag, Berlin and NY.

A decade of work by the Food Chain Research Group, at Scripps Institution of Oceanography, on the Southern California Bight (31-34°N latitude), is summarized in the book. It reviews plankton processes and the related chemistry and physics which regulate or reflect them. The chapter presents the significance of geography, bottom topography, and climate as it relates to the habitat of plankton. Two distance regions with characteristic populations are the coastal neritic zone, defined as the continental shelf and upper slope to 200 m depth, and an oceanic regime farther offshore. Within the euphotic zone the thermocline is often associated with a layer of higher chlorophyll which may contain a species assemblage quite different from the surface layer. Few endemic species exist in the Bight, which appears continually subject to immigration and emigration. This is evidenced in El Niño conditions when tropical species invade from the equatorial regions.

Cloern, J. E. 1984. Temporal dynamics and ecological significance of salinity stratification in an estuary (South San Francisco Bay, USA). Oceanol. Acta 7(1):137-141.

Throughout 1982, four stations were monitored in San Francisco Bay for salinity distribution, chlorophyll a, nutrients and primary production. During the winter "wet" season the variations in salinity stratification coincide with spring-neap tidal variations. In the summer and fall however the bay remains well-mixed. A simple empirical function of river discharge and tidal current speed is used to predict the degree and timing of stratification. Phytoplankton biomass and primary productivity are high during prolonged salinity stratification. Increases in phytoplankton patchiness, acceleration of residual (tidally-averaged) currents, and decreases in turbidity and nutrient concentrations in the surface layer, are also associated with the stratification. Primary productivity was measured at one of the four stations using simulated, *in situ*, 24-h incubations with ^{14}C. The highest primary productivity was observed during the spring blooms and the lowest occurred during well-mixed conditions. From mid-April to mid-May, integral productivity in the photic zone exceeded 1 g $C \cdot m^{-2} \cdot d^{-1}$; a daily maximum of 1.6 g $C \cdot m^{-2} \cdot d^{-1}$ was measured on 26 April. In the summer and fall, primary productivity was consistently less than 0.3 g $C \cdot m^{-2} \cdot d^{-1}$. The annual estimate of primary production was 140 g C/m^2, half of which occurred from March to May. Results suggested that high rates of phytoplankton production resulted from increased phytoplankton biomass and decreased turbidity associated with neap tides.

Cole, B. E. and J. E. Cloern. 1987. An empirical model for estimating phytoplankton productivity in estuaries. Mar. Ecol. Prog. Ser. 36:299-305.

In previous studies it was shown that primary productivity in San Francisco Bay was highly correlated with phytoplankton biomass B (chlorophyll a concentration) and an index of light availability in the photic zone, $Z_p \times I_o$ (photic depth times surface irradiance). The data from San Francisco Bay and five other estuaries were compiled to test this relation. Daily productivity as integral P (mg $C \cdot m^{-2} \cdot d^{-1}$) was regressed against the parameter $B \times Z_p \times I_o$. Significant regressions were obtained for each estuary and over 80% of the variance in integral P was correlated with variations in $B \times Z_p \times I_o$. Results from a diversity of estuarine systems indicate that primary productivity can be estimated from simple measures of phytoplankton biomass and light availability. Responses of phytoplankton to variations in nutrient availability, temperature, salinity and photoperiod appear to exert a secondary control on production.

Cole, B. E., J. E. Cloern, and A. E. Alpine. 1986. Biomass and productivity of three phytoplankton size classes in San Francisco Bay. Estuaries 9(2):117-126.

Between January 1980 and February 1981, monthly measurements of size-fractionated chlorophyll a and productivity were made at six sites in San Francisco Bay. Results of 82 measurements suggest that spatial and temporal variations in the relative contribution of three phytoplankton size classes (<5 μm, 5-22 μm, and >22 μm) to community productivity are controlled by variations in the biomass of the three fractions. Carbon uptake was measured using

^{14}C in 24-h simulated *in situ* incubations at eight light levels. Annual mean values of total community productivity (g C•m^{-2}•d^{-1}) are provided for the six stations, as well as seasonal variation in productivities for each size class.

Cox, J. L., S. Willason, and L. Harding. 1983. Consequences of distributional heterogeneity of *Calanus pacificus* grazing. Bull. Mar. Sci. 33(2):213-226.

Grazing rates of *Calanus pacificus* were measured by two methods at 12 coastal stations between Point Loma and Point Conception, CA. Grazing rates were determined by: 1) equations and conversion factors by Mullin and Brooks (1976) based on laboratory grazing rate functions, factors for converting chlorophyll a to phytoplankton carbon, and factors for converting abundance of stages to carbon; and 2) values of laminarinase activity, a relative index of recent grazing activity. At the northerly stations, the bulk of *C. pacificus* biomass was concentrated at depths where chlorophyll concentrations exceeded a calculated critical level at which respiratory demands are met (0.9 mg/m^3 chlorophyll a). Both indices of grazing showed significant differences between northern and southern subsets of stations. The Santa Barbara Channel, proximate to active upwelling, appeared to be a favorable environment for *C. pacificus* growth. Values of 0-50 m integrated primary productivity (mg C•m^{-2}•d^{-1}), obtained by simulated *in situ* method, are provided for three stations. Values suggest that *C. pacificus* aggregates in regions of high primary production. One station midway between the regions, where a dinoflagellate bloom of *Gymnodinium splendens* occurred, had lower grazing rates and lower *C. pacificus* carbon biomass. At this station, *Parcalanus sp.* accounted for over 90% of the 333 µm zooplankton; avoidance of dinoflagellates by *C. pacificus* is suggested.

Cullen, J. J., E. Stewart, E. Renger, R. W. Eppley, and C. D. Winant. 1983. Vertical motion of the thermocline, nitracline and chlorophyll maximum layers in relation to currents on the Southern California Shelf. J. Mar. Res. 41:239-262.

Measurements of nitrate, temperature, chlorophyll fluorescence and currents were made at fixed depths in 30 m of water off Del Mar on the narrow Southern California Shelf. Vertical profiles of chlorophyll fluorescence and temperature were recorded every three hours over four days, 11-14 August 1978. Results indicated that vertical motion, associated with the semidiurnal internal tide and internal waves, could account for the distributions of temperature and nitrate. Vertical advection could also account for the temporal variation of chlorophyll fluorescence on scales less than a few hours. On longer scales however migration of phytoplankton, dominated by *Ceratium* spp., appeared to account for the vertical distribution of chlorophyll. Whereas the position of the subsurface chlorophyll maximum can vary significantly over several hours, the nitracline is stably related to the density structure over days.

Denman, K. L. and M. R. Abbott. 1988. Time evolution of surface chlorophyll patterns from cross-spectrum analysis of satellite color images. J. Geophys. Res. 93:6789-6798.

To estimate the time rate of decorrelation of surface phytoplankton chlorophyll pigment patterns, sequences of Coastal Zone Color Scanner (CZCS) images from the offshore region adjacent to Vancouver Island, Canada, were analyzed. Results for the high-pigment, high-latitude region included: estimates of pigment, from CZCS, which were lower by a factor of three than measurements from shipboard surveys; their frequency distributions were skewed in opposite directions; a discontinuity in the frequency distribution where the algorithm changes CZCS bands (at a concentration of 1.5 mg/m^3). Two-dimensional auto spectrum and cross-spectrum analysis in an array processor were conducted on image pairs and spectra of squared coherence were produced. In analogy with a time-lagged cross correlation function, plots of time vs. squared coherence estimates for several wave bands were generated. The autospectra display a power law behavior of $k^{-1.5}$ to k^{-2}. For wavelengths of 50-150 km and 25-50 km, significant coherence is lost after 7-10 d and 5-7 d respectively; coastal regions do not maintain coherence for as long a period of time as compared to regions offshore. For the band 12.5-25 km, only the offshore regions were clearly coherent for one day; after six days the coherence had dropped below significance level. These results imply that all mesoscale patterns (<150 km length scale) will not be resolved by the monthly average large-scale surface maps estimating productivity.

Dugdale, R. C., A. Morel, A. Bricaud, and F. P. Wilkerson. 1989. Modeling new production in upwelling centers: A case study of modeling new production from remotely sensed temperature and color. J. Geophys. Res. 94(C12):18119-18132.

The first application of remote sensing data in a shift-up model of new production in upwelling systems is described. Results of the model agreed well with the spatial distribution and values of new production obtained by oceanographic measurements. The rate of adaptation of nitrate uptake is predicted by the shift-up model. Surface heating rates and temperature differences between the point of upwelling and each pixel are used to obtain the time base for the production cycle. Regression equations of temperature-nitrate provided the nitrate concentrations. From the nitrate concentrations, surface distribution of new production was produced. The model can incorporate either surface temperatures or Coastal Zone Color Scanner (CZCS) imagery. The pigment concentrations from CZCS data are used to estimate diffuse attenuation coefficient and the concentrations of nitrogen on a pixel basis. Under well-mixed conditions of the euphotic zone, vertical integrations for each pixel can be made; a homogeneous distribution of phytoplankton is assumed. The development of regional models, which would utilize local oceanographic measurements to calibrate the algorithms, is advocated.

Eilers, H. P. 1981. Variations in macrophyte net production within and between four southern California salt marshes. Estuaries 4:262.

For one year, beginning Fall 1977, production estimates were determined for salt marsh macrophytes in four Southern California salt marshes: Sweetwater River Estuary, Los Penasquitos Lagoon, Upper Newport Bay, and Bolsa Bay. Averaged values of production were 3,196, 3,787, 2,150 and 2,494 g $C{\bullet}m^{-2}{\bullet}yr^{-1}$, respectively. The following parameters were also monitored: salinity of substrate, pH, nitrogen, redox, water content, temperature, and tidal level. Productions were computed by the summation of individual species production and adjustment for interval death, shedding and disappearance of dead material. Results suggest that habitat, especially drainage and salinity, exerted greater control over production than tidal level alone. High production observed at Los Penasquitos Lagoon suggests that production may be increased by reduced tidal contact.

Eppley, R. W. 1986a. People and plankton, pp. 289-304. In R. W. Eppley (ed.), Plankton dynamics of the Southern California Bight. Springer-Verlag, Berlin and NY.

Studies of effects of human impact on plankton in the Southern California Bight are discussed: 1) discharge of potentially poisonous materials into coastal waters; and 2) effects of sewage disposal. The influence of effluents on growth of plankton, by providing nutrients, may be interpreted as beneficial. Enhanced ammonium concentration in Santa Monica Bay was associated with elevated phytoplankton biomass. A negative effect was observed where chlorine, an antifouling agent in cooling water of a power plant, was discharged. Its reaction with seawater produces oxidants that reduce phytoplankton photosynthesis near the outflow. The oil well blow-out in 1966 in the Santa Barbara Channel produced deleterious effects for 1 to 2 yr (Straughan, 1971). Such events are expected to reduce phytoplankton photosynthesis short-term, if only due to reduction of light penetration. The long-term effects of petroleum releases in the Bight have not been recorded to date (1986).

Eppley, R. W. 1986b. Short term variations in primary productivity. pp. 187-195. In J. D. Burton, P. G. Brewer, and R. Chesselet (eds.), Dynamic processes in the chemistry of the upper ocean. Plenum Publishing Corporation.

Two topics in primary production are reviewed: 1) implications for studies of mixing in the surface layer, that phytoplankton are able to "remember" their past light history; and 2) the role of primary production as the driving force of the sinking flux of biogenic organic particles, and the temporal and spatial variability of production. Time scales of minutes to hours are important to the first topic. The minimum time scale of interest for the second topic is 12-24 h. These are both relatively short time scales for processes having significance for ocean chemistry and physics.

Eppley, R. W. 1989. New production: History, methods, problems, pp. 85-97. In W. H. Berger, V. S. Smetacek, and G. Wefer (eds.), Productivity of the ocean: Present and past. John Wiley & Sons Limited.

The histories of four methods of measuring new production are reviewed: 1) measurements of the flux of particulate carbon using sediment traps at the base of the euphotic zone; 2) assimilation of nitrate and phosphate during incubations; 3) calculation of a residence time for dissolved thorium, by the disequilibrium between ^{234}Th and parent ^{238}U, and combination with measurements of particulate organic carbon to produce rates of new production; and 4) using seasonal changes in oxygen, nutrients, carbon dioxide, and tritium and ^{3}He tracer distributions in the context of circulation models to estimate new production. New production (Dugdale and Goering, 1967) is defined as primary production in the euphotic zone resulting from influx of nutrients from deeper layers, atmosphere or land. Export production is defined as the flux of organic matter from the euphotic zone and is therefore equivalent to new production. It may be possible to estimate new production from satellite imagery using temperature-nitrate relationships. Empirical and analytical models have been used to estimate primary production from Coastal Zone Color Scanner (CZCS) imagery (pigment concentration); these models are in a rapid state of development. The success of application is dependent on the relation between near-surface chlorophyll and depth-integrated pigment. Recent estimates of new production and global estimates of primary production are summarized. Current estimates of annual oceanic primary production are at the upper part of the range 20-60 Gt; new production of carbon is 5-10 Gt.

Eppley, R. W. and O. Holm-Hansen. 1986. Primary production in the Southern California Bight, pp. 176-215. In R. W. Eppley (ed.), Plankton dynamics of the Southern California Bight. Springer-Verlag, Berlin and NY.

The chapter addresses the main factors which influence the magnitude of primary productivity in the Southern California Bight. Primary production in the area around Point Conception and the Channel Islands, including Santa Barbara Basin, is generally higher than that of the southern and inner regions of the Bight. The evaluations of primary productivity are based on measurements made with ^{14}C for: 1) 21 weeks in 1967 at three stations off La Jolla; 2) monthly intervals for 1969 and 1972 as a component of the California Cooperative Fisheries Investigations (CalCOFI) program (Owen and Sanchez, 1974); and 3) 1984 CalCOFI survey.

Data compiled from 20 cruises (220 stations) indicate average primary production in the region is 0.39 g $C \cdot m^{-2} \cdot d^{-1}$ over an area of 30,000 km^2; total production is 4.3 x 10^6 metric tons carbon/year. This is in comparison to a global ocean productivity of 30 x 10^9 metric tons carbon/year. The Bight is approximately 1.7 times more productive per unit area than the ocean average.

Eppley, R. W. and E. H. Renger. 1988. Nanomolar increase in surface layer nitrate concentration following a small wind event. Deep-Sea Res. 35(7):1119-1125.

An opportunity to study the effects of wind-forced nitrate input into the surface layer occurred during an April 1986 cruise of the Southern California Bight Studies program. Winds increased to 8-9 m/s and persisted above 5 m/s for approximately 40 h. Ambient nitrate concentrations, prior to the wind event, averaged 20 nmol above the nitracline. After the wind event maximum concentrations of 100 nmol were observed. Within a single day, the nitrate entrained from the nitracline (500 $\mu mol/m^2$) during the wind event was consumed. Rates of nitrate uptake measured in water samples incubated on deck agreed with apparent *in situ* rates of nitrate consumption. A deepening of the mixed layer of about 4 m occurred. Observed rates of primary production at two stations are provided: 666 and 716 mg $C \cdot m^{-2} \cdot d^{-1}$ following the wind event.

Eppley, R. W. and E. H. Renger. 1989. Nitrate-based primary production in nutrient-depleted surface waters off California. Oceanogr. Trop. 21:229-238.

The vertical structure of nitrate distributions of the euphotic zone, as it relates to new production, was examined on two cruises in the Southern California Bight (SCBS-24 and SCBS-25), in October of 1985 and 1986. Temperature, salinity, visible light, ^{14}C productivity, POC, PON, pigment concentration, nitrate, phosphate, and silicic acid were measured. Nitrate-based primary production was determined by multiplying the rate of nitrate use by POC/PON. Using the estimation by Harrison *et al.* (1987), that new production averaged about 64% of total ^{14}C production, profiles of nitrate-based production were derived. The range of depth integrated daily primary productivity was 0.4 to 1.5 g $C \cdot m^{-2} \cdot d^{-1}$. New production, as nitrate-based production, occurs primarily in the lower layer of a two-layer euphotic zone. The nitracline bisects the euphotic zone into an upper nutrient-poor, light-rich layer and a lower layer of higher nutrients and less light. The nitrate-based production of the upper layer was small, albeit not trivial. Approximately half of the primary production occurs above the nitracline. The results emphasize the importance of nitrate-based production within the nitracline, where 90% occurred. The source of nitrate will determine whether production is new (based on a nitrate source from outside the euphotic zone) or regenerated (from biological processes within the euphotic zone).

Eppley, R. W., A. F. Carlucci, O. Holm-Hansen, D. Kiefer, J. J. McCarthy, and P. M. Williams. 1972. Evidence for eutrophication in the sea near Southern California coastal sewage outfalls, July 1970. Calif. Mar. Res. Comm., CalCOFI Rept. 16:74-83.

Eutrophication of seawater at the Point Loma and Whites Point sewage outfalls off southern California has been demonstrated by measurements of primary productivity two to three times the normal seasonal averages along the coast. Associated with this enhanced phytoplankton production were high concentrations of chlorophyll a, adenosine triphosphate (ATP), and particulate organic carbon and nitrogen. These parameters provide evidence for high phytoplankton standing stock. However, there were no appreciable differences in the nutrients or dissolved organic constituents between outfall areas and the normal coastal background. This latter condition suggests rapid uptake of nutrients and/or effective dispersal from the outfall origins.

Eppley, R. W., F. M. H. Reid, and E. Stewart. 1984. Length of phytoplankton species patches on the Southern California Shelf. Cont. Shelf Res. 3:259-266.

Longshore measurements of chlorophyll fluorescence and temperature were recorded during a 97-km transect between San Clemente and San Diego, CA in October 1981. Water samples were collected and preserved for enumeration of phytoplankton species and microplankton. The study was designed to test the hypothesis that assemblages of species of phytoplankton (patches) can take on the length scale corresponding to the currents in which they are transported. The length scale of low frequency currents on the Southern California shelf, approximately 25 km, was determined in an earlier study (Winant, 1983). Results indicated that length scales, 22-27 km, of patches of phytoplankton species assemblages may be related to low-frequency, longshore currents. The boundaries of patches are probably not independent of changes in temperature, chlorophyll fluorescence, and bottom topography. Some of the boundaries of patches occurred at submarine canyons. That patches vary with temperature and bottom topography may reflect the modulation of low-frequency fluctuations in currents by topography, and responses of the water column to the modulation.

Eppley, R. W., E. Stewart, M. R. Abbott, and R. W. Owen. 1987. Estimating ocean production from satellite-derived chlorophyll: Insights from the Eastropac data set, pp. 109-113. In Proceedings International Symposium on Equatorial Vertical Motion, Paris, 6-10 May 1985. Oceanol. Acta.

The relation of primary production, measured with the ^{14}C method, and near-surface chlorophyll is examined for the Eastern tropical Pacific. The analysis is useful to reconstruct estimates of primary productivity from Coastal Zone Color Scanner (CZCS) derived images of chlorophyll-like pigments. Shipboard data was collected during the Eastropac expedition, consisting of seven 2-mo cruises between February 1967 and April 1968 between 20°N and 20°S latitude to 119°W longitude. Multiple regression and analytical models of primary production (Pi) were compared. The model of Smith and Baker (1978), relating Pi and Ck (near-surface chlorophyll-like pigments) to the photoadaptive state of nutrient-sufficient phytoplankton, was more successful in explaining the variation in Pi. The photoadaptive state of the plankton, reflecting its recent light history, depends upon irradiance, daylength, and depth of mixing. The values for F, a ratio of Pi/Ck, was highest for the North Equatorial Counter Current and North Equatorial Current; these waters are oligotrophic and stratified. F was lowest in the nutrient-rich Southern Equatorial Current. Changes in primary production resulted from changes in stability and mixing. A knowledge of the temporal and spatial variation in mixing may be necessary to make accurate estimates of production from satellite-derived pigment concentrations.

Fellows, D. A., D. M. Karl, and G. A. Knauer. 1981. Large particle fluxes and the vertical transport of living carbon in the upper 1,500 m of the northeast Pacific Ocean. Deep-Sea Res. 28A(9):921-936.

Vertical distributions and magnitude of adenosine triphosphate (ATP), total adenine nucleotide (At), and energy charge (ECA) were measured during an experiment conducted 80 km southwest of Point Sur, CA. The objective of the study was to estimate the contribution of biomass (living) carbon to the total particulate organic pools. Particulates of two classes were measured: 1) the "suspended" fraction which are fine-grained, low density, relatively abundant and collected with bottles, and 2) the larger, rarer particles captured by sediment trap. Results indicated that the larger particles with associated living organisms contribute 100 times more carbon than the "suspended" particles. Primary productivities, measured during the four-day drift of the MULTITRAP, were derived using metal-free collection and processing procedures (Knauer and Martin, 1981). Water samples were inoculated with $H_{14}CO_3^-$ and incubated *in situ* for periods ranging from 4-6 h. Primary productivities were determined from equations in Strickland and Parsons (1972). Average daily carbon production derived from ^{14}C measurements was 9-22 μg C/l. The net daily carbon fixation in the euphotic zone averaged 760 mg C/m^2. This value represents production of particulate organic matter restricted to surface waters and the process of photosynthesis. RNA synthesis however can be detected at depths well below the euphotic zone. This additional production of POM occurs at the expense of dissolved organic nutrients.

Fiedler, P. C. 1984. Satellite observations of the 1982-1983 El Niño along the U.S. Pacific coast. Science 224:1251-1254.

Several effects of the 1982-1983 El Niño were revealed in satellite infrared temperature images: warm sea surface temperatures with larger coastal anomalies, weakened coastal upwelling, and changes in the pattern of surface circulation. Coastal Zone Color Scanner imagery of pigment concentration indicated that productivity was reduced during the event. Imagery suggests that the initial reduction was associated with weakened upwelling. Conventional shipboard or buoy data would not have provided the extensive and synoptic coverage of the El Niño that satellite imagery presents.

Foster, M. S. and D. R. Schiel. 1985. The ecology of giant kelp forests in California: A community profile. U.S. Fish Wild. Serv. Biol. Rept. 85(7.2). 152 pp.

A review of the literature on California kelp forests attempts to compare and contrast this system with forests in other areas. Chapter 1 introduces the biology and ecology of surface canopy kelps, especially *Macrocystis pyrifera*. Chapter 2 reviews physical, chemical, and geological aspects of the environment. Community structure and energetics are described in Chapter 3; Chapter 4 examines the natural history of organisms in the kelp forest. Chapter 5 addresses problems in present understanding of kelp forest ecology. Resource management is the focus of Chapter 6, and Chapter 7 provides a summary. Estimations of primary productivity, difficult to obtain in a plant which has large, complex morphology, include: 1) the monthly range of 0.4-3.0 wet kg/m^2 (Gerard, 1976) for Monterey (based on frond addition and growth measurements); and 2) 152 wet kg$\cdot$m$^{-2}\cdot$yr^{-1} off San Diego (Jackson, 1977). The productivity survey suggests that a total net macroalgal primary productivity (including all of the understory plus *Macrocystis*) might be the highest of any plant community.

Fuhrman, J. A. and F. Azam. 1982. Thymidine incorporation as a measure of heterotrophic bacterioplankton production in marine surface waters: Evaluation and field results. Mar. Biol. 66(2):109-120.

A procedure for measuring growth in bacterioplankton, based on incorporation of tritiated thymidine into DNA, is tested under field and laboratory conditions. The technique is specific for nonphotosynthetic bacteria and provides good estimates of production for all "active" (growing) bacteria. Sampling was conducted at 16 stations in conjunction with the Southern California Bight Study (SCBS) program during Cruise SCBS-16 in May 1980. It was estimated that bacterioplankton production is about 5-25% of the primary production in the Southern California Bight; at a 50% assimilation efficiency, bacterioplankton would conserve 10-50% of the total fixed carbon.

Fuhrman, J. A., R. W. Eppley, A. Hagstrom, and F. Azam. 1985. Diel variations in bacterioplankton, phytoplankton, and related parameters in the southern California Bight. Mar. Ecol. Prog. Ser. 27:9-20.

This study focused on the following objectives: 1) a determination of the coupling between microheterotrophs and phytoplankton in the shelf region off Southern California; 2) a comparison of different measures of primary and bacterial secondary production; and 3) to examine whether restrictions on the sampling time of microheterotrophs are as important as for studies of autotrophs. To examine the diel cycles of biological and related parameters, two experiments were performed, 8-9 May and 3-4 October 1981. Sampling strategy was to follow drogues by ship and collect samples from an isotherm using a CTD rosette system. The following parameters all exhibited significant diel changes: chlorophyll, ^{14}C bicarbonate incorporation, bacterial abundance and thymidine incorporation, frequency of dividing cells (FDC), carbon and nitrogen and their ratios, and dissolved oxygen. During the day, all parameters had higher values than at night; this suggests a coupling between the microheterotrophs and phytoplankton. A maximum in the ratio of *in vivo* to extracted chlorophyll a fluorescence was observed at midnight and the minimum occurred at midday. An endogenous rhythm is suggested by this result. Experiments were conducted 6 km offshore of Dana Point at depths of 100 and 500 m in a moderately oligotrophic region. Nearly identical rates of primary production were obtained for 27-h incubation (46 μg C/l) and seven back-to-back incubations ranging from 1-4.7 h each (totaling 27 h and giving a production of 46.7 μg C/l). Estimates of primary production from the ^{14}C-method and the net changes in dissolved oxygen, differed by approximately 10% and were not significantly different.

Gerard, V. A. 1976. Some aspects of material dynamics and energy flow in a kelp forest in Monterey Bay, California. Ph.D. thesis, Univ. of California, Santa Cruz. 173 pp.

The dynamics of the attached kelp population and the drift kelp are studied within the Hopkins Marine Life Refuge at Point Cabrillo, CA. The drift kelp is composed of broken off fronds, smaller fragments, and whole plants that have been detached. The relationships and temporal fluctuations in standing crops, production and loss of *Macrocystis pyrifera* were examined. Each season, from Fall 1973 through Winter 1976, measurements of plant density, plant size, and frond size were made. Estimated standing crop of *M. pyrifera* ranged from 6.3 kg/m^2 in Spring 1974 to 0.7 kg/m^2 in Spring 1975. No apparent seasonal trends in kelp standing crop were observed. Production as total wet weight of *M. pyrifera* per month ranged from 0.4-3.0 kg/m^2, with an average monthly value of 1.9 kg/m^2. An annual production of 23 kg/m^2 or 50 metric tons for the 2,000 m^2 study area was estimated. Cycles of loss and recruitment are generated by severe winter storms and holdfast damage by isopods. A relation between the frequency and severity of environmental fluctuations and the persistence of biomass has been observed in many kelp communities.

Goodman, D., R. W. Eppley, and F. M. H. Reid. 1984. Summer phytoplankton assemblages and their environmental correlates in the Southern California Bight. J. Mar. Res. 42:1019-1049.

Weekly observations of physical and chemical properties and phytoplankton assemblages were obtained from mid-April to mid-September in 1967 at three stations north of La Jolla, CA. Results of principal component analysis resolved 25 selected taxa of phytoplankton into four species assemblages. Two were considered characteristic of upwelling situations and one was dominated by a "red tide" dinoflagellate, *Gonyaulax polyedra*, associated with non-upwelling conditions. Distinct sets of temperature-salinity-nutrient conditions were associated with the periods of abundance of each assemblage. During the observations there were three peaks in phytoplankton abundance. Nutrient abundance was associated with each of these events (Eppley *et al.*, 1970).

Hakanson, J. L. 1987. The feeding condition of *Calanus pacificus* and other zooplankton in relation to phytoplankton pigments in the California Current. Limnol. Oceanogr. 32(4):881-894.

In April 1984, *Calanus pacificus* copepodite V stages were collected at 40 stations in the California Current and examined for wax ester and triglyceride content. Wax ester and dry weight of *Calanus* has higher correlations with primary production than with total integrated chlorophyll a. The Southern California Bight had low to intermediate chlorophyll a concentrations, which was reflected in the copepod feeding condition. Measurements of primary productivity were taken at 12 of the 40 stations as part of the California Cooperative Fisheries Investigations (CalCOFI) sampling program (Cruise Report SIO Ref. 84-25).

Hayward, T. L. 1986. Variability in production and the role of disturbance in two pelagic ecosystems, pp. 133-140. In A. C. Pierrot-Bults, S. van der Spoel, B. J. Zahuranec, and R. K. Johnson, (eds.), Pelagic Biogeography. UNESCO Technical Papers in Marine Science, Vol. 49.

The patterns of production and standing stocks in the central North Pacific and California Current (CC) ecosystems are compared in order to examine whether these environments are sufficiently stable so that interspecific interactions have a major role in determining species structure. The CC has greater seasonal and interannual variation in primary production and standing stocks than the central North Pacific. Variability in given biotic properties is low on all spatial and temporal scales in the central North Pacific. Species proportions close to "steady-state" suggest that interspecific interactions play the dominant role in determining species composition. Mesoscale patchiness in the CC is the dominant feature; properties may differ by a factor of 50 between patches. The great variability in species proportions between samples in the CC should decrease the relative importance of interspecific interactions in regulating the community.

Heine, J. N. 1983. Seasonal productivity of two red algae in a central California kelp forest. J. Phycol. 19:146-152.

The *in situ* productivity of two understory macrophytes, *Botryocladia pseudodichotoma* (Farl.) Kyl. and *Rhodymenia californica* var. *californica* Kyl., was measured monthly from July 1980 through June 1981 at 11 m in the *Macrocystis pyrifera* forest in Monterey Bay. Gross productivities for the two species were highest in October: 1.23 and 4.62 mg C per g dry wt per h for *B. pseudodichotoma* and *R. californica* var. *californica* respectively. Rates were generally lower in summer and respiration was variable throughout the year for both species. Productivity in populations of *B. pseudodichotoma* at 11 m was 45% higher than productivity for shallow (3 m) populations incubated at 11 m. When 11 m populations of *B. pseudodichotoma* were incubated at 3 m they had 50% higher productivity than the shallow population. At 3 m shade-adapted plants had 77% higher productivity than populations growing in the sun. Respiration in shade-adapted plants was only one-half that of the sun-adapted. The lack of strong patterns in seasonal productivity and the highly variable light regime suggests that understory algae may be adapted for rapid growth during short periods of high light, regardless of the season.

Holmes, R. W., P. M. Williams, and R. W. Eppley. 1967. Red water in La Jolla Bay, 1964-1966. Limnol. Oceanogr. 12:503-512.

Between May 1964 and December 1966 five red water blooms of dinoflagellates occurred in La Jolla Bay, CA. Numerically dominant species in each bloom were: *Gymnodinium* spp. and *Cochlodinium* spp. in May 1964; *Prorocentrum micans* in April 1965; and *Gonyaulax polyedra* in June-July 1964, June-July 1965 and December 1966. Values of cell concentration and chlorophyll a as high as 20 x 10^6 cells/l and 500 μg chlorophyll a/l were observed. Organisms occurred in defined patches during the day, but dispersed at night. Measurements of photosynthetic rate, nitrate reductase activity, and motility indicated that the dinoflagellates were physiologically active, even in the densest patches. The carbon and nitrogen content of organisms often exceeded that of the surface water. Increases in dissolved organic carbon, orthophosphate and monophosphate esters were associated with the demise of the blooms. Grazing by *Polykrikos* sp., *Noctiluca* sp., and rotifers decimated the May 1964 bloom. Blooms of dinoflagellates were associated with steep shallow thermoclines.

Karl, D. M. and G. A. Knauer. 1984. Detritus-microbe interactions in the marine pelagic environment: Selected results from the VERTEX experiment. Bull. Mar. Sci. 35(3):550-565.

The results from three stations monitored in the north Pacific Ocean as part of the Vertical Transport and Exchange Program (VERTEX) are presented. Sediment traps were positioned at 10-12 depths in the mesopelagic zone (100-2,000 m) at each station to collect sinking particulate matter. The goals of the program were: 1) to determine the magnitude and downward vertical flux of selected elements; 2) to examine the relationship between sinking organic matter, microbial biomass and rates of decomposition; and 3) to obtain measures of metabolic activity of microorganisms associated with the particles. The *in situ* interactions of microbes and detritus were determined by a combination of *in situ* extraction/preservation techniques and unpreserved traps. "Hotspots" of isolated productivity with large enough effects to produce an increased flux or organic matter with increasing water depth were discovered. Chemolithotrophic bacterial activity (production to organic matter from CO_2) is proposed as the source of the *in situ* carbon production. VERTEX data was used to develop a detritus-microbe interaction model. One of the stations, VERTEX I, located 160 km off Pt. Sur was studied in 1980. Primary autotrophic carbon production was measured using ^{14}C. For the four VERTEX sites reviewed, the ratio of total microbial carbon production to primary carbon production averaged 1.8. Values of integral primary production are not provided in this review.

