NOAA Technical Memorandum NMFS-F/AKR-30

Impacts to Essential Fish Habitat from Non-Fishing Activities in Alaska

EFH 5-Year Review: 2018 to 2023

Impacts to Essential Fish Habitat from Non-Fishing Activities in Alaska

EFH 5-Year Review: 2018-2023

Prepared by:

Douglas Limpinsel

Sean McDermott

Charlene Felkley

Erika Ammann

Stephanie Coxe

Gretchen A. Harrington

Seanbob Kelly

Jodi L. Pirtle

Linda Shaw

Molly Zaleski

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

National Marine Fisheries Service

Alaska Region, Habitat Conservation Division
P.O. Box 21668 709 W. 9th Street
Juneau, Alaska 99802

(907) 271-5006

For Assistance with this Document

Hard copies may be obtained by contacting: Doug.Limpinsel@noaa.gov or Charlene.Felkley@noaa.gov

Suggested changes, additions, or questions should be directed to Doug.Limpinsel@noaa.gov for consideration in updating this document.

This document is available online in an interactive format at: https://alaskafisheries.noaa.gov/habitat/efh

Every effort has been made to make this document accessible to individuals of all abilities and compliant with Section 508 of the Rehabilitation Act. The complexity of this document may make access difficult for some. If you encounter information that you cannot access or use, please email us at Alaska.webmaster@noaa.gov or call us at 907-586-7228 so that we may assist you.

Photo Credits

Chapters 1 and 3 title page photos: Linda Shaw.

Chapter 2 title page photo: Image captured using NASA's Scientific Visualization Studio https://climate.nasa.gov/interactives/climate-time-machine

Chapter 4 title page photo: Linda Shaw.

Chapter 5 title page photo: Original image from NASA Earth Observatory, featured on NOAA-AFSC website https://www.fisheries.noaa.gov/feature-story/spring-and-fall-phytoplankton-blooms-eastern-bering-sea-during-1995-2011

Chapter 6 title page photo: Linda Shaw.

Suggested Citation

Limpinsel, D., S. McDermott, C. Felkley, E. Ammann, S. Coxe, G.A. Harrington, S. Kelly, J.L. Pirtle, L. Shaw, and M. Zaleski. 2023. Impacts to Essential Fish Habitat from Non-Fishing Activities in Alaska: EFH 5-year review from 2018-2023. National Marine Fisheries Service, Alaska Region, Juneau, Alaska. U.S. Dep. Commerce, NOAA Tech. Memo. NMFS-F/AKR-30. doi: 10.25923/9z4h-n860

Executive Summary

In 1996, the United States Congress declared that, "One of the greatest long-term threats to the viability of the commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States." (16 USC 1801(a)(9)). The Magnuson-Stevens Fishery Conservation and Management Act (MSA) is the primary law governing marine fisheries management in the United States, including the protection of essential fish habitat (EFH). EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) published the Final Rule for the MSA's EFH provisions on January 17, 2002. That rule establishes the mandatory content of fishery management plans, described in nine components, to assist the Regional Fishery Management Councils and the Secretary of Commerce, through NMFS, in the description and identification of EFH, the identification of adverse effects to EFH, and the identification of actions to conserve and enhance EFH. Those regulations require a complete review of the nine EFH components at least once every 5 years.

Consistent with the requirement to review potential impacts to EFH from non-fishing activities (EFH component 4), the *Impacts to Essential Fish Habitat from Non-Fishing Activities in Alaska* report (Non-Fishing Impacts Report) is a NMFS led initiative, though its Habitat Conservation Division, to improve the Federal consultation process and improve public awareness to support proactive habitat conservation and enhancement. This report includes:

- A compilation and review of non-fishing impacts to EFH (see also Appendix A);
- A review of climate change indicators and impacts to EFH; and
- Conservation recommendations to mitigate non-fishing impacts and climate change effects on EFH.
- Descriptions of EFH attributes (Section 1.4, EFH Attributes) and ecosystem processes that support fish;

Non-fishing impacts are anthropogenic impacts on biodiversity, direct or indirect, involving overexploitation of natural resources; habitat modification, conversion, and fragmentation; the introduction of exotic (nonnative) species; and pollution (Steffen et al. 2011, Sponsel 2013, Lewis and Maslin 2015). The purpose of this report is to guide understanding of the potential adverse effects of non-fishing activities on EFH and provide conservation recommendations to avoid and minimize those effects. The MSA requires NMFS to provide conservation recommendations to Federal and State agencies for actions that may adversely affect EFH. Implementing the conservation recommendations provided in this report, as well as other best management practices, will support the conservation and enhancement of healthy fish habitats at the foundation of Alaska's sustainable fisheries and promote environmentally sound development and energy production.

The required EFH components are included in the North Pacific Fishery Management Council's six Fishery Management Plans:

- Groundfish of the Bering Sea and Aleutian Islands Management Area

- Groundfish of the Gulf of Alaska
- Bering Sea/Aleutian Islands King and Tanner Crabs
- Scallop Fishery off Alaska
- Salmon Fisheries in the EEZ off Alaska
- Fish Resources of the Arctic

EFH text descriptions and maps (EFH component 1) are found in the appendices of each Fishery Management Plan and should be referenced for the EFH consultation process. That information can be augmented with additional resources described in Section 1.6 (Tools for EFH Consultations).

The information contained herein can inform the required consultation process with Federal action agencies, planning of development and energy projects within EFH, and coordination on state actions. Extensive information supports the conservation recommendations in a user-friendly format for Federal action agencies, resource managers, restoration practitioners, and the public.

Ecosystem-based Fisheries Management

Alaska encompasses arctic, subarctic, and temperate climate zones. Alaska's five Large Marine Ecosystems defined by NOAA are: (1) the Gulf of Alaska, (2) Aleutian Islands, (3) eastern Bering Sea, (4) northern Bering Sea and Chukchi Sea, and (5) Beaufort Sea. The northern Bering Sea, Chukchi Sea, and Beaufort Sea together are referred to as the Arctic (NOAA 2019, 2022a)[1]. Seventeen coastal zones are identified across Alaska's shorelines and eight terrestrial ecoregions are defined above the high tide line to the interior (Nowacki et al. 2001, Piatt and Springer 2007). Within this geographic context, the Non-fishing Impacts Report takes an ecosystem-based fisheries management (EBFM) approach in evaluating adverse effects to EFH and providing conservation recommendations.

EBFM is defined as geographically specific, adaptive accounting for ecosystem knowledge and uncertainties, considering multiple external influences, and striving to balance diverse societal objectives (NMFS 2016), where habitat science is a fundamental element (Peters et al. 2018). EBFM aims to maintain ecosystems in a healthy, productive, and resilient condition to support sustainable fisheries by accounting for ecosystem interactions and considerations. NMFS strives for an EBFM approach to EFH, including our consultation and project management activities for the conservation and enhancement of fish habitat. All ecosystem functions come into play when assessing effects of a proposed action, such as species interactions and the effects of environmental changes, anthropogenic impacts, including climate change, and other stressors on habitat. EBFM ensures that these elements are considered to more effectively assess the effects of an action and develop the best conservation recommendations to mitigate those effects. An EBFM approach supports a more efficient and effective accomplishment of our habitat mandates and promotes consideration of the full range of cumulative effects and trade-offs across various

[1] The Alaska Fisheries Science Center combines the northern Bering and Chukchi Seas as one Large Marine Ecosystem in their Strategic Science Plan for FY2023-FY2027 (NOAA 2022). The boundaries of Alaska's Large Marine Ecosystems are distinct from North Pacific Fishery Management Council's Fishery Management Plans.

management strategies and human uses. The information, analyses, and conservation recommendations within this report reflect this commitment to EBFM.

Non-fishing Impacts Report Overview

This report is organized to provide foundational information for a topic (climate change) or an ecosystem (watersheds, estuaries and nearshore, and offshore), and to facilitate access of specific information to support environmentally sustainable development. Each chapter includes: Alaska specific metrics and the physical, chemical, and biological properties to set the foundation: a description of potential sources of anthropogenic impact; and conservation recommendations to mitigate those potential impacts. The review captured in this report reflects the best available information and our professional experience. It is not an exhaustive assessment of total potential impacts and conservation recommendations. New information is continually being developed. Our understanding of anthropogenic activities and related impacts, especially related to greenhouse gases and climate change, is evolving.

Chapter 1 Introduction includes 1) a discussion of the report's purpose, 2) a brief history of this report, 3) an EFH overview, 4) a description of EFH attributes, 5) a review of the EFH consultations process, 6) tools to support EFH consultations, 7) an overview of Ecosystem-based Fisheries Management, and 8) the role of the North Pacific Fishery Management Council in that process. Alaska's dynamic, often ice-covered seas are home to a remarkable diversity of marine and aquatic life, including those species important to commercial, recreational, and subsistence fishing. Alaska's fisheries are among the best-managed, most sustainable in the world. Healthy habitat is the foundation of those fisheries. This chapter provides the foundation for understanding what EFH is, why it is important to the Alaska fisheries and the Federal consultation process, and information needed to support EFH conservation and enhancement.

Chapter 2 Climate Change introduces climate change as an important issue for EFH conservation, sustainable fisheries, and resilient coastal communities. Chapter 2 summarizes current scientific understanding of greenhouse gas emissions and climate change effects globally and within Alaska. Following this is a summary of climate change-related effects in the Arctic, Bering Sea, Gulf of Alaska, and riverine habitat. We provide an approach to assess climate change-related impacts on habitat using set criteria. Lastly we include conservation recommendations for large emission facilities associated with oil and gas development. Large emission facilities is the one area that conservation recommendations could result in meaningful beneficial outcome for greenhouse gas emissions and climate change.

Chapter 3 Watersheds highlights the physical, chemical, and biological processes of wetlands, forests, and rivers that provide water quality and quantity, and nutrient resources necessary for EFH. Sources of potential impacts to EFH in watersheds are identified, such as silviculture and timber harvest, mining, road crossings, urban and suburban development, freshwater use, and energy development. Recommended conservation measures for each potential source of impact inform project development and proactively mitigate project effects.

Chapter 4 Estuaries and Nearshore provides a description of the EFH components of Alaska's estuaries and nearshore marine environment. Chapter 4 highlights the physical, chemical, and biological processes that support EFH in the estuaries and the nearshore. Sources of potential impacts to EFH are identified, such as dredging, the discharge of dredged and fill material, onshore seafood processing waste, infrastructure development and utilities, invasive species, flood control and shoreline stabilization, log transfer facilities, water intake and discharge, aquaculture, energy development, and habitat restoration projects. Recommended conservation measures for each potential source of impact inform project development and proactively mitigate project effects.

Chapter 5 Offshore provides an overview of the offshore marine environment. Sources of potential impacts to EFH offshore are described, including increased vessel traffic, point source discharges, oil and gas exploration and development, mining, marine debris, and vessel scuttle. Recommended conservation measures for each potential source of impact inform project development and proactively mitigate project effects.

Chapter 6 Conclusions Healthy habitats are the foundation for sustainable fisheries. This Non-fishing Impacts Report provides an EBFM approach to informing the conservation and enhancement of EFH in the face of continuous development and energy production pressure. Climate change is a significant threat to habitat that needs full consideration. Evaluation criterion and other information provides support for long-term planning to build habitat resiliency and mitigate climate effects. This report provides a detailed assessment of non-fishing related impacts to habitat and conservation recommendations to mitigate those impacts. The background, assessments, and conservation recommendations are based on a thorough literature review. The information within this report can improve the Federal EFH consultation process, and planning for development and energy production in EFH, and proactively conserving and enhancing EFH.

Acknowledgements

This review of non-fishing impacts on essential fish habitat and recommended conservation measures were developed through decades of work conducted by past and present NMFS staff who laid much of the foundation for this document. We are grateful for their hard work and dedication. The state of knowledge on ecosystems processes, habitat in support of fisheries, and climate change has substantially improved the original review in 2003 and will continue to do so over time as new information is developed. In addition to the report authors from the Habitat Conservation Division (HCD), we want to express a special thanks for contributions to this report from former HCD staff: Sean Eagan, Ellen Ward, Joshua Markwell, John Olson, and Matt Eagleton. Their efforts supported the technical content and format of this document.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

°C	Degrees Celsius
°F	Degrees Fahrenheit
ADFG	Alaska Department of Fish and Game
AMD	Acid Mine Drainage
ATTF	Alaska Timber Task Force
BLM	Bureau of Land Management
BMP	Best management Practice
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
CFR	Code of Federal Regulations
CH_4	Methane
cm	Centimeter
CO_2	Carbon Dioxide
CR	Conservation Recommendations
CWA	Clean Water Act
dB	Decibel
DOM	Dissolved Organic Matter
EFH	Essential Fish Habitat
EBFM	Ecosystem-based Fisheries Management
EBS	East Bering Sea
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
EEZ	Exclusive Economic Zone
FERC	Federal Energy Regulatory Commission
FLIGHT	Facility Level Information on GreenHouse gases Tool
FMP	Fishery Management Plan
FPA	Federal Power Act
FR	Federal Register
ft	Foot or Feet
ft^2	Square feet
ft^3	Cubic feet
GHG	Greenhouse Gas
GOA	Gulf of Alaska
GRS	Geographic Response Strategies
HAPC	Habitat Area of Particular Concern
HEC	Hydrokinetic Energy Converter
Hz	Hertz
in	Inch
IPCC	Intergovernmental Panel on Climate Change
km	Kilometer
km^2	Square Kilometers

LME	Large Marine Ecosystem
LTF	Log Transfer Facilities
LWD	Large Woody Debris
m	Meters
m^3	Cubic Meters
MDN	Marine Derived Nutrients
mi	Miles
mi^2	Square Miles
MHK	Marine Hydrokinetic Energy Converters
MSA	Magnuson-Stevens Fishery Conservation and Management Act
N_2O	Nitrous Oxide
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPFMC or Council	North Pacific Fishery Management Council
NSR	Northern Sea Route
OCS	Outer Continental Shelf
PAH	Polycyclic Aromatic Hydrocarbons
POM	Particulate Organic Matter
PFAS	Polyfluoroalkyl Substances
Regional Councils	Regional Fishery Management Councils
rms	Root-Mean-Square
SAT	Surface Air Temperature
SAV	Submerged Aquatic Vegetation
SIE	Sea Ice Extent
SNAP	Scenarios Network for Alaska and Arctic Planning
SPL	Sound Pressure Level
SST	Sea Surface Temperature
µPa	Micropascal
U.S.	United States
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
USFS	U.S. Forest Service
VIDA	Vessel Incidental Discharge Act
yd^3	Cubic Yards
ZOD	Zone of Deposit

Chapter 1 Introduction

1.1 Purpose of the Report

The National Marine Fisheries Service (NMFS) Alaska Region's Habitat Conservation Division (HCD) developed this report to guide the understanding of the potential adverse effects of non-fishing activities (anthropogenic impacts) on essential fish habitat (EFH) and provides EFH conservation recommendations (CR) to avoid and minimize those effects. EFH is susceptible to a wide array of human activities unrelated to fishing. Broad categories of non-fishing activities include, but are not limited to: dredging, filling, excavation, mining, impoundment, discharge, water diversions, thermal additions, greenhouse gas emissions (GHG)[2], nonpoint source pollution and sedimentation, introduction of potentially hazardous materials, exotic species, and the conversion of aquatic habitat that may eliminate, diminish, or disrupt the functions of EFH. Impacts to EFH occur to habitats in (1) watersheds, (2) estuaries and the nearshore marine environment, and (3) the offshore marine environment. For each activity, this report describes known and potential adverse effects to EFH and potential EFH CRs. Appendix A provides a series of tables compiling many of those non-fishing activities and associated potential effects from Johnson et al. (2008).

Climate change is included as a non-fishing impact to EFH due to its association with human activities, and its large-scale, regional and global implications for marine and aquatic habitats and ecosystems. Climate change exacerbates all other previously recognized anthropogenic impacts to EFH. Climate change has led to warming ocean conditions and reduced Arctic sea ice extent (Stroeve et al. 2007, Stroeve et al. 2008). Such habitat changes are linked to altered trophic dynamics and species distribution shifts (Stram and Evans 2009, Hare et al. 2016, Spencer et al. 2019). EFH CRs to mitigate impacts associated with climate change are new and evolving.

The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires NMFS to provide EFH CRs to Federal and State agencies for actions that may adversely affect EFH. EFH CRs are actions the action agency or others can undertake to avoid, minimize, mitigate, or offset adverse impacts to EFH. The EFH CRs in this report identify reasonable actions to avoid or minimize adverse effects of categories of non-fishing activities to EFH. Implementation of these recommendations is at the discretion of the entities responsible for the activities and the agencies with applicable regulatory jurisdiction. The recommendations in the report may or may not be applicable on a site-specific basis. These recommendations are a starting point when consulting

[2] Primarily carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

with Federal action agencies on specific activities that may adversely affect EFH. EFH CRs are provided for specific activities on a case-by-case basis using the best and most current scientific information available. Federal action agencies undertaking EFH consultations with NMFS may use the information provided in this report to assist in preparing EFH assessments.

Many non-fishing activities have similar adverse effects on living marine resources (Appendix A). Those overlapping effects led to some redundancy in the impact descriptions and the accompanying CRs among sections in this report. See Section 1.6 (Tools for EFH Consultations) for more information to support the consultation process.

1.2 Brief History of the Non-Fishing Report

Regulations for implementing the EFH provisions of the MSA state that Regional Fishery Management Councils (Councils) and NMFS should review the EFH provisions of Fishery Management Plans (FMP) at least once every five years. The EFH provisions should be revised or amended, as warranted, based on available information (50 CFR 600.815(a)(10)). These regulations also state that the review should evaluate published scientific literature, unpublished scientific reports, information solicited from interested parties, and previously unavailable or inaccessible data.

In 2003, NMFS Alaska, West Coast, and Southwest Regions completed a collaborative evaluation of non-fishing effects to EFH (NMFS 2003b). The non-fishing impacts report served to update the information on non-fishing impacts to EFH as part of the EFH 5-year review. In 2005, we completed an Environmental Impact Statement, which included an updated, Alaska version of non-fishing impacts report as Appendix G (NMFS 2005a). The Alaska specific report was subsequently updated during the 2010 and 2017 EFH 5-year review cycles.

The North Pacific Fishery Management Council (NPFMC) completed its most recent 5-year review in April 2017 and recommended revisions to the EFH sections of its FMPs. We completed those revisions in 2018 (83 FR 31340, July 5, 2018). This report updates the 2017 Non-Fishing Impacts Report (Limpinsel et al. 2017) with new scientific information, refined EFH CRs, and a new chapter on climate change.

1.3 Essential Fish Habitat Overview

In 1996, Congress added the EFH provisions to the MSA, the federal law that governs United States (U.S.) marine fisheries management. As Congress recognized in section 2(a)(9) of the MSA, “One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of the fishery resources of the United States”.

Section 303(a)(7) of the MSA requires FMPs to describe and identify EFH, minimize the adverse effects of fishing to EFH to the extent practicable, and identify other actions to encourage the conservation and enhancement of EFH. EFH is defined as those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity (50 CFR 600.10). “Waters” include aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate; “substrate” includes sediment, hard bottom, structures underlying the waters, and associated biological communities; “necessary” means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and “spawning, breeding, feeding, or growth to maturity” covers a species' full life cycle. EFH descriptions shall be based on the best scientific information available and consider different types of information according to its scientific rigor (50 CFR 600.815(a)(1)(ii)(B)).

An adverse effect is any impact that reduces the quality and/or quantity of EFH. Adverse effects may include direct or indirect physical, chemical, or biological alterations of the waters or substrate and loss of, or injury to, benthic organisms, prey species, and their habitat, as well as other ecosystem components. Adverse effects may be site-specific or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions (50 CFR 600.910(a)).

Section 305(b)(2) of the MSA requires each Federal agency to consult with NMFS with respect to any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by such agency that may adversely affect EFH. If a Federal agency determines that the action will not adversely affect EFH, no consultation is required. Section 305(b)(4) requires that if NMFS receives information from a Fishery Management Council or Federal or State agency or determines from other sources that an action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken, by any Federal or State agency would adversely affect any EFH, NMFS shall provide CRs based on available information (50 CFR 620.925).

NMFS published Federal regulations to implement provisions of the MSA and provide guidelines to identify and conserve EFH (67 FR 2343, January 17, 2002). The implementing regulations identified nine components of an FMP for the description and identification of EFH, the identification of adverse effects to EFH, and the identification of actions to conserve and enhance EFH. The Regional Councils and NMFS subsequently identified EFH for each species managed under FMPs across the nation. Designated EFH is diverse, widely distributed, and closely interconnected with other aquatic and terrestrial environments. EFH components are included in the NPFMC’s six Fishery Management Plans[3]:

- Groundfish of the Bering Sea and Aleutian Islands Management Area
- Groundfish of the Gulf of Alaska
- Bering Sea/Aleutian Islands King and Tanner Crabs
- Scallop Fishery off Alaska
- Salmon Fisheries in the EEZ off Alaska
- Fish Resources of the Arctic[4]

EFH text descriptions and maps (EFH component 1) are found in the appendices of each FMP and should be referenced for the EFH consultation process. EFH information in the FMPs can be augmented with additional resources representing a growing portfolio of fish habitat information described in Section 1.6 (Tools for EFH Consultations).

[3] Also located on the NPFMC’s website.

[4] The Arctic Management Area, which includes the Beaufort and Chukchi Seas, is closed to commercial fishing until such a time that scientific survey and analysis provides data certainty to allow commercial fishing to occur.

1.4 EFH Attributes

In the biological sciences, an attribute is a quality or feature of a system essential to the survival of a species in that system. EFH attributes are physical, chemical and biological properties or characteristics (abiotic and biotic) that support fish populations at various life history stages (Table 1). For example, temperature is a key characteristic of water. Different fish species prefer a range of temperatures to maintain optimal metabolism, health, and recruitment. Water temperatures outside a species metabolic range may prove detrimental to reproductive success, development, mobility, respiration, and other functions necessary for survival. Similarly, fish need dissolved oxygen for respiration. Many fish species are sensitive to low concentrations of dissolved oxygen. The concentration of dissolved oxygen varies with temperature. Water temperature and dissolved oxygen also affect the quality and quantity of food resources. Independently and in combination, water temperature, dissolved oxygen and food availability are key EFH attributes that support fish. Many other ecosystem characteristics (Table 1) support EFH, all of which may be impacted by the effects of non-fishing activities.

Table 1. EFH attributes: physical, chemical and biological properties supporting EFH.

Individual Attribute	Importance and Role
Nutrient Availability	Abundant appropriate size food sources, larval through adult, terrestrial and oceanic
Water Temperature	Different fish species, multiple life history stages, often specific range of temps
Water Quality	Dissolved organic or inorganic compounds can support or degrade conditions
Dissolved Gases	Primarily oxygen, essential to all levels of trophic and ecosystem dynamics
Ocean Mixing	Tides, currents, Ekman processes, influence O_2, temperature and nutrient availability
Substrate Complexity	Hard structure, rocks, reefs, vegetation, predator avoidance, refuge opportunities
Water Clarity	Sediment, nutrient load and visibility
Water Salinity, Density	Metabolism and osmoregulation
Water Pressure and Depth	Different species and/or life stages may only exist at specific depths
Instream Flow	Hyporheic, ground and surface water interactions

1.5 EFH Consultations on Non-fishing Activities

Federal regulations at 50 CFR 600 Subpart K direct the EFH consultation process. Examples of Federal action agencies that permit, fund, or undertake activities that may trigger EFH consultation include, but are not limited to, the U.S. Army Corps of Engineers (USACE), the U.S. Environmental Protection Agency (EPA), Bureau of Ocean Energy Management (BOEM), the Federal Energy Regulatory Commission (FERC), and the Department of the Navy. Federal agencies initiate consultation by preparing and submitting to NMFS a written EFH assessment that analyzes the potential adverse effects of the proposed federal action and identifies measures to mitigate those adverse impacts on EFH.

The EFH assessment must contain:

- A description of the action.
- An analysis of the potential adverse effects of the action on EFH and the managed species.
- The Federal agency's conclusions regarding the effects of the action on EFH.
- Proposed mitigation, if applicable.
- If appropriate, the assessment should also include:
    - The results of an on-site inspection to evaluate the habitat and the site-specific effects of the project.
    - The views of recognized experts on the habitat or species that may be affected.
    - A review of pertinent literature and related information.
    - An analysis of alternatives to the action. Such analysis should include alternatives that could avoid or minimize adverse effects to EFH.
    - Other relevant information.

To promote efficiency and avoid duplication, an assessment may incorporate by reference a completed EFH assessment prepared for a similar action, supplemented with any relevant new project specific information, provided the proposed action involves similar impacts to EFH in the same geographic area or a similar ecological setting. It may also incorporate by reference other relevant environmental assessment documents. These documents must be provided to NMFS with the EFH assessment. An EFH consultation can be integrated into existing environmental review procedures under other laws such as the National Environmental Policy Act (NEPA), Endangered Species Act (ESA), or Fish and Wildlife Coordination Act.

After receiving the EFH assessment, NMFS must respond in 30 days for an abbreviated consultation or 60 days for an expanded consultation. If NMFS determines that an action would not adversely affect EFH, or if NMFS determines that no EFH CRs are needed, NMFS will notify the Federal agency either informally or in writing of its determination. If NMFS concludes the action may result in substantial adverse effects to EFH, or that additional analysis is needed to assess the effects of the action, NMFS will request in writing that the Federal agency initiate expanded consultation. After NMFS receives adequate information, NMFS will provide EFH CRs, pursuant to section 305(b)(4)(A) of the MSA. These EFH CRs include measures to avoid, minimize, mitigate, or offset the potential adverse effects to EFH.

Within 30 days of receiving NMFS's EFH CRs, Federal action agencies must provide a detailed response in writing. The response must include a description of measures the agency proposes for avoiding, mitigating, or offsetting the impact of the activity on EFH. In the case of a response that is inconsistent with NMFS's EFH CRs, the Federal agency must explain its reasons for not following the recommendations, including the scientific justification for any disagreements with NMFS over the anticipated effects of the action and the measures needed to avoid, minimize, mitigate, or offset such effects. State agencies are not required to respond to EFH CRs.

1.6 Tools for EFH Consultations

Web-based tools are available to assist Federal and State agencies in conducting their EFH assessments and to assist in EFH consultations.

Alaska Region Fishery Management Plans: Using the best available science, we work with the NPFMC and the Alaska Fisheries Science Center to designate EFH for federally managed species in the FMPs. EFH text descriptions and maps are in the appendices of the six FMPs (see Section 1.3, Essential Fish Habitat Overview)[5]. Each FMP describes and identifies EFH for targeted species based on the guidelines established by the Secretary under section 305(b)(1)(A), measures to minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat.

Alaska EFH Web Application: The Alaska Region launched the Alaska EFH Web Application, also known as the "AK EFH Mapper", in December 2018. An ESRI ArcGIS online platform hosts the complete collection of Alaska EFH maps. This online map interface provides an efficient and effective platform to view, search, and query EFH map information. Alaska EFH maps are also available on the National EFH Mapper[6], although with reduced interactive user function to query information and without ability to distinguish between EFH Levels (Alaska will include up to EFH Level 3, following the 2023 EFH 5-year Review). Updates to the AK EFH Mapper are being implemented in 2023 to improve user accessibility and function. Alaska EFH maps are also available from our website as polygon shapefiles for technical users[7]. EFH maps on the Alaska and National EFH mappers are updated following each EFH 5-year Review where new or revised EFH maps were developed.

ShoreZone: For the coastal-nearshore marine environment, the ShoreZone mapping system has mapped more than 120,000 km (km) (74,565 miles (mi)) of shoreline in Alaska, Oregon, Washington, and British Columbia. Approximately 95 percent of Alaska's extensive coastline is imaged and mapped. *ShoreZone* catalogs both geomorphic and biological resources at mapping scales of better than 1:10,000. Low tide, oblique aerial imagery sets this system apart from other mapping efforts of this type. You can "fly the coastline" by viewing the aerial video, view and download still photos, and access physical and biological data using the interactive website. Technical users can download the entire *ShoreZone* geodatabase. The high resolution, attribute-rich dataset is a useful resource for site-specific data (e.g., for oil spill response) and can also be used to develop a variety of spatial data products such as habitat maps and species distribution models and maps.

Nearshore Fish Atlas of Alaska: The Nearshore Fish Atlas of Alaska catalogs the distribution, relative abundance, and habitat use of nearshore fishes in Alaska (select link for database, information, and contacts). Shallow, nearshore waters are some of the most productive habitats in Alaska and the most vulnerable to human disturbance. Using a beach seine as the primary sampling method, more than 100 fish species in a variety of nearshore habitats are documented throughout Alaska to identify EFH. This collection was expanded in 2021 with 25 new fish survey data sets from seven organizations, including and not limited to an additional 3,800 beach

---

[5] Also located on the NPFMC's website.

[6] National EFH Mapper: https://www.fisheries.noaa.gov/resource/map/essential-fish-habitat-mapper.

[7] Alaska EFH map shapefiles: https://www.fisheries.noaa.gov/resource/data/alaska-essential-fish-habitat-efh-species-shapefiles.

seine hauls (total 5,154) and 768 nearshore trawls (total 1,017) from 1995-2018. The Nearshore Fish Atlas of Alaska provides:

- An accessible and well maintained data set to assess presence-absence of species and habitat types at nearshore sampling sites throughout Alaska.
- A resource for identifying species in areas designated for development or impacted by human disturbance (e.g., oil spill).
- Information for resource managers to identify EFH for species in the nearshore and prepare biological opinions for ESA species.
- Supports resource managers to track changes in species distribution and habitat use that may result from climate change and other habitat impacts.

Anadromous Waters Catalog: The Alaska Department of Fish and Game (ADFG) developed the *Anadromous Waters Catalog*, which identifies spawning, rearing, and migration habitat for anadromous fishes. This online catalog is a valuable resource to support the assessment of presence and absence of anadromous fish in freshwater habitat. The *Anadromous Waters Catalog* provides instream EFH information for all five Pacific salmon species[8] throughout Alaska and is updated annually.

1.7 Ecosystem-based Fisheries Management

Alaska encompasses arctic, subarctic, and temperate climate zones. Alaska's five large marine ecosystems (LME) defined by the National Oceanic and Atmospheric Administration (NOAA) are: (1) the Gulf of Alaska (GOA), (2) Aleutian Islands, (3) eastern Bering Sea (EBS), (4) northern Bering Sea and Chukchi Sea, and (5) Beaufort Sea (NOAA 2019, 2022a)[9]. The northern Bering Sea, Chukchi Sea, and Beaufort Sea comprise the U.S. Arctic. LMEs are large areas of the ocean with distinct bathymetry, hydrography, and biological productivity features that link plant and animal populations together in the food chain (NOAA 2012). Alaska's LMEs support very complex trophic dynamics and are some of the most productive marine ecosystems on Earth. Seventeen coastal zones are identified across Alaska's shorelines and eight terrestrial ecoregions are defined above the high tide line to the interior (Nowacki et al. 2001, Piatt and Springer 2007). Within this geographic context, the Non-fishing Impacts Report takes an ecosystem-based fisheries management (EBFM) approach in evaluating adverse effects to EFH and providing CRs.

EBFM is defined as geographically specific, adaptive accounting for ecosystem knowledge and uncertainties, considering multiple external influences, and striving to balance diverse societal objectives (NMFS 2016), where habitat science is a fundamental element (Peters et al. 2018). EBFM aims to maintain ecosystems in a healthy, productive, and resilient condition to support sustainable fisheries by accounting for ecosystem interactions and considerations. NMFS strives for an EBFM approach to EFH, including our consultation and project management activities for the conservation and enhancement of fish habitat. All ecosystem functions come into play when assessing effects of a proposed action, such as species interactions and the effects of

[8] Pink (*Oncorhynchus gorbuscha*), Sockeye (*O. nerka*), Coho (*O. kisuth*), Chum (*O. kita*), and Chinook (*O. tshawytscha*).

[9] The Alaska Fisheries Science Center combines the northern Bering and Chukchi Seas as one LME in their Strategic Science Plan for FY2023-FY2027 (NOAA 2022). The boundaries of Alaska's LMEs are distinct from NPFMC's Fishery Management Plans.

environmental changes, anthropogenic impacts, and other stressors on habitat. EBFM ensures that these elements are considered to more effectively assess the effects of an action and develop the best CRs to mitigate those effects. An EBFM approach supports a more efficient and effective accomplishment of our habitat mandates and promotes consideration of the full range of cumulative effects and trade-offs across various management strategies and human uses. The information, analyses, and CRs within this report reflect this commitment to EBFM.

1.8 Role of the NPFMC in EFH Consultations

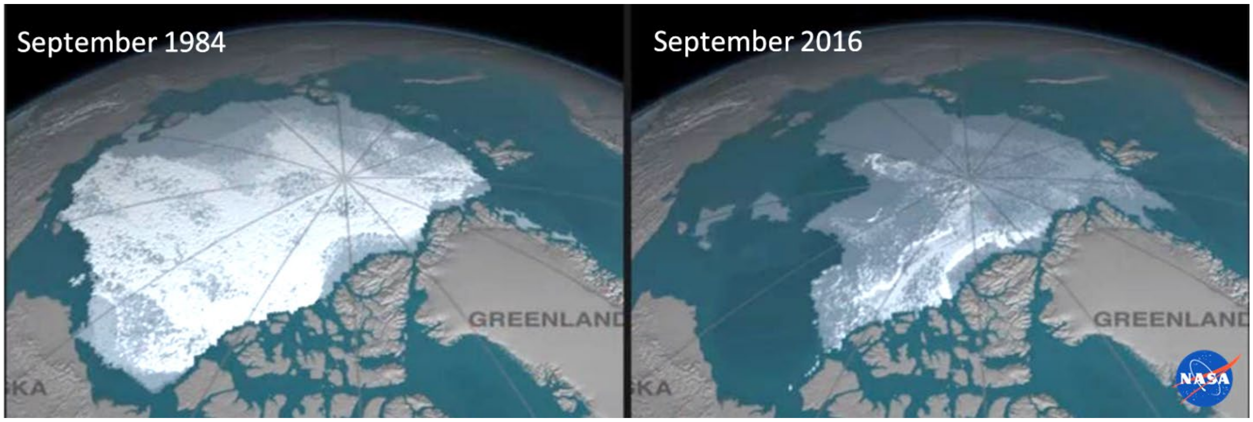
The MSA provides a role for Regional Councils in commenting on Federal or State agency actions that would affect fish habitat. Under section 305(b)(3)(A) of the MSA. Regional Councils may comment on and make recommendations to the Secretary and any Federal or State agency concerning any activity or proposed activity authorized, funded, or undertaken by the agency that, in the view of the Council, may affect the habitat, including EFH, of a fishery resource under its authority. In addition, under section 305(b)(3)(B) of the MSA, Regional Councils must provide such comments and recommendations concerning any activity that, in the view of the Council, is likely to substantially affect the habitat, including EFH, of an anadromous fishery resource under Council authority. The EFH regulations at 50 CFR 600.930(a) state that each Council should establish procedures for reviewing federal or state actions that may adversely affect the habitat, including EFH, of a species under its authority.

In 2012, the NPFMC created its EFH consultation policy and a process for their involvement in the EFH consultation process. This EFH consultation policy, in part, requests regular reports from NMFS regarding EFH consultations that may be of interest to the fishing industry, and/or that may affect habitats of direct concern to the NPFMC. The EFH consultation policy also identified the following criteria to guide NMFS in determining whether an activity is likely to be of particular interest to the NPFMC:

- The extent to which the activity would adversely affect EFH;
- The extent to which the activity would adversely affect Habitat Areas of Particular Concern (HAPC) or other areas established by the Council to protect sensitive habitat features;
- The extent to which the activity would be inconsistent with measures taken by the Council to minimize potential adverse effects of fishing on EFH; and
- The extent to which the activity would conflict with Council-managed fishing operations.

The NPFMC's policy intends to ensure that relevant activities are brought to their attention in a timely fashion and not overlooked. The NPFMC works with NMFS to provide comments and recommendations on federal or state actions that may adversely affect EFH of the species under its authority.

Chapter 2 Climate Change



2.1 Introduction

Climate change affects every aspect of NOAA's mission. Climate change and the associated problem of ocean acidification are impacting habitats, including designated EFH, from coastal rivers to estuaries and ocean waters. Significantly, the Arctic and Alaska are experiencing climate change-related effects at a rate far greater than the rest of the globe (Markon et al. 2018, Rantanen et al. 2022). Climate-related changes are projected to affect habitat, and therefore impacts commercial, recreational, and subsistence fishing, and associated traditional ways of life. This chapter provides an overview of how climate change is influencing EFH and fish in Alaska. We begin the discussion with a summary from the International Panel on Climate Change (IPCC) regarding the current scientific findings regarding GHG emissions and climate change trends. The oil and gas industry is identified as a significant GHG emission source in Alaska. We then bring the discussion to climate change effects on EFH in the Arctic and Bering Seas, Gulf of Alaska, and riverine habitat. These general ecosystems are used instead of the defined LME to provide an overview of climate change effects on EFH in Alaska. LMEs are described in Section 1.7 (Ecosystem-based Fisheries Management). This chapter closes with guidance and criterion for including climate change effects in EFH assessments, and potential CRs for large emission sources.

2.2 Greenhouse Gas Emissions and Climate Change

Scientific evidence compiled and analyzed by the IPCC clearly indicates that since the pre-industrial era emissions of GHGs have increased (Legg 2021, Masson-Delmotte et al. 2021, Pörtner et al. 2022). Human activities since the 1750s are the source of increasing GHG concentrations (Masson-Delmotte et al. 2021, Pörtner et al. 2022). The largest increases in GHG emissions have occurred in recent decades despite the growing number of international climate change mitigation policies (IPCC 2014, Legg 2021). Based on current science, the IPCC has reported the following conclusions about the current trends surrounding climate change (IPCC 2021):

- Human activity has unequivocally warmed the atmosphere, ocean and land, resulting in changes in the atmosphere, ocean, and land. Widespread and rapid changes have occurred globally.
- It is virtually certain that the global upper 0–700 meters (m) of the ocean has warmed from 1971 to 2010 and extremely likely that human influence is the main driver.
- It is virtually certain that human-caused CO2 emissions are the main driver of current global acidification of the surface open ocean.
- There is high confidence that oxygen levels have dropped in many upper ocean regions since the mid-20th century.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90 percent of the energy accumulated.

GHG emissions have resulted in changing climate patterns, including more frequent and intense extreme weather events, which has resulted in impacts to habitat (IPCC 2022). For Alaska, these trends associated with increasing GHG have resulted in warmer overall temperatures across the state, warming ocean and riverine water temperatures, reduced summer sea ice, loss of glaciers, and decrease in permafrost (Chapin et al. 2014, Notz and Stroeve 2016, Box et al. 2019). Current and projected increases in Alaska's ocean temperatures and associated changes in ocean chemistry are expected to alter habitat suitability and the general distribution and productivity of marine fishes (Chapin et al. 2014). These climate change-related effects include alterations of EFH attributes including ocean chemistry, nutrient and prey availability, salinity, water quality, and water quantity. Climate change impacts associated with increased GHGs will have significant implications for species distribution across Alaska (Spencer et al. 2019).

The EPA's Facility Level Information on GreenHouse gases Tool (FLIGHT) details emissions information for large facilities in the U.S., including Alaska[10]. A facility qualifies as a "large facility" if it emits more than 25,000 metric tons of carbon dioxide equivalent per year, more than approximately 2,300 homes or 4,600 passenger vehicles (EPA 2021). The most recent FLIGHT data for Alaska from 2019 indicate that oil and gas facilities, including petroleum and natural gas systems and refineries, are responsible for 69.2 percent of direct GHG emissions from large facilities in the state. These direct GHG emissions come from a relatively small number of projects, a total of 26 petroleum and natural gas systems and refineries, many that are located offshore and along Alaska's coast. On a per-project basis, oil and gas facilities are a large contribution to direct GHG emissions in Alaska.

Among the operations-associated GHG emissions in the oil and gas sector, methane emissions are a particular concern. Methane is a potent GHG with 28-36 times the global warming potential of carbon dioxide over 100 years (Brandt et al. 2016, Cai et al. 2017, Ekanem et al. 2018). Operations-associated methane emissions occur at various stages of the oil and natural gas supply chain, including production, gathering and processing, transmission and distribution (EPA 2021)[11]. Total GHG emissions from producing, processing and transporting oil and gas

[10] EPA Facility Level GHG Emissions Data. Website last accessed on April 1st, 2022. https://ghgdata.epa.gov/ghgp/main.do?site_preference=normal
[11] Understanding Global Warming Potentials. Website last accessed on April 4, 2022. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

account for approximately 15 percent of the total GHG emissions for the energy sector, and methane is the largest contributor to these operations-associated emissions (IEA 2020)[12].

Other sectors with large emissions facilities in Alaska include power plants (23.1 percent of direct GHG emissions), as well as mining, waste management, and seafood processing plants, which altogether account for 7.7 percent of direct GHG emissions.

2.3 Climate Change Effects on Alaska EFH

This section summarizes the connection between accumulating GHG emissions in the atmosphere, how those emissions influence atmospheric and oceanic ecosystem processes, and how those changes influence marine, estuarine and riverine EFH, and subsequently fish. To understand the changing conditions across Alaska, we need to consider changes in the Arctic. The Arctic is warming faster than any other region globally, a trend identified as Arctic Amplification (Cohen et al. 2020, Rantanen et al. 2022). Evidence indicates climate related changes in the Arctic, specifically a reduction in the sea ice extent (SIE), are driving all other atmospheric and oceanic changes we observe across the northern hemisphere and Alaska (Taylor et al. 2018, Cohen et al. 2020). Similarly, changing precipitation patterns, increasing seasonal temperatures, melting glaciers, and degrading permafrost is altering flow patterns, changing water chemistry, and warming river systems, which affects marine, estuarine, and riverine EFH (Tank et al. 2020, Kreplin et al. 2021). Therefore, changes to the Arctic and sub-Arctic landscape are included in this section because thawing permafrost, changing water chemistry, and warming river systems.

2.3.1 Arctic

The leading indicators of climate change effects in the Arctic are surface air temperature (SAT), sea surface temperature (SST), and SIE. The initial source and measure of change is the increasing SAT (Overland et al. 2019, Overland and Wang 2019, Richter-Menge et al. 2020), which was historically lower (colder). As the Arctic's average SAT increases, the Arctic ice pack increasingly thaws, becoming thinner, covering less surface area, reducing SIE. As sea ice cover decreases, more solar radiation is absorbed by the ocean, increasing the oceans temperature thus melting more sea ice. Declining SIE increases the Arctic Oceans exposure to the sun's energy further increasing SST. This relationship between SAT, SST, and SIE has been termed the ice-albedo feedback mechanism (Hall 2004, Flanner et al. 2011). As a result, late winter warmer SSTs and increased heat storage further delay fall and winter freeze-up. This annually repeating and escalating cycle of warming seas and diminishing ice has become an inherently expanding and self-generating cycle directly responsible for the reduction in the area, volume and extent of sea ice across the Arctic and subarctic environment (Overland 2020, Thoman et al. 2020).

Other factors such as reduced cloud cover, upper-ocean optic absorption and stratification are also influencing increasing temperatures in the Arctic (Timmermans and Labe 2020). Across watersheds, thawing permafrost is altering ground and surface water regimes and water chemistry (Tank et al. 2020, Beel et al. 2021, Kreplin et al. 2021, Swanson et al. 2021). Increased volumes of warmer river discharge introduce additional sources of heat to marine Arctic and sub-Arctic EFH (Park et al. 2020, Terhaar et al. 2021). Increased volumes of out-welling terrestrial detritus and nutrients once recognized as contributing to nearshore food chains

[12] International Energy Agency (IEA). Website last accessed on April 4, 2022.

and habitat substrate complexity may now also be accelerating carbon deposition in marine systems (Holmes et al. 2012, Jung et al. 2021). Increases in GHG emissions and continued loss of sea ice is driving changes in weather patterns across Alaska (Walsh et al. 2020, Yu et al. 2020). These changes in the Arctic have both direct and indirect cumulative impacts to EFH and fish in the Arctic and throughout Alaska (Mueter and Litzow 2008, Lannuzel et al. 2020, Mueter et al. 2021). For example, declining SIE is related to a northward shift in primary productivity, with decreasing production in the Bering Sea and increased production in the Arctic shelf (Jin et al. 2012). Reduced SIE is affecting the quality of habitat and availability of nutrients such that species migration patterns, spawning, and distributions are changing (e.g., Carothers et al. 2019, TenBrink 2022).

Historically, winter organic nutrients in seawater were frozen in sea ice. Under the influence of expansion and ocean circulation (e.g. increasing winter density in normal seasons and Coriolis effect), Arctic sea ice organizes and accretes migrating south through the Bering Strait in late winter and early spring (Werner et al. 2007, Hopsch et al. 2012, Wadhams 2019). Arctic sea ice routinely extended well into the EBS as far south as Bristol Bay and the Alaska Peninsula (Walsh and Chapman 2016, Walsh et al. 2017).

As sea ice melts in the spring it releases large volumes of ice algae and nutrient fueling plankton blooms. At the same time several, larval- and juvenile-stage invertebrate and fish species are seasonally present to take advantage of the food source (Grebmeier 2012, Coyle and Gibson 2017, Eisner et al. 2020). In cold years, when sea ice is at its greatest extent, the ice-associated algal bloom provides abundant volumes of lipid-rich zooplankton for fish, which supports rapid growth, higher lipid content and energy conditions. Unconsumed and un-grazed sea ice algae sink to the bottom, contributing to the benthic food chains or later recycled to shelf systems through upwelling (Grebmeier and McRoy 1989, Piepenburg 2005, Hirawake and Hunt 2020). This situation supports EFH attributes for productive habitats. However, under decreased sea ice extent in warm years the opposite occurs. The bloom provides lipid-poor zooplankton resulting in lower growth, lipid content, energy conditions, and lower survival of fish (Heintz et al. 2013, Duffy-Anderson et al. 2019, Hunt Jr et al. 2022). EFH attributes, particularly nutrient availability, are unable to support productive fisheries. The later scenario was well documented and led to a reduced commercial pollock harvest in 2007 (Ianelli et al. 2006, 2007, Hunt et al. 2011).

2.3.2 Bering Sea

Changing climate patterns are altering ecosystem processes and ocean conditions, influencing EFH attributes. Measurable change is observed in trophic dynamics, species recruitment and abundance, and the physical condition of fish and invertebrates across the Bering Sea (Duffy-Anderson et al. 2019, Eisner 2020, Fedewa et al. 2020, Hunt et al. 2020, Huntington et al. 2020, Kikuchi et al. 2020, Nishio et al. 2020, Siddon et al. 2020, Yasumiishi et al. 2020). Earliest observations indicate that large-scale ecological ‘‘regime shifts’’ have occurred in the Bering Sea during 1976–77, 1988–89, and 1998, affecting the abundance of coexisting species from primary producers to apex predators (Stockwell et al. 2001, Benson and Trites 2002, Hunt et al. 2002a, Hunt et al. 2002b). More recently, the climate regime in the Bering Sea has shifted further from one of high inter-annual variability, with a series of warm and cold years alternating, to a multi-year pattern consisting of two prolonged warm periods (2002–2005, 2014–2017) with a cold period (2006–2013) in between. This is followed by the most recent and unprecedented warmer period 2017-2019 (Stabeno et al. 2012, Stevenson and Lauth 2012, Box et al. 2019). Those earlier climate driven events present evidence of a regime shift in the Bering Sea (Grebmeier et al. 2006). The emergence and increasing frequency of these novel climate patterns may be forcing long-term changes in habitat quality and the spatial distributions of the Bering Sea's marine fauna (Stevenson and Lauth 2019, Nishio et al. 2020).

The most recent Arctic and subarctic warming event (2017-2019) is not only projected to occur more often but may continue to alter any previously understood patterns in annual SSTs, sea-ice algae, trophic dynamics, and cold pool patterns. The ecological impacts of late sea-ice cover in 2017 was not fully understood. The very early retreat of sea ice in winter and spring of 2018, and the near complete absence in 2019, resulted in the significant reduction in ice algae, ice edge bloom, and a delay of the larger offshore spring bloom (Duffy-Anderson et al. 2019, Kikuchi et al. 2020). These findings suggest the small magnitude and short pulse of the phytoplankton bloom in 2018 may have failed to transfer production and energy to a higher trophic level even within the planktonic food web (Yasumiishi et al. 2020). Additionally, the subsequent retreat of the cold pool has allowed a dramatic northward shift in marine ecosystem processes, species composition, and distribution of marine communities in the northern Bering Sea and southern Chukchi Sea (Stevenson and Lauth 2019, Waga et al. 2019, Nishio et al. 2020, Spies et al. 2020). Unusual mass mortality events of several marine species and harmful algal blooms of 2019 was likely a continuation if not an amplification of the 2018 events (Duffy-Anderson et al. 2019, Logerwell et al. 2020, Siddon et al. 2020).

2.3.3 Gulf of Alaska

Habitat changes are occurring with increasing frequency and intensity of unusually persistent warm events in the GOA (Laurel and Rogers 2020, Laurel et al. 2021b). Notably, two highly amplified atmospheric patterns (the "Ridiculously Resilient Ridge" and the “Warm Blob”) deflected the historic Pacific storm track further north and west of its seasonal mean position (Litzow et al. 2020a, Litzow et al. 2020b, Phillips and O'Neill 2020). Subsequently, these novel climate patterns decreased oceanic mixing and generated unseasonably warm waters at depth, which destabilized long established ichthyoplankton, forage fish, and groundfish communities (Hinckley et al. 2019, von Biela et al. 2019, Arimitsu et al. 2021, Laurel et al. 2021a, Nielsen et al. 2021). The recent declines of GOA Pacific cod (*Gadus microcephalus*) and walleye pollock (*G. chalcogrammus*) clearly demonstrate how changing ecosystem processes affect EFH in the form of habitat conditions that alter trophic dynamics, reduce survival of larval and young-of-year life history stages, and reduce recruitment and adult abundance (Barbeaux et al. 2020, Cheung and Frölicher 2020, Rogers et al. 2020). Based on projected increases in frequency and duration of marine heatwaves, researchers are uncertain when or if the GOA ecosystem will return to pre-Pacific marine heatwave conditions (Cheung and Frölicher 2020, Suryan et al. 2021). Modeling studies that considered end-of-century ocean conditions in the EBS showed Pacific cod and walleye pollock fisheries collapsing in greater than 35 percent and greater than 70 percent of all simulations, respectively (Holsman et al. 2020, Arimitsu et al. 2021). Modeling indicates that EBFM could be used as a tool to delay fisheries collapse but ultimately could not overcome the adverse effects to EFH posed by anthropogenic climate change.

2.3.4 Riverine

River systems experience stress from numerous anthropogenic sources, many of which are compounded under a changing climate (Best 2018). Climate effects on riverine systems include declining levels of winter snowfall, increasing summer air temperatures, and increasing precipitation levels (Bintanja 2018, Beel et al. 2021); the dramatic pace of glacial melt (Roe et al. 2021); and increasing permafrost degradation (Douglas et al. 2020, Douglas et al. 2021). These combined climate change effects are also altering the aquatic function and role of EFH attributes (Bieniek et al. 2018, Walsh et al. 2020, Mekonnen et al. 2021). For example, temperatures observed in 2019 caused heat stress in freshwater phase salmon affecting productivity and instigating pre-spawning mass mortality events (Jones et al. 2020, Shaftel et al. 2020, von Biela et al. 2020, Westley 2020). Increasing summer temperatures and precipitation levels in the Arctic and subarctic regions, with associated implications for EFH, are projected to continue and increase in the future (IPCC 2021, Legg 2021).

This combination of climate change-related effects are altering historic hydrologic regimes. Changes to hydrologic regimes at the watershed scale influence trophic dynamics in receiving nearshore and coastal waters in ways not entirely understood or predicted (Bidlack et al. 2021, Edwards et al. 2021). Thawing permafrost and receding glaciers have measurably shifted river discharge from the Yukon River to the Copper River watershed, shifting discharge from the Bering Sea to the GOA (Headley 2017, Milner et al. 2017, Shugar et al. 2017). It remains highly uncertain how these changes in water quality and quantity, and additional discharges of increasingly warm, will impact EFH.

Likewise, the current rate of permafrost degradation across Alaska is changing EFH attributes across watersheds, streams and rivers. Long-term measurements of the seasonally thawed "active layer" across central Alaska have identified an increase in permafrost degradation that is projected to continue and accelerate in coming decades (Douglas et al. 2020, Douglas et al. 2021). This degradation is measured across Alaska's surface by monitoring the simultaneous expansion of terrestrial vegetation boundaries using satellite thermal imagery (Quinton et al. 2011, Jorgenson et al. 2020). Permafrost degradation is a source of microbial and biochemical shifts across landscapes, influencing large scale changes in ecosystem processes that directly affect EFH attributes in aquatic systems (Schuur et al. 2015, Vonk et al. 2015, Colombo et al. 2018, Messan et al. 2020). Permafrost thaw is increasing transport of liberated elements and metals into surface waters (Olson and Lang 2020). Seasonal release and mobilization of trace heavy metals has always occurred in very limited quantities in Alaska, however thawing permafrost is now recognized as the source of elevated heavy metal concentrations in many areas (Barker et al. 2019, Perryman et al. 2020a, Perryman et al. 2020b). Seasonal river flow patterns are changing, with more base flow and earlier freshets (Walvoord and Kurylyk 2016, Zheng et al. 2019). These changing riverine characteristics affect the EFH attributes supporting anadromous fish, such as Pacific salmon, and their successful migration, spawning, and rearing.

2.4 Considering Climate Change Effects in EFH Assessments

Potential adverse effects of climate change on EFH and living marine resources can be assessed as part of the effects analysis for a proposed action, including cumulative and synergistic effects, and changes in the current and future states of the environment (Johnson et al. 2019). Johnson et al. (2019) provides guidance for integrating climate change information into the EFH consultation process. Climate-related effects should be included in an EFH assessment if the best available information indicates climate change may cause the action to have an adverse effect, or exacerbate the adverse effect of the action. The EFH assessment should include climate change-related projections and assessments of effects to habitats and species in the project area, to the extent practicable.

NOAA's National Mitigation Policy directs the agency to consider climate change and climate resilience when evaluating and developing mitigation measures[13]. The effects of climate change (e.g., SST, ocean acidification, changes in species range) may influence the effectiveness and resilience of CRs and mitigation approaches on a wide range of non-fishing actions. Such activities include, among others, hydropower, mining, dredging, and culvert and bridge design.

2.5 Climate Change Effects Assessment Criterion

Resource managers can use the following criterion for determining the potential climate change effect of an action and for developing CRs (Johnson et al. 2019). Conservation measures resulting from this assessment process are options to avoid and minimize adverse effects of climate change to EFH.

Criterion 1: Are species or habitats adversely affected by the action due to projected changes in the climate?

Assessing exposures and sensitivities of species and habitats to changes in climate and an action will require at least a modest level of climate change analyses to make a determination. Climate vulnerability can be interpreted as a combination of exposure to climate variables that have potential effects on the species and habitats (e.g., changes in temperature or pH), the sensitivity of the species and habitats to the climate variables (e.g., intrinsic resilience to changes in temperature or pH), and the adaptive capacity to accommodate or cope with the change with minimal disruption (Glick et al. 2011, Spencer et al. 2019).

Criterion 2: Is the expected lifespan of the action greater than 10 years?

The expected lifespan of an action is important in the context of climate change because the effects of an action must be relevant within a period of time that future climate change signals can be identified.

For example, a large-scale project with extended lifespans, such as power plants or hydropower dams, may have an operating license granted by the regulatory agency for 30 years or more. Furthermore, Federal regulations permit licensees to initiate the relicensing process several years prior to the expiration of an existing license. For these time scales, past and current climate variability is unlikely to adequately describe the environmental baseline or future conditions of an action. Assessing the effects of an action with lifespans of multiple decades will require the use of more detailed climate change analyses, including model projections for temperature, sea level rise, and other climate variables that may be appropriate. Existing climate data such as precipitation and storm events, should be evaluated for stationarity. Climate change analyses for these time scales may require modeling of both project operations and climate change (e.g., precipitation-runoff hydrologic modeling for hydropower dams).

[13] NOAA's Mitigation Policy for Trust Resources. Website last accessed December 12, 2022. https://www.noaa.gov/organization/administration/noaa-administrative-orders-chapter-216-program-management/nao-216-123-noaa-mitigation-policy-for-trust-resources

Criterion 3: Is climate change currently affecting vulnerable species or habitats and would climate change amplify the effects of a proposed action?

Short-term actions (i.e., less than 10 years) may also result in adverse effects to species or habitats if historic changes in the climate patterns (i.e., those observed during the past 50 years) are not considered in the context of the proposed action. Existing precipitation, temperature, storm event patterns should be evaluated trends shifting away from stationarity. Elevated precipitation, increased intensity of storm events and river flooding, and ocean warming events (e.g., GOA marine heatwaves), should be included in the range of climate conditions expected in the near future and the analysis of effects to EFH.

Criteria 4: Do the results of the assessment indicate climate change will amplify the effects of the action on habitats and species?

At least two possible future climate scenarios should be used, such as the IPCC Representative Concentration Pathway RCP8.5 or Shared Socioeconomic Pathway SSP5-8.5, to support a quantitative climate change assessment of future effects to EFH (IPCC 2021, Legg 2021, Masson-Delmotte et al. 2021).

Criterion 5: Can adaptive management strategies be integrated into the action to avoid or minimize climate change-related adverse effects of the proposed action?

This criterion evaluates whether an action can be modified during the life of the project or constructed in a manner that provides resiliency to the effects of climate change. Adaptive management strategies are alternatives to avoid or minimize the potential additive/cumulative effects of climate change and the action. The potential for integrating adaptive management strategies is an important exercise to evaluate project designs or operational alternatives to avoid or minimize adverse effects from a project caused by climate change.

Examples of adaptive management recommendations include:

- Hydropower licenses should include fish passage requirements that condition base flow rates and generation to future changes in water levels due to temperature or precipitation patterns.
- The design of bridge structures and culverts should account for projected hydrologic conditions, not strictly historic flows.

2.6 Conservation Recommendations for Large Emissions Facilities

An adverse effect to EFH is defined in the EFH Final Rule as “any direct or indirect effect that reduces the quality and/or quantity of the habitat.” In the context of this definition, changes in water quality and quantity driven by anthropogenic GHG emissions constitute adverse effects to EFH in Alaska. Greenhouse gas emissions from fossil fuel and industrial processes has led to increases in the concentration of atmospheric greenhouse gases (Legg 2021). This in turn drives changes ecosystem processes that result in changes in water quantity and quality that adversely affect EFH and living marine resources (Legg 2021). Therefore, we focus EFH CRs that support best management practices (BMP) for methane emissions reductions from the oil and gas sector. Across all large emissions sectors in Alaska, including mining projects, waste management, and seafood processing plants, projects should identify and assess possible measures to reduce operations-associated emissions.

The following CRs are potential actions to avoid and minimize methane emissions associated with oil and gas large facilities operations. Reducing methane emissions will promote EFH conservation. Oil and gas facilities should adopt BMPs to reduce operations-associated methane emissions. Such practices may cover a range of facility operations, including measures listed below (UNEP and CCAC 2021).

- Implement or expand upstream and downstream leak detection and repair campaigns.
- Conduct regular inspections of sites using instruments to detect leaks and emissions.
- Recover and utilize vented gas.
- Replace or upgrade high-emitting devices.
- Install flares to burn vented gas.
- Reduce unintended venting in new and existing assets.
- Cap unused wells.

Chapter 3 Watersheds

3.1 Introduction to Watersheds

Watersheds are abundant throughout Alaska. Surface waters and groundwater aquifers connect the major landscape features within watersheds, including wetlands and forests. The ecosystem processes and functions provided by watersheds are integral components of salmon EFH, ultimately supporting sustainable fisheries. Wetlands typically occur in topographic settings where surface water collects or groundwater discharges, making the area wet for extended periods of time (Tiner et al. 2002). Wetlands also exist within and between aquatic and forest habitats (Welsch et al. 1995). Wetland and forest complexes are hydrologically connected or confined (disconnected) to other ground or surface waters (Naiman et al. 2002, Furniss et al. 2010). Connected watersheds (open waters in riparian areas and floodplains) have both bidirectional and unidirectional hydrologic exchanges with riverine systems. Bidirectional flows (i.e., from wetlands or forest to streams and rivers and vice versa) occur through the lateral movement of surface water and groundwater between the channel and riparian or floodplain areas. In contrast, unidirectional flows (i.e., from wetlands to rivers and streams but not vice versa) occur in up-gradient areas (e.g., hillslopes and nearby uplands) outside the floodplains (ADEC 2015). Confined wetlands (e.g., isolated wetlands in basins, broad flats, or slopes) have the potential for only unidirectional hydrologic flows from wetlands to the river network through precipitation or flooding events but have no groundwater connection or influence (EPA 2015).

Streams, rivers, and lakes are all essential components of complex watershed ecosystems. The majority of Alaska's water resources are generally pristine due to Alaska's remoteness and sparse population. It has the fewest impaired water bodies and its unimpaired water bodies outnumber every other state in the country (ADEC 2015). Complex geomorphology, regional climate and seasonal weather patterns, and terrestrial vegetation at enormous spatial and temporal scales influence Alaska's vast watersheds. Three-dimensional subsurface groundwater regimes also influence flowing surface waters. Groundwater regimes support surface waters providing the foundation for habitat complexity, instream flow, biochemical processes, ecosystem function, and abundant fish. Surface and groundwater ecosystems are connected and viewed as linked components of a hydrological continuum (Sophocleous 2002). These hydrologic processes provide the foundation for salmon EFH, associated biogeochemical processes, and support sustainable fisheries.

3.2 Alaska Metrics

Alaska's freshwater ecosystems range from the temperate coastal rainforest of the southeast region with maritime climate and dense riparian vegetation, to the boreal forest of interior Alaska with continental climate and modest riparian vegetation, and the Arctic tundra of the North Slope with permafrost wetlands and sparse riparian vegetation (ADFG 2006).

3.2.1 Freshwater Wetlands

Snowmelt and rainfall saturate the Alaskan landscape, forming extensive freshwater wetland areas ranging from lowlands and depressions to hillsides and slopes (Hall et al. 1994). Alaska's wetlands occupy approximately 43 percent or 690,000 km^2 (266,410 mi^2) of the state's 1.7 million km^2 (663,267 mi^2) surface area (Dahl 1990). The majority of Alaska's wetlands are in the interior, Arctic, and western regions of the state. Only 42 percent of Alaska's wetlands are mapped (USFWS 2013).

Figure 1. Denslow Lake, Chuitna watershed. Photo provided by Matt Lacroix.

Alaskan wetland ecosystem types vary considerably across geographic regions and climate zones. Treeless expanses of damp and wet tundra underlain by permafrost occur in most of the Arctic and northwestern portions of Alaska, while the interior region contains millions of acres of black spruce (*Picea mariana*), muskeg, and floodplain wetlands dominated by deciduous shrubs and emergents. At least two-thirds of Alaska's wetlands are palustrine scrub, shrub, and herbaceous bogs (Hall et al. 1994). Lowland wetlands are also abundant in the valleys and basins associated with large river systems such as the Yukon, Kuskokwim, Porcupine, Tanana, and Koyukuk (Hall et al. 1994).

Predominant freshwater wetland types include bogs and grass and sedge wetlands. Bog habitats that include shrub-bog and forested-bog types occur throughout Alaska. Spongy peat deposits, tannic acidic waters, and an overlying vegetative layer of thick sphagnum moss (*Sphagnum* sp.) characterize shrub-bogs. Conifers and shrubs are the most abundant woody plants found in forested-bog habitats (Bisbing et al. 2016). Alaska's grass wetland communities are classified as mesic graminoid herbaceous, which are dominated by water-tolerant grass species that occur in clumps or tussocks. Tall sedges, cottonwood grasses, rushes, or bulrushes dominate sedge wetlands. These wetlands occur in very wet areas of floodplains; in the slow-flowing margins of ponds, lakes, streams, and sloughs; and in depressions of upland areas (Viereck et al. 1992, Walker et al. 2009).

3.2.2 Forests

Alaska has extensive forest coverage, with an estimated 485,623 hectares (120 million acres) of forested land (ADFG 2006). The majority of this forested area consists of boreal forest, or taiga. Found in the State's interior, the boreal forest extends from southcentral Alaska to the southern extent of the Brooks Range (Viereck et al. 1992). The boreal forest is underlain in different regions by discontinuous or continuous permafrost, and is constrained by a short growing season and long periods of snow cover (Gauthier et al. 2015). Dominant tree species include white (*P. glauca*) and black spruce (Viereck et al. 1992).

Forests along the coasts of southcentral and Southeast Alaska are primarily temperate rainforest ecosystems (Barrett and Christensen 2011). The coastal temperate rainforest extends from southcentral Alaska along the coast through southeast Alaska, and forms part of the larger Pacific coastal temperate rainforest. Steep watersheds as well as the mildest winters and highest average annual precipitation in the State characterize the terrain (Shanley et al. 2015, Winfree et al. 2018). Western hemlock (*Tsuga heterophylla*) and Sitka spruce (*P. sitchensis*) are dominant tree species (ADFG 2006).

3.2.3 Rivers, Lakes, and Icefields

Alaska includes 44,659 km^2 (17,243 mi^2) of inland waterways which consist of 12,000 rivers, thousands of streams and creeks, over three million lakes greater than 2 hectares and an estimated 27,000 glaciers covering five percent of the state (Markon et al. 2012, O'Neel et al. 2019). Icefields, alpine glaciers, and glacial rivers and streams connect many interior watersheds to Alaska's estuaries and marine ecosystems (ADFG 2006). Alaska Statute 16.05.871(a) requires ADFG to identify rivers, lakes, and streams, or parts of those waterbodies important for spawning, rearing, or migration of anadromous fishes, including all five species of Pacific salmon. Alaska has over 20,000 lakes, rivers or streams identified as important habitats for anadromous fish (Giefer and Graziano 2022a-f). This includes approximately 563,270 km (350,000 mi) of primary rivers; however, the majority of smaller headwaters streams remain unmapped (ADFG 2016). Thousands of km of headwater streams that are important EFH for emerging and rearing salmon are not cataloged or documented in the *Anadromous Waters Catalog* (Giefer and Graziano 2022a-f). For example, fish surveys recently conducted by the Southwest Salmon Habitat Partnership, in areas not previously surveyed (Nushagak and Kvichak River drainages) documented salmon in the majority of headwater streams (Woody and O'Neal 2010). Of the 168 km (104.3 mi) of headwater streams surveyed, anadromous salmon were present and documented in 74 percent of headwater tributaries.

Alaska's regional watersheds extend from the interior of the state to the Arctic, northwest, and southern coasts. Thousands of rivers and streams enter the GOA from southcentral to southeastern Alaska, while numerous rivers and streams enter the Bering Sea from western Alaska and the Alaskan Peninsula. The Yukon River drains a watershed of over 855,000 km^2 (330,117 mi^2) and flows for 3,187 km (1,980 mi) from its headwaters in Canada to the northern Bering Sea (NMFS 2015). Other large salmon rivers include the Copper, Kenai, Nushagak, Kuskokwim, Stikine, and Taku Rivers. The Arctic region is crossed by many northward flowing streams and contains continuous permafrost, tundra, and numerous small lakes and ponds (NMFS 2015). Lake Iliamna is Alaska's largest lake encompassing an area of approximately 2,590 km^2 (1,000 mi^2). Other large lakes include Clark, Becharof, Naknek, Ugashik, Teshekpuk, Tustumena, Kenai, and Wood-Tikchik (Augerot 2005).

Icefields are large masses of snow and ice from which glaciers flow. The Juneau Icefield is one of the world's largest non-polar icefields, stretching between Juneau and Skagway, Alaska, and is the source of 40 notable valley glaciers. Alaska's largest glacier is the Bering Glacier, measuring nearly 1,295 km^2 (500 mi^2), and when combined with the Begley Icefield, which feeds it, measures 4,921 km^2 (1,900 mi^2). These glaciers, and those from other Alaska icefields, feed and influence nearly all major riverine systems in Alaska (ADFG 2006). New freshwater habitats form through glacial retreat and nutrients from the glacial meltwater become available to the freshwater streams as well as downstream estuarine and marine habitats (Pitman et al. 2020).

3.3 Physical, Chemical, and Biological Processes

The MSA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity" (16 U.S.C. 1802(10)). EFH not only includes visible surface water and hard substrate but also ecosystem processes that provide water quality, quantity, and nutrient resources essential for survival. The following discussion provides an overview of the physical, chemical, and biological processes related to wetlands, forests, and rivers that support EFH.

3.3.1 Wetland Processes

Ecosystem functions and biochemical processes in Alaska's wetlands vary widely depending on regional climate patterns, topography, geology, hydrology, and vegetation (King et al. 2012, Walker et al. 2012, Harms et al. 2016, Callahan et al. 2017, Whigham et al. 2017). Recent studies conducted in Alaska indicate wetland processes increase biological productivity and support fish and EFH. These processes regulate water quality and provide refuge to dependent aquatic species (Wipfli et al. 2007, Whigham et al. 2012). Decomposed plant matter and detritus form the foundation of nutrient sources and trophic dynamics for many species of freshwater invertebrates and fish (Shaftel et al. 2011, Dekar et al. 2012, Whigham et al. 2012). Wetlands facilitate natural biochemical processes and provide the foundation for several EFH attributes throughout watersheds.

Generally, wetlands regulate surface and groundwater recharge and discharge, maintain water balance, and maintain instream flow (Carter 1996, Bullock and Acreman 2003). Many wetlands primarily serve as discharge areas releasing water to tributaries. Wetlands provide temporary storage of water, which decreases runoff velocity, reduces flood peaks, and distributes storm flows over an extended period. This natural water-level mitigation reduces instream erosion and scour of streambeds. Wetlands improve water quality by effectively sequestering, filtering, and removing suspended sediments, heavy metals, and pesticides. Through these natural processes, wetlands convert anthropogenic constituents into useful and beneficial organic forms (Carter 1996, Callahan et al. 2015). Finally, wetlands provide habitats, including breeding and nesting grounds, for a variety of fish and wildlife species.

3.3.2 Forest Processes

Riparian forests are three-dimensional ecotones, or regions of transition between two biological communities. They include interactions between terrestrial and aquatic components, and provide decomposition and recomposition of flora and fauna. Riparian forest ecotones extend vertically down into groundwater regimes and above the ground surface into the canopy, as well as horizontally across floodplains and the broader terrestrial landscape (Everest and Reeves 2007). Similar to wetlands, a number of forest processes shape and enhance EFH and contribute nutrients to aquatic food chains. Riparian forests affect the physical properties of instream fish habitat: shade that regulates water temperature, large woody debris (LWD) that promotes lateral channel meanders and creates pools and riffles, while supporting bank stabilization (Everest and Reeves 2007, Dekar et al. 2012).

Forest vegetation influences stream water chemistry by supplying large volumes of organic matter, modifying water movement, and stabilizing soils (Dosskey et al. 2010). Leaf litter fuels primary and secondary production and aquatic trophic dynamics (Everest and Reeves 2007). Forests play a critical role in nutrient cycling between terrestrial and aquatic habitats. Nutrient retention, especially through regulation of denitrification and organic input from dead plant material, directly influences the food availability and growth rates of fish in both main channel and floodplain habitats (ADFG 2006).

Additionally, forest ecosystems serve as an important food source for juvenile salmon rearing in freshwater bodies, since aquatic and terrestrial invertebrates that thrive in woodland watersheds comprise a substantial fraction of the diet for these fish (Broadmeadow and Nisbet 2004, Dekar et al. 2012). The diversity and density of aquatic invertebrates are higher in lakes and streams surrounded by abundant forested areas (ADFG 2006). Terrestrial invertebrate diversity is important to the riverine trophic structure. Terrestrial invertebrates comprise as much as 44 percent of fish energy budgets through the prey flux between forest and stream habitats (Nakano and Murakami 2001).