Knauer, G. A. and J. H. Martin. 1981. Primary production and carbon-nitrogen fluxes in the upper 1,500 m of the northeast Pacific. Limnol. Oceanogr. 26(1):181-186.

The relation between primary production and levels of POC and PON was evaluated from material collected in free-floating traps. Traps were deployed at six depths from a single line 80 km off the Monterey Peninsula, CA, and allowed to drift for 6.17 d. Daily ^{14}C estimates of primary production were obtained from three separate incubations (morning, noon, and afternoon) of 2-4 h using metal-free collection. The range of values of integrated primary production for days 1 through 5 was 54-68 mmol $C \cdot m^{-2} \cdot d^{-1}$. The high rate of primary production was not measured during an upwelling period and is considered high in comparison with the world average for upwelling areas [68 mmol $C \cdot m^{-2} \cdot d^{-1}$ (Ryther, 1969)]. Of the total fixed primary production however only 22% reached 65 m (a depth just below the 1% light level). A date for the experiment is not provided in the article.

Knauer, G. A., J. H. Martin, and D. M. Karl. 1984. The flux of particulate organic matter out of the euphotic zone. Global Ocean Flux Study. Proceedings of a Workshop, National Academy of Sciences. pp. 136-150. National Academy Press, Washington, D.C.

Three values of primary production (mg $C \cdot m^{-2} \cdot d^{-1}$) are provided for stations within the region of the MMS survey: 690 for central California in December 1978; 520 for central California VERTEX 1, September 1980; and 1,140 for central California VERTEX 5c, June 1984.

Lee, C. and C. Cronin. 1984. Particulate amino acids in the sea: Effects of primary productivity and biological decomposition. J. Mar. Res. 42:1075-1097.

The flux of amino acids associated with sinking particles, collected by sediment traps, were measured at two sites in the Pacific Ocean. Results were compared with measurements from six other sites; one site, 100 km off Pt. Sur, CA (VERTEX 1) is within the region of interest for the MMS survey. For this site, productivity measurements are reported as part of the VERTEX 1 program (Karl and Knauer, 1984). Comparisons showed that the flux of amino acids on sinking particles is related to primary productivity. Amino acid flux increases with productivity as a power function; for every 10-fold increase in productivity, the flux of amino acids increases by about 250-fold. Amino acid flux peaked seasonally with the peak in surface production.

Mahall, B. 1981. Effects of natural environmental factors on production of *Spartina* and *Salicornia* in tidal marshes of San Francisco. Estuaries 4:262.

Measurements of annual maximum standing crop were used to derive net production of *Spartina folissa* and *Salicornia virginica* along salinity and tidal gradients in two marshes. Production and biomass of *Spartina* declined landward with increasing soil salinity, while *Salicornia* biomass and production declined seaward with increased tidal flooding.

Martin, J. H., G. A. Knauer, and W. W. Broenkow. 1985. VERTEX: The lateral transport of manganese in the northeast Pacific. Deep-Sea Res. 32(11):1405-1427.

The distribution of dissolved manganese (Mn) from 0-2,000 m was examined during the VERTEX program on Cruises IV and V at five stations in the northeast Pacific. Common features of vertical profiles included: surface maxima, subsurface minima and low levels at depth, and association of the maxima with the oxygen minimum layer. The maxima in Mn appears to be the result of lateral advective transport processes; *in situ* particulate scavenging was not responsible for the minimum in dissolved Mn. The minimum was associated with the shallow salinity minimum, a water mass which sinks in higher latitude (47°N latitude) and flows to the south and east. The flow at the Mn maximum, or oxygen minimum, is northward and offshore. Mn should provide a tracer of great potential due to its inshore enrichment and depletion offshore. A station map for VERTEX Cruises II, III, IV, and V is useful to identify sites of measurement of primary productivity made during the program and addressed in other papers by these authors.

Martin, J. H., G. A. Knauer, D. M. Karl, and W. W. Broenkow. 1987. VERTEX: Carbon cycling in the northeast Pacific. Deep-Sea Res. 34(2):267-285.

The flux of particulate organic carbon, measured with free-floating particle traps, is examined for nine stations during the VERTEX program. The flux data from six offshore stations (2, 4, 5, II, III, NPEC) were combined and fitted to a normalized power function to obtain mean flux rates. The fluxes varied only by a factor of 2.4. Solute regeneration rates, oxygen utilization rates and regeneration rates for C, H, and N were also estimated. Trap-derived new productivities in the open Pacific (1.5 mol $C \cdot m^{-2} \cdot yr^{-1}$) were substantially less than those estimated from oxygen utilization rates in the Sargasso Sea (4 mol $C \cdot m^{-2} \cdot yr^{-1}$). Lateral transport and decomposition of slow or non-sinking POC in the Sargasso Sea may be responsible for the discrepancy. Global estimates of ocean productivity, 42 Gt/yr, were determined from open ocean primary productivities of 130 g $C \cdot m^{-2} \cdot yr^{-1}$. Removal of organic C from the surface via particulate sinking (new production) is on the order of 6 Gt/yr. Fifty percent of this C is regenerated in the upper 300 m of the water column. The ratio of new production (trap measurements) to total primary production (via ^{14}C) is 0.14. Primary productivities from three stations off California (i.e., Stations Pre-VERTEX, 1, and 2) are relevant to the survey by MMS. The primary productivity at Station 2, at the western edge of the California Current, was lower than at Stations Pre-VERTEX and 1, which were more coastal (119 versus 250 and 420 g $C \cdot m^{-2} \cdot yr^{-1}$, respectively). It was concluded that the ^{14}C technique yields reasonable estimates of primary productivity provided that heavy metal contamination is prevented.

Matrai, P. A. and R. W. Eppley. 1989. Particulate organic sulfur in the waters of the Southern California Bight. Global Biogeochem. Cycles 3(1):89-103.

The concentration, distribution and flux of particulate organic sulfur in suspended and sinking particles was studies during four cruises in the Southern California Bight: Cross-2, May 1986; Cross-3, October 1986; SCBS-28, August 1987, and CaBS-7, October 1987. The relationships between sulfur, carbon, nitrogen and chlorophyll in particulate matter in coastal waters are discussed. The subsurface maximum in suspended particulate organic sulfur (POS) deepened offshore. The average POS concentrations in suspended matter within the euphotic zone was 1.26 ± 0.5 μg S/l. Downward fluxed of mass, carbon, nitrogen and sulfur of sinking particulate matter increased with depth to 350 m. Integral primary productivities, determined by the ^{14}C method (Steeman-Nielsen, 1952), are presented for nine stations during SCBS-28 and three stations during CaBS-7. Selection of sampling depths was determined from the downcast irradiance profile. Samples were incubated for 24 h at surface seawater temperature. Primary production was highest above the chlorophyll maximum; this is typically observed in the area (Eppley and Holm-Hansen, 1986). The ranges in primary production ($mg\ C \cdot m^{-2} \cdot d^{-1}$) during SCBS-28 and CaBS-7 are 634-2,070 and 634-1,030, respectively.

Michaelsen, J., X. Zhang, and R. C. Smith. 1988. Variability of pigment biomass in the California Current as determined by satellite imagery, 2, temporal variability. J. Geophys. Res. 93:10883-10896.

Characteristics of temporal variability in the California Current System (CCS) are analyzed using 129 images collected by the Coastal Zone Color Scanner (CZCS) over a 30-mo time series between August 1979 and December 1981. A periodic annual cycle accounts for 20-25% of the variance in satellite-derived chlorophyll. Analysis of ship-based chlorophyll measurements, collected during the Southern California Bight Studies (SCBS) cruises, revealed a winter peak only in the upper layer of the euphotic zone and a peak in the vertically integrated chlorophyll in the spring upwelling season. Satellite chlorophyll measurements will need to be coupled with a seasonally varying model of mixed layer depth and upwelling strength to produce reasonable estimates of total chlorophyll production. The most important mode of variability, accounting for one third of the variance, consists of coherent fluctuations throughout the entire study area; this likely represents a biological response to atmospheric forcing of the physical structure of the ocean. The second component shows an inverse relationship between the regions north of Point Conception and south of San Diego. That the north and south are out of phase, and that the oscillation is strongest near the coast, suggests that continental shelf waves may be important. A strong 5-6 d oscillation in the availability of useful satellite imagery modulated the studies of intra-annual variability. The oscillation results from a combination of satellite orbital dynamics, which generate images 4 out of 6 d, and cloud cover oscillation which determines the availability of clear images. The imagery is biased by the cloud cover oscillation which is also present in coastal winds affecting surface circulation. In-phase fluctuations throughout the coastal region of southern and central California characterize the predominant mode of nonseasonal variability.

Napp, J. M. 1987. Primary productivity maxima in the Southern California Bight: Distribution, predicted depth and nutritional content. Oceanol. Acta 10(3):329-337.

The spatial and temporal vertical distributions of primary productivity and two indices of plant biomass (particulate carbon and chlorophyll a) are examined in the Southern California Bight. An ability to predict the depth of the primary productivity maximum would enable *in situ* feeding experiments of zooplankton to be conducted in this hypothesized region of enhanced grazing. Vertical distributions of primary productivity were more stratified and less variable seasonally than microzooplankton biomass. The primary productivity maximum is, in general, above the particulate carbon maxima, which is shallower that the chlorophyll a maxima. There is only a slight difference between the carbon to nitrogen ratio of the particulate matter, an index of food quality, between the primary productivity and chlorophyll a maxima. A linear equation relating depth of the primary productivity maximum to chlorophyll a maximum, one percent light level and daily insolation, was useful to predict the primary productivity maximum in the spring. Predictions of the depth of the maximum in other seasons were not successful, suggesting the seasonal dependence of variables. The investigation is based on data from 21 cruises (1974-1983; 230 vertical profiles) of the Southern California Bight Study (SCBS). The main data set of 16 stations (SCBS 1-21) was supplemented with data from six additional cruises. Depths sampled were determined by the penetration of surface-incident sunlight so as to match the specific neutral-density screens chosen for simulated *in situ* primary productivity measurements. Methods are described by Eppley *et al.* (1979).

Nelson, J. R., J. R. Beers, R. W. Eppley, G. A. Jackson, J. J. McCarthy and A. Soutar. 1987. A particle flux study in the Santa Monica-San Pedro Basin off Los Angeles: Particle flux, primary production, and transmissometer survey. Cont. Shelf Res. 7(3):307-328.

The flux of organic carbon at 100 m, measured in nearshore basins off Los Angeles, was 15% of the mass flux (as dry weight) and 5% of the rate of primary production measured in the euphotic zone. The biomass carbon of microorganisms was dominated by nano- and picoplankton-size categories. During a six month (May-November) sediment trap deployment, the deeper trap at 824 m had a higher mass flux, indicating the near-bottom transport of resuspended sediments. Primary productivities were measured by the ^{14}C method (Eppley *et al.*, 1979) at a total of six stations during the two short-term sediment trap drift studies. Six sampling depths were determined from irradiance profiles and neutral density screens were used to simulate percent surface illumination for incubations. The mean primary production for the six stations was 730 mg $C \cdot m^{-2} \cdot d^{-1}$.

North, W. J. 1971. The biology of giant kelp beds (*Macrocystis*) in California. Nova Hedwigia. 32:1-600.

The volume provides a thorough, extensive compilation of the biology and ecology of the giant kelp *Macrocystis*. Among the many topics covered is the question of kelp vs. phytoplankton productivity. Using an estimate of one ton per acre-year of net phytoplankton production in coastal water, a 10-mi square would produce 64,000 tons/year. A kelp harvest of 100,000 wet tons is equivalent to about 9,000 tons of organic matter. These values suggest that removal of organic matter via kelp harvesting is small compared to the synthesis of organic matter by phytoplankton off southern California.

Onuf, C. P. 1981. Meters vs. kilometers and months vs. years: The causes and consequences of the variability in the biomass and production of a Southern California salt marsh. Estuaries 4:262.

Biomass of *Salicornia virginica* at Mugu Lagoon, Ventura County, CA, was highly variable between adjacent 1/16 m^2 plots, between transect; between locations set at different distances from the mouth of the lagoon; and between months. Significant interactions were found between years and locations, and between years and distance from the edge of the marsh. Variation between years was associated with severe flooding in 1978 and 1980, after which higher biomass was observed. Results suggest that patch formation by flotsam deposition is a major determinant of production.

Owen, R. W., Jr., and C. K. Sanchez. 1974. Phytoplankton pigment and production measurements in the California Current region, 1969-72. U.S. Dept. of Commerce, NOAA, Data Rept. 91. 184 pp.

Data presented on phytoplankton production, standing stocks, and environmental characteristics, represent the first set of measurements from which seasonal cycles, annual variability and coherent spatial variations in the California Current region can be described. Measurements were made from 1969 through 1972 during the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. The basic CalCOFI station plan includes stations along transects perpendicular to the coast from southern Baja California to northern California. Water samples from 10 depths were collected for fluorometric pigment analysis and production; sampling depths were determined by the Secchi depth or by standardized depths. Determinations of mixed layer depth, from salinity-temperature-depth (STD) systems, and solar radiation were also made.

Pace, M. L., G. A. Knauer, D. M. Karl, and J. H. Martin. 1987. Primary production, new production and vertical flux in the eastern Pacific Ocean. Nature 325(26):803-804.

A new model of the vertical flux of particulate organic carbon (POC) and particulate organic nitrogen (PON) is presented. Measurements of primary production and fluxes were made during the VERTEX (Vertical Transport and Exchange) Program in the northeast Pacific. Vertical fluxes for the upper 2,000 m were measured with free floating particle traps at nine stations in the Pacific. Primary productivity was measured using heavy-metal-free ^{14}C method (Fitzwater *et al.*, 1982) at each site. Measurements of primary productivity made at five oligotrophic sites during VERTEX ranged from 245-760 mg $C \cdot m^{-2} \cdot d^{-1}$ with a median value of 400 mg $C \cdot m^{-2} \cdot d^{-1}$. Primary productivity data used in the Suess model were lower than measurements made in the VERTEX program. Predicted POC fluxes for the VERTEX model are 3-5 times greater than the Suess model. Station locations and individual measurements of primary productivity are not provided in the article. Mean primary productivity for VERTEX was 517 mg $C \cdot m^{-2} \cdot d^{-1}$.

Pelaez, J. and J. A. McGowan. 1986. Phytoplankton pigment patterns in the California Current as determined by satellite. Limnol. Oceanogr. 3:927-950.

A high degree of heterogeneity is observed in the satellite-derived phytoplankton pigment concentrations off California. Within the California Current recurrent phytoplankton pigment structures can be identified. Dominant features include: two sharp boundaries of the California Current several hundred kilometers long; eddies of low pigment concentration interwoven with structures of higher pigment inshore; an intrusion of low pigment in the Southern California Bight and a region of higher pigment farther offshore; eddies which appear "attached" to shallow coastal regions; and rings of the California Current spawned far offshore. Throughout the year there is remarkable continuity of the larger scale structures of phytoplankton pigment; shifting, wobbling and erosion of the structures does occur. Spring and summer structures are stronger than those in other seasons. For a given season there is continuity in patterns of distribution over the three years analyzed (1980-1982). Examination of the dynamic height field and satellite-derived sea surface temperature indicate that ocean circulation is important in generating the distributions of phytoplankton pigment.

Peterson, D. H., M. J. Perry, K. E. Bencala, and M. C. Talbot. 1987. Phytoplankton productivity in relation to light intensity: A simple equation. Est. Cstl. Shelf Sci. 24:813-832.

A simple exponential equation is used to describe photosynthetic rate as a function of light intensity for a variety of unicellular algae and higher plants where photosynthesis is proportional to

$(1-e^{-\beta I})$. The parameter β ($= I_k^{-1}$) is derived by a simultaneous curve-fitting method, where I is incident quantum-flux density. The exponential equation is tested against a wide range of data and is found to adequately describe P vs. I curves. The errors associated with photosynthetic parameters are calculated. A simplified statistical model (Poisson) of photon capture provides a biophysical basis for the equation and for its ability to fit a range of light intensities. The exponential equation provides a nonsubjective simultaneous curve fitting estimate for photosynthetic efficiency (a) which is less ambiguous than subjective methods: subjective methods assume that a linear region of the P vs. I curve is readily identifiable. Photosynthetic parameters β and a are used widely in aquatic studies to define photosynthesis at low quantum flux. These parameters are particularly important in estuarine environments where high suspended-material concentrations and high diffuse-light extinction coefficients are commonly encountered.

Prézelin, B. B., R. R. Bidigare, H. A. Matlick, M. Putt, and B. Ver Hoven. 1987. Diurnal patterns of size-fractioned primary productivity across a coastal front. Mar. Biol. 96:563-574.

Diurnal patterns of photosynthesis and pigmentation among size-fractionated plankton were examined at four stations across a coastal thermal front in the Southern California Bight. No diurnal trends in chlorophyll a and pigment-to-chlorophyll a ratios were observed. Photosynthetic parameters were derived by fitting models to the P-I data which describe photosynthesis as a continuous function of available light. Primary productivity and chlorophyll a biomass increased more than 20-fold across the front and were greatest on the cold-water stations; values of midday P_{max} ranged from approximately 1-22 mg $C \cdot m^{-3} \cdot h^{-1}$. Computed daily integrated photosynthetic rates were given in Smith *et al.* (1987).

Reid, F. M. H., E. Stewart, R. W. Eppley, and D. Goodman. 1978. Spatial distribution of phytoplankton species in chlorophyll maximum layers off Southern California. Limnol. Oceanogr. 23:219-226.

The phytoplankton species assemblages of the chlorophyll maximum layer and the surface layer were compared in March 1976 at several stations off southern California. The assemblages in the two layers were quite different in the southern inshore part of the study area but were similar offshore and in Santa Monica Bay to the north. In both layers, the assemblages changed more abruptly offshore than alongshore and gave the impression of elongate bands of phytoplankton oriented parallel to shore. Principal component analysis resolved two axes which accounted for the preponderance of the variability of species abundances. Component I consisted of several dinoflagellate and one coccolithophorid species; component II was comprised of several diatom species and the pigmented ciliate *Mesodinium rubrum*.

Roemmich, D. 1989. Mean transport of mass, heat, salt and nutrients in southern California coastal waters: Implications for primary production and nutrient cycling. Deep-Sea Res. 36(9):1359-1378.

In the coastal region of southern California there is a close balance between Ekman divergence, based on long-term mean wind stress and geostrophic convergence relative to 500 m, calculated from quarterly California Cooperative Fisheries Investigations (CalCOFI) surveys between 1984-1987. At the base of the mixed layer, an upward area mean vertical velocity of 3.5×10^{-4} cm/s was determined from geostrophic and Ekman calculations. The geostrophic transport has large annual and between cruise variability; good estimates of the mean field require a long time series. The heat transport by ocean currents, 68 W/m^2, is in agreement with computations of air-sea heat transport. The agreement between meteorological and oceanographic data demonstrates the consistency of the simple model of mean transport, and limits possible errors arising from the reference level of the geostrophic velocity field selected. An estimate of primary production was obtained by applying the ratio 0.4, of new to total production, to new production. New production was determined by converting mean nitrate flux to carbon uptake using the Redfield ratio. These calculations produced an estimate of average total production of 600 mg $C \cdot m^{-2} \cdot d^{-1}$. This estimate was in reasonable agreement with an annual mean of 400 mg C/m^2 per half day (Hayward, in review) obtained from CalCOFI measurements. The dominant physical mechanism for importation of nutrients is the geostrophic convergence and subsequent upwelling of water rich in nutrients; alongshore advection of nutrients in the surface layer provides a smaller contribution.

Scripps Institution of Oceanography. 1984. Physical, chemical and biological data, CalCOFI Cruise 8407. Scripps Institution of Oceanography Reference 84-30.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1984a. Physical, chemical and biological data, CalCOFI Cruise 8401. Scripps Institution of Oceanography Reference 84-18.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1984b. Physical, chemical and biological data, CalCOFI Cruise 8402-3. Scripps Institution of Oceanography Reference 84-23.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1984c. Physical, chemical and biological data, CalCOFI Cruise 8404, 8405 and 8406. Scripps Institution of Oceanography Reference 84-25.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1985a. Physical, chemical and biological data, CalCOFI Cruise 8410. Scripps Institution of Oceanography Reference 85-1.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1985b. Physical, chemical and biological data, CalCOFI Cruise 8105 and 8107. Scripps Institution of Oceanography Reference 85-12.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1985c. Physical, chemical and biological data, CalCOFI Cruise 8502 and 8505. Scripps Institution of Oceanography Reference 85-14.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1986a. Physical, chemical and biological data, CalCOFI Cruise 8508 and 8511. Scripps Institution of Oceanography Reference 86-6.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1986b. Physical, chemical and biological data, CalCOFI Cruise 8602. Scripps Institution of Oceanography Reference 86-9.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1986c. Physical, chemical and biological data, CalCOFI Cruise 8605 and CW86. Scripps Institution of Oceanography Reference 86-22.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1987a. Physical, chemical and biological data, CalCOFI Cruise 8609 and 8611. Scripps Institution of Oceanography Reference 87-7.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1987b. Physical, chemical and biological data, CalCOFI Cruise 8703 and 8705. Scripps Institution of Oceanography Reference 87-19.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1987c. Physical, chemical and biological data, CalCOFI Cruise SQ86. Scripps Institution of Oceanography Reference 87-17.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1988. Physical, chemical and biological data, CalCOFI Cruise 8709 and 8711. Scripps Institution of Oceanography Reference 88-8.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1989a. Physical, chemical and biological data, CalCOFI Cruise 8801 and 8805. Scripps Institution of Oceanography Reference 88-23.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Scripps Institution of Oceanography. 1989b. Physical, chemical and biological data, CalCOFI Cruise 8808 and 8810. Scripps Institution of Oceanography Reference 89-2.

Data report listing physical, chemical, and biological data including primary production data from individual CalCOFI cruises.

Shea, R. E. and W. W. Broenkow. 1982. The role of internal tides in the nutrient enrichment of Monterey Bay, California. Est. Cstl. Shelf Sci. 15:57-66.

The role of macronutrient enrichment by semidiurnal internal tides in Monterey Canyon, CA is discussed. Time series data of temperature, salinity and nutrients was compiled from a variety of studies in Monterey Bay between 1971 and 1979. Internal tidal heights ranging from 50-120 m were the largest observed; such tides probably result from the topography of Monterey Canyon. During the study a 20-m thick lens of 12°C water moved northward out of the canyon during high internal tide. The lens was subsequently pinched off from canyon water and led to a density-induced divergence. For a net divergence of 50%, the observed increase in PO_4 from low to high internal tide could sustain an increased productivity of 0.3 g $C \cdot m^{-2} \cdot d^{-1}$. This figure would account for approximately 30% of the daily primary productivity in the northern part of Monterey Bay during non-upwelling periods.

Simpson, J. J., C. J. Koblinsky, J. Pelaez, L. R. Haury, and D. Wiesenhahn. 1986. Temperature-plant pigment-optical relations in a recurrent offshore mesoscale eddy near Point Conception, California. J. Geophys. Res. 91:12919-12936.

From 9-17 January 1981, the structure of a mesoscale anticyclonic eddy, consistently found in shipboard surveys and satellite imagery and located several hundred kilometers southwest of Point Conception, CA, was examined. Profiles of temperature, salinity and optical transmissivity were obtained at each station. Remote sensing analyses included Coastal Zone Color Scanner (CZCS) and Advanced Very High Resolution Radiometer (AVHRR) observations. The near-surface chlorophyll structure of the eddy was detected by CZCS, however *in situ* optical measurements and plant pigment analysis suggest that the integrated chlorophyll is not well estimated by CZCS imagery. The boundaries of temperature and pigment in the eddy, determined from AVHRR and CZCS imagery, did not coincide spatially. It is suggested that the structure is not an isolated vortex system, but rather continuously entrains waters of nonlocal origin into the upper layers. Ratios of AVHRR/CZCS were useful in separating inshore from offshore water masses in the California Current. A historical 28-yr record of dynamic height, from the CalCOFI Program, provides evidence for the recurrence of the anticyclonic eddy throughout much of the year. The historical data and satellite imagery show that a large number of mesoscale eddies occur simultaneously in the transition zone between coastal and oceanic regions of the California Current System. The eddy system should impose an offshore boundary condition to flow in the California Current.

Simpson, J. J., C. J. Koblinsky, L. R. Haury, and T. D. Dickey. 1984. An offshore eddy in the California Current system. Prog. Oceanogr. 13:1-111.

In the fall of 1980, infrared satellite imagery was used to monitor the surface signature of the mesoscale eddy field in the offshore California Current. A quasi-stationary anticyclonic eddy-like structure was selected for detailed shipboard surveys from 9-17 January 1981. The eddy system consisted of three separate layers: a warm-core eddy from 250 m to 1,400 m originating from the California Undercurrent; a mixed layer from the surface to 75 m of entrained coastal and offshore water; and a cold-core region of coastal origin between the other layers. Chemical properties, chlorophyll and plankton distributions indicated that primary and secondary productivity were enhanced in the frontal regions and in the central dome of the cold-core region. Such eddies are ubiquitous in the offshore California Current and provide an important mechanism for lateral transport and stirring of chemical properties and populations in the California Current system.

Small, L. F., M. R. Landry, R. W. Eppley, F. Azam, and A. F. Carlucci. 1989. Role of plankton in the carbon and nitrogen budgets of Santa Monica Basin, California. Mar. Ecol. Prog. Ser. 56:57-74.

A particle budget for carbon and nitrogen was determined for the Santa Monica Basin, CA. Measurements of standing stocks of phytoplankton, bacteria and zooplankton, primary production, new production, and particle flux from the photic zone, are reported for a collection of stations monitored during five cruises of the SCBS and CaBS programs. Rates of fecal pellet production by macrozooplankton and consumption by bacteria and zooplankton are compared with the other measured variables. During spring and fall, particulate carbon (PC) had a shorter residence time than particulate nitrogen (PN) in the photic zone. Values of new production, determined from nitrate uptake experiments or PN flux, are approximately half the value of PC flux determined from sediment traps. The carbon flux was a greater fraction of daily primary production than the estimate obtained from the product of PN flux and Redfield ratio. Results suggest differential cycling of C and N and N-limitation of phytoplankton growth rates. A budget of PC and PN showed that most of the primary production was recycled in the photic zone; this implies heavy grazing by plankton <200 μm and by macrozooplankton which produce slowly settling fecal debris. Primary production was determined from samples collected at six depths selected in the photic zone, taken as three times the Secchi depth. Samples were inoculated with ^{14}C bicarbonate and incubated for 24 h in a surface-water cooled unit on deck. The inshore station showed higher median integral production than stations farther offshore. Fourteen values of primary production at Station SCBS-305 in the Santa Monica Basin are provided for the spring and fall periods. Median values for March-May and September-November were 1,050 and 531 mg $C \cdot m^{-2} \cdot d^{-1}$, respectively.

Smith, R. C., R. R. Bidigare, B. B. Prézelin, K. S. Baker, and J. M. Brooks. 1987. Optical characterization of primary productivity across a coastal front. Mar. Biol. 96:575-591.

The study details the primary productivity and optical properties of a frontal region in July 1985 along 33.7°N latitude in the Southern California Bight. A thermal front, of high phytoplankton variability, is persistently observed at the eastern end of the Santa Barbara Channel during the spring and summer. Three techniques were combined in the study: a Bio-Optical Profiling System (BOPS); P-I studies; and high-performance liquid-chromatography (HPLC). Seawater samples containing ^{14}C-bicarbonate were dispensed in scintillation vials and placed in "photosynthetrons", near *in situ* temperatures, for 1.5-2 h. Various incubation irradiances were obtained with combinations of neutral density Plexiglas disks. Photosynthetic parameters were obtained by fitting (P-I) data to three models which describe photosynthesis as a continuous function of light. Computed daily integrated photosynthetic rate, P_a, is presented for three stations: 3,323 mg $C \cdot m^{-2} \cdot d^{-1}$ for cold water; 2,810 for a frontal station; 227 for the warm water side of the front.

Smith, R. C., X. Zhang, and J. Michaelsen. 1988. Variability of pigment biomass in the California Current System as determined by satellite imagery. J. Geophys. Res. 93(D9):10863-10882.

Spatial variability of chlorophyll in the California Current system was analyzed using Coastal Zone Color Scanner (CZCS) imagery. A total of 48 images, over a 30-mo time series (from July 1979 to December 1981), were analyzed to produce seasonal averages and variances, gradients, and power spectra. Shipboard chlorophyll data sets for 22 Southern California Bight Studies (SCBS) cruises (1974-1983) were selected for the ship and satellite intercomparison. Roughly one third to one half of the variance in pigment biomass can be explained by consistent, large-scale gradients. In general, biomass is higher in the north and in nearshore areas. Nearshore areas also have proportionally more small-scale variability than the areas offshore. Slopes of the power spectra for nearshore areas are about -2.2 (for spatial scales of 10-100 km), while slopes for offshore areas are about -3. In addition, the power spectra show evidence of a change in slope at about 10 km, with slopes of about -1 for shorter-length scales. This may indicate that biological processes dominate the smaller scales, while mesoscale eddies and geostrophic currents dominate the larger scales.

Smith, R. E. and T. J. Conomos. 1981. A comparison of the hydrographic properties of ten northwest estuaries. Estuaries 4:250.

Hydrographic measurements were made during high and low river discharge periods in 10 northwest estuaries. The timing and location of major processes modifying distributions were identified. Relations among tidal volume, basin geometry, river discharge rate, and the extent of urbanization were evaluated to compare river-modulated physical effects. One of the general patterns observed, pertaining to an estuary within California, was that the chlorophyll maximum occurred at the freshwater-seawater interface in San Francisco Bay.

Spero, H. J. and S. L. Parker. 1985. Photosynthesis in the symbiotic planktonic foraminifer *Orbulina universa*, and its potential contribution to oceanic primary productivity. J. Foraminiferal Res. 15(4):273-281.

The potential contribution of photosynthetic symbiotic algae, of the planktonic foraminifer *Orbulina universa*, to ocean primary productivity is estimated. It is estimated that a single, large *Orbulina universa* would be 20,000 times more productive than an equivalent volume of water. Individual specimens were hand-collected by SCUBA off Santa Catalina Island and transported to the laboratory. Measurements were made to describe photosynthetic rate variability over 24 h. Photosynthetic rates were measured using a modified version of a "photosynthetron" (Lewis and Smith, 1983) and methods of Strickland and Parsons (1968). A photosynthetic rate (P_{max}) of 17×10^{-7} μmol C per cell per h was determined for *Orbulina universa* symbionts.

Straughan, D. (ed.) 1971. Biological and oceanographical survey of the Santa Barbara Channel oil spill 1969-1970. Vol. 1, Biology and bacteriology. Allan Hancock Foundation, Univ. Southern California, Los Angeles. Sea Grant Publ. No. 2. 432 pp.

The volume provides a review of the biological consequences of the 1969 oil spill in the Santa Barbara Channel. A blowout at the Union Oil well on Platform A occurred on 28 January. Large areas of waterfront and ocean were polluted in the following weeks. Reviews of the effects of the oil on birds, fish, marine mammals, benthos and zooplankton are presented. Chapter 3 presents results of a study on the productivity in the Santa Barbara Channel. Primary productivity was determined at 11 stations during 12 separate samplings in order to assess background production and those departures associated with the oil spill. There was no conclusive evidence that the oil produced a major effect on the phytoplankton, however this result must be considered in light of the very limited knowledge of the plankton of the region. Reductions in productivity however may have been due to the use of dispersants.

Tegner, M. J. and P. K. Dayton. 1987. El Niño effects on Southern California kelp forest communities. Advances in Ecological Res. 17:243-279.

The effects of the 1982-1983 El Niño on the nearshore kelp communities of the Southern California Bight are reviewed. The normal structure of Southern California kelp forests include: 1) a canopy of *Macrocystis*; 2) an understory (*Pterygophora california* and *Eisenia arborea*); 3) a prostrate canopy above the substrate (*Laminaria farlowii*); 4) turf composed of many species of coralline and filamentous red algae; and 5) pavement of encrusting coralline algae. The most severe storm season in decades occurred in the winter of 1982-1983. The canopy of *Macrocystis* along Palos Verdes Peninsula near Los Angeles declined from 196 to 18 ha within three weeks. The reduction in the Point Loma canopy between the fall of 1982 and the storm season was from 600 to 40 ha. Two major types of storm damage to *Macrocystis* were observed: 1) ripping of holdfasts from substrate, and 2) entanglement of attached plants with drifting plants, resulting is loss of stipe. The storm damage to the understory was less severe. Warm, nutrient-poor waters during El Niño appeared to retard recovery of plants damaged by storms. The warm water conditions of the summer and fall of 1983 also had devastating effects on the Point Loma kelp forest. Tops of most *Macrocystis* were 6-8 m below the surface; since 50% or more of the biomass is usually within the top 1 m, major effects to the community ecology are expected.

Thomas, A. C. and P. T. Strub. 1989. Interannual variability in phytoplankton pigment distribution during the spring transition along the west coast of North America. J. Geophys. Res. 94:18095-18117.

To examine changes in the large-scale patterns of the concentration of chlorophyll pigment, a five-year time series of CZCS imagery (1980-1983, 1986) was analyzed between 23°N to 43°N latitude off the coast of California and Baja California. The effects of physical forcing, with the spring transition in winds and currents, are examined. At the time of the transition event, strong interannual variability in patterns of pigment concentration are observed. Increases in pigment concentration occurred in 1980 and 1981 (from 0.5 mg/m^3 to >3.0 mg/m^3 in 1980 and from 0.3 mg/m^3 to >1.5 mg/m^3 in 1981). Increases in these years (as well as in 1982) were observed between 33°N to 41°N latitude, however the offshore position varied between years. For years 1983 and 1986, there was no appreciable difference in either pattern or concentration of pigment associated with the transition.

Tont, S. A. 1976. Short-period climate fluctuations: Effects on diatom biomass. Science 194:942-944.

An analysis of the weekly averages of diatom biomass measured near the coast of southern California (32°50'N latitude, 117°10'W longitude) during the period from 1928 through 1939 indicates that three major blooms account for 85 percent of each year's diatom biomass. The data analyzed is part of the historical phytoplankton collections by W. E. Allen made from the pier at Scripps Institution of Oceanography, La Jolla. The average duration of a single bloom was 5.5 weeks. The diatom blooms coincide with upwelling, but their individual characteristics depend on the detailed features of the circulation patterns of the water masses. That is, if upwelling takes place after a large influx of subtropical or even tropical water because of the slackening California Current, the resulting diatom blooms are smaller by several orders of magnitude than those observed when the flow of the current is strong. This influx of subtropical water into the region is reflected in positive anomalies of temperature, salinity, and sea level.

Tont, S. A. 1981. Temporal variations in diatom abundance off southern California in relation to surface temperature, air temperature and sea level. J. Mar. Res. 39:191-201.

Temporal variations in diatom abundance off the southern California coast during the 1920-1939 period can be explained by a combination of the changes in the circulation patterns of major water masses and variations associated with upwelling events. Monthly, tri-monthly, seasonal and yearly anomalies of diatom abundances have significant negative correlation with the anomalies of sea surface temperature (SST), air temperature, and sea level. Changes of SST, indicative of upwelling events, are the primary cause of diatom growth; correlations between anomalies of diatom counts and SST are higher during the first part of the year than the latter part when nutrients may be more depleted in the water column.

Traganza, E. D., J. C. Conrad, and L. C. Breaker. 1981. Satellite observations of a cyclonic upwelling system and giant plume in the California Current, pp. 228-241. In F. A. Richards (ed.), Coastal upwelling. Am. Geophys. Union, Washington, DC.

Studies of an upwelling feature off Pt. Sur, CA in April 1979, revealed a cyclonic motion and seaward extension of the structure. Satellite imagery and *in situ* underway measurements of nutrients and temperature indicated the presence of sharp thermal plumes extending across the California Current. The presence of blooms of microplankton adjacent to the sharp gradients suggests a relationship between horizontal nutrients and primary production, and in general between chemical, biological, and physical mesoscale processes in the upper layer. Living microplankton biomass (bacteria, algae, and microzooplankton) was estimated by adenosine triphosphate (ATP) analysis from samples collected every 3 km over the cruise track. Phytoplankton biomass was estimated from continuous fluorescence (Lorenzen, 1966).

Venrick, E. L. and T. L. Hayward. 1984. Determining chlorophyll on the 1984 CalCOFI surveys. CalCOFI Reports 25:74-79.

The magnitudes and implications of two sources of error arising from methodology of chlorophyll determination during the 1984 California Cooperative Fisheries Investigations (CalCOFI) Program are discussed. GF/C glass fiber filters do not completely retain the phytoplankton <1.2 µm and therefore underestimate the contribution of sizes <3 µm. Pigment from the picoplankton (0.5-3 µm), which may be an important photosynthetic component, will not be accurately sampled; this error has a bias of -15%. Error is also introduced by the incomplete recovery of chlorophyll from the filter where it is allowed to extract in acetone for 24 h, instead of grinding the filter in acetone. A relative bias of about -8% is introduced by the 24-h extraction procedure. The expected true chlorophyll concentration is estimated to be between 1.1 and 1.3 times larger than the values obtained by these methodologies.

Ward, B. B. 1987. Nitrogen transformations in the Southern California Bight. Deep-Sea Res. 34(5/6):785-805.

Oxidation and assimilation of ammonium and nitrate were measured in profiles from surface to 1,000 m during two cruises in the Southern California Bight. Assimilative processes dominated the turnover of these nitrogen compounds in the nutrient depleted photic zone. At one of the four stations, Station 205, $^{14}CO_2$ tracer experiments were performed in parallel to ^{15}N experiments. At the end of a 24-h incubation, samples were filtered, stored and later prepared for autoradiography. The autotrophic activity of the nitrifiers, measured by ^{14}C-autoradiography, combined with immunofluorescent counts, was minimal at the surface and increased at depth. Measurements of total primary production at three of the four stations are provided: 0.253, 0.419, 0.651 for Stations 21-205, 21-TRP, and 22-TRP3 in g $C \cdot m^{-2} \cdot d^{-1}$, respectively. Total primary production (Renger and Eppley, unpublished data) was measured using 24-h incubations with $NaH^{14}CO_3$ (Eppley *et al.*, 1979). Integrated primary production was computed, by the polygon method, for the upper 50-60 m of the water column (the 1% light level).

Ward, B. B., K. A. Kilpatrick, E. H. Renger, and R. W. Eppley. 1989. Biological nitrogen cycling in the nutricline. Limnol. Oceanogr. 34:493-513.

Physical transport of nitrate across the nitracline is the main nitrogen source for new production by phytoplankton in the surface ocean. The intersection of the nitracline with the bottom of the photic zone makes this depth interval a region of rapid nitrogen cycling, involving assimilatory and regenerative transformations, as well as physical transport. Investigations were conducted on the pathways of nitrogen transformations in surface, nitracline, and subnitracline samples by following changes in concentration and ^{15}N:^{14}N ratio in dissolved and particulate pools in the same bottles for 24 h. Fluxes of nitrite and nitrate among pools were detected from tracer distributions but were not always reflected in changes in nutrient concentrations. The production of nitrate by nitrification could be detected by tracer methods even when nitrate concentration decreased. Nitrification was detected within and below the nitracline by both oxidation of $^{15}NO_2^-$ and dilution of initially labeled nitrite (ammonium oxidation) or nitrate (nitrite oxidation) pools. Significant nitrate production by nitrification, relative to nitrate assimilation, implies that some of the nitrate assimilated by phytoplankton is functionally regenerated rather than new nitrogen. These observations also suggest an important role for a labile organic nitrogen pool of unknown identity, possibly involving bacterial mediation, in the nitrogen cycling of surface waters.

Wroblewski, J. S. and J. G. Richman. 1987. The non-linear response of plankton to wind mixing events - implications for survival of larval northern anchovy. J. Plankton Res. 9(1):103-123.

A one-dimensional (z,t) model of the plankton ecosystem is used to investigate the general mechanisms related to survival of larval anchovy, *Engraulis mordax*. The survival of the larval anchovy is dependent on high concentrations of zooplankton on which to feed. Wind mixing dissipates the concentration of zooplankton in the surface waters and enhances it below the euphotic zone. Although the secondary production is increased after a wind-mixing event, due to the increase in food availability for zooplankton, the herbivore biomass is not as concentrated. The time required for zooplankton to return to initial concentrations will determine the mortality in *Engraulis mordax*; that period will depend on rates of phytoplankton growth, herbivore grazing and reproduction, and vertical migration. If the mixing event produces a net nutrient flux to the euphotic zone, it is possible that the recovery concentrations of zooplankton will exceed prior values and enhance survival of larval anchovy.

Zimmerman, R. C. 1983. Seasonal patterns in the productivity of a giant kelp (*Macrocystis pyrifera*) forest: the effect of nutrient availability. Ph.D. thesis, Univ. of Southern California. 182 pp.

The importance of nutrient availability in controlling the productivity of the giant kelp, *Macrocystis pyrifera* is quantified by examining the source and timing of nitrogen flux into the kelp forest. An *in situ* nitrogen enrichment experiment was performed to determine whether growth was nutrient limited in the summer. Measurements of growth, changes in metabolism, and standing stock of the giant kelp were obtained. There was a strong relationship between frond elongation and nutrient availability. Nitrogen storage in the kelp was in the form of amino acids. There were no significant seasonal trends in daily rates of photosynthesis and dark respiration. Net production averaged approximately 5 mg O_2 per gm kelp per d. The lack of seasonal variability in daily net production is not surprising considering that: 1) *M. pyrifera* saturates at a light intensity corresponding to 5% of the intensity at noon on a summer day (100 $\mu E \cdot m^{-2} \cdot s^{-1}$), and 2) that most photosynthetically active tissue occurs in the upper 2 m of the water column.

WASHINGTON-OREGON REGION

Anderson, G. C. 1964. The seasonal and geographic distribution of primary productivity off the Washington and Oregon coasts. Limnol. Oceanogr. 9:284-302.

Distribution of chlorophyll a and phytoplankton productivity off the Washington and Oregon coasts were observed during 14 bimonthly cruises of three-weeks duration from January 1961 to June 1962. Surface waters in the area covered by the Columbia River effluent generally contained more phytoplankton and had a higher rate of photosynthesis than ambient waters. Densest and most variable populations were found during summer in coastal upwelling areas and directly off the river mouth. Although there was little seasonal change in standing stock, production was quite variable with a minima in winter and summer, a large spring bloom, and a smaller autumn pulse. The major influence of Columbia River water on phytoplankton production was in the timing of events in the seasonal cycle. Phytoplankton development was noticeably affected by differences in depth of the mixed layer and a sharp summer pycnocline. Total annual production both inside and outside the plume was similar (60 g $\mathrm{C \cdot m^{-3} \cdot yr^{-1}}$). Seasonal variation in ^{14}C uptake:chlorophyll a ratios was marked. Figures summarize seasonal and horizontal distribution of chlorophyll a and primary productivity in surface waters and in the euphotic zone. Vertical and seasonal distribution of chlorophyll and primary productivity are also included.

Anderson, G. C. 1969. Subsurface chlorophyll maximum in the northeast Pacific Ocean. Limnol. Oceanogr. 14:386-391.

A well-developed subsurface chlorophyll maximum is present during summer in oceanic waters off the Oregon coast. It appears to be formed at depth by a photosynthetically active phytoplankton community that is adapted to low light intensity (measurements taken from one station off Oregon). It may be present and affect the distributions and concentrations of primary production, oxygen, and nutrients over large areas of the North Pacific Ocean.

Anderson, G. C. 1972. Aspects of marine phytoplankton studies near the Columbia River, with special reference to a subsurface chlorophyll maximum, pp. 219-240. In A. T. Pruter and D. L. Alverson (eds.), The Columbia River estuary and adjacent ocean waters: Bioenvironmental studies. Univ. of Washington Press, Seattle, WA.

Studies which began in 1961 of the phytoplankton and primary production processes in waters off the Washington and Oregon coasts are reviewed. Particular reference is made to the effect of the Columbia River on these waters. The seasonal and areal distributions of phytoplankton concentrations and primary production rates are described, and relations of these distributions to the hydrography of the area are discussed. Also included are studies of the size fractionation of phytoplankton populations in different areas and seasons, adaptations of populations to changes in light, excretion of dissolved organic matter by phytoplankton, small-scale variations in selected areas, and the seasonal and vertical distribution of particulate matter in the deep sea. Recent studies dealing with mechanisms regulating the supply of nutrients to surface waters and to processes responsible for forming chlorophyll concentrations at depth are emphasized. The mechanisms effective in forming a subsurface chlorophyll layer over the continental shelf and a maximum layer in oceanic waters seaward of the continental shelf appear to be different. The importance of these chlorophyll layers to the production processes of Columbia River effluent is discussed.

Anderson, G. C. and R. P. Zeutschel. 1970. Release of dissolved organic matter by marine phytoplankton in coastal and offshore of the northeast Pacific Ocean. Limnol. Oceanogr. 15:402-407.

The rate of release of dissolved organic matter during phyoplankton photosynthesis was measured in eutrophic and oligotrophic areas at seven stations of the northeast Pacific Ocean between 15-31 July 1968. A method using liquid scintillation counting techniques is described that allows sample preparation to be done simply and accurately at sea. Absolute amounts of dissolved organic matter release were generally greatest near the surface and in eutrophic waters but, relative to total production, were greatest in oligotrophic areas. A close correlation was found between the production of particulate organic matter and the release of dissolved organic matter. Production values of particulate organic matter (mg C/m^2 per half day) and chlorophyll a (mg/m^3) are presented graphically.

Bakun, A. 1973. Coastal upwelling indices, west coast of North America, 1946-1971. U.S. Dept. of Commerce, NOAA Tech. Rept. NMFS SSRF-671. 103 pp.

A series of monthly indices of intensity of large-scale, wind-induced coastal upwelling at selected locations along the west coast of North America is presented for the period 1946 through 1971. The indices are based on calculations of offshore Ekman surface wind transport from monthly mean surface atmospheric pressure data. Summaries by quarter and by year are included. The effect of using monthly mean pressure data is evaluated by comparison to a similar series of monthly means of transports computed every 6 h over a 4.5-yr period. The correlation between the two series at any particular location was found to be high. However, the slope of the regression line varies at different locations. Also values off southern California during summer may be amplified relative to other locations as a result of the discontinuity in the atmospheric pressure gradients caused by the coastal mountain range between the thermal low in the interior of southern California and the higher pressure offshore. The conclusion is that these series may be satisfactory indicators of temporal variations of upwelling at each location, but less satisfactory indicators of spatial distributions.

Bakun, A. 1975. Daily and weekly upwelling indices, west coast of North America, 1967-1973. U.S. Dept. of Commerce, NOAA Tech. Rept. NMFS SSRF-693. 114 pp.

Daily and weekly indices of intensity of large-scale wind-induced coastal upwelling at selected locations along the west coast of North America are presented for the seven-year period, 1967-1973. The indices are based on computations (6-h time periods) of the offshore component of Ekman transport using the synoptic surface atmospheric pressure analyses produced by the Fleet Numerical Weather Central to estimate the sea surface stress. The magnitude of offshore transport is considered an indication of resultant upwelling through the bottom of the Ekman layer. A spatial distortion in absolute magnitude results in noncomparibility of numerical values between different locations.

Bolger, J. and M. J. Perry. 1987. Primary productivity values for the Washington coast between 1961 and 1982, pp. 2-5. In J. Marra (ed.), Biowatt News. Columbia Univ., Palisades, NY.

This report compares primary productivity data collected along the Washington-Oregon coast between 1961-1973 with data collected from 1974-1982. They found that primary production data from the earlier period was lower for all seasons and oceanic regimes. No definitive explantions are given for these differences although several methodological changes are suggested as contributing causes. Systematic differences such as these will significantly affect assessment of production in coastal waters.

Chavez, F. P. and R. T. Barber. 1987. An estimate of new production in the equatorial Pacific. Deep-Sea Res. 34:1229-1243.

Two estimates of new production in the equatorial Pacific are presented and the similarity between the physically-based estimate and an estimate based on measurements of primary productivity is emphasized. The new production calculated by both methods is on the order of 1 gigaton C/yr (1 x 10^{15} g C/yr), an order of magnitude greater than previous estimates for this region. The new estimates suggest that equatorial Pacific circulation supports a significant proportion (18-56%) of the global new production calculated by Eppley and Peterson (1979, Nature 282:677-680).

Curl, H., Jr. and L. F. Small. 1965. Variations in photosynthetic assimilation ratios in natural, marine phytoplankton communities. Limnol. Oceanogr. 10(Suppl.):R67-R73.

Thirteen *in situ* measurements of primary production were made 25 mi (46 km) west of Newport, OR between April 1962 and June 1964. Assimilation ratios (mg C per mg chlorophyll a per h) at light saturation ranged between 6 and 21. The mean value was 8.6

with a 95% confidence interval of ± 1.3. There was no correlation between maximum assimilation ratios and total daily solar radiation. The highest values observed were associated with recently upwelled water. It is suggested on the basis of these experiments and the work of others that assimilation ratios of 0-3 indicate nutrient depletion; ratios between 3 and 5 indicate borderline nutrient deficiency and ratios between 5 and 10 indicate nutrient-rich waters. It is concluded that empirically determined assimilation ratios, derived from as near-natural experiments as possible, should be used in production equations.

Dortch, Q. and J. R. Postel. 1989. Phytoplankton-nitrogen interactions, pp. 139-174. In M. L. Landry and B. M. Hickey (eds.), Coastal oceanography of Washington and Oregon. Elsevier, Amsterdam.

In order to characterize nitrogen uptake by phytoplankton off the Washington coast, ^{15}N uptake was measured at selected stations from 1971-1979. Three types of information were obtained during these studies: 1) experimental data on light, nitrogen concentration and size dependence of nitrogen uptake; 2) the space and time distribution of nitrate, ammonium, and urea uptake; and 3) the relationship between primary production and nitrogen uptake. While the results can be examined in many different ways, the most important question to be addressed is the role of nitrogen supply in regulating primary production.

Eppley, R. W. 1982. The PRPOOS program. EOS, Trans. Am. Geophys. Union. 63:522-523.

A brief overview of the Plankton Rate Processes in Oligotrophic Oceans Study (PRPOOS) is given. The program focuses on delineating the fundamental differences between oligotrophic subtropical oceanic gyres and temperate coastal waters and the impact of these differences on the study of primary production and the dynamics of the planktonic system.

Gross, M. G., A. G. Carey, Jr., G. A. Fowler, and L. D. Kulm. 1972. Distribution of organic carbon in surface sediment, northeast Pacific Ocean, pp. 254-264. In A. T. Pruter and D. L. Alverson (eds.), The Columbia River estuary and adjacent ocean waters: Bioenvironmental studies. Univ. of Washington Press, Seattle, WA.

Organic carbon in surface sediment is most abundant on the continental slope and on the Cascadia Basin near the edge of the continent; it is least abundant in the coarse-grained sediment on the inner continental shelf (<90 m) and on the deep-ocean floor, seaward of Juan de Fuca and Gorda Ridges. Factors controlling organic-carbon concentrations include grain size, dissolved-oxygen concentrations in near-bottom water, and rates of sediment accumulation. Surface and subsurface currents, the submarine ridge system, and seachannels on the ocean bottom are all more or less parallel to the coast. These processes apparently restrict the seaward movements of sediment-associated organic carbon and cause the observed zoned distribution parallel to the coast. Terrigenous organic matter derived from rivers, especially from the Columbia River, contributes organic carbon to sediments in the seavalleys and seachannels on the ocean bottom. At the inner continental shelf there appears to be little correlation between areas of high primary productivity at the ocean surface and the organic carbon concentrations in the sediment accumulating on the nearby ocean bottoms.

Hameedi, M. J. 1974. Quantitative studies of phytoplankton and zooplankton and their interrelationships off Washington and Oregon. Ph.D. diss., Univ. of Washington, Seattle, WA. 287 pp.

A large data base on the seasonal and geographic distribution of phytoplankton and zooplankton off the coast of Washington and Oregon, collected from 1961 to 1963, was evaluated. Twelve environmental variables were studied along with relationships between specific primary productivity, light, and nutrients. A quantitative analysis of the dynamics of phytoplankton-zooplankton relationships in the region is presented.

Hermann, A. J., B. M. Hickey, M. L. Landry, and D. F. Winter. 1989. Coastal upwelling dynamics, pp. 211-254. In M. L. Landry and B. M. Hickey (eds.), Coastal oceanography of Washington and Oregon. Elsevier, Amsterdam.

The results of two experiments designed to elucidate the physical control of mesoscale (approximately 10 km) biomass and nutrient patterns in a region where the upwelling processes may be quasi-two-dimensional are described. Although the study region (the mid-Washington shelf) exhibits significant alongshore gradients in physical and biological properties, it is not nearly as three-dimensional as persistent upwelling centers near large promontories, such as near Point Conception, CA (Brink, 1983). The approach used is to distinguish conservative flux using simultaneous measurements of currents, salt, chlorophyll, and nutrients. Nonconservative changes are then inferred by comparing predicted conservative changes with observed changes in dissolved and suspended constituents. The relative contributions of individual conservative processes (e.g., longshore advection, cross-shelf advection, mixing) to the observed constituent variance are compared with each other and with the contribution of nonconservative processes under various physical environments.

Hobson, L. A. 1966. Some influences of the Columbia River effluent on marine phytoplankton during January 1961. Limnol. Oceanogr. 11:223-234.

Distribution of the phytoplankton standing crop along the coasts of Oregon and Washington during January 1961 is described. Authors evaluate influences of freshwater runoff on marine phytoplankton populations. Marine diatoms and microflagellate concentrations are larger in the Columbia River plume than in the ambient water. Inshore, transition, and offshore species assemblages are identified. Silicate, nitrate, and phosphate concentrations are adequate to support phytoplankton growth in the three areas. Surface stability and critical-to-mixed-depth ratios are much larger in the plume than in the oceanic water. There is a correlation between the critical-to-mixed-depth ratios and the size of the phytoplankton standing crop. Freshwater runoff increased the area in which a neritic diatom flora could exist in winter. Sixty-seven stations were sampled from 10-27 January. Primary production was measured using ^{14}C uptake.

Jawed, M. 1973. Ammonia excretion by zooplankton and its significance to primary productivity during summer. Mar. Biol. 23:115-120.

Excretion rates of ammonia for zooplankton were investigated off the coasts of Washington and Oregon. Ammonia released by zooplankton in the offshore Columbia River plume contributed about 90% of the total nitrogen requirements of observed rates of primary production during summer months. The ammonia-N contribution was 36% in oceanic waters and relatively unimportant in offshore waters and upwelling areas in the inshore region. Significance of eddy diffusion in offshore waters and upwelling in inshore waters is discussed. Tables summarize excretion rates of ammonia by zooplankton and primary production, nitrate concentrations, and zooplankton biomass in oceanic, inshore, and Columbia River plume waters.

Landry, M. R. and W. K. Peterson. 1986. Mechanisms of transfer of energy and biomass in coastal marine ecosystems of the Pacific Northwest. Final report, 1971-1985. A final report by the Univ. of Washington, School of Oceanography for the U.S. Department of Energy. Report No. DOE/EV/75026-125. Contract No. AT06-72EV75026. 16 pp.

This report summarizes the accomplishments of the program subsequent to its reorganization as a separate biological component in 1971. It identifies important areas of research, cruises and data reports, students trained, and resulting publications. In approximately 1974, the focus of research shifted from the Columbia River *per se* to waters overlying the continental shelf of Washington. Integrated field and laboratory, and theoretical, studies were undertaken to better understand processes that affect and regulate communities of organisms in the pelagic, benthic, and surf-zone environments. Field investigations of the Washington pelagic environment were conducted on numerous oceanographic cruises over the period from 1971 to 1983. These cruises have provided extensive background data on the distributions of physical, chemical, and biological parameters (i.e., temperature, salinity, density, oxygen, nutrients, phytoplankton pigments, ^{14}C-primary production, and species abundance) as functions of season, depth, and distance from shore. Experimental studies of specific process rates and interactions involved nutrient and light effects on primary production, benthic metabolism, particulate flux, and zooplankton-grazing impact. The field program included a long-term descriptive and experimental study of surf-zone diatom communities along Washington and Oregon beaches. A series of numerical models formulated new hypotheses regarding the processes controlling observed seasonal and vertical features in the distributions and production of phytoplankton. A coupled biological and physical model was advanced to explain patterns in the occurrence and production of surf-diatom communities. In addition, explicit, quantitative hypotheses regarding benthic deposit feeders were generated by a model based on optimal foraging. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Landry, M. L. and B. M. Hickey. 1989. Coastal oceanography of Washington and Oregon. Elsevier, Amsterdam.

The regional, seasonal, and interannual patterns in the distributions of water-column properties and their relationship to time-variable physical and biological processes are described. The magnitude and control of primary production on the Washington coast is discussed along with interactions between phytoplankton and zooplankton. Various aspects of particle movement on the shelf and slope are investigated. A review of chemical inputs to the water column and sediments and their relationship to physical and biological processes is presented. The influence of oceanographic processes on the biology of the area is discussed along with suggested areas for future research.

Landry, M. L., J. R. Postel, W. K. Peterson, and J. Newman. 1989. Broad scale patterns in the distribution of hydrographic variables, pp. 1-40. In M. L. Landry and B. M. Hickey (eds.), Coastal oceanography of Washington and Oregon. Elsevier, Amsterdam.

This chapter represents an effort to compile and synthesize hydrographic data from the Washington/Oregon shelf region. The goal is to provide a general, descriptive background for the following chapters and also to meet a regional need for the compilation and synthesis of hydrographic information in a format which can be useful in interpreting the results of past research programs and in designing new initiatives. The emphasis is on the net effects of *in situ* biological, chemical, and physically-mediated processes, regional cycles in solar radiation, river runoff, prevailing winds, periodic storm events, and global-scale effects on ocean circulation.

Perry, M. J., J. P. Bolger, and D. C. English. 1989. Primary production in Washington coastal waters, pp. 117-138. In M. L. Landry and B. M. Hickey (eds.), Coastal oceanography of Washington and Oregon. Elsevier, Amsterdam.

The spatial patterns of phytoplankton and their primary production as directly determined from the shipboard program conducted between 1974 and 1982 and as inferred from the Coastal Zone Color Scanner satellite imagery and pigment-productivity algorithms applied to satellite imagery are described. Because the shipboard sampling program conducted over the past decade in Washington coastal waters was limited in its temporal and spatial coverage, it is not possible to determine interannual patterns of variability in primary production. However, from available ship-board productivity data and from analysis of more recently available satellite color imagery of the spatial extent of the highly productive regions, it is estimated that an average of 11.5 metric tons of carbon are fixed annually in the waters overlying the shelf and slope off Washington.

Pruter, A. T. and D. L. Alverson. 1972. The Columbia River estuary and adjacent ocean waters: Bioenvironmental studies. Univ. of Washington Press, Seattle, WA.

This book summarizes research conducted prior to 1971 to provide a description of biological, chemical, and physical processes in the Columbia River estuary and adjacent ocean waters and to provide a description of radionuclides in biota and the physical environment. All the studies have bearing on understanding the fate of radionuclides introduced into the environment. They provide information on the nature of fauna, sediments, and ocean processes. Chapters are grouped into five sections, including: background papers; Columbia River-ocean relationships; composition and distribution of the biota of the marine environment; radionuclides in the ecosystem; and summary.

Shuman, F. R. 1978. The fate of phytoplankton chlorophyll in the euphotic zone-Washington coastal waters. Ph.D. diss., Univ. of Washington, Seattle, WA. 250 pp.

The importance of grazing and sinking losses to phytoplankton in a fjord-like estuary was evaluated. Chlorophyll was used to estimate the abundance of phytoplankton, and phaeophorbide, a chlorophyll degradation product resulting from herbivore grazing, was employed as a measure of grazing. Data were taken on seven three- to four-day cruises to Dabob Bay, an arm of Puget Sound, and one three-week cruise to the Washington continental shelf. When phytoplankton standing stock and ^{14}C productivity were low to moderate, the zooplankton appeared to be controlling the phytoplankton production. During periods of high standing stock and productivity, the grazers were only consuming one-third to one-half of the production. At these times the phytoplankton community was usually not totally available to the grazers because of the size distribution of the phytoplankton. It was not always possible to observe the increase in chlorophyll standing stock during these cruises. The highest variability in chlorophyll standing stock was also associated with these times.

Strickland, R. M. and D. J. Chasan. 1989. Coastal Washington: A synthesis of information. Washington Sea Grant Program, Seattle, WA. 233 pp.

This book assembles and integrates a large amount of information concerning the natural and human environment of coastal Washington. It is intended as an initial document for studying and understanding Washington's coastal environment and how it may change if and when offshore oil and gas development occurs.

Vezina, A. F. and T. Platt. 1988. Food web dynamics in the ocean: I. Best estimates of flow networks using inverse methods. Mar. Ecol. Prog. Ser. 42:269-293.

The application of inverse methods to the estimation of food web fluxes in undersampled ocean environments is described. The general objective is to deduce the flow networks that conserve mass, satisfy basic biological constraints, and are compatible with the observed structure of the food web. Given inevitable gaps in the observational data, a number of different networks will fit these requirements. The simplest possible network is estimated, that is, the network that minimizes 1) the sum total of the rate constants that relate flux to stock, and 2) the differences among the constants. A general framework for the application of the inverse algorithm is presented: 1) a linear compartmental model of the oceanic food web that initially includes all the possible inter-compartmental fluxes, and 2) a set of constraints on the flow estimates that reflect contemporary knowledge of the limits and efficiencies of ecophysiological processes. The methodology is applied to detailed observations of food web structure and dynamics in two areas off the English coast. The inverse solutions are discussed in terms of current concepts of the role of the microbial loop in the pelagic marine ecosystem.

UNPUBLISHED DATA REPORTS

Biological oceanography of the northwest coastal zone. June 1976:RLO-2225-T26-42.

This report contains data obtained during cruises from July 1974 to October 1975 of the R/V THOMAS G. THOMPSON and the R/V YAQUINA regarding seasonal information on the physical, chemical, and biological properties of the waters over the continental shelf off Washington.

Data report of the DOE-sponsored Northwest Marine Sciences Group, October 1978 cruise. April 1980:DE-EV-10047-1.

This report contains data collected during the October 1978 cruise of the R/V THOMAS G. THOMPSON as part of a continuing program to study the processes affecting phytoplankton productivity and distribution in Washington coastal waters. This cruise investigated the variables and processes in the transitional period between late autumn and early winter conditions.

Data report of the DOE-sponsored Northwest Marine Sciences Group, July-August 1979 cruise. November 1980:DE-EV-10047-2.

This report contains data from the July-August 1979 cruise of the R/V THOMAS G. THOMPSON undertaken to collect detailed information of the processes affecting plankton productivity, abundance, and distribution off the Washington coast, and on the chemistry, distribution, and flux of particulate material in these waters.

Data report of the DOE-sponsored Northwest Marine Sciences Group, September-October 1980 cruise. January 1982:DE-EV-10047-5.

This report contains data from the September-October cruise of the R/V WECOMA undertaken to collect detailed information of the processes affecting plankton productivity, abundance, and distribution off the Washington coast, and on the chemistry, distribution, and flux of particulate material in these waters. The timing of the cruise was chosen to correspond to autumn conditions.

Data report of the DOE-sponsored Northwest Marine Sciences Group, August-September 1981 cruise. March 1983:DE-EV-10047-6.

This report contains data collected during the August-September 1981 cruise of the R/V THOMAS G. THOMPSON regarding the mechanisms of transfer of energy and biomass in coastal marine ecosystems, particularly in waters over the continental shelf and slope off Washington.

Data report of the DOE-sponsored Northwest Marine Sciences Group, June 1982 cruise. July 1984:DE-EV-10047-8.

This report contains data collected during the June 1982 cruises of the R/V WECOMA and the R/V CAYUSE undertaken to establish baseline parameters of water currents and hydrography, phytoplankton biomass and growth, and dissolved nutrient distributions along a transect from near shore to off the slope near Copalis Beach, WA.

Hydrographic and biological observations on the Washington continental slope and shelf during the periods 30 March-5 April, 8-15 June, and 6-11 September 1978. January 1980:DE-EV-75026-94.

This report contains data from the 1978 cruises of the R/V CAYUSE undertaken to collect seasonal information on the processes affecting phytoplankton production and distribution and data on the settling rate of organic matter in the sea during spring, early summer, and autumn conditions.

Mechanisms of transfer of energy and biomass in coastal marine ecosystems of the Pacific northwest, v.II. June 1979:RLO-2225-T26-74.

This report contains data obtained during the September 1976 to August 1977 cruises of the R/V THOMAS G. THOMPSON regarding seasonal information on the physical, chemical, and biological properties of the waters over the continental shelf off Washington.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, January-June 1961. July 1963:TR-86.

This report contains oceanographic data collected on five offshore cruises of the R/V BROWN BEAR during the months of January to June 1961. The objectives of the study were to determine the gross features of the movement and dispersion of Columbia River effluent water in the open sea off the mouth of the river and along the adjacent coast.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, July-August 1961. October 1964:TR-112.