3.3.3 River Processes

Rivers are instream EFH for anadromous Pacific salmon, providing migratory corridors for inbound adults and outbound juveniles, spawning and rearing substrates, protection from winter conditions as embryos in gravel substrates, and nutrients and prey during spring emergence and rearing (Scheuerell et al. 2007). Salmon require cool waters in sufficient quantities to allow for successful migration and spawning. Relevant geomorphic stream characteristics include channel width, depth and slope, substrate composition and complexity, and pool and riffle sequences. Organic inputs come from canopy leaf litters and riparian grasses that provide nutrient subsidies. LWD provides shelter, nutrients, and geomorphic complexity (Scheuerell et al. 2007). Salmon provide nutrient subsidies to watersheds, aquatic and terrestrial species of flora and fauna, and their own progeny. These biochemical and geomorphic influences are the ecosystem processes within watersheds that directly influence the sustainability of salmon populations at numerous life history stages (Boulton et al. 1998, Gende et al. 2004).

3.3.3.1 Hyporheic Zone

The hyporheic zone is the ecotone between surface water and groundwater beneath and alongside rivers and streams (Stanford and Ward 1988, 1993, Brunke and Gonser 1997, Bolton and Monohan 2001). It is the gravel substrate where adult salmon deposit eggs and the salmon embryos develop over the winter. The condition of that substrate and the water moving through that substrate has an integral role in embryo development and over winter survival. Hyporheic zones are characterized in three major types: wetted channel, parafluvial, and floodplain scale (Naiman et al. 2000). Interactions within these hydrologic regimes are based on geology and riverine topography are often temporal in response to instream flows and seasonal influences (Naiman et al. 2000, Malcolm et al. 2004a, Youngson et al. 2004). The relative contribution of groundwater and surface water to this zone also varies based on local channel morphology, riparian-stream linkages, and hydrology. The hyporheic zone influences various watershed ecosystem processes such as nutrient cycling, vital gaseous exchange, thermal regimes, and even pollutant buffering (O'Keefe and Edwards 2002, Mulholland and Webster 2010).

Depending on the region, watershed, species, or even individual fish run, salmon eggs and embryos can be deposited in redds throughout summer and fall months (Schindler et al. 2010). The embryos reside in redds until the following spring when they emerge as fry. The hyporheic zone subsequently supports salmon egg and embryo survival and development through Alaska's often harsh winters under freezing conditions (Cunjak and Power 1986, Cunjak 1988, 1996). In Japan, Urabe et al. (2014) reported that channel morphology via hyporheic flow was a significant determinant in maintaining population diversity in chum salmon. Salmon spawning activity is usually observed in gravel substrate with favorable hydraulic properties, water gradients and associated temperature (Geist et al. 2002, Malcolm et al. 2005).

3.3.3.2 Headwater Streams

The watershed network can be partitioned into headwater and network systems based on hydrologic (e.g., precipitation, heat dynamics), geomorphic (e.g., channel reach type, woody debris), and biological (e.g., organic matter, energy input) process characteristics. These systems are important sources of sediments, water, nutrients, and organic matter for downstream reaches (Gomi et al. 2002). Four topographic units compose headwater streams:

1) Hillslopes (divergent or straight contour lines, typically no channelized flow;
2) Zero-order basins (an unchannelized hollow with convergent contour lines);
3) Transitional channels (temporary or ephemeral channels emerging from zero-order basins); and
4) First- (upper-most, unbranched channels with perennial or sustained intermittent flows) and second- (headwaters) stream channels.

The complex interaction of geomorphic and hydrologic processes affects the biological processes at various temporal and spatial scales. The frequency, intensity, and duration of these spatial-temporal scales are important factors altering the responses and recovery times of riparian vegetation, channel morphology, and biological communities (Gomi et al. 2002, Benton et al. 2008).

Figure 2. Wetland, pond, stream complex; headwaters upstream of the confluence of the North and South fork Koktuli River. Photo provided by Sarah O'Neal and Carrol Ann Woody.

Headwater streams provide habitat complexity, increased prey availability, and refuge from predation (Meyer et al. 2007, Whigham et al. 2012). In Alaska, headwater streams are abundant and can be an important spawning and rearing habitat for juvenile salmonids (Woody and O'Neal 2010, Copeland et al. 2014). Food webs in headwater reaches are reliant on terrestrial subsidies from invertebrates, riparian areas, and instream nutrients (Piccolo and Wipfli 2002, Wipfli and Gregovich 2002, Walker et al. 2012).

Not all Pacific salmon emerge from substrate and emigrate to the sea. Depending on the region, watershed, species, habitat conditions, and forage opportunities, some salmon species such as coho and Chinook, disperse into small streams to take advantage of rearing and prey opportunities (Ebersole et al. 2006, Copeland et al. 2014). Armstrong et al. (2013) recently documented the freshwater phase juvenile coho salmon moving considerable distances (350 to 1,300 m), up and down stream, daily, between warmer and colder water habitats to take advantage of abundant prey opportunities. Freshwater phase coho exhibiting these feeding migrations had accelerated metabolism and digestion, grew faster, and were better prepared for the marine phase. Suitable overwinter habitat for rearing juvenile salmonids forms by hyporheic water processes and components that create microhabitats, such as groundwater influence, high levels of dissolved oxygen, low-flow velocities, instream cover LWD, and anchor ice (Heifetz et al. 1986, Reynolds 1997, Brown et al. 2011, Adams et al. 2021).

3.3.3.3 Organic Matter

Organic matter, particularly dissolved organic matter (DOM), is an important source of nutrients for primary production in freshwater ecosystems. Organic matter is incorporated into stream ecosystems through autotrophic (macrophytes, periphyton, phytoplankton) and heterotrophic (protozoans, bacteria, macroinvertebrates, aquatic vertebrates) pathways. Heterotrophic organisms derive energy from DOM and fine and coarse particulate organic matter (POM). These organic inputs usually come from outside the aquatic ecosystem, primarily from needles and leaf litter, grasses and LWD (Vannote et al. 1980, Bisson and Bilby 1998). Adult salmon in anadromous watersheds also provide nutrients (see Section 3.3.3.4, Marine-Derived Nutrients). These organic matter sources provide the foundation for primary and secondary production in watersheds. Energy flows out of net production through shredding, grazing, and decomposition of POM and gradual excretion of DOM. Of these, the main energy flow from producers is through direct grazing of living tissues and detritus from external sources (Murphy 1998).

In diverse stream environments, benthic macroinvertebrates have an important influence on nutrient cycles, primary production, decomposition, and translocation of materials. Benthic invertebrates graze on periphyton from mineral and organic substrates and on decomposing vascular plant tissue. They also feed directly on living vascular macrophytes, decomposing wood, fine POM, and animal tissue, acting as filters to remove particulate matter from suspension (Mulholland 1992, Wallace and Jackson 1996). The linkages between flow parameters, resource availability, respiratory and thermal requirements, and biotic interactions (e.g., competition and predation) influence the structure and function of benthic stream ecosystems. Secondary production within these stream ecosystems includes a combination of features such as abundance, biomass, growth, reproduction, survivorship, and generation time (Wallace and Jackson 1996). Estimated production of macroinvertebrate prey and predators in first and second-order, low-gradient streams indicated that invertebrate predators represented 25 to 35 percent of macroinvertebrate production (Wallace and Jackson 1996, Wipfli and Gregovich 2002).

3.3.3.4 Marine-Derived Nutrients

Pacific salmon accumulate up to 99 percent of carbon, nitrogen, and phosphorus (among other nutrients) in their body mass during their ocean phase growth. The salmon spawning migrations transport large volumes of these marine-derived nutrients (MDN) back into watersheds. These nutrients cross ecosystem boundaries, providing nutrient subsidies to other aquatic species (invertebrates and fish) and terrestrial species (e.g., bears, wolves, and passerine birds) and fertilize a variety of riparian vegetation (Naiman et al. 2002, Gende et al. 2004, DeForest et al. 2011). MDN increases stream and river productivity immediately after spawning and during the following spring. These nutrient subsidies introduced during the summer and fall of one year persist in hyporheic substrates through the following year, providing nutrient sources to resident fish and invertebrate populations and increases prey abundance for emerging salmon fry the following spring (Bilby et al. 1998, O'Keefe and Edwards 2002, Hocking et al. 2009, Rinella et al. 2013). Salmon also distribute nutrients through other mechanisms, such as disturbing streambeds during redd excavation, thereby suspending nutrient-laden sediments into the water column (Moore 2006).

Salmon-based MDN influences food webs through bottom-up effects of increased primary and secondary production (Schindler et al. 2003, Verspoor et al. 2010, Verspoor et al. 2011) and when consumers switch their diets to salmon (Gende et al. 2007, Scheuerell et al. 2007, Swain and Reynolds 2015). The assimilation of MDN into riparian ecosystems via these pathways (e.g., hyporheic flow paths, epilithon layer) varies over time and among different areas (Mitchell and Lamberti 2005, Helfield and Naiman 2006, Cak et al. 2008, Albers 2010). MDNs in the riverine environment incorporate into a variety of biological pools including soil organic matter, vegetation, microbial biomass, and roots (Ben-David et al. 1998, Bilby et al. 2003, Bartz and Naiman 2005, Gende et al. 2007). Nutrients not immediately assimilated into watershed processes are transported downstream from headwater streams to estuaries and nearshore zones. Salmon smolts also transfer nutrients during their migration to the ocean (Scheuerell et al. 2005).

3.3.3.5 Riparian Zones

The riparian zone transitions from aquatic vegetation at the wetted edge to terrestrial vegetation of the upslope forest. The surrounding riparian vegetation influences stream processes like solar radiant exposure, supply and storage of organic matter (wood and litter) and the structure of stream banks (Richardson et al. 2010). Retention and routing of allochthonous organic matter (e.g., riparian and lateral input of leaf litter and LWD) are important factors affecting the biological processes in headwater streams (Gomi et al. 2002). Riparian zones connect to lotic systems (e.g., small headwater streams to large braided rivers) via the exchange of materials and organisms. Aquatic food webs derive energy from both instream and terrestrial sources (Vannote et al. 1980). Terrestrial subsidies (e.g., invertebrates, coniferous needles, deciduous leaves, and woody materials) act as basal resources for many aquatic organisms (Gutierrez 2011). For instance, terrestrial invertebrates are an important food source for salmon in headwater and small streams; they account for 50 percent of the prey consumed by juvenile salmon (Allan et al. 2003).

3.3.3.6 Hydrology

The hydrology and geology of freshwater ecosystems influence the physical and chemical characteristics of rivers and streams. For instance, ground strata and bedrock geology strongly affect the quality of surface water and groundwater (Brabets et al. 2000). Land cover influences a number of hydrologic factors such as snow accumulation, soil moisture depletion, surface runoff, infiltration, and erosion. These factors can affect stream or river water quality. The composition of vegetation may also affect water quality. In addition, land cover directly influences the permafrost because of the thermal properties that determine the quantity of heat entering and leaving the underlying ground where the permafrost occurs (Brabets et al. 2000). Streamflow quantity and variability also have considerable influence on the quality of surface water. The quantity of water in a stream or river influences its ability to support aquatic communities, to assimilate or dilute waste discharges, and to carry suspended sediment and geochemical weathering products (Brabets et al. 2000).

The presence of LWD significantly affects instream flow dynamics, shoreline and benthic deposition and erosion, and sediment transport in woodland river and stream ecosystems. The persistence of LWD influences channel dynamics by stabilizing banks and substrate material and by providing subsequent succession of riparian vegetation cover for terrestrial predators. LWD promotes the formation of pool habitat and provides spawning bed integrity for aquatic invertebrates, elevating instream productivity. LWD groundings often lead to the formation of downstream islands, bars, and slough habitats in large rivers, whereas in smaller streams, lakes, and ponds, LWD plays an important role in habitat creation immediately adjacent to the input point. Decaying terrestrial debris often accumulates near LWD, providing a food source for aquatic invertebrates and habitat for salmon through prey production (Naiman et al. 2000, Gurnell et al. 2002).

3.3.3.7 Surface and Groundwater Regimes

Surface water regimes support instream flow dynamics that supply the primary medium and energy source for the movement of water, sediment, organic material, nutrients, and thermal energy (Ziemer and Lisle 1998). Important hydrologic pathways include subsurface, overland, and Hortonian overland flows (tendency of water to flow horizontally across land surfaces when rainfall has exceeded infiltration and storage capacity). Subsurface flow accounts for nearly all the water delivered to stream channels from undisturbed forested hillslopes. In channels and floodplains, subsurface flow is important to benthic and hyporheic organisms. Surface water flows occur where the ground strata and soils become fully saturated, consequently forcing subsurface waters to emerge as flowing surface water regimes. Increased areas of Hortonian overland flow directly contribute to stream peak flows during storms in headwater channels and have a greater capacity to erode and transport sediment.

In contrast to hillslope runoff, stream flow pertains only to surface flow in the channel (Ziemer and Lisle 1998). Annual seasonal floods distribute sediment and organic debris through the stream system, scour the bed, and remove newly established vegetation in the active channel. These floods can cause mortality of certain benthic invertebrates, altering food webs that affect the trophic structure. Through erosion, scouring, and deposition, extreme floods can create new surfaces that renew dynamic processes of both aquatic and riparian ecosystems. Recessional spring and early summer flows, punctuated by peak flows, control the success of riparian plant seeds to germinate on stream banks and floodplains. Summer low flows allow the settlement of sediments, clearer water, and low-energy habitats to expand (Ziemer and Lisle 1998).

3.3.3.8 Channel Morphology

Stream channels are important avenues of sediment transport that deliver eroded material from freshwater ecosystems to the ocean. Channels ranging in size from small ephemeral streams to large rivers exhibit a wide variety of morphologies but share a number of basic processes (Montgomery and Buffington 1998). Channel morphology is influenced by variations in sediment input from upslope sources (frequency, volume, and size of sediment supply), the ability of the channel to transport these loads to downslope reaches (frequency, magnitude, duration of discharge, and gradient), and the effects of vegetation on channel processes (bank strength, in-channel size, rates of delivery or decay, and orientation or position). Deglaciation influences channel morphology in braided glacial streams, often signaling channel migration and flow changes within a braided plain (Curran et al. 2017). Potential channel adjustments to altered discharge and sediment load include changes in width, depth, velocity, bed slope, roughness, and sediment size (Montgomery et al. 1995, Montgomery and Buffington 1998). Spatial variability in sediment supply may govern channel morphology in different portions of a drainage network (Montgomery et al. 1995, Montgomery and Buffington 1998). Position within a stream network and difference between the transport capacity to sediment supply ratio allow segregation of channel reaches into source, transport, and response segments. Source segments are headwater colluvial channels that act as transport-limited sediment storage sites subject to intermittent debris flow scour. Transport segments are composed of morphologically resilient, supply-limited reaches (bedrock, cascade, and step-pool) that rapidly convey increased sediment inputs. Response segments consist of lower gradient, more transport-limited reaches (plain-bed, pool-riffle, and dune-ripple) in which significant morphological adjustments occur in response to the increased sediment supply. The distribution of these segment types defines watershed-scale patterns of sensitivity to altered discharge and sediment supply (Montgomery et al. 1995, Montgomery and Buffington 1998).

3.4 Anadromous Waters

Salmon are anadromous, meaning they migrate up rivers and streams from salt water to spawn. Because of this migration, salmon EFH is designated for both their marine and freshwater life history stages. All anadromous waters, meaning streams, lakes, ponds, wetlands, and other water bodies that are accessible to salmon, are considered part of salmon EFH (NPFMC 2021). This represents a wide and varied area and considers both streams and rivers that are currently used by salmon and those that had historical anadromous use. The *Anadromous Waters Catalog* is the tool used to identify salmon freshwater EFH areas. ADFG produces this catalog annually. This catalog identifies waters with species-specific observations of salmon use for presence, spawning, and/or rearing (Giefer and Graziano 2022a-f).

Figure 3. Salmon parr found during surveys of headwater tributaries in the upstream of the confluence of the North and South fork of the Koktuli River. Photo provided by Sarah O’Neal and Carrol Ann Woody.

Absent data, it is best to take a precautionary approach when determining if headwater tributaries in Alaska support anadromous salmon or not. For example, many upper reaches within watersheds south of the Brooks Range still require surveys and mapping to determine the seasonal presence or abundance of the five Pacific salmon species (ADFG 2006). This remains especially true of the smallest hard to reach headwater wetlands (Woody and O’Neal 2010). If there is no specific evidence of salmon in upper tributary reaches, there are likely natural barriers such as waterfalls, steep elevations or inadequate flows. Generally, watersheds draining toward the Arctic Ocean are less likely to support runs of salmon though occasional presence has been observed.

Each species of Pacific salmon known to inhabit Alaska watersheds migrate through and populate various habitat types seasonally depending on their life history stage and watershed of origin (Hilborn et al. 2003). Larger environmental cues as well as genetics also play a role in specific stock run timing (Hodgson and Quinn 2002, Hodgson et al. 2006, Schindler et al. 2010). Adult immigration and smolt emigration seasons should be considered when planning and implementing survey designs to inform selecting seasonal construction windows, construction methods, determining adequate fish passage design methods and seasonally determining minimal water levels for water management plans.

3.5 Sources of Potential Impacts and EFH Conservation Recommendations

This section presents an overview of EFH impacts from upland activities primarily associated with extraction, transportation and development activities. Also included is an evaluation of organic debris removal (Section 3.5.6, Organic Debris Removal), water use (Section 3.5.8, Freshwater Use and Inputs), and power generation (Section 3.5.9, Hydropower Projects and Section 3.5.10, In-River Hydrokinetic Energy Converter). In-river hydrokinetic energy converters (HEC) have different effects on fish and water compared with traditional hydropower facilities associated with dams and need separate consideration. Additional information about point source pollution impacts from domestic and industrial activities is available in Section 4.4.11(Point-Source Discharges).

3.5.1 Nonpoint Source Pollution

A nonpoint pollution source is any pollution source that does not meet the Clean Water Act (CWA) section 502 definition for point source pollution: "discernable, confined, and discrete conveyance… from which pollutants are or may be discharged." Several of the following subsections present an overview of EFH impacts from upland activities that produce primarily nonpoint source pollution and some point source pollution, including Sections 3.5.2 (Silviculture and Timber Harvest), 3.5.3 (Hardrock Mining), 3.5.4 (Sand, Gravel and Placer Mining), 3.5.5 (Roads and Transportation Corridors), and 3.5.7 (Urban and Suburban Development). Additional information about nonpoint source pollution impacts from flood control and shoreline protection activities is available in Section 4.4.7 (Flood Control and Shoreline Protection).

Nonpoint source pollution is considered the "greatest pollution threat" facing U.S. oceans and coasts and an important driver of aquatic habitat degradation (McCarthy et al. 2008). The severity of the threat of any specific pollutant to fish is affected by a number of factors, including concentration, exposure duration, and synergistic toxicity caused by the presence of other contaminants. These dynamics complicate efforts to understand nonpoint source pollution effects. Contaminant exposure from nonpoint source pollution is usually lower in intensity than an acute point source event but may be more damaging to fish habitat in the long term because of chronic health outcomes for affected fish (Bukola et al. 2015). Population impacts may be difficult to attribute to any one event or source and may be difficult to correct, clean up, or mitigate.

A classic example of a point source pollution is a discharge pipe from a factory or a sewage treatment plant. The definition of a point source sometimes expands to include an eroding section of road or the drainage from a parking lot. In evaluating adverse impacts from the sources in sections below, considerations of the effects of climate change may be appropriate.

Sections 2.3 (Climate Change Effects on Alaska EFH), 2.4 (Considering Climate Change Effects in EFH Assessments), and 2.5 (Climate Change Effects Assessment Criterion) provide discussion on integrating climate change information into the assessment of adverse effects and the development of CRs.

3.5.2 Silviculture and Timber Harvest

Revisions to federal and state timber harvest regulations in Alaska and BMPs have resulted in increased protection of EFH on federal, state, and private timberlands (USDA 2015). However, when BMPs are not fully implemented, timber harvest can have short- and long-term impacts to EFH. Additionally, timber harvests predating these new measures in Alaska were not conducted under the current protective standards and have degraded EFH in some watersheds. This section provides an overview of potential adverse impacts associated with timber harvest, followed by recommended measures to mitigate those impacts.

3.5.2.1 Potential Impacts

Five major silviculture activities are associated with adverse effects to EFH: (i) roads, (ii) culverts, (iii) vegetation removal, (iv) log transfer facilities (LTF), and (v) in-water log storage. Activities (i)-(iii) are described below. For more information on impacts associated with LTFs and in-water log storage, see Section 4.4.8 (Log Transfer Facilities and In-Water Log Storage).

(i) Roads

Improperly engineered, constructed, or maintained logging roads destabilize slopes and increase erosion and sedimentation to instream habitats. Roads are generally the major source of sediment to water bodies adjacent to harvested forestlands (EPA 2005). Two major types of erosion may occur: mass wasting and surface erosion. Road building on high-hazard soils and unstable slopes can directly or indirectly cause or exacerbate mass wasting, such as landslides, debris slides, slumps, earthflows, debris avalanches, and debris flows. Thus, accelerated erosion rates from roads may greatly exceed the natural rate in forested areas (Sidle et al. 1985). Erosion from roadways is most severe when construction practices do not include properly located, sized, and installed culverts or proper water control (Furniss et al. 1991). Eroded sediment delivery to downslope waterways reduces habitat quality and quantity for aquatic macroinvertebrates on which salmon feed, reduces the exchange of oxygenated water in spawning gravels, and decreases the survival time of salmon eggs and embryos (Murphy 1995). Although mass wasting potentially has the slightly positive effect of providing new sources of woody debris and gravel, it also negatively affects aquatic habitats by smothering eggs (USDA 2003).

(ii) Culverts

Perched, undersized, blocked, or deteriorated culverts adversely affect EFH. Perched culverts interrupt the streambed and create a physical barrier to fish passage. Undersized culverts can accelerate stream flows that act as velocity barriers for migrating fish. Blocked culverts resulting from undersized designs or inadequate debris maintenance can result in stream displacement from the downstream channel to the roadway or roadside ditch, resulting in dewatering of the downstream channel and increasing roadway erosion. Failure to replace or remove culverts at the end of their useful life may result in particle or full collapse of the structure, or reduced instream flow volume due to leakage through corroded portions of the culvert. The complete blockage or impediment to upstream and downstream fish migration can eliminate or reduce access to spawning sites, and promote habitat fragmentation (Daigle 2010, Maitland et al. 2016).

(iii) Vegetation Removal

Timber harvest activities that remove streamside vegetation increase the amount of solar radiation reaching the stream and can result in warmer instream temperatures, especially in small, shallow, and low velocity streams. Logging adjacent to streams can result in significant changes in maximum water temperature (Meehan 1969, Moore et al. 2005). Adverse effects to Pacific salmon from warm-water temperatures include delayed or blocked adult migration, increased adult mortality, reduced spawning success, reduced growth of alevins and juveniles, reduced competitive success relative to other fishes, reduced disease resistance, and potential magnification of other habitat stressors (Materna 2001, McCullough et al. 2001, Sauter et al. 2001). The removal of riparian vegetation can result in lower winter water temperatures and increase in ice formation, as well as damage and delay the development of incubating fish eggs and alevin.

In addition to altering instream temperatures, vegetation removal affects instream habitat attributes important to fish, including a reduction in the supply of LWD and increases in sediment deposition. LWD reductions reduce habitat complexity critical for successful salmonid spawning and rearing (Murphy and Koski 1989, Bisson and Bilby 1998). Sediment deposition in streams reduces benthic community production and can cause mortality of incubating salmon eggs and cap sediment impeding the emergence of alevins (Culp and Davies 1983, Heifetz et al. 1986). Cumulative sedimentation from logging activities significantly reduces the egg-to-fry survival of coho and chum salmon (Cederholm and Reid 1987). Section 3.3.2 (Forest Processes) provides more information about the habitat value of LWD.

3.5.2.2 Recommended Conservation Measures

Guidance for logging in Alaska includes the U.S. Forest Service (USFS) plans for the Tongass and Chugach National Forests and State of Alaska guidelines for timber harvest operations (USFS 2016, ADNR 2018, USFS 2020). The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of logging on EFH and to promote the conservation, enhancement, and proper function of EFH.

(i) Watershed Analysis

- Incorporate watershed analysis into timber and silviculture projects when possible (Nichols et al. 2013). Watershed analyses involve field-based site evaluations that include field inventory of all affected stream reaches to verify fish presence, stream classes, and channel types; consideration of cumulative effects of past, present, and future timber sales; and assessment of current condition. A watershed analysis can focus interdisciplinary discussions on key watershed resources, including fish habitat (USDA 2008).

(ii) Roads

- Incorporate erosion control and stabilization measures in project plans for all soil disturbances to prevent or minimize sedimentation and erosion of unstable soils.

- Engineer, construct, and maintain logging roads to reduce risk of landslides. Avoid locating roads and landings on a slope greater than 67 percent, on an unstable slope, or in slide-prone areas. Seed with a native seed mix, mulch, develop terraces, or combine treatments to control erosion after logging road construction.
- Avoid construction of roads across alluvial floodplains, mass wastage areas, and braided bottomlands.
- Locate roads to avoid fish streams. Stream crossings will be considered only when other locations are not feasible and fish habitat can be protected. Where roads are located near fish streams, avoid the introduction of sediment and debris during clearing, construction, and operation activities.
- Manage sediment runoff and discharge to streams. Restrict traffic on logging roads during the wet season and consider closing logging roads to manage sediment runoff.
- Excess excavation material should not be located adjacent to the stream course. Deposit all excess material in a suitable, stabilized upland site.
- Minimize ground cover disturbance between the road and the stream as practicable. Felling of trees should be away from all fish-bearing waters, standing waters, and other surface waters to prevent introducing debris.
- Incorporate aquatic organism passage design features at locations where roads or railroads cross fish streams[14].
- Specify permissible uses of heavy machinery and the timing of road construction activities.
- Design roads so that drainage structures intercept and carry runoff from the hillside and inside portions of a crowned road surface for forest roads using through-cuts or partial/full bench road construction.
- Install and space drainage structures as necessary to accommodate peak flows or to ensure adequate drainage of unstable soils. Slope drainage ditches along the roadbed to the nearest relief culvert. Discharge from road ditches should drain to filter on natural forest floor rather than flow directly into streams.
- Avoid the introduction or spread of invasive species during road construction, reconstruction, and maintenance.

(iii) Culverts

- Follow BMPs for the proper sizing and maintenance of culverts (USFWS 2022), which prohibit perched culverts and require sizing designed to allow for the passage of fish and significant flood events.
    - For more guidance on this topic, see Section 3.5.5 (Roads and Transportation Corridors).

[14] Culvert Design Guidelines for Ecological Function. Website Accessed last on April 1, 2022. https://www.fws.gov/alaska-culvert-design-guidelines

(iv) Vegetation removal

- Maintain vegetated buffers along all streams. Riparian buffers required on USFS lands are included in the Tongass and Chugach National Forests Resource Management Plans (USFS 2016, 2020). Riparian management in the Tongass National Forest is also performed in accordance with the Tongass Timber Reform Act, which does not allow commercial harvesting within 30.5 m (100 ft) on either side (horizontal distance) of Class I streams and Class II streams that flow directly into a Class I stream. Riparian buffers required on other lands must comply with the State of Alaska Forest Resources & Practices Regulations (ADNR 2013).
- Maintain vegetated buffers adjacent to estuaries and beaches. The estuary fringe is an area of approximately 305 m (1,000 ft) slope distance around all identified estuaries. The beach fringe is an area of approximately 305 m (1,000 ft) slope distance inland from mean high tide around all marine coastlines. Maintain the beach fringe as mostly undisturbed forest that contributes to the maintenance of the ecological integrity of the biologically rich tidal and intertidal zones (USFS 2016).

3.5.3 Hardrock Mining

Proposed mining operations in watersheds inhabited by anadromous pacific salmon need to complete a thorough EFH assessment, as intrinsically most large scale mining operations need to remove all surface and ground water from the region to access mineral deposits below. The risk of potential adverse effects to EFH are greatly reduced for mining operations in a regions where salmon populations do not exist, the mineral deposits are sited in higher elevations (above the aquafers) or in arid regions with little immediate ground and surface water interaction. However, cumulative impacts to downstream water quality from exposed excavations, overburden, leachate and liberated processing chemicals may pose harmful effects to downstream water bodies and groundwater regimes.

Groundwater naturally moves down gradient through porous saturated substrate eventually resulting in surface waters downstream. Adult salmon preferentially build redds and spawn on and near upwelling water sources (Geist 2000, Geist et al. 2002, Malcolm et al. 2004b). Such groundwater influenced upwelling supports egg and larval survival in Alaska's freezing winter conditions (Cunjak 1996, Roussel et al. 2004). These interactions between ground and surface waters support aquatic communities through temperature regulation (Boulton et al. 1998, Sophocleous 2002, Hancock et al. 2005). The abundance of water supports bio-chemical connectivity to numerous secondary ecosystem processes that fuel food chain dynamics essential for salmon fry and parr survival and growth (Naiman et al. 2000, Wipfli et al. 2007).

An assessment of effects on salmon EFH from mining activity needs to consider the presence and abundance of water and salmon, spatial and temporal impacts, and a focus on aquatic ecosystem processes such as water quality. It remains highly uncertain how different species and life stages of salmon would adapt to the changes in ground and surface water quality resulting from the mine and the resultant water quality impacts. EFH assessments need to be prepared for mines proposed on, or adjacent to, watersheds known to support anadromous Pacific salmon EFH. This includes where mining excavations and operations could affect supporting ground and surface waters. The following topics should be considered when preparing an EFH assessment:

- Design surveys to consider high variability among species, e.g. run timing, life stages, seasonality and environmental influences (Schindler et al. 2010, Armstrong et al. 2013).
- Conduct robust fish surveys using repeatable and robust methods to inform statistical analysis and provide defensible conclusions regarding salmon distribution and abundance at different life history stages.
- Evaluate the role, value and function of different stream and river characteristics, types of habitat, supporting aquatic processes, and both up and down stream of the impact area.
- Consider the numbers of salmon including early freshwater life stages, e.g., juveniles, fry parr and smolt present in the watershed.
- Analyze the direct and indirect impacts to salmon EFH associated with removing and altering the surface and groundwater regimes underneath and downstream of any large scale mine site, and changing water quality throughout the watershed.
- Identify the EFH attributes that support a species range and distribution at specific life history stages is essential to assess impacts and designing mitigation measures (Gunderson 1993, Johnson et al. 2008, Cochrane et al. 2009, Johnson et al. 2012).

Often overlooked in mining impacts analysis is degradation of natural trophic dynamics. Nutrient availability is an EFH attribute essential for emerging fry and parr survival. Analysis should consider whether affected ecosystems will recover after a disturbance or if the impacts will continue to degrade ecosystem functions in a continual cumulative or synergistic manner.

3.5.3.1 Potential Impacts

Large-scale mining projects in salmon bearing watersheds have the potential to induce different degrees of effects on EFH depending on the nature, scale and scope of the project and surrounding ecosystem processes (Younger et al. 2002, Lottermoser 2010a, b). Large tailing failures can affect the marine environment, even with mines that are many miles inland. The EFH assessments should discuss EFH in the shallow marine environment as well as EFH in rivers and streams. Five major mining activities are associated with adverse effects to EFH: (i) water removal, (ii) water storage and treatment, (iii) acid mine drainage, (iv) heavy metals, and (v) tailings and tailings dam failures.

Figure 4. HCD staff survey a mine tailings impoundment in coastal watershed. Photo credit Molly Zaleski.

(i) Water Removal

Abundant volumes of cold, well-oxygenated water are an essential habitat attribute supporting freshwater phase salmon populations. However, most mining operations need to remove water (ground and surface water) from the mine site and excavated pit, and manage water both upstream and downstream of the excavation. Water is essential to mineral processing as well as tailings facility management. However, water and oxygen are the catalyst in initiating the oxidative sulfide reactions that generate acid mine drainage (AMD). Water is also the mechanism that moves AMD and mine contact water downhill and downstream through and over the surrounding landform. Water is essential to salmon; however, water removal and management is needed to facilitate mining where groundwater and surface water are present.

Large-scale, open-pit operations to access mineral deposits require continuous removal of significant volumes of groundwater from the mining site. Dewatering wells can remove millions of gallons of water from the ground, creating a cone of depression[15], and altering both ground and surface water flows and changing hydrology for unknown distances surrounding an active mine site. Altered water regimes change instream channel morphologies, bank and benthic substrates, and disrupt the equilibrium between flow and sediment transport in tributaries (Montgomery and Buffington 1998, Sophocleous 2002, Johnson and Host 2010). Mine activity affects riverine habitat for many miles upstream and downstream of the site, thus, affecting EFH and anadromous species by limiting access to migratory, spawning and rearing habitat. Groundwater and associated aquatic processes in the mine footprint are completely and permanently removed prior to excavation. Tailings impoundments or water storage and settling ponds completely bury other areas outside the mine footprint. The full scope of mining activity can significantly alter the natural water quality and quantity, and aquatic processes surrounding the mine for decades, centuries, or in perpetuity.

The extent of impacts to the surrounding area and the severity of impacts are easy to identify post-mining though difficult to predict prior to mining. Future water quality and quantity are challenging to model and therefore are very difficult to predict, especially in regions with high hydrologic conductivity. As large excavations expand in width and depth, it becomes increasingly necessary to remove greater volumes of water from the surrounding landform, further altering and decreasing available surface waters and further expanding the dewatered cone(s) of depression surrounding the mine. Water quality, quantity, and aquatic processes may resume naturally some distance downstream, though this distance is often unknown, highly variable, and difficult to determine definitively prior to mining.

Salmon depend on water availability in smaller tributaries during their crucial freshwater phase for spawning and juvenile rearing and survival. Removing large volumes of water from a mine site and surrounding area affects salmon spawning, incubation and rearing habitat. Decreasing water volumes alters stream temperature, dissolved oxygen, forage opportunities and overall habitat suitability.

(ii) Water Storage and Treatment

Proposed water storage and treatment processes are often ineffective in treating large volumes of mine contact water in perpetuity, especially in watersheds with high hydrologic connectivity. Mining operations managing large volumes of waste rock, acid generating ore, and processing ores often exceed predicted and permitted discharges of mine contact water when located in regions with significant ground and surface water interaction (Banks et al. 1997, Kuipers 2000, Younger et al. 2002, Maest et al. 2005, Castendyk and Eary 2009). The exceedances and

[15] A cone of depression occurs in an aquifer when groundwater is pumped from a well resulting in a reduction in the pressure head surrounding the pumped well.

impacts to water quality are very difficult to remediate once the mine is operating or after the mine is closed. Exceedances in metals or total dissolved solids often result from:

- Error or uncertainty in the modeling used to predict metal precipitates removed versus metal precipitates remaining in solution and expelled;
- Water treatment systems that are overwhelmed by rapidly changing weather patterns, seasonal precipitation, and unpredicted or under estimated volumes of rain water;
- Inadequately engineered or installed equipment for unanticipated water scenarios; and
- Mitigation measures and facility designs that do not perform as predicted or anticipated in Arctic or subarctic conditions.

(iii) Acid Mine Drainage

Post-mining studies indicate that diffuse mining-related pollution in rivers may significantly contribute to the loading of metals (Younger 2000, Younger et al. 2002). Minerals and metals liberated from mined substrates interact with atmospheric oxygen and water and produce AMD (Jennings et al. 2000, Jennings et al. 2008). The introduction of mineral and metal rich AMD into an aquatic ecosystem can adversely affect the ecology of entire watersheds. Once started, the generation of AMD is difficult to stop or reverse (Younger et al. 2002, Jennings et al. 2008).

AMD is toxic to fish, algae, zooplankton, and aquatic invertebrate populations at the ecosystem, metabolic, and cellular levels (Buhl and Hamilton 1991, Saiki et al. 1995, West et al. 1995, Barry et al. 2000, Peplow and Edmonds 2005). The release of cadmium via AMD can cause salmon mortality (Barry et al. 2000). Chronic exposure to cadmium can cause pronounced sublethal effects such as decreased growth, inhibited reproduction, and population alterations (Levit 2010). The hyporheic zone is susceptible to AMD, a habitat feature that supports salmon spawning and incubating eggs as well as production of aquatic insects and aquatic vegetation. Contaminated groundwater may enter the hyporheic zone in an undiluted condition, leading to injury and mortality of aquatic organisms (including salmon eggs and alevin) prior to the dilution effects of the overlying streamflow (Brunke and Gonser 1997). Salmon are particularly vulnerable to low pH when undergoing the physiological changes when transitioning from freshwater to saltwater as smolts and from saltwater to freshwater as adults (Chambers et al. 2012).

(iv) Heavy Metals

Low concentrations of metals have detrimental impacts to salmon (Baldwin et al. 2003, Hecht et al. 2007, Baldwin et al. 2011). Heavy metals are widely recognized to persist in the environment, becoming bioavailable to, and bio-accumulating within freshwater and marine organisms where they magnify in concentration as they move through food chains (Di Giulio and Hinton 2008). Metals in mine contact water adversely affect salmon survival and growth to maturity, and can interrupt migrations. Similar negative responses are observed in many different fish species (Di Giulio and Hinton 2008).

Metal contamination and exposure influences simple migratory behavior and avoidance mechanisms in fish populations (Farag et al. 1998, Goldstein et al. 1999, Brix et al. 2001). Numerous studies have shown how exposure to toxic contaminants in surface waters can affect fish olfaction, which is critical for behaviors such as mating, locating prey, and avoiding predators (Sandahl et al. 2004, Tierney et al. 2010). Copper contamination in surface waters is common in watersheds with mining activities. Juvenile coho salmon exposed to copper were unresponsive to their chemosensory environment, unprepared to evade nearby predators, and less likely to survive an attack sequence (McIntyre et al. 2012). Additional studies indicate that salmonids exposed to sub lethal levels of metals are susceptible to increasing levels of fish pathogens due to physiological stress and suppressed immune responses (Jacobson et al. 2003, Spromberg and Meador 2005).

The ability to treat or neutralize AMD is very site specific and often highly unpredictable. Mine waste is exposed to weathering, oxygen and water over a long period of time (CSS 2002). Invertebrate community recovery in the hyporheic zone may take longer than surface macroinvertebrate recovery due to the continued and perpetual release of metals by oxidation reductive dissolution and exposure to AMD (Bernhardt and Palmer 2011, Byrne et al. 2012, Palmer and Hondula 2014, Resongles et al. 2014, Kruse Daniels et al. 2021). Depending on the scale of the mining operation, associated topography and hydrogeomorphic processes, aggressive active treatment to neutralize AMD may need to last in perpetuity to be effective (Kuipers et al. 2006, Jennings et al. 2008, Sergeant et al. 2022).

Mining projects have the potential to cause substantial adverse effects on salmon EFH near the mine site and downstream areas. Substantial adverse effects pose serious threats to EFH that engineered modifications cannot always alleviate. Open pit and surface strip mines fundamentally change surface and groundwater regimes in the immediate vicinity and surrounding area, and often result in decreased water volumes and stream discharges, habitat complexity, and water quality. Salmon EFH and population resilience significantly diminishes when those impacts combine with reduced forage opportunities and increasing water temperatures. These cumulative adverse effects to salmon EFH are often permanent and the success of any mitigation efforts is highly uncertain, especially in large-scale, long-lived mining projects attempting to manage tremendous volumes of water and waste in regions with high levels of precipitation.

(v) Tailings and Tailings Dam Failures

Development of large-scale mining operations usually include construction and maintenance of multiple earthen tailings facilities (dams to store pyritic and bulk tailings) and potentially acid-generating and metal-leaching materials. Large volumes of inert waste, rock, and the overburden from such excavations are often used to create earthen tailing dams to store these waste materials and contaminated water.

Historically, the number of tailings dams failures has been difficult to determine for numerous reasons (Lumbroso et al. 2019). The development and application of new technologies has greatly increased the accuracy of such analysis (Islam and Murakami 2021). A review conducted by the EPA provides peer reviewed sources (EPA 2014, Kossoff et al. 2014). In summary, the National Inventory of Dams (USACE 2000) lists over 1,400 tailings dams in the United States while the International Commission on Large Dams compiled a database of 221 tailings dam incidents and failures that occurred from 1917 through 2000 (Szymanski and Davies 2004). Though tailings dam failures were previously seen as rare events, 46 occurred in the past 20 years and the number has been rising (WISE Uranium Project 2016, Armstrong et al. 2019).

Advances in mining technology increase the ability to exploit lower grade mineral deposits, increasing volumes of waste, which increases pressure on tailings facilities. Of four recent tailings dam failures in countries with a strong mining tradition (Los Frailes in Spain, Mt Polley in Canada, Samarco and Brumadinho in Brazil), mineral processing and production increased while cost-cutting measures were implemented prior to the accidents (Armstrong et al. 2019). Mine operators increase risk in scenarios of low probability, high catastrophic consequences.

Failure of tailings embankments made to contain the pyritic tailings, bulk tailings, and water management ponds often leads to catastrophic consequences for humans and EFH. When tailings embankments catastrophically fail, EFH is adversely affected for potentially miles downstream. For example, when the Samarco tailings dam in Brazil collapsed in November 2015, it released 50 million m^3 (65,400,000 yd^3) of mine tailings into the Rio Doce River, destroying two villages, killing 19 people, and polluting 650 km (404 mi) of the Rio Doce River (Queiroz et al. 2018). The tailings arrived in the marine estuary 17 days later with continued lingering impacts (Bernardino et al. 2019, Gabriel et al. 2021, Queiroz et al. 2021).

In addition to the natural aging and decay of tailings dam impoundments, engineering studies have shown seismic activity and seasonal freeze-thaw cycles further weaken the predicted shear strength and behavior of tailings impoundment materials (Korshunov et al. 2016, Li et al. 2018, Lin et al. 2021). Factors that alter shear mechanical parameters include:

1) Seismic exposure and liquefaction vulnerability;
2) Intensity and frequency of freeze-thaw cycles;
3) Combinations of changing confining pressures;
4) Porosity and physical-mechanical properties of the tailings material; and
5) Volumes of water contained.

Macroscopic changes in shear strength indexes emerge that decrease the stability of tailings dam structures. Many analyses of tailings composites subjected to freeze-thaw cycles show changes on the porosity, bound water, and arrangement of the tailings particles and materials (Jin et al. 2019, Lyu et al. 2019, Islam and Murakami 2021).

Even if mine waste and mine contact water appear contained, potentially acid generating or metal leaching rock contact water can infiltrate groundwater and resurface as water harmful to salmon (Younger et al. 2002, Lottermoser 2010a, b). One study demonstrates migration and the movement of tracers in pollutants from terrestrial sources through the ground to marine waters (Glenn et al. 2013, Amato et al. 2016, Swarzenski et al. 2017). Seepage and penetration of water through and underneath tailings dams and impoundments is a known concern in mining operations. Santamarina et al. (2019) presents a very defensible discussion identifying the mechanistic failures that lead to several notable dam failures; overtopping due to water mismanagement (Merriespruit, South Africa, 1994); shear failure of foundation soils (Mount Polley, Canada, 2014); and shear of compressible low-permeability tailings placed near the perimeter of the impoundment (Samarco, Brazil, 2015). By the very nature of water, gravity and geology, AMD and mine contact water will infiltrate groundwater to reemerge downstream and down gradient, contributing to adverse effects to EFH.

3.5.3.2 Recommended Conservation Measures

The following recommended conservation measures are separated into three categories: (i) all mines, (ii) underground mines, and (iii) open pit mines. The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of mining on EFH and to promote the conservation, enhancement, and proper function of EFH.

(i) All Mines

- On the ground and in-water engineering designs, methods, and technologies need to anticipate unpredicted large volumes of waters containing the anticipated mine wastes and their proven effectiveness in Arctic and subarctic environments. Such planning would improve the effectiveness of the water treatment plans and reduce the risk of impacts to water quality in salmon streams.
- The landowners should develop a plan to address a tailings dam breach, pit leakage or acid drainage from tailings. These tailings storage areas will be present and at risk of failing long after the mining operations end.
- Dry stack or filtered tailings facilities are preferable to avoid the oxidation process that leads to acid mine drainage. Relying on reservoirs or ponds to keep tailings submerged is not recommended.
- Keep water treatment plants operational at least 30-years post mine closure as acid mine drainage takes time to develop.
- Incorporate climate change predictions into the potential stream discharge calculations. We encourage the applicant to incorporate Precipitation Projections for Alaska Infrastructure as described in Lader et al. (2020b).
- Establish specific procedures to identify and separate potential acid generating from non-acid generating rock, and metal leaching from non-metal leaching rock.
- Test all mine contact waters prior to discharge and meet all state and federal water quality standards.
- Regardless of the source of the mine contact water, mixing zones and site specific water quality standards are not a feasible approach for discharging mine contact waters.
- Prepare a hazardous materials spill response for concentrate slurry pipelines.
- Many Alaskan mines require a port to export product. In addition to port construction EFH CRs, develop a response plan to clean up heavy metal spills from the port.
- Large scale and long-lived projects should evaluate impacts of Climate Change and explain how the water management plans account for changes, including the increasing or decreasing levels of precipitation or more frequent winter rain or less snowmelt. Section 2.4 (Considering Climate Change Effects in EFH Assessments) provides a process for integrating climate change information into EFH consultations.

(ii) Underground Mines

- Return all pyritic tailings to the mine.

- Return a higher percentage of tailings to the mine. Tailings returned to the mine pose less risk to EFH than tailings placed in either a filtered tailing pile or a tailings dam.
- Develop detailed sub-aqueous closure plans. Sub-aqueous closure plans are complicated and expensive. Stating this issue 'will be addressed' is insufficient.

(iii) Open Pit Mines

- Develop a plan for recharging the aquifer surrounding the mine site with water injection wells while simultaneously keeping the mine pit dry.
- Build the pyritic tailings liner to last 50 years beyond the current project timeline to avoid groundwater infiltration of mine contact water.

3.5.4 Sand, Gravel and Placer Mining

Riverine sand and gravel mining is extensive in Alaska and can involve several surface mining methods including: wet-pit mining (removal of material from below the water table); dry-pit mining on beaches; excavating exposed bars and ephemeral streambeds; and subtidal mining and excavations. Placer mining operations excavate streambeds and alluvial deposits for gold. Project proponents should follow the Bureau of Land Management (BLM) stream restoration protocols[16].

3.5.4.1 Potential Impacts

Primary impacts to salmon EFH associated with riverine sand and gravel mining activities include: the creation of turbidity plumes and re-suspension of sediment and nutrients, the removal of spawning habitat, and the alteration of channel morphology. These primary impacts often lead to a series of secondary impacts (NMFS 2005b):

- Alteration of migration patterns;
- Creation of physical or thermal barriers to migration corridors;
- Increased fluctuation in water temperature;
- Decreased dissolved oxygen;
- High mortality of sensitive early life stages;
- Increased susceptibility to predation;
- Loss of suitable habitat;
- Decreased nutrients (from loss of floodplain connection and riparian vegetation); and
- Decreased prey availability.

Turbidity plumes can smother spawning habitat for several kilometers downstream. Reduction in water clarity by sediment plumes can also have behavioral and physiological impacts to fish species. Behavioral impacts may include temporary impacts to trophic dynamics and increased

[16] Reclamation Effectiveness Monitoring (REM) for Placer Mined Streams. Website last accessed on April 1, 2021. https://www.blm.gov/sites/blm.gov/files/policies/Policy_IMAK2015-004-%20a2.pdf; and https://www.blm.gov/policy/im-ak-2017-009.

energy demands (Michel et al. 2013). Sand and gravel mining in riverine, estuarine, and coastal environments can also suspend materials at the mining sites. Sedimentation may be delayed because gravel removal typically occurs at low flow when the stream has the least capacity to transport fine sediments out of the system. Another delayed sedimentation effect results when freshets inundate extraction areas that are less stable than they were before the activity occurred. For salmon, gravel operations can interfere with migrations past the site if they create physical or thermal changes either at or downstream from the work site (Williamson et al. 1995).

Extraction of sand and gravel in rivers and streams can reduce or eliminate spawning gravels if the extraction rate exceeds the deposition rate of new gravel in the system or exposes bedrock. Gravel excavation can alter channel morphology by making the stream channel wider and shallower. The suitability of stream reaches as rearing habitat for juvenile salmon may decrease, especially during summer low-flow periods when deeper cooler waters are important for survival. Reduction in pool frequency may adversely affect migrating adults that require holding pools. Changes in the frequency and extent of bed load movement, and increased erosion and turbidity can also scour out redds (resulting in a direct loss of eggs and young), or reduce their quality by deposition of increased amounts of fine sediments or even remove all spawning substrates (Williamson et al. 1995).

3.5.4.2 Recommended Conservation Measures

The following recommended conservation measures are adapted from the Federal Interagency Working Group (FIWG 2006), NMFS (2005a) and Williamson et al. (1995). These measures are potential actions to avoid and minimize adverse impacts of sand and gravel mining to EFH and to promote the conservation, enhancement, and proper function of EFH.

- To the extent practicable, avoid sand/gravel mining in waters, water sources and watersheds, riparian areas, hyporheic zones, and floodplains that serve as habitat for anadromous species.
- Identify upland or off-channel (where the channel will not be captured) gravel extraction sites as alternatives to gravel mining sites in or adjacent to EFH.
- Avoid mining operations in EFH.
- Design, manage, and monitor sand and gravel mining operations to minimize potential direct and indirect impacts to EFH. For example, minimize the areal extent and depth of extraction.
- Include restoration, mitigation, and monitoring plans, as appropriate, in sand/gravel extraction plans.
- Implement seasonal restrictions to avoid impacts to habitat during critical life history stages (e.g., spawning season/egg and larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.

- Implement the BLM's stream restoration protocols of placer mining operations[17].

3.5.5 Roads and Transportation Corridors

Alaska has approximately 36,000 miles of roads and approximately 600 miles of rail line. The Fish Passage Inventory Database evaluated and mapped 2,500 streams crossings[18]. Alaska Department of Transportation and Public Facilities, USFS, and BLM construct most of the roads that affect anadromous fish habitat in Alaska. Project planning typically begins one to three years prior to construction, with scoping six months before an EFH consultation formally begins. By providing these four pieces of information during scoping, agencies can help streamline the EFH consultation process:

- List the anadromous species potentially affected by the proposed road or transportation corridor.
- Extent of upstream anadromous habitat above the crossing using ADFG's *Anadromous Waters Catalog*.
- An estimate of acres of wetland that this project may fill.
- A description of the type of wetland in general terms – intertidal, estuary, freshwater, scrub, or forested.

Stream crossing projects benefit from early coordination to avoid surprises, delays, or expensive revisions late in the process. Ideally, informal consultation begins during the design process. The following design elements should be considered during early coordination and the consultation process.

- Location;
- Align the crossing perpendicular to the channel;
- Understand how the channel will evolve in the future;
- Abutment placement;
- Passing LWD;
- Passing sediment;
- Fish passage blocked by insufficient water depth;
- Fish passage blocked by excessive water velocity;
- Complex habitat;
- Pollution from road surface;
- Alaskan specific situations; and

---

[17] Reclamation Effectiveness Monitoring for Placer Mined Streams. Website last accessed on April 1st, 2021. https://www.blm.gov/sites/blm.gov/files/policies/Policy_IMAK2015-004-%20a2.pdf; and https://www.blm.gov/policy/im-ak-2017-009

[18] Culvert Design Guidelines for Ecological Function. Last Accessed April 4, 2022. https://www.fws.gov/alaska-culvert-design-guidelines

- Climate change.

Road alignment is the primary factor influencing whether the road affects fish habitat. Before 1960, engineers in Alaska aligned roads to minimize the need for fill material. Along the coast, this meant 3 m (10 feet [ft]) above the high tide line and often at the forest margin. These early roads were less direct and designed for slower driving speeds; however, they often crossed streams by installing culverts, many of which were undersized.

To obtain federal highway funds, road designs need to meet federal safety standards appropriate for a specific road classification. Understanding the federal safety requirement will support the EFH consultation process and the potential for avoiding or minimizing impacts to EFH. For example, if the road can be designated a lower classification, the federal requirements for turn radius, width, and driving speed will be less stringent. This lower designation allows the consulting agency more latitude to address EFH concerns.

3.5.5.1 Potential Impacts

Habitat fragmentation is a significant impact associated with roads and transportation corridors. Roads, railways, and other linear routes are contiguous features on the landscape that interrupt the connectivity within habitat features. Water flow and migratory (or residential) movement are two ecological functions most notably affected. Section 3.5.2 (Silviculture and Timber Harvest) provides more details regarding the impacts of causeways and stream crossings to EFH.

(i) Causeways

Causeways affect wetlands in a variety of ways. On the upstream side of a causeway, water temperatures can become too warm for juvenile salmon (Mauger et al. 2017, Jones et al. 2020, Shaftel et al. 2020). The upstream side can also become a freshwater pond, with more freshwater tolerant vegetation, and cease to be an estuary. The same road design principles apply in tidal wetlands and upland wetland; however, the salinity gradient is less of an issue.

Coastal and estuarine wetlands have a mixture of fresh and saltwater (salinity gradient) that creates crucial habitat for smolt (McCormick and Saunders 1987, Sakamoto et al. 1993, Quinn 2018). Chinook and coho juveniles rear in freshwater, but spend several days to three months rearing in estuaries. Many pink salmon populations rear almost entirely in estuaries; however, some populations also rear in freshwater. Sockeye move through estuaries more quickly than other species (Moore et al. 2007). Juveniles of all species swim to a location with the salinity they need at that point in their smoltification. If the water on the upstream side of a causeway is predominantly fresh water (less than 5 parts per thousand) and downstream of the causeway the water is brackish (greater than 20 parts per thousand), both sides may be habitat for some life stages, but the causeway has diminished the salmon smolt habitat in that estuary.

In an unaltered wetland, the distributary channels migrate across the wetland through time. A road surface elevated on piles would allow the channels to migrate freely and be an excellent mitigation measure; however, this expensive alternative is unlikely to be selected unless ESA listed species are present. Road engineers look at where the main distributary channel is at the time of project planning and typically design causeways with a large culvert or small bridge that can accommodate the 100-year recurrence flow. This action fixes the channel in one place, which often leads to channel incision, a lower water table and diminished wetland habitat. In the area downstream of the causeway both ground elevation changes and plant communities change (Van Proosdij et al. 2009).

(ii) Stream Crossing

Crossing streams and rivers is often the largest effect of a road on EFH. Some crossings block all fish passage leading to a complete loss of EFH. Other crossings impede passage of certain fish species depending on the instream structure and flows. Stream crossings fix a channel in one place, restricting its natural functions. Many crossings narrow the stream channel, altering flow velocities during high water conditions. Causeways restrict the natural flow and exchange of water in estuaries and freshwater wetlands, resulting in fewer acres of high quality EFH.

The impacts of an individual crossing can appear slight; however, the cumulative effects of hundreds of poorly designed crossings have led to ESA listing and extirpation of anadromous fish in other states. The EFH consultation process can support the design and construction of stream crossings that avoid or minimize impacts to EFH, including upgrading existing crossings that block or impede fish passage.

3.5.5.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts from roads and transportation corridors to EFH habitat in wetlands and streams and to promote the conservation, enhancement, and proper function of EFH.

(i) General

- Refer to the Culvert Design Guidelines for Ecological Function which was written specifically for Alaska salmonids[19].
- Address the cumulative impacts of past, present, and foreseeable activities involving fill in the wetland during the review process for new causeways.
- If boulders in the channel seem too large for the stream to move, consult a geomorphologist.
- Beneath large bridges, ensure that there is light penetration for vegetated banks, substrates that will host invertebrates, and both swift and slow water habitats.
- Complete a study on the frequency of anomalous geomorphic and hydrologic processes (ice jams, jökulhlaups, landslides, debris flows) on a particular river and in neighboring watersheds to evaluate increase risk of impacts on proposed infrastructure.
- Construction activities negatively affect EFH temporarily by increasing turbidity for the construction season; therefore, a longer lasting structure leads to protecting EFH.

(ii) Location

- Cross in a location where the stream channel is stable. Determine the best location to cross the stream and then connect the road segments to that crossing.
- Avoid extensive wetlands to the extent practicable.

[19] Culvert Design Guidelines for Ecological Function. Last Accessed June 7, 2022. https://www.fws.gov/alaska-culvert-design-guidelines

- Consider alternative functional road classifications to allow road designers more leeway to accommodate EFH CRs.
- Reduce the road prism footprint through the wetland by steeping the angle of the sides, narrowing the road shoulders, and limiting turnouts.
- Locate the road prism as high up the tidal gradient as possible.
- Avoid burying submerged aquatic vegetation (SAV), such as eelgrass (*Zostera marina*) 20 and kelp. SAV provides juvenile rearing habitat and cover from larger predatory fish.
- Locate the roadbed on bedrock because, in most cases, it provides habitat for the fewest species in the tidal zone.
- Place fill in the most common shore zone type[21] and avoid impacts to shore zone classifications that are less common in that area.
- Place abutments on bedrock where possible.

(iii) Alignment

- Align the river crossing perpendicular to the 10-year flow event. Crossing the stream channel at any other angle usually increases impact on riparian vegetation and negatively affects EFH.
- If the road alignment cannot avoid crossing multiple side channels or sloughs, provide additional culverts to keep those channels connected.
- Ensure gravel is not so coarse and deep that during low flow periods the surface water disappears into the gravels. Appropriate sized spawning gravel is good, but it should contain some percentage fines.

(iv) Understand How the Channel Will Evolve in the Future

- Determine if the channel aggrading or incising. For aggrading or incising streams, bridge abutment design should receive special attention.
- Determine if it has multiple braided channels upstream or downstream. Side channels and sloughs provide juvenile EFH habitat, so designing the road/bridge abutments to avoid them protects EFH. Forcing a stream through a narrow bridge opening often eliminates side channel EFH for several hundred meters downstream.
- Establish multiple smaller openings in the causeway to allow the main channel to migrate across the wetland. Multiple openings are most appropriate in areas with very little gradient. Alaska Department of Transportation and Public Facilities prefers that stream crossing structures have openings less than 6 m (20 ft) wide as the federal highway standards exempt these narrower structures from the biennial inspections required for wider openings.

---

[20] Eelgrass is the dominant seagrass in Alaska. Scouler's surfgrass (*Phyllospadix scouleri*) and serrated surfgrass (*P. serulatus*) are present but less common.

[21] See the Alaska ShoreZone tool https://www.fisheries.noaa.gov/alaska/habitat-conservation/alaska-shorezone

- Provide bottomless causeway opening, or culverts set sufficiently low that they can accommodate scour.
- Design a lower layer in the road prism to be of high permeability. Water flows through the hyporheic zone in the wetland soils. The fill compaction necessary to build a road usually compromises this shallow groundwater transfer.
- Design stream crossings with a natural bottom to support riverine and biological processes.

(v) Abutment Placement

- Constructing abutments usually involve placing fill in EFH habitat. If the design can place either abutment on bedrock, strongly consider that location.

(vi) Passing LWD

- Consider the size of vegetation on the upstream streambanks (e.g., tree size). Determine whether the stream can transport that vegetation if it enters the waterway (Gubernick et al. 2003). Trees hung up across a culvert or bridge during a flood event can lead to structure failure in a matter of minutes.
- Avoid multiple adjacent culverts.

(vii) Passing Sediment

- Use the Precipitation Projections for Alaska Infrastructure provided by Scenarios Network for Alaska and Arctic Planning (SNAP) and "Estimating flood magnitude and frequency at gaged and ungagged sites on streams in Alaska and conterminous basins into inform the stream crossing design" (Curran et al. 2017, Fresco et al. 2021).
- Survey the channel and floodplain for the largest rounded boulders. In most cases, precipitation events triggered large flow events that moved those boulders. Determine if the proposed bridge/culvert can withstand the impact of those boulders.
- Glacier deposited boulders (glacial erratics) may remain in place for several centuries unmoved by the current stream. If you suspect the potential for glacial erratics to affect a culvert or bridge, consult a geomorphologist. See Alaska Specific Situations, below, for more information.

(viii) Fish Passage

- Determine the target species for providing fish passage and consult the literature for minimum zone of passage depth (Quinn 2018). Natural streams have a thalweg that is deeper than the rest of the channel and provides fish passage during dry periods. In flat bottom culverts, this deeper pathway may not exist. An artificial, flat-bottom channel may pass the 100-year recurrence; however, it could result in a fish barrier much of the year.
- Ensure that the gravel is not so deep and coarse that all flow will pass through the hyporheic zone during dry spells thereby blocking fish passage.
- Each species of salmon has burst and sustained swimming speeds (Reiser 2005). Once a culvert type, size, and bottom material is preliminarily selected, the applicant should use hydraulic models to determine the velocity of water passing through it at different

discharges. Model the hydraulics of the culvert and display velocities at various flows up to the 2-year recurrence discharge. These velocities should not exceed the burst speeds of the fish in that stream if the culvert is shorter than 5 m (16 ft). For longer culverts, compare the velocities to the sustained speed of the fish species.

(ix) Habitat Complexity

- While passing adult fish upstream and smolt downstream through a crossing is the basic requirement of a well-designed crossing, some crossing designs provide fish habitat and food. Investigate whether the bridge design can retain streambank vegetation.
- Consider options to provide fast water areas and pools beneath the bridge.
- Design for high flows that will retain gravels, which provide habitat for macroinvertebrates.

(x) Pollution from Road Surface

- Design bridge drainage such that runoff from pavement drains to an infiltration site away from the river.
- If appropriate, consider the environmental effects of deicing products.
- For more on road runoff, see Section 3.5.8 Freshwater Use and Inputs.

(xi) Alaska Specific Situations

- Consider the frequency of rain-on-snow events to inform the stream crossing design (Bieniek et al. 2018).
- Evaluate the occurrence of ice jams in the waterway.
- Evaluate the risk of a jökulhlaup releasing a glacier outburst flood (Capps et al. 2008).
- Evaluate the risk of landslides upstream of this crossing.

Rain-on-snow events, ice jams, jokulhlaups, and landslides can produce flows larger than the predicted by a combination of SNAP precipitation data and watershed models. Stream crossings designed by companies not familiar with Alaska are particularly prone to these oversights.

(xii) Climate Change

- Stream crossing designs should anticipate future stream flows. Understanding processes that drive high flows help project how flows might change in the future. See Chapter 2 Climate Change for a broader discussion of the topic (Curran and Biles 2021).

3.5.6 Organic Debris Removal

Organic debris is important for maintaining aquatic habitat structure and function, and salmon EFH, throughout the freshwater, coastal and marine environments. In riverine systems, LWD supports many ecosystem functions (Ralph et al. 1994, Abbe and Montgomery 1996, Gurnell et al. 2002), including:

- Cover for anadromous species;
- Promoting lateral channel meander and pool riffle sequences;

- Providing undercut banks and side channel sloughs;
- Providing spawning bed complexity;
- Habitat for aquatic invertebrates, thereby increasing instream productivity;
- Retaining hyporheic substrate; and
- Maintaining underlying channel structure.

In the marine environment, LWD enriches local nutrient availability by serving as a source of terrestrially based carbon to benthic ocean habitats and the broader ocean food chain (Maser and Sedell 1994).

LWD and macrophyte wrack are removed from streams, estuaries, and the coastal shores for road crossing protection, hydropower operations, aesthetic concerns, and other commercial and recreational purposes. Since these sources of organic debris are important for shaping fish habitat, their removal may have adverse impacts to EFH.

3.5.6.1 Potential Impacts

The removal of organic debris from natural systems may reduce EFH structure and function. In rivers and streams, the removal of LWD from rivers to improve navigability alters channel morphology and reduces habitat complexity. This in turn negatively affects habitat quality for spawning and rearing salmonids (Sedell and Luchessa 1982, Koski 1992).

In estuaries, a loss of LWD reduces the number of spatially complex and diverse channel systems that provide productive salmon habitat (NRC 1996). Reductions in LWD inputs to estuaries may also affect fish habitat by altering nutrient transport, sediment deposition, and the availability of in-water cover for larval and juvenile fish.

On the coast, beach grooming and wrack removal can substantially alter the macrofaunal community structure (Dugan et al. 2000). The species richness, abundance, and biomass of macrofauna associated with beach wrack, including sand crabs, isopods, amphipods, and polychaetes, are higher on ungroomed beaches (Dugan et al. 2000).

3.5.6.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of organic debris removal on EFH and to promote the conservation, enhancement, and proper function of EFH. Whenever possible, leave naturally occurring organic material, such as LWD and vegetation, where it lies.

- Encourage the preservation of LWD whenever possible.
- If instream LWD must be disturbed, explore options to move it downstream, or reposition and anchor it to the shoreline, rather than remove it from the system entirely.
- Where LWD removal occurred, support instream restoration activities to restore habitat complexity.
- Educate landowners and recreationalists about the benefits of maintaining LWD.
- Localize and minimize beach grooming practices whenever possible.

- Kelp harvesters should follow State of Alaska guidance provided by the Alaska Department of Fish and Game on areas closed to the harvest of kelp and other seaweeds, and rules for harvest in open sections of the coast (Morris 2015).

3.5.7 Urban and Suburban Development

Urban and suburban development can have major impacts on EFH, whether through single large projects or small, cumulative effects. In an assessment of habitat loss and compensation, urban development, roads and highways had the greatest negative impact to areal fish habitat (Harper and Quigley 2005). Urban and suburban development and the corresponding infrastructure result in four broad categories of impacts to aquatic ecosystems: hydrological, physical, water quality, and biological (CWP 2003).

This section summarizes direct impacts of urban and suburban development on EFH. Additional development-related impacts are discussed in Section 4.4.1 (Dredging), Section 4.4.3 (Discharge of Fill Material), and Section 4.4.7 (Flood Control and Shoreline Protection).

3.5.7.1 Potential Impacts

Urban and suburban development activities within watersheds and in coastal marine areas can impact EFH at long- and short-term timeframes (NRC 1996). The Center for Watershed Protection conducted a comprehensive review of the impacts associated with impervious cover and urban development and found a negative relationship between watershed development and 26 stream quality indicators (CWP 2003). The primary impacts identified include: (1) the loss of hyporheic zones, (2) loss of riparian and shoreline habitat and vegetation, and (3) runoff. These impacts can adversely affect water quality and the shape of the hydrograph in downstream estuaries and coastal waters (EPA 2007, Lohse et al. 2008).

Removal of riparian and upland vegetation increases stream water temperatures, reduce supplies of LWD, and reduce sources of prey and nutrients to the water system (Kalny et al. 2017, Trimmel et al. 2018). Such impacts can alter the structure of benthic and fish communities. Shoreline stabilization projects that alter reflective wave energy can impede or accelerate natural movements of shoreline substrates, thereby affecting intertidal and subtidal habitats (see Section 4.4.7, Flood Control and Shoreline Protection). The channelization of rivers causes a loss of floodplain connectivity and a simplification of habitat. The resulting sediment runoff can also restrict tidal flows and elevations, resulting in losses of important fauna and flora (e.g., SAV).

Increases in impervious surfaces in a watershed results in a decreased infiltration to groundwater and increased runoff volumes. Runoff from impervious surfaces (e.g., buildings, rooftops, sidewalks, parking lots, roads, gutters, storm drains, and drainage ditches) is the most widespread source of pollution into the nation's waterways (McCarthy et al. 2008, Weiss et al. 2008). Impacts from urban and suburban development are generally difficult to control because of the intermittent nature of rainfall and runoff, the large variety of pollutant source types, and the variable nature of source loadings (Safavi 1996). Runoff includes pollutants such as construction sediments, car exhaust, oil from vehicles, road salts, bacteria from failing septic systems, and inorganic and organic contaminants (i.e., heavy metals) (McIntyre et al. 2015, Feist et al. 2017, McIntyre et al. 2018). The most recent EPA National Water Quality Inventory: Report to

Congress (EPA 2017)[22] reported that runoff from urban areas is a leading source of impairment in surveyed freshwater shorelines and open waters, transporting PCBs, dioxins, and mercury into freshwater habitat. Our understanding of the individual, cumulative, and synergistic effects of all contaminants on the coastal ecosystem are incomplete; however, studies indicated that toxic chemical discharges negatively affect the growth and survival of fish, the productivity of fish prey species, and the biological integrity of habitats that support productive fish populations (McCarthy et al. 2008). Urban areas can have a chronic and cumulative pollution potential that one-time events, such as oil spills, do not incur. See Section 3.5.8 (Freshwater Use and Inputs).

The proportion of impervious cover in a watershed impacts Salmonids and other anadromous fish (NRC 1996, CWP 2003). In a study in the Pacific Northwest, coho salmon were seldom found in watersheds with greater than 10 or 15 percent of impervious cover (Luchetti and Feurstenburg 1993). Other studies have shown impacts to stream quality when a watershed exceeds 10 percent impervious cover (CWP 2003). Key stressors in urban streams, such as higher peak flows, reduce habitat complexity (e.g., fewer pools, LWD, and hiding places) change water quality, and may change salmon species composition, favoring cutthroat trout (*Oncorhynchus clarkii*) populations over the natural coho populations (May et al. 1997, Livingston et al. 1999).

Stormwater management systems move water quickly away from roads, resulting in increased velocities and higher peak volumes in streams after a precipitation event or spring run-off. Uncontrolled higher velocities and higher peak flow volumes of urban stormwater have a greater erosive capacity than stormwater from a forested watershed. Higher velocities and flow volumes erode streambanks and increase stream sediment loads. Reduced canopy cover associated with urban development can often cause higher stream temperatures (Kalny et al. 2017, Trimmel et al. 2018). A simulation model comparing an urban watershed with a forested watershed demonstrated that runoff from an urban watershed had 5.5 times greater volume and sediment than runoff from a forested watershed (Corbett et al. 1997). Literature reviews and ongoing research illustrate the adverse impacts of urban stormwater discharge and growing communities on freshwater and marine invertebrate, fish, and marine mammal populations (McCarthy et al. 2008, Weiss et al. 2008).

Urban stormwater also discharges nonpoint pollutants to soil and water, leading to their eventual bioaccumulation in aquatic species (McIntyre et al. 2015, Feist et al. 2017, McIntyre et al. 2018). Polycyclic aromatic hydrocarbons (PAH) are among the most toxic to aquatic life and can persist for decades (Short 2003). Waterborne PAH levels are often significantly higher in urbanized than non-urbanized watersheds (Fulton et al. 1993). Petroleum-based contaminants contain PAHs, which can cause acute toxicity to managed species and their prey at low concentrations when released into the environment through spill, combustion, and atmospheric deposition. Some PAHs are known carcinogens and mutagens and can disrupt biological processes including immunity (Neff 1985, Reynaud and Deschaux 2006).

Sublethal effects of fish exposure to chemical and metal pollutants in stormwater over time may prove more deleterious than concentrations that are immediately lethal. Subtle sublethal effects on fish may include changes in behavior, feeding habits, and reproductive success (Murty 1986).

[22] National Water Quality Inventory Report to Congress. Last accessed on April 4, 2022. https://www.epa.gov/waterdata/national-water-quality-inventory-report-congress

Stormwater contaminants negatively alter cellular function and biochemical machinery in many aquatic organisms. These impacts may lead to increased mortality in fish species via carcinogenesis through oxidized metabolites, interference with DNA repair mechanisms, and/or initiation of teratogenesis (prenatal toxicity that causes structural or functional defects in the developing embryo or fetus). Some stormwater contaminants disrupt neurotoxic and olfactory responses that maintain normal homing, predator avoidance, and spawning behavior. They can weaken immune system response and inadvertently increase susceptibility and mortality from diseases (Reynaud and Deschaux 2006). These conclusions are well documented in a variety of fish species (Cherr et al. 2017, Hartwell et al. 2017, Grosell and Pasparakis 2021).

Failing septic systems and combined sewer overflows are an outgrowth of urban development. The EPA estimates that 10 to 25 percent of all individual septic systems are failing at any one time, introducing excrement, detergents, chlorine, and other chemicals into the environment. Even treated wastewater from urban areas can alter the physiology of intertidal organisms (Moles and Hale 2003). Sewage discharge is a major source of coastal pollution, contributing a significant portion of the total pollutant load for nutrients, bacteria, oils, and toxic metals, respectively (Kennish 1998). Nutrients such as phosphorus concentrations are particularly indicative of urban stormwater runoff (Holler 1990) and may lead to algal blooms, eutrophication, loss of biodiversity, and the expansion of invasive species. Sewage waste may also contain significant amounts of organic matter that exert a biochemical oxygen demand (Brauko et al. 2020, Cooper et al. 2020). Organic contamination contained within urban runoff can also increase susceptibility to diseases in juvenile salmon (Arkoosh et al. 1998, Arkoosh et al. 2001, Jacobson et al. 2003).

3.5.7.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of urban and suburban development on EFH and to promote the conservation, enhancement, and proper function of EFH.

- Implement BMPs for sediment control during construction and maintenance operations (EPA 1993). These BMPs may include:
  - Avoid ground-disturbing activities during the wet season;
  - Minimize exposure time of disturbed lands;
  - Use erosion prevention and sediment control methods;
  - Minimize the spatial extent of vegetation disturbance;
  - Maintain buffers of vegetation around wetlands, streams, and drainages; and
  - Avoid building activities in areas with steep slopes and areas prone to mass wasting events with highly erodible soils.
- Use structural BMPs such as sediment ponds, sediment traps, vegetated swales, or other facilities designed to slow water runoff and trap sediment and nutrients.
- Avoid using hard engineering structures for shoreline stabilization and channelization when possible. Use bioengineering approaches (i.e., approaches with principles of geomorphology, ecology, and hydrology) to protect shorelines and riverbanks. For

example, use native vegetation for soil stabilization. Do not alter naturally stable shorelines and river banks.

- Encourage comprehensive planning for watershed protection and avoid or minimize filling and building in coastal and riparian areas affecting EFH. Development site plans should minimize clearing and grading, cut-and-fill, and new impervious surfaces.
- Where feasible, remove obsolete impervious surfaces, such as abandoned parking lots and buildings, from riparian and shoreline areas and reestablish water regime, wetlands, and native vegetation.
- Protect and restore vegetated buffer zones of appropriate width along streams, lakes, and wetlands that include or influence EFH.
- Manage stormwater to replicate the natural hydrologic cycle, maintaining natural infiltration and runoff rates to the maximum extent practicable.
- Where instream flows are insufficient to maintain the water quality and quantity needed for EFH, establish conservation guidelines for water use permits and encourage the purchase or lease of water rights and the use of water to conserve or augment instream flows in accordance with state and federal water laws.
- Use best available technologies to upgrade wastewater systems to avoid combined sewer overflow and chlorinated sewage discharges into rivers, estuaries, and the ocean.
- Design and install proper wastewater treatment systems away from open waters, wetlands, and floodplains.
- Where vegetated swales are not feasible, install oil/water separators to treat runoff from impervious surfaces in areas adjacent to marine or anadromous waters. Ensure regular maintenance of oil/water separators to prevent clogging and support proper function on a continuing basis.

3.5.8 Freshwater Use and Inputs

An increasing demand for potable water combined with the inefficient use of freshwater resources and a changing climate have led to a reduction in freshwater habitat for fish habitats (Lennox et al. 2019). As human populations continue to increase in the U.S., water use and shortages will likely increase (Brown et al. 2019). Groundwater supplies 83 percent of Alaska's 1,602 public drinking water systems and ninety percent of the private drinking water supplies (ADEC 2008). Aquifers, which support riverine systems, also provide roughly 1,500,000 m^3 per day (330 million gallons per day) for use in domestic, commercial, industrial, and agricultural purposes in Alaska (ADEC 2008). Surface water provides drinking water to communities with permafrost and fine-textured soils that limit groundwater availability (Callegary et al. 2013).

In contrast to water removal, the addition of freshwater into riverine systems can have several sources and associated impacts. Water from storms, snowmelt, glacial retreat, human activities, etc. can change the natural system in which it enters and impact the downstream habitat. The GOA receives freshwater discharges at a yearly rate about 1.5 times the average flow of the Mississippi River (Beamer et al. 2016). These freshwater inputs will increase with climate change in some areas, like Southeast Alaska, as precipitation is predicted to increase (Lader et al.

2020a). Problems associated with increased freshwater inputs and stream flows include water temperature and salinity changes, the introduction of pathogens and toxic contaminants, and increased sedimentation. Chapter 2 (Climate Change) summarizes the potential impacts and effects of climate change on stream temperature, flow and habitat.

3.5.8.1 Potential Impacts

The diversion of freshwater, either withdrawals (reduced flow) or discharges (increased flow), for domestic and commercial uses, can impact EFH by (1) altering natural flows and the processes associated with flow rates, (2) altering riparian habitats by removing or adding water (3) altering the distribution of prey bases, (4) affecting water quality, and (5) entrapping, entraining, or impinging fish.

Water withdrawal and water inputs alter natural flows and stream processes associated with flow rates. Reduced water levels and flow speed also reduce habitat complexity by changing flow patterns, disconnecting pools, and leaving dry, exposed areas along the stream bank (Lennox et al. 2019). The loss of vegetation along the streambank and greater areas of exposed sediment can change water temperature (Kalny et al. 2017, Trimmel et al. 2018). Higher flow rates may increase habitat by increasing the area available for spawning and rearing (Lennox et al. 2019). These changes affect habitat availability, vegetation and organic materials, and fish distribution (Lennox et al. 2019, Spurgeon et al. 2019), all of which will be exacerbated with climate change (Trimmel et al. 2018).

Diversions can physically divert or entrap anadromous species. Lower water levels, through natural droughts or withdrawal for projects, can result in low dissolved oxygen levels, which stress fish and/or cause mortality (Cott et al. 2008, Mosley 2015). Due to ice cover, fish are susceptible to decreased oxygen levels from water withdrawals during the winter months. Ice limits the amount of available habitat for overwintering fish when compared with open-water periods (Cott et al. 2008). Water level fluctuations can be especially influential on the natural dispersion of larval and juvenile fish to rearing areas. Water level and temperature variations outside normal seasonal conditions can accentuate diel temperature patterns, affect primary production, affect dissolved oxygen levels, and impact aquatic invertebrates (Cott et al. 2008, Mosley 2015, Lennox et al. 2019). Sections 3.5.3 (Hardrock Mining), 3.5.4 (Sand, Gravel and Placer Mining), and 3.5.9 (Hydropower Projects) provide more information regarding impacts and recommendations for water use in large operations.

The introduction of pollutants via freshwater inputs includes road runoff, airport runoff or wastewater, and stormwater suspending contaminants (3.5.5, Roads and Transportation Corridors, 3.5.5.1 Potential Impacts). Road runoff can include fuel spills, de-icing materials, and vehicle-related inorganic debris. Airport runoff can include fuel spills, de-icing fluids, and firefighting foams. The use, pollution, and impacts from firefighting foams have limited data, but include per- and polyfluoroalkyl substances (PFAS) that have been measured in five communities[23]. While the impacts are unknown, PFAS can bioaccumulate in fish tissue when fish are exposed to contaminated waters and/or sediments (Goodrow et al. 2020). Pesticides that target arthropods, and herbicides that target invasive plants, are for agricultural crops, residential homes, commercial and industrial facilities, transportation corridors, parks, and timberlands.

[23] Alaska PFAS information at https://dot.alaska.gov/airportwater/. Accessed April 13, 2022.

While they are toxic to the species they are targeting and have an indirect effect on fish by disrupting their prey or habitat, they are also toxic to fish species and therefore have a direct impact (Macneale et al. 2010).

3.5.8.2 Recommended Conservation Measures

Responsible water utilization can help reduce domestic and commercial water usage and minimize the impacts to EFH. Prudent planning and water usage at the commercial scale also has the advantage of being cost effective. The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of domestic and commercial water use and freshwater inputs to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Design water diversion and impoundment projects to create flow conditions that provide adequate fish passage, particularly during critical life history stages.
- Avoid creating low water levels that strand juveniles and dewater redds.
- Incorporate juvenile and adult fish passage facilities on all water diversion projects (e.g., fish bypass systems).
- Install screens at water diversions on fish-bearing streams, as needed, to avoid fish entrainment. Size the screens according to the life history stage of the fish present to prevent impingement.
- Record stream flow rates before, during, and after any projects that introduce contaminated or freshwater into waterways.
- Maintain appropriate flow velocity and water levels to support continued stream functions; maintain and restore channel, floodplain, riparian, and estuarine conditions.
- Where practicable, implement water conservation measures that reduce the volume of water diverted or impounded.
- Prevent the introduction of pollutants or debris at the entry points. Temporary blockages should be removed at the end of construction activity.
- Regularly monitor project construction sites for any leaks or pollutants that could enter the watershed and have a restoration strategy in place. Maintain or restore the water quality necessary to support fish populations by monitoring and adjusting water temperature, sediment loads, and pollution levels.

3.5.9 Hydropower Projects

Dams are a major contributor to habitat alteration and fragmentation on the landscape. Many dams in the U.S. eliminate EFH by blocking fish passage and altering habitat and flow conditions. Alaska has thousands of streams with hydropower development potential without obstructing fish passage. However, some existing hydropower facilities do prevent migration of Pacific salmon. These projects may affect fish passage, spawning flows, egg incubation flows, and juvenile rearing flows that are necessary for salmon to complete the freshwater portion of their life history. Regulators and hydropower developers also need to consider the impacts from stream flow alteration.

Existing hydropower facilities need to renew their federal license based every 30 to 50 years. The FERC relicensing process under the Federal Power Act (FPA) has several distinct opportunities for agency and public comments, from scoping to the final NEPA analysis document. At the initial agency-scoping meeting, resource agencies should explain that FPA Section 18 fishway prescriptions are mandatory conditions of the licensing process. Resource agencies, such as NMFS, can provide comments early in the licensing process that inform the design of fish passage facilities (NMFS 2022a). The FPA licensing process can be used to fulfill the EFH consultation requirements (50 CFR 600.920(a)(2)).

The most effective tools to protect salmon habitat from the effects of hydropower development are FPA Section 10(j) recommendations to protect fish habitat and FPA Section 18 to allow fish passage to that habitat. For Alaskan projects, FERC typically adopts Section 10(j) recommendations as hydropower license conditions. FERC has the option to modify or reject the 10(j) recommendations. NMFS can provide identical recommendations as EFH CRs under MSA. The FPA Section 10(j) recommendations and EFH CRs are both mechanisms to protect fish habitat. However, FPA is generally a more effective tool than EFH CRs for hydropower projects.

In support of effective CRs, study requests should be filed with FERC that clearly connect the study with project related impacts and how the data derived will inform the decision-making process. Further, the resource agencies and the hydropower developer should ideally come to agreement on specific measures, including fish passage and seasonal flows, before the mandatory conditions and recommendations are filed on the FERC docket. This avoids conflict between the resource agencies and the hydropower developer, as well as avoiding competing recommendations from multiple agencies.

3.5.9.1 Potential Impacts - Anadromous Fish Passage

Hydropower projects on anadromous waters should provide safe, timely, and effective passage such that the project is "invisible" to migrating fish. Projects blocking adult upstream passage decrease the spawning and rearing area available to one or more species of salmon. This leads to fewer redds, fewer juveniles rearing, and fewer adult salmon in the ocean.

Downstream passage of juveniles through facility works, such as turbines and sluiceways, may result in mortality. Specific modes of injury include pressure differential created by the drop height, the type of turbine, shear stresses, and the presence of predators. These all affect the percentage of smolt survival at hydropower facilities (Hogan et al. 2014, Trumbo et al. 2014, Mueller et al. 2020). Barotrauma results from changes in pressure: less than 20 m (66 ft) of head differential injures fewer juveniles; over 40 m (132 ft) of head differential causes greater juvenile mortality. Direct blade strike sometimes inflicts an immediately fatal wound, although delayed mortality from internal injuries is also common. Many studies of the effects of turbines on juveniles have not included a mechanism to measure delayed mortality. New turbine designs with thicker blades create hydraulics that push more smolt out of the way. Turbines with slower rotations reduce mortality. Hydraulics within the turbine and shear stress disorient juveniles making the stunned juveniles easy prey for both predatory fish and predatory birds that congregate near the tailrace pool.

In support of the decision-making process, a lifecycle model should be requested during the study request period for each species to determine the percentage of the population potentially lost at each stage of a salmon's life that will not limit the long-term productivity of the population (Hendrix et al. 2017, Stich et al. 2018). High survival of outmigrating juveniles is critical to population robustness.

3.5.9.2 Potential Impacts - Water Flow and Temperature

The six critical functions of instream flows facilitate salmon to complete their freshwater life cycle are: adult spawning, egg incubation, juvenile rearing, channel maintenance, water temperature regulation, and stranding avoidance. Impounding water with a dam and withdrawing it from a river for energy generation can affect these six functions. The following is a list of potential adverse impacts to instream flows from hydropower projects.

Following each impact are considerations to evaluate appropriate EFH and Section 10(j) CRs, and potentially support FPA Section 18 fishway prescriptions. Developing the appropriate CR and fishway prescriptions and filing supporting documentation on the appropriate FERC docket is key to influencing the FERC licensing process and the final license conditions.

(i) Flows for Migration and Spawning

Hydropower operations may affect instream flows and impede or eliminate migration and spawning. After successful migration, instream flows above spawning gravels must provide sufficient depth over the gravels to submerge females. These spawning flows must always be provided for streams with Chinook, coho and chum, and most often be considered for streams with pink, and sockeye, as some populations of sockeye salmon spawn in rivers (Quinn 2018). Pink salmon often spawn in estuaries significantly downstream of the hydropower facility. The following information will support the assessment of project related impacts related to migration and spawning flows:

- Determine which species are present in the river and the water depth required for spawning using the *Anadromous Waters Catalog* or a FERC required study.
- Determine the date range during which anadromous species have returned to the river or a similar sized local watershed in the last decade. Salmon often move up river in pulses (Quinn 2018) so the goal is for the date range to encompass all major pulses.
- Many salmon stocks migrate from the ocean to their natal spawning ground and immediately spawn. Other stocks are premature migraters (Quinn 2018) and may mature, feed, or just hold in deep pools prior to spawning. Section 10(j) recommendations benefit from site specific information.
- Conduct visual surveys for redds to identify occupied spawning areas and potential future spawning areas. Complete spawning surveys in at least two different years as the different run years may use different spawning gravel (Brennan et al. 2019).
- Develop river hydraulics models for a channel's geometry to include depths and velocities at a range of discharges over the identified spawning areas. Stream transects that inform the model should be closely spaced in river reaches with spawning redds.

(ii) Flows for Egg Incubation

Incubation flows submerge salmon redds, thereby delivering oxygenated water to the eggs during their incubation period (fall-winter) and the flows prevent the eggs from freezing. To supply oxygenated water and remove carbon dioxide, water must move through the hyporheic zone (stream gravels) (Boulton et al. 1998). Larger bodied salmon have larger eggs and need more water movement through the gravel (Quinn 2018). While eggs can survive at lower dissolved oxygen concentrations, Chinook alevin need 6 milligram per liter dissolved oxygen (Groves and Chandler 2005). Hydropower developers rarely provide sufficient data to understand the hyporheic zone flow vectors; however, if lateral shallow groundwater flows into rivers can be empirically demonstrated all winter, and contain sufficient dissolved oxygen, these flows could supplement oxygenated water to salmon redds (Boulton et al. 1998). Lateral groundwater flows allow sockeye to spawn at some lake margins. Utilities often request to use the Tennant method (Tennant 1976) which is simply leaving a percentage of the natural flow in the river each month. This method does not consider the lifecycle needs of the species that are present. The following information will support the assessment of project related impacts related to instream flows supporting egg incubation.

- Use a river hydraulics model to determine the flows required to submerge known redds. Some portion of stream discharge will be flowing through the gravels. This promotes egg growth. Additional flow discharge may be required beyond the model output because river hydraulic models treat the stream bottom as impermeable, which is not the case in rivers with salmon.
- Field-verify the modeled low winter flows actually submerge the gravels used for spawning.

(iii) Flows for Juvenile Rearing Habitat

Chinook, sockeye, coho, and chum salmon need lower velocity areas for juvenile growth during the summer. Chinook and coho need winter rearing habitat (Davis 2013). Most pink juveniles immediately swim downstream and eat little prior to arriving in the estuary, where they rear for a few weeks (Groot 1991). The capacity of a stream for incubating embryos is far greater than its capacity for sustaining juveniles (Quinn 2018). Ideal juvenile habitat has lower velocities, a food source, and slightly warmer water (but not too warm). Rearing habitat exists in stream margins, side channels, sloughs, and occasionally, in the main channel behind large rocks or woody debris that create eddies. Hydropower operations can affect all these flow related habitat attributes through diversions, pulse releases, and other project activity. The following information will support the assessment of project related impacts related to juvenile rearing habitat.

- Conduct field studies to determine where juveniles rear during the summer. Repeat these studies in the winter for streams that contain Chinook or coho.
- Use a river hydraulics model to determine if a given flow will provide sufficient depth in the sloughs and side channels and allow juveniles access. Sloughs and side channels can be important rearing habitat; however, they can also trap juveniles if access to the main channel severs and the slough warms or freezes.
- Use physical habitat simulation models based on recommended flow levels to assess potential new channel areas that will provide the attributes necessary for juvenile rearing under the proposed future flows. Correctly calibrated and validated models are an approximate representation of future river conditions.

- Target flows that inundate several areas that may, based on field surveys, provide good juvenile habitat in each river reach.

(iv) Flows for Channel Maintenance

Hydropower operations affect seasonal flows that support EFH and overall habitat functions and values. Spawning gravels and side channel rearing habitat appear static during a single summer; both are impermanent habitats that need higher flows for maintaining their function (Kondolf et al. 2000). An armor layer of large, cemented cobbles can develop on the stream bottom. This armor layer inhibits salmon from accessing the appropriately sized gravel below and therefore prevents spawning. Over time, fine particles imbed themselves in spawning gravels, greatly reduce the circulation of oxygenated water; thereby retarding egg development. Alevin may not be able to emerge from the gravel if those gravels contain excessive amounts of 0.01 - 0.1 centimeter (cm) (0.04 – 0.39 in) particles (Kondolf et al. 2000). While hydropower operations can attempt to maintain spawning gravel with periodic releases and/or gravel augmentation, natural high flows are generally better for sustaining habitat. Channel maintenance flows can reverse armoring processes that render otherwise suitable habitat as unusable for spawning. In all natural rivers, a variety of large flows play a critical role in maintaining salmon habitat. In the absence of large flows, riparian vegetation encroaches on side channels and sloughs and eventually they become a meadow, and the riparian sediment characteristics shift. The following information will support the assessment of project related impacts related to maintaining channel habitat complexity.

- A single, optimum, channel-maintenance flow does not exist. Ideally, the stream channel will experience a variety of large flows over the license term. Two, five, and 10-year recurrence flows flush the fines out of gravels by reshuffling the gravels and cobbles, importing new gravel, and reconnecting side channel habitat. A 20-year recurrence flow may import the larger cobbles Chinook prefer, but scour out shallower coho redds. Conversely, a 5-year recurrence flow may refresh the gravels coho rely on, however, it will neither budge nor clean out the larger cobbles chinook needed for spawning.
- Fifty and 100-year recurrence events have the potential to scour out all redds and negatively affect an entire cohort of juvenile fish.
- Rivers that carry large amounts of fine sediment, such as glaciated watersheds, may need more frequent maintenance flows to support spawning and egg incubation.
- Hydropower operators generally do not have trouble meeting the channel maintenance flows as rain-on-snow events frequently meet and exceed the required flow (Sergeant et al. 2020, Curran and Biles 2021).

(v) Flows to Regulate Water Temperatures

Hydropower projects with storage dams alter water temperatures potentially causing salmon mortality. High temperatures will impede spawning in Alaska in the future (Shaftel et al. 2020). Temperatures above 13°C (55.4 °F) are lethal to eggs, and temperatures above 18°C (64.4 °F) are detrimental to spawning and rearing salmon (Mauger et al. 2017). FERC required a variable depth intake structure and specific outflow temperatures in the Grant Lake License (P-13212). The following information will support the assessment of project related impacts related to maintaining a thermal regime suitable for migrating, spawning and rearing salmon.

- Each salmon species and individual population has a temperature where spawning is reduced and a higher temperature where it stops completely (Martins et al. 2012a, Martins et al. 2012b). When water is released from the hydropower facility, it must be below the temperature where spawning is impacted. For a long, shallow river the water might warm between the hydropower release site and the redds.
- Hydropower facilities with variable elevation intakes can control water release temperature. Water temperatures flows through redds can be managed where a mixture of dam released water and tributary water mix.
- Eggs need to hatch and alevin need to emerge from the gravel on an optimal date for growth and survival (Quinn 2018). Marine survival depends heavily on the size of the juvenile and the date of entry into the ocean (Quinn 2018). Ideal hatch date is when food is available in the stream. Projects should maintain the natural level of degree days of incubation to support timely juvenile development.
- Juvenile salmon grow faster in side channels and sloughs that are warmer and have lower velocity than the main stem. During the warmer months, release sufficient flows to maintain at least periodic water exchange between the side channels and sloughs, and the cooler main channel.
- Record water temperature every 15 minutes. This is feasible with in-situ temperature loggers for a relatively low cost. Deployment of temperature loggers should include several summers and spatial variability in crucial habitats across reaches, channels, and sloughs. Next, select one or two average or high temperature locations and construct a telemetry system to convey those temperatures to the hydropower operators or to the supervisory control and data acquisition system. This real time data can support protocols for when temperatures reach levels that impede salmon life processes.

(vi) Flows that Result in Fish Stranding

Restricting ramping rates helps prevent stranding of fish as a result of abrupt flow reductions or flushing fish downriver with rapid flow increases (Hunter 1992). The following information will support the assessment of project related impacts related to ramping and operations that result in fish stranding.

- Maximum down ramping rates are usually limited to 3 to 5 centimeters (1.2 to 2.0 inches) per hour. Maximum down ramping rate can also be expressed as a maximum flow decrease or a percentage of the existing discharge.
- When evaluating the effects of down ramping, specify a location where that stage is measured and the acceptable stage changes over what duration. An existing USGS gage station is an ideal location as there is already a trusted third party measuring stage.
- Stage recording devices often provide imprecise data as waves propagate across the water surface making it not flat, especially in steep streams experiencing flood conditions.
- To determine the maximum up ramping rate, study the 15-minute USGS data from frequent storm events and see how fast the river stage naturally rises. The salmon population has likely evolved to survive these quick up ramping rates. Up ramping rate can be less restrictive than the down ramping rate.

- The rates of change, stage measurement location, and instrument type should be determined in consultation with the hydropower operator.

3.5.9.3 Recommended Conservation Measures

The following recommended conservation measures should be considered during the EFH consultation and for the FPA licensing process (Sections 10(a), 10(j), and 18) to avoid and minimize adverse impacts of hydropower structures that impede fish passage.

(i) General Recommendations

- Consider siting hydropower facilities in locations that avoid or minimize effects to anadromous fish.
- Water withdrawals should return flow back into the river at or above the highest point of anadromy (e.g., reduce the length of river reach bypassed) to support a suitable zone of passage for adults and juveniles.
- Site the intakes in deeper water to decrease entrainment. Juveniles tend to swim in the upper half of the water column.
- Read through the six critical functions of flow on EFH (Section 3.5.9.2 Potential Impacts - Water Flow and Temperature) and then request/design studies during the FERC pre-licensing period that will determine what the potentially impacted fish population needs. Review those six critical functions for each project. Once the applicant has completed the studies, use that information to draft EFH CRs and/or Section 10(j) recommendations under the FPA.
- Site conditions and species present should be evaluated to determine if a minimum flow release is required to support Pacific salmon migration, spawning, and rearing.
- Recommend minimum flows that submerge eggs for all 12 months. Hydropower facilities in Alaska generally do not operate or withdraw water mid-winter because there is insufficient flow. Therefore they do not need to worry about affecting redds. Climate change trends may cause hydropower developers to seek to increase operations over a greater portion of the year.

(ii) Fish Passage

- Provide upstream and downstream fish passage facilities that will provide volitional passage past the barrier for all anadromous species.
- Fishway designs should incorporate features specific to the target species.
- The fishway design should provide sufficient water to ensure safe, timely, and effective passage past the project. This includes proper depth, volume, and velocity.
- Use suitably designed screens on the intake to avoid entraining and impinging juveniles.
- Seasonal shutdown of turbines during the juvenile outmigration period supports safe passage past the project.

- Downstream bypass discharge below the project should consider design features that reduce the risk of predation. Predator control will be an ongoing challenge as predators respond to prey availability.
- Incorporate future climate change considerations into engineering designs of fish passage facilities (NMFS 2022b).

(iii) Flows for Migration and Spawning

- Identify flows for the duration of the migration window in which 95 percent of salmon will return. This will likely provide sufficient spawning flows for the majority of spawners every year. In Alaska, some salmon populations have multiple runs in a single year (Groot 1991) and coho runs can extend over several months.
- Include a consultation process with the resource agencies to evaluate changes to the migration and spawning date range. The FERC licenses are for 30 to 50 years and changing ocean and stream temperatures are altering salmon return/spawning dates.

(iv) Flows for Juvenile Rearing Habitat

- Recommend adaptive management plans for modifying minimum flows such that if the juveniles fail to use targeted rearing habitat at a given flow release, the discharge may change or physical changes to the channel may be implemented.

(v) Flows for Channel Maintenance

- Recommend seasonal flows that support channel substrate and complexity maintenance. Complex channels are maintained by a widely varied hydrograph. The ideal magnitude, duration and periodicity of channel maintenance flows is different for every river. Salmon prefer to spawn in complex channels, with uneven bed slopes, large bars, and complex eddies likely because these features create areas of downwelling and upwelling through the gravels (Brunke and Gonser 1997).
- In each 10-year period post license, provide flows in two different years that exceed a minimum flow (based on Instream Flow Incremental Methodology or similar study) of a minimum duration (as supported by the administrative record).
- Climate change is increasing the magnitude of most recurrence events. Evaluate U.S. Geological Survey (USGS) flood frequency curves for stationarity provided the river has at least a 20-year gage record.

(vi) Flows to Regulate Water Temperature

- For each month of the year set high and low temperature limits for water hydropower facilities returned to the stream that allows for adult spawning, egg incubation, and juvenile rearing to continue unimpeded.
- Provide a mechanism for periodic resource agency consultation for realistic target temperatures.
- The release water temperatures should remain within a natural degree range for that river (0.5 - 6 °C [32.9 – 33.1 °F). If the recommendation range is too narrow, it will lead to minor violation that do not usually affect egg survival. Accumulated thermal units needed to incubate a salmon egg are known for southeast Alaska population, and

somewhat known for western Alaska populations (Groot 1991). Use accumulated thermal unit data from a relevant region of Alaska.

- Monitor water temperatures in juvenile habitat during the summer. If this monitoring indicates temperatures in the slough are approaching detrimental levels, the operator would be required to release more cool water to promote more water influx from the main channel.

(vii) Flows to Prevent Fish Stranding

- River stage at a specified location should not decrease by more than 3 cm (1.2 in) per hour.
- River stage should not increase by more than 5 cm (2 in) per hour.

3.5.10 In-River Hydrokinetic Energy Converter

In-river HEC generate electricity from the free movement of water without a dam. HEC devices tested in Alaska are bottom-mounted structures that resemble the blades on a combine that harvests wheat. They turn based on differential pressure as water flows across their blades. They are designed to spin faster than the current is flowing and can be positioned at specific depths. HEC technology largely remains at the research and development stage. An HEC unit is located on the Kvichak River at Igiugig[24][25]. It is being evaluated for economic viability and potential impacts to fish.

Because there is no water control or diversion, fish are not forced through the turbine; however, there have been a limited number of studies evaluating fish passing next to, over, or through HECs (Zydlewski et al. 2010, Viehman 2016, Viehman and Zydlewski 2017). Several factors make it challenging for humans or artificial intelligence to evaluate the risk of injury or mortality to fish, including technology limitations, turbidity, and sampling techniques. Section 4.4.15 (Marine Hydrokinetic Energy Converters) provides a discussion of marine HEC technology.

3.5.10.1 Potential Impacts

The physical presence of HECs alters the habitat within the project footprint. Since they are designed for high energy habitats, there is potential for impacts to the surrounding environment. In-river HECs sit on the substrate, occupying habitat supporting natural ecological functions. Future HEC designs may include monopoles, anchors, lines, buoys, and other apperenture features supporting operations. Cables extend from the HEC unit to the shore requiring a “landing” at the shoreline. Cables are typically buried at this landing site to protect it from weather and wave action. HECs have the potential to introduce chemical discharge (lubricant spills, anti-fouling leachate, etc.) into the environment.

In-river turbines could potentially harm returning adult salmon, however, this has not been observed. The turbines are typically located in the strongest currents, and the returning adults generally swim up the sides of the river, where the current is weaker, to conserve energy.

[24] The Igiugig Project (P-13511).
[25] In addition to the Igiugig Project, FERC lists only one pending preliminary permit for an HEC project nationally (Filter Bend HK Energy, P-15283) as of this publishing.

Additionally, adults are moving slowly upriver and may choose to avoid unfamiliar structures like an in-river turbine.

In-river turbines could strike and potentially injure or kill juvenile salmon, however, this too has not been observed. The blades are typically rotating slower than turbines in traditional hydropower facilities. The level of injury caused by slow blade strike related to an in-river HEC unit has not been determined. Cameras have shown some juveniles that swim through a turbine flip to unnatural swim positions. From the underwater videos, researchers cannot determine if the blade actually touched the fish or if the hydraulics created by the unit's blade flipped them. We also do not know how quickly the flipped fish returns to regular orientation. Conversely, a few juveniles swim through turbines with no effect on their trajectory at all. These individuals are mostly likely not injured.

The vast majority of juvenile sockeye leave Iliamna Lake under the cover of darkness or dusk. In June, this is from about 12:00 to 3:00 A.M. Alaska Standard Time. Juveniles prefer to stay in the fastest current. This tends to be slightly below the surface and in the upper half of the water column. The presence of fish, avian, or human predators could cause these juveniles to "sound" and go deeper, which would lead them into contact with the spinning turbine. The currents in Alaska's large rivers are so swift that even if a juvenile can recognize a turbine as dangerous, the majority cannot swim fast enough to avoid the turbine.

For the most current environmental information regarding HEC impacts and the HEC industry generally, the Pacific Northwest National Laboratory hosts a data repository for HEC and wind energy technologies[26]. The current state of the science has been reviewed in recent years for marine HEC technology (Copping et al. 2016, Copping 2018, Copping et al. 2021)

3.5.10.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of in-river HEC turbines to EFH and Pacific salmon, and to promote the conservation, enhancement, and proper function of EFH. Section 4.4.15 (Marine Hydrokinetic Energy Converters) provides additional CRs applicable to in-river HECs.

- Stop the HEC turbines or put them in slow mode during the hours out migrating juvenile fish are expected pass the project. Studies may be necessary to develop this site specific information.
- Situate HEC units in the lower 25 percent of the water column to decrease the chance of juvenile fish coming into contact with them.
- Minimize the total cross section area of the HEC turbines to give juvenile fish more routes to pass safely.

[26] Environmental Effects of Wind and Marine Renewable Energy https://tethys.pnnl.gov

Chapter 4 Estuaries and Nearshore

4.1 Introduction

Coastal zones comprise some of the world's most ecologically productive and biologically diverse ecosystems (Sheaves et al. 2015). This land-sea interface provides a complex and dynamic exchange of energy, water, nutrients, sediments, and organisms (Gleason et al. 2011). In this chapter we focus specifically on estuaries, landscape features where watersheds meet the sea. We also focus more broadly on the nearshore marine environment, defined here generally as the area from the high tide line to 20 m (60 ft) depth, which can be further characterized by intertidal and subtidal zones.

4.2 Alaska Metrics

Alaska's coastline is over 70,000 km (44,000 mi). The surface area of coastal bays and estuaries in Alaska is approximately 53,448 km^2 (33,211 mi^2), nearly three times the estuarine area found in the lower 48 states (Saupe et al. 2005). These estuaries and nearshore zones have highly variable water conditions, physical and biological processes, salinity, geomorphology and substrate types, and complex trophic dynamics; each are subject to significant seasonal climate and environmental influences (Baker et al. 2011). Marine- and terrestrial-driven influences fuel the rich biodiversity within these coastal zones (Caddy and Bakun 1995, NMFS 2013). Large coastal watersheds provide significant volumes of terrestrially-derived nutrients and sediments to estuaries and nearshore areas, which in turn provide habitat complexity, prey, and support biodiversity (Hall 1988). Of the 30 coastal and nearshore zones identified in Alaska, 17 are distinctly associated with estuarine complexes within arctic, subarctic, and temperate climate and oceanic influences (Piatt and Springer 2007).

Alaska's extensive coastline provides a diversity of terrain features from sheltered bays to exposed rock outcrops (Alaska ShoreZone[27]). Many combinations of substrate types are along beaches and at subtidal depths, including amalgams of muds, sands, pebbles, gravels, cobbles, and boulders. In some regions there are expansive micro- and macro-algal beds, eelgrass meadows, and kelp forests (Spurkland and Iken 2011). Seasonal ice scour in Arctic regions of Alaska shape the nearshore benthic habitat (Conlan et al. 1998). Sea ice has a fundamental role

---

[27] Alaska ShoreZone website: https://www.fisheries.noaa.gov/alaska/habitat-conservation/alaska-shorezone.

in the biochemical and physical processes. Spring sea ice melt releases trapped algae and nutrients in estuarine and nearshore habitats providing essential nutrition to larval and juvenile species (Sigler et al. 2014, Lowry et al. 2018).

The following sections describe the landscape structure and coastal regions of Alaska's LMEs.

4.2.1 Gulf of Alaska

Figure 5. Eelgrass (*Zostera marina*) in Prince William Sound. Published in *Coastal Impressions, A Photographic Journey along Alaska's Gulf Coast*; A.P.J., 2012.

The GOA stretches west from the Alaska Peninsula near Kodiak Island to the southern tip of Prince of Wales Island. Its northern boundary is the coast of Alaska and the southern extent is a line from the southern end of Kodiak Island to the Dixon Entrance. It includes Cook Inlet, Prince William Sound, the Copper River Delta and the 400-mile long Alexander Archipelago. In southeast Alaska, the Alexander Archipelago has over 2,900 estuaries encompassing a total surface area of 30,721 km^2 (11,861 mi^2) (Albert and Schoen 2007). At 1,181 hectare (2,900 acres), the Stikine River Delta is the largest of these estuaries. The GOA includes two large estuary systems: Cook Inlet, which is approximately 370 km^2 (230 mi^2) with the second largest tidal range (12 m [39 ft]) in North America, and Prince William Sound covering over 9,000 km^2 (5,600 mi^2). Prince William Sound is a glacially carved system with a convoluted coastline that is approximately 4,500 km (2,800 mi) in length (Saupe et al. 2005). From southeast Alaska to the end of the Alaska Peninsula, there are thousands of miles of coastline inside sheltered and semi-enclosed bays. The ten largest estuaries of the Alexander Archipelago encompass 30,985 hectare (76,747 acres) of habitat supporting salt marsh, mudflat, and algal bed communities (Carstensen 2007). The extensive 48,000 km (29,800 mi) of coastline provides ideal habitat for canopy kelps and understory macroalgal communities, which occur from the splash zone in the very high intertidal zone to approximately 30 m (90 ft) depth (Lindstrom 2009). Eelgrass beds in Alaska are distributed along sheltered portions of the coastline from southeast Alaska to the Seward Peninsula (ADFG 2006).

In the southcentral GOA, the Copper River Delta, encompassing 500 km^2 (311 mi^2) of intertidal mudflats with extensive inland wetlands, serves as feeding and rearing grounds for a variety of migratory species (e.g., seabirds and salmonids) as well as resident demersal species (e.g., Dungeness crabs [*Cancer magister*]) (Powers et al. 2002). The Copper River provides the largest source of freshwater, sediment load and terrestrial nutrients to the delta. The Copper River delivers 62 million metric tons (69 million tons) of suspended sediments annually to the delta from its 63,000 km^2 (24,324 mi^2) drainage basin (Brabets 1997).

4.2.2 Aleutian Islands

The Aleutian Islands are a long, porous arc consisting of over 300 small, volcanic islands extending 2,260 km (1,404 mi). This arc has a narrow continental shelf with steep slopes separated by deep-water passes. The bathymetry changes dramatically from the depths of the Aleutian Trench to sea level in a distance of less than 150 km (93.2 mi), providing dramatic variety of habitats (NPFMC 2007, 2020). The north-south width of the continental shelf also varies east to west from 4 km (2.5 mi) to less than 80 km (49.7 mi) east of Samalga Pass (NPFMC 2007, 2020). These landscape features influence tidal mixing between the shallow, colder Bering Sea and the deep, warmer Pacific Ocean. This mixing of waters (deep and shallow, warm and cold) provides marine nutrients to fuel complex food chains that support rich marine biodiversity. A species and diversity habitat gradient appears in local food webs along the Aleutian chain with Atka mackerel (*Pleurogrammus monopterygius*), Pacific cod, and neritic zooplankton being prominent to the west of the deeper passes, and walleye pollock and oceanic zooplankton being more frequent to the east (Hunt and Stabeno 2005, Logerwell et al. 2005, Neidetcher et al. 2014).

4.2.3 Eastern Bering Sea

The largest embayments in the Bering Sea are Norton Sound and Bristol Bay, which themselves consist of many smaller estuaries. There are a multitude of smaller estuarine embayments draining coastal watersheds such as the Kuskokwim and Hazen Bays. One of the largest Alaskan riverine deltas, the Yukon, flows into Norton Sound, whereas the second largest river, the Kuskokwim, flows into Kuskokwim Bay (Kammerer 1990, Brabets et al. 2000). The Nushagak, Kvichak, and Wood Rivers are three of the largest rivers draining into Bristol Bay (WWF and TNC 1999, NMFS 2013).

The largest salt marsh complex, the Yukon-Kuskokwim Delta in the Bering Sea, encompasses over 40,469 km^2 (15,625 mi^2) (Glass 1996). On the Alaska Peninsula in the southern Bering Sea, the Izembek Lagoon contains the largest eelgrass bed (160 km^2 [62 mi^2]) in the world (Tippery 2013). Eelgrass cover dominates approximately 31,000 hectare (76,600 acres) or 91 percent of the SAV on the lower Alaska Peninsula (Hogrefe et al. 2014).

Bristol Bay is notable for supporting one of the richest fish nurseries. Bristol Bay comprises numerous smaller bay and estuary complexes, including Nushagak and Kvichak Bays, Togiak and Kulukak Bays in the north, Egegik and Ugashik Bays in the south, and numerous other semi-enclosed bays along the Alaska Peninsula shoreline (NMFS 2013). Bristol Bay is comprised of a wide range of benthic substrate ranging from muds, clays and silts, to fine grained sands and course grained gravels. Gravels and sands tend to dominate nearshore zones while finer grained sands, silts and muds tend to dominate as depth and distance increases from the inner bay influences of tides and river outwelling. This grading is particularly noticeable in Bristol Bay and immediately westward. The condition occurs because settling velocity of particles decreases with decreasing particle size (Stokes Law), as does the minimum energy necessary to re-suspend or move them (Smith and McConnaughey 1999).

4.2.4 Arctic

Much of the nearshore coastline of the northern Bering Sea, with the exception of part of the Seward Peninsula, is mostly shallow with offshore bars and lagoons. Sand and silt are the primary components over most of the seafloor of the Bering Sea, with sand predominating in waters at a depth of less than 60 m (197 ft) (NMFS 2004, NPFMC 2020). Seasonal ice cover in the northern Bering Sea, north of Nunivak Island, generally begins in November and often increases to greater than 80 percent coverage of the continental shelf during its maximum extent in late February or early March. Shallow water nearshore zones exposed to the seasonal influence of sea ice can be heavily scoured and may provide little beneficial habitat to the early life history stages of fish and invertebrates.

Numerous estuaries exist where watersheds meet the Chukchi and Beaufort Seas. In the Chukchi Sea, Kasegaluk Lagoon is over 190 km (120 mi) long and 8 km (5 mi) wide, and Kotzebue Sound is 160 km (100 mi) long and 110 km (70 mi) wide. In the Beaufort Sea, the Colville River Delta near Prudhoe Bay spans over 40 km (25 mi) in width with its shallow waters (< 3 m [10 ft]) extending 16 km (10 mi) or more offshore (NMFS 2015). The adjacent Canadian Mackenzie River Delta (12,170 km [7,562 mi] long) also provides a vast majority of the freshwater input to the Beaufort Sea (Dunton et al. 2012, Casper et al. 2015).

In northern regions of Alaska, the seasonal influence of ice, tides, currents, storm surge, and wave energy severely limits suitable shallow nearshore habitat complexity. This is evident along Arctic and subarctic coastlines and seasonally as far south as Bristol Bay (Weingartner et al. 1998, Gutt 2001). Survival at life stage of marine species reduces under these conditions. In contrast, deeper nearshore habitats below the influence of ice scour remain unaffected along with the vast majority of Alaska's coastline and sheltered bays in subarctic zones and farther south.

4.3 Physical, Chemical, and Biological Processes

The MSA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity" (16 U.S.C. 1802(10)). EFH not only includes water and hard substrate but also habitat and ecosystem processes that provide water quality, quantity, and nutrient resources essential for survival. The following discussion provides an overview of the physical, chemical, and biological processes related to estuaries and nearshore habitat that support EFH.

4.3.1 Estuaries and River Plumes: Dynamic and Valuable EFH

River systems throughout Alaska contribute to estuaries that are important habitat for early life stages of FMP species, including the Copper River in the GOA; the Kenai River in southcentral Alaska; the Nushagak, Kvichak and Wood Rivers in Bristol Bay; the Yukon River in the Bering Sea; and the Mackenzie River in the Arctic, among others. Rivers entering the coastal zone are important contributors to the physical, chemical, and biological processes (Osadchiev and Yankovsky 2022). River plumes influence mixing processes, salinity, heat, sediment load, nutrients and other habitat characteristics that support EFH.

Estuaries and associated river plumes comprise EFH that is particularly valuable for supporting early life stages of FMP species. Estuaries are critical links that transfer DOM and nutrients between terrestrial and marine ecosystems, supporting estuarine and nearshore food chains. High concentration of suspended terrigenous detritus and sediments result in high turbidity and provide refuge from predators for many fish and invertebrate species (Litz et al. 2014). This refuge increases residence times, increases growth rates and biomass, and collectively enhances biological production and diversity (Kudela et al. 2010).

In addition to seeking refuge, forage and anadromous fish species can take advantage of ample feeding opportunities in estuaries and river plumes nearshore (Campbell et al. 2011, Litz et al. 2014). Surveys of Alaska estuaries indicate abundant invertebrate prey species, including

Euphausiids, amphipods, copepods, pteropods, chaetognaths, and polychaetes (Turek et al. 1987, Moulton 1997, Radenbaugh 2010, Radenbaugh and Pederson 2011, Hartwell et al. 2016). An abundance of size-appropriate prey availability at these trophic levels is essential to the fitness and survival of larval and juvenile fish (Beamish and Mahnken 2001, Beamish et al. 2004, Moss et al. 2005, Farley et al. 2007, Farley et al. 2011). Taken together, these attributes underscore the crucial role of estuaries as EFH supporting early life stages of fish species in Alaska.

Estuaries are particularly important habitats for juvenile salmon. In addition to increased feeding and refuge opportunities, these estuaries allow for osmoregulatory adaptation between the marine and freshwater zones. Alaskan juvenile coho salmon will move between marine and freshwater habitats to take advantage of abundant prey opportunities (Hoem Neher et al. 2014).

4.3.2 Nearshore Habitat: Important Fish Nurseries

Figure 6. Scientists from Ted Stevens Marine Research Institute conducting nearshore Surveys.

Alaska's estuaries and nearshore areas contribute approximately 15 percent of the total landed weight and 32 percent of the total dollar value of commercial landings in the state (Arimitsu and Piatt 2008, Lellis-Dibble et al. 2008, Johnson et al. 2012). While adult stages of many commercially important species spawn in offshore waters, ocean currents transport their eggs, larval and juvenile stages to nearshore habitats (Nichol 1998, Coyle and Pinchuk 2002, Wilderbuer et al. 2002, Dew and McConnaughey 2005, Norcross and Holladay 2005, Lanksbury et al. 2007, Cooper et al. 2014, Hurst et al. 2015). These early life stages settle in a variety of rearing substrates and habitat types that provide increased refuge and forage, and decreased predation risk. As many fish grow, they gradually return offshore, where they are caught as adults in commercial fisheries (Gillanders et al. 2003, Able 2005, Brown 2006, Lanksbury et al. 2007, Laurel et al. 2007, Hurst et al. 2015).

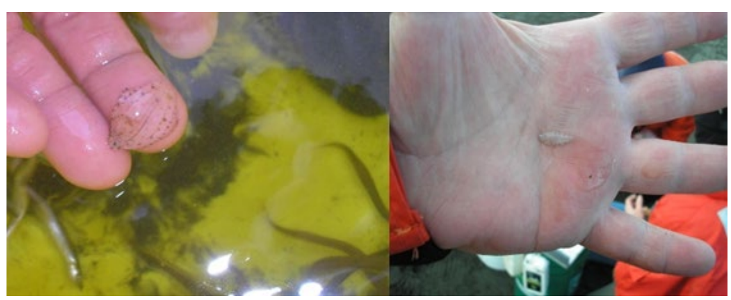


Figure 7. Young-of-year (larval) flat fish captured in near shore surveys in Resurrection Bay. Displayed on scientists' hands for context.

Field surveys in Alaska confirm that nearshore areas are important nurseries for early life stages of FMP species and their prey. A majority of species caught in nearshore surveys are in larval, juvenile and subadult life stages. Walleye pollock, pink salmon, and chum salmon are among the most common FMP species observed in surveys supporting the Nearshore Fish Atlas of Alaska database. These nearshore surveys and others have also identified the presence of ecologically important forage fish species in these early stages, including Pacific sand lance (*Ammodytes hexapterus*), Pacific herring (*Clupea pallasii*), Pacific sandfish (*Trichodon trichodon)*, and capelin (*Mallotus villosus)*. Nearshore fish communities are often characterized by strong seasonality in abundance and species composition, driven by the arrival of age-0 fish (Ormseth et al. 2016).

Although several FMP species inhabit the nearshore in early life history stages, less is known about the specific EFH attributes and ecosystem processes supporting their presence and success in these rearing habitats. The Nearshore Fish Atlas of Alaska database provides information on nearshore EFH and fish presence by habitat types, resulting from nearshore surveys. NMFS AKR has invested in keeping the Nearshore Fish Atlas of Alaska database up to date with a recent expansion in 2021. NMFS AKR also supports ecological process studies of species in estuaries and nearshore habitats (e.g., Laurel et al. 2016), and is developing species distribution models to map nearshore EFH for FMP species and their prey (Grüss et al. 2021).

4.4 Sources of Potential Impacts and EFH Conservation Recommendations

Alaska's human population centers are sparse, as most areas are not accessible or linked by a continuous road system. Further, communities 'boom and bust' as resource developments and their associated industries rise and fall. A large portion of Alaska's population resides near the state's coastline (NMFS 2010). Historically, coastal features such as estuaries and embayments have been ideal for fishing, farming, and hunting and have provided sheltered waters with transportation access to rivers and the ocean. The expansion of port facilities, urbanization, filling of aquatic habitat and wetlands, and other forms of development surrounding estuaries and nearshore areas can have adverse impacts on fish habitat and fish populations.

The dredging and filling of coastal wetlands for commercial, residential, port, and harbor development directly removes important coastal habitats and alters the habitat surrounding the developed area. Physical changes from shoreline construction can result in secondary impacts, such as increased suspended sediment loading, shading from piers and wharves, and the introduction of chemical contaminants from land-based human activities (Robinson and Pederson 2005). Even development projects that appear to have minimal individual impacts can have significant cumulative effects on the aquatic ecosystem (Johnson et al. 2008).

Marine debris affects habitats throughout the marine environment. We include marine debris in Section 5.3.4 (Marine Debris) and address potential impacts and CRs for nearshore and offshore marine habitats.

In evaluating adverse impacts from the sources considered below, an evaluation of the cumulative and synergistic effects of climate change is appropriate. Section 2.5 (Climate Change Effects Assessment Criterion) provides a discussion on integrating climate change information into evaluations of adverse impacts to EFH.

4.4.1 Dredging

Marine and freshwater dredging operations are conducted to improve navigation, remove contamination, mitigate flood risk (including beach nourishment), and/or to generate aggregate for fill (Pledger et al. 2021). Additionally, periodic dredging maintains the required depths after sediment is deposited into these facilities. Dredging also creates deepwater navigable channels and maintains existing channels that periodically fill with sediments.

Shipping activity is increasing globally (see Section 5.3.1, Increasing Vessel Traffic). Port expansion has become an almost continuous process due to economic growth, competition between ports, and significant increases in vessel sizes. The associated coastal development, including dredging, will intensify, increasing potential impacts to EFH and fish.

Dredging extensively modifies fish habitat whether it is port development/maintenance, seabed mining or beach nourishment and land reclamation (Wenger et al. 2017). Dredging operations have been linked to shifts in the species composition of fish communities and habitat-forming biota, loss of species, bioaccumulation of contaminants and deformities, increased rates of disease, and decrease in fish catch per unit effort (Wenger et al. 2018). Ultimately the risk of impacts to EFH will depend on local physical and environmental conditions and the tolerance thresholds to the various stressors for species of concern (Wenger et al. 2018).

4.4.1.1 Potential Impacts

Dredging activities can adversely affect benthic and water column habitats. A limitation in evaluation risk due to dredge operation is the degree of uncertainty surrounding the variation in effect thresholds for many marine species (McQueen et al. 2020). The potential environmental effects of dredging on managed species and designated EFH include:

- The direct removal/burial of organisms;
- Increased turbidity and siltation, including decreasing light attenuation;
- Contaminant release and uptake, including nutrients, metals, and organics;
- The release of oxygen-consuming substances (e.g., chemicals and bacteria);
- Entrainment in suction and clamshell dredges;
- Noise disturbances, injury, and mortality; and
- Alterations to hydrodynamic regimes and physical habitat.

Many managed species forage on infaunal and bottom-dwelling organisms. Dredging may adversely affect these prey species by directly removing or burying them (Van Der Veer et al. 1985, Newell et al. 1998). Recolonization studies suggest that recovery may not be straightforward. Physical factors, including particle size, distribution, currents, and compaction/stabilization processes, can limit recovery after dredging events. Recolonization can take up to one to three years in areas with strong currents and five to 10 years in areas with weaker currents. Additionally, post-dredging recovery in cold waters at high latitudes may require additional time because these benthic communities can be composed of large, slow-growing species (Newell et al. 1998). Therefore, forage resources for benthic feeders may be substantially reduced in dredged areas. For example, the shallow subtidal macrobenthos at Port Valdez, Alaska, had not fully recovered 2.5 years after the dredging event (Blanchard and Feder 2003). Although macrobenthic communities may recover total abundance and biomass within a few months or years, their taxonomic composition and species diversity may remain different from pre-dredging to post-dredging for more than three to five years (Michel et al. 2013).

Dredging operations can elevate levels of mineral particles or suspended sediment smaller than silt and organic matter in the water column. The associated turbidity plumes of suspended particulates may reduce light penetration and lower the rate of photosynthesis for subaquatic vegetation and the primary productivity of an aquatic area, if particles remain suspended for extended periods of time. Sediment plumes impact the physicochemistry of the water (e.g., negative spikes in dissolved oxygen) and benthic habitats and directly impact the macroinvertebrate and fish communities. This can result in significant reductions in benthic community abundance, taxonomic richness, and diversity (Pledger et al. 2021), and therefore, prey availability for managed species.

Extensive turbidity plumes are primarily associated with the suspension or resuspension of fine silt/clay particles that have relatively slow settling velocities, whereas sand and gravel that make up the coarse-grained sediment fraction resettle rapidly in the immediate vicinity of the dredge before they can be transported offsite (Schroeder 2009). Maintaining fine suspended sediment concentrations below 44 milligram per liter, and for less than 24 hours, would protect 95 percent of fishes from dredging induced mortality. Implementation of season restrictions during peak periods of reproduction and recruitment could further protect species from dredging impacts; however, larvae and juveniles are much more vulnerable and are far more likely to experience lethal impacts at concentrations and exposure durations found during dredging activities (Wenger et al. 2018). If suspended sediment loads remain high, fish may suffer reduced feeding ability and be prone to gill injury (Nightingale and Simenstad 2001a). Moreover, habitat usage by fish is altered due to the behavioral avoidance of the sediment plume (Pledger et al. 2021).

Climate change may significantly affect how sediment moves through watersheds and they are delivered to harbors and navigation channels. The effect of climate change on sediment yield and dredging is likely to vary significantly by location and will influence future streamflow and sediment loads (Dahl et al. 2018). Chapter 2 (Climate Change) provides a discussion on the effects of climate change on marine, estuarine, and riverine habitats, and criteria for assessing impacts.

SAV beds, mudflats, and other sensitive habitats may be directly and indirectly affected by dredging operations. Eelgrass, macroalgae, and other habitat-forming biota provide key ecological services, including organic carbon production and export, nutrient cycling, sediment stabilization, enhanced biodiversity, and trophic transfers to adjacent habitats (Orth et al. 2006). Eelgrass beds, in particular, are critical to nearshore food web dynamics (Murphy et al. 2000). Studies have shown seagrass beds to be among the areas of highest primary productivity in the world (Waycott et al. 2009, Barbier et al. 2011, Murphy et al. 2021). This primary production provides high rates of secondary production in the form of fish (Herke and Rogers 1993). Direct impacts of dredging include the physical removal or burial of the vegetation, while indirect impacts can result from increased sedimentation/turbidity (Erftemeijer and Lewis 2006). The suspension of disturbed sediments during the dredging process minimizes the light intensity that reaches SAV which depends on photosynthesis. Depending on the depth at which the vegetation occurs, high turbidity can cause a significant reduction in light availability leading to sublethal effects or death and, in turn, impact the aquatic wildlife which depends on this vegetation for nourishment and habitat (Erftemeijer and Lewis 2006). SAV thrives in specific habitat conditions that include substrate type, depth and light attenuation, and nutrient concentration (Short et al. 2002). Dredging permanently or temporarily alters those specific physical, chemical and biological requirements.

Suspended material from dredging may react with dissolved oxygen and result in short-term oxygen depletion to aquatic resources (Nightingale and Simenstad 2001a). Dredging can also disturb aquatic habitats by resuspending bottom sediments and releasing nutrients, toxic metals (e.g., lead, zinc, mercury, cadmium, copper), hydrocarbons (e.g., polyaromatics), hydrophobic organics (e.g., dioxins), pesticides, and pathogens into the water column (EPA 2000, Erftemeijer and Lewis 2006). Toxic metals and organics, pathogenic microorganisms (i.e., bacteria and viruses), and parasites, notably helminthes and protozoa, may become biologically available to organisms either in the water column or through food chain processes.

Dredges have the potential to entrain fishes and invertebrates during all life cycle phases including adults, juveniles, larvae, and eggs. Entrainment is the direct uptake of aquatic organisms caused by the suction field generated by hydraulic dredges (e.g., hopper and cutterhead dredges). Benthic infauna is particularly vulnerable to entrainment by dredging (Reine and Clarke 1998). Some mobile epibenthic and demersal species, such as shrimp, crabs, and fish, can be susceptible to entrainment as well (Nightingale and Simenstad 2001a). Salmonids are commonly cited in studies of fish entrainment. For instance, in the Fraser River, Canada, juvenile salmonids and eulachon were the dominant taxa entrained during dredge operations, but non anadromous estuarine and marine demersal species were the most frequently entrained (Larson and Moehl 1990, McGraw and Armstrong 1990).

Underwater soundscape is important for marine life because sounds are used for a variety of purposes including communication, orientation, predatory avoidance, and foraging (McQueen et al. 2020). The noise generated by pumps, cranes, and the mechanical action of the dredge has the ability to alter the behavior of fish and other aquatic organisms. The noise levels and frequencies produced from dredging depend on the type of dredging equipment being used, the depth and thermal variations in the surrounding water, and the topography and composition of the surrounding sea floor (Nightingale and Simenstad 2001a, Stocker 2002). Several studies have indicated that dredge noise occurs in the low frequency range (< 1200 Hertz [Hz]) which is within the audible range of many species of fish (Reine et al. 2014b). According to a study by Clarke et al. (2003), cutterhead dredges produce peak sound levels in the range of 100 to 110 decibel (dB) re 1 micropascal (μPa) root-mean-square (rms) with rapid attenuation occurring at short distances from the dredge and sound levels becoming essentially inaudible at a distance of approximately 500 m (approximately 1,640 ft). Sound levels were recently recorded during hydraulic and mechanical dredging operations at depths of 3 and 9.1 m (9.8 and 29.9 ft) (Reine et al. 2014a). Source levels ranged from 170 to 175 dB re 1μPa rms during hydraulic cutterhead suction dredge operations and from 164 to 179 dB re 1μPa rms during backhoe dredge operations. The sound pressure levels (SPL) measured in this study were below levels that would cause physical injury to any fish species in the study area (Reine et al. 2014a).

Underwater sounds from dredging operations are spatially and temporally dynamic dependent on the activity (e.g., excavation, transit, placement, and pumping). Site specific variations can also create localized impacts based on conditions like substrate type and bathymetry (McQueen et al. 2020). Due to the rapid attenuation of low frequencies in shallow water, dredge noise normally is undetectable underwater at ranges beyond 20 km (12.4 mi) to 25 km (15.5 mi) (Richardson et al. 1995). Established noise exposure thresholds for fishes are limited to interim criteria developed by the Fisheries Hydroacoustic Working Group for impulsive pile-driving noise. There are no specific criteria for evaluating the potential impacts of continuous dredging noise on marine fishes. It has been hypothesized that dredging-induced sound may block or delay the migration of anadromous fishes, interrupt or impair communication, or impact foraging behavior (Popper and Hastings 2009, Reine et al. 2014b). Noise from dredging may be continuous, thus impacting fish for extended time periods (Nightingale and Simenstad 2001a).

Dredging and dredging equipment, such as pipelines, may physically alter, damage, or destroy spawning, nursery, and other sensitive habitats including eelgrass and kelp beds. Dredging may also affect hydrodynamic regimes by modifying current patterns and water circulation via alterations to substrate morphology. These alterations can cause changes in the direction or velocity of water flow, water circulation, or dimensions of the waterbody traditionally used by fish for food, shelter, or reproductive purposes. Altered hydrodynamics may affect estuarine circulation, including short-term (diel) and long-term (seasonal or annual) changes (Deegan and Buchsbaum 2005).

Eggs and larvae are the most likely life history stages to experience sublethal and lethal impacts, indicating the potential benefits of seasonal restrictions on dredging during peak spawning and recruitment periods (Wenger et al. 2017). Larval supply directly influences the recruitment of fishes and thus the regulation of fish populations. Recruitment rates can heavily influence age structure and mortality rates and therefore are crucial to managing fish species. Thus, anthropogenic actions and processes that affect recruitment success may have negative impacts on a population (Harvey et al. 2017).

4.4.1.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of dredging operations to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Avoid dredging in sensitive habitat areas to the maximum extent practicable. Activities that would likely require dredging (e.g., placement of piers, docks, marinas) should instead be located in deeper water or designed to minimize the need for maintenance dredging.
- Avoid dredging and the placement of dredging equipment in special aquatic sites and other high-value habitat areas (e.g., kelp beds, eelgrass beds, salt marshes).
- Reduce the area and volume of material to dredge to the maximum extent practicable.
- Implement seasonal restrictions to avoid impacts to habitat during species critical life history stages (e.g., spawning season, egg/larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Seasonal restrictions that reduce or halt dredging activities during times of the year when the risk of dredging-related impacts is high should be considered during sensitive life history events, such as spawning and migration. Seasonal restrictions should be designed to protect a wide range of fishes during vulnerable life history stages from all potential dredging related stressors (Wenger et al. 2018).
- Utilize BMPs to limit and control turbidity and sedimentation. Standard BMPs may include silt fences/curtains, cofferdams, and operational modifications (e.g., use of hydraulic dredge instead of mechanical dredge).
- For new dredging projects, undertake multi-season and pre- and post-dredging biological surveys to assess the cumulative impacts to EFH and allow for implementation of adaptive management techniques.
- Prior to dredging, test the sediments for contaminants as per EPA and USACE requirements.

- Provide appropriate compensation for significant impacts (short-term, long-term, and cumulative) to benthic and SAV habitats resulting from dredging.
- Identify sedimentation sources in the watershed that prompts repetitive maintenance dredging activities. Implement appropriate management actions, if possible, to control those causes.
- Determine a reasonable background turbidity level based on regular monitoring of ambient conditions. Establish turbidity limits (percent maximum allowable exceedance above the best estimates of background turbidity). Apply mitigation measures (e.g., temporary cessation or modification of dredging or disposal) if these limits are exceeded during dredge operations (Erftemeijer and Lewis 2006).

4.4.2 Disposal of Dredged Material

Disposal of dredged material can directly alter the habitat surrounding the developed area. The discharge of dredged materials in aquatic or marine habitats can result in covering or smothering existing submerged substrates, loss or conversion of habitat function, and adverse effects on benthic communities. Fine sediments can impact the benthic communities far from a disposal site where larger particles and rocks settle out faster and closer to the disposal site (Harvey et al. 2017).

4.4.2.1 Potential Impacts

The disposal of dredged material can reduce the suitability of habitat for managed species and their prey by:

- Reducing flood water retention in wetlands;
- Reducing nutrients uptake and release;
- Decreasing the amount of detrital input, an important food source for aquatic invertebrates (Mitsch and Gosselink 1993);
- Altering habitat by changing water depth or substrate type;
- Removing aquatic vegetation and preventing natural revegetation;
- Impeding physiological processes (e.g., photosynthesis, respiration) to aquatic organisms via increased turbidity and sedimentation (Barr 1993, Benfield and Minello 1996, Nightingale and Simenstad 2001a, Harvey et al. 2017);
- Directly eliminating sessile or semi-mobile aquatic organisms via entrainment or smothering (Larson and Moehl 1990, McGraw and Armstrong 1990, Barr 1993, Newell et al. 1998);
- Altering water quality parameters (i.e., temperature, oxygen concentration, and turbidity); and
- Releasing contaminants such as petroleum products, metals, and nutrients (EPA 2000, Harvey et al. 2017).

4.4.2.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of dredged material disposal to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Avoid disposing of dredged material in wetlands, SAV, and other special aquatic sites. Assess all options, including upland disposal sites, for the disposal of dredged materials and select disposal sites that minimize adverse effects to EFH.
- Test sediment compatibility for open-water disposal per EPA and USACE requirements for inshore and offshore, unconfined disposal.
- Ensure that disposal sites are properly managed (e.g., disposal site marking buoys, inspectors, the use of sediment capping and dredge sequencing) and monitored (e.g., chemical and toxicity testing, benthic recovery) to minimize impacts associated with dredged material, even after dredging activity has ceased.
- Acquire and maintain disposal sites for the entire project life when long-term maintenance dredging is anticipated.
- Use clean sediments to cap contaminated sediments and implement long-term monitoring of sediment cap integrity.
- Encourage beneficial uses of dredged materials. Consider using dredged material for beach replenishment and construction. When dredging material is placed in open water, consider the possibilities for enhancing marine habitat.

4.4.3 Discharge of Fill Material

Like the discharge of dredged material, the discharge of fill material to create upland areas removes habitat and eliminates important habitat functions for the surrounding area. Section 3.5.5 (Roads and Transportation Corridors) provides a more complete discussion of the role of fill in road causeways.

4.4.3.1 Potential Impacts

The placement of fill impacts EFH through a reduction in the quality and quantity of habitat, since it represents the permanent loss of habitat (Johnston 1981, Peterson and Lowe 2009). Aquatic habitats sustain remarkably high levels of productivity and support various life stages of fish species and their prey. These habitats are used for multiple purposes, including spawning, breeding, feeding, and supporting growth to maturity of a variety of fish species. The introduction of fill material eliminates those functions and permanently removes ecological functions and values of habitat supporting federally managed fish.

The loss of this habitat has implications for juvenile salmon and flatfish. In coastal waters, fill that causes the loss of low gradient habitat or native substrate will likely negatively affect salmon rearing in the area. Nearshore shallow slopes are important to juvenile salmonids because they provide optimal feeding habitat, shelter from high currents, and shelter from predators. Habitat gradients affect the abundance and productivity of adult salmon and salmon prey (Celewycz and Wertheimer 1994, Sturdevant et al. 1994). In addition to salmon, fill in coastal waters may affect juvenile flatfish that rear in nearshore areas and have specific depth, slope, and substrate preferences that limit their distribution and abundance (Moles and Norcross 1995). Nearshore juvenile flatfish habitat preferences vary by species, but those that rear in nearshore areas generally prefer intertidal to shallow subtidal areas with substrate conditions that allow the animal to easily bury itself.

The placement of fill can also result in a reduction in EFH quality in waters surrounding the filled area by modifying currents and water circulation (Johnston 1981). As a result, adverse changes can occur in the location, structure, and dynamics of aquatic communities, including changes in shoreline and substrate erosion and deposition rates; the deposition of suspended particulates; the rate and extent of mixing of dissolved and suspended components of the water body; and water stratification. The loss of circulation can diminish important food sources for juvenile salmon and other managed species such as pelagic zooplankton. Pelagic zooplankton, an important food source for juvenile pink and chum salmon, depends on currents for transport from offshore to nearshore areas (Sturdevant et al. 1996).

In addition, the placement of fill affects wetland habitat functions with the following impacts (Mitsch and Gosselink 1993):

- Reduces the production of detritus, an important food source for aquatic invertebrates (e.g., shredders);
- Alters the uptake and release of nutrients to and from adjacent aquatic and terrestrial systems;
- Reduces wetland vegetation, an important source of food for fish and invertebrates;
- Hinders physiological processes in aquatic organisms (e.g., photosynthesis, respiration) because of degraded water quality and increased turbidity and sedimentation;
- Alters hydrological dynamics, including flood control and groundwater recharge;
- Reduces filtration and absorption of pollutants from uplands; and
- Alters nitrogen and oxygen cycles.

4.4.3.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts from the discharge of fill material to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Avoid the placement of fill in estuarine and nearshore habitats, particularly SAV, shallow water habitat, and mudflats. Where feasible, seek land-based alternatives rather than filling aquatic and marine habitats. Ideally, filling should only be considered if the proposed activity is water dependent and there are no feasible alternatives (Johnston 1981).
- If avoiding impacts to estuarine and nearshore habitat is not practicable to meet project goals, consider alternatives to the placement of fill or options to minimize the extent of fill required (e.g., elevated structures) to minimize adverse effects of shading on EFH. In a roadbuilding situation where a coastal wetland cannot be avoided, bridging is a preferred alternative to filling an embankment to create roadbeds (Johnston 1981).

- Water circulation and sedimentation patterns should be evaluated when planning the placement of fill in estuaries to prevent the creation of stagnant water (Johnston 1981). Such evaluation is particularly important for linear fill to create causeways.
- After fully considering avoidance and minimization, evaluate and provide the appropriate compensatory mitigation for the acres of filled EFH. Identify and characterize EFH functions/services in the project area so that appropriate mitigation is selected.
- As with dredging, implement BMPs to limit turbidity (Johnston 1981).
- Fill should be sloped to maintain shallow water and photic zone productivity, allow for unrestricted fish migration, provide refuge for juvenile fish, and control water circulation (Johnston 1981). The design of sloped fill should not increase the total disturbance footprint of a project.
- In marine areas with kelp and other aquatic vegetation, design fill (including artificial reefs) to maximize kelp colonization and provide areas for juvenile fish to shelter from high currents and predators.
- Do not use excessively alkaline or acidic fill material. Fill materials should be tested and be within the neutral range of 7.5 to 8.4 pH. In marine waters, this pH range will maximize colonization by marine organisms.

4.4.4 Harbor Infrastructure, Docking Facilities, and Vessel Operations

In Alaska, the demand for increased infrastructure to accommodate marine vessels is consistent with a global trend responding to human-based needs in coastal areas. As coastal areas grow, there are associated increases in vessel operations for cargo handling activities, water transportation services, and recreational opportunities (Johnson et al. 2008). Improving existing and building new harbors is an important factor in Alaska because of the limited number of roads. Overwater structures associated with marine vessels include commercial and residential piers and docks, floating breakwaters, barges, rafts, booms, and mooring buoys. These structures are typically located from the intertidal zone out to about 15 m (49 ft) below mean lower low tide (Hanson et al. 2005).

4.4.4.1 Potential Impacts

Activities associated with overwater structures and vessel operations can directly and indirectly impact EFH. Impacts to EFH can occur during both construction and operation phases. Although the effects of some individual overwater structures on EFH may be minimal, the overall impact may be substantial when considering cumulative effects of multiple structures in a given area. Potential impacts include (Nightingale and Simenstad 2001a):

- Loss and/or impairment of benthic, shoreline, and pelagic habitats;
- Altered light regimes and loss of SAV;
- Altered temperature regimes;
- Increased siltation, sedimentation, and turbidity;
- Release of contaminants and debris;
- Altered tidal, current, and hydrologic regimes; and

- Introduction of invasive or nonnative species (Section 4.4.14, Invasive Species).

A significant habitat impact related to port or marina facilities is the alteration or loss of physical space taken up by the structures required for such a facility. In Alaska, open cell sheet pile docks with backfill are often used to construct or expand existing facilities. Such designs replace existing areas of intertidal and shallow habitat with deeper water habitat. This changes the water energetics from slower moving water at the shallow interface with fast moving water across a sheer sheet pile wall. The sheltered areas of slower moving water where juvenile fish tend to be more abundant are eliminated along with the clearer water microhabitats in the intertidal area that allow for visual feeding.

Overwater structures affect light penetration to aquatic plant and animal communities, creating a shade effect. Piling density, deck height and width, and orientation can also affect the amount of light attenuation created by dock structures (Burdick and Short 1999, Gladstone and Courtenay 2014, Logan et al. 2022). High, narrow piers and docks produce narrower, more diffuse shadows than low, wide structures. In addition, less light is reflected underneath structures built with light-absorbing materials (e.g., wood) than structures built with light-reflecting materials (e.g., concrete or steel) (Hanson et al. 2005). Light-transmitting decking (e.g., aluminum grating) also minimizes shading compared to non-grated material such as wooden planks (Landry et al. 2008). The preferred orientation for docks and other overwater structures depends on the orientation of the shoreline and angle of the sun at the site. Minimizing the width and maximizing the height of the structure and by orienting the structure in a manner that decreases the area and time the space under the structure is left shaded during the day can reduce shade (Landry et al. 2008, Gladstone and Courtenay 2014).

Under-pier light levels can fall below threshold amounts for the photosynthesis of diatoms, benthic algae, eelgrass, salt marsh vegetation, and associated epiphytes. These photosynthesizers are an essential part of the nearshore habitat and the estuarine and nearshore food webs that support many fish species. Partial shading can reduce or eliminate eelgrass and macrophytes presence (Landry et al. 2008, Gladstone and Courtenay 2014). Shading from overwater structures may also indirectly affect fish by reducing prey abundance and habitat complexity via a decrease in aquatic vegetation and phytoplankton abundance (Kahler et al. 2000, Haas et al. 2002).

Distributions of plants, invertebrates, and fishes appear severely limited in under-dock environments when compared to adjacent, unshaded, vegetated habitats. Epibiotic assemblages on pier pilings at marinas subject to shading were markedly different than in surrounding areas (Glasby 1999). Other studies indicate a reduction of epibenthos from shading relative to that in open areas. These factors are likely responsible for the observed reductions in juvenile fish populations under piers and the reduced growth and survival of fishes held in cages under piers when compared to open habitats (Able et al. 1998, Duffy-Anderson and Able 1999).

Areas under large overwater structures like piers are suboptimal habitats not only for benthic fishes but also for many of the abundant pelagic fishes (Able et al. 2013). Shading can adversely affect fish that rely on visual cues for spatial orientation, prey capture, schooling, predator avoidance, and migration (Quinn 2005). The reduced-light conditions found under an overwater structure may limit the ability of fishes, especially juveniles and larvae, to perform these essential activities. For instance, several studies have shown that juvenile salmonids avoided swimming beneath overwater structures, suggesting that these structures may delay the outmigration of juvenile salmon and increase the risk of predation by exposing young salmon to larger fish (Toft et al. 2007, Munsch et al. 2014).

The construction of seawalls and bulkheads can alter nearshore temperature regimes and biological communities. Modified shorelines invariably contain less vegetation than natural shorelines and can reduce natural shading and cause increases in water temperatures in the nearshore intertidal zone and in rivers. Conversely, seawalls and bulkheads constructed along north facing shorelines may reduce light levels (and primary production rates) and reduce water temperatures in the water column adjacent to the structures (Johnson et al. 2008).

The potential alterations of wave and current energy regimes from overwater structures can impact the nearshore detrital food web by altering the size, distribution, and abundance of substrate and detrital materials (Hanson et al. 2005). The structures can disrupt transport, thus altering substrate composition, and can act as barriers to natural processes which build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning (Hanson et al. 2005).