This report contains oceanographic data collected on three offshore cruises of the R/V BROWN BEAR during the months of July and August 1961. The objectives of the study were to determine the gross features of the movement and dispersion of Columbia River effluent water in the open sea off the mouth of the river and along the adjacent coast.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, September-December 1961, v.II. December 1964:TR-115.

This report contains data from R/V BROWN BEAR Cruise 297 conducted in late 1961. This cruise provides data about the water characteristics along the Washington-Oregon coast with emphasis on the effluent from the Columbia River. The objectives of the study were to determine the gross features of the movement and dispersion of Columbia River effluent water in the open sea off the mouth of the river and along the adjacent coast.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, January-October 1962, v.I-IV. August 1965:TR-119.

This report contains oceanographic data collected during some of the offshore cruises of the R/V BROWN BEAR made during 1962. These cruises provide data about the water characteristics along the Washington-Oregon coast with emphasis on the effluent from the Columbia River. The objectives of the study were to determine the gross features of the movement and dispersion of Columbia River effluent water in the open sea off the mouth of the river and along the adjacent coast.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, January-June 1963, v.IV-V. March 1966:TR-134.

This report contains oceanographic data collected during cruises of the R/V BROWN BEAR and the R/V OSHAWA-2 during 1963. These cruises provide data about the water characteristics along the Washington-Oregon coast with emphasis on the effluent from the Columbia River. The objectives of the study were to determine the gross features of the movement and dispersion of Columbia River effluent water in the open sea off the mouth of the river and along the adjacent coast.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, July-December 1963, v.I-IV. October 1966:TR-159.

This four-volume report contains data collected by the University of Washington Department of Oceanography and cooperating agencies during the months of July through December 1963 by the R/V BROWN BEAR and the R/V OSHAWA. The objectives of this study were to determine the properties, distribution, and movement of the Columbia River effluent against the background of ambient oceanic water and nearshore coastal water that has been modified by other land drainage, and ultimately to establish a base for predicting the general behavior of the effluent and the associated river-borne materials.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, 1964, v.I-III. December 1966:TR-180.

This three-volume report contains oceanographic data collected by the University of Washington Department of Oceanography and cooperating agencies during 1964 on the R/V BROWN BEAR and the R/V OSHAWA. The objectives of this study were to determine the properties, distribution, and movement of the Columbia River effluent against the background of ambient oceanic water and nearshore coastal water that has been modified by other land drainage, and ultimately to establish a base for predicting the general behavior of the effluent and the associated river-borne materials.

University of Washington Department of Oceanography. Physical, chemical and biological data from the northeast Pacific Ocean: Columbia River effluent area, 1965, v.I-II. February 1967:TR-182.

This two-volume report contains oceanographic data collected by the University of Washington Department of Oceanography, on 11 cruises of the R/V BROWN BEAR during 1965. The objectives of this study were to determine the properties, distribution, and movement of the Columbia River effluent against the background of ambient oceanic water and nearshore coastal water that has been modified by other land drainage, and ultimately to establish a base for predicting the general behavior of the effluent and the associated river-borne materials.

ALASKA REGION

Alexander, V. and R. T. Cooney. 1978. Bering Sea ice edge ecoysytem study: Nutrient cycling and organic matter transfer. Environmental Assessment of the Alaskan Continental Shelf, U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annual Reports 6:216-448.

The objectives of this study were to determine the seasonal and spatial dynamics of the Bering Sea phytoplankton production in areas subject to future OCS development, with emphasis on the ice-edge community. The compression of annual primary production into a short spring period over much of the Bering Sea shelf implies that hazards associated with development could be particularly critical during short periods of the year. The ice-edge is associated with an intense bloom each spring. This area is also critical to higher trophic levels, and large numbers of birds and mammals are found along the receding seasonal ice. The nature of the transfer of the spring production to the zooplankton population is not clear, and the possibility exists that much of the annual feeding involves detritus from the products of the spring bloom or even previous years. This project was closely coordinated with the zooplankton work of Cooney in order to make preliminary estimates of zooplankton grazing in conjunction with the phytoplankton production work as a means of estimating the proportion of production used immediately during the spring period.

Alexander, V. and H. J. Niebauer. 1989. Recent studies of phytoplankton blooms at the ice edge in the southeast Bering Sea. Rapp. P.-v. Réun. Cons. Int. Explor. Mer. 188:98-107.

Recent studies at the ice-edge zone of the Bering Sea during the spring phytoplankton bloom have provided insight into physical/biological interactions which may be very important to the southeast Bering Sea ecosystem. Spring phytoplankton blooms at retreating ice edges are recognized as important contributors to the annual primary production. They are associated with and initiated within the region of enhanced density gradients and fronts which result from active ice melting. Ice-edge blooms generally precede any significant primary production in the water column south of the maximum extent of the ice. The hydrography of the southeast Bering Sea shelf is characterized by a series of three fronts. Evidence suggests that ice-melt processes play a role in the manifestation of the inner shelf front in the spring, and that this front serves as a conduit for supplying nutrients to the surface water during the ice-edge bloom as it passes over the 50-m isobath. Thus, the area between the 50- and 100-m isobaths is a region of intense primary production as the ice melts. Given appropriate winds, ice-edge upwelling may be another mechanism, possibly more important in those cold years when the ice extends out towards the shelf break. Comparison of depth-integrated (to 20 m) chlorophyll and nitrate shows the progress from pre-bloom conditions through the bloom in the vicinity of the inner shelf front, and the progression from water-column stratification at the ice edge to post-bloom conditions seaward of the ice-edge front. A time series of transects is used to illustrate the progress of the development of the physical and biological structure.

Appolonio, S. 1959. Hydrobiological measurements on IGY drifting station Bravo. Nat. Acad. Sci. Geophys. Year Bull. 27:16-19.

No annotation. Document unavailable.

Clasby, R. C., V. Alexander, and R. Horner. 1976. Primary productivity of sea-ice algae, pp. 289-304. In Ass. Arctic Marine Environ. Inst. Mar. Sci., Univ. of Alaska, Fairbanks.

A study of algal primary productivity associated with sea ice was carried out in the nearshore Chukchi Sea. Divers applied the ^{14}C method using specially designed incubation chambers for *in situ* work. The seasonal distribution of the "ice bloom" activity was determined, resulting in an annual input estimate of about 5 g C/m^2 by the ice community. Therefore, this ice-related primary production appears responsible for a significant proportion of the total annual photosynthetic carbon input into Arctic coastal waters. Species composition and the role of factors related to primary production are also discussed.

Coachman, L. K. 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. Cont. Shelf Res. 5(1-2):23-108.

The goal of this research has been a quantitative description of the hydrographic regime of the southeastern Bering Sea shelf, and the circulation, mixing, and transport of properties thereon, at the time and space scales affecting the distributions of biological materials and organisms.

Dawson, W. A. 1965. Phytoplankton data from the Chukchi Sea 1959-1962. Univ. of Wash. Tech. Rept. No. 117. Seattle, WA. 99 pp.

This report contains tabulations of the measurements of phytoplankton standing crops by plant pigment analysis, and measurements of primary productivity carried out on five cruises to the Chukchi Sea, together with corresponding measurements of temperature, salinity, and incident solar radiation. Overall aspects of the distribution and abundance of phytoplankton in the Chukchi Sea are discussed.

Dodimead, A. J., F. Favorite, and T. Hirano. 1963. Salmon of the North Pacific Ocean, Part II: Review of the oceanography of the subarctic Pacific region. Internat. North Pacific Fish. Comm. Bull. No. 13. 195 pp.

In this report, fragmentary information from research conducted prior to the commencement of the INPFC has been summarized. This information and the knowledge obtained from research conducted by the Commission has been synthesized into a presentation of the structure of the water within the Subarctic Pacific Region and a discussion of some of the mechanisms and processes that establish or alter the structure. The dominant features of the structure are used to show the distribution of properties during the years 1955 through 1959. From these distributions, specific domains have been identified, the extent and position of which denote the major changes of conditions during the years considered.

Duggins, D. O., C. A. Simenstad, and J. A. Estes. 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. Science 245:170-173.

Kelps are highly productive seaweeds found along most temperate latitude coastlines, but the fate and importance of kelp production to nearshore ecosystems are largely unknown. The trophic role of kelp-derived carbon in a wide range of marine organisms was assessed by a natural experiment. Growth rates of benthic suspension feeders were greatly increased in the presence of organic detritus (particulate and dissolved) originating from large benthic seaweeds (kelps). Stable carbon isotope analysis confirmed that kelp-derived carbon is found throughout the nearshore food web.

Dunton, K. D. 1985. Trophic dynamics in marine nearshore ecosystems of the Alaskan high Arctic. Ph.D. diss., Inst. Mar. Sci., Univ. of Alaska, Fairbanks. 247 pp.

This dissertation describes two ecological studies in the Arctic Alaskan nearshore zone: 1) the productivity and growth strategies of Arctic kelp and; 2) the use of natural carbon isotope abundances to examine food web structure and energy flow in the marine ecosystem. Linear growth of the kelp, *Laminaria solidungula* is greatest in winter and early spring when nutrients are available for new tissue growth. Since over 90% of this growth occurs in complete darkness beneath a turbid ice canopy, the plant draws on stored food reserves and is in a carbon deficit during the ice covered period.

Dunton, K. D. and D. M. Schell. 1986. Seasonal carbon budget and growth of *Laminaria solidungula* in the Alaskan high Arctic. Mar. Ecol. Prog. Ser. 31:57-66.

Laminaria solidungula is the dominant member of an Arctic kelp community subjected annually to eight months of darkness under a turbid ice canopy. Seasonal changes in total tissue carbon were measured for 24 sporophytes incubated *in situ* for one year. Net annual production was calculated from these measurements and compared to carbon fixation rates from *in situ* ^{14}C uptake experiments. *L. solidungula* reallocates stored reserves to produce new frond tissue during ice-covered periods that replaces about 80% of the previous year's carbon content.

Dunton, K. D. and C. M. Jodwalis. 1988. Photosynthetic performance of *Laminaria solidungula* measured *in situ* in the Alaskan high Arctic. Mar. Biol. 98:277-285.

Photosynthetic performance in the kelp *Laminaria solidungula* J. Agardh was examined from photosynthesis irradiance (P-I) parameters calculated from *in situ* ^{14}C uptake experiments, using whole plants in the Stefansson Sound Boulder Patch, Alaskan Beaufort Sea, in August 1986. Rates of carbon fixation were determined from meristematic, basal blade, and second blade tissue in young and adult sporophytes. Differences in saturating irradiance (I_k, measured as photosynthetically active radiation, PAR), photosynthetic capacity (P_{max}), and relative quantum efficiency (a) were observed both between young and adult plants and between different tissue types. I_k was lowest in meristematic tissue (20 to 30 $\mu E \cdot m^{-2} \cdot s^{-1}$) for both young and adult plants, but consistently 8 to 10 $\mu E \cdot m^{-2} \cdot s^{-1}$ higher in young plants compared to adults in all three tissues. Average I_k for non-meristematic tissue in plants was 38 $\mu E \cdot m^{-2} \cdot s^{-1}$. Under saturating irradiances, young and adult plants exhibited similar rates of carbon fixation on an area basis, but under light limitation, fixation rates were highest in adult plants for all tissues. P_{max} was generally highest in the basal blade and lowest in meristematic tissue. Photosynthetic efficiency (a) ranged between 0.016 and 0.027 $\mu mol\ C \cdot cm^{-2} \cdot h^{-1} \cdot \mu E^{-1} \cdot m^{-2} \cdot s^{-1}$, and was highest in meristematic tissue. The relatively lower I_k and higher a exhibited by *L. solidungula* in comparison to other kelp species are distinct adaptations to the near absence of light during the eight-month ice-covered period and in summer when water turbidity is high. Continuous measurement of *in situ* quantum irradiance made in summer showed that maximum PAR can be less than 12 $\mu E \cdot m^{-2} \cdot s^{-1}$ for several days when high wind velocities increase water turbulence and decrease water transparency.

English, T. S. 1959. Primary production in the North Polar Sea, Drifting Station Alpha, 1957-1958. Unpublished manuscript [cited in Ryther, J. H. 1959. Geographic variation in productivity, pp. 347-380. In M. N. Hill (ed.), The Sea. J. Wiley and Sons, New York, NY.

Productivity measurements were taken at the U.S. drifting stations "Alpha" at 70°N to 75°N latitude. These stations are ice covered 10 mo of the year. Productivity is low, with values of 0.006 and 0.005 g $C \cdot m^{-2} \cdot d^{-1}$ in late July and early August.

Eppley, R. W., E. H. Renger, E. L. Venrick, and M. M. Mullin. 1973. A study of plankton dynamics and nutrient cycling in the central gyre of the North Pacific Ocean. Limnol. Oceanogr. 18(4):534-551.

The dynamics of phytoplankton growth in relation to nutrient concentrations were studied in the subtropical central gyre of the North Pacific in November 1971. Rates of excretion of phosphate, ammonium, and urea-N by zooplankton and rates of assimilation of carbon, nitrate, ammonium, and urea-N by phytoplankton were measured. The growth rate of phytoplankton was estimated to be about 0.2 to 0.3 doublings per day in the 70 to 80 m mixed layer, apparently limited by concentrations of both nitrogen and phosphate. Only nitrogen concentration was so limiting at a station near the western edge of the California Current. No diel changes in concentrations of ambient nutrients were observed. Urea-N appears to be an important source of nitrogen for phytoplankton growth in these waters and to be an important excretory product of zooplankton. Concentrations of phosphate and ammonium were extremely low, but turnover times were estimated to be of the order 3 to 5 d for ammonium and >10 d for urea and phosphate. Biomass of phytoplankton in the mixed layer was also very low, and corresponded approximately to that expected if a laboratory culture were operated as a nitrogen-limited chemostat with a concentration of about 0.48 μg-atom N per liter in the incoming culture medium and a dilution rate of about 0.13 per day. Physiological differences were noted between the phytoplankton in the mixed layer and that living below the thermocline, as were differences in chemical composition (ratio of C:Chl a and C:N).

Feder, H. M., A. S. Naidu, M. Basharan, K. Frost, J. M. Hameedi, S. C. Jewett, W. R. Johnson, J. Raymond, and D. Schell. 1989. Bering Strait-Hope Basin: Habitat utilization and ecological characterization. Draft Final Report, NOAA - Ocean Assessment Division (Anchorage), Inst. Mar. Sci., School of Fisheries and Ocean Science, Univ. of Alaska, Fairbanks. Cooperative Program (RU 690). 400 pp.

Primary production in the northern Bering Sea and southern Chukchi Sea ranks among the highest in the world and supports a rich consumer fauna including many species of fishes, birds and mammals important to the commercial and subsistence needs of man. Within this region, however, pronounced local variability in primary production is apparently due to the complex oceanographic processes supplying nutrients to the euphotic zone and the interaction of seasonal extremes of light and ice upon the phytoplankton communities. Kotzebue Sound represents one of these locales and assessment of its importance to the "valued ecosystem components" depends upon its context in the regional ecosystem. The processes of primary production and trophic dynamics in the Kotzebue Sound ecosystem were assessed by limited field measurements of carbon fixation rates and by indirect estimation from nutrient availability and water column characteristics on two cruises in September and October of 1986 and 1987. In addition, the carbon and nitrogen stable isotope ratios of fauna were used to estimate trophic levels and food chain lengths and couplings of consumers. The data set acquired was compared and integrated with information sets resulting from the NSF-sponsored ISHTAR Program. In addition to water column production, ice-associated algal populations probably contribute to the annual carbon fixation in areas where the winter ice cover does not include sediment. Parrish (1987) estimated that the ice algae of the southeastern Chukchi Sea fixed about 13 g C/m^2, but the shallow waters of Kotzebue Sound and the inclusion of sediment into the ice from fluvial inputs almost certainly means this estimate is too high for this embayment. Researchers did not conduct any measurements of ice algal productivity and, therefore, no estimates of epontic primary production were made.

Feder, H. M., A. S. Naidu, J. M. Hameedi, S. C. Jewett, and W. R. Johnson. 1989. The Chukchi Sea continental shelf: Benthos-environmental interactions. Final Report, NOAA - Ocean Assessment Division (Anchorage), Inst. Mar. Sci., School of Fisheries and Ocean Science, Univ. of Alaska, Fairbanks. Cooperative Program (RU 687). 294 pp.

The sources of energy supporting the marine biological system in the southern Chukchi Sea are suggested by the high primary productivity of water in the western Bering Strait (Sambrotto *et al.*, 1984). Nutrient-rich water from the Gulf of Anadyr moves northward across the northeastern Bering Sea shelf supporting high concentrations of phytoplankton in the water column, as well as in water moving through the Strait. This production supports a large zooplankton crop and a high benthic biomass north of the Strait (Stoker, 1978; Grebmeier *et al.*, 1988). It is suggested by this study that the northward movement of the productive waters of the southern Chukchi, and its contained particulate organic carbon, provides a food resource to the benthos of the northern Chukchi Sea as well.

Gowing, M. M. and S. L. Coale. 1989. Fluxes of living radiolarians and their skeletons along the Northeast Pacific transect from coastal upwelling to open ocean waters. Deep-Sea Res. 36(4):561-576.

Sinking fluxes of living polycystine and phaeodarian radiolarians and their intact empty skeletons were measured from surface waters to 2,000 m using free-floating particle interceptor traps at three sites ranging from highly productive coastal upwelling to oligotrophic central gyre waters in the northeast Pacific Ocean. Total radiolarian fluxes and living phaeodarian fluxes were generally highest at the coastal site throughout the water column. There was no consistent site-specific pattern for fluxes of living polycystines, polycystine empty skeletons, and phaeodarian empty skeletons. Living phaeodarians were the only group that showed the same rank order of sites with respect to flux at both the base of the euphotic zone and at 2,000 m. Thus different short-term processes occurring in the water column (e.g., destructive and non-destructive predation and midwater addition of living radiolarians) altered radiolarian fluxes. Neither radiolarian fluxes at the base of the euphotic zone nor fluxes at 2,000 m showed a simple correspondence with primary production, indicating that short-term measurements did not reveal long-term patterns. At most depths at all sites, fluxes of living, skeleton-bearing phaeodarians outnumbered fluxes of empty phaeodarian skeletons. In contrast, at most depths at all sites, fluxes of empty polycystine skeletons outnumbered fluxes of living, skeleton-bearing polycystines. Relatively large, living skeleton-less phaeodarians were the numerically dominant radiolarian in the uppermost traps at the oceanic and coastal sites. These phaeodarians agglutinate siliceous skeletons of other plankton, and contributed 5% of the silicoflagellate flux, 16% of the polycystine flux, and 2% of the centric diatom flux at these depths. The resemblance of skeleton-less phaeodarians to fecal pellets may cause them to be misidentified as fecal material when trap contents are dried for processing. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Grebmeier, J. M., C. P. McRoy, and H. M. Feder. 1988. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. 1. Food supply source and benthic biomass. Mar. Ecol. Prog. Ser. 48(1):57-67.

Even though the shelf waters of the northern Bering and Chukchi Seas are ice-covered for 7 mo of the year, they are characterized by high benthic biomass. Coupling between water-column primary production and the benthos was investigated in the summers of 1984 to 1986 by measurements of sediment characteristics in relation to those of the water column. Low surface sediment C/N ratios (5.8 to 7.6) suggested a higher quality, nitrogen-rich marine carbon supply to the benthos in the highly productive (≈250 to 300 g $C \cdot m^{-2} \cdot yr^{-1}$) Bering Shelf-Anadyr Water (BSAW) compared to lower quality, higher C/N ratios (7.7 to 14.0) in sediment under the less productive (≈50 g $C \cdot m^{-2} \cdot yr^{-1}$) Alaska Coastal Water (ACW). Mean benthic biomass was significantly different between water locations, with mean benthic biomass decreasing from 20.2 g C/m^2 under BSAW to 6.3 g C/m^2 under ACW. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Hameedi, M. J. 1978. Aspects of water column productivity in the Chukchi Sea during summer. Mar. Biol. 48:37-46.

Measurements of primary productivity, chlorophyll a, incident solar radiation, phosphate-P, silicate-Si, nitrate-N, ammonium-N, temperature, and salinity were made in the marginal ice zone of the Chukchi Sea in summer 1974. Low to moderate levels of primary productivity (0.07-0.97 g C/m^2 per half day) were observed; primary productivity exceeded 3 g C/m^2 per half day at two stations. Surface primary productivity was nitrogen-limited at most stations. Mean chlorophyll a concentration in the photic zone varied from 0.4-17.8 mg/m^3. Higher concentrations and significant subsurface accumulation of chlorophyll a, reaching 40 mg/m^3, were observed in July at stations near the ice-edge than those in open water. No chlorophyll maximum was noted in September, when values ranged from 0.4-2.2 mg/m^3. It is postulated that the contribution of sea-ice algae to the total chlorophyll content can be substantial, but that the stay of these cells in the water column may not be long. Non-linear regression estimates from solar radiation and chlorophyll-specific primary productivity data showed a maximal photosynthetic rate of 18 mg C per mg chlorophyll a per half day, an optimal light intensity of 54 langleys/half day, and markedly reduced primary productivity at moderately higher light intensities. These features indicate that phytoplankton was shade-adapted.

Hood, D. W. 1983. The Bering Sea, pp. 337-373. In B. H. Ketchum (ed.), Estuaries and Enclosed Seas. Ecosystems of the World 26. Elsevier, Amsterdam.

In the Bering Sea it is apparent that ice conditions exert important influences on the birds and mammals, acting at a gross level as a seasonally variable partition between species which normally reside in ice-covered water and those which are excluded when ice is present. In the spring of the year the primary productivity which occurs in the sea ice is vital to grazing organisms and possibly serves as a source of detritus for benthic biota underlying the ice floes.

Horner, R. A. 1981. Beaufort Sea plankton studies. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 13:65-314.

The purpose of this project was to provide basic seasonal information on the organisms in the Beaufort Sea that are at the lower end of the trophic system. These organisms, the phytoplankton and zooplankton, are the primary producers and primary and secondary consumers in the ecosystem, and, as such, provide food for all higher trophic levels including fish, birds, and mammals. Knowledge of the species present, their abundance, distribution throughout the year, and the levels of primary production is necessary to understand their relationships within the ecosystem. Samples were collected during icebreaker cruises in 1972, 1973, 1974, 1976, 1977, and 1978. Data are reported here from non-OCSEAP sponsored cruises because one of our objectives was to identify and report on archived samples. The data reported here provide basic background information about the plankton populations in the Beaufort Sea in August and September. Data from other times of the year from most areas of the Beaufort Sea are still generally unavailable, although some winter-spring information from the nearshore area will be included in the final winter studies report for Stefansson Sound.

Horner, R. A., K. O. Coyle, and D. R. Redburn. 1974. Ecology of the plankton of Prudhoe Bay, Alaska. Inst. Mar. Sci., Univ. of Alaska, Fairbanks. Scient. Rept. No. R74-2. 78 pp.

The original purpose of this project was to obtain basic quantitative information on the phytoplankton of the Prudhoe Bay area. The phytoplankton community was selected for study because phytoplankton are the primary energy source upon which the marine food web is based and any major changes in the phytoplankton composition might affect the entire ecosystem.

Karohji, K. 1972. Regional distribution of phytoplankton in the Bering Sea and western northern subarctic regions of the North Pacific Ocean in summer, pp. 99-115. In A. Y. Takenouti (ed.), Biological oceanography of the northern North Pacific Ocean. Idemitsu Shoten, Tokyo, Japan.

Phytoplankton distribution in the Bering Sea and Subarctic region of the North Pacific Ocean were observed in the summers of 1957, 1959-1961. The standing crops were large in the western Aleutian waters, northern and easternmost Bering Sea, and Kurile waters, and small in the Bering Sea, western Subarctic waters and south of eastern Aleutian Islands, the largest being 100 to 200 times the smallest. Oceanic populations are prevalent throughout the area. Neritic populations are in the western Aleutian waters, Kamchatka coastal waters, and northern and eastern continental shelf of the Bering Sea. Phytoplankton distributions are discussed in relation to hydrographic features.

Kinder, T. H., L. K. Coachman, and J. A. Gault. 1975. The Bering Slope Current system. J. Phys. Ocean. 5:231-244.

The Bering Slope Current flows from southeast to northwest across the Aleutian Basin of the Bering Sea, parallel to the continental slope of the eastern Bering Sea shelf. The water mass characteristics and distributions and the flow field were investigated in August 1972 during Cruise 071 aboard the R/V T.G. THOMPSON.

Kinney, P. J. 1985. Environmental characterization and biological utilization of Peard Bay. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 35:406-440.

The purpose of the present work in Peard Bay, which lies along the northeast Chukchi coast south of Point Barrow and is a system of spits and offshore barrier islands, was to describe the primary production and nutrient dynamics of the lagoon. Specifically, the objectives included 1) the determination of the total microbial biomass which serves the "base" of the food web and which supports all higher trophic levels, 2) the determination of the rate of production of organic matter by phytoplankton, and 3) the determination of the factors which limit the rate of primary production so that an estimate of its availability as food to vertebrate populations can be made.

Koblents-Mishke, O. I. 1965. Primary production in the Pacific. Oceanology 5:104-116.

The present paper contains information on the volume of primary production in the Pacific, and on its seasonal and geographic variations.

Larrance, J. D. 1969. Primary productivity data, Subarctic Pacific Region, 1966-68. Bureau Comm. Fish., Biol. Lab., Seattle, WA. 202 pp.

Primary productivity and related oceanographic and meteorological data are reported in tabular form from 10 cruises in the Subarctic Pacific Region in 1966-1968 by research vessels of the BCF Seattle Biological Laboratory, Seattle, WA. The methods used for sampling and analysis are presented, and the format of the data tables is explained.

Larrance, J. D. 1977. Phytoplankton and primary productivity in the northeast Gulf of Alaska and lower Cook Inlet. Final Report. Research Unit 425. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annual Reports 10:1-136.

The general intent of the study was to document the species composition and standing stock of the phytoplankton, primary productivity, and the environmental factors controlling production. These parameters were measured in lower Cook Inlet with sufficient frequency during Spring and Summer 1976, to develop a picture of the seasonal succession of events involving productivity and species composition.

Larrance, J. D. and A. J. Chester. 1979. Source, composition, and flux of organic detritus in lower Cook Inlet. Final Report. Research Unit 425. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Reports of Principal Investigators 46:1-71.

Comparisons of organic carbon and nitrogen content (dry-weight percent) of the sediment trap samples among the three sampling locations generally reflected the primary productivity in overlaying waters. Kachemak Bay (eastern Inlet) samples averaged 2.8% carbon compared with an average of 1.3% in the central Inlet and Kamishak Bay (western Inlet). Very high primary productivity (as high as 7.8 g $C \cdot m^{-2} \cdot d^{-1}$) persisted over several months at Kachemak, which accounted for the larger proportion of organic carbon and nitrogen. The total supplies of organic carbon to the bottom over the four-month study were 60 g C/m^2 at Kachemak Bay, 17 g C/m^2 in central Inlet, and 40 g C/m^2 in Kamishak Bay. These values account for approximately 12% of the total primary productivity over the same period. These values indicate the transfer of substantial organic matter (which is a needed nutrition source for the benthos) from surface waters to the benthos, much of it via zooplankton fecal pellets. Such particles, if contaminated with oil, act as transfer agents for oil from the surface, thus affecting the benthic community.

Martin, J. H., R. M. Gordon, S. Fitzwater, and W. W. Broenkow. 1989. VERTEX: Phytoplankton-iron studies in the Gulf of Alaska. Deep-Sea Res. 36(5):649-680.

VERTEX studies were performed in the Gulf of Alaska in order to test the hypothesis that iron deficiency was responsible for the phytoplankton's failure to remove major plant nutrients from these waters. In view of the observed Fe distributions and the results of phytoplankton Fe enrichment experiments, it was concluded that Gulf of Alaska atmospheric Fe input rates are sufficient to support moderately high rates of primary productivity; however, not enough Fe is available to support the high growth rates that would lead to normal major nutrient depletion. Enhanced Fe input does occur along the Alaska continental margin, where normal NO_3 surface depletion is observed. Coccolithophores were able to cope with low Fe conditions; however, they cannot compete with diatoms when Fe is readily available. Iron may be more important than available N in determining global rates of phytoplankton new production. Offshore Pacific Ocean water, replete with major nutrients, appears to be infertile without supplemental iron from the atmosphere or continental margin. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

McAllister, C. D. 1969. Aspects of estimating zooplankton production from phytoplankton production. J. Fish. Res. Bd. Canada 26:199-220.

Primary productivity and zooplankton data from Ocean Station P are used to compare estimates of phytoplankton and herbivore production calculated on the assumption of continuous grazing by the animals with estimates obtained on the assumption of three different types of nocturnal grazing. Effective plant production, that corrected for the effects of grazing on the size of the phytoplankton stock and hence on the magnitude of the plant repiratory loss, was less than the measured production and was least under the assumption of continuous grazing. The small differences in effective production resulting from the choice of different grazing schemes resulted in large differences in estimates of secondary production and varied markedly with zooplankton respiration and with the phytoplankton growth rate.

McGowan, J. A. and T. L. Hayward. 1978. Mixing and oceanic productivity. Deep-Sea Res. 25:771-793.

An unusual oceanographic event in 1969 allowed investigation as to how nutrients are mixed into the euphotic zone of the oligotrophic central gyre of the North Pacific. A doubling of the rate of primary production and a significant increase in the standing crop of zooplankton were the original evidence. Interpretation of these and other physical data indicates that a mixing episode, or rather a series of small mixing events, took place. It is hypothesized that the mixing was upward from below the euphotic zone rather than downward from the surface. A layer where the depth variance of isotherms was at a maximum was observed. This was also a maximum in the frequency of temperature inversions. The layer could be due to a large number of intrusions of water of anomalous temperatures and, therefore at a given density, anomalous salinity. T-S diagrams do not indicate that such anomalous salinities were present. The authors interpreted the depth variance of the isotherm layer as being the result of up and down movement of the water, perhaps internal waves. Although present in other years, this layer was shoaled in 1969, bringing it to the top of the nutricline and closer to the bottom of the euphotic zone. It is suggested that shear induced turbulence of breaking internal waves, or both, may act as a nutrient pump in an otherwise stably stratified water column.

McRoy, C. P., J. J. Goering, and W. E. Shiels. 1972. Studies of primary production in the eastern Bering Sea, pp. 199-216. In A. Y. Takenouti (ed.), Biological oceanography of the northern North Pacific Ocean. Idemitso Shoten, Toyko.

Measurements of productivity were made during February, March, June, and July at numerous stations in the Eastern Bering Sea. Surface productivity during June and July in the Aleutian Islands ranged from 2.2-165 mg $C \cdot m^{-3} \cdot d^{-1}$ with an average of 27.9. The standing stock of phytoplankton ranged from 0.2-9.9 mg chlorophyll a/m^3 with an average of 1.88. Integrated productivity of the water column averaged 243 mg C•m^{-2}•d^{-1} for this region. Measurements obtained in June at a Bering Strait station were very high (surface = 410 mg C•m^{-3}•d^{-1}). The integrated value of ^{14}C fixed was 4.1 g C•m^{-2}•d^{-1}. This region is one of the most productive in the Bering Sea. The summer productivity of a lagoon located on the Alaska coast of the Bering Sea ranged from 26.8 to 194 mg C•m^{-3}•d^{-1} with an average of 78.8. The average standing stock was 1.5 mg chlorophyll a/m^3. This lagoon exchanges daily most of its water with the surrounding sea and contributes to near-shore productivity. Winter observations of productivity in ice-covered surface water ranged from 0.17-4.09 mg C•m^{-3}•d^{-1} with an average of 1.20. Standing stocks of phytoplankton averaged 0.53 mg chlorophyll a/m^3. The water column productivity averaged 20.9 mg C•m^{-2}•d^{-1} with an associated standing stock of 8.75 mg chlorophyll a/m^2. The low productivity and standing stock of surface water were in striking contrast to the microalgae in the undersurface of the ice. The productivity of this population averaged 44.4 mg C•m^{-3}•d^{-1} with a standing stock of 6.83 mg chlorophyll a/m^3. The ^{15}N technique of measuring productivity was also utilized in this study. A high percentage of nitrate uptake at most summer stations verifies the high summer productivity of the sea which results from large supplies of inorganic nutrients and sufficient light. The annual cycle of primary production in the Bering Sea apparently begins with a bloom of non-planktonic algae in the sea ice. This late winter bloom in the ice is followed by a phytoplankton bloom in the water column in spring.

McRoy, C. P. and J. J. Goering. 1974. Primary production budget for the Bering Sea. In D.W. Hood and Y. Takenouti (eds.), Bering Sea Oceanography: An Update 1972-1974. Inst. Mar. Sci., Univ. of Alaska, Fairbanks. Rept. No. 75-2:97-107.