Changes in water quality due to increased siltation, sedimentation, and turbidity can result from marina/port facility construction and operation. The inadequate flushing of marinas may cause changes in water quality (USACE 1993, Klein 1997). For instance, poor circulation in marinas can increase water temperature and raise phytoplankton populations, resulting in nocturnal organism derived hypoxia and pollutant inputs (Cardwell et al. 1980). However, an exchange of at least 30 percent of the water in the marina during a tidal change should minimize temperature increases and dissolved oxygen problems (Cardwell et al. 1980).

An increase in the number and size of operating vessels can cause more erosive wave and surge effects on shorelines. Vessel wakes can cause a significant increase in shoreline erosion, deteriorating wetland habitat, and increase water turbidity. Vessel prop wash can also damage aquatic vegetation and disturb sediments, which may increase turbidity and suspend contaminants (Klein 1997, Warrington 1999). When anchored in shallow nearshore waters, mooring buoys can drag the anchor chain across the bottom (anchor sweep), destroying submerged vegetation and creating a circular scour hole (Walker et al. 1989).

Figure 8. Satellite image of shoreline coastal development, generated using Google Earth Pro.

Treated wood used for pilings and docks releases contaminants into saltwater environments, including up to 1 meter into sediments (Duncan 2014). Creosote-treated wood commonly release PAHs. PAHs can cause a variety of deleterious effects (e.g., cancer, reproductive anomalies, immune dysfunction, and growth and development impairment) to exposed fish (Johnson et al. 1999, Johnson 2000, Stehr et al. 2000, Duncan et al. 2017, West et al. 2019). Wood is also commonly treated with other chemicals such as ammoniacal copper zinc arsenate, and chromated copper arsenate (Poston 2001). These preservatives leach into marine waters and substrate after installation or removal. Concrete and steel, on the other hand, are relatively inert and do not leach contaminants into the water.

Vessel operations pose a risk of accidental spills of fuels and hazardous materials, which would affect water quality and the organisms and habitats present (Michel et al. 2013). Diesel, the most commonly used fuel, is one of the most acutely toxic types of oil. Fish, invertebrates, and plants that come in direct contact with a diesel spill may be killed. Fish kills have been reported for small spills in confined, shallow waters. Small diesel spills in shallow, nearshore areas can affect crabs and bivalves. These organisms bioaccumulate the oil but will also depurate the oil, usually over a period of several weeks after exposure (Michel et al. 2013).

During port development, impervious surfaces, such as concrete and asphalt, typically replace large sections of shoreline. These surfaces exacerbate stormwater runoff and can increase the siltation, sedimentation and contaminant loads in estuarine and marine habitats. This increase in hard surfaces close to the marine environment intensifies nonpoint surface discharges, adds debris, and reduces buffers between land use and the aquatic ecosystem. This alteration leads to direct, indirect, and cumulative impacts on a variety of habitats including shallow subtidal, deep subtidal, eelgrass bed, mudflat, sand shoal, rocky reef, and salt marsh habitats. Bulkheads, jetties, docks, and pilings can create water traps that accumulate contaminants or nutrients washed in from land-based sources, vessels, and facility structures. These conditions may create areas of low dissolved oxygen, dinoflagellate blooms, and elevated toxins (Johnson et al. 2008). Structures generally interfere with longshore sediment transport processes resulting in altered substrate amalgamation, bathymetry, and geomorphology. Changes in the type and distribution of sediment may alter key plant and animal assemblages, starve nearshore detrital-based food webs, and disrupt the natural processes that build spits and beaches (Nightingale and Simenstad 2001b). In addition, the protected, low-energy nature of marinas and ports may alter fish behavior as juvenile fish show an affinity to structures and may congregate around breakwaters or bulkheads (Nightingale and Simenstad 2001b).

Marine vessel infrastructure such as harbors, docks, and pilings as well as smaller overwater structures are susceptible to marine invasive species. In Alaska, four invasive tunicates (*Botryllus schlosseri, B. violaceous, Ciona savigni, Didemnum vexillum*) and the bryozoans *Bugula neritina* have been found in Southeast Alaska harbors or overwater structures (Ruiz et al. 2006, Cohen et al. 2011, Jurgens et al. 2018). Movement of older materials in replaced docks and infrastructure for re-use can transport these marine invasive species to new areas. Section 4.4.14 (Invasive Species) has a more detailed discussion on potential impacts and CRs for invasive species.

The construction and maintenance of marine vessel infrastructure and overwater structures often involves dredging (Section 4.4.1) and pile driving (Section 4.4.6) and; both activities may adversely affect EFH.

4.4.4.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of vessel operations and overwater structures to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Use upland boat storage whenever possible to minimize the need for overwater structures.
- Design piers, docks, and floats to be multi-use facilities to reduce the overall number of such structures and to limit impacted nearshore habitat.

- Locate marinas in areas of low biological abundance and diversity as part of the alternatives analysis. When possible, avoid the disturbance of eelgrass or other SAV, macroalgae, mudflats, and wetlands. In situations where such impacts are unavoidable, evaluate mitigation options.
- Locate facilities in areas with enough water velocity to maintain water quality levels within acceptable ranges.
- Locate marinas where they will not interfere with natural processes to avoid impacts on adjacent habitats.
- Use floating rather than fixed breakwaters whenever possible, and remove them during periods of low dock use. Encourage seasonal use of docks with off-season haul-out.
- Place overwater structures in deep enough waters to avoid intertidal or shallow subtidal light limitation, minimize or preclude dredging, minimize grounding of structure, and avoid displacement of SAV. Siting and design development may include site survey to delineate resources.
- Maintain at least 0.30 m (1 ft) of water between the substrate and the bottom of the floats at extreme low tide.
- Incorporate measures that increase the ambient light transmission under piers and docks. These measures include, but are not limited to, the following:
    - Maximize the height of the structure and minimize the width to decrease the shade footprint.
    - Use reflective materials (e.g., concrete or steel) instead of materials that absorb light (e.g., wood) on the underside of the dock to reflect ambient light.
    - Explore the use of artificial light to mitigate dock shading impacts (see Ono et al. 2010).
    - Use the fewest number of pilings necessary to support the structures to allow light into under-pier areas and minimize impacts to the substrate.
    - Align piers, docks, and floats in a north-south orientation to allow the arc of the sun to cross perpendicular to the structure to reduce the duration of light limitation.
- When docks are over eelgrass or other SAV, consider these measures to minimize impacts to the vegetation (Gladstone and Courtenay 2014, Logan et al. 2022).
    - Build docks so that they extend out into deep water for boating purposes to maintain the integrity of the shallow water eelgrass beds.
    - Use light transmitting docks (e.g., aluminum mesh decking instead of wooden decks) to reduce eelgrass loss and bed fragmentation due to shading.
    - Minimize the effects of shading by minimizing the dock width, maximizing the dock height, and orienting the dock in a manner that decreases the area and time that shading occurs.
- Maintain riparian buffers in place to help maintain water quality and nutrient input.

- Include low-wake vessel technology, appropriate routes, and BMPs for wave attenuation structures as part of the design. Operate vessels at sufficiently low speeds to reduce wake energy. Designate no-wake zones near sensitive habitats.
- Incorporate BMPs to prevent or minimize contamination from ship bilge waters, antifouling paints, shipboard accidents, shipyard work, maintenance dredging and disposal, and nonpoint source contaminants from upland facilities related to vessel operations and navigation.
- Locate mooring buoys in waters deep enough to avoid grounding and to minimize the effects of prop wash. Use subsurface floats, midline buoys, or other methods to prevent contact of the anchor line (chain sweep) with the substrate.
- Use catchment basins for collecting and storing surface runoff from upland repair facilities, parking lots, and other impervious surfaces to remove contaminants prior to delivery to any receiving waters.
- To facilitate the movement of fish around breakwaters, incorporate breach gaps and construct shallow shelves to serve as "fish benches," as appropriate. Often benches are expanded shelf features used in common toe-slope stabilization transitions within the breakwater design. Benches need to provide for unrestricted fish movement throughout all tidal stages.
- Design harbor facilities to include BMPs for reducing, containing, and cleaning up petroleum spills.
- Stage oil spill response equipment at several planned locations throughout the shipping route to facilitate any accidental spillage of vessel cargo or fuels.
- To the extent practicable, avoid the use of treated wood timbers or pilings. If possible, use alternative materials such as untreated wood, concrete, or steel.
- Conduct in-water work when managed species and prey species are least likely to be impacted.
- Mitigate for unavoidable impacts to benthic habitats. Mitigation should follow current national or regional policy and should be adequate to compensate impacts, monitored for effectiveness, and adaptively managed.
- Avoid spreading marine invasive species via overwater structures or vessel infrastructure in harbors by inspecting for fouling organisms before placement in new areas. Dry, clean or safely treat any infested components followed by final inspection to ensure absence or completely killed fouling organisms before transport and placement in new areas. Section 4.4.14 (Invasive Species) provides further discussion on this topic.

4.4.5 Pile Driving

Pilings are an integral component of many overwater and in-water structures. They support the decking of piers and docks, function as fenders and dolphins to protect structures, support navigation markers, and assist in breakwater and bulkhead construction. Materials used in pilings include steel, concrete, wood (both treated and untreated), plastic, or a combination of these materials (Hanson et al. 2005).

Impact or vibratory hammers are typically used to drive piles into the substrate (Daryaei et al. 2020). Impact hammers consist of a heavy weight dropped onto the top of the pile to drive the pile into the substrate. Vibratory hammers use a combination of a stationary, heavy weight and vibration in the plane perpendicular to the long axis of the pile to force the pile into the substrate. The type of hammer used depends on a variety of factors including pile material and substrate type. Impact hammers can be used to drive all types of piles, while vibratory hammers are generally most efficient at driving piles with a cutting edge (e.g., hollow steel pipe) and are less efficient at driving displacement piles (those without a cutting edge that must displace the substrate). Displacement piles include solid concrete, wood, and closed-end steel pipe (Hanson et al. 2005).

The underwater sounds produced by pile driving are characterized by multiple rapid increases and decreases in sound pressure over a very short period. The peak pressure is the highest absolute value of the measured waveform and can be a negative or positive pressure peak (Popper 2006). The type and intensity of the sounds produced during pile driving depend on a variety of factors, including the type and size of the pile, the firmness of the substrate, the depth of water, and the type and size of the pile-driving hammer. SPLs are positively correlated with the size of the pile since more energy is required to drive larger piles. Wood and concrete piles appear to produce lower SPLs than hollow-steel piles of a similar size; hollow-steel piles have been shown to produce SPLs that can injure fish (Reyff and Donovan 2003), though it is unclear if the sounds produced by wood or concrete piles are harmful to fishes. Nevertheless, woodpiles treated in creosote have a longer negative impact on fish habitat (see Section 4.4.6, Pile Removal). Firmer substrates require more energy to drive piles and produce more intense SPLs. Sound attenuates more rapidly with distance from the source in shallow water than it does in deep water (CalTrans 2015).

4.4.5.1 Potential Impacts

Pile driving can generate intense underwater sound pressure waves that may adversely affect prey species, an EFH attribute. These pressure waves have been shown to injure and kill fish (CalTrans 2001). Sound waves are much more likely to affect bottom-living fishes and invertebrates than those in the water column, and also fishes with swim bladders more so than fishes without gas-filled cavities (Hawkins et al. 2015, Popper and Hawkins 2019). Fish injuries associated directly with pile driving include the rupture of the swim bladder and internal hemorrhaging (CalTrans 2001, Hawkins et al. 2015, Hawkins et al. 2020). The noise produced can disrupt fish schooling behavior and their ability to coordinate movements with each other (Herbert-Read et al. 2017). One recent study indicates that environmental variables and substrate can influence the degree of injury (Hawkins et al. 2021). However, there are still data gaps about the effects of anthropogenic sounds on wild fish populations (Popper and Hastings 2009, Hawkins et al. 2014, Hawkins and Popper 2017).

Fish responses to sound are a key difference between impact and vibratory hammers. Impact hammers produce intense, sharp spikes of sound that can easily reach injurious levels to fish. Vibratory hammers produce sounds of lower intensity with a rapid repetition rate, longer duration (minutes versus milliseconds), and more energy in the lower frequency range (15 to 26 Hz versus 100 to 800 Hz) (Würsig et al. 2000, Carlson et al. 2001). Impact hammers, however, produce such short spikes of sound with little energy in the infrasound range that fish fail to respond to the particle motion (Carlson et al. 2001). When exposed to sounds that are similar to those of a vibratory hammer, fish consistently displayed an avoidance response (Enger et al.

1993, Dolat 1997, Knudsen et al. 1997, Sand et al. 2000), and they did not habituate to the sound even after repeated exposures (Dolat 1997, Knudsen et al. 1997). Their avoidance response may result in leaving an area for different spawning grounds or avoiding natural migration paths because of noise disturbances. In contrast, fish may respond to the first few strikes of an impact hammer with a startle response. After these initial strikes, the startle response wanes, and fish may remain within the field of a potentially harmful sound (Dolat 1997, NMFS 2001b). Thus, impact hammers may be more harmful than vibratory hammers because they produce more intense pressure waves and the sounds produced do not elicit an avoidance response in fishes.

The degree of damage is not related directly to the distance of the fish from the pile but the received level and duration of sound exposure (Hastings and Popper 2005). The degree to which an individual fish exposed to sound is affected depends on a variety of variables including:

- Fish species;
- Fish size;
- Presence of a swim bladder;
- Physical condition of the fish;
- Peak sound pressure and frequency;
- Shape of the sound wave (rise time);
- Depth of the water around the pile;
- Depth of the fish in the water column;
- Amount of air in the water;
- Size and number of waves on the water surface;
- Bottom substrate composition and texture;
- Effectiveness of bubble curtains and other sound/pressure attenuation technology;
- Tidal currents; and
- Presence of predators.

Depending on these factors, adverse effects on fish can range from behavioral changes to immediate mortality (Hastings and Popper 2005, Popper 2006). Section 4.4.1 (Dredging) and Section 5.3.2 (Oil and Gas Exploration, Development, and Production) provides additional discussion on the impacts of sound.

In 2008, the Fisheries Hydroacoustic Working Group developed the *Agreement in Principle for Interim Criteria for Injury to Fish from Pile Driving Activities*. Based on this agreement, NMFS considers physical injury to begin when peak SPLs reach 206 dB re 1 μPa during a single strike and/or when the accumulated sound exposure level from multiple strikes reaches 187 dB re 1 μPa for large fishes (≥ 2 grams [0.07 ounces]) or 183 dB re 1 μPa for small fishes (< 2 grams [0.07 ounces]) (CalTrans 2015). Since that agreement, more research and literature reviews provide guidelines for potential injury and mortality thresholds to fish with or without swim bladders, and eggs and larvae (Popper and Hawkins 2019). Fish without a swim bladder are less susceptible to injury from a point source compared to fish with a swim bladder, and those with swim bladders have different reactions depending on the function of their swim bladder (see Table 2 in Popper and Hawkins 2019).

Smaller fish are more prone to injury by intense sound than are larger fish of the same species (Yelverton et al. 1975). For example, a number of shiner perch (*Cymatogaster aggregata*) and striped surfperch (*Embiotoca lateralis*) were killed during impact pile driving (Stadler 2002). Most of the dead fish were the smaller shiner perch and similar-sized specimens of striped surfperch even though many larger striped surfperch were in the same area. Dissections revealed that the swim bladder of the smallest fish (0.80 cm [3.15 inches] fork length) was completely destroyed, while that of the largest individual (1.70 cm [6.69 inches] fork length) was nearly intact, indicating a size-dependent effect. Of the reported fish kills associated with pile driving, all have occurred during use of an impact hammer on hollow-steel piles (CalTrans 2001, NMFS 2001a, 2003a). An important note is that not all mortality events from pile driving are detected because some fishes killed do not float to the surface (Teachout and Lacey 2012).

4.4.5.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of pile driving to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Do not install or replace old piles with creosote-treated piles. See Section 4.4.6 (Pile Removal), for more on the impacts of creosote.
- Use a vibratory hammer when driving hollow steel piles. When impact hammers are required due to seismic stability or substrate type, drive the pile as deep as possible with a vibratory hammer first and then use the impact hammer to drive the pile to its final position.
- If using an impact hammer, use one with adjustable energy level like a hydraulic impact hammer.
- Install piles at a time of year when larval and juvenile stages of fish species with designated EFH are not present.
- Follow standard procedures to measure and analyze the underwater noise from pile driving (see CalTrans 2015). Implement measures to attenuate the sound should levels exceed the interim criteria thresholds (Popper and Hawkins 2019). If sound levels are anticipated to exceed these acceptable limits, implement appropriate mitigation measures, when practicable. Methods to reduce the SPLs and sound exposure levels include, but are not limited to, the following:
    - Surround the pile with an air bubble curtain system or air-filled cofferdam (Tsouvalas and Metrikine 2016). Systems using air bubbles reduce noise and the adverse effects of underwater sound from pile driving on fish. Both confined (i.e., metal or fabric sleeve) and unconfined air bubble systems have been shown to attenuate underwater sound pressures (Longmuir and Lively 2001). The characteristics of the bubble curtain and the frequency of the acoustic energy from the underwater sound both impact successful noise reduction (Tsouvalas and Metrikine 2016).

- Use a smaller hammer to reduce sound pressure. The size of the hammer relates to the force driving the pile, which in turn relates to the sound produced. If needed, drive the pile as far as possible with a smaller hammer before driving to the greatest resistance with a larger hammer (see CalTrans 2015).
- Drive piles when the current is reduced (i.e., centered on slack current) in areas of strong current to minimize the number of fish exposed to adverse levels of underwater sound. This is also important when using an air bubble curtain to maintain the effectiveness of the curtain.

- Depending on the size and scope of the project, include sound intensity and fish kill event monitoring in the project design.

4.4.6 Pile Removal

Pile removal introduces adverse impacts through sediment suspension and possible pollutant reintegration into the water column more so than impacts from underwater sound. Pile removal is often an important step in habitat restoration or harbor improvements. Long-term positive outcomes can offset the short-term adverse impacts.

4.4.6.1 Potential Impacts

The primary adverse effect of removing piles is the suspension of sediments that may result in harmful levels of turbidity and the release of contaminants contained in those sediments. The methods generally used for pile removal are vibratory removal, breaking or cutting below the mudline, direct pull, and use of a clamshell. Vibratory pile removal tends to cause the sediments to slough off at the mudline, resulting in relatively low levels of suspended sediments and contaminants. Vibratory removal of piles is gaining popularity because it can be used on all types of piles as long as they are structurally sound. Breaking or cutting the pile below the mudline may suspend only small amounts of sediment if the stub remains in place, and little digging is required to access the pile. Direct pull or use of a clamshell to remove broken piles may suspend large amounts of sediment and contaminants. When pulling the piling from the substrate using these two methods, the sediments clinging to the piling slough off as it rises through the water column, producing a potentially harmful plume of turbidity and/or releasing contaminants. Moreover, the use of a clamshell may suspend additional sediment if it penetrates the substrate while grabbing the piling.

While there is a potential to adversely affect EFH during the removal of piles, many of the piles removed in Alaska are old creosote-treated timber piles. A Puget Sound study linked the removal of creosote treated piles to a short-term increase in exposure due to suspended contaminants (West et al. 2019). However, removal of these piles may provide long-term benefits to EFH since chemicals from the piles can leach out, introducing toxins (e.g., PAH) into the water column (Perkins 2009). Fish eggs, like herring spawn, exposed to creosote or deposited on creosote pilings can result in reduced hatch rates, skeletal defects, and negative impacts to swimming ability (Duncan et al. 2017). Also, the concentration of contaminants leaching from creosote pilings changes seasonally, with increased concentrations in the summer due to warmer water, more sun exposure, and more vessel activity. Therefore, in some cases, removing a chronic source of contamination may outweigh the temporary adverse effects of removal.

4.4.6.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of pile removal to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Remove structurally sound piles completely rather than cutting or breaking them off.
- Minimize the suspension of sediments and disturbance of the substrate when removing piles. Measures to accomplish this include, but are not limited to, the following:
    - When practicable, remove piles with a vibratory hammer rather than using the direct pull or clamshell methods.
    - Remove the pile slowly to allow sediment to slough off at or near the mudline.
    - Knock or vibrate the pile to break the bond between the sediment and the pile to minimize the potential for the pile to break and to reduce the amount of sediment sloughing off the pile during removal.
    - Encircle the pile or piles with a silt curtain that extends from the surface of the water to the substrate to help contain the sedimentation.
- If pile stubs are removed with a clamshell, complete each pass of the clamshell to minimize suspension of sediment.
- Place piles on a barge equipped with a basin to contain attached sediment and runoff water after removal. Creosote-treated timber piles should be disposed of in an upland location to prevent reuse in the marine environment, and all debris, including attached contaminated sediments, should be disposed of in an approved upland facility.
- If unable to remove the entire pile, use a pile driver to drive broken/cut stubs far enough below the mudline to prevent the release of contaminants into the water column as an alternative to their removal.

4.4.7 Flood Control and Shoreline Protection

Structures placed along the shoreline to protect infrastructure and property from flooding events include berms, breakwaters, jetties, dikes, levees, ditches, concrete or wood seawalls, rip-rap revetments (sloping piles of rock placed against the toe of the dune or bluff in danger of erosion from wave action), dynamic cobble revetments (natural cobble placed on an eroding beach to dissipate wave energy and prevent sand loss), vegetative plantings, and sandbags. These structures can cause changes in the physical, chemical, and biological characteristics of shoreline and riparian habitat and can have long-term adverse effects on EFH (PFMC and NMFS 2014). With sea level rise, thawing permafrost, and more intense rainfall events in parts of Alaska (Hamilton et al. 2016, Lader et al. 2020a), the use of flood control and shoreline protection structures will increase.

4.4.7.1 Potential Impacts

Although highly variable, tidal marshes typically have freshwater vegetation on the landward side, saltwater vegetation on the seaward side, and gradients of species in between that are in equilibrium with the prevailing climatic, hydrographic, geological, and biological features of the coast. These systems normally drain freshwater through tidal creeks that empty into bays or estuaries (PFMC and NMFS 2014). Dikes, levees, ditches, or other flood control structures at the upper end of a tidal marsh can cut off all tributaries feeding the marsh, preventing the flow of freshwater, annual renewal of sediments and nutrients, and the formation of new marshes. Water controls within the marsh can intercept and divert freshwater drainage, thus blocking freshwater from flowing across seaward portions of the marsh or increasing the speed of runoff of freshwater to the bays or estuaries. These effects can lower the water table which may permit saltwater intrusion into the marsh and create migration barriers for aquatic species (PFMC and NMFS 2014). Changes in the hydrology of coastal salt marshes can reduce estuarine productivity, restrict suitable habitat for aquatic species, and result in salinity extremes during droughts and floods (Neubauer 2013).

Long-term effects of shoreline protection structures on tidal marshes include land subsidence (sometimes even submergence), soil compaction, conversion to terrestrial vegetation, reduced invertebrate populations, and general loss of productive wetland characteristics (PFMC and NMFS 2014). Armoring shorelines to prevent erosion and to maintain or create shoreline real estate can impair habitats by limiting feeding, reproduction, and connectivity of species (Munsch et al. 2017). Potential hydraulic effects on the shoreline include increased energy seaward of the armoring, reflected wave energy, dry beach narrowing, substrate coarsening, beach steepening, changes in sediment storage capacity, loss of organic debris, and downdrift sediment starvation. The installation of breakwaters and jetties can change the local community via burial or removal of resident biota, modify hydrology, and nearshore sediment transport, and result in a change to the species communities and diversity (Munsch et al. 2017).

Restoration projects often use bank stabilization and in-stream structures to create new habitat; however, these projects often fail to consider the physical, chemical, and biological processes that drive the riverine ecosystem (Beechie et al. 2010). Vegetated riprap is one method for using a combination of rock and dormant cuttings to stabilize a streambank.

4.4.7.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of flood control and shoreline protection on EFH and to promote the conservation, enhancement, and proper function of EFH.

- Do not dike or drain tidal marshlands or estuaries.
- Encourage coastal wetland habitat preservation.
- Wherever possible, use soft engineering approaches (e.g., beach nourishment, vegetative plantings, or placement of LWD) in lieu of “hard” shoreline stabilization and modifications (e.g., concrete bulkheads and seawalls or concrete or rock revetments).
- Properly model the hydrodynamics and sedimentation patterns and ensure the structure design avoids erosion to adjacent properties when “hard” shoreline stabilization is necessary.
- In energetic environments, avoid creating a flat facing surface to reduce wave energy reflection.
- If stabilizing a bank with riprap, use live cuttings of local vegetation placed between the joints of rocks to provide additional strength to the slope. Include efforts to preserve and

enhance fishery habitat to offset impacts. For example, provide new gravel for spawning or nursery habitats; remove barriers to natural fish passage; and use weirs, grade control structures, and low flow channels to provide the proper depth and velocity for fish.

- Avoid installing new water control structures in tidal marshes and freshwater streams. If the installation of new structures is required, ensure the design allows for optimal fish passage and natural water circulation.
- Monitor water control structures for potential changes in water temperature, salinity, dissolved oxygen concentration, and other parameters.
- Use seasonal restrictions to avoid impacts to habitat during species critical life history stages (e.g., spawning and egg/larval development periods). Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Address the cumulative impacts of past, present, and foreseeable future development activities on aquatic habitats by considering them in the review process for flood control and shoreline protection projects.

4.4.8 Log Transfer Facilities and In-Water Log Storage

Rivers, estuaries, and bays were historically the primary means of transporting and storing logs in the Pacific Northwest (PFMC and NMFS 2014). This practice is still common in Alaska, primarily in Southeast Alaska with some in Prince William Sound. LTFs are constructed wholly or in part in waterways and used to transfer commercially harvested logs to or from a vessel or log raft or to consolidate logs for incorporation into log rafts (EPA 2000). LTFs may use a crane, A-frame structure, conveyor, slide, or ramp to move logs from land into the water. Logs can also be placed in the water by helicopters.

4.4.8.1 Potential Impacts

The potential physical impacts of LTFs on EFH are similar to shading and other effects of floating docks and other overwater structures (see Section 4.4.4, Harbor Infrastructure, Docking Facilities, and Vessel Operations). However, the accumulation of bark debris is unique to LTFs (PFMC and NMFS 2014). Bark and wood debris may accumulate on the substrate of the waterway during the process of bundling the logs into rafts and hooking them to a tug for shipment (PFMC and NMFS 2014). Debris can change the benthic habitat and degrade the water quality (Levings and Northcote 2004). The debris may smother clams, mussels, seaweed, kelp, and eelgrasses (PFMC and NMFS 2014). Kelp and eelgrass beds are important habitats for juvenile pollack and Pacific cod (Grüss et al. 2021).These changes may be long term since debris can sometimes remain in the area for decades. The accumulation of bark debris in shallow- and deep-water environments has been shown to decrease benthic species richness and abundance (Jackson 1986, Kirkpatrick et al. 1998) which can reduce the availability of food for some groundfish species and life stages (PFMC and NMFS 2014).

Log storage may cause adverse impacts via the leaching of soluble organic compounds from stored logs. Log bark may affect groundfish habitat by significantly increasing oxygen demand within the area of accumulation (Pacific Northwest Pollution Control Council 1971). High oxygen demand can lead to an anaerobic zone within the bark pile where toxic sulfide compounds are generated, particularly in brackish and marine waters. Reduced oxygen levels, anaerobic conditions, and the presence of toxic sulfide compounds can reduce the production of salmon and their forage organisms as well as the available habitat (PFMC and NMFS 2014). In addition, soils at onshore facilities where logs are decked can become contaminated with gasoline, diesel fuel, solvents, and other pollutants from trucks and heavy equipment. These contaminants could leach into nearshore EFH (PFMC and NMFS 2014).

4.4.8.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of LTFs to EFH and to promote the conservation, enhancement, and proper function of EFH.

Potential adverse physical, chemical, and biological effects of LTF operations can be substantially reduced by adhering to appropriate siting and operational constraints (PFMC and NMFS 2014). In 1985, the Alaska Timber Task Force (ATTF) developed guidelines[28] to "delineate the physical requirements necessary to construct a log transfer and associated facilities, and in context with requirements of applicable law and regulations, methods to avoid or control potential impacts from these facilities on water quality, aquatic and other resources." Since 1985, the ATTF guidelines have been applied to new LTFs through the requirements of National Pollution Discharge Elimination System (NPDES) permits and other state and federal programs (EPA 1996). Adherence to the ATTF operational and siting guidelines and BMPs in the NPDES General Permit will reduce the amount of bark and wood debris that enters the marine and coastal environment, the potential for displacement or harm to aquatic species, and the accumulation of bark and wood debris on the ocean floor. The following conservation measures reflect those guidelines.

- Avoid establishing new log transfer facilities.
- Restrict or eliminate storage and handling of logs from waters where state and federal water quality standards cannot be met outside of the authorized zone of deposition.
- Use effective bark and wood debris control, collection, and disposal methods at log dumps, raft building areas, and mill-side handling zones; avoiding free-fall dumping of logs; using easy let-down devices for placing logs in the water; and bundling logs before water storage (bundles should not be broken except on land and at mill-side zones).
- Do not store logs in the water if they will ground at any time or shade sensitive aquatic vegetation such as eelgrass.
- Avoid citing log-storage areas and LTFs in sensitive habitats such as kelp and eelgrass beds and areas important for specified species as required by the ATTF guidelines.
- Site log storage areas and LTFs in areas with good currents and tidal exchanges.
- Use land-based storage sites, where possible, with the goal of eliminating in-water storage of logs.

[28] The Log Transfer Facility Guidelines developed by the ATTF in 1985 were incorporated into the USFS' Tongass National Forest Land and Resource Management Plan (2008) as Appendix G. The specific guidelines can be found at: https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5445506.pdf

4.4.9 Utility Lines, Cables, and Pipelines

Utility lines, cables, and pipelines can have direct and indirect impacts on offshore, nearshore, estuarine, wetland, beach, and rocky shore coastal zone habitats. This section provides an overview of adverse impacts associated with this infrastructure, followed by CRs to mitigate those adverse impacts. For impacts associated with oil and gas infrastructure, please see Section 5.3.2 (Oil and Gas Exploration, Development, and Production). For CRs to minimize adverse impacts to EFH from natural gas leaks, please see Section 2.6 (Conservation Recommendations for Large Emissions Facilities).

4.4.9.1 Potential Impacts

Impacts associated with the installation of utility lines, cables, and pipelines include destruction of organisms and habitat, increases in turbidity, and contaminant release (PFMC and NMFS 2014). The destruction of organisms and habitats can occur in the pipeline or cable right-of-way and can lead to long-term or permanent damage, particularly in vertically complex hard bottom habitats such as hard corals and vegetated rocky reefs (Hanson et al. 2005). Dredging and burial of pipeline, utility line, and cable can alter benthic substrates used for feeding or shelter. Increased turbidity resulting from the installation of pipelines, utility lines, and cables can cause a decrease in primary production (Hanson et al. 2005). Adverse impacts may increase during certain times of the year, such as during highly productive spring phytoplankton blooms or when organisms are already under stressed conditions. Depending on the severity of the turbidity, changes in water clarity may also affect the EFH for species higher in the food chain. Shallow-water environments, rocky reefs, nearshore and offshore rises, wetlands, and estuaries are more likely to be adversely affected than open-water habitats due to their higher sustained biomass and lower water volumes. Lower water volumes decrease the ability to dilute and disperse suspended sediments (Gowen 1978). The installation of pipelines, utility lines, and cables can result in the resuspension and release of contaminants, such as heavy metals and pesticides can have lethal effects (Gowen 1978). Spills of petroleum products, solvents, and other construction-related material can also adversely affect EFH.

Once the infrastructure is installed, potential impacts include the impairment of benthic species migration and distribution, and changes to coastal hydrology, including saltwater intrusion. Subsea pipelines placed on the substrate surface have the potential to create physical barriers to benthic invertebrates during migration and movement. Erosion around buried pipelines and cables can uncover the structure and form escarpments that interfere with the migratory patterns of benthic species (Johnson et al. 2008). Additionally, pipeline canals have the potential to change the hydrology of coastal areas, facilitating rapid drainage of interior marshes during low tides or low precipitation, reducing or interrupting freshwater inflow and associated littoral sediments, and allowing saltwater to move farther inland during high tides (Chabreck 1972). This saltwater intrusion can lead to a loss of salt-intolerant emergent and submerged aquatic plants, erosion, and the net loss of soil organic matter (Chabreck 1972, Craig et al. 1979, Pezeshki et al. 1987).

4.4.9.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of cable, pipeline, and utility lines to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Use existing rights-of-way whenever possible to lessen overall encroachment and disturbance of wetlands.
- Use horizontal directional drilling where cables or pipelines would cross anadromous fish streams, salt marsh, vegetated intertidal zones, or steep erodible bluff areas adjacent to the intertidal zone.
- Store and contain excavated material on uplands. If storage in wetlands or waters cannot be avoided, use alternating stockpiles to allow the continuation of sheet flow. Store stockpiled materials on construction cloth rather than bare marsh surfaces, eelgrass, macroalgae, or other SAV.
- Backfill excavated wetlands with either the same or comparable material capable of supporting similar wetland vegetation. Restore original marsh elevations. Stockpile topsoil and organic surface material, such as root mats, separately and return it to the surface of the restored site. Use adequate material to ensure the pre-project elevation is attained following the settling and compaction of the material. After backfilling, implement erosion protection measures where needed.
- Limit equipment access to the immediate project area. Tracked vehicles are preferred over wheeled vehicles. Consider using mats and boards to protect sensitive areas.
- Caution equipment operators to avoid sensitive areas. Clearly mark sensitive areas to ensure that equipment operators do not traverse them.
- Limit construction equipment to the minimum size necessary to complete the work. Use shallow-draft equipment to minimize grounding effects and to eliminate the necessity for temporary access channels. Use the push-ditch method in which the trench is immediately backfilled to minimize the impact duration when possible.
- Conduct construction during the time of year when it will have the least impact on sensitive habitats and species.
- Suspend transmission lines beneath existing bridges or conduct directional boring under streams to reduce the environmental impact. If transmission lines span streams, site towers at least 61 m (200 ft) from streams.
- Align crossings along the least damaging route. Avoid known fished and sensitive areas such as deep sea corals, SAV, emergent marshes, and anadromous fish bearing streams.
- Apply compensatory mitigation to mitigate the permanent loss of habitat (Hanson et al. 2003).
- Bury pipelines and submerged cables where possible. Unburied pipelines or pipelines buried in areas where scouring or wave activity eventually exposes them run a much greater risk of damage leading to leaks or spills.
- Shunt drill cuttings through a conduit and either discharge the cuttings near the seafloor or transport them ashore.
- Locate drilling and production structures, including pipelines, at least 1.6 km (1 mi) from the base of a hard bottom habitat.

- Bury pipelines at least 0.9 m (3 ft) beneath the sea floor whenever possible. Particular considerations (i.e., currents, ice scour) may require deeper burial or weighting to maintain adequate cover.
- Periodically examine buried pipelines and cables for maintenance of adequate cover.
- Locate alignments along routes that will minimize damage to marine and estuarine habitat.
- Avoid laying cable over high-relief bottom habitat and across live bottom habitats such as corals and sponges.
- Remove inactive pipelines and submerged cables unless they are located in sensitive areas (e.g., SAV). If pipelines remain in place, ensure that they are properly decommissioned.

4.4.10 Seafood Processing Waste

Seafood processing includes any activity that modifies the physical condition of a fishery resource. Seafood processing is conducted throughout much of coastal Alaska where processing facilities may be located onshore. Seafood processing facilities may also be located on anchored facilities and vessels offshore[29]. Onshore and offshore facilities are permitted separately under the NPDES.

The Alaskan fishing industry targets a number of marine fish and invertebrate species assemblages, including groundfish, salmon, herring, and shellfish (e.g., crabs, shrimp, clams, scallops, abalone, sea urchins, and sea cucumbers). There are currently over 100 permitted onshore seafood processing facilities operating in Alaska that discharge waste to coastal and freshwater systems and about 100 permitted seafood processing vessels operating offshore that discharge waste to Alaska state waters or waters of the U.S. EEZ. These vessels may process any number of species of fish and marine invertebrates, where the majority are groundfish and crabs. The Alaskan fishing industry produces over one million metric tons of by-product and waste annually (EPA 2019).

EPA promulgated the Seafood Processing Effluent Guidelines and Standards (Canned and Preserved Seafood Category; 40 CFR Part 408) in 1974 and 1975. The regulation covers wastewater discharges from facilities that preserve and can seafood and is incorporated into NPDES permits. Alaska has a NPDES State Program Authorization to issue Alaska Pollutant Discharge Elimination System permits (40 CFR Part 123). Pollutants of concern from seafood processing wastewater under the EPA guidelines and standards are primarily components of the biological wastes generated by processing raw seafood into a marketable form, as well as the chemicals used to maintain sanitary conditions for processing equipment and fish containment structures, and refrigerants. Processors discharging seafood waste are required to obtain permits, where various water quality standards are all considerations in the issuance of such permits and regular reporting is required.

---

[29] Seafood processing waste affects both nearshore (Chapter 4) and offshore (Chapter 5) habitats and is included in Chapter 4 for efficiency.

4.4.10.1 Potential Impacts

Seafood processing operations have the potential to adversely affect EFH through the discharge of nutrients, chemicals, fish byproducts, and stickwater (water and entrained organics originating from the draining or pressing of steam-cooked fish products). EPA investigations illustrate that the effluent discharge influences receiving water quality. In areas with strong currents and high tidal ranges, waste materials disperse rapidly. In areas of quieter waters, waste materials can accumulate and result in shell banks, sludge piles, dissolved oxygen depressions, and associated aesthetic problems (EPA 2019). If adequate disposal technology is not available or employed in processing facilities that generate large quantities of nutrient rich fish waste, there is a potential to saturate designated mixing zones (LaLiberte and Ewing 2006).

The chronic increase in accumulating nutrient load can eventually cause eutrophication and create anoxic and hypoxic conditions. The impacts and effects of hypoxic conditions are documented in coastal benthos and estuarine habitats (Brandt et al. 2016, Breitburg et al. 2009, Levin et al. 2009). Seafood processing discharges influence nutrient loading, eutrophication, and anoxic and hypoxic conditions, significantly influencing marine species diversity and water quality (Lotze et al. 2003, Roy Consultants Ltd. et al. 2003, Thériault et al. 2006). Chemicals such as ammonia, sulfides, and others at micro-toxin levels are also shown to be amplified in these habitats (Lalonde et al. 2008). Seasonal changes in water temperature and depth influences the impacts to marine water carrying capacity resulting from the decomposition rate (Ahumada et al. 2004, Verity et al. 2006). Although biological fish waste is biodegradable, fish parts that are ground to fine particles may remain suspended for some time, thereby overburdening habitats with particle suspension (NMFS 2005a). Localized effects depend on the differences in habitats and seafood processing methods. Alaska seafood processors can deposit fish parts in a zone of deposit (ZOD) (ADEC 2008, EPA 2019, ADEC 2021). Seafood processing waste deposits, which can be several meters deep, alter benthic habitat, reduce localized SAV and invertebrate populations via smothering, increase localized bacterial load, and lower dissolved oxygen levels in overlying waters (Martich 2015). Severe anoxic conditions can occur adjacent to effluent piles which undergo periodic gas eruptions, suspending waste in the water column and releasing toxic noxious gasses (EPA 2013). Impacts to species generally go undetected. Recent reauthorizations of seafood processing facility permits require regular surveys of ZODs and avoidance of anchoring or discharging seafood waste into or onto living substrates (e.g., ADEC 2008, 2021).

4.4.10.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of fish processing waste to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Consider tidal return and reflex when evaluating potential environmental mechanisms influencing water quality standards in mixing zones.
- Base effluent limitations on site-specific water quality concerns to the maximum extent practicable.
- Encourage the use of secondary or wastewater treatment systems where possible.
- When a ZOD is not necessary, seek disposal options that avoid an accumulation of waste. Explore options to eliminate or reduce ZODs at existing facilities.

- Promote sound recreational fish waste management through a combination of fish-cleaning restrictions, public education, and proper disposal of fish waste.
- Encourage alternative uses of fish processing wastes (e.g., fertilizer for agriculture and animal feed).
- Explore options for additional alternatives for waste processing.
- Monitor ZOD sites regularly (e.g., by diver, drop camera, remotely operated vehicle).
- Monitor biological and chemical changes to the site of seafood processing waste discharges regularly.
- Locate waste outfall in areas with adequate natural flushing or exposed to higher currents.
- Collect local and traditional knowledge to evaluate potential impacts of the fish waste ZOD on community well-being (e.g., subsistence activities) and provide an opportunity for open dialog on this issue.
- Accurately represent volumes of discharge and waste when assessing potential impacts when developing water quality standards for effluent mixing zones.
- Consider alternatives in the method of grinding fish that reduce the potential impacts to benthic habitat and water quality. See Thorne at al. (2006) for a discussion on this recommendation.
- Accurately assess and account for the volume of fish processing waste discarded on a seasonal basis, as well as tidal volumes, velocities and effluent dilution.

4.4.11 Point-Source Discharges

Point source pollutants typically enter the marine environment via a pipe, culvert, or similar outfall structure. These discharge structures are often associated with domestic or industrial activities or located in conjunction with collected runoff from roadways and other developed portions of the coastal landscape. Waste streams from sewage treatment facilities and watershed runoff may combine in a single discharge. Point source discharges introduce inorganic and organic contaminants into aquatic habitats where they may become bioavailable to living marine resources (Johnson et al. 2008). Determining the fate, transport and ecological effect of natural and synthetic contaminants in the environment requires an interdisciplinary approach to identify and evaluate all processes sensitive to pollutants. This approach is critical since adverse effects may be manifested at the biochemical level in organisms in a manner particular to the species or life stage exposed (Luoma 1996, Necibi and Mzoughi 2017). See Section 3.5.1 (Nonpoint Source Pollution) for a discussion on nonpoint source pollution.

A pollutant's fate and transport depend on a variety of factors including site-specific ecological conditions, the physical state of the contaminant introduced into the aquatic environment, and the chemical properties of the substance. Soluble or miscible substances usually enter waterways in an aqueous phase, ultimately adsorbing onto organic and inorganic particles. However, contaminants may also enter aquatic systems as either particle-borne suspensions (e.g., microplastics) or solutes (Wu et al. 2005, Carbery et al. 2018, Hader et al. 2020). Physical factors, such as the presence of significant currents or a strong thermocline or pycnocline, may influence the spatial extent of contaminant dispersal. In particular, turbulent mixing or diffusion disperses contaminant patches in coastal waters which results in larger, comparatively diluted contaminant distributions farther away from the initial point source, creating areas where turbulence and mixing occur (Bishop 1984). Subsequent biological activity and geochemical processes intercede and typically result in contaminant partitioning between the aqueous and particulate phases (Turner and Millward 2002).

Physical dispersal, biological activity, and other ecological factors play significant roles in the distribution of contaminants in aquatic habitats; however, certain ambient environmental conditions govern the partitioning of contaminants, notably salinity, pH, and the physical nature of local sediments (Leppard and Droppo 2003, Wu et al. 2005, Tourinho et al. 2019). Highly reactive suspended particles serve as important carriers of aquatic contaminants and are largely responsible for their bioavailability, transport, and ecological fate as they disperse into receiving waters (Harder and Stewart 1996, Turner and Millward 2002). Additionally, hyporheic exchange between overlying surface water and groundwater can alter salinity, dissolved oxygen concentration, and other water chemistry aspects in ways that influence the affinity of local sediment types for particulate contaminants or otherwise affect contaminant behavior (Ren and Packman 2002, Tourinho et al. 2019).

4.4.11.1 Potential Impacts

Exposure to pollutants can inhibit the following biological attributes (Thurberg and Gould 2005, Petitjean et al. 2019):

- Basic detoxification mechanisms (e.g., production of metallothioneins or antioxidant enzymes);
- Disease resistance;
- Individual or population level ability to counteract pollutant-induced metabolic stress;
- Reproductive processes, including gamete development and embryonic viability;
- Growth and successful development through early life stages;
- Normal processes, including feeding, respiration, osmoregulation; and
- Overall fitness that can affect local adaptation or maladaptation, with strong impacts on the evolutionary trajectories of wild fish populations.

If located improperly, discharge sites may modify habitat by creating adverse impacts to sensitive areas such as freshwater shorelines and wetlands, emergent marshes, eelgrass, and macroalgae (e.g., kelp). Extreme effluent discharge velocities may cause scouring at the discharge site and may also entrain particulates and create turbidity plumes. These turbidity plumes of suspended particulates can reduce light penetration and lower the rate of photosynthesis and the primary productivity of an area while elevated turbidity persists. The contents of the suspended material can react with the dissolved oxygen in the water and result in oxygen depletion or smother SAV, including eelgrass beds and kelp beds.

Suspended material can create a continuous shower of sediments falling from the upper layers of the water column to the benthos, known as marine snow. Accumulation of these outfall sediments may also alter the composition and abundance of infaunal or epibenthic invertebrate communities. Many benthic organisms are quite sensitive to grain size, and accumulation of sediments can also submerge food organisms. For example, benthic organisms impacted by oiled marine snow respond with motility, sensitivity to hypoxia and oil toxicity, and modified feeding habits (Ferraro et al. 1991, Van Eenennaam et al. 2018).

The introduction of pollutants through direct discharges can create lethal or sublethal habitat conditions to salmon and their prey. For example, fish kills may be due to a pesticide runoff event, an increase in water temperatures, or an algal bloom caused by excess nutrients depleting the oxygen content in the receiving water. Pollutant and water quality impacts can also have chronic effects that are detrimental to fish survival. Discharged anthropogenic contaminants demonstrate free movement within the aquatic and marine environments in an uncontrolled manner (Lopez-Pacheco et al. 2019). Anthropogenic contaminants can assimilate into fish tissues by absorption across the gills or through bioaccumulation through consuming contaminated prey. Pollutants suspended in the water column (e.g., nitrogen, contaminants, microplastics and fine sediments) or settled on the bottom (through food chain effects) can also affect salmon. When these solid particles are deposited, heavy metals, persistent organic compounds, or their degradation products can bioaccumulate in benthic organisms at much higher concentrations than in the surrounding waters (Good et al. 1987, Stein et al. 1995, Van Eenennaam et al. 2018, Miller et al. 2020). Adverse impacts on fish populations can occur from chronic low-level pollution from PAH-containing sources such as anthropogenic stormwater runoff (Gardner et al. 2019).

Microplastic contamination is well documented across a range of habitats and for a large number of organisms in the marine environment. Microplastics and associated chemical additives bioaccumulate and may biomagnify across the marine food web (Miller et al. 2020). Similarly, many heavy metals and persistent organic compounds (e.g. pesticides and polychlorinated biphenyls) tend to adhere to solid particles like microplastics. The bioaccumulation of microplastics increases the risk of trophic transfer of microplastics and contaminants within marine food webs (Carbery et al. 2018).

4.4.11.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of point source discharges to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Locate discharge points in coastal waters well away from shellfish beds, eelgrass and macroalgae beds, structural invertebrates, and other similar fragile and productive biogenic habitats.
- Monitor water quality discharges following NPDES and Alaska Pollutant Discharge Elimination System permit requirements from all discharge points, including municipal stormwater systems, and actively reduce the size of mixing zones that discharge to coastal areas and watersheds.
- Reduce potentially high velocities by diffusing effluent to acceptable velocities.
- Determine baseline benthic productivity by sampling before construction activities begin to facilitate monitoring of environmental changes.

- Provide for mitigation when degradation or loss of habitat occurs from placement and operation of the outfall structure and pipeline.
- Institute source-control programs that effectively reduce noxious materials to avoid introducing these materials into the waste stream.
- Ensure compliance with pollutant discharge permits which set effluent limitations and/or specify operation procedures, performance standards, or BMPs.
- Establish and update, as necessary, pollution prevention plans, spill control practices, and spill control equipment for the handling or transporting of toxic substances.
- Treat discharges to the maximum extent practicable including up-to-date methodologies for reducing discharges of biocides (e.g., chlorine) and other toxic substances (e.g., dissolved copper).
- Use land-treatment and upland disposal or storage techniques where possible. Limit the use of vegetated wetlands as natural filters and pollutant assimilators for large-scale discharges to those instances when other less damaging alternatives are not available.
- Avoid siting pipelines and treatment facilities in wetlands and streams.
- Consider the ecological effects of marine snow in point and nonpoint source contamination management.

4.4.12 Water Intake Structures and Discharge Plumes

Withdrawals of riverine, estuarine, and marine waters are common for a variety of uses, such as power plant cooling water and creating temporary ice roads and ice ponds. In the case of power plants, the subsequent discharge of heated and/or chemically treated discharge water can also occur (Johnson et al. 2008).

4.4.12.1 Potential Impacts

Water intake structures and effluent discharges can interfere with or disrupt EFH functions in the source or receiving waters via impacts related to: (1) entrainment, (2) impingement, (3) degrading water quality and quantity, (4) operation and maintenance, and (5) construction.

With the use of intake structures, aquatic organisms may be entrained along with the cooling water into the infrastructure system. Entrained organisms are usually at the egg and larval stages of aquatic species including managed species and their prey, but may include juveniles and adults. Entrainment can subject these life stages to adverse conditions resulting from the effects of increased heat, antifouling chemicals, physical abrasion, rapid pressure changes, and other detrimental effects. Long-term water withdrawal may adversely affect fish and shellfish populations by adding another source of mortality to the early life stage, which often determines recruitment and year-class strength (Travnichek et al. 1993, Stich et al. 2018). Pink salmon are likely to be more susceptible to entrainment because they typically enter estuarine and marine habitats immediately after emergence and are much smaller. Based on entrainment studies conducted at power plants located in coastal areas, a large percentage of entrained larvae are composed of resident fishes that serve as a forage base for other species, such as salmon. Power plants located in open coastal environments have less potential for population-level effects on fish populations than power plants located in coastal bays (EPRI 2007).

Impingement occurs when organisms are pushed against the screening device by the flow of water. The organisms cannot escape because the force of flowing water pushing them against the screen is greater than their swimming capabilities. Similar to entrainment, the withdrawal of water can trap particular species, especially weaker swimmers.

Thermal effluents in riverine and inshore habitats can cause severe problems by directly altering benthic communities or killing organisms, especially ichthyoplankton. Temperature influences biochemical processes of the environment and the behavior (e.g., migration) and physiology (e.g., metabolism) of these organisms (Coutant 1976). Power plants may use once-through cooling biocides, such as sodium hypochlorite and sodium bisulfate that are extremely toxic to aquatic life, to clean the intake and discharge structures.

4.4.12.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of water intake and discharge to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Locate facilities that rely on surface waters for cooling in areas other than estuaries, inlets, heads of submarine canyons, rock reefs, or small coastal embayments where managed species or their prey concentrate.
- Locate discharge points in areas with low concentrations of living marine resources.
- Ensure that pipes extend a substantial distance offshore and are buried deep enough not to affect shoreline processes.
- Incorporate cooling towers at discharge points to control temperature, and use safeguards to ensure against release of pollutants into the aquatic environment in concentrations that reduce water quality.
- Design intake structures to minimize entrainment or impingement. Use velocity caps that produce horizontal intake or discharge currents and ensure that intake velocities across the intake screen do not exceed 0.15 m per second (0.5 ft per second).
- Design power plant cooling structures to meet the best available technology requirements as developed pursuant to Section 316(b) of the CWA. Use alternative cooling strategies, (e.g., closed cooling systems) to avoid entrainment or impingement impacts in all industries that require cooling water. When alternative cooling strategies are not feasible, other options may include fish diversion or avoidance systems; fish return systems that convey organisms away from the intake; mechanical screen systems that prevent organisms from entering the intake system; and, if impacts are unavoidable, habitat restoration measures to mitigate for expected losses of juvenile fish, larvae, and eggs.
- Regulate discharge temperatures (both heated and cooled effluent) to minimize effects to ambient temperature to avoid changes in species assemblages and ecosystem function in the receiving waters.
- Implement technologies to diffuse heated effluent.
- Avoid the use of biocides (e.g., chlorine) to prevent fouling where possible. Implement the least damaging antifouling alternatives.

- Treat all discharge water from outfall structures to meet state water quality standards at the terminus of the pipe.
- Set buildings and associated structures far enough back from the shoreline to preclude the need for bank armoring.

For most applications in Alaska, water withdrawals consume small quantities (compared to large power plants, factories, etc). ADFG has information and best practices on intake structures. In most cases, a fish habitat permit from ADFG is required.

4.4.13 Aquaculture

Commercial aquaculture operations often use productive embayments. Embayments provide protected waters for kelps (bull, sugar, ribbon), geoduck (*Panopea generosa*), oyster (*Crassostrea gigas* and *C. sikamea*), and blue mussel (*Mytilus edulis*) culturing. In 1988, Alaska passed the Alaska Aquatic Farming Act which encourages the establishment and growth of an aquatic farming industry in the state. The Alaska Aquatic Farming Act requires four criteria the Alaska Department of Natural Resources issues an aquatic farm permit, including the requirement that the farm may not significantly affect fish, wildlife, or other habitats in an adverse manner.

Mariculture is a specialized branch of aquaculture that produces food products in open water, and is also known as marine farming. Aquaculture in Alaska was advanced through the formation of the Mariculture Task Force by the Alaska Mariculture Initiative in 2016 (NMFS and PSMFC 2020). The goal is to develop mariculture over the next 20 years and includes outreach to the private sector that has led to increased entry into the industry. Through the Executive Order Promoting American Seafood Competitiveness and Economic Growth (Executive Order 13921), coastal states can develop Aquaculture Opportunity Areas. Advanced mapping tools can help determine which locations will benefit from aquaculture farms while avoiding adverse impacts to the environment and negative interactions with marine mammals and other industry operations.

Kelp aquaculture is increasing in Alaska with farms ranging from 1.0 to 100 acres. Kelp aquaculture often includes multiple kelp species in one farm like bull kelp, sugar kelp, ribbon kelp, and dulce. Kelp aquaculture has a relatively low impact on EFH, especially in areas where SAV or kelp beds would not be present (Grebe et al. 2019). Studies show an ecosystem benefit with greater species richness in farmed kelp assemblages (Radulovich et al. 2015, Walls et al. 2016). This is because kelp and both patchy and continuous eelgrass beds are important habitat components for groundfish including early juvenile Pacific cod (Grüss et al. 2021). Kelp aquaculture can also benefit wild kelp populations by minimizing the need for wild harvests, from which kelp is recovering at slower rates with climate change (Krumhansl et al. 2017). To that end, kelp acts as a carbon sink and plays an important role in climate change mitigation (Chung et al. 2013, Filbee-Dexter and Wernberg 2020).

Shellfish culture in EFH consists primarily of oyster culture and includes clams, mussels, and abalone (PFMC and NMFS 2014). Geoducks, sea cucumbers (*Apostichopus californicus*), and red and blue king crab (*Paralithodes camtschaticus* and *P. platypus*) are cultured for research activities. Similar to kelp aquaculture, shellfish aquaculture can benefit fish habitat by providing structural habitat and food resources (Theuerkauf et al. 2021). Shellfish aquaculture also tends to have less impact to EFH than finfish aquaculture because the shellfish generally are not fed or treated with chemicals (OSPAR Commission 2009).

In Alaska, state law prohibited finfish farming within state waters. There are, however, hatcheries throughout Alaska producing salmon, trout, and Arctic char (*Salvelinus alpinus*). Salmon hatcheries release juveniles to the ocean. There is not the need for continual feeding or treatments to adulthood or marketability in the nearshore environment. There are 31 salmon hatcheries in Alaska, including a NOAA research hatchery (Wilson and Laman 2020).

4.4.13.1 Potential Impacts

Potential adverse impacts to EFH by aquaculture operations include: (1) the risk of introducing undesirable or invasive species and disease, (2) the physical disturbance of intertidal and subtidal areas, and (3) impacts to estuarine food webs, including the disruption of eelgrass habitat (e.g., dumping of shell on eelgrass beds, repeated mechanical raking or trampling, and impacts from predator exclusion netting).

Aquaculture includes the risk of introducing undesirable or invasive species and diseases into the natural environment. Depending on the species of shellfish and their natural habitat features (water temperature, salinity, etc.), farmed species could successfully reproduce in or adjacent to their farm operation. Alaska currently produces two species of oyster with temperature limits for reproducing in northern climates (Fofonoff 2018). In addition to direct introduction of nonnative species as target mariculture organisms and their diseases, invasive species may be introduced inadvertently from infrastructure being transferred from one body of water to another. Such was the case for oyster culture floating docks where the colonial tunicate *D. vexillum* was discovered in Sitka, Alaska. Transport of infrastructure from British Columbia is suspected to have been a factor in bringing this species to Alaska (Cohen et al. 2011). Section 4.4.14 (Invasive Species) provides more information on the impacts of invasive species.

Concern has been expressed about extensive shellfish culture in estuaries and its impact on estuarine food webs. Oysters are efficient filter feeders and reduce microalgae and zooplankton that are also food for salmon prey species. The extent to which this may adversely affect managed prey species is unknown. However, because bivalves remove suspended sediments and phytoplankton from the water column, aquaculture may also improve water quality in eutrophic areas and can assist in recycling nutrients from the water column to the sediment (Emmett 2002).

Various methods of shellfish culture and harvest, such as mechanical harvest in eelgrass beds, harrowing, off-bottom culture, and raft and line culture, also have the potential adverse effects to EFH. The greatest impacts are temporary and result from mechanical harvest or harrowing which involve physical disturbance of the benthic zone (PFMC and NMFS 2014). Hydraulic dredges used to harvest oysters in coastal bays can cause long-term adverse impacts to eelgrass beds by reducing or eliminating the beds (Phillips 1984), though oyster farms in Alaska primarily use floating culture. Dumping of oyster shells during harvest can also damage the beds and disrupt the benthic environment. Use of chemicals to control burrowing organisms detrimental to oyster culture may also adversely affect EFH, and policies have been developed to regulate the use of chemicals in natural habitat and offset losses to eelgrass beds (WDF and WDOE 1992).

Kelp aquaculture does not offer as many concerns as shellfish operations, though with both there is the risk of gear loss. Aquaculture gear can introduce plastic or synthetic lines, bags, crates, and equipment into the ocean. Storm events or entanglement with vessels or marine mammals can cause gear loss and the introduction of plastic pollution. Kelp aquaculture can impact the marine food web because kelp is a common spawn surface for Pacific herring (Haegele and Schweigert 1985). Herring spawn timing may overlap with kelp harvests in Alaska, and a loss of herring as a prey component would adversely impact salmon and groundfish EFH. This concern is reflected in existing ADFG kelp aquaculture regulations requiring that, if herring spawn on the site, "the herring eggs must not be disturbed or removed" and that ADFG shall be notified, "within five days of the initial discovery" (5 AAC 41.250(a)(6)).

4.4.13.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of aquaculture facilities to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Site aquaculture operations away from existing kelp or eelgrass beds. If aquaculture operations are to be located adjacent to existing kelp or eelgrass beds, monitor these beds on an annual basis and re-site the aquaculture facility if monitoring reveals adverse effects like shading.
  - Complete survey efforts for eelgrass beds during the summer active growth season. NMFS' *California Eelgrass Mitigation Policy and Implementation Guidelines* suggest a survey is considered valid for 60 days, after which the growth of beds may have occurred beyond the boundaries originally observed (NMFS 2014).
  - Scale the survey area appropriately for the size of the potential action and the potential extent and distribution of eelgrass impacts, including both direct and indirect effects. The resolution of mapping should be adequate to address the scale of effects reasonably expected to occur.
- Encourage development of harvesting methods that minimize impacts on SAV and the loss of food and/or habitat to fish populations during harvesting operations. For example, do not dump oyster shells on eelgrass beds during production or harvest.
- Survey mariculture sites for herring presence in the spring and for herring spawn. If spawn-on-kelp is present, no kelp harvests can occur until after the eggs have hatched.
- Do not enclose or impound tidally influenced wetlands for aquaculture.
- Take into account the size of the facility, migratory patterns of federally managed species, competing uses, hydrographic conditions, and upstream uses when siting facilities.
- To the extent possible, use new materials and do not move aquaculture equipment from one waterbody to another.
  - If materials are sourced from a used farm site, ensure that gear, spat, and related items transported from other areas are free of invasive species. For control of tunicates, remove nets, floats, and other structures from salt water periodically and allow them to dry thoroughly and/or soak them in fresh water.
- Undertake a thorough scientific review and risk assessment before any non-native species are introduced into the natural environment.

    - Take into consideration predicted temperature changes in the marine environment if the mariculture operation is relying on temperature controls of non-native species.
    - Aquaculture facilities rearing non-native species should be located upland and use closed-water circulation systems whenever possible.
- Remove all buoys, lines, anchors, etc. and restore the aquatic farm site once vacating the operation to minimize continued impacts to EFH, including additional marine debris, from abandoned structures. Provide financial assurances for site reclamation when the aquaculture stops.

4.4.14 Invasive Species

Presidential Executive Order 13112 defines an invasive species as a species that is nonnative to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health. The introduction of aquatic invasive species into estuarine, riverine, and marine habitats has been well documented (Kohler (Kohler and Courtenay 1986, Ruiz and Carlton 2003, McGeoch et al. 2010, Meyerson et al. 2019) and can be intentional (e.g., stock or pest control, recreational fishing) or unintentional (e.g., fouling organisms)[30]. Exotic fish, invertebrates, microorganisms (including pathogens), and aquatic plants can spread via industrial and commercial shipping, recreational boating, transportation corridors, aquaculture, biotechnology, and aquariums. The introduction of nonnative organisms to new environments can have severe impacts on habitats. Coordination and cooperation among Alaska's existing organizations and their available resources is critical to successfully control and prevent invasive species in Alaska (ADFG 2002).

A wide diversity of non-native taxonomic groups have colonized coastal ecosystems in other parts of the U.S. (McGee et al. 2006, Cuthbert et al. 2022). Alaska's geographic isolation, harsh climate conditions, limited number of highly disturbed habitat areas, stringent plant and animal transportation laws, and low human population density may explain the relative lack of invasion compared to more temperate sites in North America (ADFG 2002, 2006).

However, invasive species pose a serious threat to Alaska's native flora and fauna (Ware et al. 2016). Long borders, long coastlines, busy shipping centers, and a large amount of imported goods give invasive species a vector to enter Alaskan waters. As economic activity and population size increase and the climate continues to change, the likelihood of aquatic invasive species establishing in Alaska will increase (Grebmeier et al. 2006, McGee et al. 2006). Climate change warms temperatures and extends seasons for species to spawn successfully and grow to reproductive maturity and alters salinity regimes as glaciers and sea ice retreat (de Rivera et al. 2011, Reimer et al. 2017). According to (ADFG 2002), "potential introduction pathways include fish farms, the intentional movement of game or bait fish from one aquatic system to another, the movement of large ships and ballast water from the U.S. West Coast and Asia, fishing vessels docking at Alaska's busy commercial fishing ports, construction equipment, trade of live seafood, aquaculture, and contaminated sport angler gear brought to Alaska's world-renowned

[30] Illustrating the depth of research available, the scholarly journal *Biological Invasions*, first published in 1999, focuses on research and synthesis papers, and policy and management issues, specific to biological invasions in terrestrial, freshwater, estuarine, and marine ecosystems.

fishing sites." Natural dispersal northward along the west coast of North America is another mode of introduction as is currently occurring for green crab.

Ballast water, water that is taken in or released by cargo vessels to compensate for changes in a ship's weight as cargo is loaded or unloaded or as fuel and supplies are consumed, is a major source of introducing invasive species into aquatic ecosystems (Bailey 2015). When a vessel takes in ballast water, it also takes in aquatic organisms that may be carried from one port to another along the vessel's route. When ballast water is released, invasive species may be introduced into new environments where they can cause environmental harm. The U.S. Coast Guard (USCG) prohibits ships to discharge untreated ballast water in U.S. waters.

In addition to ballast water, ships can also introduce invasive species to aquatic ecosystems from biofouling. Biofouling refers to organisms attached to or associated with underwater or wetted surfaces of a vessel, including boat hulls, propellers, rudders, and intakes, which can accumulate attached organisms. Globally, 55.5 to 69.2 percent of non-native species are established because they were spread by biofouling (Scianni et al. 2017).

The Vessel Incidental Discharge Act (VIDA) establishes a framework for the regulation of discharges, including ballast water, incidental to the normal operation of a vessel under the CWA Section 312(p). The purpose of the VIDA, also called the Frank LoBiondo Coast Guard Authorization Act of 2018, is to streamline requirements from federal, state, and local authorities for the commercial vessel community. It also includes specific references to areas within Alaska (e.g. Alexander Archipelago and Kachemak Bay).

Many recognized freshwater, estuarine and marine invasive species threatening Alaska are in the state or along the west coast of North America with the potential to spread to Alaska (Table 3 and Table 4). The status of invasive species is subject to rapid change. We recommend consulting additional reference material for up to date information on these species range, occurrence and management.

Table 2. Invasive aquatic species considered threats to Alaska's freshwater environment.

Common Name	Species
northern pike	*Esox lucius*
signal crayfish	*Pacifastacus leniusculus*
zebra mussel	*Dreissena polymorpha*
New Zealand mudsnail	*Potamopyrgus antipodarum*
Waterweed	*Elodea spp*
water thyme	*Hydrilla verticillata*
dotted duckweed	*Landoltia [Spirodela] punctata*
purple loosestrife	*Lythrum salicaria*
Eurasian water-milfoiland	*Myriophyllum spicatum*
reed canary grass	*Phalaris arundinacea*
Japanese knotweed	*Polygonum cuspidatum*
swollen bladderwort	*Utricularia inflata*

Table 3. Invasive aquatic species considered threats to Alaska's estuarine environment.

Common Name	Species
saltmarsh cordgrass	*Spartina alterniflora*
dense-flowered cordgrass	*S. densiflora*
Chinese mitten crab	*Eriocheir sinensis*
blue mud shrimp parasitic bopyrid isopod	*Orthione griffensis*

Table 4. Invasive aquatic species considered threats to Alaska's marine environment.

Common Name	Species
Atlantic salmon	*Salmo salar*
green crab	*Carcinus meanas*
wakame algae	*Undaria pinnatifida*
tunicates	*B. violaceus, B. scholsseri, C. savignyi, and D. vexillum*

4.4.14.1 Potential Impacts

Invasive species can create five types of negative effects to EFH: (1) habitat alteration, (2) trophic alteration, (3) spatial alteration, (4) gene pool alteration, and (5) introduction of parasites and diseases.

Invasive species can cause direct impacts to valuable habitats. Green crab, which are steadily moving northward along the west coast of North America, cause direct impacts by eating eelgrass rhizomes and indirect impacts by digging for food with resulting bioturbation (Schooler 2020). In British Columbia, increasing crab populations have led to declines in eelgrass beds (Howard et al. 2019). Another example of habitat alteration includes the excessive colonization by sessile invasive species, which precludes the growth of endemic organisms. The colonial tunicate *D. vexillum*, discovered in Whiting Harbor in Sitka, Alaska, grows as a smothering mat on hard surfaces. Its distribution includes the seafloor of Georges Banks fishing grounds of the northeast United States, where it has been implicated in reduced groundfish foraging ability as well as impacts to scallop and biodiversity in general (Cohen et al. 2011, Kaplan et al. 2017, 2018).

Invasive species may alter community structure, particularly the trophic structure, by preying on native species and by increasing their own population levels. Introduced organisms may compete with indigenous species or prey on indigenous species that can reduce native fish and shellfish populations. For example, in freshwater lakes on Alaska's Kenai Peninsula, introduced northern pike (*Esox lucius*) have depleted local salmonid populations through rampant juvenile predation (ADFG 2007). Spatial alteration occurs when introduced species compete with and displace native species. The introduction of invasive organisms also threatens native biodiversity. Invasive species can lead to changes in relative abundance of species and individuals that are of ecological and economic importance.

Long-term impacts from the introduction of nonindigenous species can include a decrease in the overall fitness and genetic diversity of natural stocks. Although hybridization is rare, it may occur between native and introduced species and can result in gene pool deterioration. Potential long-term impacts also include the spread of lethal diseases. The introduction of bacteria, viruses, and parasites is a severe threat to EFH as it may reduce habitat quality. New pathogens or higher concentrations of disease can spread throughout the environment, resulting in deleterious habitat conditions.

4.4.14.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of invasive species to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Adhere to fish and game regulations of the Alaska Board of Fisheries (AS 16.05.251) and Board of Game (AS 16.05.255) which prohibit and regulate the live capture, possession, transport, or release of native or exotic fish or their eggs.
- Adhere to regulations and use BMPs outlined in the State of Alaska Aquatic Nuisance Species Management Plan (ADFG 2002) and Management Plan for Invasive Northern Pike in Alaska (ADFG 2007).
- Comply with USCG and EPA regulations for ballast water and biofouling. Check on the status of these regulations as they are in phases of development at the time of this review.
- Visually inspect and clean vessel surfaces (e.g., propellers, hulls, anchors, fenders) brought from other areas over land via trailer that may harbor non-native plant or animal species. Empty bilges and clean thoroughly using hot water or a mild bleach solution. Perform these activities in an upland area to prevent the introduction of non-native species during the cleaning process.
- Treat effluent from public aquaria displays, laboratories, and educational institutes using non-native species before discharge to prevent the introduction of viable animals, plants, reproductive material, pathogens, or parasites into the environment.
- Encourage the proper disposal of seaweeds and other plant materials used for packing purposes when shipping fish or other animals. These materials may harbor invasive species and pathogens and should be treated accordingly.
- Undertake a thorough scientific review and risk assessment before any non-native species are introduced into the environment.
- Use native plants to stabilize construction areas along roads, airports, and other developments. Avoid spreading invasive species in these areas when mowing or otherwise performing weed and brush control.
- When using biocides to control or eradicate aquatic invasive species, ensure that impacts to non-target organisms, ecosystems and human health are avoided or minimized with taxa targeted biocides, monitoring and adaptive management.
- Avoid spreading marine invasive species via overwater structures or vessel infrastructure in harbors by inspecting for fouling organisms. If fouling is present, dry, clean, and treat any infested components. Be mindful of requirements for using toxic chemicals. A final

inspection before transport and placement in new areas confirms fouling organisms are lacking or dead.

4.4.15 Marine Hydrokinetic Energy Converters

Marine hydrokinetic energy converters (MHK), a marine and estuarine category HEC technology, is an emerging renewable energy technology in Alaska (Bedard et al. 2010, Johnson and Pride 2010). MHK technology largely remains at the research and development stage[31]. Proposed projects locations in Alaska include Cook Inlet and in coastal Southeast Alaska. This section considers EFH impacts associated with nearshore deployment of MHK technology (Johnson and Pride 2010). Section 3.5.10 (In-River Hydrokinetic Energy Converter) provides a discussion of the riverine application of HECs. The Annex IV State of the Science Report (Copping et al. 2016, Copping 2018) provides detailed updated information on the industry and potential impacts. For the most current environmental information regarding MHK impacts and the HEC industry generally, the Pacific Northwest National Laboratory hosts a data repository for HEC and wind energy technologies.[32]

The Energy Independence and Security Act defines marine hydrokinetic renewable energy as electrical energy from waves, tides, and currents in oceans, estuaries, and tidal areas (DoE 2009). MHK devices can be categorized into rotating machines and wave energy conversion devices (Bedard 2005). Rotating machines include a rotor that spins in response to the movements of ocean currents. Consisting of conventional propeller-type blades or helical blades, the rotor can be encased in a duct that channels the flow or can be open like a wind turbine. Wave energy converters harness the energy possessed by a body of water because of its elevation (i.e., head) relative to a reference point. The converters oscillate based on changes in the height of ocean waves. These devices must be secured to the ocean bottom by pilings driven into the sediments or by anchors and mooring cables (Cada et al. 2007).