The seasonality of productivity in the Bering Sea results in complex, overlapping pulses of productivity that combined, give this ocean very high annual production. This must, in large part, be the explanation for the many populations of abundant harvestable invertebrates, fin fishes, and mammals. All of the previous annual budgets of primary production in the Bering Sea have not included under ice productivity. This feature, as well as upgraded productivity estimates for spring, summer, and fall using recently available data, was included in this analysis.

McRoy, C. P., A. S. Springer, D. Hansell, and J. J. Goering. 1987. Productivity station data 1985/1986. ISHTAR Data Rept. No. 7, Inst. Mar. Sci., Univ. of Alaska, Fairbanks. 67 pp.

Productivity and nutrient data are compiled for the Inner Shelf Transfer and Recycling (ISHTAR) study area of the north Bering and Chukchi Sea. Integrated ^{14}C values are presented for July-September 1985 and 1986.

McRoy, C. P., A. S. Springer, W. Robie, and G. Holmes (in prep.). Productivity station data 1987/1988/1989. ISHTAR Data Rept. No. 11, Inst. Mar. Sci., Univ. of Alaska, Fairbanks.

Productivity and nutrient data are compiled for the ISHTAR study area of the north Bering and Chukchi Seas. Integrated ^{14}C values are presented for July-September 1987, 1988, and 1989.

Niebauer, H. J., V. Alexander, and R. T. Cooney. 1981. Primary production at the eastern Bering Sea ice edge: The physical and biological regimes, pp. 763-780. In D. W. Hood and J. A. Calder (eds.), The eastern Bering Sea shelf: Oceanography and resources. Univ. of Washington Press, Seattle, WA.

In this chapter, the melting of the ice edge in the Bering Sea is shown to promote high primary production in spring by increasing the stability of the water column. Hydrographic sections of temperature, salinity, sigma-t, nitrate, ammonia, and chlorophyll a through the ice-edge zone in the spring of 1975, compared with sections taken later in the spring, seem to support this hypothesis.

Niebauer, H. J., C. P. McRoy, J. J. Goering, and R. Iverson. 1981. PROBES Data Rept. PDR 82-009 Productivity. Inst. Mar. Sci., Univ. of Alaska, Fairbanks. 225 pp.

Processes and Resources of the Bering Sea shelf (PROBES) is a six-year multi-institutional, interdisciplinary study of the marine ecosystem of the Bering Sea. The major effort is to understand the processes that contribute to the production of enormous numbers of animals (including crabs, fish, birds, mammals) in secondary and higher trophic levels in the vast region of the sea extending over the outer continental shelf. The project is structured around the hypothesis that the exceptional width of the shallow Bering Sea shelf, coupled with a specific combination of oceanographic features, combine with the timing of biological events to maintain the needed transfer of energy and materials from primary to secondary and higher trophic levels. The project focuses on production of Alaska pollock (*Theragra chalcogramma* Pallas) as an example of mass and energy transfer. The PROBES field study utilizes extensive time series (R/V ACONA, R/V T.G. THOMPSON, R/V ALPHA HELIX) to detail the magnitude and sequencing of oceanographic events which lead to and support the annual production and transfer of organic matter and energy in the Bering Sea. More particularly, the overall goal is to understand the processes involved in energy transfer to secondary trophic levels in the newly-discovered and complex system of oceanic fronts and interfront regions that are the primary oceanographic features of the southeastern Bering Sea. Because of intensive fishing (4% of the total annual world landing) and scheduled oil and gas exploration and development, the results of PROBES will be valuable in providing an ecological basis for management aspects of the resources of this continental shelf.

Pace, M. L., G. A. Knauer, D. M. Karl, and J. H. Martin. 1987. Primary production, new production and vertical flux in the eastern Pacific Ocean. Nature 325:803-804.

The sinking of particulate organic matter in the ocean links food webs beneath the euphotic zone to surface primary production and is an important pathway for the downward transport of many elements. The flux of particulate organic carbon (POC) is also an important parameter in the global carbon cycle and may be related to long-term changes in atmospheric CO_2. In 1980, Suess synthesized existing measurements from sediment trap studies into a model to predict the vertical flux of POC from depth (z) and primary production (PP). The Suess model has become the standard for evaluating vertical flux data, for estimating the annual flux of POC in the ocean and for parameterizing ocean carbon cycle models. In the present analysis, a new model is presented for the vertical flux of POC and particulate organic nitrogen (PON) from a set of contemporaneous measurements of PP and fluxes made during the VERTEX Program in the northeast Pacific. The VERTEX model indicates that PP and vertical fluxes of POC and PON, in the oligotrophic ocean are greater than previously suggested. In addition, the vertical flux of PON from the photic zone represents a measure of the PP that is supported by new nitrogen (new production). In the northeast Pacific, new production ranged from 13 to 25% of primary production and was positively related to total PP.

Parrish, D. M. 1986. An estimate of annual primary production in the Alaskan Arctic Ocean. M.S. thesis, Univ. of Alaska, Fairbanks. 166 pp.

An estimate of annual ice algal and phytoplankton production was made for Alaskan arctic waters, using a total ice algal production to biomass (P:B) relationship. This was calculated from chlorophyll a concentrations in ice cores and a P:B relationship derived from the literature. The estimated average of ice algal production for the nearshore Beaufort Sea was 1.6 g $C \cdot m^{-2} \cdot yr^{-1}$ and an estimate from offshore Chukchi Sea cores was 13.1 g $C \cdot m^{-2} \cdot yr^{-1}$. An estimate of ice algal production in the offshore Beaufort Sea was not made. Phytoplankton productivity measurements were synthesized with nutrient, light, and ice retreat data to produce a contoured map of estimated phytoplankton production. The highest productivity was in the southern Chukchi Sea (>150 g $C \cdot m^{-2} \cdot yr^{-1}$), due to periodic upwelling associated with southeasterly summer winds.

Parsons, T. R. and C. M. Lalli. 1988. Comparative oceanic ecology of the plankton communities of the subarctic Atlantic and Pacific Oceans. Oceanogr. Mar. Biol. Annu. Rev. 26:317-359.

The seasonal cycles and production processes of plankton in the subarctic North Pacific and North Atlantic are compared. The seasonal cycle in the North Atlantic is limited by the depth of mixing in the spring and by nitrate limitation in the late summer. In contrast, the seasonal cycle of primary productivity in the North Pacific is limited by low temperature and grazing by micro- and macrozooplankton in the spring and summer, and possibly by an unidentified nutrient during July and August. The strategy for zooplankton survival in the North Pacific leads to dominance by large-sized copepods having a single generation per year. In the North Atlantic, the copepod population is dominated by smaller copepods having several generations per year. In spite of these differences in ecological structure, the two areas appear to have similar annual productions of phytoplankton and macrozooplankton. Planktivorous predators appear to be generally similar in both oceans. The close coupling of primary and secondary production in the North Pacific may, however, lead to greater production of pelagic fishes while, in the North Atlantic, a greater production of phytodetritus may favor a larger proportion of benthic fish.

Platt, T., W. G. Harrison, M. R. Lewis, W. K. L. Li, S. Sathyendranath, R. E. Smith, and A. F. Vezina. 1989. Biological production of the oceans: The case for a consensus. Mar. Ecol. Prog. Ser. 52:77-88.

Biological dynamics in the pelagic ocean are intermittent rather that steady. In oceanic regimes, where nitrogen is limiting to phytoplankton growth, an important fraction of the annual, primary production depends on transient episodes of increased nitrate supply; at such times, the role of locally-regenerated nitrogen is correspondingly less. Proper averaging of these variable rates, in time and space, is the key of reconciliation of existing data on the biogenic fluxes of oxygen and carbon in the ocean. The magnitude of oceanic production supported by nitrate (the new production) is higher than previously thought.

Reed, R. K. and J. D. Schumacher. 1986. Physical oceanography, pp. 57-76. In D. W. Hood and S. T. Zimmerman (eds.), The Gulf of Alaska: Physical environment and biological resources. U.S. Dept. of Commerce and U.S. Dept. of the Int. MMS Report 86-0095. U.S. Govt. Printing Office, Washington, DC.

The state of knowledge for both circulation and physical properties for the Gulf of Alaska is reviewed. The largest-scale feature evaluated is the offshore boundary current. This current is relatively wide and slow on the east side of the Gulf, but it narrows to less than 100 km from Kodiak Island westward, with peak speeds of about 100 cm/s. Although occasional large changes occur in the path, transport, and properties of the Alaskan Stream, high-frequency variability is not typical. The stream may transfer heat and momentum into coastal waters, although the relative importance of this process has not been established.

Sambrotto, R. N. and C. J. Lorenzen. 1986. Phytoplankton and primary production, pp. 249-284. In D. W. Hood and S. T. Zimmerman (eds.), The Gulf of Alaska: Physical environment and biological resources. U.S. Dept. of Commerce and U.S. Dept. of the Int. MMS Report 86-0095. U.S. Govt. Printing Office, Washington, DC.

Changes in both the amount of daily light and in the depth of mixing initiate a predictable, positive response in phytoplankton productivity throughout the subarctic Gulf of Alaska during the spring. In the oceanic regions, however, this productivity increase is not accompanied by a commensurate increase in the phytoplankton standing crop. Chlorophyll a levels in this region usually do not exceed 1 mg/m^3, diatom cells are not especially numerous, and the phytoplankton community is numerically dominated by microflagellates. The discrepancy between increased productivity and the size of the standing crop is generally attributed to the rapid rate with which phytoplankton cells are removed from the surface water by endemic North Pacific macrozooplankton. Recent measurements suggest that, in addition to the influence of macrozooplankton, grazing by microzooplankton coupled with the number of phytoplankton cells that sink are also important loss factors. Seasonal ^{14}C productivity measurements at Ocean Station P vary from winter values that are generally less than 50 mg $C \cdot m^{-2} \cdot d^{-1}$ to summer values that range between 200 and 400 mg $C \cdot m^{-2} \cdot d^{-1}$ and suggest annual productivity of about 50 g C/m^2. However, a mass balance of phytoplankton nutrient consumption indicates that the yearly production may actually exceed 100 g C/m^2 for the Central Subarctic Domain. The Gulf of Alaska shelf is extremely productive and in the areas near Adak Island, lower Cook Inlet, and the Kenai shelf, annual production is about 300 g C/m^2. Production in these areas may be associated with upwelling that is induced by both coastal and near-shelf water movements. Such productivity suggests that previous estimates of the Gulf's productivity may need to be adjusted upward. Coastal areas are environmentally heterogeneous, and measurements suggest that the annual production in the various embayments ranges from 140 to over 200 g C/m^2. Large standing crops of phytoplankton build up near the shore. Dense chlorophyll a concentrations usually appear briefly in surface waters, although subsurface chlorophyll a layers may persist throughout the summer.

Sambrotto, R. N., H. J. Niebauer, J. J. Goering, and R. L. Iverson. 1986. Relationships among vertical mixing, nitrate uptake and phytoplankton growth during the spring bloom in the southeast Bering Sea middle shelf. Cont. Shelf Res. 5:161-198.

The temporal development of a spring diatom bloom in the southeast Bering Sea middle shelf for three consecutive ice-free years is analyzed. Physical and chemical criteria are used to divide the bloom period into pre-bloom, bloom, and post-bloom stages. At this shelf depth, the shallowing of the mixed layer was most important in triggering bloom conditions by diminishing phytoplankton respirational losses. This occurred in late April to early May during a hiatus in wind mixing associated with low pressure systems.

Sanger, G. A. 1972. Fishery potentials and estimated biological productivity of the subarctic Pacific Region, pp. 561-574. In A. Y. Takenouti (ed.), Biological oceanography of the northern North Pacific Ocean. Idemitsu Shoten, Tokyo.

Pertinent literature on the primary production and fishery potential of the Subarctic Pacific Region are reviewed. An original estimate of the annual primary production of the region is derived, and relations of the present fish production with estimated potential biological productivity are discussed.

Sayles, M. A., K. Aagaard, and L. K. Coachman. 1979. Oceanographic atlas of the Bering Sea Basin. Univ. of Washington Press, Seattle, WA. 158 pp.

This document comprises an atlas of the water masses of the deep basin in the Bering Sea. Water masses characterized by temperature, salinity, density and sometimes oxygen are presented in horizontal and vertical profiles.

Schell, D. M. 1982. Primary production and nutrient dynamics in Simpson Lagoon and adjacent waters. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 24:69-112.

This report deals with the primary productivity in the Simpson Lagoon-barrier island ecosystem. The estimates of carbon fixation are compared with other imputs of carbon to the system arising from shoreline erosion and fluvial input from the Kuparuk and Colville Rivers. Finally, the ecological importance of the terrestrial carbon sources is assessed relative to marine phytoplankton production based upon carbon isotope abundances in consumer organisms from Simpson Lagoon. Personnel of LGL-Alaska did not perform any of the primary productivity studies and the principal work was undertaken by the author who cooperated with the LGL study to provide estimates of energy influx and to determine the role of peat detritus in the lagoon food web.

Schell, D. M. and S. M. Saupe. 1989. Primary production, carbon energetics, and nutrient cycling. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 60:99-140.

This project seeks to describe the nutrient dynamics, primary productivity, and trophic energetics of the nearshore waters of the North Aleutian shelf. Through consideration of the availability of nutrients and the consequent primary productivity, the carbon derived from *in situ* primary producers has been quantified and compared with that derived from allochthonous sources, in this case, the extensive eelgrass (*Zostera marina*) beds in Izembek Lagoon. Researchers used natural abundances of radiocarbon isotopes as indicators of primary production by phytoplankton in upwelled waters and abundances of stable carbon isotopes as tracers of eelgrass carbon in the coastal food webs. Results confirm that the deep-mixing and advection of nutrient-rich waters onto the shelf in the vicinity of Unimak Pass subsequently produces very high rates of primary productivity over much of the study area during the spring and summer seasons. Vertical mixing in the region of the inner frontal system separating the coastal and middle shelf domains produces water columns rich in nutrients. Nitrate-N concentrations were often in excess of 5 mg-atoms/m^3 in the euphotic zone with the exception of apparent nutrient depleted water sampled throughout the study area in July. Integrated water column productivities were high, with the fastest rate being 6.7 g $C \cdot m^{-2} \cdot d^{-1}$. The annual productivity in the study area is about 220 to 240 g $C \cdot m^{-2} \cdot yr^{-1}$ although our temporal coverage is not sufficient for confident estimates. In spite of the extensive *Zostera* beds in Izembek Lagoon, the role of eelgrass in the food web energetics of the nearshore zone appears to be minimal. The stable isotope data indicate that *in situ* phytoplankton production supplies nearly all carbon in the nearshore food web. Estimates of primary productivity by phytoplankton also indicate that the *in situ* inputs of carbon to the inner shelf waters exceed that derived from eelgrass by about three-fold inside the 50-m contour near Izembek Lagoon. Although eelgrass has the potential to contribute a substantial amount of energy to the food web, the conversion of detrital eelgrass to animal biomass may proceed through a microbial-meiofaunal pathway, and the conversion efficiency losses in the trophic steps alone might account for the lack of eelgrass carbon in higher levels.

Schumacher, J. D. and R. K. Reed. 1980. Coastal flow in the northwest Gulf of Alaska: The Kenai Current. J. Geophys. Res. 85:6680-6688.

Recent data from the northwest Gulf of Alaska reveal a coastal current which flows westward along the Kenai Peninsula, enters Shelikof Strait, and exits to the southwest of Kodiak Island. This flow, termed the Kenai Current, has a large seasonal variation in baroclinic transport and maximum surface speed.

Starodubtsev, Y. G., A. A. Loginov, and S. P. Zakharov. 1988. Chlorophyll a in the northwestern Pacific Ocean. Oceanology 28(1):91-94.

The distribution of chlorophyll a on a meridional profile 50° in length lasting 20 d is discussed. The characteristics of the vertical chlorophyll distribution in different water masses are described. The highest concentration was found in the subarctic water mass and the lowest in the north tropical water mass.

Stephens, K. 1964. Data record. Productivity measurements in the northeast Pacific with associated chemical and physical data, 1958-64. J. Fish. Res. Bd. Canada, Manuscript Report Series (Oceanogr. and Limnol.) No. 179:168.

This report covers the results of a continuing program to monitor variations in primary production at Ocean Weather Station P.

Stephens, K. 1966. Data record. Primary production data from the N. E. Pacific Ocean, January 1964 to December 1965. J. Fish. Res. Bd. Canada, Manuscript Report Series (Oceanogr. and Limnol.) No. 209:14.

This report covers the results of a continuing program to monitor variations in primary production at Ocean Weather Station P.

Stephens, K. 1968. Data record. Primary production data from the N. E. Pacific Ocean, January 1966 to December 1967. J. Fish. Res. Bd. Canada, Manuscript Report Series (Oceanogr. and Limnol.) No. 957:58.

This report covers the results of a continuing program to monitor variations in primary production at Ocean Weather Station P. Plant pigments were measured by the modification of the Richards with Thompson (1952) method described by Strickland and Parsons (1960). Productivity samples were taken from the surface and from five depths which matched the percentage transmission of light by a graded series of neutral density filters. The samples were incubated in daylight simulating *in situ* conditions.

Swift, J. H. and K. Aagaard. 1976. Upwelling near Samalga Pass. Limnol. Oceanogr. 21:399-408.

Recent summer hydrographic data from the vicinity of Samalga Pass in the eastern Aleutians show upwelling of relatively saline water, poor in oxygen and rich in nutrients. A steady state oxygen model, in which the photosynthetic production of oxygen in the euphotic zone is balanced by an upwelling of low-oxygen water, yields an upper bound on the vertical velocity of 7×10^{-3} cm/s. Examination of various possible driving mechanisms for the upwelling, including winds and entrainment, suggests that the upwelling is driven by subsurface convergence.

Takahashi, K. 1986. Seasonal fluxes of pelagic diatoms in the subarctic Pacific, 1982-1983. Deep-Sea Res. 33(9A):1225-1251.

An assessment of the vertical flux of pelagic diatoms was conducted on PARFLUX sediment trap samples collected during September 1982 to September 1983 at the subarctic Pacific Station PAPA (50°N latitude, 145°W longitude; water depth 4,200 m). A total of 24 time-series sediment trap samples were collected for 11- to 16-d periods during the year. Seasonal fluxes of 18 encountered taxa are reported. All of the taxa fall into one of five different types of seasonal flux patterns. Generally, taxa in Types 1 to 3 are indicators for high mass, opal, and organic carbon fluxes (based on correlation analysis with mass and opal fluxes). Among them, *Chaetoceros atlanticum, Rhizosolenia styliformis*, and *Asteromphalus robustus* are the best indicators for production. Unique signals from *Cosmodiscus marginatus* are present in the October-December high flux season and the January-March high percentage values. (Copyright 1989, Lockheed DIALOG Information Retrieval Service).

Truett, J. C. and P. C. Craig (eds). 1986. Evaluation of environmental information for the Unimak Pass area, Alaska. U.S. Dept. of Commerce, and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 58:1-392.

This report identified and describes the important biological resources of the marine environment of the eastern Aleutian Islands, Alaska, between 164°W and 170°W longitude, and discusses the physical and chemical processes and components that support these resources. It evaluates the potential effects of oil and gas activities on the biota and identifies information needs. It is based solely on a review and analysis of existing information. Major points follow under the headings History of Investigation, Marine Mammals, Birds, Fish, Invertebrates, Primary Production, Physiocochemical Processes, and Regional Comparisons and Potential Impacts. In terms of primary production, phytoplankton is by far the major primary producer in the study area, though eelgrass and benthic algae are locally important in shallow areas. The annual production of phytoplankton in the study area is quite large, apparently driven largely by nutrients upwelled from deep Pacific and Bering Sea waters, and probably peaks in late spring and early summer.

Venrick, E. L. 1988. The vertical distributions of chlorophyll and phytoplankton species in the North Pacific central environment. J. Plank. Res. 10(5):987-998.

The phytoplankton species in the North Pacific central environment are known to be distributed into two vertically distinct assemblages during most of the year. Key species are defined for each assemblage. The vertical distributions of these key species indicate that the increase in abundance of deep species closely parallels the increase in chlorophyll a at the top of the chlorophyll maximum layer. The chlorophyll maximum is comprised of species characteristic of the deep assemblage, with only insignificant numbers of shallow species.

Walsh, J. J., C. P. McRoy, T. H. Blackburn, L. K. Coachman, J. J. Goering, K. Henriksen, P. Andersen, J. J. Nihoul, P. L. Parker, A. M. Springer, R. B. Tripp, T. E. Whitledge, and C. D. Wirick. 1989. The role of Bering Strait in the carbon/nitrogen fluxes of polar marine ecosystems, pp. 90-120. In L. Rey and V. Alexander (eds.), Proc. Sixth Conf. Comite Arctique Intern., 13-15 May 1985. E. J. Brill, New York, NY.

Seasonal and interannual variation of transport of Pacific water north through the Bering Strait returns to the surface Arctic Ocean about 10-50% of the dissolved CO_2 removed by polar downwelling of Norwegian Sea water south of the Denmark Strait and the Faeroe Bank Channel. The associated nutrient flux onto the Bering Sea shelf is the same as that of the productive Peru upwelling system; about half of this arctic nutrient input is stripped by the primary producers of the southeastern Bering shelf; the other half remains unused as slope-derived water transits the northwestern Bering shelf. Estimated primary productivity of the waters between St. Lawrence Island and Bering Strait 250 km to the north suggests that these nutrients are consumed here, forming the organic input to the carbon deposits of the Chukchi shelf sediments.

Walsh, J. J., C. P. McRoy, L. K. Coachman, J. J. Goering, J. J. Nihoul, T. E. Whitledge, T. H. Blackburn, P. L. Parker, C. D. Wirich, P. G. Shuert, J. M. Grebmeier, A. M. Springer, R. D. Tripp, D. A. Hansell, S. Djenidi, E. Deleersnijder, K. Henriksen, B. A. Lund, P. Andersen, F. E. Muller-Karger, and K. Dean. 1989. Carbon and nitrogen cycling within the Bering/Chukchi Seas: Source regions for organic matter effecting AOU demands of the Arctic Ocean. Prog. Oceanogr. 22:279-361.

Recent results of the Inner Shelf Transfer and Recycling (ISHTAR) Program show that organic matter fixed south of the Arctic Ocean and carried north through Bering Strait, together with a concomitant Pacific import of "new" dissolved nitrogen for production on the Chukchi and east Siberian shelves, can balance such carbon demands of the polar basins. The ISHTAR Program was designed to explore the fate of both the dissolved and particulate phases of carbon, nitrogen, phosphorus, and silicon within interannual variations of a strong current system at the western boundary of the Bering Sea.

Whitledge, T. E., W. S. Reeburg, and J. J. Walsh. 1986. Seasonal inorganic nitrogen distributions and dynamics in the southeastern Bering Sea. Cont. Shelf Res. 5:109-132.

The annual cycle of the distribution of nitrate and ammonium concentrations in the PROBES area of the southeastern Bering Sea was highly interactive with the physical and biological processes. Nitrate concentrations were replenished over the shelf during the autumn and winter at a very uniform rate until the spring bloom commenced. In the middle shelf after nitrate concentrations were depleted in the upper mixed layer during the spring bloom, large quantities of ammonium were produced in the bottom layer. Cross-shelf diffusion, vertical diffusion, vertical mixing by storms, benthic release, and possibly nitrification interacted to supply nitrogen utilized by primary production. Nitrogen uptake by photosynthetic processes as estimates made by radiocarbon uptake rate measurements and CO_2 budgets.

Whitledge, T. E., R. R. Bidigare, S. I. Zeeman, R. N. Sambrotto, P. F. Roscigno, P. R. Jensen, J. M. Brooks, C. Trees, and D. M. Veidt. 1988. Biological measurements and related chemical features in Soviet and United States regions of the Bering Sea. Cont. Shelf Res. 8(12):1299-1319.

The U.S. results of a joint U.S. - U.S.S.R. expedition to the Bering Sea in 1984 investigated the chemical and biological interactions in the south, east, north, and west regions. The nutrients, phytoplankton biomass and primary productivity were enhanced near the ends of a north-south transect of stations. The southern end of the transect had characteristics of the North Pacific Ocean with high nutrient and low phytoplankton concentrations and an elevated concentration of peridinin indicative of dinoflagellates. The middle station of the transect, near the shelf break, had low nutrients and phytoplankton in the upper euphotic zone, but a submerged chlorophyll b maximum indicated green algae was located on the upper boundary of high ammonium concentration and pycnocline. The north end of the transect over the shelf at mid-depth on the boundary of high nitrate and ammonium concentrations produced the highest primary production. Pigment analysis (chlorophyll a, diadinoxanthin, and fucoxanthin) indicated the dominance of diatoms and was coincidental to oxygen saturation values as large as 150%. The highest phaeophorbide a concentrations were also observed in this area, suggesting relatively high grazing stress. Measurements of low molecular weight hydrocarbons also suggest high microbiological degradation rates of organic matter in the sediments in the north region. Overall, this research strongly related nutrient, oxygen, and pigment concentrations to the production, decomposition, and recycling processes in the open and shelf areas of the Bering Sea.

APPENDIX B
ANNOTATED BIBLIOGRAPHY:
COASTAL AND MARINE HABITATS

APPENDIX B
ANNOTATED BIBLIOGRAPHY: COASTAL AND MARINE HABITATS

To facilitate reader access to and identification of the various data sources employed in the present analysis, the citations within the following annotated bibliography have been divided into two groups, consisting of 1) literature sources, containing peer-reviewed journal publications and Federal and/or State agency reports; and 2) graphic data sources. Graphic data sources (e.g., maps, charts, graphics, visuals) have been grouped by Planning Area and represent the primary sources cited in Sections 3.0 and 4.2 of the preceding text. For all entries noted in this latter section, agency and title information have been drawn directly from the graphic source of interest. Explanations are offered below regarding the unique format employed in the citation of referenced maps and charts.

The title of an individual map or map set has been provided as part of the citation, along with the issuing agency and the year of issuance, followed by the annotation. As an example:

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985a. Topographic/Bathymetric Chart, Northeastern United States Regional Map.

> Presented at a 1:1,000,000 scale, this maps shows accurate and consistent bathymetric contours across the Mid- and North Atlantic continental shelf of the United States. Major geologic features, submarine canyons, and seamounts are delineated. Lease blocks are superimposed, but exact Planning Area boundaries are not specifically delineated.

In several instances where maps from a particular map series were issued over several years, that portion of a large map set which is applicable to a specific Planning Area has been bracketed (i.e., the years of issuance for that portion of the map set used have been integrated as part of the citation). As an example:

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1987. NWI Wetlands Classification Maps.

In this example, drawn from the Mid-Atlantic Planning Area subsection, the NWI Wetlands Classification Maps for the coastal segments adjacent to this Planning Area were issued intermittently between 1979 and 1987. Because a total of 14 maps were reviewed as a complete set in the present analysis of the Mid-Atlantic region, these maps have been grouped for purposes of proper citation. In these instances, the names and publication dates of individual maps have also been provided as part of the annotation.

In those instances where a map set was issued in a single year, the citation appears as follows:

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980. Atlantic Coast Ecological Inventory Maps.

Multiple publications from the same agency during the same year have been denoted via use of small case letters, distinct for each citation, as follows:

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985a. Topographic/Bathymetric Chart, Northeastern United States Regional Map.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985b. Outer Continental Shelf Resource Management Map, North Aleutian Basin Regional Map.

On several occasions, graphic information has been drawn from environmental impact statements issued by the U.S. Department of the Interior. In those instances, only those graphics (or visuals) used in the present analysis have been cited and annotated. The source document for the graphic of interest has been noted either within the annotation or as part of the title.

LITERATURE SOURCES

Ambrose, R. F., D. C. Reed, J. M. Engle, and M. F. Caswell. 1989. California Comprehensive Offshore Resource Study: Summary of biological resources. California State Lands Commission, Sacramento, CA. 146 pp.

This report provides concise information of California's biological coastal resources as outlined in the Study Guide to the California Comprehensive Offshore Resource Study (CCORS), prepared by the California State Lands Commission (October 1988). The resources examined are kelp beds, artificial reefs, areas used for education and research, protected areas, hard-bottom habitats, special habitats, and mariculture. There are two types of kelp beds in California, giant kelp beds and bull kelp beds. The commercial harvest consists almost exclusively of giant kelp, with most of the harvest taken south of Point Conception. Although kelp beds vary in size from year to year, there has been a general decrease in the annual kelp harvest in the last 10 yr; this is largely a result of poor growing conditions. In contrast to harvesting wild populations, as is the case for kelp in California, many other marine species have been domesticated and are being commercially grown and harvested on farms. Such ocean farming, or mariculture, is a rapidly growing industry in California that relies extensively on the calm waters of bays and estuaries; offshore mariculture activities are largely confined to the protected waters near Santa Barbara. In other areas, the Department of Fish and Game is seeking to enhance natural populations of game fish by constructing artificial reefs. Most of these reefs have been built in southern California, where fishing pressure is quite high and the availability of suitable fish habitat is relatively low. Nearshore rocky habitat is generally less abundant in southern California, with the Channel Islands being a notable exception. Much less is known about the distribution of rocky habitat offshore of California. Many nearshore and offshore areas have received official protective designations in order to safeguard them from impacts that might diminish their value. Seventeen categories of protection under six different authorities were identified. Certain rocky areas or habitats are known to be of special ecological significance, yet they lack any protective status. Such habitats include many rocky headlands, offshore rocks and islets, nearshore submarine canyons and submarine reefs, banks and pinnacles. Lastly, coastal areas are used for education and research and serve as an important resource for a wide variety of users. Most of these areas are aggregated around population centers such as San Francisco Bay, Monterey Peninsula and southern California.

Armstrong, D. A., L. K. Thorsteinson, and C. A. Manen. 1984. Coastal habitats and species, pp. 35-45. In L. K. Thorsteinson (ed.), The North Aleutian Shelf environment and possible consequences of offshore oil and gas development. Proceedings of a Synthesis Meeting, 9-11 March 1982, Anchorage, AK.

This report describes the broad-scale ecology of the North Aleutian Shelf and the dominant physical and biological features that may be affected by offshore oil and gas activities, specifically the extraction, transportation, and storage of crude oil.

Arneson, P. D. 1980. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 15:1-363.

Density maps by species and season for marine and coastal birds, organized by OCS planning areas include descriptive information on coastal habitats from the eastern Gulf of Alaska to the North Alaskan Peninsula.

Blake, J. A., B. Hecker, J. F. Grassle, B. Brown, M. Wade, P. D. Boehm, E. Baptiste, B. Hilbig, N. Maciolek, R. Petrecca, R. E. Ruff, and V. Starczyk. 1986. Study of biological processes on the U.S. South Atlantic Slope and Rise. A draft final report for the U.S. Department of the Interior, Minerals Management Service, Atlantic OCS Office, Vienna, VA. Contract No. 14-12-0001-30064. 385 pp.

A total of 16 stations were established during a two-year field program designed to characterize the biological, chemical, and sedimentary processes on the slope and rise off North and South Carolina. A total of 130 box cores were taken at depths of 600 to 3,500 m. A census of the infauna yielded a total of 1,202 species, 520 of which are new to science. Two stations off Cape Hatteras in depths of 600 and 2,000 m are unique in their biology, chemistry, and geology. Faunal densities are higher at both depths than recorded elsewhere on the U.S. Atlantic Slope and Rise. Species which dominate at 600 m are more characteristic of continental shelf habitats. The Cape Lookout transect faunal density and diversity patterns are more typical in terms of density, diversity, and community structure. Departures from this pattern on the Cape Fear and Charleston transects are probably due to different sediment regimes in the southernmost transects. Epifaunal transects were most unusual on the Charleston Bump, where a unique hard-bottom fauna was discovered in an area strongly swept by the Gulf Stream. The fauna is rich and dominated by filter feeding corals and sponges. Consistent differences were found between the fauna on the upstream and downstream side of the bump. Data generated in the infaunal and epifaunal surveys support the

view that a partial zoogeographic barrier is present on the slope off North Carolina. This break is most evident between Cape Lookout and Cape Fear.

Bright, T. J. and R. Rezak. 1981. Northern Gulf of Mexico Topographic Features Study. A final report to U.S. Department of the Interior, Bureau of Land Management, Gulf of Mexico OCS Office, New Orleans, LA. Contract No. AA551-CT8-35. (4 volumes.)

This report, presented in four volumes, details and summarizes several years of surveys. Topographic, physical, and biological data concerning numerous reefs and banks in the northwestern Gulf of Mexico are presented. Maps locating the topographic features surveyed are presented, along with data on the aerial extent and species of organisms comprising the biological community seen at individual banks.