MHK development involves four phases of activities that can potentially affect EFH: preconstruction, construction, operation and maintenance, and decommissioning phases (DoE 2009, Boehlert and Gill 2010, Kramer et al. 2010). Pre-construction activities may include site evaluations and technology testing, which may include similar (though smaller-scale) impacts as full deployment for cable and structure placement. Construction activities typically include horizontal directional drilling or trenching to land cables from the device to the shoreline, laying of subsea transmission cable, installation of foundations/moorings, subtidal trenching for cable placement, and deployment and commissioning of device(s). Operation and maintenance activities include monitoring the mechanical functioning of the devices, as well as inspecting and repairing equipment. Decommissioning at the end of the project, typically after 5 to 30 years of operation, involves the removal of all equipment in the water column and transmission cables and site restoration, with adverse impacts including the abandonment of equipment (such as cables, pilings, anchors or other frame structures) in place. Related activities that pertain to both the construction and operations phases include the installation and maintenance of navigation buoys to mark the deployment area and port infrastructure to accommodate work vessels, as well

[31] As of this publishing, FERC lists one licensed MHK project (PacWave South Hydrokinetic, P-14616, in Oregon) and one MHK pending preliminary permit (Western Passage Tidal, P-15285, in Maine).
[32] Environmental Effects of Wind and Marine Renewable Energy: https://tethys.pnnl.gov

as the delivery of large hydrokinetic devices to pier-side for repair and maintenance, which may including the beaching of devices (PFMC and NMFS 2014).

4.4.15.1 Potential Impacts

MHK project construction and decommissioning, and operations are associated with a range of adverse effects to EFH. Copping et al. (2021) provides a recent review of those potential effects.

(i) Construction and Decommissioning

Adverse effects associated with the construction and decommissioning of hydrokinetic facilities include changes to benthic habitat, loss of benthic organisms and changes in species composition, increases in turbidity and sedimentation, including localized sedimentation and erosion associated with bottom mounted structures, the mobilization of contaminants, fuel spills, and noise. Disturbances to benthic habitat may occur during construction vessel anchoring; the clearing, digging, and refilling of trenches for power cables; and the installation of permanent anchors, pilings, and other mooring devices. Prior to installation of a buried cable, debris is typically cleared from the cable route; cables are then buried, after which they may be exposed and reburied as needed for repair (Carter 1996). Burying cables may be active (through backfilling the trench) or passive (the trench refills over time from local environmental processes). Leaving a subtidal trench open in a low energy environment can create silty, anoxic holes. Alternatively, there is no need to backfill if the environment is high energy and rapidly changing.

Construction and decommissioning activities can crush, smother, or displace benthic organisms (MMS 2007). Such activities are also associated with increased turbidity, which can harm SAV by limiting photosynthesis, reducing the availability of planktonic organisms that serve as a base of the aquatic food chain. This vegetation loss also limits forage and shelter habitats for fish (MMS 2007). Additionally, the alteration of benthic community structure associated with substrate disturbance may lead to sediment structure alteration and changing habitat suitability for select species (Engel and Kvitek 1998). The addition of vertical structures introduces new complexity for organism recruitment.

Sediment disturbance from the installation and removal of foundations, anchors, and transmission cables can mobilize contaminants that impact fish, their prey and their habitats. Contaminants may be released via fuel spills and lubricant leaks as a result of accidents or wear and tear, or from sediments disturbed during pile removal (MMS 2007). Noise associated with construction and decommissioning activities, in particular pile driving, can disturb or harm fish (MMS 2007).

(ii) Operations

Adverse effects from the operation of MHK infrastructure include contaminant release, generation of electromagnetic fields, physical interaction of aquatic organisms, impacts to the migration behavior of fish, and predator aggregation. The impacts of facility operation noise are not well understood (MMS 2007, PFMC and NMFS 2014); however, background noise in highly dynamic environments should be considered during analysis of effects.

Operations may result in the release of contaminants from infrastructure or as a result of accidental releases or leaks from service vessels (MMS 2007). Anti-fouling coatings may result in the chronic release of dissolved metals or organic compounds (DoE 2009). In addition, the presence of electromagnetic fields associated with transmission cables can affect the behavior of migrating adult and juvenile salmonids (PFMC and NMFS 2014). Electric fields from submarine cables may result in attraction or avoidance by some fish species (Gill 2005).

MHK operations may also impact aquatic organisms via entrainment, impingement, or entrapment, depending on the MHK device design (DoE 2009, Kramer et al. 2010). Depending on device design, fish can be impinged on screens, entrained through turbines, or trapped within water collection chambers. The greatest risk of collision for marine vertebrates is with rotating turbines since a fish struck by a rotor can be injured or killed (MMS 2007). Field and laboratory studies indicate that fish may be able to detect and avoid devices at some distance or pass through some MHK devices without harm (Wilson et al. 2007, Hammar et al. 2013, Copping et al. 2016).

Operating MHK arrays may affect migration and rearing habitat for juvenile and adult salmonids (DoE 2009). Large arrays comprising multiple turbines could affect habitat connectivity and interfere with migration (Hammar et al. 2013). Floating and submerged structures, mooring lines, and transmission cables can create complex structural habitats that act as fish aggregation and attraction devices and provide substrate for invertebrate attachment. Salmonids may be attracted to forage fish that congregate around the structure (PFMC and NMFS 2014). Captures from passive fishing gear entangled on facility infrastructure can reduce the quality of salmon migration routes. Lighted, fixed surface structures including navigation buoys marking the project area can aggregate predators, such as fish, marine mammals, and sea birds that threaten salmon migration corridor safety via increased predation risk (PFMC and NMFS 2014).

4.4.15.2 Recommended Conservation Measures

The following recommended conservation measures are potential actions to avoid and minimize adverse impacts of MHK development to EFH from the preconstruction phase through to construction, operations and decommissioning, and to promote the conservation, enhancement, and proper function of EFH.

- Conduct detailed site-specific analysis to understand potential project related impacts. Evaluate cumulative effects of deploying multiple devices (MMS 2007, Boehlert and Gill 2010, PFMC and NMFS 2014).
- Conduct pre-construction contaminant surveys of the sediment in excavation and scour prone areas.
- Locate and operate devices at sites and times of the year to avoid impacts to salmon migration.
- Follow BMPs for pile driving and removal to mitigate the impacts of noise and turbidity. Sections 4.4.5 (Pile Driving) and 4.4.6 (Pile Removal) provide additional information on pilings, their impacts and CRs.
- Schedule transmission cable installation to minimize overlap with salmon migration.
- Minimize seafloor disturbance during installation of MHK units and underwater cables. Section 4.4.9 (Utility Lines, Cables, and Pipelines) provides more information on cable installation BMPs.
- Bury transmission cables on the seafloor to minimize benthic and water column electromagnetic field exposure.

- Sheath or armor transmission cable(s) to reduce the transmission of electromagnetic fields if burying the cable is not practical.
- Align transmission cables along the least environmentally damaging route. Avoid sensitive habitats (e.g., salt marsh rocky reef, kelp beds, eelgrass) and critical migratory pathways.
- Use horizontal drilling where cables cross nearshore and intertidal zones to avoid disturbance of benthic and water column habitats. Properly manage the resulting waste material.
- Design the mooring systems to minimize footprint by reducing anchor size and chain sweep. Consider the use of midline buoys to minimize impacts.
- Develop and implement a device maintenance program to remove entangled, derelict fishing gear and other materials that may affect aquatic species.
- Use nontoxic paints and lubricating fluids at the facility where feasible.
- Implement job safety plans and other operating procedures that reduce the likelihood of vessel accidents and fuel spills.
- If multiple devices must be used at a site, consider an array pattern that provides adequate space for fish to pass through and reorient safely (Hammar et al. 2013).
- Use brightly colored or fluorescent rotors on turbines which can be more easily visually detected in turbid waters (Hammar et al. 2013).
- To avoid predator concentration at the site, consider design features to prevent or minimize pinniped haul outs and bird roosting on above-water structures.

4.4.16 Habitat Restoration and Enhancement

Habitat loss and degradation are major, long-term threats to the sustainability of fishery resources (NMFS 2015). The rapid loss of coastal habitat, and in particular coastal wetland habitat in the United States, has implications for the quality and quantity of EFH in the country. This is because over 75 percent of commercial fisheries, and 80 to 90 percent of recreational marine and anadromous fishes, depend on estuarine, coastal and riverine habitats for all or part of their life-cycles (NMFS 2002). Viable coastal and estuarine habitats are important to maintaining healthy fish stocks, and good water quality and quantity, appropriate substrate, ample food sources, and adequate shelter from predators are needed to sustain fisheries (NMFS 2002). Habitat restoration and enhancement assists in sustaining and rebuilding fish stocks by increasing or improving ecological structure and functions. In Alaska, habitat restoration and enhancement activities include projects such as:

- Removing debris (solid, man-made items) from the coastal and marine environment, including removal of derelict fishing gear, and other persistent material.
- Removing barriers to fish passage for all life stages (e.g., fish ladders, improving culverts or bridges that allow for passage of fish, water, sediment and debris.
- Subtidal planting or seeding of SAV or marine algae.

- Fish, wildlife, and vegetation management to control or remove localized invasive species populations; support the re-establishment of native species; and monitoring for newly introduced species.
- Wetland restoration through the adding or removing of substrate to achieve the proper elevation for wetland plant growth; and protecting or restoring transition zones such as tidal shorelines through shoreline stabilization methods.
- Freshwater stream restoration through the placement of habitat structures such as woody debris (including LWD); reconnecting floodplains to stream channels; stabilizing, protecting, or restoring stream banks; creating or restoring off-channel habitats; or removing riprap.
- Levee and culvert removal, modification, and set-back, berm breaching, and removal of other impediments to allow historic/natural tidal flow or hydrology in wetlands.
- Upgrading or decommissioning roads that pass through or near sensitive habitats such as wetlands or streams, or adversely affect these habitats. Trail restoration to reduce erosion and enhance low-impact recreational uses.
- Signage and access management (fences other barriers) to prevent or discourage access to recovering habitat.
- Conservation transactions, including purchasing or transferring ownership or easements, usage rights, or access to water or land; securing water right reservations for fish species; and purchasing or transferring conservation credits.

4.4.16.1 Potential Impacts

Habitat restoration and enhancement projects generally occur in urban areas impacted by human development and pollution as well as in remote rural locations. A wide variety of coastal habitats are restored under various restoration and mitigation programs, including riparian corridors, fish passage, shorelines, salt marshes, SAV, kelp, shellfish beds, and artificial reefs. These habitats are targeted for restoration because of degradation and loss of habitat resulting from dredging, filling, pollution, development, and erosion. Each discussion provides a description of potential restoration activities and an assessment of their impacts to EFH. Restoration activities result in localized and temporary adverse impact but will generally provide beneficial habitat and ecological functions in the long-term.

- Riparian habitat restoration includes re-vegetation activities and placement of LWD. Manual placement of LWD, often with heavy equipment, may result in minor disturbance of the surrounding habitat. This may result in soil compaction as well as disturbance of existing vegetation or other habitat structures.
- Fish passage restoration and other hydrologic restoration activities, such as the removal of culverts, in-stream structures, or other in-water activities require temporary water control measures and heavy equipment. This can temporarily disturb onsite or adjacent habitats by altering hydrologic conditions and flows, and increase turbidity during project implementation.
- Shoreline restoration typically involves the removal of invasive species, which may result in potential adverse impacts to non-target species. Invasive species removal includes

using chemical, mechanical, biological and ecological control methods, depending on the characteristics of the target species. Herbicide application is often effective in the removal of invasive species, but minor impacts to surrounding areas may occur. Rainfall and wind may cause herbicides to leach into the surrounding soil or contact non-invasive plants, causing unintentional damage. The physical removal of invasive species may also be effective, but potential impacts may occur if revegetation by native species does not occur immediately following invasive species removal.

- Salt marsh restorations generally involve removal of invasive vegetation, revegetation of native plants, culvert replacement to restore tidal flushing, and other control methods. Revegetation may result in minor disturbance of the surrounding habitat through increased foot traffic. This may result in soil compaction as well as disturbance of existing vegetation or other habitat structures. Restoration of tidal flow often requires heavy equipment, access routes, and placement of 'marsh mats'. The restored tidal flow may result in temporary erosion at select pinch points.
- Eelgrass restoration often involves transplanting eelgrass from existing donor beds, which can cause short- and long-term adverse impacts to the donor bed. These include temporary and permanent damage to existing beds by substrate disturbance, plant removal, and trampling, which may reduce the quality and quantity of EFH in the donor area. Damage of eelgrass during transplanting may occur. Planting in the recipient area may result in disturbance of existing bottom substrate from trampling, clearing or digging.
- Kelp restoration may include tying down mature kelp plants on vacant substrate, removing grazers or competitors, seeding the area with spores from healthy plants, and tagging and monitoring the growth of kelp. Activities may require the use of divers to prepare, plant and maintain project sites. Impacts may include damages to kelp beds from equipment, boats, anchoring, and divers themselves. The greatest potential for short-term impacts is the possibility of divers damaging kelp beds during project implementation.
- The restoration of shellfish beds involves the hand placement of shell material at specific sites during low tide. Potential impacts may include temporary increases in turbidity when shellfish are removed or transplanted, conversion of habitat types (mudflat to shell), smothering of existing invertebrate species, and a shift in the community structure.
- Artificial reefs can be used for nearshore habitat enhancement, and to date in Alaska have been implemented in Prince William Sound near Whittier and in the Lynn Canal north of Juneau (Levy and Brown 2017). These structures have the potential to create a loss or conversion of EFH depending on the location of material placement and the suitability of materials used for construction. Usually, reef materials are set on flat sand bottoms or "biological deserts," where they may bury or smother bottom-dwelling organisms at the site or prevent mobile forms (e.g., benthic-oriented fish species) from using the area as habitat. Some materials used as artificial reefs may be inappropriate for the marine environment (e.g., automobile tires), since they deteriorate in sea water and release toxins, oil derived compounds and PAHs (Collins et al. 1994).

4.4.16.2 Recommended Conservation Measures

Habitat restoration and enhancement projects are designed to promote the conservation, enhancement, and proper function of EFH. The following recommended conservation measures are options to avoid and minimize adverse impacts associated with the implementation of habitat restoration. Additional project-specific and generally applicable mitigation measures can be found in Environmental Assessment for Implementing the Community-Based Restoration Program (NMFS 2002).

- Debris removal projects with in-water depths less than 30 m (100 ft) deep should include divers to hand-remove nets and lines from the seabed by cutting away encrusted or severely entangled lines or netting to minimize entanglement of fish or invertebrates.
- Physical removal and mechanical measures to remove invasive plants should include proper disposal of the removed material. Bury on site, bag and incinerate, or dispose of in a sanitary landfill all removed invasive plant material. This will prevent seed spread and allow sunlight to reach the soil surface to promote germination of native plants.
- Limit fish and habitat monitoring that includes destructive sampling techniques (e.g. biomass sampling, benthic cores, and fish capture) to experimental designs tailored to require the fewest number of samples to achieve the desired purpose.
- Evaluate benthic productivity of a target restoration site before any construction activity in the case of subtidal enhancement (e.g., artificial reefs).
- Mooring locations for barges and other boats needed to move equipment should be chosen to minimize damage to existing healthy reefs or adjacent SAV beds.
- Sediments used in placement activities should closely match the general makeup of the existing sediment in terms of grain size, color and mineral content.
- Abide by seasonal work periods where appropriate for managed species and prey. Hydraulic and topographic measurements as part of a restoration action may be completed at any time, provided that the affected area is not occupied by congregating spawning adult fish.
- Use turbidity curtains, hay bales, and erosion mats to protect the water column.
- Plan staging areas in non-wetland areas and keep impact areas to a minimum size.
- Provide adequate training and education for volunteers and project contractors to ensure minimal impacts to the restoration site. Train volunteers in the use of low-impact techniques for planting, equipment handling, and any other activities associated with the restoration activity.
- Conduct monitoring before, during, and after project implementation to ensure compliance with project design and restoration success.
- Establish temporary access pathways (ingress and egress routes) before implementing restoration activities to minimize adverse impacts from project implementation.
- Clear soil material of invasive species before delivering to a restoration site. Use native vegetation to revegetate disturbed areas.

Chapter 5 Offshore

5.1 Introduction

The marine environment includes the estuary, nearshore, and offshore zones. Alaska's nearshore zone merges with the offshore marine environment, where the seaward jurisdictional boundary of the offshore zone is the U.S. EEZ.[33] Alaska's extensive offshore zone has an area of 3.33 million km^2, which is over 70 percent of the total area of the continental shelf in the lower 48 states (NMFS 2015). Most of the offshore zone is defined as EFH for the species managed under the FMPs. Using the best available science, the NPFMC designates EFH for federally managed species in the FMPs. EFH text descriptions and maps are in the appendices of the six FMPs (see Section 1.3, Essential Fish Habitat Overview)[34]. EFH maps are also available in the Alaska EFH Web Application, also known as the "AK EFH Mapper".

Section 5.2 (Physical, Chemical, and Biological Processes) provides a geographic overview and metrics of the offshore marine environment of Alaska's LMEs and highlights key ecosystem processes that support the productivity of these ecosystems. Section 5.3 (Sources of Potential Impacts and EFH Conservation Recommendations) describes sources of potential adverse impacts to these marine ecosystems, the associated introduced environmental risk, and recommended conservation measures.

5.2 Physical, Chemical, and Biological Processes

The MSA defines EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity" (16 U.S.C. 1802(10)). EFH not only includes water and hard substrate but also habitat and ecosystem processes that provide water quality, quantity, and nutrient resources essential for survival. The following discussion provides an overview of the physical, chemical, and biological processes related to offshore habitat that support EFH.

[33] Chapter 4 describes estuary and nearshore zones. The offshore zone described here in Chapter 5 has an inner boundary that is coterminous with the outer boundary of the nearshore zone.
[34] Also located on the NPFMC's website.

5.2.1 Gulf of Alaska

The GOA is a large, semicircular bight located in the eastern North Pacific Ocean off the southern and southeastern coast of Alaska and the western coast of Canada. The GOA continental shelf, from shore to the shelf break is around 200 m (656 ft) depth and is characterized by varied seafloor terrain. Bathymetric rises are formed by pinnacles, banks, and submerged glacial features and a network of distinct glacial troughs extends from shallower depths seaward to the upper continental slope (Carlson et al. 1982, Harris 2014). The continental slope varies in depth up to 3,000 m (9,842 ft) and transitions to the relatively flat abyssal plain to 5,000 m (16,404 ft) depth (Airamé et al. 2003, DoN 2011). Three groupings of 24 major seamounts occur on the abyssal plain (Maloney 2004) with summit depths from 170 to 4,200 m (558 to 13,780 ft) (NMFS 2015).

Defining oceanic currents of the GOA ecosystem are the Alaska Coastal Current that flows over the continental shelf, and the northward flowing Alaska Current that originates in the eastern GOA and turns westward to form the Alaskan Stream that follows the isobaths along the continental slope (Stabeno et al. 2004). These currents interact with gap winds to form surface eddies several km in diameter at regular locations. These eddies travel along the continental shelf break until conditions no longer sustain their formation (Ladd and Cheng 2016, Ladd et al. 2016). Downwelling of surface water at the Alaska coast and seasonal freshwater discharge results in a highly stratified system in the summer (Stabeno et al. 2004, Stabeno et al. 2016a, Stabeno et al. 2016b). This complex system creates substantial ecological differences between the eastern and western GOA (divided at 144°W) directed by local effects of ecosystem drivers as opposed to basin-wide inputs (e.g., Ferriss and Zador 2021). The GOA Management Area[35] includes several HAPCs, Coral Habitat Protection Areas, Slope Habitat Conservation Areas, and Alaska Seamount Habitat Protection Areas[36].

5.2.1.1 Ocean Temperature

Decadal variability patterns in SST, including the Pacific Decadal Oscillation and El Niño Southern Oscillation, drive oceanographic changes in the GOA that affect fish populations (Ferriss and Zador 2021). In addition to these processes, global climate change is leading to an increase in temperature in the GOA, with the North Pacific Ocean showing positive upper ocean heat content anomalies over both the period 1968-2019 and 1993-2019, indicating that multidecadal warming is occurring (Johnson and Lyman 2020).

Increased incidence of marine heatwaves, defined as "discrete periods of extreme regional ocean warming," have been observed in regions of the global ocean with longer term warming trends and have adversely affected species across a range of trophic levels in marine ecosystems (Smale 2020). In the GOA, effects from recent marine heatwaves have cascaded through multiple trophic levels of the ecosystem, including federally managed species like walleye pollock. Beginning in the winter of 2013-14 the GOA was marked by a marine heatwave, nicknamed "the Blob," characterized by SSTs three standard deviations above normal values and unusually low salinity values in the top 200 m (656 ft) of the water column (Rogers et al. 2020). This marine heatwave extended from the coast of Alaska to Baja California (Cavole et al. 2016). A more

[35] Fishery Management Plan for Groundfish of the Gulf of Alaska. Available at: https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf.
[36] North Pacific HAPCs. Available at: https://media.fisheries.noaa.gov/dam-migration/hapc-ak-akr.pdf.

recent marine heatwave in the North Pacific, this time originating during summer conditions and dubbed “Blob 2.0”, occurred in 2019 (Amaya et al. 2020). This latest marine heatwaves indicates that such events in the North Pacific Ocean can emerge from multiple atmospheric and oceanographic mechanisms and at multiple times of year. This phenomenon broadens the scope for potential future sources of marine heatwaves in the region. Chapter 2 (Climate Change) provides more information on climate change effects to EFH with CRs.

5.2.1.2 Ocean Circulation

The GOA shelf is predominantly a downwelling system (Henson and Thomas 2008). Although downwelling dominates the GOA coastal regions for seven to eight months of the year, short reversals of wind during the summer can occur and lead to brief periods of intense upwelling, delivering nutrients, among other mechanisms (Stabeno et al. 2004). Water transport over seafloor terrain features can also induce upwelling in localized regions along the coast. Further offshore, deep waters upwell along the continental shelf break and in the Alaska Gyre (Mundy and Spies 2005, Weingartner 2005). The open-ocean interior of the GOA is considered an upwelling region; however, this upwelling is weak, on the order of 1 m (3.2 ft) per day (Sugimoto 1993, Xie and Hsieh 1995).

5.2.2 Bering Sea

The Bering Sea is a semi-enclosed high-latitude sea bounded on the north and west by Russia, on the east by western Alaska, and on the south by the Aleutian Islands. The Bering Sea has a deep central basin and the surrounding areas of the western and eastern continental shelf and slope are separate LMEs (NMFS 2015, NPFMC 2019). The northern Bering Sea is included with the Chukchi Sea as a separate LME and part of the U.S. Arctic (e.g., Ferriss and Zador 2021, NOAA 2022b). The EBS LME continental shelf is much broader than in the western Bering Sea and breaks at approximately 170 m (558 ft) depth (Stabeno et al. 1999). Seven major canyons are present on the continental slope, including three of the largest submarine canyons in the world, the Zhemchug, Navarinsky, and Bering Canyons (Harris et al. 2014, Harris 2014, Zimmermann and Prescott 2018). Multiple biogeographic regions are present within the EBS, which supports abundant marine life and productive commercial fisheries (Sigler et al. 2011, NPFMC 2019). The waters in the Bering Sea form part of the North Pacific subarctic gyre, with water entering from the GOA through several Aleutian passes, continuing counter-clockwise around the Bering Sea, and exiting through Kamchatka Strait (Stabeno et al. 1999). Northward currents over the northern Bering Sea shelf flow through the Bering Strait into the Chukchi Sea and Arctic Ocean. The northeastern continental shelf of the Bering Sea is generally covered by sea ice in the winter, whereas SIE in the southeastern Bering Sea is highly variable (NPFMC 2019). HAPC designations in the EBS within the Bering Sea and Aleutian Islands Management Area[37] include several areas of skate egg concentration. These are considered important skate EFH nursery areas.

5.2.2.1 Sea Ice

A steep decline in Bering Sea SIE associated with climate-driven warming was observed from 2012 (highest extent on record) to 2018 (lowest extent on record) (Siddon 2021). The 2019 to

[37] Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Islands Management Area. Available at: https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmp.pdf.

2020 daily mean extent of 231,518 km^2 (89,390 mi^2) was within one standard deviation of the long-term mean. Seasonal SIE has implications, for example, to the cold pool, spring bloom strength and timing, and bottom-up productivity.

Seasonal ice in the Bering Sea forms as early as November and grows to cover over 80 percent of the continental shelf during its maximum extent (NMFS 2015). Ice cover on the continental shelf takes three major forms: immobile landfast ice, which is attached to the shore and extends to variable distances offshore; stamukhi, which is grounded, ridged sea ice; and freely-drifting offshore pack ice, which includes first-year and multi-year ice and moves under the influence of winds and currents (MMS and NOAA 2007). Ice alters physical relationships on the continental shelf and in the deep basin by altering tides, currents, mixing, and upwelling, as well as by absorbing and reflecting light. The cycle of ice formation and retention is important to resident and migratory wildlife (NOAA 2013). Sea ice controls the exchange of heat and other properties between the atmosphere and ocean and, together with snow cover, determines the penetration of light into the sea. Sea ice also provides a surface for particle and snow deposition and a habitat for plankton and contributes to stratification through ice melt. The zone seaward of the ice edge is important for plankton production and planktivorous fish, birds, and mammals.

5.2.2.2 Cold Pool Extent and Ocean Temperature

In tandem with persistent marine heatwave conditions and a decline in SIE in the Bering Sea, this area had unprecedentedly low spatial extent of the cold pool during the winters of 2017 to 2018 and 2018 to 2019, resulting in the removal of the thermal barrier between the southern and northern Bering Sea shelves (Siddon 2021). Changes in marine habitat resulted in distributional shifts in groundfish stocks, for instance with more than 50 percent of the overall biomass of Pacific cod occurring in the northern Bering Sea in 2018. Ecosystem impacts in response to these conditions include changes in overall productivity and the potential for new trophic pathways.

5.2.3 Aleutian Islands

The Aleutian Islands are west of the GOA. This island chain consists of over 300 small volcanic islands extending 2,260 km (1404 mi) from the Alaska Peninsula to the Kamchatka Peninsula in Russia (NPFMC 2007, NMFS 2015). The Aleutian Islands form a partial geographic barrier separated by oceanic passes that connect the waters of the North Pacific with the Bering Sea through complex interactions with the Alaska Coastal Current, Alaskan Stream, Aleutian North Slope Current, and tidal currents (Ladd et al. 2005, Stabeno et al. 2005). The passes between the Aleutian Islands have varied bathymetry, hydrography, and geometry; from narrow, shallow passes in the east to wide, deep passes in the west (Zimmermann and Prescott 2020) and are important distinguishing features of distinct ecoregions of the Aleutian Islands LME (NPFMC 2007, Ortiz and Zador 2020). The north-south width of the continental shelf of the Aleutian Islands also varies from east to west from 4 km (2.5 mi) to over 80 km (50 mi) east of Samalga Pass (NPFMC 2007). Two unique geological features of this region are the Aleutian Trench and Bowers Ridge. The Aleutian Trench runs along the shelf margin from the southern coastline of Alaska to waters off the northeastern coast of Siberia and is one of the deepest subduction zone trenches in the eastern Pacific. The trench is approximately 3,700 km (2300 mi) in length with an average width of 50 km (31 mi) and a maximum depth of 7.7 km (4.8 mi) (Weingartner 2005). Bowers Ridge is a nearly 700 km (435 mi) long submerged ridgeline north of Petrel Bank in the Aleutian Islands, with depths as shallow as 11 m (36 ft) to over 3.7 km (2.3 mi), including several pinnacles that rise close to the surface as well as submarine canyons and a deep-sea plateau (AMCC 2004, Harris 2014). The Bowers Ridge Habitat Conservation Zone, including Bowers Ridge and Bowers Seamount, is a HAPC in the Bering Sea and Aleutian Islands Management Area, along with the Aleutian Islands Coral Habitat Protection Areas and Alaska Seamount Habitat Protection Areas[4].

5.2.3.1 Ocean Temperature

Changes in ocean temperature in the Aleutian Islands are important determinants of EFH and, like the marine environment, vary spatially across this ecosystem. The western Aleutian Islands ecoregion is shown to be consistently cooler than the eastern subregion and less subject to marine heatwaves (Ortiz and Zador 2021). Prominent SST anomalies observed during 2019 to 2020 were positive and highest in the eastern Aleutian Islands, while the western subregion may serve as a thermal refuge for species or populations from further east.

5.2.3.2 Spatial Environmental Heterogeneity

The marine environment of the Aleutian Islands is dynamic. Dramatic bathymetry variations over a relatively short distance from shore create a variety of habitat couplings between onshore, nearshore, and offshore systems (NPFMC 2007). Passes between the Aleutian Islands are part of what forms distinct ecoregions within the Aleutian Islands LME. For example, many environmental attributes change in the vicinity of Samalga Pass (Hunt and Stabeno 2005, NPFMC 2007). The east side of Samalga Pass is characterized by shallow and narrow passes, Aleutian-Low-influenced weather, warm and fresh water, depleted nutrients, generally high chlorophyll concentrations, neritic zooplankton, and abundant forage fish and flatfish. In contrast, the west side of Samalga Pass contains deep and wide passes, Asian-influenced weather, cold and salty water, abundant nutrients, generally low chlorophyll concentrations, oceanic zooplankton, and complex food webs with many demersal fish species.

5.2.4 Arctic

The Chukchi Sea and northern Bering Sea form an ecological transition zone between the boreal-arctic Bering Sea and the high-arctic Beaufort Sea (Day et al. 2013). The Chukchi Sea is an embayment of the Arctic Ocean bounded on the west by the Siberian coast of Russia and on the east by the northwestern coast of Alaska. It is predominantly a shallow sea covering an area of about 595,000 km^2 (229,731 mi^2) (NPFMC 2009). The continental shelf is approximately 500 km (311 mi) wide and averages 58 m (190 ft) deep, and extends roughly 800 km (497 mi) northward from the Bering Strait to the continental shelf break (Weingartner 2008). The wide, shallow Chukchi Sea shelf is classified as an inflow shelf to the Arctic Ocean, as waters flowing through Bering Strait, including Alaska Coastal, Anadyr, and Bering Sea waters, strongly influences its characteristics (NPFMC 2009, Stabeno et al. 2018). The peak inflow during the summer provides fresh water, heat, nutrients, and plankton to the Chukchi Sea. Beyond the shelf break, water depths increase quickly beyond 1,000 m (3281 ft) to the Chukchi Borderlands (Harris et al. 2014). The western edge of the Chukchi Sea shelf extends to Herald Canyon, and the eastern edge is defined by Barrow Canyon which separates the Chukchi and Beaufort Seas (NOAA 2013). The Hanna and Herald Shoals rise to approximately 20 m (66 ft) below sea level (MMS and NOAA 2007), while water depths range from 50 m (164 ft) to 200 m (656 ft) in the Barrow and Hanna Canyons (NOAA 2013).

In contrast to the Chukchi Sea, the Beaufort Sea has a narrow shelf and steep slope culminating in the deep Canadian Basin (Moore and Stabeno 2015). It is a semi-enclosed basin located east of the Chukchi Sea off the northern Arctic coast of Alaska and extends generally from Point Barrow eastward to the end of Demarcation Bay (NPFMC 2009). Covering approximately 476,000 km^2 (183,785 mi^2), the Beaufort Sea's narrow, shallow continental shelf is 100 km (62 mi) wide with an average water depth of approximately 37 m (382 ft) and extends from 30 to 80 km (19 to 50 mi) from the coast (NOAA 2013). The narrow Beaufort Sea shelf is classified as an interior shelf, which is mostly influenced by river inputs (NPFMC 2009). Bottom depths on the shelf increase gradually to a depth of approximately 80 m (262 ft), increasing rapidly along the shelf break and continental slope to a maximum depth of approximately 3.8 km (2.4 mi) (Weingartner 2008, NOAA 2013). Numerous narrow and low relief barrier island-lagoon systems within 1.6 to 32 km (1 to 20 mi) from the coast extend from the western Mackenzie River Delta to the Colville River (NPFMC 2009).

5.2.4.1 Sea Ice

SIE, area, thickness, age, and spatial distribution are all changing rapidly in the Arctic, with effects such as reduced extent, earlier melt onset, and later freeze-up observed (Zador 2015, Box et al. 2019). Sea ice loss in the Arctic is projected to continue with warming of the global climate, with ice-free summer conditions in the Arctic now considered "very likely" within the first half of this century (Overland and Wang 2013, Årthun et al. 2021). SIE in the Chukchi Sea can vary from full ice cover to full open water annually with full ice cover typically extending for six months (approximately December to June). The southern Chukchi Sea is free of sea ice one to two months longer each year than the northern Chukchi Sea (MMS and NOAA 2007). Over the shallow Chukchi Sea shelf, annual ice from local freezing is most common. In the Beaufort Sea, ice cover lasts 9 to 10 months from October through July. The Beaufort Sea shelf can be affected by perennial ice from the central Arctic following the circulation of the Beaufort Gyre along the shelf break, as well as annual ice formed locally over the shelf (Davis et al. 2014). In both the Chukchi and Beaufort Seas, remnants of annual landfast ice may remain near the coast during the summer even if offshore ice is gone. There are often areas of open water surrounded by sea ice, called polynyas, during the winter and spring along the Alaskan Chukchi Sea coast and in the Beaufort Sea. Landfast ice and polynyas alter physical characteristics by forming dense water and represent important areas of biological productivity during seasons with daylight (NPFMC 2009).

5.2.4.2 Importance of Lower Trophic Levels

Primary production supported by ice algae that grow on the underside of and within the sea ice itself and phytoplankton (which occur in the water column and near the ice edge) is the foundation of these Arctic ecosystem food webs. In the Chukchi Sea and Beaufort Sea ecosystems, a greater proportion of primary productivity moves through the benthic portion of the food web compared to more southern regions (e.g., southeastern Bering Sea). This makes productivity of seafloor communities particularly important (Audubon et al. 2015). Light-limitation, low temperatures, the timing of ice melt, and the nature of zooplankton advection result in the export of the majority of the primary/secondary production to the benthos (Wiese et al. 2013).

5.3 Sources of Potential Impacts and EFH Conservation Recommendations

In evaluating adverse impacts from sources considered in sections below, considerations of the effects of climate change to projects and the offshore marine environment may be appropriate. Chapter 2 (Climate Change) provides recommendations for integrating climate change information into evaluations of adverse impacts and the development of appropriate CRs.

Discharges from seafood processing waste affect both nearshore and offshore habitats. Section 4.4.10 (Seafood Processing Waste) addresses potential impacts and CRs for both nearshore and offshore habitats.

5.3.1 Increasing Vessel Traffic

Historically, vessels have had very limited access to the Arctic region. Recent warming trends and continually diminishing sea ice are extending the navigable open water season as well as increasing remote area marine accessibility (Arctic Council 2009). In the past, the Beaufort and Chukchi Seas remained frozen for well over half the year, obstructing maritime shipping from October through June (Barry et al. 1979). Currently, the Bering Sea starts forming sea ice in October, with a few remaining fragments present in June, and is essentially free of ice from July to September (Dong et al. 2019). Some climate model projections indicate most of the Arctic Ocean will remain open water for six months and transiting the Arctic via ice-strengthened vessels will be possible for almost the whole year by the end of the century (Melia et al. 2016). This transforming ecosystem is forcing mariners and the fishing industry to adapt their practices and behaviors. The fishing industry may need to make adjustments in response to climate-driven ecosystem changes because fish species important to commercial fishing are responding to warmer water temperatures by shifting their distribution northward (Silber and Adams 2019).

The current trend of diminishing sea ice and predictions of continued decline have stimulated discussions of new international trade routes through the Arctic and North Pacific Oceans. Vessel traffic through the Bering Strait has always increased in the summer as winter sea ice recedes. The primary incentive for the potential increase in shipping through Bering Strait shipping routes is to save time and reduce shipping expenses between North Pacific and North Atlantic ports (Masters 2013). The decreasing SIE has increased accessibility for marine traffic in the Bering Strait via the Northern Sea Route (NSR) and Northwest Passage (Silber and Adams 2019). Another commonly used shipping route that passes the Aleutian Islands to connect North America and East Asia is called the North Pacific Great Circle Route (Fletcher et al. 2016).

Vessel traffic in the Arctic, along the NSR, and through the Bering Sea and Strait is increasing. The number of vessels in the Arctic increased by 25 percent, from 1,298 in 2013 to 1,628 in 2019. Between 2008 and 2015, transits through the Bering Sea and Strait increased from 220 to 540, and transits through the NSR in 2016 and 2019 increased from 18 to 37 respectively (Boylan 2021). Transit statistics of the period suggest that during the 2015 season, 300 unique vessels accounted for 540 vessel transits through the Bering Strait (NSRIO 2017). Of the Arctic routes, the NSR and Northwest Passage are likely to be most viable in the near future. Both routes connect the North Atlantic with the North Pacific, which is highly useful in connecting Asia and Europe, west North America to Europe, and east North America to Asia (Boylan and Elsberry 2019). Recent analyses provides an empirical update, indicating a total of 8,329 separate voyages took place on the NSR in Arctic waters in 2016 to 2019. The number of vessels working on the NSR each year ranged between 227 and 297 and the number of voyages increased from 1,705 to 2,694, or by 58 percent. The increase in the number of voyages during the four years was the result of increased internal traffic on the NSR (by mainly service/supply vessels and icebreakers) as well as increase in destination shipping between southwest Kara Sea and European ports (Gunnarsson 2021). The Global Marine Traffic website visually represents these recent reports[38].

New environmental protection measures are being adopted or in development in response to increases in vessel traffic on the NSR and Northwest Passage. The International Maritime Organization released regulations called the International Code for Ships Operating in Polar Waters (Polar Code) in January of 2017. While the Polar Code does not apply to every vessel, it protects polar ecosystems and persons navigating in these regions by defining required measures, such as ship design, training, and pollution prevention (International Marine Organization 2021)[39]. The USCG began a Port Access Route Study for the Alaskan Arctic Coast in December of 2018 to identify future recommendations for lawmakers. The Port Access Route Study is in response to the declining SIE, which has resulted in increase of government attention, media attention, scientific research, natural resource exploration, eco and adventure tourism, and increasing commercial use of the NSR and Northwest Passage as alternative shipping routes (83 FR 65701, September 1, 2019).

Many different types of vessels operate in the Alaska region throughout the year. If ice is present, they are typically an ice-strengthened vessel or transit with an icebreaker escort. Some types of vessels traveling in the Arctic include ships related to fuel activities, research ships, passenger vessels, tugboats, fishing vessels, cargo ships, government ships, and bulk carriers (Silber and Adams 2019). Another vessel type common to Alaska are ferries. The Alaska Marine Highway supports a network of ferries year-round throughout the GOA, from Bellingham, Washington, to Dutch Harbor in the Aleutian Chain.

Vessel traffic is common throughout the EBS in order to serve coastal and inland Alaskan communities with goods, supplies and fuel. Commercial fishing vessels are also common year-round throughout the Bering Sea. In 2009, roughly 150 large commercial vessels transited the Bering Strait during the open water period from July to October (Arctic Council 2009, Boylan 2021). Approximately twenty-five were bulk carriers moving supplies or commodities into or from mining operations near Kivalina, south of Point Hope. The remaining large vessels comprised Russian bulk carriers, fuel barges serving coastal communities, and industry or government research and survey vessels involved in different phases of marine science or oil and gas exploration. A review of vessel traffic data for 2015 through 2017 indicates no increasing or decreasing trend in vessel traffic volume (Silber and Adams 2019). However, projections of vessel traffic based on recent industry surveys suggest the region will see increases in all types of vessel traffic (US-CMTS 2016, Boylan 2021).

[38] The Global Marine Traffic website provides an interactive method to research, monitor and collect data on vessel traffic globally over selected time scales: https://globalmaritimetraffic.org/gmtds.html
[39] International Maritime Organization. 2021. International Code for Ships Operating in Polar Waters (Polar Code). Accessed April 14, 2022 at: https://www.imo.org/en/OurWork/Safety/Pages/polar-code.aspx

5.3.1.1 Potential Impacts

The upward trend in vessel traffic brings with it an increased likelihood of impacts such as sinking, grounding, collision, oil discharge, and hazardous material release, which in turn increase the risk of adverse effects to EFH (USACE 2016). With increases in vessel traffic in the North Pacific and Arctic Oceans comes an increase in the risk of oil exposure to marine waters in those regions. All vessels carry some form of oil products on board as fuel or lubricating oils; others transport oil as cargo. Currently, at least on the U.S. side, oil cargo is all "nonpersistent" (Types 1 and 2) oil carried for use in communities or industrial activity in the region. Most large ships currently use heavy fuel "persistent" oil (Types 3 and 4) oil for propulsion. This persistent grade oil typically lasts longer if spilled in the environment than a non-persistent type.

Scarcity of aids to navigation as well as dated nautical charts exacerbate effects of changing sea conditions for vessel navigators. Nearshore zones are typically very shallow with poor approaches. Navigation aids such as buoys cannot be deployed in seas with such shallow depths, shifting shorelines, and heavy seasonal ice scour. Nearshore nautical charts remain dated. Only 4.1 percent of U.S. Arctic waters have been surveyed using current technology and standards. Marine transportation in the Arctic remains hazardous due to extreme weather conditions and unpredictable SIE. Modeling suggests a decrease of sea ice may lead to dangerous conditions such as increased wind speeds and wave heights (Petrick et al. 2017).

In addition to an increase of traffic in the winter stemming from an extended period of open waters, mariners should also be aware that latitudes closest to the poles experience limited hours of daylight and operating in the dark and restricted visibility could present challenges. Another anticipated shift caused by the decline of SIE is an increased use of the NSR as an optimal route of travel.

The general lack of deep draft ports and the limited emergency response capabilities in Alaska may also complicate mitigation of adverse impacts. Dutch Harbor is home to the only deep draft port in Alaska capable of accommodating deep draft vessels, such as oil and gas vessels. Nome was recently identified as the site for an additional future deep draft port as part of an infrastructure improvement effort (USACE 2015). The USACE has begun designing Nome Harbor upgrades to address existing vessel restrictions associated with limited channel depths and harbor area. The proposed upgrades would provide larger vessels improved access to Nome's existing harbor by enlarging the outer basin and creating a new deep-water basin with a depth of minus 40 feet. Dredging would be required to deepen and maintain both basins and navigation channels. Dutch Harbor is the only port in the Aleutian Islands that can currently support oil response capabilities. Emergency communications, response, and rescue capabilities are limited, further challenging already difficult and potentially dangerous operations (US-CMTS 2016).

5.3.1.2 Recommended Conservation Measures

The following recommended conservation measures are designed to avoid and minimize the adverse impacts of from vessel traffic on EFH and to promote the conservation, enhancement, and proper function of EFH.

- When transiting near an Alaska Geographic Response Strategies (GRS) site, vessel operators should be familiar with GRS, which detail environmentally sensitive areas of Alaska's coastline (ADEC 2021).
- Coordinate with other federal and state agencies to access and identify commercial activities and major infrastructure gaps that promote safe and sustainable Arctic communities.
- Coordinate with other federal and state agencies to develop safe harbor facilities for ships in need of assistance.
- Coordinate with existing data-sharing frameworks, such as Data.gov, the Alaska Regional Response Team, Ocean.gov, and Alaska Ocean Observing System to facilitate waterways planning and emergency response.
- Continue international collaboration on the Bering Strait Port Access Route Study; consider appropriate ship routes for the Bering Strait and U.S. Arctic.
- Collaborate with international, federal, state and local authorities to ensure readiness of Arctic maritime and aviation infrastructure for emergency response management.
- Support Pan-Arctic response equipment database development, best practices and information sharing for continued oil spill response planning in the Arctic.
- Develop plans to transport critical response equipment from the contiguous U.S. into the Arctic.
- Evaluate facilities currently available on the North Slope for use as seasonal staging areas for response exercises or research platforms.
- Continue scientific support for oil spill response and research directives in the Oil Pollution Act of 1990.
- Develop on-shore facilities for oil spill response (e.g. hazardous/oily waste disposal, wildlife response, responder housing).
- Follow nautical chart traffic schemes if applicable, avoid Areas to Be Avoided, anticipate Potential Places of Refuge, and report to Vessel Traffic Service where applicable.
- Adhere to the USCG's published Navigation Rules.
- Encourage vessels to perform a ballast water exchange in offshore marine waters (in accordance with the USCG's voluntary regulations) to minimize the possibility of introducing invasive estuarine species into similar habitats.
- Discourage vessels that do not perform ballast water exchange from releasing ballast waters into nearshore and estuarine-receiving waters.
- Adhere to regulations and use BMPs outlined in the State of Alaska Aquatic Nuisance Species Management Plan (ADFG 2002) and Management Plan for Invasive Northern Pike in Alaska (ADFG 2007).

5.3.2 Oil and Gas Exploration, Development, and Production

BOEM and the Bureau of Safety and Environmental Enforcement (BSEE)[40], are responsible for regulating oil and gas operations on the U.S. Outer Continental Shelf (OCS). The OCS Lands Act directs BOEM and BSEE to oversee the "expeditious and orderly development [of OCS resources] subject to environmental safeguards" (43 U.S.C. §§ 1332[3], [6], 1334[a][7]). BOEM is responsible for leasing, plan administration, environmental studies, NEPA analyses, resource evaluations, and economic analyses. BSEE is responsible for all field operations, including permitting and research, inspections, offshore regulatory programs, oil spill response, and training and environmental compliance functions. The Alaska Department of Natural Resources Division of Oil and Gas exercises similar authority over Alaska's state waters (ADNR 2020). Offshore petroleum exploration, development, and production activities have been conducted in Alaskan waters or on the Alaska OCS since the late 1950s (AOGA 2015). Offshore exploration, development, and production of natural gas and oil reserves are important aspects of the U.S. economy. As the demand for energy resources grows, efforts to balance oil and gas development and the protection of the environment will continue.

Large oil spills and chronic small oil spills can adversely affect EFH because residual oil can build up in sediments and impact living marine resources. Oil can persist in coastal and oceanic sediments for years after the initial contamination (NAS 2003), interfering with the physiological and metabolic processes of federally managed demersal fish (Wilbur and Pentony 1999, Incardona et al. 2014). Thus, the chronic toxic effects to benthic habitat are a real concern, especially for EFH.

Oil, gas, and associated contaminants can enter EFH from several natural and man-made sources. The chronic release of oil from anthropogenic sources is responsible for the majority of petroleum hydrocarbon input to North American waters and the world's oceans. Estimates of crude-oil seepage demonstrate that 47 percent of oil entering the marine environment is from natural seeps, whereas 53 percent results from leaks and spills during the extraction, transportation, refining, storage, and utilization of petroleum (Razaz et al. 2020). The chronic release of oil from natural seeps into long-term receiving bodies has different environmental transport, fate, and impacts than those associated with the man-made discharges described in this document (NAS 2003).

Accidental discharge of oil and natural gas can occur during almost any stage of exploration, development, or production on the outer continental shelf or in nearshore coastal areas. Sources include equipment malfunction, ship collisions, pipeline breaks, other human error (e.g., loss of well control), or severe storms. Support activities associated with product recovery and transportation may also contribute to oil spills (NMFS 2005a). Federal and state laws and regulations require numerous oil spill prevention and cleanup response measures. However,

[40] BOEM and BSEE were formed from the restructuring of the Minerals Management Service.

spills from oil and gas development remain a potential source of contamination to the marine environment.

One such gas leak occurred in Cook Inlet in 2021, when aging infrastructure from an oil platforms natural gas pipeline ruptured leaking between 5,947 to 9,203 m^3(210,000 to 325,000 ft^3) of natural gas (98.67 percent methane and other hydrocarbons) per day. The leak was discovered on February 7, 2017, and before coming under control was believed to have released 235,030 m^3 (8.3 million ft^3) of natural gas[41]. Since then there were several other leaks of lesser volumes, all more readily put under control.

Figure 9. Aerial photograph of the oil tanker Exxon Valdez, circa March 1989.

Although major spills (e.g., 50,000 barrels or more) do occur (e.g., the Exxon Valdez in March 1989 and the Deepwater Horizon in April 2010), smaller spills occur more frequently. From 1995 to 2012, 85 percent of the oil spills in Alaska involved less than one barrel, 99.9 percent of the spills involved less than 50 barrels, and only 0.1 percent involved more than 500 barrels. Although large catastrophic oil spills can have adverse impacts to EFH, small spills and chronic releases can also affect EFH adversely.

Nearshore habitats that are susceptible to damage from oil spills include not only the low-energy coastal bays and estuaries where oil may accumulate but also the high-energy cobble environments where wave action drives oil into the sediments. Many of the beaches in Prince William Sound with the highest persistence of oil following the Exxon Valdez oil spill (1,260,000 barrels) were high-energy environments containing large cobbles overlain with boulders. These beaches were pounded by storm waves that drove the oil into and well below the surface (Nixon and Michel 2018). The approximately 227 tons (1900 barrels) of lingering subsurface oil estimated to remain from the *Exxon Valdez* oil spill are, as of 2016, patchily distributed across the geologically complex and spatially extensive shorelines of PWS and the GOA. This oil represents 0.6 percent of the originally spilled mass of oil. While no longer generally bioavailable and increasingly chemically weathered, present removal rates for these remaining subsurface oil residues have slowed to nearly zero (Nixon and Michel 2018). PAH concentrations in most affected areas rapidly decreased with average concentrations of petroleum hydrocarbons reaching background levels within 7 to 18 months for seawater, surface sediments, and tissue samples. Hotspot areas persisted in the intertidal area where residual oils remained in the subsurface layers for longer periods. In some cases, population reductions due to delayed effects of PAHs in tidal sediments postponed recovery among some species for more than a decade following the Exxon Valdez oil spill (Peterson et al. 2003, Barron et al. 2020).

The adverse impacts of subsurface releases differ significantly from surface spills. During surface spills, like the Exxon Valdez, highly water soluble components quickly volatize and are

[41] There is no peer reviewed science papers on these actions, and very few legal documents have been attainable. Available information came from newspapers and one legal filing, all available in the public domain.

readily lost to the atmosphere, thereby limiting the extent of dissolution into the water column. Subsurface releases have different impacts on EFH because the volatile components are retained in the water column for extended periods of time (Reddy et al. 2012). A significant part of the oil released into the marine environment from surface release or subsurface spill (e.g., well blowout, shipwreck) stays in the water column with some portion of that oil reaching the benthos. The relative amount of oil that resides in the water column is a function of a number of factors including the chemical and physical nature of the oil, dispersant use, point of release, sea surface turbulence, marine snow, and other hydrographic conditions. During a subsurface spill, very favorable conditions exist for retention and transport of particulate and dissolved oil in the water column. For example, the turbulent subsurface release of the oil can enhance the formation of small droplets of oil. These droplets can be retained in the water column for a period of time during which ocean currents can carry them away from the oil spill. The formation of droplets from wave action (e.g., surface spill) or subsurface turbulence (e.g., well blowout) increases the surface area of the oil, thereby increasing the rates of physical, chemical, and biological processes such as microbial action.

The Deepwater Horizon spill resulted in the release of 5 million barrels of petroleum at a depth of 1,500 m (4,921 ft) over 87 days. Although some of this oil reached the surface and weathered similarly to vessel accidents, approximately 2 million barrels of liquid and all of the natural gasses remained in an intrusion layer between 1,000 and 1,300 m (3,280 and 4,265 ft) that persisted for at least six months. A portion of the sub-sea plume degraded during its residence time in the water column; however, a significant portion settled at the benthos through physical and biological processes. In addition, at least some of the oil that reached the surface was transported to the benthos (Reddy et al. 2012). These dual modes of deposition resulted in a "bathtub ring" formed from an oil-rich layer of water impinging upon the continental slope at a depth of 900 to 1,300 m (2,953 to 4,265 ft), and a higher-flux "fallout plume" where suspended oil particles sank to the underlying sediment at a depth of 1,300 to 1,700 m (4,265 to 5,577 ft). The sedimentation of oil and contaminants resulted from the initial buoyant rise of hydrocarbons, incorporation into the pelagic biota, biodegradation, and interventions at the wellhead (e.g., dispersant use). Overall, the fallout plume of hydrocarbons from the Macondo Well contaminated 3,200 km^2 (1,235 mi^2) of ocean floor (Valentine et al. 2014). It is important to note that some fraction of the crude oil released during a deep discharge will be entrapped in layers above the release depth, resulting in similar hydrocarbon rich layers even in relatively shallow blowouts (48 m [157 ft]) (e.g., Ixtoc blowout) (Joye et al. 2011, Ross et al. 2021).

There is potential for hydrocarbons related adverse effects to EFH between the release of the oil and the complete biodegradation of the oil (Hodson 2017, Hodson et al. 2019). Oil spills are a potential threat to the recruitment and production of fish (Hodson 2017). Once in the environment, petroleum products can be weathered and transformed through physical, chemical, and biological processes (Kostka et al. 2020). Many factors determine the degree of damage from a spill including the type of oil, spill size and duration, the geographic location, and the season. Oil does not describe a single substance; there are many different kinds of oil. When spilled, the various types of oil can affect the environment in different ways. Oils also differ in how difficult they are to clean up. Oil types differ based on viscosity (resistance to flow), volatility (how quickly the oil evaporates), and toxicity. Spill responders group oil into four basic types, listed below along with a general summary of how each type can affect EFH.

Very Light Oils (Jet Fuels, Gasoline)

- Highly volatile (should evaporate within 1 to 2 days)
- High concentrations of toxic (soluble) compounds
- Localized, severe impacts to water column and intertidal resources
- No cleanup possible

Light Oils (Diesel, No. 2 Fuel Oil, Light Crudes)

- Moderately volatile; will leave residue (up to one-third of spill amount) after a few days
- Moderate concentrations of toxic (soluble) compounds
- Will "oil" intertidal resources with long-term contamination potential
- Cleanup can be very effective

Medium Oils (Most Crude Oils)

- About one-third evaporates within 24 hours
- Oil contamination of intertidal areas can be severe and long-term
- Oil impacts to waterfowl and fur-bearing mammals can be severe
- Cleanup most effective if conducted quickly

Heavy Oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C)

- Little or no evaporation or dissolution
- Heavy contamination of intertidal areas likely
- Severe impacts to waterfowl and fur-bearing mammals (coating and ingestion)
- Long-term contamination of sediments possible
- Weathers very slowly
- Shoreline cleanup difficult under all conditions

The toxic effects of oil on EFH vary among the various types of oil. Generally, crude oil spills are well documented and tend to act in predictable ways in the marine environment. Diesel spills are more common in Alaska than crude oil spills. As noted above, diesel spills evaporate faster than heavier oils like bunker and crude oil; however, diesel and lighter oils have a higher acute toxicity that can kill fish and cause mass die-offs.

The release of various types of petroleum hydrocarbons into the marine environment occurs despite measures taken to prevent leakage during the production and shipping. Although the biodegradation of hydrocarbons by marine organisms has been occurring for millennia, hydrocarbons released during an oil spill can affect marine organisms including fish that are dependent on EFH. Hydrocarbons released during an oil spill supply plentiful energy resources to certain marine organisms; however, elements like nitrogen and phosphorus can limit the rate at which microorganisms can breakdown hydrocarbons or bio-remediate. For example, some coastal areas inundated by crude oil during the Exxon Valdez spill likely exhausted the local supply of essential nutrients, resulting in a decreased rate of hydrocarbon biodegradation (Nixon and Michel 2018, Barron et al. 2020).

5.3.2.1 Potential Impacts

Offshore activities elevate ambient sound levels at sea, which may affect marine fauna. Offshore oil and gas operations can be classified into exploration, development, and production and transportation activities (NMFS 2005a). These activities occur at different depths in a variety of habitats and can cause various physical, chemical, and biological disturbances (Firth et al. 2016). Some of these disturbances are described below. However, not all of the potential disturbances in this section apply to each activity.

(i) Noise

Seismic surveys, vessel operations, and the construction of drilling platforms or islands are the primary sources of ocean noise. As discussed in Section 4.4.5 (Pile Driving), noise generates sound pressures that may disrupt or damage marine life. The range of potential effects to fish from intense sound sources varies and is influenced by the level of sound exposure. Direct effects such as hearing damage or loss, tissue damage, or death can occur. However, indirect effects that modify fish behavior are more common and likely (NOAA 2016). Oil and gas activities generate noise from drilling activities, construction, production facility operations, seismic exploration, and vessels (including baseline levels of noise when under power and icebreaking noise during in-ice surveys). The effects of the noise generated from seismic surveys and exploratory drilling are a primary concern to fish and EFH, followed by concerns of the impacts of noise generated from regular vessel operations and icebreaking activities (NOAA 2016).

Seismic surveys direct sound waves at and into the seafloor, using the reflected waves to map the subsurface geology. Energy emitted by a typical airgun shot during seismic surveys ranges in frequency from 10 Hz to 120 Hz, which is within the hearing range of most fish. The sound level can be as high as 255 dB, well above those levels known to impact fish (NOAA 2016). Research suggests that the noise from seismic surveys may cause fish to exhibit behavioral changes including moving away from the acoustic pulse, displaying alarm responses, changing schooling patterns, changing swimming speeds and position in the water column, and interruption of feeding and reproduction affecting both fish distribution and catch rates (Fewtrell and McCauley 2012, Jones 2019). However, while there is agreement that noise from seismic surveys affects the behavior of fish, there are differences of opinion regarding the magnitude of those effects. This is due to limitations in data currently available. Well-replicated and controlled studies do not exist for hearing thresholds and dose–response curves for airgun acoustic exposure. Existing data lack insight into behavioral changes for free-ranging fish to actual seismic surveys and on lasting effects of behavioral changes in terms of time and energy budgets, missed feeding or mating opportunities, decreased performance in predator-prey interactions, and chronic stress effects on growth, development and reproduction. We also lack insight into whether any of these effects could have population-level consequences (Slabbekoorn et al. 2019).

Moreover, varying results of the effects of seismic noise on salmonids and non-salmonids reinforces the need for caution when extrapolating the effects of seismic airguns on one species to the effects on another species (PFMC and NMFS 2014). Seismic surveys may also affect fish eggs and larvae, which cannot move away from the sound source to escape exposure. Airgun noise would likely need to pass within meters of the eggs or larvae to cause any detrimental effects (NOAA 2016).

In contrast to seismic surveys, noise generated from exploratory drilling is less intense but more stationary and persistent. Drilling operations consist of loud mechanical noises emitted over a range of frequencies and intensities from a single, fixed source for up to 90 days. A stationary zone of displacement can be created around the drilling site and could negatively affect fish if this zone is near important spawning, fish rearing, or feeding habitats (NOAA 2016).

Baseline vessel noise comes from engines, generators, propellers, and pumps. Some of this noise falls within the range of fish sensory perception. Fish exhibit avoidance behaviors when confronted with noisy vessels (Ivanova et al. 2020). The noise levels from icebreaking operations vary depending on ice thickness, ice condition, the vessel used, and vessel speed. Operations can reach peak levels of 190 dB and are typically continuous in nature (Roth and Schmidt 2010). This sound level is above the threshold to initiate avoidance behavior in fish; however, the operations are transient so long-term displacement of fish is not likely (NOAA 2016).

(ii) Physical Alterations to Habitat

Habitat altering activities include construction, presence, and eventual decommissioning and removal of facilities such as islands or platforms; storage and production facilities; and laying and burying pipelines to onshore common carrier pipelines, storage facilities, refineries; dredging; and vessel anchoring. These impacts can temporarily or permanently change bottom habitat by altering substrates used for feeding or shelter. These activities may also disturb the associated epifaunal communities, which may provide feeding or predator escape habitats. Benthic organisms, especially prey species, may avoid recolonizing disturbed areas if the substrate composition is changed or if facilities are left in place after production ends (NOAA 2016). Dredging, trenching, and pipe laying generate spoils that may be disposed of on land or in the marine environment where sedimentation may smother benthic habitat and organisms. Most activities associated with oil and gas operations are conducted under permits and regulations that require companies to minimize impacts or to avoid construction or other disturbances in sensitive marine habitats.

(iii) Waste Discharges

Waste discharge may be generated from well drilling fluids, produced waters, surface runoff and deck drainage, domestic wastewaters generated from the offshore facility, solid waste from wells (drilling muds and cuttings), and other trash and debris from human activities associated with the facility. Section 4.4.11 (Point-Source Discharges) provides an additional discussion on water quality impacts[42]. The discharge of muds and cuttings from exploratory and construction activities may change the seafloor and suspend fine-grained mineral particles in the water column. These alterations may affect feeding, nursery, and shelter habitat for various life stages of managed species. Drilling muds and cuttings may adversely affect bottom-dwelling organisms at the site by covering immobile forms or forcing mobile forms to migrate. Suspended particulates may reduce light penetration and lower the rate of photosynthesis and the primary productivity of the aquatic area, especially if suspended for long intervals. High levels of

[42] The EPA and the State of Alaska issue permits for discharge of drilling muds and cuttings to ensure the activities meet Alaska's water quality standards.

suspended particulates may reduce feeding ability for groundfish and other fish species, leading to limited growth. The contents of the suspended material may react with the dissolved oxygen in the water and result in oxygen depletion. In addition, the discharge of drilling muds can change the chemical and physical characteristics of benthic sediments at the disposal site by introducing toxic chemical constituents. Changes in water clarity and the addition of contaminants may reduce or eliminate the suitability of water bodies as habitat for fish species and their prey.

(iv) Polycyclic Aromatic Hydrocarbons

Characterized as petroleum and any derivatives, oil can be a major stressor to fish habitats. Both large and small quantities of oil can affect habitats and living marine resources. Oil can be toxic to all marine organisms but certain species and life history stages are more sensitive. Oil is toxic to fish and other marine organisms even at low concentrations (parts per trillion) (Incardona et al. 2015, Hodson 2017). Studies conducted following the Exxon Valdez oil spill described toxicity in eggs, larvae, and juveniles exposed to lingering oil. PAHs are the most toxic components of crude oil (Almeda et al. 2013a, Almeda et al. 2013b). PAHs elicit a range of toxic effects depending on their chemical structure and can persist in marine habitats for many years, creating pathways for biological exposure to lingering oil and associated adverse effects. In general, the early life stages (eggs and larvae) are the most sensitive; juveniles are less sensitive; and adults are the least sensitive (Pasparakis et al. 2019). Impacts include acute and delayed mortality and interference with the reproduction, cardiac development, immune function, growth, and behavior (e.g., spawning and feeding) of fish, especially from early life stage exposures (Gardner et al. 2019). Fish, like herring, exposed to PAHs in the embryonic or larval stages cause chronic cardiac defects that can be found in adult fish years after a spill occurs (Incardona et al. 2015). Fish are particularly sensitive to 3- and 4-ring PAH compounds that are relatively abundant in oil.

Exposure of fish embryos to PAHs can have population-level consequences through direct mortality and effects on growth, deformities, reproduction, and behavior with long-term consequences on subsequent marine survival (Almeda et al. 2013a). Even low levels of petroleum components from chronic pollution may accumulate in fish tissues and cause acute and chronic effects, particularly during embryonic development (Romero et al. 2018). For example, low doses of PAHs (1 part per trillion) can have sublethal effects on embryonic heart development which can cause permanent secondary changes in the heart shape and cardiac output in individuals within a population. Studies on the Deepwater Horizon oil spill reinforced these finding, specifically that PAHs found in crude oil have deleterious impacts on fish hearts, resulting in acute mortality in individuals and reduced fitness for some pelagic fish populations (Brette et al. 2014, Incardona et al. 2014).

In an oil spill, spatial variation in mortality can be extremely important when assessing the impact of oil pollution on pelagic fish eggs and larvae. Mortality impacts from an oil spill can vary based on the timing and location of spawning, vertical swimming behavior of the fish larvae, water conditions such as current speed and direction, location of the oil spill, toxicity of the different oil-components and variation in toxic sensitivity among species and life stages. Spatial variation in mortality may significantly alter the effect of an oil spill on the recruitment of marine fish. Thus, there is a need for considering spatial variability when assessing the risk of accentuation of an oil spill effect over time (Langangen et al. 2017).

(v) Oil spills

The impacts of oil spills on the marine food webs differ based on the environment in which the oil is released (coastal sublittoral, deep water, temperature, etc.). The degradation of oil can have negative effects on marine organisms and EFH (e.g., algae blooms, eutrophication, smothering) (Joye et al. 2011). Moreover, oil can kill marine organisms (acute toxicity), cause delayed mortality, reduce their fitness through sublethal effects (chronic toxicity), and disrupt the structure and function of the marine ecosystem (NRC 2003).

Oil weathers slower in cold water. Sea ice can encapsulate oil during formation, suspending degradation until the oil is released during break up. Oil is likely to accumulate and persist along the margins, in openings, and under sea ice, all rearing habitats of embryos and larvae (Laurel et al. 2019). The contaminants contained in the spilled oil can persist in that environment for long periods of time (e.g., the Exxon Valdez spill impacted coastal areas for a decade or more), causing both acute and chronic toxic effects on individuals and populations (Almeda et al. 2013a, Almeda et al. 2013b, Fodrie et al. 2014). Similarly, spilled oil can cause acute and chronic effects to kelp and other marine plants that provide food, spawning habitat, and nursery habitat for managed species like herring, salmon, and groundfish (BOEM 2012). Oil-spill cardio-toxicity is conveyed across vertebrates, thus the toxicant pathways affect fish and humans similarly (Marris et al. 2020).

Diluted bitumen (dilbit; e.g., Athabasca oil sands Alberta, Canada) is a petroleum product with a greater potential to have adverse effects to EFH and HAPC than crude oil or diesel. Dilbit is denser than crude oil because it is an asphaltic-dominated petroleum residue. Unlike conventional crude oil, dilbit floats briefly in water and can sink as the light components evaporate and debris collects. The remaining bitumen can make cleaning up a spill more difficult than a conventional oil spill, particularly if dredging is considered too ecologically damaging. Therefore, bitumen spills could result in a different set of ecological exposures and effects to consider during the assessment of natural resource injuries under the Oil Pollution Act of 1990. The 2010 dilbit spill on the Kalamazoo River showed that certain types of petroleum products can increase the likelihood of adverse impacts to the benthos when released in the environment.

(vi) Oil Spill - Polar Cod Impacts

Oil spills pose increasing risk to keystone species and the ecosystems they support. Polar cod (*Boreogadus saida*) are a source of energy-rich forage for marine mammals, seabirds, and other fish. Polar cod are highly sensitive to the developmental impacts of crude oil. Exposure to low levels of oil caused a dysregulation of lipid metabolism while growth persisted in morphologically normal juveniles. Lipid content is critical for overwinter survival and recruitment especially at high latitudes. Losses of Polar cod following an arctic oil spill is likely to have consequences of both near-term and delayed mortality. These losses will likely influence energy flow within Arctic food webs (Laurel et al. 2019). Polar cod eggs are buoyant and accumulate crude oil droplets on the chorion. Crude oil disrupts embryonic cardiac function and larval lipid metabolism. Juvenile growth and lipid content are reduced following brief embryonic oil exposure. PAH are toxic to cod in parts per trillion concentrations (Laurel et al. 2019).

(vii) Oil Spill - Nearshore Impacts

Accidents and spills occurring during the transport and transfer of oil from ships or pipelines to refineries are the greatest potential threats to EFH because the spilled oil is likely to affect shallow nearshore areas or sensitive habitats such as tidal flats, kelp beds, estuaries, river mouths, and streams (PFMC and NMFS 2014). Oil spills may cover and degrade coastal habitats and associated benthic communities or may produce a slick on surface waters which disrupts the pelagic community. A major oil spill can produce vast areas of surface slick and oiled shorelines. Impacts to EFH depends on a variety of factors including, but not limited to, type of oil, life stage affected, species distribution and abundance, habitat dependence (e.g., ocean water column, sea surface, benthos), mobility, location of spawning areas, species exposure and sensitivity to oil and gas, impacts to prey species, and the location and timing of the spill (NOAA 2016).

Oil reaching nearshore areas may affect productive nursery grounds or areas containing high densities of fish eggs and larvae. Spilled oil concentrated along the coastline and at the mouths of anadromous waters may disrupt migratory patterns for some species, such as eulachon or salmon. In some cases, toxic fractions (e.g., PAHs) of spilled oil could also reach freshwater areas where salmon eggs are deposited in stream bottoms (BOEM 2012). Carls et al. (2003) demonstrated that tides and the resultant hydraulic gradients move groundwater containing soluble and slightly soluble contaminants, such as oil, from beaches surrounding streams into the hyporheic zone where pink salmon eggs incubate.

Zooplankton play a large role in the distribution of petroleum in the sea (Graham et al. 2010, Quigg et al. 2021). Zooplankton ingest hydrocarbons and passively adhere droplets of oil on their bodies, resulting in bioaccumulation of pollutants. PAHs are lipophilic and bioaccumulative in organisms, particularly invertebrates. PAHs can bioaccumulate and potentially transfer up the food web and contaminate apex predators (Almeda et al. 2013b). Moreover, zooplankton are able to excrete high concentrations of toxins like whole oil droplets and PAHs in fecal pellets, speeding the descent of contaminants to benthos. A deeper understanding of the chronic, delayed, and indirect long-term risk and impacts of PAH contamination to the deep sea bed is needed to predict impacts to EFH should a large spill or chronic small spills contaminate the benthos in Alaska.

Physical and biological forces act to reduce oil concentrations with depth and distance. Generally, the lighter-fraction hydrocarbons evaporate rapidly, particularly during high winds and wave activity. Heavier oil fractions may settle through the water column. Suspended sediment and marine snow can adsorb and carry oil to the seabed. Moreover, wave action can physically disburse hydrocarbons as small droplets into the water column, which may enhance adsorption to nearshore sediments.

An oil spill near an especially important habitat (e.g., a gyre where fish or invertebrate larvae are concentrated) could cause a disproportionately high loss of a population of marine organisms. In addition to eggs and larvae, planktonic organisms in the upper seawater column would be at risk. Eggs, larvae, and planktonic organisms are small, absorb contaminants quickly, and cannot actively avoid exposure. In addition, some organisms (e.g., zooplankton) do not have efficient metabolic mechanisms for detoxifying oil chemicals. Their proximity to the surface may make them vulnerable to photo-enhanced toxicity effects, which can multiply the toxicity of hydrocarbons (Alloy et al. 2016).

The unknown impacts of an oil-related event near and within ice are an added concern. Oil trapped in ice could affect habitats for months or years after the initial event. Cold climates are likely to affect the impacts and natural dissipation of oil products. For example, an oil spill in the Arctic during the winter months will alter the rate of oil weathering and the ability to respond because of the low temperatures, presence of ice, and length of darkness. Spilled oil could also be transported with the ice floes to a different region (NMFS 2005a). Spills occurring under ice could result in the long-term degradation of EFH because of the cleanup difficulties (BOEM 2012). Onshore and offshore habitat loss due to oiling can result in displacement and stress in the fish and other organisms that depend on these habitats. Displacement may result in blocked or impeded access to spawning, rearing, feeding, and migratory habitats important for survival (NOAA 2016).

(viii) Oil Spill - Benthos Impacts

Spilled oil may affect the benthos (Reddy et al. 2012, Almeda et al. 2013a, Valentine et al. 2014). These impacts may eventually lead to the disruption of community organization and the trophic dynamics of the affected regions. The effects of large, catastrophic spills on coastal environments (e.g., Exxon Valdez 1989) have been documented; however, the Deepwater Horizon oil spill is a reminder that large releases can also occur from drilling operations in the deep sea far from land where the response strategies and subsequent transport and fate of the crude oil differs significantly (Peterson et al. 2012).

The vertical transport of marine oil snow (namely flocculation, sedimentation, and accumulation) from surface spills and wellhead spills can significantly affect EFH through the contamination of benthic habitats. The interaction of petroleum compounds with high concentrations of marine snow and suspended particulate matter in the water column can result in rapid sedimentation from the surface to the seabed. This process is possibly intensified by the use of chemical dispersants (Kinner et al. 2014). As the hydrocarbons enter the marine environment, oil rich particles accumulate on the seafloor with consequences for benthic food webs and fauna (Montagna et al. 2013). The protracted exposure of eggs, embryos, and larvae to, and metabolism of, toxic petroleum hydrocarbons can adversely affect ecologically and economically important benthic fish. Once in the benthos, petroleum toxins will reside for extended periods due to cold temperatures, the lack of photochemical alteration, and low oxygen content if buried.

(ix) Oil Spill Response Methods

Lethal and sublethal impacts can also result from oil spill response methods such as chemical dispersants, burning, and skimming (BOEM 2012). These response activities may be more hazardous to plants and animals than the oil itself and may also adversely affect fish habitat (PFMC and NMFS 2014). Despite the potential adverse effects, studies have shown it is better to capture, burn, or disperse oil at sea before it can reach the shore (EPA et al. 2010, USCG 2014). To predict acute and long-term impacts to EFH, it is crucial to understand the fate of pelagic crude oil not captured by skimming or lost to controlled burns in the marine environment. For example, large-scale skimming during the Deepwater Horizon spill resulted in only 3 percent of the spilled crude oil being recovered and only 5 percent being burned (Lubchenco et al. 2012). While dispersants are likely deployed by planes and vessels in rougher seas, skimming and burning can be effective if equipment is nearby and calm weather prevails. Large catastrophic spills in remote areas (e.g., Chukchi Sea) can spread before gear can be deployed to such an extent that skimming (or burning) would become much more complicated (Prince 2015). Moreover, a lack of daylight would hinder response efforts. Thus, it is far more likely to address an offshore spill with chemical dispersants in Alaska.