Bright, T. J., D. W. McGrail, R. Rezak, G. S. Boland, and A. R. Trippett. 1982. The Flower Gardens: A compendium of information. A report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Metairie, LA. 103 pp.

The East and West Flower Garden Banks, located approximately 110 mi south of Galveston, are a unique biological and ecological resource on the OCS of the United States. Rising out of water depths of 100 m (328 ft) to crest at about 17 m (55 ft), these two banks harbor the northernmost extension of typically Caribbean coral reefs and their associated plant and animal communities on the Atlantic continental shelf. A good deal of local and national interest is focused on the Flower Gardens. The area is under consideration for designation as a National Marine Sanctuary by the National Oceanographic and Atmospheric Administration (NOAA) of the Department of Commerce. The Gulf of Mexico Fishery Management Council has designated the area a Habitat Area of Particular Concern for the coral reef resources. The U.S. Environmental Protection Agency requires stringent discharge restrictions on permits granted to the oil and gas industry under the National Pollution Discharge Elimination System (NPDES) program. This document summarizes past studies sponsored by the U.S. Department of the Interior (Bureau of Land Management prior to May 1982; Minerals Management Service thereafter) and presents a total of nine visuals depicting various aspects of the Flower Garden Banks system.

Broad, A. C., A. Benedict, K. Dunton, H. Koch, D. T. Mason, D. E. Schneider, and S. V. Schonberg. 1979. Environmental assessment of selected habitats in the Beaufort and Chukchi littoral systems. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessement of the Alaskan Continental Shelf, Annual Reports 3:361-542.

This report provides a detailed assessment of productivity within the Stefansson Sound kelp community and makes comparisons between this community and kelp communities seen at more temperate latitudes.

Calvin, N. I. 1979. Some benthic marine algae from the Pribilof Islands, Bering Sea: A preliminary annotated list. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 10:393-413.

This document provides a short description of the subtidal macroalgal community of the Pribilof Islands. This document was prepared as an appendix to the final report entitled "Reconnaissance of Intertidal Communities in the Eastern Bering Sea and the Effects of Ice-Scour on Community Structure," prepared by O'Clair *et al.* (1979) and published in Environmental Assessment of the Alaskan Continental Shelf, Final Reports, Biological Studies 10:109-413.

Calvin, N. I. and R. J. Ellis. 1981. Growth of subtidal *Laminaria greenlandica* in southeastern Alaska related to season and depth. Bot. Marina 24:107-114.

This report gives descriptive information on the range and extent of growth of kelp in the southeastern Alaska area.

Carlson, P. R., J. M. Fischer, and H. A. Karl. 1983. Two newly discovered submarine canyons on Alaskan continental margin of Bering Sea. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 83-24. 38 pp.

This paper describes, delineates, and compares newly-discovered submarine canyons along the Bering Sea continental margins. Included in the report are a detailed bathymetric map of the two canyon systems and sketches of seismic profiles showing the canyons and the subbottom units into which they were carved. The authors also speculate briefly on the mode and time of formation of these canyons.

Cimberg, R. L., D. P. Costa, and P. A. Fishman. 1986. Ecological characterization of shallow subtidal habitats in the north Aleutian shelf. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 44:437-646.

The objectives of the study were to determine the distribution of the major infaunal and epifaunal communities, the seasonal distribution and abundance of sea otters, the trophic relationships between sea otters and the benthic communities and the impacts of oil and gas exploration and development on these relationships. Three cruises were conducted during the spring, summer, and fall of 1982 to investigate the benthic systems and to collect sea otter scats; four aerial surveys were flown during these same periods, as well as in March 1983, to investigate seasonal changes in sea otter habitat use.

Continental Shelf Associates, Inc. 1990. The southwest Florida nearshore benthic habitat study. A final report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. MMS Rept. 89-0080. 55 pp.

Habitat distributions within 9,791,000 ac (3,962,417 ha or 15,294 mi^2) of the southwest Florida nearshore continental shelf were mapped. Within 5,170,000 ac (2,092,299 ha), habitat distributions were mapped from aerial imagery. In an additional 4,622,000 ac (1,870,523 ha), habitat distribution patterns were extrapolated from ground survey data.

Continental Shelf Associates, Inc. 1985a. Florida Big Bend seagrass habitat study: Narrative report. A final report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Metairie, LA. MMS Rept. 85-0088. 47 pp.

Seagrass distribution in the Florida Big Bend area was mapped using a combination of aerial and ground-truthing photographic surveys. Of the total area mapped [1.5 million ha (3.7 million acres or 5,830 mi^2)], 16% was characterized as dense seagrass beds, 33% as sparse seagrass beds, and 19% as patchy seagrass beds. Species zonation patterns were similar to those observed elsewhere in Florida and the Caribbean. There is a nearshore zone of pioneer or fringing species--primarily *Halodule wrightii* and (occasionally) *Halophila decipiens*; a zone of dense bed-forming *Thalassia testudinum* and *Syringodium filiforme*; and an offshore zone where fringing or pioneer species (primarily *Halophila decipiens* and *Halophila engelmanni*, with some *Halodule wrightii* in shallower water) again appear. The unique feature of the Florida Big Bend area seagrass zonation pattern is the extended nature of this offshore fringing zone. Offshore fringing or pioneer species grow from a depth of 10 m (33 ft) out to depths greater than 20 m (66 ft). Within the offshore sparse seagrass beds, macroalgae accounted for an average of 21% of total blade density. Live bottom was interspersed with seagrass beds throughout the study area and probably accounted for approximately 44% of the area between the 10- and 20-m depth contours mapped on the basis of aerial photography as sparse or patchy seagrass beds.

Continental Shelf Associates, Inc. 1985b. Southwest Florida shelf regional biological communities survey marine habitat atlas. A final report for the U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, Metairie, LA. Contract No. 14-12-0001-29036. 37 pp.

The "Southwest Florida Regional Biological Communities Survey" Marine Habitat Atlas comprises two volumes: the atlas itself and the accompanying volume of explanatory text. Volume 1 contains: 1) a survey locations map (1:500,000 scale), showing the locations of all geophysical and underwater television/still camera transects; 2) an index map (1:500,000 scale), which serves as a key to other atlas maps; 3) two regional maps of marine habitats (1:500,000 scale) showing the broad distribution of biological communities along the survey transects; and 4) 23 detailed habitat maps (1:48,000 scale) summarizing navigational post-plot, side-scan, subbottom profiler, and television data. A legend is provided which clearly defines all symbols used on the maps. Volume 2 provides more detailed discussions of each habitat and substrate type, and describes the field surveys, mapping procedures, and data analysis.

Continental Shelf Associates, Inc. 1983. North Carolina fisheries and environmental data search and synthesis study. A final report for the U.S. Department of the Interior, Minerals Management Service, Atlantic OCS Office, New York, NY. Contract No. AA851-CT1-68.

Available information on the living marine resources and habitats of the North Carolina OCS, from shore to a depth of 200 m (656 ft), was collected, annotated, and synthesized. Over 1,450 published and unpublished data sources were reviewed. Written synthesis chapters summarized the geology, oceanography, biological communities, commercial and sport fisheries, endangered and threatened species, and sensitive biological areas and unique habitats. Data gaps were identified, implications to OCS development were discussed, and suggestions for additional research were provided. In addition, a computer program was designed to catalog and sort all of the pertinent annotated information sources. The purpose of this computer program is to provide the MMS with a useful and viable method of maintaining, updating, and expanding the data base. The North Carolina OCS is a transition zone between the South and Middle Atlantic Bight. The climate, proximity and behavior of the Gulf Stream, and the

presence of cuspate projecting shoals and capes influence unique oceanographic and biological features. Extensive hard/live bottom areas are present within Onslow Bay and along the North Carolina continental shelf edge. Upwelling along the North Carolina continental shelf edge and the intrusion of nutrient rich eddies into middle- and inner-shelf waters occur frequently along this coast. The upwelling-eddy, formation-intrusion phenomenon is not well understood and its ecological implications are just beginning to be studied. The present lack of knowledge in this area makes risk assessment for OCS development activities difficult. Additional studies of the coupling of physical and biological processes along the North Carolina continental shelf are needed in order to formulate effective OCS management policies for that area.

Continental Shelf Associates, Inc. 1979. South Atlantic hard bottom study. A final report for the U.S. Department of the Interior, Bureau of Land Management, Washington, DC. Contract AA551-CT8-25. 356 pp.

Four oil and gas lease blocks in the Georgia Embayment were surveyed with a precision depth recorder, side-scan sonar, and subbottom profiler for the purpose of identifying and mapping areas of hard bottom. The primary objective of this study was to determine the efficacy with which standard geophysical equipment and techniques could identify and map hard-bottom areas. In addition, the hard bottom substrate and associated fauna were identified and described from dredge samples and color photographs.

Cooper, A. K., D. W. Scholl, T. L. Vallier, and E. W. Scott. 1982. Geology report for proposed OCS Lease Sale No. 89, St. George Basin, Alaska. Part II, Deep water area. U.S. Geological Survey, Menlo Park, CA. 86 pp.

This report presents graphics and maps showing submarine canyons and plateaus below the 700-m bathymetric contour in the St. George Basin Planning Area.

Drury, W. H., C. Ramsdell, and J. B. French. 1981. Ecological studies of the Bering Strait Region. U.S. Department of Commerce and U.S. Department of the Interior, OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Final Reports of Principal Investigators, Biological Studies 11:175-487.

This report contains valuable first-hand accounts of coastal habitats in the Kotzebue Sound region, as well as bird density maps and colony counts.

Duane, D. B. and E. P. Meisburger. 1969. Geomorphology and sediments of the nearshore continental shelf, Miami to Palm Beach, Florida. U.S. Army Corps of Engineers, Coastal Engineering Research Center, Washington, DC. TM-29. 128 pp.

The Atlantic Inner Continental Shelf off South Florida was surveyed by the Coastal Engineering Research Center to obtain information on morphology, structure, and sediments of the seafloor bottom and shallow subbottom for use in interpretation of Quaternary history and delineation of sand deposits suitable for restoration of nearby beaches.

Dunton, K. H., E. Reimnitz, and S. Schonberg. 1982. An arctic kelp community in the Alaskan Beaufort Sea. Arctic 35(4):465-484.

The discovery of the "Boulder Patch", an area of cobbles and boulders with attached kelp and invertebrate life, is reported from Stefansson Sound, Near Prudhoe Bay, AK. Geophysical surveys using side-scan sonar and low-frequency recording fathometers reveal that cobbles and boulders occur in patches of various sizes and densities. Despite a seasonal influx of sediments, the Boulder Patch is a nondepositional environment. Physical disruption of cobbles and boulders by deep draft ice is minimal due to offshore islands and shoals which restrict the passage of large ice floes into Stefansson Sound. The apparent absence of similar concentrations of rocks with attached biota along the Alaskan Beaufort Sea coast is explained by the scarcity of rocks in areas protected from ice abrasion and with no net sediment deposition. In Stefansson Sound, the rocks provide a substratum for a diverse assortment of invertebrates and several species of algae.

Eleuterius, L. 1989. Catastrophic loss of seagrass in Mississippi Sound (Abstract only). Tenth Annual Information Transfer Meeting, 5-7 December 1989. MMS, Gulf of Mexico OCS Region, New Orleans, LA.

The author presents maps, aerial photographs, and historical data showing diminished seagrass coverage in the Mississippi Sound area since the late 1960's.

Feder, H. M. and S. C. Jewett. 1986. The Subtidal Benthos, pp. 347-399. In D. W. Hood and S. T. Zimmerman (eds.), The Gulf of Alaska physical environment and biological resources. U.S. Dept. of Commerce and U.S. Dept. of the Int., Washington, DC. MMS Report 86-0095. U.S. Govt. Printing Office, Washington, DC.

This chapter considers the subtidal benthos of the Gulf of Alaska shelf, the Gulf's embayments, and its fjords. It presents a brief historical review of both fisheries and non-fisheries work, examines benthic data in order to assess both infaunal and epifaunal species-distribution patterns and biomass, discusses those environmental variables that are responsible for community composition, and briefly considers trophic groups and the feeding interactions between invertebrates and fishes. Benthic production estimates for the shelf of the northeast Gulf and for lower Cook Inlet are also calculated. The mean macrofaunal production for the northeast Gulf of Alaska is estimated at 4.5 g $C \cdot m^{-2} \cdot yr^{-1}$, with total benthic (microflora, meiofauna, and macrofauna) production estimated at 13.7 g $C \cdot m^{-2} \cdot yr^{-1}$. Infaunal production estimates for lower Cook Inlet vary between 2.5 and 10 g $C \cdot m^{-2} \cdot yr^{-1}$. The chapter also covers the relationships between the physiographic and the oceanographic features of the Gulf as well as those carbon-concentrating mechanisms that lead to benthic enrichment.

Feder, H. M., D. G. Shaw, and A. S. Naidu. 1976. The arctic coastal environment of Alaska. Vol. II, A compilation and review of scientific literature on the arctic marine environments. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, AK. Sea Grant Rept. 76-9. 201 pp.

An extensive, though slightly dated, description of coastal and shallow shelf habitats is given.

Fischer, J. M., P. R. Carlson, and H. A. Karl. 1982. Bathymetric map of Navarin Basin province, northern Bering Sea: U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. No. 82-1038. 11 pp.

This report details the methodology used to produce a bathymetric map of outer margin of the Navarin Basin continental shelf.

Foster, M. S., A. P. DeVogelaere, C. Harrold, J. S. Pearse, and A. B. Thum. 1988. Causes of spatial and temporal patterns in rocky intertidal communities of central and northern California. California Academy of Science, No. 9. 45 pp.

The objective of this review is to summarize present knowledge about the causes of variation in species composition, distribution, and abundance of rocky intertidal plants and animals along the coastline of central and northern California. Examination of the causes of such variation in the intertidal zone, both in space and time, has been the subject of numerous studies in different parts of the world for over 50 years. The most valuable of these studies have included experimental manipulation of populations in the field.

Foster, M. S., A. P. DeVogelaere, C. Harrold, K. Langan, J. S. Pearse, A. B. Thum, and D. Wilson. 1986. Annotated bibliography: Rocky intertidal communities of central and northern California. A final report for the U.S. Department of the

Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, CA. MMS Rept. 86-0052. 602 pp.

Technical reports and published literature pertaining to the study of successional and seasonal variation, and natural and man-induced disturbances of the central and northern California rocky intertidal communities were reviewed and annotated. Each annotated citation is included in the bibliography, representing more than 1,100 entries. The references were derived from computer and manual literature searches as well as abstraction from personal libraries. Subjects covered include species composition, distribution and abundance, recolonization, and succession of rocky intertidal populations, as well as biological responses to natural and man-induced perturbations. Both qualitative and quantitative information was reviewed. A tabulated format was selected for each entry to enable the reader to rapidly identify specific areas of information. This format includes a complete citation, identification of where the work was done, sampling methodology, conclusions, and our evaluation of the work as it relates to this project.

Harger, B. W. 1983. A historical overview of kelp in southern California, pp. 70-83. In W. Bascom (ed.), The effects of waste disposal on kelp communities. Southern California Coastal Water Research Project, Long Beach, CA.

This report reviews aerial imagery beginning with the 1940's and delineates specific areas where kelp coverage has observably declined since the early reports of Crandall (1915).

Healey, F. P. 1972. Photosynthesis and respiration of some arctic seaweeds. Phycologia 11:267-271.

Measurements of photosynthesis and respiration on three species of macroalgae (*Halosaccion* sp., *Fucus* sp., and *Laminaria* sp.) collected from Nunivak Island indicated that net growth could take place at 0°C or less under 70 cm of ice from which snow had been removed.

Hess, G. R. and C. H. Nelson. 1982. Geology report for proposed Norton Sound OCS and Gravel Lease Sale. U.S. Geological Survey Open-File Rept. 89-997.

This report provided a summary of the sediment distributional patterns across the Norton Basin Planning Area. Only one map, originally produced at a scale of 1:2,500,000, is cited from this study. The map is cited as it appeared in Figure IIIA-3, "Generalized Sediment Distribution of the Northeastern Bering Sea, in MMS, 1985, Norton Basin Sale 100, Final Environmental Impact Statement. Alaska OCS Region, Anchorage, AK, p. III-A-3.

Hopkins, D. M. and R. W. Hartz. 1978. Coastal morphology, coastal erosion, and barrier islands of the Beaufort Sea, Alaska. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 78-1063. 58 pp.

This report provides an excellent description of the beach substrates and permafrost peat bluffs seen along the Beaufort Sea barrier islands.

Johnson, K. R. and C. H. Nelson. 1984. Side-scan sonar assessment of gray whale feeding in the Bering Sea. Science 225:1150-1152.

An analysis of the importance of gray whale feeding to sedimentology and nutrient cycling in the northern Bering Sea includes an estimate of the contribution of ampeliscid amphipod concentrations in the area to gray whale food requirements.

Jones, G. F. 1969. The benthic macrofauna of the mainland shelf of Southern California. Allan Hancock Monographs in Marine Biology No. 4. 219 pp.

This paper is an excellent historical review of the use of cluster analysis to analyze benthic community data. The emphasis is directed towards showing associations of benthic communities rather than productivity or standing crops.

King, J. G. and C. D. Dau. 1981. Waterfowl and their habitats in the eastern Bering Sea, pp. 739-753. In D. W. Hood and J. A. Calder (eds.), The Eastern Bering Sea Shelf: Oceanography and resources. Univ. of Washington Press, Seattle, WA.

Waterfowl population sizes and areas of habitat in the region are reported. The habitat descriptions are extremely valuable. Species accounts are included.

Lamont-Doherty Geological Observatory of Columbia University. 1983. Canyon and slope processes study. A final report for the U.S. Department of the Interior, Minerals Management Service, Atlantic OCS Office, Vienna, VA. Contract No. 14-12-0001-29178. (3 volumes). 542 pp.

The objective of this study was to examine the physical and biological processes operating in submarine canyons and on the slope, and to determine how these processes might transmit the effects of OCS activities to benthic communities. The following specific objectives are discussed:
a) characterization of currents and hydrography within submarine canyons and on the slope; b) determination of the abundance and distribution of epifaunal communities in selected

canyon and slope areas; c) characterization of suspended sediment and nutrient exchange between canyons and the adjacent shelf and slope; d) determination of the abiotic and biotic processes affecting the distribution and abundance of epifaunal communities; e) documentation of the along-slope structure of currents and the influence of canyons on slope currents; f) identification of communities which may be affected by oil and gas operations; and g) identification of measures for alleviating or eliminating the effects of oil and gas operations on the epifaunal communities. This report summarizes the results and conclusions obtained from a three-year study of canyon and slope processes.

Lees, D. and R. J. Rosenthal. 1977. An ecological assessment of the littoral zone along the outer coast of the Kenai Peninsula. Final Report. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Annual Reports 7:277-476.

A comprehensive account of macrophyte, macroalgal, and benthic invertebrate distribution, abundance, and biomass from previously unstudied, and probably representative, locations on the central Gulf of Alaska coast is contained in this report.

Lees, D. C., J. P. Houghton, D. E. Erickson, W. B. Driskell, and D. E. Boettcher. 1980. Ecological studies of intertidal and shallow subtidal habitats in Lower Cook Inlet, Alaska. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 44:1-435.

Field studies were conducted from May 1976 to November 1979 in intertidal and shallow subtidal habitats in lower Cook Inlet and the northeast Gulf of Alaska to examine species composition, zonation, seasonal patterns, trophic structure, rates of production and energy pathways. Habitats examined included rocky intertidal and subtidal areas, sand beaches and mud flats.

Lewbel, G. S. 1984. Environmental hazards to petroleum industry development. In J. C. Truett (ed.), The Barrow Arch environment and possible consequences of planned offshore oil and gas development. Proceedings of a Synthesis Meeting, 30 Oct - 1 Nov 1983, Girdwood, AK.

This report deals with the effects of coastal winter icing on shoreline and nearshore habitats and sediment structure.

Littler, M. M. 1978. Variations in the rocky intertidal biota near Dutch Harbor, San Nicolas Island, California, pp. 1-79. In Science Applications, Inc. (ed.), Southern California baseline study, Intertidal, Year Two. Final Report. A final report for the U.S. Department of the Interior, Bureau of Land Management, Pacific OCS Office, Los Angeles, CA.

Productivity in surface waters in areas of upwelling above seaward basins is compared with productivity in landward areas without upwelling.

Lynch, M. P., B. L. Laird, N. B. Theberge, and J. C. Jones. 1976. An assessment of estuarine and nearshore marine environments. U.S. Fish and Wildlife Service. SRAMSOE No. 93. 132 pp.

A synopsis of all U.S. coastal regions is presented. The synopsis includes a brief description of the coast, a review of the legal status of estuarine management, resources of estuaries, and impacts of predicted water resource uses.

Maciolek, N., J. F. Grassle, B. Hecker, B. Brown, J. A. Blake, P. D. Boehm, R. Petrecca, S. Duffy, E. Baptiste, and R. E. Ruff. 1987. Study of biological processes on the U.S. North Atlantic Slope and Rise. A final report for the U.S. Department of the Interior, Minerals Management Service, Atlantic OCS Region, Vienna, VA. Contract No. 14-12-0001-30064. MMS Report 86-0051. (2 Volumes). 403 pp.

Temporal and spatial variations in infaunal community structure, sediment texture, and concentrations of total organic carbon, hydrogen, nitrogen, and hydrocarbons in sediments were sampled at 14 stations six times between November 1984 and July 1986. Stations were located at four depth intervals: 225, 550, 1,220-1,350, and 2,100 m. Megafaunal populations were studied along a transect near the U.S./Canadian boundary, a second transect to the west, and along the 2,100-m isobath near Lydonia Canyon. The fauna appears to change along depth gradients. The most distinct communities were seen on the upper slope, where sediments are coarse and currents presumably are strong. Mid-slope (1,200- to 1,350-m) stations are characterized by fine sediments that, in comparison to sediments at deeper (2,010- to 2,500-m) stations, have higher percentages of total organic carbon and nitrogen and higher levels of total polycyclic aromatic hydrocarbons. These stations are dominated by large-bodied infaunal sipunculans and aplacophoran molluscs. Metazoan epifauna is sparse on the mid-slope of the western transect, but the densities of giant protozoans (sxenophyophores) peak at these depths. The infaunal communities on the lower slope (2,100 m) are dominated primarily by small polychaetes, and the epifauna is dominated by echinoderms. Statistically significant differences in the fauna between canyon and noncanyon stations at 550 m were seen; these differences are probably related to higher currents in the canyon. Only minor evidence of seasonality was found: both infauna and epifauna appear to be temporally stable. Recolonization experiments indicate slow rates of recovery of disturbed environments. A

flux of particulate matter to the seafloor, probably the remains of a phytoplankton bloom, was observed in April 1985 and April 1986.

McBride, D. N., J. H. Clark, and L. S. Bulkis. 1982. Assessment of intertidal aquatic plant abundance in the Togiak area of Bristol Bay, Alaska, 1978 through 1980, with emphasis on *Fucus* sp. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau, AK. Tech. Rept. No. 74. 16 pp.

Average weights of *Fucus* sp. (the dominant beach cover), kelp (*Laminaria* sp.), and eel grass (*Zostera* sp.) are reported.

McRoy, C. P. and J. J. Goering. 1974. Coastal Ecosystems of Alaska, pp. 124-131. In H. T. Odum, B. J. Copeland, and E. A. McMaham (eds.), Vol. I, Coastal ecological systems of the United States. The Conservation Foundation, Washington, DC.

This section of Volume I from the Coastal Ecological Systems of the United States document divides Alaska into six regions. Estimated miles of tidal shoreline, and types and locations of specific coastal habitats are given for each of these regions.

McRoy, C. P., J. J. Goering, M. T. Gottschalk, M. Mueller, and S. Stoker. 1971. Survey of macrophyte resources in the coastal waters of Alaska. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, AK. Sea Grant Rept. No. R71-6. 16 pp.

Preliminary report is limited to species lists for stations in southeastern Alaska and one Alaska peninsula station. No later reports from this study have been identified.

McRoy, C. P. 1970. Standing stocks and other features of eel grass (*Zostera marina*) populations on the coast of Alaska. J. Fish Res. Bd. Canada 27:1811-1821.

Standing stocks of eel grass were measured at 10 locations in Alaska, from the southeastern portion to the Seward Peninsula. Stocks (biomass) were highest in Kinzarof and Izembek Lagoons. Estimates of the total crops for sampled areas are given.

Miley, J. M. and P. W. Barnes. 1986. 1985 field studies, Beaufort and Chukchi Seas, conducted from the NOAA ship DISCOVERER. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 86-202. 57 pp.

Scientific studies were conducted in the Beaufort and Chukchi Seas from 5 September to 6 October 1985. The broad objectives of the cruise was to provide the Ocean Assessments Division, Alaska Office, Outer Continental Shelf Environmental Assessment

Program with: 1) comprehensive data and information on the Alaskan OCS; 2) a better definition and refinement of ecological processes and the probable impact of oil exploration and production; and 3) a data base for ecosystem models. The objective of the U.S. Geological Survey in this continuing program is to adequately describe the geologic environment of the Chukchi and Beaufort Seas.

U.S. Department of the Interior, Minerals Management Service. 1987s. Description of the affected environment, pp. III-A-1 through III-B-37. In Chukchi Sea Sale 109, Draft Environmental Impact Statement. U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK.

This section of the Draft EIS for Sale 90 presents a good summary of coastal and nearshore marine benthic features. A variety of useful graphics and location maps are presented.

U.S. Department of the Interior, Minerals Management Service. 1987a. Detailed Decision Documents. Proposed Final 5 - Year Leasing Program: Mid-1987 to Mid-1992.

This document discusses the relative marine productivity and environmental sensitivity of the Outer Continental Shelf Planning Areas. Of particular importance to this 1990 update are the 26 Planning Area-specific tables presented in Appendix I-1 (Relative marine productivity and environmental sensitivity) of this document.

U.S. Department of the Interior, Minerals Management Service. 1986b. Washington and Oregon, pp. III, C-1 to III C-30. In Final Environmental Impact Statement, Proposed Outer Continental Shelf Oil and Gas Leasing Program: Mid-1987 to Mid-1992. U.S. Department of the Interior, Minerals Management Service, Washington, DC.

This section of the 5-Year Leasing Program EIS document summarizes the geology, oceanography, and biological environment in the Washington/Oregon Planning Area.

U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region. 1985e. Description of the affected environment, pp. III-A-1 to III-B-19. In Norton Basin Sale 100, Final Environmental Impact Statement. U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK.

These two subsections in the much larger EIS document provide a good synthesis of the geological and biological features of this region. Several useful graphics of coastal and marine habitats are provided.

U.S. Department of the Interior, Minerals Management Service. 1984b. Physical Environment, pp. III-1 to III-19. In Final Environmental Impact Statement, Proposed Gulf of Alaska/Cook Inlet Lease Sale 88. U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK. MMS Report 84-0023.

This section of the Final EIS contains a description of the Physical Environment in the Cook Inlet/Shelikof Strait region.

U.S. Department of the Interior, Bureau of Land Management. 1980a. Important Marine and Coastal Habitats pp. 3-48 through 3-60. In Final Environmental Impact Statement, Proposed 1981 Outer Continental Shelf Oil and Gas Lease Sale Offshore Central and Northern California, OCS Sale No. 53. U.S. Department of the Interior, Bureau of Land Management, Pacific OCS Office, Los Angeles, CA.

These pages of the EIS discuss hard bottom/rocky bank habitats in central and northern California. Also described are the kelp and coral species present in these habitats.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1981. Key Largo Coral Reef National Marine Sanctuary deep water resource survey. NOAA Tech. Rept. CZ/SP1. 144 pp.

The Key Largo Coral Reef Marine Sanctuary extends from the State's territorial sea off Key Largo, Florida, seaward to the 91-m (300-ft) isobath. It is approximately 32.2 km (20 mi) long, and 8.05 km (5 mi) wide. About half of the Sanctuary lies in 30.4-91.4 m (100-300 ft) of water. Results from this survey fill some of the significant gaps in baseline data on the Sanctuary deep water resources, thereby providing Sanctuary managers with scientific information to make intelligent management decisions. The survey effort was designed as a two-phased approach. Phase I was an extensive side-scan sonar and bathymetric survey. Phase II was a qualitative submersible reconnaissance and resource inventory.

Neushul, M. 1981. Historical review of kelp beds in the southern California Bight. Southern California Edison Company, Research Report Series Number 81-RD-98. 75 pp.

The objective of this study was to use maps and photographs to produce a historical record of the extent and variability of the kelp forests of the Southern California Bight. This is the most comprehensive retrospective study of southern California kelp forests done to date. This report serves as a guide to the methods used and the data base that has been assembled.

During this study, over 15,000 aerial photographs were examined. Over 6,000 photographs were copied and printed to a standard scale, and then fitted together to make 269 photomosaics, from which 72 manuscript maps were ultimately made. The photomosaic records of the southern California kelp forests that were assembled provide an accurate standard against which both past and future measurements can be compared. In making these photomosaics, many precautions were taken to ensure that coastal features were matched with those on the 7.5 min U.S. Geological Survey quadrangle maps of the coastline used as standards. The results of the study show that the 30 remaining kelp forests (Beds 1, 11, and 12 have been lost) have generally decreased in area, with about one-third of the area, mapped by Crandall in 1911 having been lost. The 25-yr mean area for Beds 1 through 33 is 92.2 km^2 (35.6 mi^2). Crandall's maps (which were reduced to the standard 1:24,000 scale and measured) show an area of 137.8 km^2 (53.5 mi^2). Prior measurements have not been accurate because of scaling error; the original maps should be used as the historical baseline. All losses and changes in area in the kelp forests since 1911 can now be compared with Crandall's first survey. The most spectacular losses of coastal kelp beds have been documented by North (1974, 1975), for beds at Point Loma and Palos Verdes. The results of the present study show that other beds at Ventura (18), Pitas Point (19), Carpenteria (20) and Summerland (21) seem to be deteriorating. Even the old established beds at Santa Barbara (22), Isla Vista (27) and Ellwood (28) seem to be less robust than in the past and are worthy of careful monitoring. In contrast with beds that seem to be decreasing in area and cover, other beds, like those at Point Loma and Palos Verdes, are increasing in area, presumably as a result of management and controlled plantings.

Pace, S. 1984. Environmental characterization of the north Aleutian shelf nearshore region: Characterization, processes, and vulnerability to development. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 38:1-473.

This report contains information of the species components of coastal marshes and eel grass beds in the North Aleutian Basin Planning Area.

Parker, R. O., Jr. and S. W. Ross. 1984. Observations from submersibles of offshore reef fishes off North Carolina. NOAA, National Marine Fisheries Service, Southeast Fisheries Center, Beaufort, NC. 15 pp.

A number of visual observations and fish counting transects were run across hard-bottom areas off North Carolina using the Johnson-Sea-Link submersibles. Several visual fish censusing techniques were tested.

Parker, R. O., Jr., D. R. Colby, and T. D. Willis. 1983. Estimated amount of reef habitat on a portion of the U.S. South Atlantic and Gulf of Mexico continental shelf. Bull. Mar. Sci. 33:935-940.

The amount of reef habitats (rock, coral, and sponge) on the continental shelf of the South Atlantic and Gulf coasts was estimated from observations made with submersible television. Percentages of all reef habitat and reef habitat greater than one meter are given for the following strata: Cape Hatteras - Cape Fear, Cape Fear - Cape Canaveral, Key West - Pensacola, Pensacola - Pass Cavallo, and Pass Cavallo - Rio Grande.

Pederson, L. R. 1965. United States. 1. Area and boundaries, pp. 473-475. In Vol. 27, Encyclopedia Americana. Americana Corp., New York, NY.

This discussion breaks down the coastline of the United States by state.

Phillips, R. C. 1984. The ecology of eel grass meadows in the Pacific northwest: A community profile. National Coastal Ecosystems Team, U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-84/24. 85 pp.

This document synthesizes the extant literature pertinent to the ecology of eel grass beds of the Pacific Northwest: that part of the coast extending from Cape Flattery, WA, to Cape Mendocino, CA. This report describes the physiographic setting of the eel grass community, the distribution of the grass beds, autecology of the eel grass in terms of growth and reproductive strategies and physiological requirements and functions. The ecological and functional attributes of the eel grass system or community are also described. This approach encompasses both detailed site descriptions and a broader overview of the eel grass community and its ecological role within the estuarine complex. The final section discusses management considerations and takes into account local issues and impact scenarios.

Phillips, R. L. 1983. Chukchi Sea geology and processes - Surficial sediments within the Chukchi Sea. In Chukchi Sea Sale 109, Draft Environmental Impact Statement (1987). U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region, Anchorage, AK. (Figure III-4.)

This figure illustrates the nearshore distribution of surficial sediment types within the Chukchi Sea Planning Area.

Phillips, R. L., P. Barnes, R. E. Hunter, T. E. Reiss, and D. M. Rearic. 1988. Geologic investigations in the Chukchi Sea, 1984, NOAA

ship SURVEYOR cruise. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 88-25. 82 pp.

Studies of the high latitude shelf environment of the Chukchi Sea were initiated to provide the Federal government and the public with adequate knowledge to safely lease offshore lands. This report presents preliminary findings from a study of the geologic environment of the Chukchi Sea from Point Hope north to 71°38'N latitude, to the U.S. - U.S.S.R. Convention Line on the western part of the shelf, and to the vicinity of Point Franklin on the eastern shelf.

Phillips, R. L., T. E. Reiss, E. Kempema, and E. Reimnitz. 1984. Nearshore geological investigations, Wainwright to Skull Cliff, northeast Chukchi Sea. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 84-108. 33 pp.

Between 21 August and 1 September 1981, marine geologic investigations were conducted on part of the inner shelf of the northeast Chukchi Sea using the USGS R/V KARLUK. The purpose of this investigation was to define marine processes and geologic hazards that characterize the sea floor for the regions generally shallower than 20 to 30 m depth on the inner shelf of the Chukchi Sea. The area of the initial reconnaissance investigation covered the nearshore region from Wainwright (70°36'N latitude) north to Skull Cliff at approximately 71°00'N latitude.

Phillips, R. L. and T. E. Reiss. 1984a. Nearshore marine geologic investigations, Icy Cape to Wainwright, northeast Chukchi Sea. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 84-828. 27 pp.

This report summarizes the results of reconnaissance investigations in the Chukchi Sea within the nearshore region (less than 30 m depth) from Icy Cape (70°20'N latitude) north to Wainwright (70°36'N latitude). The survey was conducted between 1-21 August 1982. The purpose of this investigation was to identify marine geologic hazards as well as locate potential shelf sand and gravel resources.

Phillips, R. L. and T. E. Reiss. 1984b. Nearshore marine geologic investigations, Point Barrow to Skull Cliff, northeast Chukchi Sea. U.S. Geological Survey, Menlo Park, CA. USGS Open-File Rept. 84-50. 22 pp.

Between 1-22 August 1982, marine geologic investigations were conducted on the inner shelf of the northeast Chukchi Sea from onboard the R/V KARLUK. This report summarizes the results of the reconnaissance investigation of the Chukchi Sea shelf from 14 km north of Pt. Barrow (71°29'N latitude) south to Skull Cliff (71°08'N latitude). The purpose of this study was to identify marine geologic hazards and locate potential sand and gravel deposits on the inner shelf of the Chukchi Sea.

Proctor, C. M., J. C. Garcia, D. V. Galvin, G. C. Lewis, L. C. Loehr, and A. M. Massa. 1980. An ecological characterization of the Pacific Northwest Coastal Region, pp. 1-1 to 3-184. Vol. 2, Characterization Atlas - Regional Synopsis. National Coastal Ecosystems Team, U.S. Fish and Wildlife Service, Washington, DC. FWS/OBS-79/12.

The ecological characterization of the Pacific Northwest Coastal Region is one of four similar projects of the U.S. Fish and Wildlife Service to characterize key coastal areas of the United States in order to provide the means of assessing and minimizing impacts of human activities on important fish and wildlife habitats. The ecological characterization compiles and integrates information currently available concerning ecosystems of the study area, but does not claim to include all the data needed for detailed assessments of impacts. The objectives of the study were: 1) To obtain and synthesize available environmental data which identify and describe important resources, ecological processes, and their interrelationships within the study area and to provide an analysis of their functional relationships; 2) To identify additional information that may be required to more completely characterize the study area and recommend special studies to fulfill this need; and 3) To present information obtained in the form of detailed reports, graphic illustrations, and descriptive models.

Reed, J. K. 1980. Distribution and structure of deep-water *Oculina varicosa* coral reefs off central eastern Florida. Bull. Mar. Sci. 30(3):667-677.

Data on the distribution and growth-form of the scleractinian *Oculina varicosa* were compiled from 135 submersible dives with the Johnson-Sea-Link submersibles and 57 dredge and trawl records by the R/V GOSNOLD and R/V AQUARIUS. A deep-water form of *O. varicosa*, lacking zooxanthellae, was found in depths of 50 to 100 m off central eastern Florida. These colonies are arborescent with highly anastomosed, irregular dendritic branches. Over 50 sites were located at which living colonies of *O. varicosa* from 0.25 to 2 m diameter occur either singly or as sparsely scattered groups. Nine areas were found with massive thickets of contiguous colonies up to 2 m in height. Extensive banks of *Oculina* thickets were found at five locations. The banks have a relief of 17 to 24 m and steep slopes of 30-45°, especially on the south side which faces into the Florida Current. The structure of these thickets and banks is very similar to deep-water *Lophelia prolifera* banks. Temperatures on the *Oculina* banks ranged from 7.5 to 26.5°C and had a yearly mean of 15°C.

Richmond, C. and D. J. Burdick. 1981. Geologic hazards and constraints of offshore central and northern California. Offshore Technology Conference Proceedings. OTC 4117. p. 9-3.

This short paper presents an exceptionally good diagramatic representation of geologic hazards and hard-bottom areas off central and northern California. It forms the basis for MMS Visual No. 2, Geologic Structures, produced in association with the EIS for Lease Sale No. 73 (USDOI, MMS, 1983d).

Schell, D. M. and S. M. Saupe. 1989. Primary production, carbon energetics, and nutrient cycling. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 60:99-140.

This report describes the nutrient dynamics, primary productivity, and trophic energetics of the nearshore waters of the North Aleutian shelf. Through consideration of the availability of nutrients and the consequent primary productivity, the carbon derived from *in situ* primary producers has been quantified and compared with that derived from allochthonous sources, in this case, the extensive eel grass (*Zostera marina*) beds in Izembek Lagoon.

Science Applications, Inc. 1980. Environmental assessment of the Alaskan continental shelf: Kodiak Interim Synthesis Report. Prepared for U.S. Department of Commerce, National Oceanic and Atmospheric Administration, OCSEAP. Boulder, CO.

A valuable summary of data, with emphasis on fish and benthos is contained in this document. Included is an excellent section on distribution, biomass, and productivity of macroalgae in the Kodiak region.

Sears, H. S. and S. T. Zimmerman. 1977. Alaska intertidal survey atlas. National Marine Fisheries Service, Auke Bay, AK. 449 pp.

This study consisted of aerial surveys covering the Alaska coastline from Yakutat to Cape Prince of Wales in the Bering Strait. Observers recorded beach substrates, biological cover, macrophytes, birds, and marine mammals on USGS 1:100,000 scale maps.

Smith, F. G. W. 1972. Atlantic Reef Corals. Univ. of Miami Press. 164 pp.

This book was designed to meet the requirements of both amateur and scientific readers who need a simple guide for the rapid identification of corals. General overviews of coral reef

ecology and reef distribution are presented as well as plates and keys to Atlantic reef coral species.

Strauch, J., Jr. 1980. Environmental Assessment of the Alaskan Continental Shelf: Kodiak Interim Synthesis Report, pp. 157-297. In Outer Continental Shelf Environmental Assessment Program-- Management Function. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, OCSEAP, Juneau, AK.

Kodiak's coastal and offshore waters provide a rich, biological environment. The area supports major commercial fisheries for king crab, Tanner crab, dungeness crab, pink shrimp, pink salmon, chum salmon, coho salmon, king salmon, sockeye salmon, and Pacific halibut. Other species such as herring, smelt, pollock, and other groundfishes use the area for spawning, rearing, and feeding. Coastal fjords and embayments are important nursery areas for many of these species. Pink salmon, in particular, use Alitak and Uganik Bays; chum salmon concentrate on the southwest side of Kodiak Island; and sockeye salmon spawn on the southwest side of Kodiak Island and the west side of the Strait of Shelik. Kelp beds provide protective habitat for larval and juvenile salmon and juvenile king and Tanner crabs and are used by mammals, birds, and fishes. Major kelp beds and other macrophyte assemblages occur near the Aiaktalik/Cape Trinity and Right Cape/Kiliuda Bay areas, and Ugak, north Afognak, Sitkalidak, and Sitkinak Islands.

Sugihara, T., C. Yearsley, J. B. Durand, and N. P. Psutz. 1979. Comparison of natural and altered estuarine systems: Analysis. Publ. No. NJ/RU-DEP-11-9-79. Rutgers University Center for Coastal and Environmental Studies. 274 pp.

Outstanding comparison of biotic functioning in a highly disturbed and a relatively undisturbed salt marsh estuary. This document is particularly useful for its concentration on systems level interactions and quantitative information on higher trophic levels.

Thompson, M. J. and L. E. Gilliland. 1979. Topographic mapping of shelf edge prominences off Southeastern Florida. S.E. Geol. 21(2):155-164.

Three areas of the southeastern Florida continental shelf were systematically mapped using side-scan sonar and fathometer tracings during 1977-1978. Two of these sites were shelf-edge features and the third was a section of the limestone outcrop which divides the inner and outer shelf zones along this coast. These efforts represent the first attempt to generate precise topographic contour maps of outer shelf and shelf-edge prominences in this area. Generated maps reveal one area,

Sebastian Pinnacle System, to be of extreme complexity. This area contains a concentration of major prominences not recorded elsewhere on the southeastern Florida continental margin. These bottom formations apparently result from the combined action of many geophysical and biological forces. Substrate distribution patterns indicate strong depositional and erosional activity by the Florida Current. A series of submersible dives using the Johnson-Sea-Link II of Harbor Branch Foundation, Inc., was made to validate bottom topography in the Sebastian Pinnacle area. These dives confirmed the morphological complexity of both topography and substrate composition indicated by side-scan sonographs and fathometer tracings.

Thomson, D. 1989. Invertebrates. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Final Reports of Principal Investigators 60:141-215.

A variety of distributional maps and productivity data on both habitats and individual commercial species appear in this report.

U.S. Department of Commerce. 1975. The coastline of the United States. U.S. Govt. Printing Office, Washington, DC.

This six panel pamphlet presents a vast amount of data useful in the present research effort. Included are definitions of the terms "General Coastline" and "Tidal Shoreline", tables giving the official NOAA estimates of the coastlines of all the states, and summary tables giving coastline mileage by geographic region.

University of Maryland Eastern Shore. 1985. Federal OCS Oil and Gas Activities: A Relative Comparison of Marine Productivity Among the Outer Continental Shelf Planning Areas. Draft Report. A draft report for the U.S. Department of the Interior, Minerals Management Service, Washington, DC. Cooperative Agreement No. 14-12-0001-30114. 1,450 pp.

This two volume draft final report summarizes both water column and coastal productivity data bases. This literature review was considered current through approximately 1983. The information on coastal features and habitats contained in these volumes has been cited numerous times throughout the current review. Only a limited amount of data on offshore marine features or habitats appears in this work.

Woodward-Clyde Consultants. 1982. Central and northern California coastal marine habitats: Oil residence and biological sensitivity indicates. U.S. Department of the Interior, Minerals Management Service, Pacific OCS Region, Los Angeles, CA. 226 pp.

Differences between oil residence and biological sensitivity are analyzed. The coastal mainland is divided into outer coastal zone, inner coastal zone, and inlet zone; shore-zone components (e.g. sand, rock, boulder veneer) are discussed for each zone.

Zieman, J. C. 1989. The ecology of the seagrass meadows of the west coast of Florida: A community profile. U.S. Fish and Wildlife Service, National Wetlands Research Center, Slidell, LA. Biological Rept. 85 (7.25). 156 pp.

This report summarizes information on the ecology of seagrass meadows on the west coast of Florida, from south of Tampa Bay to Pensacola. This area contains more than 3,500 ha of seagrass beds, dominated by three species, *Thalassia testudinum* (turtle grass), *Syringodium filiforme* (manatee grass), and *Halodule wrightii* (shoal grass). Beds occur both on the shallow, zero-energy continental shelf and in inshore bays and estuaries. Species ecology, distribution, biomass, and productivity of these dominant seagrass species are discussed. Seagrass beds support a very diverse assemblage of organisms, and fauna; these organisms, and seagrass detritus, form the base of a productive food chain. Seagrass beds are important nursery areas providing both cover and food, for a number of commercial and sports fishery species. Along the west Florida coast, estuarine grass beds are noticeably more stressed and exhibit a greater degree of impact arising from human activities than the more pristine nearshore beds. Urban development and dredging and filling are the major threats to seagrass beds in this region.

Zieman, J. C. 1982. The ecology of seagrasses of south Florida: A community profile. National Coastal Ecosystem Team, U.S. Department of the Interior, Washington, DC. FWS/OBS-82/85. 123 pp.

The information in the report gives a basic understanding of the seagrass community and its role in the regional ecosystem of south Florida. The primary geographic area covered lies along the coast between Biscayne Bay on the east and Tampa Bay on the west.

Zimmerman, S. T. (ed.). 1982. The Norton Sound environment and possible consequences of planned offshore oil and gas development. Proceedings of a synthesis meeting, 28-30 Oct, Anchorage, AK. 55 pp.

The emphasis of this report is on impacts, however much useful information on fish, bird, and manual distributions and coastal habitats is included.

Zimmerman, S. T., J. L. Hanson, J. T. Fujioka, N. I. Calvin, J. A. Gharrett, and J. S. MacKinnon. 1978. Intertidal biota and subtidal kelp communities of the Kodiak Island area. U.S. Dept. of Commerce and U.S. Dept. of the Int., OCSEAP, Environmental Assessment of the Alaskan Continental Shelf, Biological Studies 4:316-508.

The extent of the beds, biomass, and floating standing stock of kelp in the Kodiak Island area were measured. Biomass measurements were wet weight.

GRAPHIC DATA SOURCES

North Atlantic Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985a. Topographic/Bathymetric Chart, Northeastern United States Regional Map.

Presented at a 1:1,000,000 scale, this map shows accurate and consistent bathymetric contours across the Mid- and North Atlantic continental shelf of the United States. Major geologic features, Submarine Canyons, and seamounts are delineated. Lease blocks are superimposed, but exact Planning Area boundaries are not specifically delineated.

U.S. Department of the Interior, Minerals Management Service. 1984a. Bottom Sediments (Visual No. 3).

This map shows bottom sediments, geological features, hazards, and drilling constraints for the North Atlantic, and a portion of the Mid-Atlantic Planning Areas. The scale is 1:1,000,000 and is stated as approximate only. The map was produced in association with the February 1984 North Atlantic Lease Offering.

U.S. Department of the Interior, Minerals Management Service. 1987b. Outer Continental Shelf of the North Atlantic from 39° to 45°N latitude (Georges Bank) Official Protraction Diagram.

This protraction diagram shows the boundaries of the North Atlantic Planning Area. Limited bathymetry is presented across the Planning Area and Submarine Canyons and seamounts are delineated. The scale on this map is 1:750,000.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1982a. NWI Wetlands Classification Maps.

These maps utilize varying scales of aerial imagery to delineate wetland areas on USGS 1:100,000 scale base maps throughout the United States. The following National Wetlands Inventory Maps were utilized in conducting the coastal and marine habitat assessment of the North Atlantic Planning Area:

Eastport, ME	Published 1979
Machias, ME	Published 1979
Petit Manan Point, ME	Published 1979
Bar Harbor, ME	Published 1979
Bath, ME	Published 1979
Kittery, ME - NH	Published 1982
Gloucester, MA - NH - ME	Published 1980
Provincetown, MA	Published 1982
Martha's Vineyard, MA	Published 1981

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980a. Atlantic Coast Ecological Inventory Maps.

These maps represent a series of 1:250,000 scale habitat maps that cover the entire U.S. Atlantic seaboard. The following specific maps were utilized in conducting the coastal and marine habitat assessment of the North Atlantic Planning Area:

East Port, ME - 44066-A1-EI-250
Bath, ME - 43068-A1-EI-250
Bangor, ME - 44068-A1-EI-250
Portland, ME - NH - 43070-A1-EI-250
Boston, MA - CT - ME - NH - 42070-A1-EI-250

Mid-Atlantic Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985a. Topographic/Bathymetric Chart, Northeastern United States Regional Map.

(Annotation provided under North Atlantic Planning Area.)

U.S. Department of the Interior, Minerals Management Service, 1987c. Outer Continental Shelf of the Mid-Atlantic from 35° to 42°N latitude Protraction Diagram.

This protraction diagram shows the coastline and boundaries of the Mid-Atlantic Planning Area. Some bathymetric data are superimposed across the lease blocks and many, but not all, of the Submarine Canyons within this Planning Area are shown. The scale on this map is 1:750,000.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1987. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were utilized in conducting the coastal and marine habitat assessment of the Mid-Atlantic Planning Area:

Block Island	Published 1982
Hartford S.E.	Published 1983
Hartford S.W.	Published 1987
New York N.E.	Published 1983
New York N.W.	Published 1983
Newark	Published 1979
Trenton	Published 1981
Hammonton	Published 1981
Atlantic City	Published 1981
Cape May	Published 1980
Salisbury S.W.	Published 1983

Chincoteague	Published 1985
Cheritor	Published 1981
Virginia Beach	Published 1981

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980a. Atlantic Coast Ecological Inventory Maps.

The following specific 1:250,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment of the Mid-Atlantic Planning Area:

New York, NY - CT - NJ - 40072-A1-EI-250
Hartford, CT - MA - NJ - NY - 41072-A1-EI-250
Newark, NJ - NY - PA - 40074-A1-EI-250
Wilmington, DE - MD - NJ - PA - 39074-A1-EI-250
Salisbury, MD - DE - NJ - VA - 38074-A1-EI-250
Washington, DC - MD - VA - 38076-A1-EI-250
Richmond, VA - 37076-A1-EI-250
Norfolk, VA - NC - 36076-A1-EI-250

South Atlantic Planning Area

Continental Shelf Associates, Inc. 1983. Bottom Types (Visual 1).

This map, presented at a scale of 1:500,000, is part of a set of five visuals developed in conjunction with the North Carolina Fisheries and Environmental Data Search and Synthesis Study, MMS Contract 14-12-0001-29189. It was utilized in the present analysis as a supplemental data source for information on nearshore (<200 m) Hard Bottom habitats off North Carolina.

Espey, Huston and Associates, Inc. 1989. Study Area for Coastal North Carolina.

The map used in this study was an AutoCAD reproduction of a digitized map data base developed by Espey, Huston and Associates, Inc. from information based on environmental Sensitivity Maps prepared by the North Carolina Land Resources Information Service. The scale on the map utilized was 1:289,646 and it showed coastal habitats from Albemarle Sound (around Cape Hatteras) to Bogue Sound. This map was used as a supplementary data source for coastal habitats.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986a. Topographic/Bathymetric Chart, Southeastern United States Regional Map.

Presented at a scale of 1:1,000,000, this map shows accurate and consistent bathymetric contours across the entire South Atlantic Planning Area, and much of the Straits of Florida Planning Area. Major geologic features, Submarine Canyons, and seamounts are delineated. Lease blocks are superimposed, but exact Planning Area boundaries are not specifically delineated.

U.S. Department of the Interior, Minerals Management Service. 1987d. Outer Continental Shelf of the South Atlantic from 28°17'10" to 35°N latitude Protraction Diagram.

This protraction diagram shows the boundaries of the South Atlantic Planning Area. Some bathymetric data have been superimposed over the lease blocks. The scale on this map is 1:750,000.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980a. Atlantic Coast Ecological Inventory Maps.

The following specific 1:250,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment of the South Atlantic Planning Area:

Manteo, NC - 35074-A1-EI-250
Beaufort, NC - 34076-A1-EI-250
James Island, SC - 32078-A1-EI-250
Savannah, GA - SC - 32080-A1-EI-250
Brunswick, GA - 31080-A1-EI-250
Jacksonville, FL - 30080-A1-EI-250
Daytona Beach, FL - 29080-A1-EI-250
Orlando, FL - 28080-A1-EI-250

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980-1983. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were utilized in conducting the coastal and marine habitat assessment of the South Atlantic Planning Area:

Georgetown, SC	Published 1980
James Island, SC	Published 1980
Walterboro, SC	Published 1980
Beaufort, SC - GA	Published 1980
Wassaw Sound, GA	Published 1980
Jesup, GA	Published 1982

Brunswick, GA	Published 1983
Fernandina Beach, FL - GA	Published 1980

U.S. Department of the Interior, U.S. Fish and Wildlife Service and U.S. Geological Survey. 1985. Wetland and Deepwater Habitats of Florida.

This 1:500,000 scale map is a color composite map showing all of Florida. It is based on USFWS 1:100,000 scale interpretations of National Wetlands Inventory imagery. The map was prepared for the U.S. Army Corps of Engineers, Jacksonville District, and has been used in the current analysis as a supplemental data source for coastal habitats.

Straits of Florida Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986b. Topographic/Bathymetric Chart, Eastern Gulf of Mexico Regional Map.

Presented at a scale of 1:1,000,000, this map shows accurate and consistent bathymetric contours across the Straits of Florida, Eastern Gulf of Mexico, and portions of the Central Gulf of Mexico Planning Areas. Major geologic features and Submarine Canyons are delineated. Lease blocks are superimposed, but exact Planning Area boundaries are not specifically delineated.

U.S. Department of the Interior, Bureau of Land Management. 1979a. Outer Continental Shelf Resource Management Map, Coral Distribution, Fort Jefferson National Monument, The Dry Tortugas.

This 1:30,000 scale map of Coral Reef, Hard Bottom, and Submerged Vegetation habitats at Fort Jefferson National Monument, the Dry Tortugas, supplements the detailed habitat mapping done in the contiguous Florida Keys.

U.S. Department of the Interior, Bureau of Land Management and Florida Department of Natural Resources. 1979. Florida Reef Tract Marine Habitats and Ecosystems.

This data source is composed of a set of ten, 1:30,000 scale maps which delineate Coral Reef, Hard Bottom, and Submerged Vegetation habitats throughout the southern side of the Florida Keys (i.e., within or immediately adjacent to the Straits of Florida Planning Area). Although there are newer maps at larger scales covering this area, these older, small (1:30,000) scale maps give the most detailed information on marine habitats present in this critical area. Specific charts from which habitat data have been taken are:

1) Miami
2) Elliott Key
3) Key Largo
4) Key Largo
5) Islamorada
6) Long Key
7) Marathon
8) Big Pine Key
9) Sugarloaf Key
10) Key West

U.S. Department of the Interior, Minerals Management Service. 1987e. Outer Continental Shelf of the South Atlantic from 22° to 29°N latitude (Straits of Florida) Protraction Diagram.

This map, presented at 1:750,000 scale, shows the boundaries of the Straits of Florida Planning Area. Official lease blocks and limited bathymetric data are also provided.

U.S. Department of the Interior, Minerals Management Service. 1990b. The Southwest Florida Nearshore Benthic Habitat Study Atlas. MMS Report 89-0080.

This two volume atlas set contains 40 maps each at a 1:40,000 scale delineating nearshore marine habitats throughout southwest Florida from Cape Sable to Dry Tortugas. Information from these atlases has been used extensively in developing the Submerged Vegetation and Hard Bottom habitat estimates presented for the Eastern Gulf of Mexico Planning Area. In the Straits of Florida Planning Area, information concerning seagrass and Hard Bottom areas between Key West and Dry Tortugas (The Quicksands and Marquesas areas), has been used to supplement the two mapping studies referenced previously [i.e., USDOI, BLM, and Florida Department of Natural Resources (1979) and USDOI, BLM (1979a)].

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were utilized in conducting the coastal and marine habitat assessment of the Straits of Florida Planning Area:

West Palm Beach, FL	Published 1979
Fort Lauderdale, FL	Published 1979
Miami, FL	Published 1979
Homestead, FL	Published 1979

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980. Atlantic Coast Ecological Inventory Maps.

The following specific 1:250,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment of the Straits of Florida Planning Area:

Fort Pierce, FL - 27080-A1-EI-250
West Palm Beach, FL - 26080-A1-EI-250
Miami, FL - 25080-A1-EI-250

U.S. Department of the Interior, U.S. Fish and Wildlife Service and Minerals Management Service. 1983. Florida Ecological Atlas Biological Series.

These maps, presented at 1:100,000 scale, are part of a larger set of atlas maps that cover all of western Florida. The maps cited below are all part of the Biological Resources (Series A) data set from this atlas, and were utilized as a supplemental data source on coastal and nearshore marine habitats.

Homestead	Map A32
Islamorada	Map A33
Key West	Map A29
Dry Tortugas	Map A23

Eastern Gulf of Mexico Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986b. Topographic/Bathymetric Chart, Eastern Gulf of Mexico Regional Map.

(Annotation provided under Straits of Florida Planning Area.)

U.S. Department of the Interior, Minerals Management Service. 1983a. Bottom Sediments and Selected Endangered and Threatened Species (Visual No. 3).

This map, published in 1983 by the MMS Gulf of Mexico OCS Region, represents a synthesis of a variety of environmental and sensitive habitat data available at that time. These maps are only representations of data produced through a variety of MMS and other agency-sponsored research programs and are therefore called "visuals". Despite their lack of true cartographic accuracy, these "visuals" have been utilized to indicate coastal and marine habitat trends in many Planning Areas. In the Eastern and Central Gulf of Mexico, this particular map was utilized to supplement marine Hard Bottom habitat estimates.

U.S. Department of the Interior, Minerals Management Service. 1983b. Selected Areas of Environmental Importance (Visual No. 10).

This 1:1,200,000 scale map, published in 1983 by the MMS Gulf of Mexico OCS Region, is a composite map representing the synthesis of environmental data provided by a number of studies. These graphic sources are deliberately referred to as "visuals" rather than charts to indicate a lack of true cartographic exactness in data presentation. In the Central and Western Gulf of Mexico Planning Areas, this visual has been used as a supplemental data source for development of the wetlands (Estuary/Wetlands), Submerged Vegetation, and Hard Bottom habitat estimates.

U.S. Department of the Interior, Minerals Management Service. 1985a. The Florida Big Bend Seagrass Habitat Study, Composite Map, MMS Report 85-0088.

This composite map is based upon the interpretation of 1:40,000 scale imagery. The map itself is presented at a scale of 1:250,000. It shows detailed distributional patterns of seagrasses in the Florida Big Bend area, between Tarpon Springs and Ochlockonee Bay.

U.S. Department of the Interior, Minerals Management Service. 1987f. Eastern Gulf of Mexico Planning Area Protraction Diagram.

This map, presented at 1:840,000 scale, shows the coastline of western Florida and the boundaries of the Eastern Gulf of Mexico Planning Area only. No bathymetric or other data are given.

U.S. Department of the Interior, Minerals Management Service. 1990b. The Southwest Florida Nearshore Benthic Habitat Study Atlas. MMS Report 89-0080.

(Annotation provided under Straits of Florida Planning Area).

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1981. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment of the Eastern Gulf of Mexico Planning Area:

Cape Sable, FL	Published 1979
Everglades City, FL	Published 1979
Sanibel, FL	Published 1979
Charlotte Harbor, FL	Published 1980

Sarasota, FL	Published 1981
St. Petersburg, FL	Published 1981
Fort Walton Beach, FL	Published 1981

U.S. Department of the Interior, U.S. Fish and Wildlife Service and Minerals Management Service. 1983-1984. Florida Ecological Atlas Biological Series.

The following 1:100,000 scale maps for Series A, Biological Resources, were used as a supplemental data source on coastal and marine habitats of the Eastern Gulf of Mexico Planning Area:

Cape Sable	A28
Everglades City	A27
Naples	A26
Sanibel	A22
Ft. Myers	A25
Charlotte Harbor	A21
Sarasota	A20
St. Petersburg	A19
Tarpon Springs	A18
Inverness	A17
Ocala	A16
Cedar Keys	A14
Cross City	A13
Carrabelle	A10
Tallahassee	A9
Port St. Joe	A7
Panama City	A6
Ft. Walton Beach	A4
Pensacola	A2
Bay Minette	A1

Central Gulf of Mexico Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986c. Topographic/Bathymetric Chart, Western Gulf of Mexico Regional Map.

This 1:1,000,000 chart provides detailed bathymetry and indicates major geological features across both the Central and Western Gulf of Mexico. Lease blocks are indicated, but the boundaries of the specific Planning Areas are not clearly marked.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1983b. Topographic/Bathymetric Chart, Eastern Gulf of Mexico Regional Map.

(Annotation provided under Straits of Florida Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1983b. Selected Areas of Environmental Importance (Visual No. 10).

(Annotation provided under Eastern Gulf of Mexico Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1986a. Bottom Sediments and Vegetation (Visual No. 4).

This 1:800,000 (approximate) scale visual has been produced by the MMS Gulf of Mexico OCS Region as a source for the visualization of overall sediment trends and vegetation types within the Western Gulf of Mexico Planning Area. While not as cartographically exact as some other data sources, this visual has been useful in checking the extent of wetland habitat fronting the Western Gulf of Mexico Planning Area. It has also been used in conjunction with other data sources to help develop the Hard Bottom habitat estimates for this Planning Area.

U.S. Department of the Interior, Minerals Management Service. 1987g. Central Gulf of Mexico Planning Area Protraction Diagram.

This map, produced at a scale of 1:84,000, shows only the coastline, lease blocks, and boundaries of the Central Gulf of Mexico Planning Area. No other data are provided.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980b. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting the coastal and marine habitat assessments for the Central Gulf of Mexico Planning Area:

North Islands, LA	Published 1980
Black Bay, LA	Published 1980
Mississippi River Delta, LA	Published 1980
Burrwood Bayou, LA	Published 1980
Terreboune Bay, LA	Published 1980
Atchafalaya Bay, LA	Published 1980

U.S. Department of the Interior, U.S. Fish and Wildlife Service and Bureau of Land Management. 1981. Mississippi Deltaic Plain Region Ecological Atlas.

The following 1:100,000 scale maps from Series F, Biological Resources, were used as a supplemental data source for coastal and marine habitats of the Central Gulf of Mexico Planning Area:

Mobile	F2
Pouchatoula	F3
Gulf Port	F4
Biloxi	F5
Burrwood Bayou	F13
Morgan City	F7
Black Bay	F9
North Islands	F10
Atchafalaya Bay	F11
Terrebonne Bay	F12

U.S. Department of the Interior, U.S. Fish and Wildlife Service and Minerals Management Service. 1984. Ecological Atlas of Coastal Alabama.

These 1:100,000 scale maps from Series A, Biological Resources, were used as a supplemental coastal and marine habitat data source for the Central Gulf of Mexico Planning Area:

Pensacola	A6
Bay Minette	A4
Mobile	A3
Biloxi	A5

Western Gulf of Mexico Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986c. Topographic/Bathymetric Chart, Western Gulf of Mexico Regional Map.

(Annotation provided under Central Gulf of Mexico Planning Area.)

U.S. Department of the Interior, Minerals Management Service. 1982a. East Flower Garden Bank Biotic Zonation.

This 1:1,000 scale map has been used to provide detailed Coral Reef and Hard Bottom habitat data from the East Flower Garden Bank.

U.S. Department of the Interior, Minerals Management Service. 1982b. West Flower Garden Bank Biotic Zonation.

This 1:1,000 scale map has been used to provide detailed Coral Reef and Hard Bottom habitat data from the West Flower Garden Bank.

U.S. Department of the Interior, Minerals Management Service. 1983b. Selected Areas of Environmental Importance (Visual No. 10).

(Annotation provided under Central Gulf of Mexico Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1986a. Bottom Sediments and Vegetation (Visual No. 4).

(Annotation provided under Central Gulf of Mexico Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1987h. Western Gulf of Mexico Planning Area Protraction Diagram.

This protraction diagram, presented at a scale of 1:840,000, shows the coastline, lease blocks, and boundaries of the Western Gulf of Mexico Planning Area. No other data appear on this map.

Southern California Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1983. Outer Continental Shelf Resource Management Map, Southwestern United States Regional Map.

This map presents detailed nearshore bathymetry from the major portion of the Southern California Planning Area. The scale of this map is 1:1,000,000. Bathymetry for the deeper and more distal (i.e., offshore) portions of this Planning Area (<4,000 m depths) are not shown on this chart.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984a. San Diego to Santa Rosa Island, NOAA Chart 18740.

This chart, published at a scale of 1:234,270, was used to provide supplemental data on island coastline and nearshore Hard Bottom in the Southern California Planning Area.