Chemical oil dispersants are applied to spills to enhance the rate of oil degradation to minimize the impacts to nearshore and coastal areas and surface inhabitants (e.g., birds, marine mammals) (Philibert et al. 2019). Chemical dispersants are introduced to surface slicks by spraying via an airplane or ship. Wave action and turbulence mixes and breaks up the free oil products into small oil droplets that disperse into the top several meters of the water column. Similarly, dispersants can be used in the subsea in an uncontrolled well release.

Dispersant toxicity varies by species and dispersant type. Newer dispersant formulations (e.g., COREXIT® 9500) appear to be significantly less toxic to fish than oil alone; however, few species have been tested. Regardless of the type of chemical dispersant deployed, the added toxicity from oil-dispersant mixtures could be significant for some species (Hemmer et al. 2011). The use of dispersants causes a larger volume of the water column to be impacted by oil chemicals, but it may increase dilution and degradation rates. Chemical dispersants move the impacts associated with spilled oil from the sea surface into the water column, and a portion of that oil eventually accumulates in benthos. Application of chemical dispersants is typical for waters deeper than 10 m (33 ft) to avoid or reduce potential toxicity to nearshore organisms (NOAA 2016); however, the offshore application of chemical dispersants could degrade water quality and affect pelagic organisms.

Dispersants generally increase the total concentrations of petroleum compounds (dissolved and particulate oil) in seawater (Zhao et al. 2016). The use of dispersants in an oil spill increases the concentration of less water-soluble hydrocarbons, which can induce enzymatic activity that can metabolize PAHs into toxic forms that cause a variety of detrimental effects. The photic zone (0 to 200 m [0 to 656 ft]) is particularly vulnerable because aromatic hydrocarbons are phototoxic. Sunlight can intensify the toxic effects (2 to 1,000 fold increase in toxicity) of oil, especially dispersed oil, on transparent life stages of embryonic and larval fish (Incardona et al. 2012a, Incardona et al. 2012b, Aranguren-Abadía et al. 2022). One study on the impacts of crude versus dispersed oil on salmon post-smoltification found that dispersant treatment significantly decreased the lethal potency of crude oil to salmon smolts (Lin et al. 2009).

Components of the planktonic biota mitigate many of the adverse effects of spilled oil by absorption, transformation, and excretion. The chemical dispersion of the oil results in increased bioremediation of the oil by microorganisms (Karlapudi et al. 2018); however, the addition of dispersants is known to increase the total concentration of PAH components in the surrounding water (Philibert et al. 2019). Chemical dispersants accelerate the vertical transport of oil from the surface through the water column; therefore, there is less opportunity for volatile hydrocarbons (e.g., PAH) to evaporate at the surface (Prince 2015). Similarly, dispersed oil is more likely to be concentrated and transported to the benthos through biological interactions in the food web (Almeda et al. 2013a, Almeda et al. 2013b, North et al. 2015).

(x) Platform Storage and Pipeline Decommissioning

Oil and gas platforms may consist of a lattice-work of pilings, beams, and pipes that support diverse fish and invertebrate populations and are considered de facto artificial reefs (Van Elden et al. 2019). Because decommissioning includes plugging and abandoning all wells and removing the platforms and associated structures from the ocean, impacts to EFH are possible during removal. The demolition phase may generate underwater sound pressure waves that impact marine organisms. Removal of these midwater structures may eliminate habitat for invertebrates and fish. In some areas of the U.S., offshore oil and gas platforms are left in place or submerged after decommissioning to provide permanent habitat for some organisms (Meyer-Gutbrod et al. 2020)

Depending upon the circumstances, region or marine environment, after an oil and gas platform has outlived its use, it must be decommissioned according to the terms of the Department of the Interior lease and terms by which the platform was authorized (Broughton 2012). Department of Interior regulations include a disposal option that, under certain circumstances, allows keeping a biologically valuable structure in the marine environment as an artificial reef through a process called "Rigs-to-Reefs." Artificial reefs not only can enhance aquatic habitat, but also provide an additional option for conserving, managing, and/or developing fishery resources and can provide recreational opportunities.

5.3.2.2 Recommended Conservation Measures

The following recommended conservation measures are designed to avoid and minimize the adverse impacts of oil and gas exploration and development to EFH and to promote the conservation, enhancement, and proper function of EFH.

- Conduct pre-construction biological surveys in consultation with resource agencies to determine the extent and composition of biological populations or habitat in the proposed impact area. Site construction to minimize impacts to fishery resources.
- During seismic surveys, use ramp-up procedures to allow fish to move away from the source before exposure to detrimental sound levels occur (NOAA 2016). Use marine vibroseis instead of airguns when possible. Use the least powerful airguns that will meet the needs of the survey. Survey the smallest area possible to meet the needs of the survey.
- Any seismic activity should avoid anadromous river and stream mouths. Activities should maintain a distance of at least 400 m (1,315 ft) from these areas.
- When salmon are migrating through the seismic survey areas, provide sufficient breaks in the survey to allow transit through the area.
- Schedule exploration and development activities when the fewest species and least vulnerable life stages are present. Establish appropriate work windows based on multiple season biological sampling. Recommended seasonal work windows are generally specific to regional or watershed-level environmental conditions and species requirements.
- Avoid the discharge of produced waters into marine waters and estuaries. Reinject produced waters into the oil formation whenever possible.

- Avoid discharge of muds and cuttings into the marine and estuarine environment. Use methods to grind and reinject such wastes down an approved injection well or use onshore disposal wherever possible. When this is not possible, provide for a monitoring plan to ensure that the discharge meets EPA effluent limitations and related requirements.
- To the extent practicable, avoid the placement of fill to support construction of causeways or structures in the nearshore marine environment.
- As required by federal and state regulatory agencies, encourage the use of GRS that identify EFH and environmentally sensitive areas. Identify appropriate cleanup methods and response equipment.
- Evaluate the potential impacts to EFH that may result from decommissioning activities. Minimize such impacts to the extent practicable.
- Vessel operations and shipping activities should be familiar with Alaska GRS, which detail environmentally sensitive areas of Alaska's coastline. GRS exist for the many areas including southeast Alaska, southcentral Alaska, Kodiak Island, Prince William Sound, Cook Inlet, Bristol Bay, Northwest Arctic, North Slope, and the Aleutian Islands.
- Consider the potential impacts to EFH as part of oil spill response planning.
- Include an analysis of impacts to EFH as part of any damage assessment analysis.
- When alternative methods are available, avoid using dispersants in areas that could adversely affect EFH or HAPC.
- Conduct pre-construction water quality sampling specific for PAHs as a tool to determine or accurately compare PAHs during pre and post events.
- Account for all sources of uncertainty including spatial structure in mortality to avoid an underestimation of possible oil spill effects (Langangen et al. 2017).

5.3.3 Marine Mining

Marine mining activities can lead to the direct loss or degradation of EFH. Offshore mining can increase turbidity, re-suspend fines, or directly injure or displace fish (NMFS 2005a). Direct impacts to eggs, hatched larvae, and adult fish may occur. Mining large quantities of beach gravel can also increase turbidity and may affect the transport and deposition of sand and gravel along the shore at the mining site and at down-current sites (NMFS 2005a).

Offshore dredging and the discharge of spoils have the potential to affect aquatic resources via habitat alteration, including increased turbidity, entrainment of organisms, exposure to trace metals, noise and disturbances, and fuel spills (MMS 1991). Previous mining operations off Nome resulted in considerable localized substrate alteration. Sediment fines destabilized by mining operations were redistributed by local currents and sea conditions (Jewett et al. 1999). Studies also indicate that recolonization of benthic communities to their original structure may not occur after mining disturbances; instead, a different assemblage may result. Actual recovery times for a community to stabilize (i.e., recolonization of dredged sites to comparable density, biomass, and number of taxa) are unknown. Studies associated with the Nome Offshore Placer Project showed that even seven years after mining, seafloor habitats and species assemblages had not recovered to pre-disturbance conditions (Gardner and Jewett 1994).

5.3.3.1 Potential Impacts

Impacts of mining on EFH include both physical impacts (e.g., intertidal dredging) and chemical impacts (e.g., additives such as flocculates) (NMFS 2005a). Physical impacts may include:

- Removal of substrates that serve as habitat for fish and invertebrates;
- Habitat creation or conversion to less productive or uninhabitable sites, such as anoxic holes or silt bottom;
- Burial of productive habitats, such as in nearshore disposal sites (e.g., beach nourishment);
- Increased turbidity;
- Release of harmful or toxic materials either in association with actual mining or in connection with machinery and materials used for mining;
- Creation of harmful turbidity levels; and
- Adverse modification of hydrologic conditions to cause erosion of desirable habitats.

Submarine disposal of mine tailings can also alter the behavior of marine organisms. Submarine mine tailings may not provide suitable habitat for some benthic organisms. In laboratory experiments, benthic dwelling flatfish and crabs strongly avoided mine tailings (Johnson et al. 1998). Beach gravel mining increases water turbidity. The resuspension of organic materials can affect less mobile organisms (e.g., eggs and recently hatched larvae). These actions can damage or destroy benthic habitats. Changes in bathymetry and bottom type may also alter population and migrations patterns (Hurme and Pullen 1988).

Offshore gold placer mining in the Norton Sound region has occurred for many years. The largest and most notable offshore placer mining project was in operation from late 1985 through September 1990 (Gardner 1992). The project mined the seafloor with a 170-m (558-ft) dredge vessel incorporating a bucket ladder system of 134 buckets. Each bucket had a 0.84 m^3 (1.1 yd^3) capacity. The dredge could operate in water depths of up to 45 m (148 ft) and cut to a depth of 3 m (10 ft) below the seafloor. Typically, 7,646 to 15,291 m^3 (10,000 to 20,000 yd^3) of material were processed each day, and mining occurred in water depths of 6 to 18 m (20 to 60 ft).

Studies of the offshore placer mining project note several impacts that offshore placer mining may have on the benthic community: habitat loss and alteration, re-suspension of fine sediments, removal of benthic infauna and epifauna, and injured marine organisms (Garnett and Ellis 1995). Dredged areas are visible and void of re-colonization to date. Injured organisms may not reach maturity to reproduce and/or may be subject to increased predation. The long-term result of such disturbances is an overall decrease in benthic species and their habitats.

Studies documented that deeper waters (deeper than 6 m [20 ft]) support more diverse and abundant species complexes, especially in the cobble habitats. These studies also suggest that significant storm events and longshore currents cause extensive mixing of nearshore sediments and alteration of the seafloor. These natural events occur within nearshore waters less than 7.6 m (25 ft) in depth (Jewett 1999). Ice gouging is also a common occurrence in the region. The seaward edge of the ice typically extends to the 18-m (60-ft) isobath and may be anchored by ice keels in depths from 9 to 18 m (30 to 60 ft) (Jewett 1999).

These studies further conclude that the re-colonization of species after disturbance occurs at a slow rate with a wide range of impacts. Suspended sediments can travel well outside the disturbed area and settle on other undisturbed marine substrates. Sediment was found in red king crab stomachs, but it is not known if this was due to increases in suspended sediment or associated with a food source. Fine sediments may inhibit the growth in some species and smother less mobile or sedentary benthic organisms.

Benthic communities do not recover quickly from rapid change, and effects may not be easily measured. NMFS studies related to the effects on benthic substrates and their inhabitants (NMFS 2005a) found that many seafloor organisms are slow growing and reach their age of maturity (spawning age) later during their life history. Additionally, in Alaskan waters, many species' life history traits are unknown. According to video analysis results, even the smallest of epifauna (sponge, tunicate, or sea pen) will be in association with a larger fish or crab. Direct association is unknown; however, the larger species are often attracted to the structure, possibly for cover or feeding.

5.3.3.2 Recommended Conservation Measures

The following recommended conservation measures are designed to avoid and minimize the adverse impacts of marine mining on EFH and to promote the conservation, enhancement, and proper function of EFH.

- To the extent practicable, avoid mining in waters containing sensitive marine benthic habitat, including EFH (e.g., spawning, migrating, and feeding sites).
- Minimize the area extent and depth of extraction to reduce recolonization times.
- Monitor turbidity during operations, and cease operations if turbidity exceeds permitted threshold levels. Use sediment or turbidity curtains to limit the spread of suspended sediments and minimize the area affected.
- Monitor individual mining operations to avoid and minimize cumulative impacts.
- Evaluate the proposed mine location for past activity. The disturbance of previously contaminated mining areas may cause additional loss of EFH.
- Use seasonal restrictions, as appropriate, to avoid and minimize impacts to EFH during critical life history stages (e.g., migration and spawning) of managed species.
- Deposit tailings within as small an area as possible.
- Any seismic activity should avoid anadromous river and stream mouths. Activities should maintain a distance of at least 400 m (1315 ft) from these areas.

5.3.4 Marine Debris

Marine debris is defined by NOAA and the USCG as any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or the Great Lakes (Lippiatt et al. 2013). Marine debris has become one of the most recognized pollution problems in the world's oceans and waterways today (Lippiatt et al. 2013).

Marine debris consists of a wide variety of materials, including general litter, plastics, hazardous wastes, and discarded or lost fishing gear. Marine debris litters shorelines, fouls estuaries, entangles fish and wildlife, and creates hazards in the open ocean. Alaska's coastline accumulates marine debris from many sources, including vessel activity and ocean currents that deliver debris from other countries including Russia, Japan and China (Polasek 1997).

Nationally, land-based sources account for about 80 percent of the marine debris found on beaches and in U.S. waters. Alaska experiences sizable ocean-based debris that covers shorelines of low populated areas such as the Aleutian Islands due to geographic location for shipping traffic. Marine debris typically originates from:

- Combined sewer overflows and storm drains;
- Stormwater runoff;
- Landfills;
- Solid waste disposals;
- Poorly maintained garbage bins;
- Floating structures; and
- Littering of beaches, rivers, and open waters.

Several laws and regulations address land-based sources of inorganic debris; the Beaches Environmental Assessment and Coastal Health Act of 2000, which authorizes the EPA to fund programs to assess and monitor floatable debris; the Shore Protection Act of 1988, which contains provisions to ensure that municipal and commercial solid wastes are not deposited in coastal waters during vessel transport from the source to the waste-receiving station; and the CWA, which regulates the discharge of pollutants into U.S. waters.

Ocean-based sources of debris, including discarded or lost fishing gear, galley waste, and trash from commercial merchant, fishing, military, and other vessels, also create problems for managed species (Johnson et al. 2008). Laws and regulatory programs exist to prevent and control debris disposal from ocean sources, including from commercial merchant vessels, recreational boaters and fishing vessels, offshore oil and gas exploration activities, development and production facilities, military and research vessels, and commercial fishing vessels (Johnson et al. 2008). These laws include the International Convention for the Prevention of Pollution from Ships MARPOL V, Save our Seas Act, and the Marine Protection, Research, and Sanctuaries Act, Titles I and II (also known as the Ocean Dumping Act), which prevents ocean dumping of specific waste types by ships based on their proximity to shore. Although laws and regulatory programs exist to prevent or control these issues, marine debris continues to affect aquatic resources.

In 2006, Congress authorized the NOAA Marine Debris Program as the U.S. Federal government's lead for addressing marine debris through the Marine Debris Act. The Marine Debris Program achieves its mission through prevention, removal, research, monitoring and detection, response, and coordination. NOAA's vision for the Marine Debris Program is a global ocean and its coasts free from the impacts of marine debris. In addition, Congress passed the Save Our Seas 2.0 Act establishing the Marine Debris Foundation as a charitable and nonprofit organization. The Marine Debris Foundation augments NOAA and other relevant agencies efforts to address marine debris.

Since its inception in 2006, more than 35 projects have been funded in Alaska that have removed over 900 metric tons of debris from shorelines[43]. On many beaches, removal efforts are paired with surveys to determine debris re-accumulation rates and track changes in the types of debris that come ashore.

5.3.4.1 Potential Impacts

The types of marine debris varies greatly; each has potential adverse impacts to EFH. Hard plastic is a prevalent type of marine debris on Alaska's shorelines, making up 60 percent of total debris by weight in a recent survey of 80 km (50 mi) of National Park Service coastline in the Western Arctic and GOA (Polasek et al. 2017). Plastic debris can have a range of effects to EFH. Toxic substances in plastics can kill or impair fish and invertebrates that use habitats polluted by these materials (Vegter et al. 2014). Chemicals that leach from plastics can persist in the environment and bioaccumulate throughout the food web. Plastics do not fully degrade in these environments, posing a long-term pollution hazard (Kennish 2002). Plastics are also subject to fouling. Harmful algal bloom species are known to thrive on floating plastics (Masó et al. 2003). Mortality also occurs through bio-magnification and bioaccumulation of toxic chemicals inducing transgenerational epigenetic effects on physiology and behavior, and has sublethal implications up the food chain (Myers et al. 2013).

Microplastics, defined as plastic pieces of less than 5 mm (0.2 in) in size, are an emerging marine pollutant (Lusher 2015). Since microplastics can resemble the prey species of some commercially important fish species, these fish may directly ingest microplastics (Wright et al. 2013). The ingestion of microplastics by zooplankton suggests that lower trophic level species (copepods and euphausiids) also mistake plastic for food, raising the potential risk to higher trophic level species such as salmon (Wright et al. 2013, Desforges et al. 2015). Other species, such as shore crab, may draw microplastics into their gill cavity (Watts et al. 2014). Nanometer-sized microplastics pass through cell membranes, affecting organisms at the cellular level (Lusher 2015).

Marine debris impacts EFH at the water's surface and on the ocean floor. Floating or suspended debris can directly affect managed species via consumption or entanglement, which may lead to starvation, suffocation, and increased vulnerability to predation (Kennish 2002). Once floatable debris settles to the bottom, it may continue to cause environmental problems. Plastics and other materials with a large surface area can cover and suffocate immobile animals and plants, creating large spaces devoid of life. Currents may carry suspended debris to underwater reef habitats where the debris can become snagged, damaging these sensitive habitats. There are many unknowns on how marine debris affects EFH. Marine debris could physically damage SAV. Collected on the shoreline, debris could change localized moisture and temperature and disrupt intertidal communities. Microplastics could restructure the sediment necessary for locomotion of intertidal species.

[43] https://marinedebris.noaa.gov/alaska

5.3.4.2 Recommended Conservation Measures

The following recommended conservation measures are designed to avoid and minimize the adverse impacts of marine debris to EFH and to promote the conservation, enhancement, and proper function of EFH.

- When removing marine debris from sensitive intertidal habitat, follow BMPs outlined by NOAA's Office of Response and Restoration, including minimizing unnecessary disturbance of natural sediment, organic matter, and vegetation (NOAA 2014).
- Incorporate monitoring of habitat recovery after debris removal to estimate habitat recovery rates (NOAA 2016). Find opportunities to fill other data gaps related to marine debris and habitat impacts.
- Educate the public, boaters, fishermen and industries on the impact of marine debris and provide guidance on how to reduce or eliminate the release of debris into the environment (NOAA 2016).
- Encourage proper trash disposal, particularly in coastal and ocean settings and support coastal monitoring and cleanup activities.
- Vessels should abide by all applicable laws and regulatory programs regarding waste management and disposal.
- Develop incentives and funding mechanisms to recover lost fishing gear.
- Implement structural controls and routine maintenance, such as trash racks, mesh nets, bar screens, and trash booms, to collect and remove trash before it enters nearby waterways. Concentrate floating debris and trash and prevent it from traveling downstream.
- Consider the use of centrifugal separation to physically separate solids and floatables from the water in combined sewer outflows by increasing the settling time of trash and particles.
- Existing and new commercial construction projects near the coast should evolve and implement refuse disposal plans.

5.3.5 Vessel Scuttles

Scuttling is the intentional sinking of vessels by flooding the hull. The Marine Protection, Research, and Sanctuaries Act authorizes the EPA to designate areas for ocean dumping, including vessel scuttles, and requires sites selected in locations that mitigate adverse impacts to the greatest extent practicable[44]. The EPA established criteria for ocean dumping permits including the sites and time periods at which ocean disposal can occur. Under Title 40, CFR, Section 229.3, entitled "Transportation and Disposal of Vessels", EPA allows vessels to be disposed of at sea under specified conditions designed to minimize potential adverse

[44] U.S. Environmental Protection Agency Disposal of Vessels at Sea. Last updated June 7, 2021, accessed April 4, 2022. https://www.epa.gov/ocean-dumping/disposal-vessels-sea

environmental impacts (Helton 2005). EPA's Ocean Disposal Site Designation website provides detailed information about vessel scuttling.

The EPA is required to consult with NMFS prior to disposal to ensure the action will not adversely affect EFH or any HAPC and is not in an area commercially fished or managed by NMFS or the State of Alaska (40 C.F.R. § 229.3). The process is for resource agencies (EPA, NMFS, U.S. Fish and Wildlife Service, USCG, and the State of Alaska) to discuss and agree as to the exact scuttle location, including depth, with the vessel owner or harbormaster.

The EPA provides disposal and site selection criteria (40 C.F.R. § 228.5 and 40 C.F.R. § 228.6). Specific factors considered when choosing the disposal site include geographic position and depth, oceanic conditions, existing water quality and ecology and natural resources that use the site or nearby areas, among others. Disposal of the vessel should occur in a site designated on current NOAA charts for the disposal of wrecks; or at least 12 miles from the nearest land and in water at least 91 m (300 ft) deep[45].

5.3.5.1 Potential Impacts

Scuttling ships can introduce several possible negative impacts to EFH, including damage to sensitive habitats, alteration of the benthic topography, sediment disturbance, and contamination. Proper planning for vessel preparation and scuttling position are important mitigation measures.

Vessel preparation and disposal site is determined with consideration to limit environmental contamination by fuel, paint, solvents, coolants, etc. (Helton 2005). Vessels disposed of at sea not clean of oils and lubricants will likely introduce contaminants into marine waters and EFH. Vessels to be disposed of at sea must be emptied of oil, contaminants, and potential hazardous debris like detachable materials, in a suitable disposal facility following appropriate disposal guidelines[46]. After inspection, the ships are towed to a designated place and sunk, mostly via flooding. Although all fuels should have been removed from the vessel, there is a potential for sheening from compartments that could not be thoroughly cleaned (Helton 2005). There is also the possibility for heavy metals and residual hydrocarbons leaching once the vessel begins to corrode (MacLeod et al. 2004).

Changes to the benthic topography can be manifested in different ways through vessel scuttling and include both disturbance of existing habitat and introduction of new structures. Site selection is important to avoid established sensitive habitats where a scuttled vessel could cause damage, alteration, or loss of marine habitat. Damage to habitat-forming invertebrates can take decades to recover (Roark et al. 2005, Choy et al. 2020). An important component of site selection is understanding the currents in the area to ensure the vessel release location from the surface aligns with the intended resting location; the vessel could drift or plane, from its surface location to a different seafloor location which may contain different habitats than those assessed for

[45] U.S. Environmental Protection Agency Ocean Disposal Site Designation. Last updated Sept. 11, 2020, accessed April 4, 2022. Available at: https://www.epa.gov/ocean-dumping/ocean-disposal-site-designation
[46] International Maritime Organization, Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter. 2006. Signed November 13, 1972. Accessed August 21, 2021. Available at: https://www.imo.org/en/About/Conventions/Pages/Convention-on-the-Prevention-of-Marine-Pollution-by-Dumping-of-Wastes-and-Other-Matter.aspx

disposal. Adverse weather conditions increase not only the potential for complications during the scuttling operation, but also planing from intended seafloor location.

A possible positive impact includes creating an artificial reef, however the efficiency of that is yet to be proven. Scuttled vessels could develop as artificial reefs because of hull colonization of corals and other filtering organisms (Devault et al. 2017). Artificial reefs are used to increase fish reserves, i.e. as nurseries for larvae and juvenile stages (Burt et al. 2009). The additional benthic structure could attract different or more diverse species, which could have both positive and adverse impacts to the existing benthic food web. The additional structure could also act as a snag for commercial fishing gear. If the sunken vessel is located in an area with high commercial fishery catch rates, fishing may relocate to non-optimal grounds and this non-fishing effect could impact fishing efforts and impacts to EFH. Increasing effort in a previously unused location may result in affecting seafloor habitats.

5.3.5.2 Recommended Conservation Measures

The following recommended conservation measures are designed to avoid and minimize the adverse impacts of vessel scuttling on EFH and to promote the conservation, enhancement, and proper function of EFH.

- Evaluate all land-based disposal options considering scuttling vessels.
- Ensure the vessel is cleaned of oil and lubricants prior to sea-disposal (per USCG regulation, 40 C.F.R. § 229.3).
- Scuttling is preferred during daylight hours to log any unforeseen sheen from compartments.
- Dispose of vessels in waters or on seafloor substrates not commercially fished, such as deeper waters (greater than 500 m [1640 ft]]), to avoid fishing gear and outside fished areas of importance.
- Avoid scuttling a vessel atop of a known or designated HAPC. A “buffer” area of ½ nautical mile centered on scuttle location should be included if the site selection is near a HAPC.
- Report the disposal location to resource agencies and the harbormaster to assist with future disposal options and possible corrosion monitoring.
- Avoid stockpiling scuttled vessels to lessen cumulative effects on the seafloor. Check known records of previously scuttled vessels during the siting process.
- Disposal should occur at slack current to limit planing of sinking vessels and drifting out of the disposal area.
- Avoid the risk to re-distribute unknown contaminants via tidal currents, if any.
- If possible, monitor the scuttle site and surrounding sediments for long-term heavy metal contaminants from vessel corrosion.

Chapter 6 Conclusions

NMFS is responsible for the stewardship of the nation's ocean resources and their habitat. As part of this stewardship responsibility, NMFS Alaska Region's HCD provides vital services to ensure the sustainability of healthy ecosystems, which increases resilience of coastal ecosystems, communities, and economies. Healthy habitats are the foundation for life in oceans, estuaries, and watersheds. Central to HCD's role supporting this stewardship responsibility for healthy habitats are the EFH consultation regulations of the EFH Final Rule.

Section 305(b) of the MSA requires Federal action agencies to consult with NMFS, through HCD, on activities that may adversely affect EFH. HCD is required to provide CRs - based on science - to avoid, minimize, mitigate, or otherwise offset adverse effects of federal activities on marine, coastal, and riverine EFH for federally managed species. This required consultation process provides NMFS with many opportunities each year to guide coastal development in a manner that protects vital fish habitat while supporting economic opportunity. The EFH consultation process requires good communication and an exchange of scientifically sound habitat information among NMFS, state and federal action agencies, project proponents, and stakeholders.

NMFS' HCD in the Alaska Region provides this report proactively to inform state and federal action agencies, tribal governments, project proponents, academia, the public, and non-governmental organizations, on the potential impacts various non-fishing related human activities have on EFH. This report represents an extensive literature review and accumulated experience reviewing development and energy projects. As a science based agency committed to EBFM, we cite recent scientific literature to support the discussions as well as seminal works, findings, and concepts that provide the foundation to all other analysis on the subject. The goal of providing this information in one compendium is to support communication and information exchange needed to complete an effective EFH consultation, encourage early coordination to design projects with habitat in mind, and achieve our stewardship responsibilities for healthy habitats.

For more information on HCD and their conservation work visit:
https://www.fisheries.noaa.gov/region/alaska#habitat

For more information on NOAA Fisheries visit: https://www.fisheries.noaa.gov/

Literature Cited

Abbe, T. B., and D. R. Montgomery. 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regulated Rivers: research & management **12**:201-221.

Able, K. W. 2005. A re-examination of fish estuarine dependence: evidence for connectivity between estuarine and ocean habitats. Estuarine, Coastal and Shelf Science **64**:5-17.

Able, K. W., T. M. Grothues, and I. M. Kemp. 2013. Fine-scale distribution of pelagic fishes relative to a large urban pier. Marine Ecology Progress Series **476**:185-198.

Able, K. W., J. P. Manderson, and A. L. Studholme. 1998. The distribution of shallow water juvenile fishes in an urban estuary: The effects of manmade structures in the lower Hudson River. Estuaries **21**:731-744.

Adams, J. E., R. S. Brown, and P. V. Hodson. 2021. The bioavailability of oil droplets trapped in river gravel by hyporheic flows. Environmental Pollution **269**:116110.

ADEC (Alaska Department of Environmental Conservation). 2008. Groundwater in Alaska. Alaska Department of Environmental Conservation, Division of Environmental Health, Drinking Water Program, Anchorage, Alaska.

ADEC (Alaska Department of Environmental Conservation). 2015. Alaska water quality monitoring & assessment strategy. Alaska Department of Environmental Conservation, Division of Water, Water Quality Assessment & Monitoring Program, Juneau, Alaska.

ADFG (Alaska Department of Fish and Game). 2002. Alaska aquatic nuisance species management plan. RIR 5J02-10. Alaska Department of Fish and Game and the State of Alaska, Juneau, Alaska.

ADFG (Alaska Department of Fish and Game). 2006. Our wealth maintained: a strategy for conserving Alaska's diverse wildlife and fish resources. Alaska Department of Fish and Game, Juneau, Alaska.

ADFG (Alaska Department of Fish and Game). 2007. Management plan for invasive northern pike in Alaska. Prepared by the Southcentral Alaska Northern Pike Control Committee.

ADFG (Alaska Department of Fish and Game). 2016. Anadromous waters catalog. Alaska Department of Fish and Game, Juneau, Alaska. Accessed 20 January 2016. https://www.adfg.alaska.gov/sf/SARR/AWC/.

ADNR (Alaska Department of Natural Resources). 2013. Alaska forest resources & practices regulations 11 AAC 95. Division of Forestry, Alaska Department of Natural Resources.

Agency, U. E. P. 2021. Inventory of US greenhouse gas emissions and sinks: 1990–2019. US Environmental Protection Agency Washington (DC.

Ahumada, R., A. Rudolph, and S. Contreras. 2004. Evaluation of coastal waters receiving fish processing waste: Lota Bay as a case study. Environmental Monitoring and Assessment **90**:89-99.

Airamé, S., S. Gaines, and C. Caldow. 2003. Ecological linkages: marine and estuarine ecosystems of central and northern California. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, Maryland.

Alaska Department of Environmental Conservation. 2018. Alaska Pollutant Elimination System Permit Fact Sheet for Offshore Seafood Processors General Permit AKG523000. Wastewater Discharge Authorization Program, Anchorage, Alaska. .

Alaska Department of Environmental Conservation. 2021. Geographic Response Strategies. Accessed 15 August 2021.

Alaska Department of Natural Resources. 2018. Alaska Forest Resoruces and Practices Regulations. 11AAC 95. Updated may 2018.

Albers, S. J. 2010. The salmon disturbance regime: effects on biofilm, sediment and water. Master's thesis. University of Northern British Columbia.

Albert, D., and J. Schoen. 2007. A conservation assessment for the coastal forests and mountains ecoregion of southeastern Alaska and the Tongass National Forest. Chapter 2 in J. Schoen and E. Dovichin, editors. The coastal forests and mountain ecoregion of southeastern Alaska and the Tongass National Forest. Audubon Alaska and The Nature Conservancy, Anchorage, Alaska.

Allan, J. D., M. S. Wipfli, J. P. Caouette, A. Prussian, and J. Rodgers. 2003. Influence of streamside vegetation on inputs of terrestrial invertebrates to salmonid food webs. Canadian Journal of Fisheries and Aquatic Sciences **60**:309-320.

Alloy, M., D. Baxter, J. Stieglitz, E. Mager, R. Hoenig, D. Benetti, M. Grosell, J. Oris, and A. Roberts. 2016. Ultraviolet radiation enhances the toxicity of Deepwater Horizon oil to mahi-mahi (*Coryphaena hippurus*) embryos. Environmental Science & Technology **50**:2011-2017.

Almeda, R., Z. Wambaugh, C. Chai, Z. Wang, Z. Liu, and E. J. Buskey. 2013a. Effects of crude oil exposure on bioaccumulation of polycyclic aromatic hydrocarbons and survival of adult and larval stages of gelatinous zooplankton. PLoS ONE **8**:e74476.

Almeda, R., Z. Wambaugh, Z. Wang, C. Hyatt, Z. Liu, and E. J. Buskey. 2013b. Interactions between zooplankton and crude oil: toxic effects and bioaccumulation of polycyclic aromatic hydrocarbons. PLoS ONE **8**:e67212.

Amato, D. W., J. M. Bishop, C. R. Glenn, H. Dulai, and C. M. Smith. 2016. Impact of submarine groundwater discharge on marine water quality and reef biota of Maui. PLoS ONE **11**:e0165825.

AMCC (Alaska Marine Conservation Council). 2004. Bowers Ridge Habitat Area of Particular Concern. Habitat Areas of Particular Concern (HAPC) proposal #10. Anchorage, Alaska.

AOGA (Alaska Oil and Gas Association). 2015. AOGA fact sheet: Cook Inlet oil & gas production.

Aranguren-Abadía, L., F. Yadetie, C. E. Donald, E. Sørhus, and L. E. Myklatun, et al. 2022. Photo-enhanced toxicity of crude oil on early developmental stages of Atlantic cod (*Gadus morhua*). Science of the total Environment **807**:150697.

Arctic Council. 2009. Arctic marine shipping assessment 2009 report.

Arimitsu, M. L., and J. F. Piatt. 2008. Forage fish and their habitats in the Gulf of Alaska and Aleutian Islands: pilot study to evaluate opportunistic use of the U.S. Fish and Wildlife Refuge support vessel for long-term studies. North Pacific Research Board project 630 final report.

Arimitsu, M. L., J. F. Piatt, S. Hatch, R. M. Suryan, and S. Batten, et al. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. Glob Chang Biol **27**:1859-1878.

Arkoosh, M. R., E. Casillas, E. Clemons, A. N. Kagley, R. Olson, P. Reno, and J. E. Stein. 1998. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal of Aquatic Animal Health **10**:182-190.

Arkoosh, M. R., E. Clemons, P. Huffman, A. N. Kagley, E. Casillas, N. Adams, H. R. Sanborn, T. K. Collier, and J. E. Stein. 2001. Increased susceptibility of juvenile chinook salmon to vibriosis after exposure to chlorinated and aromatic compounds found in contaminated urban estuaries. Journal of Aquatic Animal Health **13**:257-268.

Armstrong, J. B., D. E. Schindler, C. P. Ruff, G. T. Brooks, K. E. Bentley, and C. E. Torgersen. 2013. Diel horizontal migration in streams: juvenile fish exploit spatial heterogeneity in thermal and trophic resources. Ecology **94**:2066-2075.

Armstrong, M., R. Petter, and C. Petter. 2019. Why have so many tailings dams failed in recent years? Resources Policy **63**:101412.

Årthun, M., I. H. Onarheim, J. Dörr, and T. Eldevik. 2021. The seasonal and regional transition to an ice-free Arctic. Geophysical Research Letters **48**:e2020GL090825.

Audubon, OCEANA, Ocean Conservancy, The PEW Charitable Trusts, and WWF (World Wildlife Fund). 2015. A synthesis of important areas in the U.S. Chukchi and Beaufort Seas: the best available data to inform management decisions. April 2015. Available at http://tinyurl.com/zvp7pl6.

Augerot, X. 2005. Atlas of Pacific salmon: the first map-based status assessment of salmon in the North Pacific. University of California Press, Berkeley and Los Angeles, California.

Bailey, S. A. 2015. An overview of thirty years of research on ballast water as a vector for aquatic invasive species to freshwater and marine environments. Aquatic Ecosystem Health & Management **18**:261-268.

Baker, L., K. Koski, D. Albert, and N. Cohen. 2011. A conservation action plan for estuarine ecosystems of southeastern Alaska. The Nature Conservancy.

Baldwin, D. H., J. F. Sandahl, J. S. Labenia, and N. L. Scholz. 2003. Sublethal effects of copper on coho salmon: impacts on nonoverlapping receptor pathways in the peripheral olfactory nervous system. Environmental Toxicology and Chemistry **22**:2266-2274.

Baldwin, D. H., C. P. Tatara, and N. L. Scholz. 2011. Copper-induced olfactory toxicity in salmon and steelhead: extrapolation across species and rearing environments. Aquatic Toxicology **101**:295-297.

Banks, D., P. L. Younger, R.-T. Arnesen, E. R. Iversen, and S. B. Banks. 1997. Mine-water chemistry: the good, the bad and the ugly. Environmental Geology **32**:157-174.

Barbeaux, S. J., K. Holsman, and S. Zador. 2020. Marine Heatwave Stress Test of Ecosystem-Based Fisheries Management in the Gulf of Alaska Pacific Cod Fishery. Frontiers in Marine Science **7**.

Barbier, E. B., S. D. Hacker, C. Kennedy, E. W. Koch, A. C. Stier, and B. R. Silliman. 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs **81**:169-193.

Barker, A. J., T. A. Douglas, A. Ilgen, and T. Trainor. 2019. Lead and antimony from bullet weathering in newly constructed target berms: chemical speciation, mobilization, and remediation strategies. Science of The Total Environment **658**:558-569.

Barr, B. W. 1993. Environmental impacts of small boat navigation: vessel/sediment interactions and management implications. Pages 1756-1770 in O.T. Magoon, editors. Coastal Zone '93: Proceedings of the Eighth Symposium on Coastal and Ocean Management. American Shore and Beach Preservation Association, New Orleans, Louisiana.

Barrett, T. M., and G. A. Christensen. 2011. Forests of Southeast and South-Central Alaska, 2004–2008: Five-year forest inventory and analysis report. Gen. Tech. Rep. PNW-GTR-835. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 156 p. **835**.

Barron, M. G., D. N. Vivian, R. A. Heintz, and U. H. Yim. 2020. Long-term ecological impacts from oil spills: comparison of Exxon Valdez, Hebei Spirit, and Deepwater Horizon. Environmental Science & Technology **54**:6456-6467.

Barry, K. L., J. A. Grout, C. D. Levings, B. H. Nidle, and G. E. Piercey. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences **57**:2032-2043.

Barry, R., R. E. Moritz, and J. Rogers. 1979. The fast ice regimes of the Beaufort and Chukchi Sea coasts, Alaska. Cold Regions Science and Technology **1**:129-152.

Bartz, K. K., and R. J. Naiman. 2005. Effects of salmon-borne nutrients on riparian soils and vegetation in southwest Alaska. Ecosystems **8**:529-545.

Beamer, J., D. Hill, A. Arendt, and G. Liston. 2016. High-resolution modeling of coastal freshwater discharge and glacier mass balance in the Gulf of Alaska watershed. Water Resources Research **52**:3888-3909.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography **49**:423-437.

Beamish, R. J., C. Mahnken, and C. M. Neville. 2004. Evidence that reduced early marine growth is associated with lower marine survival of coho salmon. Transactions of the American Fisheries Society **133**:26-33.

Bedard, R. 2005. Overview of technology classes and key terminology. Pages 5-8 in Proceedings of the Hydrokinetic and Wave Energy Technologies Technical and Environmental Issues Workshop. U.S. Department of Energy, Washington, D.C.

Bedard, R., P. T. Jacobson, M. Previsic, W. Musial, and R. Varley. 2010. An overview of ocean renewable energy technologies. Oceanography **23**:22-31.

Beechie, T. J., D. A. Sear, J. D. Olden, G. R. Pess, J. M. Buffington, H. Moir, P. Roni, and M. M. Pollock. 2010. Process-based principles for restoring river ecosystems. BioScience **60**:209-222.

Beel, C., J. Heslop, J. Orwin, M. Pope, A. Schevers, J. Hung, M. Lafrenière, and S. Lamoureux. 2021. Emerging dominance of summer rainfall driving High Arctic terrestrial-aquatic connectivity. Nature communications **12**:1-9.

Ben-David, M., T. A. Hanley, and D. M. Schell. 1998. Fertilization of terrestrial vegetation by spawning Pacific salmon: the role of flooding and predator activity. Oikos **83**:47-55.

Benfield, M. C., and T. J. Minello. 1996. Relative effects of turbidity and light intensity on reactive distance and feeding of an estuarine fish. Environmental Biology of Fishes **46**:211-216.

Benson, A. J., and A. W. Trites. 2002. Ecological effects of regime shifts in the Bering Sea and eastern North Pacific Ocean. Fish and Fisheries **3**:95-113.

Benton, P. D., W. E. Ensign, and B. J. Freeman. 2008. The effect of road crossings on fish movements in small Etowah Basin streams. Southeastern Naturalist **7**:301-310.

Bernardino, A. F., F. S. Pais, L. S. Oliveira, F. A. Gabriel, T. O. Ferreira, H. M. Queiroz, and A. C. A. Mazzuco. 2019. Chronic trace metals effects of mine tailings on estuarine assemblages revealed by environmental DNA. PeerJ **7**:e8042.

Bernhardt, E. S., and M. A. Palmer. 2011. The environmental costs of mountaintop mining valley fill operations for aquatic ecosystems of the Central Appalachians. Ann N Y Acad Sci **1223**:39-57.

Best, J. 2018. Anthropogenic stresses on the world’s big rivers. Nature Geoscience **12**:7-21.

Bidlack, A. L., S. M. Bisbing, B. J. Buma, H. L. Diefenderfer, and J. B. Fellman, et al. 2021. Climate-Mediated Changes to Linked Terrestrial and Marine Ecosystems across the Northeast Pacific Coastal Temperate Rainforest Margin. BioScience **71**:581-595.

Bieniek, P. A., U. S. Bhatt, J. E. Walsh, R. Lader, B. Griffith, J. K. Roach, and R. L. Thoman. 2018. Assessment of Alaska rain-on-snow events using dynamical downscaling. Journal of Applied Meteorology and Climatology **57**:1847-1863.

Bilby, R. E., E. W. Beach, B. R. Fransen, J. K. Walter, and P. A. Bisson. 2003. Transfer of nutrients from spawning salmon to riparian vegetation of western Washington. Transactions of the American Fisheries Society **132**:733-745.

Bilby, R. E., B. R. Fransen, P. A. Bisson, and J. K. Walter. 1998. Response of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) to the addition of salmon carcasses to two streams in southwestern Washington, U.S.A. Canadian Journal of Fisheries and Aquatic Sciences **55**:1909-1918.

Bintanja, R. 2018. The impact of Arctic warming on increased rainfall. Scientific Reports **8**:1-6.

Bisbing, S. M., D. J. Cooper, D. V. D'Amore, and K. N. Marshall. 2016. Determinants of conifer distributions across peatland to forest gradients in the coastal temperate rainforest of southeast Alaska. Ecohydrology **9**:354-367.

Bishop, J. M. 1984. Applied oceanography. M.E. McCormick and R. Bhattacharyya, editors. John Wiley & Sons, New York, New York.

Bisson, P. A., and R. E. Bilby. 1998. Organic matter and trophic dynamics. Pages 373-398 in R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer, New York.

Blanchard, A. L., and H. M. Feder. 2003. Adjustment of benthic fauna following sediment disposal at a site with multiple stressors in Port Valdez, Alaska. Marine Pollution Bulletin **46**:1590–1599.

Boehlert, G. W., and A. B. Gill. 2010. Environmental and ecological effects of ocean renewable energy development: A current synthesis. Oceanography **23**:68-81.

BOEM (Bureau of Ocean Energy Management). 2012. Outer continental shelf oil and gas leasing program: 2012-2017. Final programmatic environmental impact statement. OCS EIS/EA BOEM 2012-030. U.S. Department of the Interior, Bureau of Ocean Energy Management.

Bolton, S., and C. Monohan. 2001. A review of the literature and assessment of research needs in agricultural streams in the Pacific Northwest as it pertains to freshwater habitat for salmonids. Prepared for Snohomish County, King County, Skagit County, and Whatcom County for the Center for Streamside Studies, University of Washington.

Boulton, A. J., S. Findlay, P. Marmonier, E. H. Stanley, and H. M. Valett. 1998. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics **29**:59-81.

Box, J. E., W. T. Colgan, T. R. Christensen, N. M. Schmidt, and M. Lund, et al. 2019. Key indicators of Arctic climate change: 1971–2017. Environmental Research Letters **14**:045010.

Boylan, B. M. 2021. Increased maritime traffic in the Arctic: Implications for governance of Arctic sea routes. Marine Policy **131**:104566.

Boylan, B. M., and D. T. Elsberry. 2019. Increased maritime traffic in the Arctic: implications for International Cooperation and Security. University of Alaska Fairbanks: Fairbanks, AK, USA:1-17.

Brabets, T. P. 1997. Geomorphology of the Lower Copper River, Alaska. USGS professional paper 1581. U.S. Department of the Interior, U.S. Geological Survey.
Brabets, T. P., B. Wang, and R. H. Meade. 2000. Environmental and hydrologic overview of the Yukon River Basin, Alaska and Canada. Water-resources investigations report 99-4204. U.S. Geological Survey, Anchorage, Alaska.
Brandt, A. R., T. Yeskoo, M. S. McNally, K. Vafi, S. Yeh, H. Cai, and M. Q. Wang. 2016. Energy intensity and greenhouse gas emissions from tight oil production in the bakken formation. Energy & Fuels **30**:9613-9621.
Brandt, S., S. Ludsin, D. Mason, B. Boicourt, M. Roman, and D. Kimmel. 2005. Hypoxia effects on the living resources of the northern Gulf of Mexico. National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory.
Brauko, K., A. Cerveira, R. Freitas, H. Hadlich, T. Beras, A. Fonseca, and P. Pagliosa. 2020. Comparing structural and functional approaches to distinguish benthic communities from eutrophic and non-eutrophic estuaries. Marine Pollution Bulletin **157**:111290.
Breitburg, D. L., J. K. Craig, R. S. Fulford, K. A. Rose, and W. R. Boynton, et al. 2009. Nutrient enrichment and fisheries exploitation: interactive effects on estuarine living resources and their management. Hydrobiologia **629**:31-47.
Brennan, S. R., D. E. Schindler, T. J. Cline, T. E. Walsworth, G. Buck, and D. P. Fernandez. 2019. Shifting habitat mosaics and fish production across river basins. Science **364**:783-786.
Brette, F., B. Machado, C. Cros, J. P. Incardona, N. L. Scholz, and B. A. Block. 2014. Crude oil impairs cardiac excitation-contraction coupling in fish. Science **343**:772-776.
Brix, K. V., D. K. DeForest, and W. J. Adams. 2001. Assessing acute and chronic copper risks to freshwater aquatic life using species sensitivity distributions for different taxonomic groups. Environmental Toxicology and Chemistry **20**:1846-1856.
Broadmeadow, S., and T. R. Nisbet. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. Hydrology and Earth System Sciences **8**:286-305.
Broughton, K. 2012. Office of National Marine Sanctuaries Science Review of Artificial Reefs. Marine Sanctuaries Conservation Series ONMS-12-05. US Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD.
Brown, J. A. 2006. Using the chemical composition of otoliths to evaluate the nursery role of estuaries for English sole *Pleuronectes vetulus* populations. Marine Ecology Progress Series **306**:269-281.
Brown, R. S., W. A. Hubert, and S. F. Daly. 2011. A primer on winter, ice, and fish: what fisheries biologists should know about winter ice processes and stream-dwelling fish. Fisheries **36**:8-26.
Brown, T. C., V. Mahat, and J. A. Ramirez. 2019. Adaptation to Future Water Shortages in the United States Caused by Population Growth and Climate Change. Earth's Future **7**:219-234.
Brunke, M., and T. Gonser. 1997. The ecological significance of exchange processes between rivers and groundwater. Freshwater Biology **37**:1-33.
Buhl, K. J., and S. J. Hamilton. 1991. Relative sensitivity of early life stages of arctic grayling, coho salmon, and rainbow trout to nine inorganics. Ecotoxicology and Environmental Safety **22**:184-197.

Bukola, D., A. Zaid, E. I. Olalekan, and A. Falilu. 2015. Consequences of anthropogenic activities on fish and the aquatic environment. Poultry, Fisheries & Wildlife Sciences.

Bullock, A., and M. Acreman. 2003. The role of wetlands in the hydrological cycle. Hydrology and Earth System Sciences **7**:358-389.

Burdick, D. M., and F. T. Short. 1999. The effects of boat docks on eelgrass beds in coastal waters of Massachusetts. Environmental Management **23**:231-240.

Burt, J., A. Bartholomew, A. Bauman, A. Saif, and P. F. Sale. 2009. Coral recruitment and early benthic community development on several materials used in the construction of artificial reefs and breakwaters. Journal of Experimental Marine Biology and Ecology **373**:72-78.

Byrne, P., P. Wood, and I. Reid. 2012. Impairment of River Systems by Metal Mine Contamination: A Review Including Remediation Options. Critical reviews in environmental science and technology.

Cada, G., J. Ahlgrimm, M. Bahleda, T. Bigford, and S. Damiani Stavrakas, et al. 2007. Potential impacts of hydrokinetic and wave energy conversion technologies on aquatic environments. Fisheries **32**:174-181.

Caddy, J. F., and A. Bakun. 1995. Marine catchment basins and anthropogenic effects on coastal fishery ecosystems. Pages 119-133 in Effects of riverine inputs on coastal ecosystems and fisheries resources. FAO fisheries technical paper no. 349.

Cai, H., A. Burnham, R. Chen, and M. Wang. 2017. Wells to wheels: Environmental implications of natural gas as a transportation fuel. Energy Policy **109**:565-578.

Cak, A. D., D. T. Chaloner, and G. A. Lamberti. 2008. Effects of spawning salmon on dissolved nutrients and epilithon in coupled stream-estuary systems of southeastern Alaska. Aquatic Sciences **70**:169-178.

Callahan, M. K., M. C. Rains, J. C. Bellino, C. M. Walker, S. J. Baird, D. F. Whigham, and R. S. King. 2015. Controls on temperature in salmonid-bearing headwater streams in two common hydrogeologic settings, Kenai Peninsula, Alaska. Journal of the American Water Resources Association **51**:84-98.

Callahan, M. K., D. F. Whigham, M. C. Rains, K. C. Rains, and R. S. King, et al. 2017. Nitrogen subsidies from hillslope alder stands to streamside wetlands and headwater streams, Kenai Peninsula, Alaska. JAWRA Journal of the American Water Resources Association **53**:478-492.

Callegary, J., C. Kikuchi, J. C. Koch, M. Lilly, and S. Leake. 2013. Groundwater in Alaska (USA). Hydrogeology Journal **21**:25-39.

CalTrans (California Department of Transportation). 2001. Fisheries impact assessment, pile installation demonstration project for the San Francisco - Oakland Bay Bridge east span seismic safety project. California Department of Transportation, Sacramento, California.

CalTrans (California Department of Transportation). 2015. Technical guidance for assessment and mitigation of the hydroacoustic effects of pile driving on fish. Report no. CTHWANP-RT-15-306.01.01. Division of Environmental Analysis, California Department of Transportation, Sacramento, California.

Campbell, R., A. Schroth, and J. Crusius. 2011. Seasonal changes in productivity in the Copper River plume and coastal Gulf of Alaska. Oral presentation at the 13th Copper River Delta Science Symposium, March 2011, Cordova, Alaska.

Carbery, M., W. O'Connor, and T. Palanisami. 2018. Trophic transfer of microplastics and mixed contaminants in the marine food web and implications for human health. Environ Int **115**:400-409.

Cardwell, R. D., M. I. Carr, and E. W. Sanborn. 1980. Water quality and flushing of five Puget Sound marinas. Technical report no. 56. Washington Department of Fisheries Research and Development, Olympia, Washington.
Carls, M. G., R. E. Thomas, M. R. Lilly, and S. D. Rice. 2003. Mechanism for transport of oil-contaminated groundwater into pink salmon redds. Marine Ecology Progress Series **248**:245-255.
Carlson, P. R., T. R. Bruns, B. F. Molnia, and W. C. Schwab. 1982. Submarine valleys in the northeastern Gulf of Alaska: characteristics and probable origin. Marine Geology **47**:217-242.
Carlson, T. J., G. Ploskey, R. L. Johnson, R. P. Mueller, M. A. Weiland, and P. N. Johnson. 2001. Observations of the behavior and distribution of fish in relation to the Columbia River navigation channel and channel maintenance activities. Prepared for the U.S. Army Corps of Engineers by Pacific Northwest National Laboratory, Richland, Washington.
Carothers, C., T. L. Sformo, S. Cotton, J. C. George, and P. A. Westley. 2019. Pacific Salmon in the rapidly changing Arctic. Arctic **72**:273-288.
Carstensen, R. 2007. Coastal habitats of southeast Alaska. Chapter 5.3 in J. Schoen and E. Dovichin, editors. The coastal forests and mountain ecoregion of southeastern Alaska and the Tongass National Forest. Audubon Alaska and The Nature Conservancy, Anchorage, Alaska.
Carter, L., D. Burnett, S. Drew, G. Marle, L. Hagadorn, D. Bartlett-McNeil, and N. Irvine. 2009. Submarine cables and the oceans: connecting the world. UNEP-WCMC biodiversity series no. 31. The United Nations Environment Programme World Conservation Monitoring Centre.
Carter, V. 1996. Technical aspects of wetlands: wetland hydrology, water quality, and associated functions. Pages 35-48 in J.D. Fretwell, J.S. Williams, and P.J. Redman, compilers. National water summary on wetland resources. U.S. Geological Survey water-supply paper 2425.
Casper, A. F., M. Rautio, C. Martineau, and W. F. Vincent. 2015. Variation and assimilation of arctic riverine seston in the pelagic food web of the Mackenzie River delta and Beaufort Sea transition zone. Estuaries and Coasts **38**:1656–1663.
Castendyk, D. N., and L. E. Eary. 2009. Mine pit lakes: characteristics, predictive modeling, and sustainability. SME.
Cederholm, C. J., and L. M. Reid. 1987. Impact of forest management on coho salmon (*Oncorhynchus kisutch*) populations of the Clearwater River, Washington: a project summary. Pages 373-398 in E.O. Salo and T.W. Cundy, editors. Streamside management: forestry and fishery interactions. University of Washington, Institute of Forest Resources, Seattle, Washington.
Celewycz, A. G., and A. C. Wertheimer. 1994. Distribution, abundance, size, and growth of juvenile pink and chum salmon in western Prince William Sound after the *Exxon Valdez* oil spill. Chapter 2 in A.C. Wertheimer, et al., editors. Impact of the oil spill on juvenile pink and chum salmon and their prey in critical nearshore habitats. *Exxon Valdez* oil spill, state/federal damage assessment final report. Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska.
Chabreck, R. H. 1972. Vegetation, water and soil characteristics of the Louisiana coastal region. Louisiana State University Agriculture Experiment Station, Baton Rouge, Louisiana.

Chambers, D., R. Moran, and L. Trasky. 2012. Bristol Bay's wild salmon ecosystems and the Pebble Mine: key considerations for a large-scale mine proposal. Wild Salmon Center and Trout Unlimited.

Chapin, F. S., III, S. F. Trainor, P. Cochran, H. Huntington, and C. Markon, et al. 2014. Chapter 22: Alaska. Pages 514-536 in J.M. Melillo, T.C. Richmond, and G.W. Yohe, editors. Climate change impacts in the United States: the third national climate assessment. U.S. Global Change Research Program.

Cherr, G. N., E. Fairbairn, and A. Whitehead. 2017. Impacts of petroleum-derived pollutants on fish development. Annual review of animal biosciences **5**:185-203.

Cheung, W. W., and T. L. Frölicher. 2020. Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific. Scientific Reports **10**:1-10.

Choy, E., K. Watanabe, B. Williams, R. Stone, and P. Etnoyer, et al. 2020. Understanding growth and age of red tree corals (Primnoa pacifica) in the North Pacific Ocean. PLoS ONE **15**:e0241692.

Chung, I. K., J. H. Oak, J. A. Lee, J. A. Shin, J. G. Kim, and K.-S. Park. 2013. Installing kelp forests/seaweed beds for mitigation and adaptation against global warming: Korean Project Overview. ICES Journal of Marine Science **70**:1038-1044.

Cochrane, K., C. De Young, D. Soto, and T. Bahri. 2009. Climate change implications for fisheries and aquaculture. FAO Fisheries and aquaculture technical paper **530**:212.

Cohen, C. S., L. McCann, T. Davis, L. Shaw, and G. M. Ruiz. 2011. Discovery and significance of the colonial tunicate *Didemnum vexillum* in Alaska. Aquatic Invasions.

Cohen, J., X. Zhang, J. Francis, T. Jung, and R. Kwok, et al. 2020. Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. Nature Climate Change **10**:20-29.

Collins, K. J., A. C. Jensen, A. P. M. Lockwood, and S. J. Lockwood. 1994. Coastal structures, waste materials and fishery enhancement. Bulletin of Marine Science **55**:1240-1250.

Colombo, N., F. Salerno, S. Gruber, M. Freppaz, M. Williams, S. Fratianni, and M. Giardino. 2018. Impacts of permafrost degradation on inorganic chemistry of surface fresh water. Global and Planetary Change **162**:69-83.

Conlan, K., H. Lenihan, R. Kvitek, and J. Oliver. 1998. Ice scour disturbance to benthic communities in the Canadian High Arctic. Marine Ecology Progress Series **166**:1-16.

Cooper, D. W., J. T. Duffy-Anderson, B. L. Norcross, B. A. Holladay, and P. J. Stabeno. 2014. Nursery areas of juvenile northern rock sole (Lepidopsetta polyxystra) in the eastern Bering Sea in relation to hydrography and thermal regimes. ICES Journal of Marine Science **71**:1683-1695.

Cooper, J., J. Kavanagh, A. Razmjou, V. Chen, and G. Leslie. 2020. Treatment and resource recovery options for first and second generation bioethanol spentwash–a review. Chemosphere **241**:124975.

Copeland, T., D. A. Venditti, and B. R. Barnett. 2014. The importance of juvenile migration tactics to adult recruitment in stream-type chinook salmon populations. Transactions of the American Fisheries Society **143**:1460-1475.

Copping, A. 2018. The state of knowledge for environmental effects: driving consenting/permitting for the marine renewable energy industry. Prepared for Ocean Energy Systems. Annex IV Nations. January 2018.

Copping, A., N. Sather, L. Hanna, J. Whiting, and G. Zydlewski, et al. 2016. Annex IV 2016 state of the science report: Environmental effects of marine renewable energy

development around the world. Pacific Northwest National Laboratory on behalf of the US Department of Energy (the Annex IV Operating Agent).
Copping, A. E., L. G. Hemery, H. Viehman, A. C. Seitz, G. J. Staines, and D. J. Hasselman. 2021. Are fish in danger? A review of environmental effects of marine renewable energy on fishes. Biological Conservation **262**:109297.
Corbett, C. W., M. Wahl, D. E. Porter, D. Edwards, and C. Moise. 1997. Nonpoint source runoff modeling: a comparison of a forested watershed and an urban watershed on the South Carolina coast. Journal of Experimental Marine Biology and Ecology **213**:133-149.
Cott, P. A., P. K. Sibley, W. M. Somers, M. R. Lilly, and A. M. Gordon. 2008. A review of water level fluctuations on aquatic biota with an emphasis on fishes in ice-covered lakes. Journal of the American Water Resources Association **44**:343-359.
Coutant, C. C. 1976. Thermal effects on fish ecology.
Coyle, K., and G. Gibson. 2017. Calanus on the Bering Sea shelf: probable cause for population declines during warm years. Journal of Plankton Research **39**:257-270.
Coyle, K. O., and A. I. Pinchuk. 2002. The abundance and distribution of euphausiids and zero-age pollock on the inner shelf of the southeast Bering Sea near the Inner Front in 1997-1999. Deep-Sea Research Part II **49**:6009-6030.
Craig, N. J., R. E. Turner, and J. W. Day, Jr. 1979. Land loss in coastal Louisiana (U.S.A.). Environmental Management **3**:133-144.
CSS (Center for Streamside Studies). 2002. Environmental impacts of hardrock mining in Eastern Washington. College of Forest Resources and Ocean and Fishery Sciences, University of Washington, Seattle, Washington.
Culp, J. M., and R. W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1208. Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, British Columbia.
Cunjak, R. A. 1988. Behaviour and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. Canadian Journal of Fisheries and Aquatic Sciences **45**:2156-2160.
Cunjak, R. A. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences **53**:267-282.
Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences **43**:1970-1981.
Curran, J. H., and F. E. Biles. 2021. Identification of seasonal streamflow regimes and streamflow drivers for daily and peak flows in Alaska. Water Resources Research **57**:e2020WR028425.
Curran, J. H., M. G. Loso, and H. B. Williams. 2017. Glacial conditioning of stream position and flooding in the braid plain of the Exit Glacier foreland, Alaska. Geomorphology **293**:272-288.
Cuthbert, R. N., S. G. Kotronaki, J. T. Carlton, G. M. Ruiz, P. Fofonoff, and E. Briski. 2022. Aquatic invasion patterns across the North Atlantic. Global Change Biology **28**:1376-1387.
CWP (Center for Watershed Protection). 2003. Impacts of impervious cover on aquatic systems. Watershed protection research monograph no. 1. Center for Watershed Protection, Ellicott City, Maryland.

Dahl, T. A., A. D. Kendall, and D. W. Hyndman. 2018. Impacts of projected climate change on sediment yield and dredging costs. Hydrological Processes **32**:1223-1234.
Dahl, T. E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Fish and Wildlife Service, Washington, D.C.
Daigle, P. 2010. A summary of the environmental impacts of roads, management responses, and research gaps: a literature review. BC Journal of Ecosystems and Management **10**:65–89.
Daryaei, R., M. Bakroon, D. Aubram, and F. Rackwitz. 2020. Numerical evaluation of the soil behavior during pipe-pile installation using impact and vibratory driving in sand. Soil Dynamics and Earthquake Engineering **134**:106177.
Davis, P. E. D., C. Lique, and H. L. Johnson. 2014. On the link between arctic sea ice decline and the freshwater content of the Beaufort Gyre: insights from a simple process model. Journal of Climate **27**:8170-8184.
Day, R. H., T. J. Weingartner, R. R. Hopcroft, L. A. M. Aerts, and A. L. Blanchard, et al. 2013. The offshore northeastern Chukchi Sea, Alaska: a complex high-latitude ecosystem. Continental Shelf Research **67**:147-165.
de Rivera, C. E., B. P. Steves, P. W. Fofonoff, A. H. Hines, and G. M. Ruiz. 2011. Potential for high-latitude marine invasions along western North America. Diversity and Distributions **17**:1198-1209.
Deegan, L. A., and R. N. Buchsbaum. 2005. The effect of habitat loss and degradation on fisheries. Pages 67-96 in R. Buchsbaum, J. Pederson, W.E. Robinson, editors. The decline on fisheries resources in New England: evaluating the impact of overfishing, contamination, and habitat degradation. MIT Sea Grant College Program, Cambridge, Massachusetts.
DeForest, D., B. Gensemer, E. V. Genderen, and J. Gorsuch. 2011. Protectiveness of water quality criteria for copper in western US waters relative to predicted olfactory responses in Pacific salmon. Presentation at the AFS Annual Meeting, 6 September 2011.
Dekar, M. P., R. S. King, J. A. Back, D. F. Whigham, and C. M. Walker. 2012. Allochthonous inputs from grass-dominated wetlands support juvenile salmonids in headwater streams: evidence from stable isotopes of carbon, hydrogen, and nitrogen. Freshwater Science **31**:121-132.
Desforges, J.-P. W., M. Galbraith, and P. S. Ross. 2015. Ingestion of microplastics by zooplankton in the northeast Pacific Ocean. Archives of environmental contamination and toxicology **69**:320-330.
Devault, D. A., B. Beilvert, and P. Winterton. 2017. Ship breaking or scuttling? A review of environmental, economic and forensic issues for decision support. Environmental Science and Pollution Research **24**:25741-25774.
Dew, C. B., and R. A. McConnaughey. 2005. Did trawling on the brood stock contribute to the collapse of Alaska's king crab? Ecological Applications **15**:919-941.
Di Giulio, R. T., and D. E. Hinton. 2008. The toxicology of fishes. Crc Press.
DoE (U.S. Department of Energy). 2009. Report to Congress on the potential environmental effects of marine and hydrokinetic energy technologies. U.S. Department of Energy, Wind and Hydropower Technologies Program.
Dolat, S. W. 1997. Acoustic measurements during the Baldwin Bridge demolition. Prepared for White Oak Construction by Sonalysts, Inc., Waterford, Connecticut.

DoN (Department of the Navy). 2011. Gulf of Alaska Navy training activities preliminary final environmental impact statement/overseas environmental statement. Volume I. U.S. Department of the Navy, U.S. Pacific Fleet, Pearl Harbor, Hawaii.

Dong, C., X. Gao, Y. Zhang, J. Yang, H. Zhang, and Y. Chao. 2019. Multiple-scale variations of sea ice and ocean circulation in the Bering Sea using remote sensing observations and numerical modeling. Remote Sensing **11**:1484.

Dosskey, M. G., P. Vidon, N. P. Gurwick, C. J. Allan, T. P. Duval, and R. Lowrance. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. Journal of the American Water Resources Association **46**:261-277.

Douglas, T. A., C. A. Hiemstra, J. E. Anderson, R. A. Barbato, K. L. Bjella, E. J. Deeb, A. B. Gelvin, P. E. Nelsen, S. D. Newman, and S. P. Saari. 2021. Recent degradation of Interior Alaska permafrost mapped with ground surveys, geophysics, deep drilling, and repeat airborne LiDAR. The Cryosphere Discussions:1-39.

Douglas, T. A., M. R. Turetsky, and C. D. Koven. 2020. Increased rainfall stimulates permafrost thaw across a variety of Interior Alaskan boreal ecosystems. npj Climate and Atmospheric Science **3**.

Duffy-Anderson, T. J., and W. K. Able. 1999. Effects of municipal piers on the growth of juvenile fishes in the Hudson River estuary: a study across a pier edge. Marine Biology **133**:409-418.

Duffy-Anderson, J. T., P. Stabeno, A. G. Andrews, K. Cieciel, and A. Deary. 2019. Responses of the Northern Bering Sea and Southeastern Bering Sea pelagic ecosystems following record-breaking low winter sea ice. Geophysical Research Letters **46**:9833-9842.

Dugan, J. E., D. M. Hubbard, D. L. Martin, J. M. Engle, D. M. Richards, G. E. Davis, K. D. Lafferty, and R. F. Ambrose. 2000. Macrofauna communities of exposed sandy beaches on the southern California mainland and Channel Islands. Pages 339-346 in D.R. Brown, K.L. Mitchell, and H.W. Chang, eds. Proceedings of the Fifth California Islands Symposium. Minerals Management Service Publication # 99-0038.

Duncan, D. 2014. The toxicity of creosote treated wood to Pacific Herring (*Clupea pallasi*) embryos and characterization of polycyclic aromaic hdyrocarbons near creosoted pilings in Juneau, Alaska. University of Alaska Fairbanks, School of Fisheries and Ocean Sciences **Master's Thesis**.

Duncan, D. L., M. G. Carls, S. D. Rice, and M. S. Stekoll. 2017. The toxicity of creosote-treated wood to Pacific herring embryos and characterization of polycyclic aromatic hydrocarbons near creosoted pilings in Juneau, Alaska. Environmental toxicology and chemistry **36**:1261-1269.

Dunton, K. H., S. V. Schonberg, and L. W. Cooper. 2012. Food web structure of the Alaskan nearshore shelf and estuarine lagoons of the Beaufort Sea. Estuaries and Coasts **35**:416–435.

Ebersole, J. L., P. J. Wigington, Jr., J. P. Baker, M. A. Cairns, M. R. Church, B. P. Hansen, B. A. Miller, H. R. LaVigne, J. E. Compton, and S. G. Leibowitz. 2006. Juvenile coho salmon growth and survival across stream network seasonal habitats. Transactions of the American Fisheries Society **135**:1681–1697.

Edwards, R. T., D. V. D'Amore, F. E. Biles, J. B. Fellman, E. W. Hood, J. W. Trubilowicz, and W. C. Floyd. 2021. Riverine Dissolved Organic Carbon and Freshwater Export in the Eastern Gulf of Alaska. Journal of Geophysical Research: Biogeosciences **126**.

Eisner, L. 2020. The Bering Sea: Current status and recent trends. PICES Press **28**:60-64.

Eisner, L. B., E. M. Yasumiishi, A. G. Andrews III, and C. A. O'Leary. 2020. Large copepods as leading indicators of walleye pollock recruitment in the southeastern Bering Sea: sample-Based and spatio-temporal model (VAST) results. Fisheries Research **232**:105720.

Ekanem, N., J. Udoh, and K. Afolabi. 2018. Genetic and dietary strategies for mitigating enteric methane emissions in ruminant animal production: a review. Journal of Agricultural Production and Technology ISSN **2360**:9364.

Emmett, B. 2002. A discussion document associated with shellfish aquaculture in Baynes Sound. Prepared for Mr. Joe Truscott, Coast and Marine Planning Office, Ministry of Sustainable Resource Management.

Engel, J., and R. Kvitek. 1998. Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conservation Biology **12**:1204-1214.

Enger, P. S., H. E. Karlsen, F. R. Knudsen, and O. Sand. 1993. Detection and reaction of fish to infrasound. ICES Marine Science Symposia **196**:108-112.

EPA (U.S. Environmental Protection Agency). 1993. Guidance specifying management measures for sources of nonpoint pollution in coastal waters. 840-B-92-002. Environmental Protection Agency, Office of Water, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1996. Authorization to discharge under the National Pollutant Discharge Elimination System (NPDES) for Section 402 modifications of Section 404 permits for log transfer facilities which received a Section 404 permit prior to October 22, 1985. NPDES permit number AK-G70-1000. EPA response to comments from September 1996.

EPA (U.S. Environmental Protection Agency). 2000. Environmental screening checklist and workbook for the water transportation Industry.

EPA (U.S. Environmental Protection Agency). 2005. National management measures to control nonpoint source pollution from urban areas. EPA-841-B-05-004. U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 2007. National management measures to control nonpoint source pollution from hydromodification. EPA 841-B-07-002. Nonpoint Source Control Branch; Office of Wetlands, Oceans and Watersheds; U.S. Environmental Protection Agency; Office of Water.

EPA (U.S. Environmental Protection Agency). 2013. Alaskan seafood processing effluent limitations guidelines. Federal Register **78**:66916-66929.

EPA (U.S. Environmental Protection Agency). 2014. An assessment of potential mining impacts on salmon ecosystems of Bristol Bay, Alaska. EPA Region **10**.

EPA (U.S. Environmental Protection Agency). 2015. Connectivity of streams and wetlands to downstream waters: a review and synthesis of the scientific evidence. EPA/600/R-14/475F. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC.

EPA (U.S. Environmental Protection Agency). 2019. Authorization to Discharge Under the National Pollutant Discharge Elimination System (NPDES) for Offshore Seafood Processors in Alaska (Reissuance of final NPDES General Permit AKG524000). 84 FR 28044.

EPA (U.S. Environmental Protection Agency), USCG (United States Coast Guard), and ADEC (Alaska Department of Environmental Conservation). 2010. The Alaska federal/state preparedness plan for response to oil and hazardous substance discharges/releases (Unified plan).

EPRI (Electric Power Research Institute). 2007. Assessment of cooling water intake structure impacts to California coastal fisheries. Electric Power Research Institute, Palo Alto, California.

Erftemeijer, P. L. A., and R. R. R. Lewis, III. 2006. Environmental impacts of dredging on seagrasses: a review. Marine Pollution Bulletin **52**:1553-1572.

Everest, F. H., and G. H. Reeves. 2007. Riparian and aquatic habitats of the Pacific Northwest and southeast Alaska: ecology, management history, and potential management strategies. General technical report PNW-GTR-692. United States Department of Agriculture, Forest Service, and Pacific Northwest Research Station, Portland, Oregon.

Farag, A. M., D. F. Woodward, J. N. Goldstein, W. Brumbaugh, and J. S. Meyer. 1998. Concentrations of metals associated with mining waste in sediments, biofilm, benthic macroinvertebrates, and fish from the Coeur d'Alene River Basin, Idaho. Archives of Environmental Contamination and Toxicology **34**:119-127.

Farley, E. V., Jr., J. M. Murphy, M. Adkison, and L. Eisner. 2007. Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. Journal of Fish Biology **71**:1145-1158.

Farley, E. V., A. Starovoytov, S. Naydenko, R. Heintz, M. Trudel, C. Guthrie, L. Eisner, and J. R. Guyon. 2011. Implications of a warming eastern Bering Sea for Bristol Bay sockeye salmon. ICES Journal of Marine Science **68**:1138-1146.

Federal Interagency Working Group. 2006. Sediment removal from active stream channels in Oregon: considerations for federal agencies for the evaluation of sediment removal actions from Oregon streams. Developed with support from U.S. Fish and Wildlife Service, National Marine Fisheries Service, U.S. Army Corps of Engineers, and U.S. Environmental Protection Agency.

Fedewa, E. J., T. M. Jackson, J. I. Richar, J. L. Gardner, and M. A. Litzow. 2020. Recent shifts in northern Bering Sea snow crab (Chionoecetes opilio) size structure and the potential role of climate-mediated range contraction. Deep Sea Research Part II: Topical Studies in Oceanography **181**:104878.

Feist, B. E., E. R. Buhle, D. H. Baldwin, J. A. Spromberg, S. E. Damm, J. W. Davis, and N. L. Scholz. 2017. Roads to ruin: conservation threats to a sentinel species across an urban gradient. Ecological Applications **27**:2382-2396.

Ferraro, S. P., R. C. Swartz, F. A. Cole, and D. W. Schults. 1991. Temporal changes in the benthos along a pollution gradient: discriminating the effect of natural phenomena from sewage-industrial wastewater effects. Estuarine, Coastal and Shelf Science **33**:383-407.

Ferriss, B. E., and S. Zador. 2021. Ecosystem Status Report 2021: Gulf of Alaska, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Fewtrell, J. L., and R. D. McCauley. 2012. Impact of air gun noise on the behaviour of marine fish and squid. Marine Pollution Bulletin **64**:984–993.

Filbee-Dexter, K., and T. Wernberg. 2020. Substantial blue carbon in overlooked Australian kelp forests. Scientific Reports **10**:1-6.

Firth, L. B., A. M. Knights, D. Bridger, A. Evans, N. Mieskowska, P. J. Moore, N. E. O'Connor, E. V. Sheehan, R. C. Thompson, and S. J. Hawkins. 2016. Ocean sprawl: challenges and opportunities for biodiversity management in a changing world.

Flanner, M. G., K. M. Shell, M. Barlage, D. K. Perovich, and M. Tschudi. 2011. Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2008. Nature Geoscience **4**:151-155.

Fletcher, S., T. Robertson, B. Higman, M. Janes, A. Sughroue, P. DeCola, and C. Mom. 2016. Bering Sea Risk Analysis., Nuka Research and Planning Group, LLC.

Fodrie, F. J., K. W. Able, F. Galvez, K. L. Heck, Jr., O. P. Jensen, P. C. López-Duarte, C. W. Martin, R. E. Turner, and A. Whitehead. 2014. Integrating organismal and population responses of estuarine fishes in Macondo spill research. BioScience **64**:778-788.

Fofonoff, P. W., G. M. Ruiz, B. Steves, C. Simkanin, and J. T. Carlton. 2018. National Exotic Marine and Estuarine Species Information System.

Fresco, N., C. Tauxe, M. Lindgren, P. Bieniek, and J. Walsh. 2021. Future Projections of Precipitation for Alaska Infrastructure. Alaska. Department of Transportation and Public Facilities. Research and ….

Fulton, M. H., G. I. Scott, A. Fortner, T. F. Bidleman, and B. Ngabe. 1993. The effects of urbanization on small high salinity estuaries of the southeastern United States. Archives of Environmental Contamination and Toxicology **25**:476-484.

Furniss, M. J., T. D. Roelofs, and C. S. Yee. 1991. Road construction and maintenance. Pages 297-323 in W.R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Bethesda, Maryland.

Furniss, M. J., B. P. Staab, S. Hazelhurst, C. F. Clifton, and K. B. Roby, et al. 2010. Water, climate change, and forests: watershed stewardship for a changing climate. General technical report PNW-GTR-812. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Gabriel, F. Â., A. D. Ferreira, H. M. Queiroz, A. L. S. Vasconcelos, T. O. Ferreira, and A. F. Bernardino. 2021. Long-term contamination of the Rio Doce estuary as a result of Brazil's largest environmental disaster. Perspectives in Ecology and Conservation **19**:417-428.

Gardner, L. A. 1992. Regulatory processes associated with metal-mine development in Alaska: A case study of the WestGold BIMA. US Department of the Interior, Bureau of Mines.

Gardner, L. A., and S. C. Jewett. 1994. To evaluate the suitability of a coarse-grain hydraulic bucket sampler for marine placer deposits and mine tailings sites. 1993 benthic monitoring results final report. Document no. 6938-001-400 Box :16.

Gardner, L. D., K. A. Peck, G. W. Goetz, T. L. Linbo, J. R. Cameron, N. L. Scholz, B. A. Block, and J. P. Incardona. 2019. Cardiac remodeling in response to embryonic crude oil exposure involves unconventional NKX family members and innate immunity genes. J Exp Biol **222**.

Garnett, R., and D. Ellis. 1995. Tailings disposal at a marine placer mining operation by WestGold, Alaska. Marine georesources & geotechnology **13**:41-57.

Gauthier, S., P. Bernier, T. Kuuluvainen, A. Z. Shvidenko, and D. G. Schepaschenko. 2015. Boreal forest health and global change. Science **349**:819-822.

Geist, D. R. 2000. Hyporheic discharge of river water into fall chinook salmon (*Oncorhynchus tshawytscha*) spawning areas in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences **57**:1647-1656.

Geist, D. R., T. P. Hanrahan, E. V. Arntzen, G. A. McMichael, C. J. Murray, and Y.-J. Chien. 2002. Physicochemical characteristics of the hyporheic zone affect redd site selection by

chum salmon and fall chinook salmon in the Columbia River. North American Journal of Fisheries Management **22**:1077-1085.
Gende, S. M., A. E. Miller, and E. Hood. 2007. The effects of salmon carcasses on soil nitrogen pools in a riparian forest of southeastern Alaska. Canadian Journal of Forest Research **37**:1194-1202.
Gende, S. M., T. P. Quinn, M. F. Willson, R. Heintz, and T. M. Scott. 2004. Magnitude and fate of salmon-derived nutrients and energy in a coastal stream ecosystem. Journal of Freshwater Ecology **19**:149-160.
Giefer, J., and S. Graziano. 2022a. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Arctic Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-01, Anchorage.
Giefer, J., and S. Graziano. 2022b. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Interior Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-02, Anchorage.
Giefer, J., and S. Graziano. 2022c. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southcentral Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-03, Anchorage.
Giefer, J., and S. Graziano. 2022d. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southeastern Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-04, Anchorage.
Giefer, J., and S. Graziano. 2022e. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southwestern Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-05, Anchorage.
Giefer, J., and S. Graziano. 2022f. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Western Region, effective June 15, 2022, Alaska Department of Fish and Game, Special Publication No. 22-06, Anchorage.
Gill, A. B. 2005. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology **42**:605-615.
Gillanders, B. M., K. W. Able, J. A. Brown, D. B. Eggleston, and P. F. Sheridan. 2003. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series **247**:281-295.
Gladstone, W., and G. Courtenay. 2014. Impacts of docks on seagrass and effects of management practices to ameliorate these impacts. Estuarine, Coastal and Shelf Science **136**:53-60.
Glasby, T. M. 1999. Effects of shading on subtidal epibiotic assemblages. Journal of Experimental Marine Biology and Ecology **234**:275-290.
Glass, R. L. 1996. Alaska wetland resources. Pages 107-114 in J.D. Fretwell, J.S. Williams, and P.J. Redman, compilers. National water summary on wetland resources. U.S. Geological Survey water-supply paper 2425.
Gleason, M. G., S. Newkirk, M. S. Merrifield, J. Howard, and R. Cox, et al. 2011. A conservation assessment of West Coast (USA) estuaries. The Nature Conservancy, Arlington, Virginia.
Glenn, C. R., R. B. Whittier, M. L. Dailer, H. Dulaiova, A. I. El-Kadi, J. Fackrell, J. L. Kelly, C. A. Waters, and J. Sevadjian. 2013. Lahaina groundwater tracer study--Lahaina, Maui, Hawaii.

Glick, P., B. A. Stein, and N. A. Edelson, eds. 2011. Scanning the conservation horizon: a guide to cliamte change vulnerability assessment. National Wildlife Federation, Washington, D.C.
Goldstein, J. N., D. F. Woodward, and A. M. Farag. 1999. Movements of adult chinook salmon during spawning migration in a metals-contaminated system, Coeur d'Alene River, Idaho. Transactions of the American Fisheries Society **128**:121-129.
Gomi, T., R. C. Sidle, and J. S. Richardson. 2002. Understanding processes and downstream linkages of headwater systems. BioScience **52**:905-916.
Good, J. W., R. G. Hildreth, R. E. Rose, and G. Skillman. 1987. Oregon territorial sea management study: executive summary. Prepared for the Oregon Department of Land Conservation and Development by Marine Resource Management Program, College of Oceanography, Oregon State University and Ocean and Coastal Law Center, University of Oregon Law School, Corvallis, Oregon.
Goodrow, S. M., B. Ruppel, R. L. Lippincott, G. B. Post, and N. A. Procopio. 2020. Investigation of levels of perfluoroalkyl substances in surface water, sediment and fish tissue in New Jersey, USA. Science of the total Environment **729**:138839.
Gowen, A. W. 1978. The environmental effects of OCS pipelines: initial findings. New England River Basins Commission, Boston, Massachusetts.
Graham, W. M., R. H. Condon, R. H. Carmichael, I. D'Ambra, H. K. Patterson, L. J. Linn, and J. Frank J. Hernandez. 2010. Oil carbon entered the coastal planktonic food web during the *Deepwater Horizon* oil spill. Environmental Research Letters **5**:045301.
Grebe, G. S., C. J. Byron, A. S. Gelais, D. M. Kotowicz, and T. K. Olson. 2019. An ecosystem approach to kelp aquaculture in the Americas and Europe. Aquaculture Reports **15**:100215.
Grebmeier, J. M. 2012. Shifting patterns of life in the Pacific Arctic and sub-Arctic seas. Annual Review of Marine Science **4**:63-78.
Grebmeier, J. M., and C. P. McRoy. 1989. Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. 111. Benthic food supply and carbon cycling. Mar. Ecol.-Prog. Ser **53**:79-91.
Grebmeier, J. M., J. E. Overland, S. E. Moore, E. V. Farley, E. C. Carmack, L. W. Cooper, K. E. Frey, J. H. Helle, F. A. McLaughlin, and S. L. McNutt. 2006. A major ecosystem shift in the northern Bering Sea. Science **311**:1461-1464.
Groot, G. 1991. Pacific salmon life histories. UBC press.
Grosell, M., and C. Pasparakis. 2021. Physiological responses of fish to oil spills. Annual review of marine science **13**:137-160.
Groves, P. A., and J. A. Chandler. 2005. Habitat quality of historic Snake River fall Chinook salmon spawning locations and implications for incubation survival. Part 2: intra-gravel water quality. River Research and Applications **21**:469-483.
Grüss, A., J. L. Pirtle, J. T. Thorson, M. R. Lindeberg, A. D. Neff, S. G. Lewis, and T. E. Essington. 2021. Modeling nearshore fish habitats using Alaska as a regional case study. Fisheries Research **238**:105905.
Gubernick, B., K. Clarkin, and M. J. Furniss. 2003. Design and construction of aquatic organism passage at road-stream crossings: site assessment and geomorphic considerations in stream simulation culvert design. Pages 30-41 in C.L. Irwin, P. Garrett, K.P. McDermott, editors. Proceedings of the 2003 International Conference on Ecology and

Transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina.
Gunderson, D. R. 1993. Surveys of fisheries resources. John Wiley & Sons.
Gunnarsson, B. 2021. Recent ship traffic and developing shipping trends on the Northern Sea Route—Policy implications for future arctic shipping. Marine Policy **124**:104369.
Gurnell, A. M., H. Piégay, F. J. Swanson, and S. V. Gregory. 2002. Large wood and fluvial processes. Freshwater Biology **47**:601-619.
Gutierrez, L. 2011. Terrestrial invertebrate prey for juvenile chinook salmon: abundance and environmental controls in an interior Alaska River. Master's thesis. University of Alaska Fairbanks, Fairbanks, Alaska.
Gutt, J. 2001. On the direct impact of ice on marine benthic communities, a review. Polar Biology **24**:553-564.
Haas, M. A., C. A. Simenstad, J. R. Cordell, D. A. Beauchamp, and B. S. Miller. 2002. Effects of large overwater structures on epibenthic juvenile salmon prey assemblages in Puget Sound, Washington. Final research report no. WA-RD 550.1. Prepared for the Washington State Transportation Commission and the U.S. Department of Transportation.
Hader, D. P., A. T. Banaszak, V. E. Villafane, M. A. Narvarte, R. A. Gonzalez, and E. W. Helbling. 2020. Anthropogenic pollution of aquatic ecosystems: Emerging problems with global implications. Sci Total Environ **713**:136586.
Haegele, C., and J. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Canadian Journal of Fisheries and Aquatic Sciences **42**:s39-s55.
Hall, A. 2004. The role of surface albedo feedback in climate. Journal of Climate **17**:1550-1568.
Hall, J. V. 1988. Alaska coastal wetlands survey. National wetlands inventory, Alaska. Cooperative report for the U.S. Fish and Wildlife Service and National Oceanic and Atmospheric Administration.
Hall, J. V., W. E. Frayer, and W. O. Wilen. 1994. Status of Alaska wetlands. U.S. Fish and Wildlife Service, Alaska Region, Anchorage, Alaska.
Hamilton, L. C., K. Saito, P. A. Loring, R. B. Lammers, and H. P. Huntington. 2016. Climigration? Population and climate change in Arctic Alaska. Population and environment **38**:115-133.
Hammar, L., S. Andersson, L. Eggertsen, J. Haglund, M. Gullström, J. Ehnberg, and S. Molander. 2013. Hydrokinetic turbine effects on fish swimming behaviour. PLoS ONE **8**:e84141.
Hancock, P. J., A. J. Boulton, and W. F. Humphreys. 2005. Aquifers and hyporheic zones: towards an ecological understanding of groundwater. Hydrogeology Journal **13**:98-111.
Hanson, H., S. Aarninkhof, M. Capobianco, J. Jimenez, M. Larson, R. Nicholls, N. Plant, H. Southgate, H. Steetzel, and M. Stive. 2003. Modelling of coastal evolution on yearly to decadal time scales. Journal of Coastal Research:790-811.
Hanson, J., M. Helvey, and R. Strach, eds. 2005. Nonfishing effects on West Coast groundfish essential fish habitat and recommended conservation measures. Appendix D of Pacific coast groundfish fishery management plan for the California, Oregon, and Washington groundfish fishery. Prepared for the Pacific Fishery Management Council by National Marine Fisheries Service (NOAA Fisheries), Alaska Region, Northwest Region, Southwest Region.

Harder, L. F., Jr., and J. P. Stewart. 1996. Failure of Tapo Canyon tailings dam. Journal of Performance of Constructed Facilities **10**:109-114.

Hare, J. A., W. E. Morrison, M. W. Nelson, M. M. Stachura, E. J. Teeters, R. B. Griffis, M. A. Alexander, J. D. Scott, L. Alade, and R. J. Bell. 2016. A vulnerability assessment of fish and invertebrates to climate change on the Northeast US continental shelf. PloS one **11**:e0146756.

Harms, T. K., J. W. Edmonds, H. Genet, I. F. Creed, D. Aldred, A. Balser, and J. B. Jones. 2016. Catchment influence on nitrate and dissolved organic matter in Alaskan streams across a latitudinal gradient. Journal of Geophysical Research: Biogeosciences **121**.

Harper, D. J., and J. T. Quigley. 2005. A comparison of the areal extent of fish habitat gains and losses associated with selected compensation projects in Canada. Fisheries **30**:18-25.

Harris, P., M. Macmillan-Lawler, J. Rupp, and E. Baker. 2014. Geomorphology of the oceans. Marine Geology **352**:4-24.

Harris, P. T. 2014. Shelf and deep-sea sedimentary environments and physical benthic disturbance regimes: a review and synthesis. Marine Geology **353**:169-184.

Hartwell, S. I., A. D. Apeti, A. Pait, and T. Radenbaugh. 2016. Bioeffects assessment in Kvichak and Nushagak Bay, Alaska: characterization of soft bottom benthic habitats, animal body burdens and contaminant baseline assessment. NPRB project 1315 final report. North Pacific Research Board.

Hartwell, S. I., D. A. Apeti, A. S. Pait, T. Radenbaugh, and R. Britton. 2017. Bioeffects assessment in Kvichak and Nushagak Bays, Alaska: characterization of soft bottom benthic habitats, fish body burdens and sediment contaminant baseline assessment.

Harvey, E., A. Wenger, B. Saunders, S. Newman, S. Wilson, M. Travers, N. Browne, C. Rawson, D. Clarke, and J. Hobbs. 2017. Effects of dredging-related pressures on critical ecological processes for finfish: a review and possible management strategies. Report of Theme.

Hastings, M. C., and A. N. Popper. 2005. Effects of sound on fish. Prepared for the California Department of Transportation by Jones & Stokes, Sacramento, California.

Hawkins, A. D., R. A. Hazelwood, A. N. Popper, and P. C. Macey. 2021. Substrate vibrations and their potential effects upon fishes and invertebrates. The Journal of the Acoustical Society of America **149**:2782-2790.

Hawkins, A. D., C. Johnson, and A. N. Popper. 2020. How to set sound exposure criteria for fishes. The Journal of the Acoustical Society of America **147**:1762-1777.

Hawkins, A. D., A. E. Pembroke, and A. N. Popper. 2014. Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries **25**:39-64.

Hawkins, A. D., A. E. Pembroke, and A. N. Popper. 2015. Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries **25**:39-64.

Hawkins, A. D., and A. N. Popper. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. ICES Journal of Marine Science **74**:635-651.

Headley, R. M. 2017. River redirected. Nature Geoscience **10**:327-328.

Hecht, S. A., D. H. Baldwin, C. A. Mebane, T. Hawkes, S. J. Gross, and N. L. Scholz. 2007. An overview of sensory effects on juvenile salmonids exposed to dissolved copper: applying a benchmark concentration approach to evaluate sublethal neurobehavioral toxicity.

Heifetz, J., M. L. Murphy, and K. V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. North American Journal of Fisheries Management **6**:52-58.

Heintz, R. A., E. C. Siddon, E. V. Farley, Jr., and J. M. Napp. 2013. Correlation between recruitment and fall condition of age-0 pollock (*Theragra chalcogramma*) from the eastern Bering Sea under varying climate conditions. Deep-Sea Research II **94**:150-156.

Helfield, J. M., and R. J. Naiman. 2006. Keystone interactions: salmon and bear in riparian forests of Alaska. Ecosystems **9**:167-180.

Helton, D. 2005. Intentional scuttling of vessels as a response alternative. Pages 901-904 *in* International Oil Spill Conference. American Petroleum Institute.

Hemmer, M. J., M. G. Barron, and R. M. Greene. 2011. Comparative toxicity of eight oil dispersants, Louisiana sweet crude oil (LSC), and chemically dispersed LSC to two aquatic test species. Environmental Toxicology and Chemistry **30**:2244-2252.

Hendrix, N., A.-M. K. Osterback, E. Jennings, E. Danner, V. Sridharan, C. M. Greene, and S. T. Lindley. 2017. Model Description for the Sacramento River Winter-run Chinook Salmon Life Cycle Model. Appendix H of California WaterFix Biological Opinion prepared by NOAA Fisheries.

Herbert-Read, J. E., L. Kremer, R. Bruintjes, A. N. Radford, and C. C. Ioannou. 2017. Anthropogenic noise pollution from pile-driving disrupts the structure and dynamics of fish shoals. Proceedings of the Royal Society B: Biological Sciences **284**:20171627.

Herke, W. H., and B. D. Rogers. 1993. Maintenance of the estuarine environment. Pages 263-286 in C.C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences **100**:6564-6568.

Hinckley, S., W. Stockhausen, K. Coyle, B. Laurel, G. Gibson, C. Parada, A. Hermann, M. Doyle, T. Hurst, and A. Punt. 2019. Connectivity between spawning and nursery areas for Pacific cod (Gadus macrocephalus) in the Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography **165**:113-126.

Hirawake, T., and G. L. Hunt. 2020. Impacts of unusually light sea-ice cover in winter 2017-2018 on the northern Bering Sea marine ecosystem – An introduction. Deep Sea Research Part II: Topical Studies in Oceanography **181-182**.

Hocking, M. D., R. A. Ring, and T. E. Reimchen. 2009. The ecology of terrestrial invertebrates on Pacific salmon carcasses. Ecological Research **24**:1091-1100.

Hodgson, S., and T. P. Quinn. 2002. The timing of adult sockeye salmon migration into fresh water: adaptations by populations to prevailing thermal regimes. Canadian Journal of Zoology **80**:542-555.

Hodgson, S., T. P. Quinn, R. Hilborn, R. C. Francis, and D. E. Rogers. 2006. Marine and freshwater climatic factors affecting interannual variation in the timing of return migration to fresh water of sockeye salmon (*Oncorhynchus nerka*). Fisheries Oceanography **15**:1-24.

Hodson, P. V. 2017. The toxicity to fish embryos of PAH in crude and refined oils. Archives of environmental contamination and toxicology **73**:12-18.

Hodson, P. V., J. Adams, and R. S. Brown. 2019. Oil toxicity test methods must be improved. Environmental Toxicology and Chemistry **38**:302-311.

Hoem Neher, T. D., A. Rosenberger, C. Zimmerman, C. Walker, and S. Baird. 2014. Use of glacier river-fed estuary channels by juvenile coho salmon: transitional or rearing habitats? Environmental Biology of Fishes **97**:839-850.

Hogan, T. W., G. F. Cada, and S. V. Amaral. 2014. The status of environmentally enhanced hydropower turbines. Fisheries **39**:164-172.

Hogrefe, K. R., D. H. Ward, T. F. Donnelly, and N. Dau. 2014. Establishing a baseline for regional scale monitoring of eelgrass (*Zostera marina*) habitat on the lower Alaska peninsula. Remote Sensing **6**:12447-12477.

Holler, J. D. 1990. Nonpoint source phosphorus control by a combination wet detention/filtration facility in Kissimmee, Florida. Florida Scientist **53**:28-37.

Holmes, R. M., J. W. McClelland, B. J. Peterson, S. E. Tank, E. Bulygina, T. I. Eglinton, V. V. Gordeev, T. Y. Gurtovaya, P. A. Raymond, and D. J. Repeta. 2012. Seasonal and annual fluxes of nutrients and organic matter from large rivers to the Arctic Ocean and surrounding seas. Estuaries and Coasts **35**:369-382.

Holsman, K., A. Haynie, A. Hollowed, J. Reum, K. Aydin, A. Hermann, W. Cheng, A. Faig, J. Ianelli, and K. Kearney. 2020. Ecosystem-based fisheries management forestalls climate-driven collapse. Nature communications **11**:1-10.

Hopsch, S., J. Cohen, and K. Dethloff. 2012. Analysis of a link between fall Arctic sea ice concentration and atmospheric patterns in the following winter. Tellus A: Dynamic Meteorology and Oceanography **64**:18624.

Howard, B. R., F. T. Francis, I. M. Côté, and T. W. Therriault. 2019. Habitat alteration by invasive European green crab (Carcinus maenas) causes eelgrass loss in British Columbia, Canada. Biological Invasions **21**:3607-3618.

Hunt, G. L., Jr., C. Baduini, and J. Jahncke. 2002a. Diets of short-tailed shearwaters in the southeastern Bering Sea. Deep-Sea Research II **49**:6147-6156.

Hunt, G. L., Jr., K. O. Coyle, L. B. Eisner, E. V. Farley, R. A. Heintz, F. Mueter, J. M. Napp, J. E. Overland, P. H. Ressler, S. Salo, and P. J. Stabeno. 2011. Climate impacts on eastern Bering Sea foodwebs: a synthesis of new data and an assessment of the oscillating control hypothesis. ICES Journal of Marine Science **68**:1230–1243.

Hunt, G. L., Jr., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp, and N. A. Bond. 2002b. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Research II **49**:5821-5853.

Hunt, G. L., Jr., and P. J. Stabeno. 2005. Oceanography and ecology of the Aleutian Archipelago: spatial and temporal variation. Fisheries Oceanography **14**:292-306.

Hunt, G. L., E. M. Yasumiishi, L. B. Eisner, P. J. Stabeno, and M. B. Decker. 2020. Climate warming and the loss of sea ice: the impact of sea-ice variability on the southeastern Bering Sea pelagic ecosystem. ICES Journal of Marine Science.

Hunt Jr, G. L., E. M. Yasumiishi, L. B. Eisner, P. J. Stabeno, and M. B. Decker. 2022. Climate warming and the loss of sea ice: the impact of sea-ice variability on the southeastern Bering Sea pelagic ecosystem. ICES Journal of Marine Science **79**:937-953.

Hunter, M. A. 1992. Technical. Report Number: 119.

Huntington, H. P., S. L. Danielson, F. K. Wiese, M. Baker, P. Boveng, J. J. Citta, A. De Robertis, D. M. Dickson, E. Farley, and J. C. George. 2020. Evidence suggests potential transformation of the Pacific Arctic ecosystem is underway. Nature Climate Change **10**:342-348.

Hurme, A. K., and E. J. Pullen. 1988. Biological effects of marine sand mining and fill placement for beach replenishment: lesson for other use. Marine Mining **7**:123-136.
Hurst, T. P., D. W. Cooper, J. T. Duffy-Anderson, and E. V. Farley. 2015. Contrasting coastal and shelf nursery habitats of Pacific cod in the southeastern Bering Sea. ICES Journal of Marine Science **72**:515-527.
Ianelli, J. N., S. Barbeaux, T. Honkalehto, S. Kotwicki, K. Aydin, and N. Williamson. 2006. Assessment of Alaska pollock stock in the eastern Bering Sea. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section **1**:35-138.
Ianelli, J. N., S. Barbeaux, T. Honkalehto, S. Kotwicki, K. Aydin, and N. Williamson. 2007. Eastern Bering Sea walleye pollock. Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section **1**:41-138.
Incardona, J. P., M. G. Carls, L. Holland, T. L. Linbo, D. H. Baldwin, M. S. Myers, K. A. Peck, M. Tagal, S. D. Rice, and N. L. Scholz. 2015. Very low embryonic crude oil exposures cause lasting cardiac defects in salmon and herring. Scientific Reports **5**:13499.
Incardona, J. P., L. D. Gardner, T. L. Linbo, T. L. Brown, and A. J. Esbaugh, et al. 2014. *Deepwater Horizon* crude oil impacts the developing hearts of large predatory pelagic fish. Proceedings of the National Academy of Sciences **111**:E1510-E1518.
Incardona, J. P., C. A. Vines, B. F. Anulacion, D. H. Baldwin, and H. L. Day, et al. 2012a. Unexpectedly high mortality in Pacific herring embryos exposed to the 2007 *Cosco Busan* oil spill in San Francisco Bay. Proceedings of the National Academy of Sciences **109**:E51–E58.
Incardona, J. P., C. A. Vines, T. L. Linbo, M. S. Myers, and C. A. Sloan, et al. 2012b. Potent phototoxicity of marine bunker oil to translucent herring embryos after prolonged weathering. PLoS ONE **7**:e30116.
IPCC. 2014. Climate change 2014: synthesis report., Intergovernmental Panel on Climate Change, Geneva, Switzerland.
IPCC. 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3−32, doi:10.1017/9781009157896.001.
IPCC. 2022. Summary for Policymakers [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (eds.)]. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3–33, doi:10.1017/9781009325844.001.
Islam, K., and S. Murakami. 2021. Global-scale impact analysis of mine tailings dam failures: 1915–2020. Global Environmental Change **70**:102361.

Ivanova, S. V., S. T. Kessel, M. Espinoza, M. F. McLean, C. O'Neill, J. Landry, N. E. Hussey, R. Williams, S. Vagle, and A. T. Fisk. 2020. Shipping alters the movement and behavior of Arctic cod (*Boreogadus saida*), a keystone fish in Arctic marine ecosystems. Ecological Applications **30**:e02050.

Jackson, R. G. 1986. Effects of bark accumulation on benthic infauna at a log transfer facility in southeast Alaska. Marine Pollution Bulletin **17**:258-262.

Jacobson, K. C., M. R. Arkoosh, A. N. Kagley, E. R. Clemons, T. K. Collier, and E. Casillas. 2003. Cumulative effects of natural and anthropogenic stress on immune function and disease resistance in juvenile chinook salmon. Journal of Aquatic Animal Health **15**:1-12.

Jennings, S. R., D. J. Dollhopf, and W. P. Inskeep. 2000. Acid production from sulfide minerals using hydrogen peroxide weathering. Applied Geochemistry **15**:235-243.

Jennings, S. R., D. R. Neuman, and P. S. Blicker. 2008. Acid mine drainage and effects on fish health and ecology: a review. Prepared for U.S. Fish and Wildlife Service, Anchorage Fish and Wildlife Field Office by Reclamation Research Group, LLC, Bozeman, Montana.

Jewett, S. C. 1999. Assessment of red king crabs following offshore placer gold mining in Norton Sound. Alaska Fishery Research Bulletin **6**.

Jewett, S. C., H. M. Feder, and A. Blanchard. 1999. Assessment of the benthic environment following offshore placer gold mining in the northeastern Bering Sea. Marine Environmental Research **48**:91-122.

Jin, J., S. Li, C. Song, X. Zhang, and X. Lv. 2019. Ageing deformation of tailings dams in seasonally frozen soil areas under freeze-thaw cycles. Sci Rep **9**:15033.

Jin, M., C. Deal, S. H. Lee, S. Elliott, E. Hunke, M. Maltrud, and N. Jeffery. 2012. Investigation of Arctic sea ice and ocean primary production for the period 1992–2007 using a 3-D global ice–ocean ecosystem model. Deep Sea Research Part II: Topical Studies in Oceanography **81**:28-35.

Johnson, J. B., and D. J. Pride. 2010. River, tidal, and ocean current hydrokinetic energy technologies: status and future opportunities in Alaska. Prepared for Alaska Center for Energy and Power.

Johnson, L. 2000. An analysis in support of sediment quality thresholds for polycyclic aromatic hydrocarbons (PAHs) to protect estuarine fish. White paper prepared by the National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington.

Johnson, L. B., and G. E. Host. 2010. Recent developments in landscape approaches for the study of aquatic ecosystems. Journal of the North American Benthological Society **29**:41-66.

Johnson, L. L., S. Y. Sol, G. M. Ylitalo, T. Hom, B. French, O. P. Olson, and T. K. Collier. 1999. Reproductive injury in English sole (*Pleuronectes vetulus*) from the Hylebos Waterway, Commencement Bay, Washington. Journal of Aquatic Ecosystem Stress and Recovery **6**:289-310.

Johnson, M. R., C. Boelke, L. A. Chiarella, P. D. Colosi, K. Greene, K. Lellis-Dibble, H. Ludemann, M. Ludwig, S. McDermott, J. Ortiz, D. Rusanowsky, M. Scott, and J. Smith. 2008. Impacts to marine fisheries habitat from nonfishing activities in the northeastern United States. NOAA Technical Memorandum NMFS-NE-209. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Gloucester, Massachusetts.

Johnson, M. R., C. Boelke, L. A. Chiarella, and K. Greene. 2019. Guidance for Integrating Climate Change Information in Greater Atlantic Region Habitat Conservation Division Consultation Processes. Greater Atlantic Region Policy Series 19-01. NOAA Fisheries Greater Atlantic Regional Fisheries Office. 235p.

Johnson, S. W., A. D. Neff, J. F. Thedinga, M. R. Lindeberg, and J. M. Maselko. 2012. Atlas of nearshore fishes of Alaska: a synthesis of marine surveys from 1998 to 2011. NOAA Technical Memorandum NMFS-AFSC-239. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Johnson, S. W., R. P. Stone, and D. C. Love. 1998. Avoidance behavior of ovigerous Tanner crabs *Chionoecetes bairdi* exposed to mine tailings: a laboratory study. Alaska Fishery Research Bulletin **5**:39-45.

Johnston, S. A. 1981. Estuarine dredge and fill activities: a review of impacts. Environmental Management **5**:427-440.

Jones, L. A., E. R. Schoen, R. Shaftel, C. J. Cunningham, S. Mauger, D. J. Rinella, and A. St. Saviour. 2020. Watershed-scale climate influences productivity of Chinook salmon populations across southcentral Alaska. Global Change Biology **26**:4919-4936.

Jones, N. 2019. Ocean uproar: saving marine life from a barrage of noise. Nature **568**:158-162.

Jorgenson, M. T., T. A. Douglas, A. K. Liljedahl, J. E. Roth, T. C. Cater, W. A. Davis, G. V. Frost, P. F. Miller, and C. H. Racine. 2020. The roles of climate extremes, ecological succession, and hydrology in repeated permafrost aggradation and degradation in fens on the Tanana Flats, Alaska. Journal of Geophysical Research: Biogeosciences **125**:e2020JG005824.

Joye, S. B., I. R. MacDonald, I. Leifer, and V. Asper. 2011. Magnitude and oxidation potential of hydrocarbon gases released from the BP oil well blowout. Nature Geoscience **4**:160-164.

Jung, J., J. E. Son, Y. K. Lee, K.-H. Cho, Y. Lee, E. J. Yang, S.-H. Kang, and J. Hur. 2021. Tracing riverine dissolved organic carbon and its transport to the halocline layer in the Chukchi Sea (western Arctic Ocean) using humic-like fluorescence fingerprinting. Science of the total Environment **772**:145542.

Jurgens, L. J., M. Bonfim, D. P. Lopez, M. F. Repetto, G. Freitag, L. McCann, K. Larson, G. M. Ruiz, and A. L. Freestone. 2018. Poleward range expansion of a non-indigenous bryozoan and new occurrences of exotic ascidians in southeast Alaska. BioInvasions Rec **7**:357-366.

Kahler, T., M. Grassley, and D. Beauchamp. 2000. A summary of the effects of bulkheads, piers, and other artificial structures and shorezone development on ESA-listed salmonids in lakes. Final report. Prepared for City of Bellevue, Bellevue, Washington by The Watershed Company and University of Washington.

Kalny, G., G. Laaha, A. Melcher, H. Trimmel, P. Weihs, and H. P. Rauch. 2017. The influence of riparian vegetation shading on water temperature during low flow conditions in a medium sized river. Knowledge & Management of Aquatic Ecosystems.

Kammerer, J. C. 1990. Largest rivers in the United States. Water fact sheet. Open-file report 87-242. U.S. Department of Interior, U.S. Geological Survey.

Kaplan, K. A., D. R. Hart, K. Hopkins, S. Gallager, A. York, R. Taylor, and P. J. Sullivan. 2017. Evaluating the interaction of the invasive tunicate Didemnum vexillum with the Atlantic sea scallop Placopecten magellanicus on open and closed fishing grounds of Georges Bank. ICES Journal of Marine Science **74**:2470-2479.

Kaplan, K. A., D. R. Hart, K. Hopkins, S. Gallager, A. York, R. Taylor, and P. J. Sullivan. 2018. Invasive tunicate restructures invertebrate community on fishing grounds and a large protected area on Georges Bank. Biological Invasions **20**:87-103.

Karlapudi, A. P., T. Venkateswarulu, J. Tammineedi, L. Kanumuri, B. K. Ravuru, V. ramu Dirisala, and V. P. Kodali. 2018. Role of biosurfactants in bioremediation of oil pollution-a review. Petroleum **4**:241-249.

Kennish, M. J. 1998. Pollution impacts on marine biotic communities. CRC Press, New York, New York.

Kennish, M. J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation **29**:78-107.

Kikuchi, G., H. Abe, T. Hirawake, and M. Sampei. 2020. Distinctive spring phytoplankton bloom in the Bering Strait in 2018: A year of historically minimum sea ice extent. Deep Sea Research Part II: Topical Studies in Oceanography **181**:104905.

King, R. S., C. M. Walker, D. F. Whigham, S. J. Baird, and J. A. Back. 2012. Catchment topography and wetland geomorphology drive macroinvertebrate community structure and juvenile salmonid distributions in south-central Alaska headwater streams. Freshwater Science **31**:341–364.

Kinner, N. E., L. Belden, and P. Kinner. 2014. Unexpected sink for *Deepwater Horizon* oil may influence future spill response. Eos, Transactions American Geophysical Union **95**:176-176.

Kirkpatrick, B., T. C. Shirley, and C. E. O'Clair. 1998. Deep-water bark accumulation and benthos richness at log transfer and storage facilities. Alaska Fishery Research Bulletin **5**:103-115.

Klein, R. 1997. The effects of marinas & boating activity upon tidal waterways. Community & Environmental Defense Services, Owings Mills, Maryland.

Knudsen, F. R., C. B. Schreck, S. M. Knapp, P. S. Enger, and O. Sand. 1997. Infrasound produces flight and avoidance responses in Pacific juvenile salmonids. Journal of Fish Biology **51**:824-829.

Kohler, C. C., and W. R. Courtenay, Jr. 1986. American Fisheries Society position on introductions of aquatic species. Fisheries **11**:39-42.

Kondolf, G. M., E. W. Larsen, and J. G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management **20**:1016-1028.

Korshunov, A. A., S. P. Doroshenko, and A. L. Nevzorov. 2016. The impact of freezing-thawing process on slope stability of earth structure in cold climate. Procedia engineering **143**:682-688.

Koski, K. V. 1992. Restoring stream habitats affected by logging activities. Pages 343-404 in G.W. Thayer, editor. Restoring the nation's marine environment. Publication UM-SG-TS-92-06. Maryland Sea Grant College, College Park, Maryland.

Kossoff, D., W. E. Dubbin, M. Alfredsson, S. J. Edwards, M. G. Macklin, and K. A. Hudson-Edwards. 2014. Mine tailings dams: Characteristics, failure, environmental impacts, and remediation. Applied Geochemistry **51**:229-245.

Kostka, J. E., S. B. Joye, W. Overholt, P. Bubenheim, S. Hackbusch, S. R. Larter, A. Liese, S. A. Lincoln, A. Marietou, and R. Müller. 2020. Biodegradation of petroleum hydrocarbons in the deep sea. Pages 107-124 Deep Oil Spills. Springer.

Kramer, S., M. Previsic, P. Nelson, and S. Woo. 2010. Deployment effects of marine renewable energy technologies: framework for identifying key environmental concerns in marine renewable energy projects. RE Vision DE - 003. Prepared for U.S. Department of Energy by RE Vision Consulting, LLC.

Kreplin, H. N., C. S. Santos Ferreira, G. Destouni, S. D. Keesstra, L. Salvati, and Z. Kalantari. 2021. Arctic wetland system dynamics under climate warming. WIREs Water.

Krumhansl, K. A., J. N. Bergman, and A. K. Salomon. 2017. Assessing the ecosystem-level consequences of a small-scale artisanal kelp fishery within the context of climate-change. Ecological Applications **27**:799-813.

Kruse Daniels, N., J. A. LaBar, and L. M. McDonald. 2021. Acid mine drainage in Appalachia: sources, legacy, and treatment. Pages 193-216 Appalachia's Coal-Mined Landscapes. Springer.

Kudela, R. M., A. R. Horner-Devine, N. S. Banas, B. M. Hickey, and T. D. Peterson, et al. 2010. Multiple trophic levels fueled by recirculation in the Columbia River plume. Geophysical Research Letters **37**:L18607.

Kuipers, J. R. 2000. Hardrock reclamation bonding practices in the western United States. Prepared for National Wildlife Federation by Center for Science in Public Participation.

Kuipers, J. R., A. S. Maest, K. A. MacHardy, and G. Lawson. 2006. Comparison of predicted and actual water quality at hardrock mines: the reliability of predictions in environmental impact statements. Kuipers & Associates and Buka Environmental.

Ladd, C., and W. Cheng. 2016. Gap winds and their effects on regional oceanography Part I: Cross Sound, Alaska. Deep Sea Research Part II: Topical Studies in Oceanography **132**:41-53.

Ladd, C., W. Cheng, and S. Salo. 2016. Gap winds and their effects on regional oceanography Part II: Kodiak Island, Alaska. Deep Sea Research Part II: Topical Studies in Oceanography **132**:54-67.

Ladd, C., G. L. Hunt, Jr., C. W. Mordy, S. A. Salo, and P. J. Stabeno. 2005. Marine environment of the eastern and central Aleutian Islands. Fisheries Oceanography **14**:22-38.

Lader, R., A. Bidlack, J. E. Walsh, U. S. Bhatt, and P. A. Bieniek. 2020a. Dynamical downscaling for southeast Alaska: Historical climate and future projections. Journal of Applied Meteorology and Climatology **59**:1607-1623.

Lader, R., J. E. Walsh, U. S. Bhatt, and P. A. Bieniek. 2020b. Anticipated changes to the snow season in Alaska: Elevation dependency, timing and extremes. International Journal of Climatology **40**:169-187.

LaLiberte, D., and R. D. Ewing. 2006. Effect on Puget Sound chinook salmon of NPDES authorized toxic discharges as permitted by Washington Department of Ecology. Liberte Environmental Associates and Biotech Research and Consulting, Inc.

Lalonde, B. A., P. Jackman, K. Doe, C. Garron, and J. Aubé. 2008. Toxicity testing of sediment collected in the vicinity of effluent discharges from seafood processing plants in the maritimes. Archives of Environmental Contamination and Toxicology **56**:389-396.

Landry, J. B., W. J. Kenworthy, and G. D. Carlo. 2008. The effects of docks on seagrasses, with particular emphasis on the threatened seagrass, *Halophila johnsonii*. Prepared for the National Marine Fisheries Service, Protected Resources Division by the Center for Coastal Fisheries and Habitat Research, Beaufort, North Carolina.

Langangen, O., E. Olsen, L. C. Stige, J. Ohlberger, N. A. Yaragina, F. B. Vikebo, B. Bogstad, N. C. Stenseth, and D. O. Hjermann. 2017. The effects of oil spills on marine fish: Implications of spatial variation in natural mortality. Mar Pollut Bull **119**:102-109.

Lanksbury, J. A., J. T. Duffy-Anderson, K. L. Mier, M. S. Busby, and P. J. Stabeno. 2007. Distribution and transport patterns of northern rock sole, *Lepidopsetta polyxystra*, larvae in the southeastern Bering Sea. Progress in Oceanography **72**:39-62.

Lannuzel, D., L. Tedesco, M. Van Leeuwe, K. Campbell, H. Flores, B. Delille, L. Miller, J. Stefels, P. Assmy, and J. Bowman. 2020. The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems. Nature Climate Change **10**:983-992.

Larson, K., and C. Moehl. 1990. Entrainment of anadromous fish by hopper dredge at the mouth of the Columbia River. Pages 102-112 in C.A. Simenstad, editor. Effects of dredging on anadromous Pacific coast fishes. University of Washington Sea Grant.

Laurel, B. J., L. A. Copeman, P. Iseri, M. L. Spencer, and G. Hutchinson, et al. 2019. Embryonic Crude Oil Exposure Impairs Growth and Lipid Allocation in a Keystone Arctic Forage Fish. iScience **19**:1101-1113.

Laurel, B. J., M. E. Hunsicker, L. Ciannelli, T. P. Hurst, J. Duffy-Anderson, R. O'Malley, and M. Behrenfeld. 2021a. Regional warming exacerbates match/mismatch vulnerability for cod larvae in Alaska. Progress in Oceanography **193**:102555.

Laurel, B. J., M. E. Hunsicker, L. Ciannelli, T. P. Hurst, J. Duffy-Anderson, R. O'Malley, and M. Behrenfeld. 2021b. Regional warming exacerbates match/mismatch vulnerability for cod larvae in Alaska. Progress in Oceanography **193**.

Laurel, B. J., and L. A. Rogers. 2020. Loss of spawning habitat and prerecruits of Pacific cod during a Gulf of Alaska heatwave. Canadian Journal of Fisheries and Aquatic Sciences **77**:644-650.

Laurel, B. J., M. Spencer, P. Iseri, and L. A. Copeman. 2016. Temperature-dependent growth and behavior of juvenile Arctic cod (Boreogadus saida) and co-occurring North Pacific gadids. Polar Biol. 39:1127-1135. http://dx.doi.org/10.1007/s00300-015-1761-5.

Laurel, B. J., A. W. Stoner, C. H. Ryer, T. P. Hurst, and A. A. Abookire. 2007. Comparative habitat associations in juvenile Pacific cod and other gadids using seines, baited cameras and laboratory techniques. Journal of Experimental Marine Biology and Ecology **351**:42-55.

Legg, S. 2021. IPCC, 2021: Climate Change 2021-the Physical Science basis. Interaction **49**:44-45.

Lellis-Dibble, K. A., K. E. McGlynn, and T. E. Bigford. 2008. Estuarine fish and shellfish species in U.S. commercial and recreational fisheries: economic value as an incentive to protect and restore estuarine habitat. NOAA Technical Memorandum NMFS-F/SPO-90. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Lennox, R. J., D. A. Crook, P. B. Moyle, D. P. Struthers, and S. J. Cooke. 2019. Toward a better understanding of freshwater fish responses to an increasingly drought-stricken world. Reviews in Fish Biology and Fisheries **29**:71-92.

Leppard, G. G., and I. G. Droppo. 2003. The need and means to characterize sediment structure and behaviour prior to the selection and implementation of remediation plans. Hydrobiologia **494**:313-317.

Levin, L. A., W. Ekau, A. J. Gooday, F. Jorissen, J. J. Middelburg, S. W. A. Naqvi, C. Neira, N. N. Rabalais, and J. Zhang. 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences **6**:2063-2098.

Levings, C. D., and T. G. Northcote. 2004. Effects of forestry on estuarine ecosystems supporting fishes. Pages 320-335 in T.G. Northcote and G.F.Hartman, editors. Fishes and forestry worldwide watershed interactions and management. Blackwell Publishing.

Levit, S. M. 2010. A literature review of effects of cadmium on fish. Prepared for The Nature Conservancy by the Center for Science in Public Participation, Bozeman, Montana.

Levy, C. S., and E. J. Brown. 2017. Long-term colonization of a subarctic pre-planned artificial reef system in Whittier, Alaska.

Lewis, S. L., and M. A. Maslin. 2015. Defining the anthropocene. Nature **519**:171-180.

Li, J., K. Zhou, W. Liu, and Y. Zhang. 2018. Analysis of the effect of freeze–thaw cycles on the degradation of mechanical parameters and slope stability. Bulletin of Engineering Geology and the Environment **77**:573-580.

Limpinsel, D. E., M. P. Eagleton, and J. L. Hanson. 2017. Impacts to essential fish habitat from non-fishing activities in Alaska: EFH 5 year review: 2010 through 2015.

Lin, C. Y., B. S. Anderson, B. M. Phillips, A. C. Peng, and S. Clark, et al. 2009. Characterization of the metabolic actions of crude versus dispersed oil in salmon smolts via NMR-based metabolomics. Aquatic Toxicology **95**:230-238.

Lin, G., M. Li, Y. Chen, J. Zhang, I. M. Jiskani, D. V. Doan, and L. Xu. 2021. Dynamic tensile mechanical properties and fracture characteristics of water-saturated sandstone under the freezing effect. International Journal of Geomechanics **21**:04021044.

Lindstrom, S. C. 2009. The biogeography of seaweeds in Southeast Alaska. Journal of Biogeography **36**:401-409.

Lippiatt, S., S. Opfer, and C. Arthur. 2013. Marine debris monitoring and assessment: recommendations for monitoring debris trends in the marine environment. NOAA Technical Memorandum NOS-OR&R-46. National Oceanic and Atmospheric Administration, Marine Debris Program.

Litz, M. N. C., R. L. Emmett, P. J. Bentley, A. M. Claiborne, and C. Barceló. 2014. Biotic and abiotic factors influencing forage fish and pelagic nekton community in the Columbia River plume (USA) throughout the upwelling season 1999–2009. ICES Journal of Marine Science **71**:5-18.

Litzow, M. A., M. E. Hunsicker, N. A. Bond, B. J. Burke, and C. J. Cunningham, et al. 2020a. The changing physical and ecological meanings of North Pacific Ocean climate indices. Proc Natl Acad Sci U S A **117**:7665-7671.

Litzow, M. A., M. E. Hunsicker, E. J. Ward, S. C. Anderson, and J. Gao, et al. 2020b. Evaluating ecosystem change as Gulf of Alaska temperature exceeds the limits of preindustrial variability. Progress in Oceanography **186**.

Livingston, E. H., J. R. Maxted, R. R. Horner, and C. W. May. 1999. Impervious cover, benthic community health, and stormwater BMPs: is there a relationship? In Proceedings of the Sixth Biennial Stormwater Research and Watershed Management Conference, 14-17 September 1999, Tampa, Florida.

Logan, J. M., A. Boeri, J. Carr, T. Evans, E. M. Feeney, K. Frew, F. Schenck, and K. H. Ford. 2022. A Review of Habitat Impacts from Residential Docks and Recommended Best Management Practices with an Emphasis on the Northeastern United States. Estuaries and Coasts **45**:1189-1216.

Logerwell, E. A., K. Aydin, S. Barbeaux, E. Brown, M. E. Conners, S. Lowe, J. W. Orr, I. Ortiz, R. Reuter, and P. Spencer. 2005. Geographic patterns in the demersal ichthyofauna of the Aleutian Islands. Fisheries Oceanography **14**:93-112.

Logerwell, E. A., M. Busby, K. L. Mier, H. Tabisola, and J. Duffy-Anderson. 2020. The effect of oceanographic variability on the distribution of larval fishes of the northern Bering and Chukchi seas. Deep Sea Research Part II: Topical Studies in Oceanography **177**:104784.

Lohse, K. A., D. A. Newburn, J. J. Opperman, and A. M. Merenlender. 2008. Forecasting relative impacts of land use on anadromous fish habitat to guide conservation planning. Ecological Applications **18**:467-482.

Longmuir, C., and T. Lively. 2001. Bubble curtain systems for use during marine pile driving. Fraser River Pile & Dredge Ltd., New Westminster, British Columbia.

Lopez-Pacheco, I. Y., A. Silva-Nunez, C. Salinas-Salazar, A. Arevalo-Gallegos, L. A. Lizarazo-Holguin, D. Barcelo, H. M. N. Iqbal, and R. Parra-Saldivar. 2019. Anthropogenic contaminants of high concern: Existence in water resources and their adverse effects. Sci Total Environ **690**:1068-1088.

Lottermoser, B. G. 2010a. Introduction to mine wastes. Pages 1-41 Mine wastes. Springer.

Lottermoser, B. G. 2010b. Sulfidic mine wastes. Pages 43-117 Mine wastes. Springer.

Lotze, H., I. Milewski, B. Worm, and Z. Koller. 2003. Nutrient pollution: a eutrophication survey of eelgrass beds in estuaries and coastal bays in northern and eastern New Brunswick. Conservation Council of New Brunswick Inc.

Lowry, K. E., R. S. Pickart, V. Selz, M. M. Mills, and A. Pacini, et al. 2018. Under-ice phytoplankton blooms inhibited by spring convective mixing in refreezing leads. Journal of Geophysical Research: Oceans **123**:90-109.

Lubchenco, J., M. K. McNutt, G. Dreyfus, S. A. Murawski, D. M. Kennedy, P. T. Anastas, S. Chu, and T. Hunter. 2012. Science in support of the *Deepwater Horizon* response. Proceedings of the National Academy of Sciences **109**:20212-20221.

Luchetti, G., and R. Feurstenburg. 1993. Relative fish use in urban and non-urban streams. Proceedings of a conference on wild salmon. Vancouver, British Columbia, Canada.

Lumbroso, D., C. McElroy, C. Goff, M. R. Collell, G. Petkovsek, and M. Wetton. 2019. The potential to reduce the risks posed by tailings dams using satellite-based information. International journal of disaster risk reduction **38**.

Luoma, S. N. 1996. The developing framework of marine ecotoxicology: pollutants as a variable in marine ecosystems? Journal of Experimental Marine Biology and Ecology **200**:29-55.

Lusher, A. 2015. Chapter 10 Microplastics in the marine environment: distribution, interactions and effects. Pages 245-307 in M. Bergmann, L. Gutow, and M. Klages, editors. Marine anthropogenic litter. Springer International Publishing.

Lyu, Z., J. Chai, Z. Xu, Y. Qin, and J. Cao. 2019. A comprehensive review on reasons for tailings dam failures based on case history. Advances in Civil Engineering **2019**.

MacLeod, I., P. Morrison, V. Richards, and N. West. 2004. Corrosion monitoring and the environmental impact of decommissioned naval vessels as artificial reefs. Pages 4-8 *in* Metal 04: Proceedings of the International Conference on Metals Conservation, Canberra.

Macneale, K. H., P. M. Kiffney, and N. L. Scholz. 2010. Pesticides, aquatic food webs, and the conservation of Pacific salmon. Frontiers in Ecology and the Environment **8**:475-482.

Maest, A. S., J. R. Kuipers, C. L. Travers, and D. A. Atkins. 2005. Predicting water quality at hardrock mines: methods and models, uncertainties, and state-of-the-art. Kuipers & Associates and Buka Environmental.

Maitland, B. M., M. Poesch, A. E. Anderson, and S. N. Pandit. 2016. Industrial road crossings drive changes in community structure and instream habitat for freshwater fishes in the boreal forest. Freshwater Biology **61**:1-18.

Malcolm, I. A., C. Soulsby, A. F. Youngson, and D. M. Hannah. 2004a. Spatial and temporal variability of groundwater-surface water interactions in an upland salmon-spawning stream: implications for egg survival. Hydrology: Science & Practice for the 21st Century **2**:130-138.

Malcolm, I. A., C. Soulsby, A. F. Youngson, and D. M. Hannah. 2005. Catchment-scale controls on groundwater–surface water interactions in the hyporheic zone: implications for salmon embryo survival. River Research and Applications **21**:977-989.

Malcolm, I. A., C. Soulsby, A. F. Youngson, D. M. Hannah, I. S. McLaren, and A. Thorne. 2004b. Hydrological influences on hyporheic water quality: implications for salmon egg survival. Hydrological Processes **18**:1543-1560.

Maloney, N. E. 2004. Sablefish, *Anoplopoma fimbria*, populations on Gulf of Alaska seamounts. Marine Fisheries Review **66**:1-12.

Markon, C., S. Gray, M. Berman, L. Eerkes-Medrano, and T. Hennessy, et al. 2018. Alaska. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1185–1241. doi: 10.7930/NCA4.2018.CH26

Markon, C. J., S. F. Trainor, and F. S. Chapin III. 2012. The United States national climate assessment-Alaska technical regional report. 2330-5703, US Geological Survey.

Marris, C., S. N. Kompella, M. Miller, J. P. Incardona, F. Brette, J. C. Hancox, E. Sørhus, and H. A. Shiels. 2020. Polyaromatic hydrocarbons in pollution: a heart-breaking matter. The Journal of physiology **598**:227-247.

Martich, T. 2015. Impacts of fish waste piules in Alaska. Degree of Master of Public Health. University of Alaska Anchorage.

Martins, E. G., S. G. Hinch, S. J. Cooke, and D. A. Patterson. 2012a. Climate effects on growth, phenology, and survival of sockeye salmon (Oncorhynchus nerka): a synthesis of the current state of knowledge and future research directions. Reviews in Fish Biology and Fisheries **22**:887-914.

Martins, E. G., S. G. Hinch, D. A. Patterson, M. J. Hague, S. J. Cooke, K. M. Miller, D. Robichaud, K. K. English, and A. P. Farrell. 2012b. High river temperature reduces survival of sockeye salmon (Oncorhynchus nerka) approaching spawning grounds and exacerbates female mortality. Canadian Journal of Fisheries and Aquatic Sciences **69**:330-342.

Maser, C., and J. R. Sedell. 1994. From the forest to the sea: the ecology of wood in streams, estuaries and oceans. St. Lucie Press, Delray Beach, Florida.

Masó, M., E. Garcés, F. Pagès, and J. Camp. 2003. Drifting plastic debris as a potential vector for dispersing Harmful Algal Bloom (HAB) species. Scientia Marina **67**:107-111.

Masson-Delmotte, V., P. Zhai, A. Pirani, S. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, and M. Gomis. 2021. Intergovernmental Panel on Climate Change. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK.

Masters, J. 2013. The Thawing Arctic: Risks and Opportunities. Council on Foreign Relations report. Retrieved July **15**:2015.

Materna, E. 2001. Temperature interaction. Report prepared as part of EPA Region 10 temperature water quality criteria guidance development project. EPA-910-D-01-004. U.S. Environmental Protection Agency.

Mauger, S., R. Shaftel, J. C. Leppi, and D. J. Rinella. 2017. Summer temperature regimes in southcentral Alaska streams: watershed drivers of variation and potential implications for Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences **74**:702-715.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, and E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound lowland ecoregion. Watershed Protection Techniques **2**:483-494.

McCarthy, S. G., J. P. Incardona, and N. L. Scholz. 2008. Coastal storms, toxic runoff, and the sustainable conservation of fish and fisheries. American Fisheries Society Symposium **64**:7-27.

McCormick, S. D., and R. L. Saunders. 1987. Preparatory physiological adaptations for marine life of salmonids: osmoregulation, growth, and metabolism. American Fisheries Society Symposium **1**:211-229.

McCullough, D., S. Spalding, D. Sturdevant, and M. Hicks. 2001. Summary of technical literature examining the physiological effects of temperature on salmonids. Report prepared as part of EPA Region 10 temperature water quality criteria guidance development project. EPA-910-D-01-005. U.S. Environmental Protection Agency.

McGee, S., R. Piorkowski, and G. Ruiz. 2006. Analysis of recent vessel arrivals and ballast water discharge in Alaska: toward assessing ship-mediated invasion risk. Marine Pollution Bulletin **52**:1634-1645.

McGeoch, M. A., S. H. Butchart, D. Spear, E. Marais, E. J. Kleynhans, A. Symes, J. Chanson, and M. Hoffmann. 2010. Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Diversity and Distributions **16**:95-108.

McGraw, K., and D. Armstrong. 1990. Fish entrainment by dredges in Grays Harbor, Washington. Pages 113-131 in C.A. Simenstad, editor. Effects of dredging on anadromous Pacific coast fishes. University of Washington Sea Grant.

McIntyre, J., J. Davis, C. Hinman, K. Macneale, B. Anulacion, N. Scholz, and J. Stark. 2015. Soil bioretention protects juvenile salmon and their prey from the toxic impacts of urban stormwater runoff. Chemosphere **132**:213-219.

McIntyre, J. K., D. H. Baldwin, D. A. Beauchamp, and N. L. Scholz. 2012. Low-level copper exposures increase visibility and vulnerability of juvenile coho salmon to cutthroat trout predators. Ecological Applications **22**:1460-1471.

McIntyre, J. K., J. I. Lundin, J. R. Cameron, M. I. Chow, J. W. Davis, J. P. Incardona, and N. L. Scholz. 2018. Interspecies variation in the susceptibility of adult Pacific salmon to toxic urban stormwater runoff. Environ Pollut **238**:196-203.

McQueen, A. D., B. C. Suedel, C. de Jong, and F. Thomsen. 2020. Ecological risk assessment of underwater sounds from dredging operations. Integrated environmental assessment and management **16**:481-493.

Meehan, W. R. 1969. Some effects of clearcutting on salmon habitat of two southeast Alaska streams. Institute of Northern Forestry, Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture, Juneau, Alaska.

Mekonnen, Z. A., W. J. Riley, R. F. Grant, and V. E. Romanovsky. 2021. Changes in precipitation and air temperature contribute comparably to permafrost degradation in a warmer climate. Environmental Research Letters **16**:024008.

Melia, N., K. Haines, and E. Hawkins. 2016. Sea ice decline and 21st century trans-Arctic shipping routes. Geophysical Research Letters **43**:9720-9728.

Messan, K. S., R. M. Jones, S. J. Doherty, K. Foley, T. A. Douglas, and R. A. Barbato. 2020. The role of changing temperature in microbial metabolic processes during permafrost thaw. PLoS ONE **15**:e0232169.

Meyer-Gutbrod, E. L., M. S. Love, D. M. Schroeder, J. T. Claisse, L. Kui, and R. J. Miller. 2020. Forecasting the legacy of offshore oil and gas platforms on fish community structure and productivity. Ecological Applications **30**:e02185.

Meyer, J. L., D. L. Strayer, J. B. Wallace, S. L. Eggert, G. S. Helfman, and N. E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association **43**:86-103.

Meyerson, L. A., J. T. Carlton, D. Simberloff, and D. M. Lodge. 2019. The growing peril of biological invasions. Front. Ecol. Environ **17**:191-191.

Michel, J., A. C. Bejarano, C. H. Peterson, and C. Voss. 2013. Review of biological and biophysical impacts from dredging and handling of offshore sand. OCS Study BOEM 2013-0119. U.S. Department of the Interior, Bureau of Ocean Energy Management, Herndon, Virginia.

Miller, M. J., R. Hanel, E. Feunteun, and K. Tsukamoto. 2020. The food source of Sargasso Sea leptocephali. Marine Biology **167**:1-20.

Milner, A. M., K. Khamis, T. J. Battin, J. E. Brittain, N. E. Barrand, L. Füreder, S. Cauvy-Fraunié, G. M. Gíslason, D. Jacobsen, and D. M. Hannah. 2017. Glacier shrinkage driving global changes in downstream systems. Proceedings of the National Academy of Sciences **114**:9770-9778.

Mitchell, N. L., and G. A. Lamberti. 2005. Responses in dissolved nutrients and epilithon abundance to spawning salmon in southeast Alaska streams. Limnology and Oceanography **50**:217-227.

Mitsch, W. J., and J. G. Gosselink. 1993. Wetlands. Van Nostrand Reinhold, New York, New York.

MMS (Minerals Management Service). 1991. Alaska Outer Continental Shelf (OCS) mining program. Norton Sound lease sale. Final environmental impact statement.

MMS (Minerals Management Service). 2007. Programmatic environmental impact statement for alternative energy development and production and alternate use of facilities on the outer continental shelf. Final environmental impact statement. Volume I: executive summary through chapter 4. OCS EIS/EA MMS 2007-046. U.S. Department of the Interior, Minerals Management Service, Herndon, Virginia.

MMS (Minerals Management Service), and NOAA (National Oceanic and Atmospheric Administration). 2007. Seismic surveys in the Beaufort and Chukchi Seas, Alaska. Draft programmatic environmental impact statement. OCS EIS/EA MMS 2007-01. Minerals Management Service (Alaska OCS Region) and National Oceanic and Atmospheric Administration (NMFS).

Moles, A., and N. Hale. 2003. Use of physiological responses in *Mytilus trossulus* as integrative bioindicators of sewage pollution. Marine Pollution Bulletin **46**:954-958.

Moles, A., and B. L. Norcross. 1995. Sediment preference in juvenile pacific flatfishes. Netherlands Journal of Sea Research **34**:177-182.

Montagna, P. A., J. G. Baguley, C. Cooksey, I. Hartwell, and L. J. Hyde, et al. 2013. Deep-sea benthic footprint of the *Deepwater Horizon* blowout. PLoS ONE **8**:e70540.

Montgomery, D. R., and J. M. Buffington. 1998. Channel processes, classifications, and response. Pages 13-42 in R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific coastal ecoregion. Springer, New York.

Montgomery, D. R., J. M. Buffington, R. D. Smith, K. M. Schmidt, and G. Pess. 1995. Pool spacing in forest channels. Water Resources Research **31**:1097-1105.

Moore, J. W. 2006. Animal ecosystem engineers in streams. BioScience **56**:237-246.

Moore, J. W., D. E. Schindler, J. L. Carter, J. Fox, J. Griffiths, and G. W. Holtgrieve. 2007. Biotic control of stream fluxes: spawning salmon drive nutrient and matter export. Ecology **88**:1278-1291.

Moore, R. D., D. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review1. JAWRA Journal of the American Water Resources Association **41**:813-834.

Moore, S. E., and P. J. Stabeno. 2015. Synthesis of Arctic Research (SOAR) in marine ecosystems of the Pacific Arctic. Progress in Oceanography **136**:1-11.

Morris, M. 2015. Harvesting Seaweed in Alaska. Alaska Fish and Wildlife News. December 201.

Mosley, L. M. 2015. Drought impacts on the water quality of freshwater systems; review and integration. Earth-Science Reviews **140**:203-214.

Moss, J. H., D. A. Beauchamp, A. D. Cross, K. W. Myers, E. V. Farley, Jr., J. M. Murphy, and J. H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society **134**:1313-1322.

Moulton, L. L. 1997. Early marine residence, growth, and feeding by juvenile salmon in northern Cook Inlet, Alaska. Alaska Fishery Research Bulletin **4**:154-177.

Mueller, M., K. Sternecker, S. Milz, and J. Geist. 2020. Assessing turbine passage effects on internal fish injury and delayed mortality using X-ray imaging. PeerJ **8**:e9977.

Mueter, F. J., and M. A. Litzow. 2008. Sea ice retreat alters the biogeography of the Bering Sea continental shelf. Ecological Applications **18**:309-320.

Mueter, F. J., B. Planque, G. L. Hunt Jr, I. D. Alabia, T. Hirawake, L. Eisner, P. Dalpadado, M. Chierici, K. F. Drinkwater, and N. Harada. 2021. Possible future scenarios in the gateways to the Arctic for Subarctic and Arctic marine systems: II. prey resources, food webs, fish, and fisheries. ICES Journal of Marine Science **78**:3017-3045.

Mulholland, P. J. 1992. Regulation of nutrient concentrations in a temperate forest stream: roles of upland, riparian, and instream processes. Limnology and Oceanography **37**:1512-1526.

Mulholland, P. J., and J. R. Webster. 2010. Nutrient dynamics in streams and the role of J-NABS. Journal of the North American Benthological Society **29**:100-117.

Munsch, S. H., J. R. Cordell, and J. D. Toft. 2017. Effects of shoreline armouring and overwater structures on coastal and estuarine fish: opportunities for habitat improvement. Journal of Applied ecology **54**:1373-1384.

Munsch, S. H., J. R. Cordell, J. D. Toft, and E. E. Morgan. 2014. Effects of seawalls and piers on fish assemblages and juvenile salmon feeding behavior. North American Journal of Fisheries Management **34**:814-827.

Murphy, G. E., J. C. Dunic, E. M. Adamczyk, S. J. Bittick, I. M. Côté, J. Cristiani, E. A. Geissinger, R. S. Gregory, H. K. Lotze, and M. I. O'Connor. 2021. From coast to coast to coast: ecology and management of seagrass ecosystems across Canada. Facets **6**:139-179.

Murphy, M. L. 1995. Forestry impacts on freshwater habitat of anadromous salmonids in the Pacific Northwest and Alaska--requirements for protection and restoration. NOAA Coastal Ocean Program Decision Analysis Series No. 7. NOAA National Marine Fisheries Service, Alaska Fisheries Science Center, Auke Bay Laboratory.

Murphy, M. L. 1998. Primary production. Pages 144-168 in R.J. Naiman and R.E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer-Verlag, New York.

Murphy, M. L., S. W. Johnson, and D. J. Csepp. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bulletin **7**:11-21.

Murphy, M. L., and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management **9**:427-436.

Murty, A. S. 1986. Toxicity of pesticides to fish. Volume 2. CRC Press, Boca Raton, Florida.

Myers, K. W., N. D. Davis, R. V. Walker, and M. E. Atcheson. 2013. Potential mechanisms of ocean mortality of juvenile salmon and steelhead due to ingestion of plastic marine debris. North Pacific Anadromous Fish Commission Bulletin **9**:169-170.

Naiman, R. J., R. E. Bilby, and P. A. Bisson. 2000. Riparian ecology and management in the Pacific coastal rain forest. BioScience **50**:996-1011.

Naiman, R. J., R. E. Bilby, D. E. Schindler, and J. M. Helfield. 2002. Pacific salmon, nutrients, and the dynamics of freshwater and riparian ecosystems. Ecosystems **5**:399-417.

Nakano, S., and M. Murakami. 2001. Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. Proceedings of the National Academy of Sciences **98**:166-170.

NAS. 2003. Oil in the sea III: inputs, fates, and effects. National Academy Press, Washington, D.C.

Necibi, M., and N. Mzoughi. 2017. The distribution of organic and inorganic pollutants in marine environment. Micropollutants: Sources, Ecotoxicological Effects and Control Strategies:129.

Neff, J. M. 1985. Polycyclic aromatic hydrocarbons. Pages 416-454 in G.M. Rand and S.R. Petrocelli, editors. Fundamentals of aquatic toxicology. Methods and applications. Taylor & Francis, New York, New York.

Neidetcher, S. K., T. P. Hurst, L. Ciannelli, and E. A. Logerwell. 2014. Spawning phenology and geography of Aleutian Islands and eastern Bering Sea Pacific cod (*Gadus macrocephalus*). Deep-Sea Research Part II **109**:204-214.

Neubauer, S. C. 2013. Ecosystem responses of a tidal freshwater marsh experiencing saltwater intrusion and altered hydrology. Estuaries and Coasts **36**:491-507.

Newell, R. C., L. J. Seiderer, and D. R. Hitchcock. 1998. The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. Oceanography and Marine Biology: an Annual Review **36**:127-178.

Nichol, D. R. 1998. Annual and between sex variability of yellowfin sole, *Pleuronectes asper*, spring-summer distributions in the eastern Bering Sea. Fishery Bulletin **96**:547-561.

Nichols, J., K. Schroeder, B. Frenette, J. Williams, A. Crupi, and K. Smikrud. 2013. A user guide for performing stream habitat surveys in southeast Alaska. Special Publication No. 13-04. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Anchorage, Alaska.

Nielsen, J. M., L. A. Rogers, R. D. Brodeur, A. R. Thompson, and T. D. Auth, et al. 2021. Responses of ichthyoplankton assemblages to the recent marine heatwave and previous climate fluctuations in several Northeast Pacific marine ecosystems. Global Change Biology **27**:506-520.

Nightingale, B., and C. A. Simenstad. 2001a. Dredging activities: marine issues. Prepared for Washington State Transportation Commission, U.S. Department of Transporation.

Nightingale, B., and C. A. Simenstad. 2001b. Overwater structures: marine issues. Prepared for Washington State Transportation Commission, U.S. Department of Transporation.

Nishio, S., H. Sasaki, H. Waga, and O. Yamamura. 2020. Effects of the timing of sea ice retreat on demersal fish assemblages in the northern bering and Chukchi Seas. Deep Sea Research Part II: Topical Studies in Oceanography **181**:104910.

Nixon, Z., and J. Michel. 2018. A Review of distribution and quantity of lingering subsurface oil from the Exxon Valdez Oil Spill. Deep Sea Research Part II: Topical Studies in Oceanography **147**:20-26.

NMFS (National Marine Fisheries Service). 2001a. Biological opinion for the San Francisco-Oakland Bay Bridge east span seismic safety project. Administrative record 151422SWR99SR190. Santa Rosa, California.

NMFS (National Marine Fisheries Service). 2001b. Guidelines for salmonid passage at stream crossings. National Marine Fisheries Service, Southwest Region.

NMFS (National Marine Fisheries Service). 2002. Environmental assessment. NOAA Fisheries' implementation plan for the community-based restoration program. Prepared by the NOAA Restoration Center, Office of Habitat Conservation, Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2003a. Endangered Species Act Section 7 Consultation: Biological opinion for the Benicia-Martinez new bridge project. National Marine Fisheries Service, Soutwest Region, Santa Rosa, California.

NMFS (National Marine Fisheries Service). 2003b. Non-fishing impacts to Essential Fish Habitat and recommended conservation measures. Hanson, J. et al. [eds]. National Marine Fisheries Service (NOAA Fisheries), Alaska Region, Northwest Region, and Southwest Region. Version 1 (August).

NMFS (National Marine Fisheries Service). 2004. Alaska groundfish fisheries final programmatic supplemental environmental impact statement. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Alaska Region.

NMFS (National Marine Fisheries Service). 2005a. Final environmental impact statement for essential fish habitat identification and conservation in Alaska. National Marine Fisheries Service. April 2005 (Appendix G). National Marine Fisheries Service, Alaska Region, Juneau, Alaska.

NMFS (National Marine Fisheries Service). 2005b. National gravel extraction guidance. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

NMFS (National Marine Fisheries Service). 2013. Biological characterization: an overview of Bristol, Nushagak, and Kvichak Bays; essential fish habitat, processes, and species assemblages. Prepared by National Marine Fisheries Service, Alaska Region.