U.S. Department of the Interior, Minerals Management Service. 1987i. Southern California Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Lease blocks, Planning Area boundaries, coastline, and bathymetric data at 200-, 400-, and 900-m intervals are provided.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1982b. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment for the Southern California Planning Area:

Santa Ana, CA	Published 1982
Oceanside, CA	Published 1981
Long Beach, CA	Published 1980
San Nicolas Island, CA	Published 1981
Santa Catalina, CA	Published 1982
Santa Rosa Island, CA	Published 1981
Laguna Harbor, CA	Published 1981
Santa Barbara, CA	Published 1980
Point Conception, CA	Published 1980
San Luis Obispo, CA	Published 1979

U.S. Department of the Interior, U.S. Geological Survey, National Ocean Survey. 1978. Topographic/Bathymetric Charts.

These are nearshore topographic and bathymetric charts presented at a scale of 1:250,000. In the Southern California Planning Area, they have been invaluable in delineating nearshore Submarine Canyons and potential Hard Bottom areas. The following charts from this data set have been used in the present analyses:

San Diego, CA	NI 11-11
San Clemente Island, CA	NI 11-10
Long Beach, CA	NI 11-7
Los Angeles, CA	NI 11-4
Santa Ana, CA	NI 11-8

Central California Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1982a. Outer Continental Shelf Resource Management Map, Western United States Regional Map.

This 1:1,000,000 scale chart presents detailed bathymetric data from both the Central and Northern California Planning Areas.

Submarine Canyons are delineated, but their official names do not appear on this chart.

U.S. Department of the Interior, Bureau of Land Management. 1980b. Kelp; Coral; Shoreline Types (Visual No. 5).

This habitat map covers both the Central and Northern California Planning Areas and is a visual prepared in association with the Lease Sale No. 53 Final Environmental Impact Statement (USDOI, BLM, 1980a). The original map was prepared in 1978 and was based on a synthesis of environmental data from several sources. The scale is 1:1,013,760 (approximate). This map has been used as a supplemental data source for estimation of both Submerged Vegetation and Hard Bottom habitat in the two northernmost California Planning Areas.

U.S. Department of the Interior, Minerals Management Service. 1983c. Geologic Structures (Graphic No. 2).

This map, produced at a scale of 1:1,013,760, covers major geologic features in both the Central and Northern California Planning Areas. In the present analysis, this graphic has been utilized as a supplementary data source to indicate offshore areas of bedrock or Hard Bottom outcrop.

U.S. Department of the Interior, Minerals Management Service. 1987j. Central California Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Boundaries of the Planning Area, lease blocks, and bathymetric contours at 200, 400, and 900 m are shown.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1980-1981. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting the coastal and marine habitat assessment for the Central California Planning Area:

Point Sur, CA	Published 1981
Monterey, CA	Published 1981
Cambria, CA	Published 1980

U.S. Department of the Interior, U.S. Geological Survey and U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1980. Topographic/Bathymetric Charts.

These nearshore topographic and bathymetric charts were used to supplement coastal and marine habitat data in the Central California Planning Area. They are presented at a scale of 1:250,000 and were particularly useful in delineating sand versus rock beach and nearshore areas of Hard Bottom. Charts employed in the present analysis of the Central California Planning Area were:

San Francisco, CA	NJ 10-8
Santa Rosa, CA	NJ 10-5

Northern California Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1982a. Outer Continental Shelf Resource Management Map, Western United States Regional Map.

(Annotation provided under Central California Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1987k. Northern California Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Boundaries of the Planning Area, lease blocks, and bathymetric contours at 200, 400, and 900 m are shown.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1980. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting coastal and marine habitat assessments for the Northern California Planning Area:

Crescent City, CA	Published 1979
Orich, CA	Published 1980
Eureka, CA	Published 1979

U.S. Department of the Interior, U.S. Geologic Survey, National Ocean Service. 1977-1979. Topographic/Bathymetric Charts.

The following 1:250,000 topographic and bathymetric maps from this data set were used to provide supplemental marine habitat and coastal data for the Northern California Planning Area:

Crescent City, CA - OR (NK 10-7)	Published 1977
Eureka, CA (NK 10-10)	Published 1977
Ukiah, CA (NJ 10-2)	Published 1979

Washington/Oregon Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1974. NOS Seamap Series, North Pacific Ocean, Bathymetric Chart 12042-12B.

This bathymetric map shows the coastline and bathymetric features of the Washington-Oregon Planning Area. Bathymetric contours are given at 100-m intervals and major, named submarine features are designated. The scale on this map is 1:1,000,000.

U.S. Department of the Interior, Minerals Management Service. 19871. Washington-Oregon Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Coastline, Planning Area boundaries, lease blocks, and bathymetric contours at 200, 400, and 900 m are shown.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1979-1983. NWI Wetlands Classification Maps.

The following 1:100,000 scale maps from this data set were used in conducting coastal and marine habitat assessments in the Washington-Oregon Planning Area:

Bellington, WA	Published 1982
Port Townsend, WA	Published 1982
Copalis Beach 1, WA	Published 1983
Copalis Beach 2, WA	Published 1983
Copalis Beach 3, WA	Published 1983
Nehalem River, OR	Published 1982
Yamhill River, OR	Published 1982
Newport, OR	Published 1980
Waldport, OR	Published 1980
Reedsport, OR	Published 1979
Coos Bay, OR	Published 1979
Port Orford, OR	Published 1979

Gulf of Alaska Planning Area

Alaska Department of Fish and Game. 1984. Alaska coastal habitat maps. Alaska Department of Fish and Game, Habitat Division, Anchorage, AK.

These maps are presented on a USGS 1:250,000 quadrangle base map. They cover the entire coastline of Alaska and show many important biological features. They are particularly useful for mammal distribution patterns.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1979. North Pacific Ocean (Eastern Part), Chart #50.

This map, presented at a scale of 1:10,000,000, was used as a supplemental data source for offshore features off the south Alaska coast. Despite its very large scale, it names and locates many oceanic features (e.g., seamounts) better than the available smaller scale (1:1,000,000) OCS Resource Management Maps of the Gulf of Alaska. Once a feature was located, specific measurements were made from the smaller scale charts cited.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1980. North America - West Coast, San Diego to Aleutian Islands and Hawaiian Islands, Chart #530.

This map, presented at a scale of 1:4,860,700, was used as a supplemental data source on offshore features both within the Washington-Oregon Planning Area and in the Gulf of Alaska. It also names and locates many seamount features not shown on the available smaller scale OCS Resource Management Maps.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1985b. Outer Continental Shelf Resource Management Map, Gulf of Alaska Regional Map.

This map, presented at a scale of 1:1,000,000, details the coastline and lease blocks throughout the Gulf of Alaska from the U.S.-Canada border through Montague Island. Limited bathymetry is provided for some nearshore areas.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1988a. Outer Continental Shelf Resource Management Map, Yakutat, NOS No. 7-2 (OCS).

This 1:250,000 scale OCS Resource Management Map is part of a recently published data set for the Gulf of Alaska Planning Area. This map, plus two others noted below (USDOC, NOAA-NOS, 1988b; 1988c), were used as supplemental data sources for coastal, nearshore, and offshore features. Lease block and bathymetric contours at 10-m intervals are shown on this chart.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1988b. Outer Continental Shelf Resource Management Map, Ely Seamount, NOS No. 6-8 (OCS).

The scale of this map is 1:250,000. Lease blocks and bathymetric contours at 10- and 50-m intervals are shown.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1988c. Outer Continental Shelf Resource Management Map, Dall Seamount, NOS No. 6-4 (OCS).

The scale of this map is 1:250,000. Lease blocks and bathymetric contours at 10- and 50-m intervals are shown.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1989a. Cape St. Elias to Shumagin Islands, Chart 16013.

This map, presented at a scale of 1:969,761, shows the Gulf of Alaska coastline from Cape St. Elias westward to Shumagin Island.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1989b. Dixon Entrance to Cape St. Elias, Chart 16016.

This map, presented at a scale of 1:969,761, shows the eastern half of the Gulf of Alaska from the Dixon Entrance to Cape St. Elias.

U.S. Department of the Interior, Bureau of Land Management. 1979b. Environmental Geology (Graphic No. 1), Lease Sale No. 55.

This graphic is presented at a scale of 1:750,000 and covers the coastline between Orca Inlet in the northwest and Lituya Bay in the southeast. In the present analysis, it has been used as a supplemental data source indicating nearshore Hard Bottom habitat within this area.

U.S. Department of the Interior, Minerals Management Service. 1985b. Gulf of Alaska Planning Area Protraction Diagram.

The scale on this reproduction of the official Gulf of Alaska Planning Area Protraction Diagram was calculated to be 1:965,471. This 1985 edition of the protraction diagram contains coastline, Planning Area boundaries, lease blocks, and bathymetric contours at intervals of 200, 400, 900, and 2,000 m.

U.S. Department of the Interior, Minerals Management Service. 1988. Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram.

This composite map for both the Gulf of Alaska and Cook Inlet Planning Areas is presented at a scale of 1:1,000,000 and shows coastlines, lease blocks, and bathymetric contours at 200 and 1,000 m. A clear delineation between the Gulf of Alaska and the Cook Inlet Planning Areas is not provided.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1989a. NWI Wetlands Classification Maps.

The following 1:63,360 scale maps were used in conducting the coastal and marine habitat assessment for the Gulf of Alaska Planning Area:

Bering Glacier (A-5), AK	Published 1989
Bering Glacier (A-6), AK	Published 1989
Bering Glacier (A-7), AK	Published 1989
Bering Glacier (A-8), AK	Published 1989

Cook Inlet Planning Area

U.S. Department of the Interior, Bureau of Land Management. 1976.

Lower Cook Inlet Presumed Range of Macrophytes and Commercial Species of Crustaceans, Graphic No. 9: This graphic is produced at a scale of 1:750,000, making it comparable to official protraction diagrams in many OCS Planning Areas. In the case of Cook Inlet, the official USDOI Planning Area Protraction Diagram, issued in 1988, did not include the upper Inlet area above 61°N. For the purposes of the present analysis, this Graphic (No. 9; USDOI, BLM, 1976) and the Gulf of Alaska/Cook Inlet Protraction Diagram (USDOI, MMS, 1988) showing the Shelikof Strait were used to measure General Coastline at the 1:750,000 scale.

Lower Cook Inlet Geology and Geobathymetry, Graphic No. 2: This graphic, presented at a scale of 1:750,000, shows the geologic characteristics of the Cook Inlet shoreline and bottom from 51° to 61°24"N. It has been utilized to supplement coastal and Hard Bottom habitat data.

U.S. Department of the Interior, Bureau of Land Management. 1980c. Lower Cook Inlet - Shelikof Strait Environmental Geology, Graphic No. 1.

The published scale on this graphic is 1:1,267,200; the original scale was 1:500,000. This map has been used solely as a supplemental data source for coastal habitats along the Shelikof Strait.

U.S. Department of the Interior, Minerals Management Service. 1987m. Kodiak Planning Area Protraction Diagram.

(Annotation provided under Kodiak Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1988. Gulf of Alaska/Cook Inlet Planning Areas Protraction Diagram.

(Annotation provided under Gulf of Alaska Planning Area).

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1989b. NWI Wetlands Classification Maps.

The following 1:63,360 scale maps were used in conducting the coastal and marine habitat assessment for the Cook Inlet Planning Area:

Seldovia (A-3), AK	Published 1989
Seldovia (A-4), AK	Published 1989
Seldovia (A-5), AK	Published 1989
Seldovia (A-6), AK	Published 1989
Seldovia (B-1), AK	Published 1989
Seldovia (B-2), AK	Published 1989
Seldovia (B-3), AK	Published 1989
Seldovia (B-4), AK	Published 1989
Seldovia (B-5), AK	Published 1989
Seldovia (B-6), AK	Published 1989
Seldovia (C-1), AK	Published 1989
Seldovia (C-2), AK	Published 1989
Seldovia (C-3), AK	Published 1989
Seldovia (C-4), AK	Published 1989
Seldovia (C-5), AK	Published 1989
Seldovia (D-1), AK	Published 1989
Seldovia (D-2), AK	Published 1989
Seldovia (D-3), AK	Published 1989
Seldovia (D-4), AK	Published 1989

Seldovia (D-5), AK	Published 1989
Seldovia (D-8), AK	Published 1989
Tyonek (A-1), AK	Published 1989
Tyonek (A-2), AK	Published 1989
Tyonek (A-3), AK	Published 1989
Tyonek (A-4), AK	Published 1989
Tyonek (B-1), AK	Published 1989
Kenai (A-8), AK	Published 1989
Kenai (B-7), AK	Published 1989
Kenai (B-8), AK	Published 1989
Kenai (C-4), AK	Published 1989
Kenai (C-5), AK	Published 1989
Kenai (C-6), AK	Published 1989
Kenai (C-7), AK	Published 1989
Kenai (D-1), AK	Published 1989
Kenai (D-2), AK	Published 1989
Kenai (D-3), AK	Published 1989
Iliamna (B-2), AK	Published 1989
Iliamna (B-3), AK	Published 1989
Iliamna (C-1), AK	Published 1989
Iliamna (C-2), AK	Published 1989

Kodiak Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1980. North America - West Coast, San Diego to Aleutian Islands and Hawaiian Islands, Chart #530.

(Annotation provided under Gulf of Alaska Planning Area.)

U.S. Department of the Interior, Bureau of Land Management. 1980d. Graphics to the Final Environmental Impact Statement, Western Gulf of Alaska (Kodiak) Lease Sale No 46.

Western Gulf of Alaska (Kodiak) #46, Graphic No. 1, Environmental Geology: This graphic is presented at a scale of 1:762,321 and illustrates the geologic features of the nearshore area off the islands fronting the Kodiak Planning Area. It has been used as a supplemental data source for Hard Bottom habitat estimates in the Kodiak Planning Area.

Western Gulf of Alaska (Kodiak) #46, Graphic No. 3, Nearshore and Vulnerable Intertidal Habitat: The published scale on this graphic is 1:1,387,366. This graphic shows nearshore and coastline kelp and sensitive habitat areas, shallow banks, and bathymetric contours to a depth of 200 m at 20-m contour intervals. This graphic has been used as a supplemental data set in reviewing coastline and marine habitats.

Western Gulf of Alaska (Kodiak) #46, Graphic No. 7, Location of Marine Macrophytes and Major Shellfishing Areas: This graphic is published at a scale of 1:680,000 (approximate) and shows intertidal and kelp communities surrounding the islands which lie adjacent to the Kodiak Planning Area. Bathymetric contours are given at 20-m intervals to a depth of 200 m, then at 100-m intervals to a depth of 1,000 m. Major banks and troughs are indicated. This graphic has been utilized as a supplemental data source for coastal and nearshore marine communities.

U.S. Department of the Interior, Minerals Management Service. 1987m. Kodiak Planning Area Protraction Diagram.

This 1:750,000 scale protraction diagram shows the island coastline of the land masses contained within this Planning Area. Planning Area boundaries, lease blocks, and bathymetric contours at the 100-, 200-, 400-, 900-, 1,600-, 2,000-, 2,800-, 4,000-, and 5,200-m isobaths are shown. Several unnamed seamounts are indicated on this map.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1988-1989. NWI Wetlands Classification Maps.

The following 1:63,360 scale maps were used in conducting the coastal and marine habitat assessment for the Kodiak Planning Area:

Afognak (A-2), AK	Published 1989
Kodiak (A-3), AK	Published 1988
Kodiak (A-4), AK	Published 1988
Kodiak (A-5), AK	Published 1988
Kodiak (A-6), AK	Published 1988
Kodiak (B-1 and B-2), AK	Published 1988
Kodiak (B-3), AK	Published 1988
Kodiak (B-4), AK	Published 1988
Kodiak (B-5), AK	Published 1988
Kodiak (B-6), AK	Published 1988
Kodiak (C-1), AK	Published 1988
Kodiak (C-2), AK	Published 1988
Kodiak (C-3), AK	Published 1988
Kodiak (C-4), AK	Published 1988
Kodiak (C-5), AK	Published 1988
Kodiak (C-6), AK	Published 1988
Kodiak (D-1), AK	Published 1988
Kodiak (D-2), AK	Published 1988
Kodiak (D-3), AK	Published 1988
Kodiak (D-4), AK	Published 1988
Kodiak (D-5), AK	Published 1988
Kodiak (D-6), AK	Published 1988

Shumagin Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1979. North Pacific Ocean (Eastern Part), Chart #50.

(Annotation provided under Gulf of Alaska Planning Area.)

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1980. North America - West Coast, San Diego to Aleutian Islands and Hawaiian Islands, Chart #530.

(Annotation provided under Gulf of Alaska Planning Area.)

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984b. Outer Continental Shelf Resource Management Map, North Aleutian Basin Regional Map.

(Annotation provided under North Aleutian Basin Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1987n. Shumagin Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Coastlines, lease blocks, Planning Area boundaries, and bathymetry are shown. Bathymetric contours include the 200-, 400-, 900-, 1,600-, 2,000-, 2,800-, 4,000-, 5,200-, and 6,400-m isobaths.

Aleutian Arc Planning Area

U.S. Department of Commerce, Coastal and Geodetic Survey. 1966a. Bathymetry of the Aleutian Arc, Kiska - Chart 1910N-1.

This 1:400,000 scale bathymetric map covers the Aleutian Arc Planning Area from Amchitka Pass and the Petrel Bank westward to Wall's Plateau including the major portion of Bowers Ridge. Major submarine features are delineated and bathymetric contours are given at 50-fathom intervals.

U.S. Department of Commerce, Coastal and Geodetic Survey. 1966b. Bathymetry of the Aleutian Arc, Attu - Chart 1910N-2.

This 1:400,000 scale bathymetric map covers the Aleutian Arc Planning Area from Wall's Plateau to the U.S.-U.S.S.R. Convention Line of 1867. Submarine features are delineated and bathymetric contours are given at 50-fathom intervals.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1973. NOS Seamap Series, North Pacific Ocean, Chart 16648-14B.

This 1:1,000,000 scale map covers the Aleutian Arc Planning Area from Unimak Pass to Amchitka Pass. Detailed submarine features such as canyons, valleys, basins, and ridges are shown. Bathymetric contours are presented at 100-m intervals.

North Aleutian Basin Planning Area

U.S. Department of the Interior, Minerals Management Service. 1987o. North Aleutian Basin Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Planning Area boundaries, coastlines, lease blocks, and bathymetric contours at 50-, 70-, and 100-m isobaths are shown.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984b. Outer Continental Shelf Resource Management Map, North Aleutian Basin Regional Map.

This bathymetric map, prepared at a scale of 1:1,000,000, provides additional bathymetric data in the nearshore portions of the North Aleutian Basin and Shumagin Planning Areas.

St. George Basin Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1973. NOS Seamap Series, North Pacific Ocean, Chart 16648-14B.

(Annotation provided under Aleutian Arc Planning Area.)

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984c. Outer Continental Shelf Resource Management Map, St. George Basin Regional Map.

This 1:1,000,000 scale map presents detailed bathymetric data within the St. George Basin Planning Area. Contouring intervals are 100 m to maximum depth supplemented by 20-m intervals in the shallow shelf area.

U.S. Department of the Interior, Minerals Management Service. 1987p. St. George Basin Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Coastline and Planning Area boundaries are shown. No bathymetric data are given.

St. Matthew Hall Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984d. Outer Continental Shelf Resource Management Map, Navarin Basin Regional Map.

This 1:1,000,000 scale map provides coastal and bathymetric data from the continental Shelf Slope Zone. Bathymetric contours are given at 20-m intervals upon the shelf and at 100-m intervals below the 200-m depth range.

Bowers Basin Planning Area

U.S. Department of Commerce, Coastal and Geodetic Survey. 1966a. Bathymetry of the Aleutian Arc, Kiska - Chart 1910N-1.

(Annotation provided under Aleutian Arc Planning Area).

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1973. NOS Seamap Series, North Pacific Ocean, Chart 16648-14B.

(Annotation provided under St. George Basin Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1985c. Bowers Basin Planning Area Map.

This map shows the boundaries of the Bowers Basin Planning Area. It is presented at a scale of 1:1,200,000 and shows the areas shallower than 2,000 m within this Planning Area. It was used in the present analysis as a supplemental data source for marine habitat characterizations.

Aleutian Basin Planning Area

Carlson, P. R., J. M. Fischer, and H. H. Karl. 1983. Bathymetric chart of St. Matthew Canyon, Middle Canyon, and Fan-Valley Systems. U.S. Geological Survey Open-File Rept. 83-24.

This 1:250,000 scale bathymetric map presents the results of an extensive bathymetric survey of Submarine Canyon systems on the Alaska continental margin of the Bering Sea. The canyons delineated in the present analysis lie along the dividing line between the Aleutian Basin and Navarin Basin Planning Areas. The contouring interval is 200 m.

Fischer, J. M., P. R. Carlson, and H. A. Karl. 1982. Bathymetric Map of Navarin Basin Province. U.S. Geological Survey Open-File Rept. 82-1038.

This 1:1,000,000 scale map delineates major canyons and ridges along the Shelf Slope Zone in both the Navarin Basin and extreme northern portions of the Aleutian Basin Planning Areas. Water depth and contour intervals are as follows: 0 - 150 m water depths, contours every 10 m; 150 - 200 m water depths, contours every 25 m; water depths >200 m, contours every 200 m.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984d. Outer Continental Shelf Resource Management Map, Navarin Basin Regional Map.

(Annotation provided under St. Matthew Hall Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1985d. Aleutian Basin Planning Area Protraction Diagram.

This 1:1,300,000 scale map shows the boundaries of the Aleutian Basin Planning Area and the Shelf Slope Zone, as defined in the present analysis (200- to 2,000-m depth contours). It has been used as a supplemental data source for calculating the areal extent of this marine habitat.

Navarin Basin Planning Area

U.S. Department of the Interior, Minerals Management Service. 1987q. Navarin Basin Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Boundaries of the Planning Area, lease blocks, and bathymetric contours at 200, 400, 1,000, and 2,000 m are shown.

Norton Basin Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1982b. Outer Continental Shelf Resource Management Map, Norton Sound Regional Map.

This 1:1,000,000 scale map shows the coastline and bathymetry throughout the St. Lawrence Island-Norton Sound area. Bathymetric contours are at 10-m intervals and OCS lease blocks are superimposed.

U.S. Department of the Interior, Minerals Management Service. 1987r. Norton Basin Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Coastlines, lease blocks, and boundaries of the Planning Area are shown. There are no bathymetric contours presented on this chart.

Hope Basin Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1978. Arctic Coast Chart No. 16003.

This chart covers the entire arctic coast of Alaska. The scale is 1:1,587,870 and soundings are given in fathoms. No bathymetric contours are presented.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1982b. Outer Continental Shelf Resource Management Map, Norton Sound Regional Map.

(Annotation provided under Norton Basin Planning Area).

U.S. Department of the Interior, Minerals Management Service. 1985f. Hope Basin Planning Area Protraction Diagram.

This 1:950,000 scale map shows the coastline and boundaries of the Hope Basin Planning Area only. This map was used in the present analysis to review and verify the coastal measurements made on other maps.

Chukchi Sea Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Survey. 1978. Arctic Coast Chart No. 16003.

(Annotation provided under Hope Basin Planning Area).

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1984e. Outer Continental Shelf Resource Management Map, Barrow Arch/Diapir Field Regional Map.

This 1:1,000,000 scale OCS Resource Management Map shows lease blocks and some limited bathymetric data from the western edge of the Chukchi Sea Planning Area and along the Harrison Bay portion of the Beaufort Sea Planning Area. Where they appear, contour intervals are presented in 2-m increments.

U.S. Department of the Interior, Minerals Management Service. 1987t. Chukchi Sea Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. The boundaries of the Planning Area, lease blocks, and bathymetric contours at 10-m intervals are shown.

Beaufort Sea Planning Area

U.S. Department of Commerce, National Oceanic and Atmospheric Administration - National Ocean Service. 1986d. Pt. Barrow to Herschel Island. Chart No. 16004.

This map, presented at a scale of 1:700,000 was used to help develop the Shelf Slope Zone estimates from the Beaufort Sea Planning Area. It provides bathymetric data across the shelf in this area.

U.S. Department of the Interior, Bureau of Land Management. 1979c. Graphics to the Final Environmental Impact Statement, Federal/State Oil and Gas Lease Sale, Beaufort Sea.

Land Status, Graphic No. 8: This BLM graphic, along with data contained in literature cited, was used to supplement the estimate of Submerged Vegetation within the Beaufort Sea Planning Area. The scale on this graphic is 1:250,000.

Cultural Resources, Graphic No. 10: This graphic, along with data contained in literature cited, was used to help develop the Hard Bottom estimate for the Beaufort Sea Planning Area. The scale on this graphic is 1:250,000.

U.S. Department of the Interior, Minerals Management Service. 1987u. Beaufort Sea Planning Area Protraction Diagram.

This protraction diagram is presented at a scale of 1:750,000. Coastlines, lease blocks, and Planning Area boundaries are shown. No bathymetric data are given.

U.S. Department of the Interior, U.S. Fish and Wildlife Service. 1987-1989. NWI Wetlands Classification Maps.

The following 1:63,360 scale maps were used in conducting the coastal and marine habitat assessment in the Beaufort Sea Planning Area:

Barrow (B-4), AK	Published 1988
Barrow (B-3), AK	Published 1988
Barrow (A-1), AK	Published 1988
Barrow (A-2), AK	Published 1988
Barrow (A-3), AK	Published 1988
Barrow (A-4), AK	Published 1988
Barrow (A-5), AK	Published 1988
Harrison Bay (B-1), AK	Published 1989
Harrison Bay (B-2), AK	Published 1988
Harrison Bay (B-3), AK	Published 1987
Harrison Bay (C-1), AK	Published 1987
Harrison Bay (C-3), AK	Published 1987
Harrison Bay (C-4), AK	Published 1987
Harrison Bay (C-5), AK	Published 1987
Harrison Bay (D-4), AK	Published 1987
Harrison Bay (D-5), AK	Published 1987
Flaxman Island (A-1), AK	Published 1988
Flaxman Island (A-3), AK	Published 1988
Flaxman Island (A-4), AK	Published 1988
Flaxman Island (A-5), AK	Published 1988
Flaxman Island (B-5), AK	Draft
Barter Island (A-3), AK	Published 1988
Barter Island (A-4), AK	Published 1988
Barter Island (A-5), AK	Published 1988
Demarcation Point (C-1), AK	Published 1988
Demarcation Point (C-2), AK	Published 1988
Demarcation Point (D-2), AK	Published 1988
Demarcation Point (D-3), AK	Published 1988
Demarcation Point (D-4), AK	Published 1988
Demarcation Point (D-5), AK	Published 1988
Beechey Point (A-1), AK	Published 1989
Beechey Point (A-2), AK	Published 1989
Beechey Point (A-3), AK	Published 1989
Beechey Point (B-1), AK	Published 1989
Beechey Point (B-2), AK	Published 1989
Beechey Point (B-3), AK	Published 1989
Beechey Point (B-4), AK	Published 1989
Beechey Point (B-5), AK	Published 1989
Beechey Point (C-5), AK	Published 1989

Beechey Point (C-4), AK	Published 1989
Teshekpuk (D-4), AK	Published 1988
Teshekpuk (D-5), AK	Published 1988
Teshekpuk (D-3), AK	Published 1988
Teshekpuk (D-2), AK	Published 1988
Teshekpuk (D-1), AK	Published 1988

APPENDIX C
MAP SERIES

APPENDIX C
MAP SERIES

The enclosed Map Series consists of 26 separate maps which have been developed to graphically depict the spatial extent of water column primary productivity sampling within each of the OCS Planning Areas. With the exception of the North, Mid-, and South Atlantic, all Planning Area-specific maps within this Appendix identify:

1) those sampling locations where appropriate measurement techniques were used to determine water column primary productivity, as discussed in Sections 2.1.4 and 2.1.5; and

2) the total number of observations (i.e., direct measurements of primary production) per plotted sampling location.

Variability in primary production for a given Planning Area has also been noted when sufficient sampling has allowed for this characterization. Variability in production has been depicted either directly through 1) the use of map shading (when only limited portions of a Planning Area exhibit high variability), or 2) the use of a footnote (when the entire Planning Area exhibits high variability). Definitions of low-moderate and high variability have been provided in Section 2.1.4. Each map also contains a histogram which reflects the nature of Planning Area-specific variability in primary production. This variability may be based upon seasonal or interannual differences, episodic events (e.g., upwelling or advection), or spatial differences (e.g., different water masses and water mass characteristics), as outlined in the individual Planning Area-specific discussions found in Section 2.2.

Extensive sampling of primary productivity within the North, Mid-, and South Atlantic Planning Areas precluded the plotting of individual stations during the present analysis. In lieu of station plots, the three Atlantic Planning Area maps have been shaded using different shade patterns to indicate the extent of productivity observations. Figure C1 has been provided to indicate the frequency and extent of sampling during one of the major oceanographic programs (i.e., the Marine Resource Monitoring, Assessment and Prediction [MARMAP] program) conducted within the Atlantic region. The size of the dot indicates the frequency of sampling at each station, as coded in the figure legend.

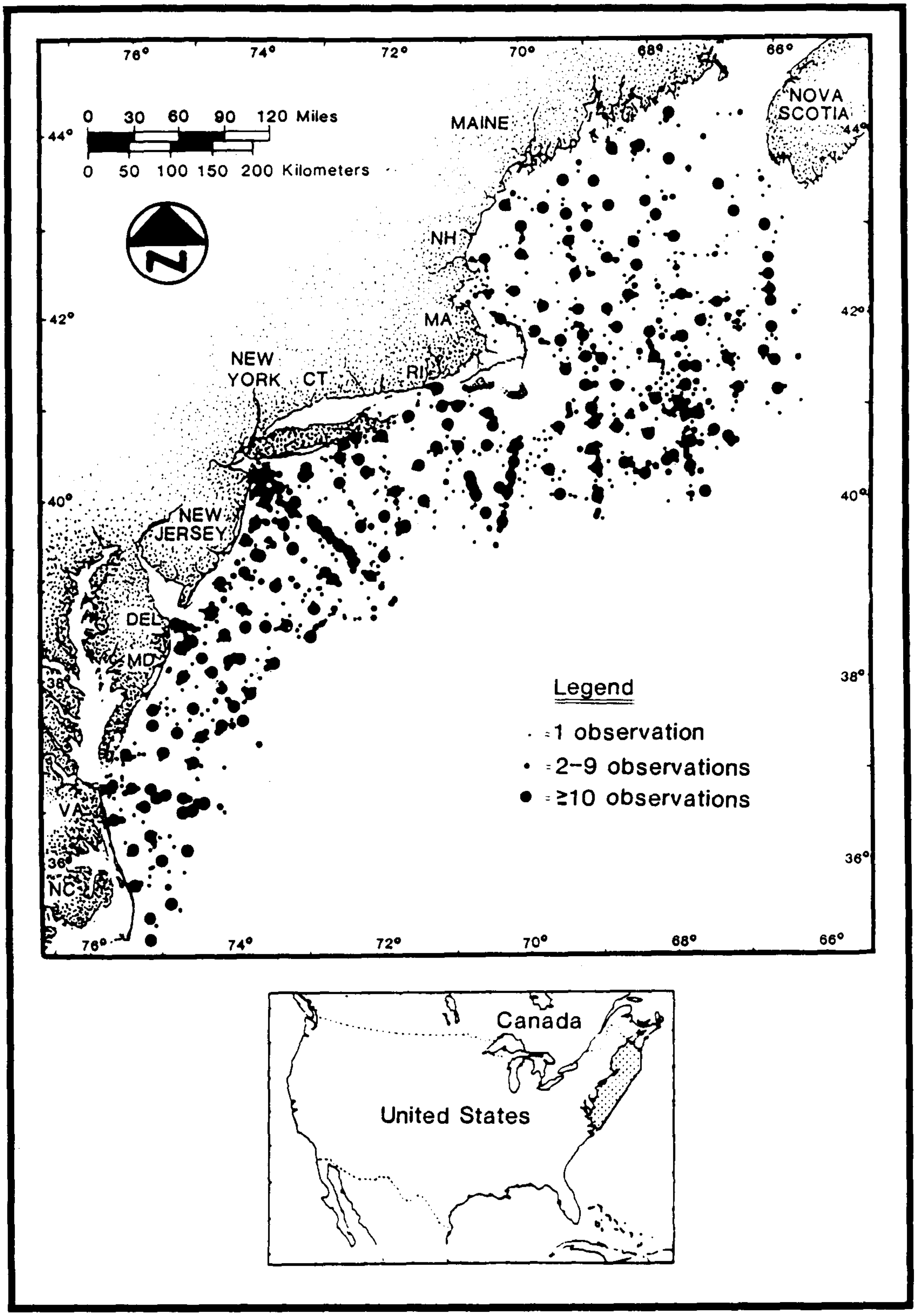

Figure C1. MARMAP sampling frequency on the northeastern U.S. continental shelf between Nova Scotia and Cape Hatteras, March 1977 through June 1982 (Adapted from: O'Reilly *et al.*, 1987).