NMFS (National Marine Fisheries Service). 2014. California Eelgrass Mitigation Policy and Implementing Guidelines. NOAA Fisheries, West Coast Region.:48 p.

NMFS (National Marine Fisheries Service). 2015. Our living oceans: habitat. Status of the habitat of U.S. living marine resources. NOAA Technical Memorandum NMFS-F/SPO-75. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

NMFS (National Marine Fisheries Service). 2016. Ecosystem-Based Fisheries Management Policy of the National Marine Fisheries Service, National Oceanic and Atmospheric Administration. Available: https://www.fisheries.noaa.gov/resource/document/ecosystem-based-fisheriesmanagement-policy.

NMFS (National Marine Fisheries Service). 2022a. NOAA Fisheries West Coast Region Anadromous Salmonid Passage Design Manual, NMFS, WCR, Portland, Oregon.

NMFS (National Marine Fisheries Service). 2022b. NOAA Fisheries West Coast Region Guidance to Improve the Resilience of Fish Passage Facilities to Climate Change - 2022. NOAA Fisheries West Coast Regional Office, 1201 Northeast Lloyd, Portland, Oregon 97232.

NMFS and PSMFC. 2020. Summary of the Alaska Mariculture Workshop. 21–22 January 2020, Ketchikan, Alaska, National Marine Fisheries Service and Pacific States Marine Fisheries Commission. Prepared by Seatone Consulting, 58 pp.

NOAA (National Oceanic and Atmospheric Administration). 2010. Office of Ocean and Coastal Resource Management. Ocean and Coastal Management in Alaska. Accessed 2010. https://coast.noaa.gov/states/alaska.html.

NOAA (National Oceanic and Atmospheric Administration). 2013. Effects of oil and gas activities in the Arctic Ocean: supplemental draft environmental impact statement. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources, Silver Spring, Maryland.

NOAA (National Oceanic and Atmospheric Administration). 2014. Best Management Practices for Removal of Debris from Wetlands and Other Intertidal Areas. National Ocean Service. NOAA Marine Debris Program, Office of Response and Restoration. National Oceanic and Atmospheric Administration, Silver Spring, M.

NOAA (National Oceanic and Atmospheric Administration). 2016. Habitat: Marine Debris Impacts on Coastal and Benthic Habitats. NOAA Marine Debris Program. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD.

NOAA (National Oceanic and Atmospheric Administration). 2019. Ecosystem Based Fisheries Management. Alaska Region Implementation Plan. 21p.

NOAA (National Oceanic and Atmospheric Administration). 2022a. Alaska Fisheries Science Center. Strategic Science Plan. FY2023-FY2027. 23p.

NOAA (National Oceanic and Atmospheric Administration). 2022b. Alaska Integrated Ecosystem Assessment. Alaska Large Marine Ecosystems. Integrated Ecosystem Assessment. Website https://www.integratedecosystemassessment.noaa.gov/regions/alaska/alaska-large-marine-ecosystems. Last accessed July 21st, 2022.

Norcross, B. L., and B. A. Holladay. 2005. Feasibility to design and implement a nearshore juvenile flatfish survey - eastern Bering Sea. Final technical report. Prepared for

Cooperative Institute for Arctic Research by University of Alaska Fairbanks, Fairbanks, Alaska.
North, E. W., E. E. Adams, A. E. Thessen, Z. Schlag, R. He, S. A. Socolofsky, S. M. Masutani, and S. D. Peckham. 2015. The influence of droplet size and biodegradation on the transport of subsurface oil droplets during the *Deepwater Horizon* spill: a model sensitivity study. Environmental Research Letters **10**:024016.
Notz, D., and J. Stroeve. 2016. Observed Arctic sea-ice loss directly follows anthropogenic CO2 emission. Science **354**:747-750.
Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey open-file report 02-297. Accessed 15 March 2016. http://agdc.usgs.gov/data/usgs/erosafo/ecoreg/.
NPFMC. 2019. Bering Sea Fishery Ecosystem Plan. North Pacific Fisheries Management Council Anchorage.
NPFMC (North Pacific Fishery Management Council). 2007. Aleutian Islands fishery ecosystem plan. North Pacific Fishery Management Council, Anchorage, Alaska.
NPFMC (North Pacific Fishery Management Council). 2009. Fishery management plan for fish resources of the Arctic management area. North Pacific Fishery Management Council, Anchorage, Alaska.
NPFMC (North Pacific Fishery Management Council). 2020. Fishery management plan for groundfish of the Bering Sea and Aleutian Islands management area., North Pacific Fishery Management Council, Anchorage, Alaska.
NPFMC (North Pacific Fishery Management Council). 2021. Fishery management plan for the salmon fisheries in the EEZ off Alaska. North Pacific Fishery Management Council, Anchorage, Alaska.
NRC (National Research Council). 1996. Upstream: salmon and society in the Pacific Northwest. National Academy Press, Washington, D.C.
NRC (National Research Council). 2003. Cumulative environmental effects of oil and gas activities on Alaska's North Slope. Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope. The National Academies Press, Washington, D.C.
NSRIO. 2017. Increase in shipping traffic volume on the Northern Sea Route in 2016. Northern Sea Route Information Office.
O'Keefe, T. C., and R. T. Edwards. 2002. Evidence for hyporheic transfer and removal of marine-derived nutrients in sockeye streams in southeast Alaska. American Fisheries Society Symposium **33**:99-107.
O'Neel, S., C. McNeil, L. C. Sass, C. Florentine, E. H. Baker, E. Peitzsch, D. McGrath, A. G. Fountain, and D. Fagre. 2019. Reanalysis of the US Geological Survey Benchmark Glaciers: long-term insight into climate forcing of glacier mass balance. Journal of Glaciology **65**:850-866.
Olson, K. R., and J. M. Lang. 2020. Sediment Delivery by the Yukon River to the Yukon Flats, Yukon Delta and the Bering Sea. Open Journal of Soil Science **10**:410-442.
Ormseth, O., K. Rand, and A. DeRobertis. 2016. Fishes and invertebrates in Gulf of Alaska bays and islands: results from nearshore ecosystem surveys in 2011 and 2013. Resources Ecology and Fisheries Management Division, Alaska Fisheries Science Center, NOAA Fisheries.

Orth, R. J., T. J. B. Carruthers, W. C. Dennison, C. M. Duarte, and J. W. Fourqurean, et al. 2006. A global crisis for seagrass ecosystems. BioScience **56**:987-996.
Ortiz, I., and S. Zador. 2020. Aleutian Islands.
Ortiz, I., and S. Zador. 2021. Ecosystem Status Report 2021: Aleutian Islands, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.
Osadchiev, A., and A. Yankovsky. 2022. Editorial: River Plumes and Estuaries. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88976-883-7.
OSPAR Commission. 2009. Assessment of impacts of mariculture. Publication number 442/2009. London, United Kingdom.
Overland, J., E. Hanna, I. Hanssen-Bauer, S. Kim, J. Walsh, M. Wang, U. Bhatt, R. Thoman, and T. Ballinger. 2019. Surface air temperature. *Arctic Report Card 2019*, J. Richter-Menege, M.L. Drunkenmiller and M. Jeffries, Eds. http://www.arctic.noaa.goc/Report-Card.
Overland, J. E. 2020. Less climatic resilience in the Arctic. Weather and Climate Extremes **30**.
Overland, J. E., and M. Wang. 2013. When will the summer Arctic be nearly sea ice free? Geophysical Research Letters **40**:2097-2101.
Overland, J. E., and M. Wang. 2019. Impact of the winter polar vortex on greater North America. International Journal of Climatology **39**:5815-5821.
Pacific Northwest Pollution Control Council. 1971. Log storage and rafting in public waters. Task force report.
Palmer, M. A., and K. L. Hondula. 2014. Restoration as mitigation: analysis of stream mitigation for coal mining impacts in Southern Appalachia. Environmental Science & Technology **48**:10552-10560.
Park, H., E. Watanabe, Y. Kim, I. Polyakov, K. Oshima, X. Zhang, J. S. Kimball, and D. Yang. 2020. Increasing riverine heat influx triggers Arctic sea ice decline and oceanic and atmospheric warming. Science advances **6**:eabc4699.
Pasparakis, C., A. J. Esbaugh, W. Burggren, and M. Grosell. 2019. Physiological impacts of Deepwater Horizon oil on fish. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology **224**:108558.
Peplow, D., and R. Edmonds. 2005. The effects of mine waste contamination at multiple levels of biological organization. Ecological Engineering **24**:101-119.
Perkins, R. A. 2009. Creosote treated timber in the Alaskan marine environment. Volume I. FHWA-AK-RD-09-08. Prepared for the Alaska Department of Transportation & Public Facilities by Alaska Department of Transportation, Research, Development, and Technology Transfer.
Perryman, C. R., C. K. McCalley, A. Malhotra, M. F. Fahnestock, N. N. Kashi, J. G. Bryce, R. Giesler, and R. K. Varner. 2020a. Thaw transitions and redox conditions drive methane oxidation in a permafrost peatland. Journal of Geophysical Research: Biogeosciences **125**:e2019JG005526.
Perryman, C. R., J. Wirsing, K. A. Bennett, O. Brennick, A. L. Perry, N. Williamson, and J. G. Ernakovich. 2020b. Heavy metals in the Arctic: Distribution and enrichment of five metals in Alaskan soils. PloS one **15**:e0233297.
Peters, R., A. R. Marshak, M. M. Brady, S. K. Brown, K. Osgood, C. Greene, V. Guida, M. Johnson, T. Kellison, and R. McConnaughey. 2018. Habitat Science is a Fundamental in an Ecosystem-Based Fisheries Management Framework: An Update to the Marine Fisheries Habitat Assessment Improvement Plan. U.S. Dept. of Commerce, NOAA.

NOAA Technical Memorandum NMFS-F/SPO-181, 29 p. https://spo.nmfs.noaa.gov/sites/default/files/TMSPO181_0.pdf.
Peterson, C. H., S. S. Anderson, G. N. Cherr, R. F. Ambrose, and S. Anghera, et al. 2012. A tale of two spills: novel science and policy implications of an emerging new oil spill model. BioScience **62**:461-469.
Peterson, C. H., S. D. Rice, J. W. Short, D. Esler, J. L. Bodkin, B. E. Ballachey, and D. B. Irons. 2003. Long-Term Ecosystem Response to the Exxon Valdez Oil Spill. Science **302**:2082-2086.
Peterson, M. S., and M. R. Lowe. 2009. Implications of cumulative impacts to estuarine and marine habitat quality for fish and invertebrate resources. Reviews in Fisheries Science **17**:505-523.
Petitjean, Q., S. Jean, A. Gandar, J. Côte, P. Laffaille, and L. Jacquin. 2019. Stress responses in fish: From molecular to evolutionary processes. Science of the total Environment **684**:371-380.
Petrick, S., K. Riemann-Campe, S. Hoog, C. Growitsch, H. Schwind, R. Gerdes, and K. Rehdanz. 2017. Climate change, future Arctic Sea ice, and the competitiveness of European Arctic offshore oil and gas production on world markets. Ambio **46**:410-422.
Pezeshki, S. R., R. D. De Laune, and W. H. Patrick. 1987. Response of the freshwater marsh species, *Panicum hemitomon* Schult., to increased salinity. Freshwater Biology **17**:195-200.
PFMC and NMFS (Pacific Fishery Management Council and National Marine Fisheries Service). 2014. Final environmental assessment and regulatory impact review. Pacific coast salmon plan, amendment 18: incorporating revisions to Pacific salmon essential fish habitat. Regulatory identifier number 0648-BC95.
Philibert, D. A., D. Lyons, C. Philibert, and K. B. Tierney. 2019. Field-collected crude oil, weathered oil and dispersants differentially affect the early life stages of freshwater and saltwater fishes. Science of the total Environment **647**:1148-1157.
Phillips, B., and L. O'Neill. 2020. Observational Analysis of Extratropical Cyclone Interactions with Northeast Pacific Sea Surface Temperature Anomalies. Journal of Climate **33**:6745-6763.
Phillips, R. C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: a community profile. FWS/OBS-84/24. U.S. Fish and Wildlife Service.
Piatt, J. F., and A. M. Springer. 2007. Marine ecoregions of Alaska. Pages 522-526 in R. Spies, editor. Long-term ecological change in the northern Gulf of Alaska. Elsevier, Amsterdam.
Piccolo, J. J., and M. S. Wipfli. 2002. Does red alder (*Alnus rubra*) in upland riparian forests elevate macroinvertebrate and detritus export from headwater streams to downstream habitats in southeastern Alaska? Canadian Journal of Fisheries and Aquatic Sciences **59**:503–513.
Piepenburg, D. 2005. Recent research on Arctic benthos: common notions need to be revised. Polar Biology **28**:733-755.
Pitman, K. J., J. W. Moore, M. R. Sloat, A. H. Beaudreau, A. L. Bidlack, R. E. Brenner, E. W. Hood, G. R. Pess, N. J. Mantua, and A. M. Milner. 2020. Glacier retreat and Pacific salmon. BioScience **70**:220-236.

Pledger, A. G., P. Brewin, K. L. Mathers, J. Phillips, P. J. Wood, and D. Yu. 2021. The effects of water injection dredging on low-salinity estuarine ecosystems: Implications for fish and macroinvertebrate communities. Ecological Indicators **122**:107244.

Polasek, L., J. Bering, H. Kim, P. Neitlich, B. Pister, M. Terwilliger, K. Nicolato, C. Turner, and T. Jones. 2017. Marine debris in five national parks in Alaska. Marine Pollution Bulletin **117**:371-379.

Polasek, L. G. 1997. Assessment of wetland habitat alterations resulting from construction of a pipeline through coastal marshes in Orange County, Texas. Final report. Texas Parks and Wildlife Department, Port Arthur, Texas.

Popper, A. N. 2006. What do we know about pile driving and fish? Pages 26-28 *in* Proceedings of the 2005 International Conference on Ecology and Transportation. North Carolina State University, Raleigh, North Carolina.

Popper, A. N., and M. C. Hastings. 2009. The effects of anthropogenic sources of sound on fishes. Journal of Fish Biology **75**:455-489.

Popper, A. N., and A. D. Hawkins. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of fish biology **94**:692-713.

Pörtner, H. O., D. C. Roberts, H. Adams, C. Adler, P. Aldunce, E. Ali, R. A. Begum, R. Betts, R. B. Kerr, and R. Biesbroek. 2022. Climate change 2022: impacts, adaptation and vulnerability.

Poston, T. 2001. Treated wood issues associated with overwater structures in marine and freshwater environments. White paper submitted to the Washington Department of Fish and Wildlife, Washington Department of Ecology and Washington Department of Transportation by Batelle.

Powers, S. P., M. A. Bishop, J. H. Grabowski, and C. H. Peterson. 2002. Intertidal benthic resources of the Copper River Delta, Alaska, USA. Journal of Sea Research **47**:13–23.

Prince, R. C. 2015. Oil spill dispersants: boon or bane? Environmental Science & Technology **49**:6376-6384.

Queiroz, H. M., G. N. Nóbrega, T. O. Ferreira, L. S. Almeida, T. B. Romero, S. T. Santaella, A. F. Bernardino, and X. L. Otero. 2018. The Samarco mine tailing disaster: A possible time-bomb for heavy metals contamination? Science of the total Environment **637**:498-506.

Queiroz, H. M., S. C. Ying, A. F. Bernardino, D. Barcellos, G. N. Nóbrega, X. L. Otero, and T. O. Ferreira. 2021. Role of Fe dynamic in release of metals at Rio Doce estuary: Unfolding of a mining disaster. Marine Pollution Bulletin **166**:112267.

Quigg, A., M. Parsons, S. Bargu, K. Ozhan, K. L. Daly, S. Chakraborty, M. Kamalanathan, D. Erdner, S. Cosgrove, and E. J. Buskey. 2021. Marine phytoplankton responses to oil and dispersant exposures: Knowledge gained since the Deepwater Horizon Oil Spill. Marine Pollution Bulletin **164**:112074.

Quinn, T. P. 2005. The behavior and ecology of Pacific salmon and trout. University of Washington Press, Seattle, Washington.

Quinn, T. P. 2018. The behavior and ecology of Pacific salmon and trout. University of Washington press.

Quinton, W., M. Hayashi, and L. Chasmer. 2011. Permafrost-thaw-induced land-cover change in the Canadian subarctic: implications for water resources. Hydrological Processes **25**:152-158.

Radenbaugh, T. 2010. Personal communication. Assistant Professor Environmental Science. University of Alaska Fairbanks, Bristol Bay Campus, Bristol Bay Environmental Science Lab. Discussion regarding recent surveys and data collection in Nushagak and Kvichak Bays.

Radenbaugh, T., and S. W. Pederson. 2011. Values of Nushagak Bay: past, present, and future. Pages 95-102 *in* A. L. Lovecraft and H. Eicken, editors. North by 2020: perspectives on Alaska's changing social-ecological systems.

Radulovich, R., S. Umanzor, R. Cabrera, and R. Mata. 2015. Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment. Aquaculture **436**:40-46.

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. Stream channel morphology and woody debris in logged and unlogged basins of western Washington. Canadian Journal of Fisheries and Aquatic Sciences **51**:37-51.

Rantanen, M., A. Y. Karpechko, A. Lipponen, K. Nordling, O. Hyvärinen, K. Ruosteenoja, T. Vihma, and A. Laaksonen. 2022. The Arctic has warmed nearly four times faster than the globe since 1979. Communications Earth & Environment **3**:1-10.

Razaz, M., D. Di Iorio, B. Wang, S. Daneshgar Asl, and A. M. Thurnherr. 2020. Variability of a natural hydrocarbon seep and its connection to the ocean surface. Scientific Reports **10**:1-13.

Reddy, C. M., J. S. Arey, J. S. Seewald, S. P. Sylva, and K. L. Lemkau, et al. 2012. Composition and fate of gas and oil released to the water column during the *Deepwater Horizon* oil spill. Proceedings of the National Academy of Sciences **109**:20229-20234.

Reimer, J., A. Droghini, A. Fischbach, J. Watson, B. Bernard, and A. Poe. 2017. Assessing the risk of non-native marine species in the Bering Sea. Anchorage, AK, US: North Pacific Research Board.

Reine, K., and D. Clarke. 1998. Entrainment by hydraulic dredges: a review of potential impacts. Technical note DOER-E1. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Reine, K. J., D. Clarke, and C. Dickerson. 2014a. Characterization of underwater sounds produced by hydraulic and mechanical dredging operations. Journal of the Acoustical Society of America **135**:3280–3294.

Reine, K. J., D. Clarke, C. Dickerson, and G. Wikel. 2014b. Characterization of underwater sounds produced by trailing suction hopper dredges during sand mining and pump-out operations. Final report ERDC/EL TR-14-3. Prepared for U.S. Army Corps of Engineers, Washington, D.C.

Reiser, D. W. 2005. Effects of pulse type flows on benthic macroinvertebrates and fish: a review and synthesis of information. R2 Resources Consultants, Inc.

Ren, J., and A. Packman. 2002. Effects of background water composition on stream-subsurface exchange of submicron colloids. Journal of Environmental Engineering **128**:624-634.

Resongles, E., C. Casiot, R. Freydier, L. Dezileau, J. Viers, and F. Elbaz-Poulichet. 2014. Persisting impact of historical mining activity to metal (Pb, Zn, Cd, Tl, Hg) and metalloid (As, Sb) enrichment in sediments of the Gardon River, Southern France. Science of The Total Environment **481**:509-521.

Reyff, J., and P. Donovan. 2003. Benicia-Martinez Bridge bubble curtain test - underwater sound measurement data. Prepared for Department of Transportation by Illingworth & Rodkin, Inc., Petaluma, California.

Reynaud, S., and P. Deschaux. 2006. The effects of polycyclic aromatic hydrocarbons on the immune system of fish: a review. Aquatic Toxicology **77**:229-238.
Reynolds, J. B. 1997. Ecology of overwintering fishes in Alaskan freshwaters. Pages 281-308 in A.M. Milner and M.W. Oswood, editors. Freshwaters of Alaska – ecological synthesis, ecological studies 119. Springer-Verlag, Inc., New York.
Richardson, J. S., Y. Zhang, and L. B. Marczak. 2010. Resource subsidies across the land–freshwater interface and responses in recipient communities. River Research and Applications **26**:55-66.
Richardson, W. J., C. R. Greene, Jr., C. I. Malme, and D. H. Thomson. 1995. Marine mammals and noise. Academic Press, San Diego, California.
Richter-Menge, J., M. L. Druckenmiller, J. K. Andersen, L. M. Andreassen, and E. H. Baker, et al. 2020. The Arctic. Bulletin of the American Meteorological Society **101**:S239-S286.
Rinella, D. J., M. S. Wipfli, C. M. Walker, C. A. Stricker, and R. A. Heintz. 2013. Seasonal persistence of marine-derived nutrients in south-central Alaskan salmon streams. Ecosphere **4**:122.
Roark, E. B., T. P. Guilderson, S. Flood-Page, R. B. Dunbar, B. L. Ingram, S. J. Fallon, and M. McCulloch. 2005. Radiocarbon-based ages and growth rates of bamboo corals from the Gulf of Alaska. Geophysical Research Letters **32**.
Robinson, W. E., and J. Pederson. 2005. Contamination, habitat degradation, overfishing - an "either-or"debate? Pages 1-10 in R. Buchsbaum, J. Pederson, W.E. Robinson, editors. The decline of fisheries resources in New England: evaluating the impact of overfishing, contamination, and habitat degradation. MIT Sea Grant College Program, Cambridge, Massachusetts.
Roe, G. H., J. E. Christian, and B. Marzeion. 2021. On the attribution of industrial-era glacier mass loss to anthropogenic climate change. The Cryosphere **15**:1889-1905.
Rogers, L. A., M. T. Wilson, J. T. Duffy-Anderson, D. G. Kimmel, and J. F. Lamb. 2020. Pollock and “the Blob”: Impacts of a marine heatwave on walleye pollock early life stages. Fisheries Oceanography.
Romero, I. C., T. Sutton, B. Carr, E. Quintana-Rizzo, S. W. Ross, D. J. Hollander, and J. J. Torres. 2018. Decadal assessment of polycyclic aromatic hydrocarbons in mesopelagic fishes from the Gulf of Mexico reveals exposure to oil-derived sources. Environmental Science & Technology **52**:10985-10996.
Ross, J., D. Hollander, S. Saupe, A. B. Burd, S. Gilbert, and A. Quigg. 2021. Integrating marine oil snow and MOSSFA into oil spill response and damage assessment. Marine Pollution Bulletin **165**:112025.
Roth, E. H., and V. Schmidt. 2010. Noise levels generated by research icebreakers and marine seismic sources in the deep-water, Arctic Ocean. U.S. Geological Survey coastal and marine geology report on Cooperative Agreement G09AC00352. Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California.
Roussel, J.-M., R. A. Cunjak, R. Newbury, D. Caissie, and A. Haro. 2004. Movements and habitat use by PIT-tagged Atlantic salmon parr in early winter: the influence of anchor ice. Freshwater Biology **49**:1026-1035.
Roy Consultants Ltd., NATECH Environmental Services Inc., and OCL Group Environmental Management Consultants. 2003. Lamèque Bay environmental management study. Report no 133-01.

Ruiz, G. M., and J. T. Carlton. 2003. Invasive species: vectors and management strategies. Island Press.
Ruiz, G. M., T. Huber, B. Steves, P. Fofonoff, K. Larson, L. McCann, and A. H. Hines. 2006. Biological invasions in Alaska's coastal marine ecosystems: establishing a baseline.
Safavi, H. R. 1996. Quality control of urban runoff and sound management. Hydrobiologia: Diapause in the Crustacea:131-141.
Saiki, M. K., D. T. Castleberry, T. W. May, B. A. Martin, and F. N. Bullard. 1995. Copper, cadmium, and zinc concentrations in aquatic food chains from the upper Sacramento River (California) and selected tributaries. Archives of Environmental Contamination and Toxicology **29**:484-491.
Sakamoto, T., S. D. McCormick, and T. Hirano. 1993. Osmoregulatory actions of growth hormone and its mode of action in salmonids: a review. Fish Physiology and Biochemistry **11**:155-164.
Sand, O., P. S. Enger, H. E. Karlsen, F. Knudsen, and T. Kvernstuen. 2000. Avoidance responses to infrasound in downstream migrating European silver eels, *Anguilla anguilla*. Environmental Biology of Fishes **57**:327-336.
Sandahl, J. F., D. H. Baldwin, J. J. Jenkins, and N. L. Scholz. 2004. Odor-evoked field potentials as indicators of sublethal neurotoxicity in juvenile coho salmon (*Oncorhynchus kisutch*) exposed to copper, chlorpyrifos, or esfenvalerate. Canadian Journal of Fisheries and Aquatic Sciences **61**:404-413.
Saupe, S. M., J. Gendron, and D. Dasher. 2005. The condition of southcentral Alaska's bays and estuaries. A statistical summary for the National Coastal Assessment Program. Prepared for the Alaska Department of Environment Conservation.
Sauter, S. T., J. McMillan, and J. Dunham. 2001. Salmonid behavior and water temperature. Report prepared as part of EPA Region 10 temperature water quality criteria guidance development project. EPA-910-D-01-001. U.S. Environmental Protection Agency.
Scheuerell, M. D., P. S. Levin, R. W. Zabel, J. G. Williams, and B. L. Sanderson. 2005. A new perspective on the importance of marine-derived nutrients to threatened stocks of Pacific salmon (*Oncorhynchus* spp.). Canadian Journal of Fisheries and Aquatic Sciences **62**:961-964.
Scheuerell, M. D., J. W. Moore, D. E. Schindler, and C. J. Harvey. 2007. Varying effects of anadromous sockeye salmon on the trophic ecology of two species of resident salmonids in southwest Alaska. Freshwater Biology **52**:1944-1956.
Schindler, D. E., R. Hilborn, B. Chasco, C. P. Boatright, T. P. Quinn, L. A. Rogers, and M. S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature **465**:609-612.
Schindler, D. E., M. D. Scheuerell, J. W. Moore, S. M. Gende, T. B. Francis, and W. J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. Frontiers in Ecology and the Environment **1**:31-37.
Schooler, S., Yamada, S., Andreasen, K. 2020. Status of green crabs in Coos Bay: Monitoring Report. South Slough National Estuarine Research Reserve.
Schroeder, P. R. 2009. USACE technical guidelines for predicting the 3Rs of environmental dredging. Proceedings of the Western Dredging Association Twentyninth Technical Conference and 40th Annual Texas A&M Dredging Seminar. Tempe, Arizona.

Schuur, E. A., A. D. McGuire, C. Schädel, G. Grosse, J. Harden, D. J. Hayes, G. Hugelius, C. D. Koven, P. Kuhry, and D. M. Lawrence. 2015. Climate change and the permafrost carbon feedback. Nature **520**:171-179.

Scianni, C., M. Falkner, and L. DeBruyckere. 2017. Biofouling in the US Pacific States and British Columbia. White Paper prepared for the Coastal Committee of the Western Regional Panel on Aquatic Nuisance Species.

Sedell, J. R., and K. J. Luchessa. 1982. Using the historical record as an aid to salmonid habitat enhancement. Pages 210-222 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Sergeant, C. J., J. A. Falke, R. A. Bellmore, J. R. Bellmore, and R. L. Crumley. 2020. A classification of streamflow patterns across the coastal Gulf of Alaska. Water Resources Research **56**:e2019WR026127.

Sergeant, C. J., E. K. Sexton, J. W. Moore, A. R. Westwood, S. A. Nagorski, J. L. Ebersole, D. M. Chambers, S. L. O'Neal, R. L. Malison, and F. R. Hauer. 2022. Risks of mining to salmonid-bearing watersheds. Science advances **8**:eabn0929.

Shaftel, R., S. Mauger, J. Falke, D. Rinella, J. Davis, and L. Jones. 2020. Thermal Diversity of Salmon Streams in the Matanuska-Susitna Basin, Alaska. JAWRA Journal of the American Water Resources Association **56**:630-646.

Shaftel, R. S., R. S. King, and J. A. Back. 2011. Breakdown rates, nutrient concentrations, and macroinvertebrate colonization of bluejoint grass litter in headwater streams of the Kenai Peninsula, Alaska. Journal of the North American Benthological Society **30**:386-398.

Shanley, C. S., S. Pyare, M. I. Goldstein, P. B. Alaback, D. M. Albert, C. M. Beier, T. J. Brinkman, R. T. Edwards, E. Hood, and A. MacKinnon. 2015. Climate change implications in the northern coastal temperate rainforest of North America. Climatic Change **130**:155-170.

Sheaves, M., R. Baker, I. Nagelkerken, and R. M. Connolly. 2015. True value of estuarine and coastal nurseries for fish: incorporating complexity and dynamics. Estuaries and Coasts **38**:401-414.

Short, F. T., R. C. Davis, B. Kopp, C. A. Short, and D. M. Burdick. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern US. Marine Ecology Progress Series **227**:253-267.

Short, J. 2003. Long-term effects of crude oil on developing fish: lessons from the *Exxon Valdez* oil spill. Energy Sources **25**:509-517.

Shugar, D. H., J. J. Clague, J. L. Best, C. Schoof, M. J. Willis, L. Copland, and G. H. Roe. 2017. River piracy and drainage basin reorganization led by climate-driven glacier retreat. Nature Geoscience **10**:370-375.

Siddon, E. 2021. Ecosystem Status Report 2021: Eastern Bering Sea, Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 1007 West Third, Suite 400, Anchorage, Alaska 99501.

Siddon, E. C., S. G. Zador, and G. L. Hunt. 2020. Ecological responses to climate perturbations and minimal sea ice in the northern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography **181-182**.

Sidle, R. C., A. J. Pearce, and C. L. O'Loughlin. 1985. Hillslope stability and land use. American Geophysical Union, Washington D.C.

Sigler, M. F., M. Renner, S. L. Danielson, L. B. Eisner, R. R. Lauth, K. J. Kuletz, E. A. Logerwell, and G. L. Hunt, Jr. 2011. Fluxes, fins, and feathers: relationships among the Bering, Chukchi, and Beaufort Seas in a time of climate change. Oceanography **24**:250–265.

Sigler, M. F., P. J. Stabeno, L. B. Eisner, J. M. Napp, and F. J. Mueter. 2014. Spring and fall phytoplankton blooms in a productive subarctic ecosystem, the eastern Bering Sea, during 1995–2011. Deep Sea Research Part II: Topical Studies in Oceanography **109**:71-83.

Silber, G. K., and J. D. Adams. 2019. Vessel operations in the Arctic, 2015–2017. Frontiers in Marine Science **6**:573.

Slabbekoorn, H., J. Dalen, D. de Haan, H. V. Winter, C. Radford, M. A. Ainslie, K. D. Heaney, T. van Kooten, L. Thomas, and J. Harwood. 2019. Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge. Fish and Fisheries **20**:653-685.

Smith, K. R., and R. A. McConnaughey. 1999. Surficial sediments of the eastern Bering Sea continental shelf: EBSSED database documentation. NOAA Technical Memorandum NMFS AFSC-104. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Sophocleous, M. 2002. Interactions between groundwater and surface water: the state of the science. Hydrogeology Journal **10**:52-67.

Spencer, P. D., A. B. Hollowed, M. F. Sigler, A. J. Hermann, and M. W. Nelson. 2019. Trait-based climate vulnerability assessments in data-rich systems: An application to eastern Bering Sea fish and invertebrate stocks. Global Change Biology **25**:3954-3971.

Spies, I., K. M. Gruenthal, D. P. Drinan, A. B. Hollowed, D. E. Stevenson, C. M. Tarpey, and L. Hauser. 2020. Genetic evidence of a northward range expansion in the eastern Bering Sea stock of Pacific cod. Evolutionary Applications **13**:362-375.

Sponsel, L. E. 2013. Human impact on biodiversity, overview. Encyclopedia of biodiversity:137-152.

Spromberg, J. A., and J. P. Meador. 2005. Relating results of chronic toxicity responses to population-level effects: modeling effects on wild chinook salmon populations. Integrated Environmental Assessment and Management **1**:9-21.

Spurgeon, J., M. Pegg, P. Parasiewicz, and J. Rogers. 2019. River-wide habitat availability for fish habitat guilds: Implications for in-stream flow protection. Water **11**:1132.

Spurkland, T., and K. Iken. 2011. Kelp bed dynamics in estuarine environments in subarctic Alaska. Journal of Coastal Research **27**:133-143.

Stabeno, P., N. Kachel, C. Ladd, and R. Woodgate. 2018. Flow patterns in the eastern Chukchi Sea: 2010–2015. Journal of Geophysical Research: Oceans **123**:1177-1195.

Stabeno, P. J., S. Bell, W. Cheng, S. Danielson, N. B. Kachel, and C. W. Mordy. 2016a. Long-term observations of Alaska Coastal Current in the northern Gulf of Alaska. Deep Sea Research Part II: Topical Studies in Oceanography **132**:24-40.

Stabeno, P. J., N. A. Bond, A. J. Hermann, N. B. Kachel, C. W. Mordy, and J. E. Overland. 2004. Meteorology and oceanography of the northern Gulf of Alaska. Continental Shelf Research **24**:859-897.

Stabeno, P. J., N. A. Bond, N. B. Kachel, C. Ladd, C. W. Mordy, and S. L. Strom. 2016b. Southeast Alaskan shelf from southern tip of Baranof Island to Kayak Island: currents, mixing and chlorophyll-a. Deep Sea Research Part II: Topical Studies in Oceanography **132**:6-23.

Stabeno, P. J., G. L. Hunt, Jr., J. M. Napp, and J. D. Schumacher. 2005. Physical forcing of ecosystem dynamics on the Bering Sea shelf. Chapter 30 in A.R. Robinson and K. Brink, editors. The Sea, volume 14. Harvard University Press, Cambridge, Massachusetts.
Stabeno, P. J., N. B. Kachel, S. E. Moore, J. M. Napp, M. Sigler, A. Yamaguchi, and A. N. Zerbini. 2012. Comparison of warm and cold years on the southeastern Bering Sea shelf and some implications for the ecosystem. Deep-Sea Research II **65-70**:31-45.
Stabeno, P. J., J. D. Schumacher, and K. Ohtani. 1999. Chapter 1: The physical oceanography of the Bering Sea. Pages 1-28 *in* T. R. Loughlin and K. Ohtani, editors. Dynamics of the Bering Sea. University of Alaska Sea Grant, AK-SG-99-03, Fairbanks, Alaska.
Stadler, J. H. 2002. Personal observation of fish-kill occurring during pile driving activity at the Winslow Ferry Terminal, Winslow, Washington on 7 October 2002 by J.H. Stadler, fish biologist, DOC/NOAA/National Marine Fisheries Service/HCD, Lacey, Washington.
Stanford, J. A., and J. V. Ward. 1988. The hyporheic habitat of river ecosystems. Nature **335**:64–66.
Stanford, J. A., and J. V. Ward. 1993. An ecosystem perspective of alluvial rivers: connectivity and the hyporheic corridor. Journal of the North American Benthological Society **12**:48-60.
Steffen, W., J. Grinevald, P. Crutzen, and J. McNeill. 2011. The Anthropocene: conceptual and historical perspectives. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences **369**:842-867.
Stehr, C. M., D. W. Brown, T. Hom, B. F. Anulacion, W. L. Reichert, and T. K. Collier. 2000. Exposure of juvenile chinook and chum salmon to chemical contaminants in the Hylebos Waterway of Commencement Bay, Tacoma, Washington. Journal of Aquatic Ecosystem Stress and Recovery **7**:215-227.
Stein, J., T. Hom, T. Collier, D. Brown, and U. Varanasi. 1995. Contaminant exposure and biochemical effects in outmigrant juvenile chinook salmon from urban estuaries of Puget Sound, WA. Environmental Toxicology and Chemistry **14**:1019-1029.
Stevenson, D. E., and R. R. Lauth. 2012. Latitudinal trends and temporal shifts in the catch composition of bottom trawls conducted on the eastern Bering Sea shelf. Deep Sea Research Part II: Topical Studies in Oceanography **65**:251-259.
Stevenson, D. E., and R. R. Lauth. 2019. Bottom trawl surveys in the northern Bering Sea indicate recent shifts in the distribution of marine species. Polar Biology **42**:407-421.
Stich, D. S., T. F. Sheehan, and J. D. Zydlewski. 2018. A Dam Passage Performance Standard Model for American Shad. Canadian Journal of Fisheries and Aquatic Sciences **76**:762-779.
Stocker, M. 2002. Fish, mollusks and other sea animals' use of sound, and the impact of anthropogenic noise in the marine acoustic environment. Journal of Acoustical Society of America **112**:2431.
Stockwell, D. A., T. E. Whitledge, S. I. Zeeman, K. O. Coyle, J. M. Napp, R. D. Brodeur, A. I. Pinchuk, and G. L. Hunt, Jr. 2001. Anomalous conditions in the south-eastern Bering Sea, 1997: nutrients, phytoplankton and zooplankton. Fisheries Oceanography **10**:99-116.
Stram, D. L., and D. C. Evans. 2009. Fishery management responses to climate change in the North Pacific. ICES Journal of Marine Science **66**:1633-1639.
Stroeve, J., M. M. Holland, W. Meier, T. Scambos, and M. Serreze. 2007. Arctic sea ice decline: faster than forecast. Geophysical Research Letters **34**:L09501.

Stroeve, J., M. Serreze, S. Drobot, S. Gearheard, M. Holland, J. Maslanik, W. Meier, and T. Scambos. 2008. Arctic sea ice extent plummets in 2007. Eos, Transactions American Geophysical Union **89**:13-14.
Sturdevant, M. V., A. C. Wertheimer, and J. L. Lum. 1994. Diet of juvenile pink and chum salmon in oiled and non-oiled nearshore habitats in Prince William Sound, 1989 and 1990. Chapter 4 in A.C. Wertheimer, et al., editors. Impact of the oil spill on juvenile pink and chum salmon and their prey in critical nearshore habitats. *Exxon Valdez* oil spill, state/federal damage assessment final report. Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska.
Sturdevant, M. V., A. C. Wertheimer, and J. L. Lum. 1996. Diets of juvenile pink and chum salmon in oiled and non-oiled nearshore habitats in Prince William Sound, 1989 and 1990. Pages 578-592 in S.D. Rice, et al., editors. American Fisheries Society Symposium 18, Proceedings of the *Exxon Valdez* Oil Spill Symposium.
Suryan, R. M., M. L. Arimitsu, H. A. Coletti, R. R. Hopcroft, and M. R. Lindeberg, et al. 2021. Ecosystem response persists after a prolonged marine heatwave. International Journal of Scientiic Reports **11**:6235.
Swain, N. R., and J. D. Reynolds. 2015. Effects of salmon-derived nutrients and habitat characteristics on population densities of stream-resident sculpins. PloS one **10**:e0116090.
Swanson, D. K., P. J. Sousanes, and K. Hill. 2021. Increased mean annual temperatures in 2014–2019 indicate permafrost thaw in Alaskan national parks. Arctic, Antarctic, and Alpine Research **53**:1-19.
Swarzenski, P. W., H. Dulai, K. D. Kroeger, C. Smith, N. Dimova, C. D. Storlazzi, N. Prouty, S. B. Gingerich, and C. R. Glenn. 2017. Observations of nearshore groundwater discharge: Kahekili Beach Park submarine springs, Maui, Hawaii. Journal of Hydrology: Regional Studies **11**:147-165.
Szymanski, M. B., and M. P. Davies. 2004. Tailings dams design criteria and safety evaluations at closure. British Columbia Mine Reclamation Symposium, University of British Columbia, Norman B. Keevil Institute of Mining Engineering.
Tank, S. E., J. E. Vonk, M. A. Walvoord, J. W. McClelland, I. Laurion, and B. W. Abbott. 2020. Landscape matters: Predicting the biogeochemical effects of permafrost thaw on aquatic networks with a state factor approach. Permafrost and Periglacial Processes **31**:358-370.
Taylor, P. C., B. M. Hegyi, R. C. Boeke, and L. N. Boisvert. 2018. On the increasing importance of air-sea exchanges in a thawing Arctic: A review. Atmosphere **9**:41.
Teachout, E., and W. Lacey. 2012. Evaluating the Effects of Underwater Sound from Pile Driving on the Marbled Murrelet and the Bull Trout. Draft. US Fish and Wildlife Service. Lacey, WA. 35p.
TenBrink, T. T. 2022. Delineating yellowfin sole (*Limanda aspera*) reproduction in the northern Bering Sea provides information across the eastern Bering Sea continental shelf. Fisheries Research **252**:106335.
Tennant, D. L. 1976. Instream flow regimens for fish, wildlife, recreation and related environmental resources. Fisheries **1**:6-10.
Terhaar, J., R. Lauerwald, P. Regnier, N. Gruber, and L. Bopp. 2021. Around one third of current Arctic Ocean primary production sustained by rivers and coastal erosion. Nature communications **12**:1-10.

Thériault, M.-H., S. C. Courtenay, C. Godin, and W. B. Ritchie. 2006. Evaluation of the Community Aquatic Monitoring Program (CAMP) to assess the health of four coastal areas within the southern Gulf of St. Lawrence with special reference to the impacts of effluent from seafood processing plants. Canadian technical report of fisheries and aquatic sciences 2649.

Theuerkauf, S. J., L. T. Barrett, H. K. Alleway, B. A. Costa-Pierce, A. St. Gelais, and R. C. Jones. 2021. Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: Pathways, synthesis and next steps. Reviews in Aquaculture.

Thoman, R. L., J. Richter-Menge, and M. L. Druckenmiller. 2020. NOAA Arctic Report Card 2020 Executive Summary.

Thorne, R., G. Thomas, and M. Bishop. 2006. Alternative seafood waste disposal procedures for Alaskan waters. Pages 1-4 *in* OCEANS 2006. IEEE.

Thurberg, F. P., and E. Gould. 2005. Pollutant effects upon cod, haddock, pollock, and flounder of the inshore fisheries of Massachusetts and Cape Cod Bays. Pages 43-66 *in* R. Buchsbaum, J. Pederson, and W. E. Robinson, editors. The decline of fisheries resources in New England: evaluating the impact of overfishing, contamination, and habitat degradation. MIT Sea Grant College Program, Cambridge, Massachusetts.

Tierney, K. B., D. H. Baldwin, T. J. Hara, P. S. Ross, N. L. Scholz, and C. J. Kennedy. 2010. Olfactory toxicity in fishes. Aquatic Toxicology **96**:2-26.

Timmermans, M. L., and Z. Labe. 2020. NOAA Arctic Report Card: Sea Surface Temperature.

Tiner, R. W., H. C. Bergquist, G. P. DeAlessio, and M. J. Starr. 2002. Geographically isolated wetlands: a preliminary assessment of their characteristics and status in selected areas of the United States. Prepared for the U.S. Department of the Interior, Fish and Wildlife Service, Northeast Region, Hadley, Massachusetts.

Tippery, A. C. 2013. A temporal comparison of the eelgrass (*Zostera marina* L.) food web and community structure at Izembek Lagoon, Alaska from the mid-1970's to 2008. Master's thesis. University of Alaska Fairbanks.

Toft, J. D., J. R. Cordell, C. A. Simenstad, and L. A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management **27**:465-480.

Tourinho, P. S., V. Koci, S. Loureiro, and C. A. M. van Gestel. 2019. Partitioning of chemical contaminants to microplastics: Sorption mechanisms, environmental distribution and effects on toxicity and bioaccumulation. Environmental Pollution **252**:1246-1256.

Travnichek, V. H., A. V. Zale, and W. L. Fisher. 1993. Entrainment of ichthyoplankton by a warmwater hydroelectric facility. Transactions of the American Fisheries Society **122**:709-716.

Trimmel, H., P. Weihs, D. Leidinger, H. Formayer, G. Kalny, and A. Melcher. 2018. Can riparian vegetation shade mitigate the expected rise in stream temperatures due to climate change during heat waves in a human-impacted pre-alpine river? Hydrology and Earth System Sciences **22**:437-461.

Trumbo, B. A., M. L. Ahmann, J. F. Renholds, R. S. Brown, A. H. Colotelo, and Z. Deng. 2014. Improving hydroturbine pressures to enhance salmon passage survival and recovery. Reviews in Fish Biology and Fisheries **24**:955-965.

Tsouvalas, A., and A. Metrikine. 2016. Noise reduction by the application of an air-bubble curtain in offshore pile driving. Journal of Sound and Vibration **371**:150-170.

Turek, J. G., T. E. Goodger, T. E. Bigford, and J. S. Nichols. 1987. Influence of freshwater inflows on estuarine productivity. NOAA Technical Memorandum NMFS-F/NEC-46. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Fisheries Center.

Turner, A., and G. E. Millward. 2002. Suspended particles: their role in estuarine biogeochemical cycles. Estuarine, Coastal and Shelf Science **55**:857-883.

UNEP and CCAC (United Nations Environment Programme and Climate and Clean Air Coalition). 2021. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme. ISBN: 978-92-807-3854-4. Job No: DTI/2352/PA.

Urabe, H., K. Shimoda, and F. Nakamura. 2014. Effect of channel morphology in sustaining population diversity in chum salmon via hyporheic flow. American Fisheries Society Annual Meeting, 17-21 August 2014, Quebec, Canada.

US-CMTS. 2016. A Ten-Year Prioritization of Infrastructure Needs in the U.S. Arctic., Washinton D.C., Report to the President.

USACE (U.S. Army Corps of Engineers). 1993. Engineering and design: environmental; engineering for small boat basins. EM 1110-2-1206. Washington, D.C.

USACE (U.S. Army Corps of Engineers). 2000. National Inventory of Dams.

USACE (U.S. Army Corps of Engineers). 2015. Alaska Deep-Draft Arctic Port System Study February 2015. Draft Integrated Feasibility Report, Draft Environmental Assessment (EA), and Draft Finding of No Significant Impact (FONSI).

USACE (U.S. Army Corps of Engineers). 2016. Preliminary Findings, Port Access Route Study: In the Chukchi Sea, Bering Strait, and Bering Sea.

USCG (United States Coast Guard). 2014. Assessment of essential fish habitat for the Alaska federal/state preparedness plan for response to oil & hazardous substance discharges/releases (Unified plan). Windward Environmental LLC.

USDA (U.S. Department of Agriculture). 2003. Biological assessment for USDA Forest Service fish passage restoration activities affecting ESA-listed animal and plant species found in eastern Oregon and the whole of Washington. Prepared for U.S. Fish and Wildlife Service and NOAA Fisheries by Region 6 U.S. Forest Service.

USDA (U.S. Department of Agriculture). 2008. Stream simulation: an ecological approach to providing passage for aquatic organisms at road-stream crossings. U.S. Department of Agriculture, Forest Service, National Technology and Development Program, San Dimas, California.

USDA (U.S. Department of Agriculture). 2015. Proposed revised land management plan for the Chugach National Forest. U.S. Forest Service, Alaska Region.

USFS (U.S. Forest Service). 2016. Land and Resources management Plan - Tongass National Forest.

USFS (U.S. Forest Service). 2020. Chugach National Forest Land Management Plan.

USFWS (U.S. Fish and Wildlife Service). 2013. Alaska national wetland survey. Accessed February 16, 2016. http://www.fws.gov/alaska/fisheries/nwi/what.htm.

USFWS (U.S. Fish and Wildlife Service). 2022. Culvert Design Guide for Ecological Function.

Valentine, D. L., G. B. Fisher, S. C. Bagby, R. K. Nelson, C. M. Reddy, S. P. Sylva, and M. A. Woo. 2014. Fallout plume of submerged oil from *Deepwater Horizon*. Proceedings of the National Academy of Sciences **111**:15906-15911.

Van Der Veer, H. W., M. J. N. Bergman, and J. J. Beukema. 1985. Dredging activities in the Dutch Wadden Sea: effects on macrobenthic infauna. Netherlands Journal of Sea Research **19**:183-190.

Van Eenennaam, J. S., S. Rahsepar, J. R. Radović, T. B. Oldenburg, J. Wonink, A. A. Langenhoff, A. J. Murk, and E. M. Foekema. 2018. Marine snow increases the adverse effects of oil on benthic invertebrates. Marine Pollution Bulletin **126**:339-348.

Van Elden, S., J. J. Meeuwig, R. J. Hobbs, and J. M. Hemmi. 2019. Offshore oil and gas platforms as novel ecosystems: A global perspective. Frontiers in Marine Science **6**:548.

Van Proosdij, D., T. Milligan, G. Bugden, and K. Butler. 2009. A tale of two macro tidal estuaries: differential morphodynamic response of the intertidal zone to causeway construction. Journal of Coastal Research:772-776.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences **37**:130-137.

Vegter, A. C., M. Barletta, C. Beck, J. Borrero, and H. Burton, et al. 2014. Global research priorities to mitigate plastic pollution impacts on marine wildlife. Endangered Species Research **25**:225-247.

Verity, P. G., M. Alber, and S. B. Bricker. 2006. Development of hypoxia in well-mixed subtropical estuaries in the southeastern USA. Estuaries and Coasts **29**:665-673.

Verspoor, J. J., D. C. Braun, and J. D. Reynolds. 2010. Quantitative links between Pacific salmon and stream periphyton. Ecosystems **13**:1020-1034.

Verspoor, J. J., D. C. Braun, M. M. Stubbs, and J. D. Reynolds. 2011. Persistent ecological effects of a salmon-derived nutrient pulse on stream invertebrate communities. Ecosphere **2**:1-17.

Viehman, H. 2016. Hydroacoustic analysis of the effects of a tidal power turbine on fishes. Electronic Theses and Dissertations. 2546. http://digitalcommons.library.umaine.edu/etd/2546. University of Maine, Orono.

Viehman, H. A., and G. B. Zydlewski. 2017. Multi-scale temporal patterns in fish presence in a high-velocity tidal channel. PloS one **12**:e0176405.

Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. General technical report PNW-GTR-286. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon.

von Biela, V. R., M. L. Arimitsu, J. F. Piatt, B. Heflin, S. K. Schoen, J. L. Trowbridge, and C. M. Clawson. 2019. Extreme reduction in nutritional value of a key forage fish during the Pacific marine heatwave of 2014-2016. Marine Ecology Progress Series **613**:171-182.

von Biela, V. R., L. Bowen, S. D. McCormick, M. P. Carey, and D. S. Donnelly, et al. 2020. Evidence of prevalent heat stress in Yukon River Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences **77**:1878-1892.

Vonk, J. E., S. E. Tank, W. B. Bowden, I. Laurion, W. F. Vincent, P. Alekseychik, M. Amyot, M. Billet, J. Canário, and R. M. Cory. 2015. Reviews and syntheses: Effects of permafrost thaw on Arctic aquatic ecosystems. Biogeosciences **12**:7129-7167.

Wadhams, P. 2019. Arctic sea ice extent and thickness. The Arctic and Environmental Change:101-119.

Waga, H., T. Hirawake, A. Fujiwara, J. M. Grebmeier, and S.-I. Saitoh. 2019. Impact of spatiotemporal variability in phytoplankton size structure on benthic macrofaunal

distribution in the Pacific Arctic. Deep Sea Research Part II: Topical Studies in Oceanography **162**:114-126.
Walker, C., R. King, M. C. Rains, D. Whigham, S. Baird, and J. Bellino. 2009. Headwater stream wetland settings and shallow ground water influence: relationships to juvenile salmon habitat on the Kenai Peninsula, Alaska. Final report. Prepared for the U.S. Environmental Protection Agency, Region 10.
Walker, C. M., R. S. King, D. F. Whigham, and S. J. Baird. 2012. Landscape and wetland influences on headwater stream chemistry in the Kenai Lowlands, Alaska. Wetlands **32**:301-310.
Walker, D. I., R. J. Lukatelich, G. Bastyan, and A. J. McComb. 1989. Effect of boat moorings on seagrass beds near Perth, Western Australia. Aquatic Botany **36**:69-77.
Wallace, J. B., and R. W. Jackson. 1996. The role of macroinvertebrates in stream ecosystem function. Annual Review of Entomology **41**:115-139.
Walls, A., R. Kennedy, R. Fitzgerald, A. J. Blight, M. Johnson, and M. Edwards. 2016. Potential novel habitat created by holdfasts from cultivated Laminaria digitata: assessing the macroinvertebrate assemblages. Aquaculture Environment Interactions **8**:157-169.
Walsh, J. E., T. J. Ballinger, E. S. Euskirchen, E. Hanna, J. Mård, J. E. Overland, H. Tangen, and T. Vihma. 2020. Extreme weather and climate events in northern areas: A review. Earth-Science Reviews:103324.
Walsh, J. E., and W. L. Chapman. 2016. Variability of sea ice extent over decadal and longer timescales." In Climate change: multidecadal and beyond, pp. 203-217.
Walsh, J. E., F. Fetterer, J. Scott Stewart, and W. L. Chapman. 2017. A database for depicting Arctic sea ice variations back to 1850. Geographical Review **107**:89-107.
Walvoord, M. A., and B. L. Kurylyk. 2016. Hydrologic impacts of thawing permafrost—A review. Vadose Zone Journal **15**.
Ware, C., J. Berge, A. Jelmert, S. M. Olsen, L. Pellissier, M. Wisz, D. Kriticos, G. Semenov, S. Kwaśniewski, and I. G. Alsos. 2016. Biological introduction risks from shipping in a warming Arctic. Journal of Applied ecology **53**:340-349.
Warrington, P. D. 1999. Impacts of outboard motors on the aquatic environment.
Watts, A. J. R., C. Lewis, R. M. Goodhead, S. J. Beckett, J. Moger, C. R. Tyler, and T. S. Galloway. 2014. Uptake and retention of microplastics by the shore crab *Carcinus maenas*. Environmental Science & Technology **48**:8823-8830.
Waycott, M., C. M. Duarte, T. J. Carruthers, R. J. Orth, and W. C. Dennison, et al. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences **106**:12377-12381.
WDF and WDOE (Washington Department of Fisheries and Washington Department of Ecology). 1992. Supplemental environmental impact statement: use of the insecticide carbaryl to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor. Washington Department of Fisheries and Washington Department of Ecology, Olympia, Washington.
Weingartner, T. 2005. Physical and geological oceanography: coastal boundaries and coastal and ocean circulation. Pages 35-48 *in* P. R. Mundy, editor. The Gulf of Alaska: biology and oceanography. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska.
Weingartner, T. 2008. Physical oceanography. Pages 6-17 in Hopcroft, R., B. Blum, and R. Gradinger, editors. 2008. Arctic Ocean synthesis: analysis of climate change impacts in

the Chukchi and Beaufort Seas with strategies for future research. Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska.
Weingartner, T. J., D. J. Cavalieri, K. Aagaard, and Y. Sasaki. 1998. Circulation, dense water formation, and outflow on the northeast Chukchi Shelf. Journal of Geophysical Research **103**:7647-7661.
Weiss, P. T., G. LeFevre, and J. S. Gulliver. 2008. Contamination of soil and groundwater due to stormwater infiltration practices: a literature review. Project report no.515. Prepared for the Minnesota Pollution Control Agency by University of Minnesota, Minneapolis, Minnesota.
Welsch, D. J., D. L. Smart, J. N. Boyer, P. Minkin, H. C. Smith, and T. L. McCandless. 1995. Forested wetlands: functions, benefits and the use of best management practices. NA-PR-01-95. United States Department of Agriculture, Forest Service, Natural Resources Conservation Service, United States Army Corps of Engineers, United States Environmental Protection Agency, and United States Department of the Interior Fish and Wildlife Service.
Wenger, A. S., E. Harvey, S. Wilson, C. Rawson, and S. J. Newman, et al. 2017. A critical analysis of the direct effects of dredging on fish. Fish and Fisheries **18**:967-985.
Wenger, A. S., C. A. Rawson, S. Wilson, S. J. Newman, M. J. Travers, S. Atkinson, N. Browne, D. Clarke, M. Depczynski, and P. L. Erftemeijer. 2018. Management strategies to minimize the dredging impacts of coastal development on fish and fisheries. Conservation Letters **11**:e12572.
Werner, I., J. Ikävalko, and H. Schünemann. 2007. Sea-ice algae in Arctic pack ice during late winter. Polar Biology **30**:1493-1504.
West, C. M., L. T. Galloway, and J. S. Lyon. 1995. Mines, stormwater pollution, and you: a citizen's handbook to stopping water pollution from mines. Mineral Policy Center, Washington, D.C.
West, J. E., A. J. Carey, G. M. Ylitalo, J. P. Incardona, R. C. Edmunds, C. A. Sloan, L. A. Niewolny, J. A. Lanksbury, and S. M. O'Neill. 2019. Polycyclic aromatic hydrocarbons in Pacific herring (*Clupea pallasii*) embryos exposed to creosote-treated pilings during a piling-removal project in a nearshore marine habitat of Puget Sound. Marine Pollution Bulletin **142**:253-262.
Westley, P. A. H. 2020. Documentation of en route mortality of summer chum salmon in the Koyukuk River, Alaska and its potential linkage to the heatwave of 2019. Ecol Evol **10**:10296-10304.
Whigham, D. F., C. Walker, J. Maurer, R. King, W. Hauser, S. Baird, J. Keuskamp, and P. J. Neale. 2017. Watershed influences on the structure and function of riparian wetlands associated with headwater streams–Kenai Peninsula, Alaska. Science of The Total Environment **599**:124-134.
Whigham, D. F., C. M. Walker, R. S. King, and S. J. Baird. 2012. Multiple scales of influence on wetland vegetation associated with headwater streams in Alaska, USA. Wetlands **32**:411-422.
Wiese, F. K., R. Merrick, G. Auad, D. Williams, P. Stabeno, and B. Kelly. 2013. Strawman conceptual ecosystem model for the Chukchi and Beaufort Seas. Whitepaper presented at the Interagency Arctic Research Policy Committee Workshop: Developing a Conceptual Model of the Arctic Marine Ecosystem. 30 April – 2 May 2013, Washington, D.C.

Wilbur, A. R., and M. W. Pentony. 1999. Human-induced nonfishing threats to essential fish habitat in the New England region. American Fisheries Society Symposium, 22: 299-321.:299-321.
Wilderbuer, T. K., A. B. Hollowed, W. J. Ingraham, Jr., P. D. Spencer, M. E. Conners, N. A. Bond, and G. E. Walters. 2002. Flatfish recruitment response to decadal climatic variability and ocean conditions in the eastern Bering Sea. Progress in Oceanography **55**:235–247.
Williamson, K. J., D. A. Bella, R. L. Beschta, G. Grant, P. C. Klingeman, H. W. Li, and P. Nelson. 1995. Gravel disturbance impacts on salmon habitat and stream health. Volume 1: summary report. Prepared for the Oregon Division of State Lands by the Oregon Water Resources Research Institute, Oregon State University.
Wilson, B., R. S. Batty, F. Daunt, and C. Carter. 2007. Collision risks between marine renewable energy devices and mammals, fish and diving birds. Strategic environmental assessment of marine renewable energy development in Scotland. Report prepared for the Scottish Executive by the Scottish Association for Marine Science, Oban, Scotland.
Wilson, M. T., and N. Laman. 2020. Interannual variation in the coastal distribution of a juvenile gadid in the northeast Pacific Ocean: The relevance of wind and effect on recruitment. Fisheries Oceanography.
Winfree, M. M., E. Hood, S. L. Stuefer, D. E. Schindler, T. J. Cline, C. D. Arp, and S. Pyare. 2018. Landcover and geomorphology influence streamwater temperature sensitivity in salmon bearing watersheds in Southeast Alaska. Environmental Research Letters **13**:064034.
Wipfli, M. S., and D. P. Gregovich. 2002. Export of invertebrates and detritus from fishless headwater streams in southeastern Alaska: implications for downstream salmonid production. Freshwater Biology **47**:957-969.
Wipfli, M. S., J. S. Richardson, and R. J. Naiman. 2007. Ecological linkages between headwaters and downstream ecosystems: transport of organic matter, invertebrates, and wood down headwater channels. Journal of the American Water Resources Association **43**:72-85.
WISE Uranium Project. 2016. Chronology of major tailings dam failures. Accessed 13 May 2016. http://www.wise-uranium.org/mdaf.html.
Woody, C. A., and S. L. O'Neal. 2010. Fish surveys in headwater streams of the Nushagak and Kvichak River drainages, Bristol Bay, Alaska, 2008-2010. Prepared for The Nature Conservancy by Fisheries Research and Consulting, Anchorage, Alaska.
Wright, S. L., R. C. Thompson, and T. S. Galloway. 2013. The physical impacts of microplastics on marine organisms: a review. Environmental Pollution **178**:483-492.
Wu, Y., R. Falconer, and B. Lin. 2005. Modelling trace metal concentration distributions in estuarine waters. Estuarine, Coastal and Shelf Science **64**:699-709.
Würsig, B., C. R. Greene, Jr. , and T. A. Jefferson. 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research **49**:79-93.
WWF (World Wildlife Fund), and TNC (The Nature Conservancy). 1999. Ecoregion-based conservation in the Bering Sea: identifying important areas for biodiversity conservation. D. Banks, M. Williams, J. Pearce, A. Springer, R. Hagenstein, and D. Olson, editors. World Wildlfie Fund and The Nature Conservancy of Alaska.
Yasumiishi, E. M., K. Cieciel, A. G. Andrews, J. Murphy, and J. A. Dimond. 2020. Climate-related changes in the biomass and distribution of small pelagic fishes in the eastern

Bering Sea during late summer, 2002–2018. Deep Sea Research Part II: Topical Studies in Oceanography **181**:104907.

Yelverton, J. T., D. R. Richmond, W. Hicks, K. Saunders, and R. Fletcher. 1975. The relationship between fish size and their response to underwater blast. Prepared for the Defense Nuclear Agency by the Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico.

Younger, P. L. 2000. The adoption and adaptation of passive treatment technologies for mine waters in the United Kingdom. Mine Water and the Environment **19**:84-97.

Younger, P. L., S. A. Banwart, and R. S. Hedin. 2002. Mine water: hydrology, pollution, remediation. Springer Pub, New York, New York.

Youngson, A. F., I. A. Malcolm, J. L. Thorley, P. J. Bacon, and C. Soulsby. 2004. Long-residence groundwater effects on incubating salmonid eggs: low hyporheic oxygen impairs embryo development. Canadian Journal of Fisheries and Aquatic Sciences **61**:2278-2287.

Yu, L., S. Zhong, T. Vihma, C. Sui, Y. Qiu, and X. Liang. 2020. North Pacific Gyre Oscillation Closely Associated With Spring Arctic Sea Ice Loss During 1998–2016. Journal of Geophysical Research: Atmospheres **125**.

Zador, S., ed. 2015. Ecosystem considerations 2015: status of Alaska's ecosystems. North Pacific Fishery Management Council, Anchorage, Alaska.

Zhao, X., W. Liu, J. Fu, Z. Cai, S. O'Reilly, and D. Zhao. 2016. Dispersion, sorption and photodegradation of petroleum hydrocarbons in dispersant-seawater-sediment systems. Marine Pollution Bulletin **109**:526-538.

Zheng, L., I. Overeem, K. Wang, and G. D. Clow. 2019. Changing arctic river dynamics cause localized permafrost thaw. Journal of Geophysical Research: Earth Surface **124**:2324-2344.

Ziemer, R. R., and T. E. Lisle. 1998. Hydrology. Pages 43-68 *in* R. J. Naiman and R. E. Bilby, editors. River ecology and management: lessons from the Pacific Coastal ecoregion. Springer, New York.

Zimmermann, M., and M. M. Prescott. 2018. Bathymetry and canyons of the eastern Bering Sea slope. Geosciences **8**:184.

Zydlewski, J., G. Zydlewski, and G. R. Danner. 2010. Descaling injury impairs the osmoregulatory ability of Atlantic salmon smolts entering seawater. Transactions of the American Fisheries Society **139**:129-136.

Appendix A

Anthropogenic Impacts

In 2008, the NMFS Greater Atlantic Regional Office publish *Impacts to Marine Fisheries Habitat from Nonfishing Activities in the Northeastern United States* (Johnson et al. 2008). This report was based the findings of a 2005 technical workshop entitled "Workshop on Impacts to Coastal Fishery Habitat from Nonfishing Activities." The workshop was held to provide information to the New England Fishery Management Council and the Mid-Atlantic Fishery Management Council to assist them in updating the nonfishing impacts to essential fish habitat (EFH) analyses within their Fishery Management Plans as required by the EFH regulations. The resulting comprehensive report provided beneficial information to a broad audience of agencies, consultants, and the public involved in marine and aquatic habitat assessment activities. Included in that report is a series of tables developed during the workshop identifying potential impacts to riverine, estuarine, and offshore habitats. The workshop participants ranked each impact from lowest to highest (1 through 5). Those tables included here, without ranking, as a reference for considering the potential impacts on EFH.

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
Introduced/Nuisance Species	Habitat alterations						
	Trophic alterations						
	Gene pool alterations						
	Alterations of communities						
	Introduced diseases						
	Changes in species diversity						
	Alteration in health of native species						
	Impacts to water quality						
Aquaculture	Discharge of organic waste						
	Seafloor impacts						
	Introduction of exotic invasive species						
	Food web impacts						
	Gene pool alterations						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Impacts to water column						
	Impacts to water quality						
	Changes in species diversity						
	Sediment deposition						
	Introduction of diseases						
	Habitat replacement/exclusion						
	Habitat conversion						
Wetland Dredging and Filling	Alteration/loss of habitat						
	Loss of submerged aquatic vegetation						
	Altered hydrological regimes						
	Reduction of dissolved oxygen						
	Release of nutrients/eutrophication						
	Release of contaminants						
	Altered tidal prism						
	Altered current patterns						
	Altered temperature regimes						
	Loss of wetlands						
	Loss of fishery productivity						
	Introduction of invasive species						
	Loss of flood storage capacity						
	Increased sedimentation/turbidity						
Overwater Structures	Shading impacts to vegetation						
	Altered hydrological regimes						
	Contaminant releases						
	Benthic habitat impacts						
	Increased erosion/accretion						
	Eutrophication from bird roosting						
	Shellfish closures because of bird roosting						
	Changes in predator/prey interactions						
Pile Driving	Energy impacts						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
and Removal	Benthic habitat impacts						
	Increased sedimentation/turbidity						
	Contaminant releases						
	Shading impacts to vegetation						
	Changes in hydrological regimes						
	Changes in species composition						
Marine Debris	Entanglement						
	Ingestion						
	Contaminant releases						
	Introduction of invasive species						
	Introduction of pathogens						
	Conversion of habitat						
Nonpoint Source Pollution and Urban Runoff	Nutrient loading/eutrophication						
	Loss/alteration of aquatic vegetation						
	Release of petroleum products						
	Alteration of water alkalinity						
	Release of metals						
	Release of radioactive wastes						
	Release of pesticides						
	Release of pharmaceuticals						
	Alteration of temperature regimes						
	Sedimentation/turbidity						
	Altered hydrological regimes						
	Introduction of pathogens						
Road Construction and Operation	Release of sediments in aquatic habitat						
	Increased sedimentation/turbidity						
	Impaired fish passage						
	Altered hydrological regimes						
	Altered temperature regimes						
	Altered stream morphology						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Altered stream bed characteristics						
	Reduced dissolved oxygen						
	Introduction of exotic invasive species						
	Loss/alteration of aquatic vegetation						
	Altered tidal regimes						
	Contaminant releases						
	Fragmentation of habitat						
	Altered salinity regimes						
Flood Control and Shoreline Protection	Altered hydrological regimes						
	Altered temperature regimes						
	Altered stream morphology						
	Altered sediment transport						
	Alteration/loss of benthic habitat						
	Reduction of dissolved oxygen						
	Impaired fish passage						
	Alteration of natural communities						
	Impacts to riparian habitat						
	Loss of intertidal habitat						
	Reduced ability to counter sea level rise						
Beach Nourishment	Altered hydrological regimes						
	Altered temperature regimes						
	Altered sediment transport						
	Alteration/loss of benthic habitat						
	Alteration of natural communities						
	Increased sedimentation/turbidity						
Petroleum Exploration, Production, and Transportation	Underwater noise						
	Habitat conversion						
	Loss of benthic habitat						
	Contaminant discharge						
	Discharge of debris						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Oil spills						
	Siltation/sedimentation/turbidity						
	Resuspension of contaminants						
	Impacts from clean-up activities						
Liquefied Natural Gas	Habitat conversion						
	Loss of benthic habitat						
	Discharge of contaminants						
	Discharge of debris						
	Siltation/sedimentation/turbidity						
	Resuspension of contaminants						
	Entrainment/impingement						
	Alteration of temperature regimes						
	Alteration of hydrological regimes						
	Underwater noise						
	Release of contaminants						
	Exclusion zone impacts						
	Physical barriers to habitat						
	Introduction of invasive species						
	Vessel impacts						
	Benthic impacts from pipelines						
Offshore Wind Energy Facilities	Loss of benthic habitat						
	Habitat conversion						
	Siltation/sedimentation/turbidity						
	Resuspension of contaminants						
	Alteration of hydrological regimes						
	Altered current patterns						
	Alteration of electromagnetic fields						
	Underwater noise						
	Alteration of community structure						
	Erosion around structure						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Spills associated w/ service structure						
Wave/Tidal Energy Facilities	Habitat conversion						
	Loss of benthic habitat						
	Siltation/sedimentation/turbidity						
	Resuspension of contaminants						
	Alteration of hydrological regimes						
	Altered current patterns						
	Entrainment/impingement						
	Impacts to migration						
	Electromagnetic fields						
Cables and Pipelines	Loss of benthic habitat						
	Habitat conversion						
	Siltation/sedimentation/turbidity						
	Resuspension of contaminants						
	Altered current patterns						
	Alteration of electromagnetic fields						
	Underwater noise						
	Alteration of community structure						
	Erosion around structure						
	Biocides from hydrostatic testing						
	Spills associated w/ service structure						
	Physical barriers to habitat						
	Impacts to submerged aquatic vegetation						
	Water withdrawal						
	Impacts from construction activities						
	Impact from maintenance activities						
	Thermal impacts associated with cables						
	Impacts associated with armoring of pipe						
	Impacts to migration						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
Dam Construction and Operation	Impaired fish passage						
	Altered hydrological regimes						
	Altered temperature regimes						
	Altered sediment/large woody debris transport						
	Altered stream morphology						
	Altered stream bed characteristics						
	Reduced dissolved oxygen						
	Alteration of extent of tide						
	Alteration of wetlands						
	Change in species communities						
	Bank erosion because of drawdown						
	Riparian zone development						
	Acute temperature shock						
Dam Removal	Release of contaminated sediments						
	Alteration of wetlands						
Stream Crossings	Impacts to fish passage						
	Alteration of hydrological regimes						
	Bank erosion						
	Habitat conversion						
Water Withdrawal and Diversion	Entrainment and impingement						
	Impaired fish passage						
	Altered hydrological regimes						
	Reduced dissolved oxygen						
	Altered temperature regimes						
	Release of nutrients/eutrophication						
	Release of contaminants						
	Altered stream morphology						
	Altered stream bed characteristics						
	Siltation/sedimentation/turbidity						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Change in species communities						
	Alteration in groundwater levels						
	Loss of forested/palustrine wetlands						
	Impacts to water quality						
	Loss of flood storage						
Dredging and Filling, Mining	Reduced flood water retention						
	Reduced nutrient uptake and release						
	Reduced detrital food source						
	Altered hydrological regimes						
	Increased storm water runoff						
	Loss of riparian and riverine habitat						
	Altered stream morphology						
	Altered stream bed characteristics						
	Siltation/sedimentation/turbidity						
	Reduced dissolved oxygen						
	Altered temperature regimes						
	Release of nutrients/eutrophication						
	Release of contaminants						
	Loss of submerged aquatic vegetation						
	Change in species communities						
Construction and Expansion of Ports and Marinas	Loss of benthic habitat						
	Siltation/sedimentation/turbidity						
	Contaminant releases						
	Altered hydrological regimes						
	Altered tidal prism						
	Altered current patterns						
	Altered temperature regimes						
	Loss of wetlands						
	Underwater blasting/noise						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Loss of submerged aquatic vegetation						
	Conversion of substrate/habitat						
	Loss of intertidal flats						
	Loss of water column						
	Altered light regime						
	Derelict structures						
Operations and Maintenance of Ports and Marinas	Contaminant releases						
	Storm water runoff						
	Underwater noise						
	Alteration of light regimes						
	Derelict structures						
	Mooring impacts						
	Release of debris						
Operation and Maintenance of Vessels	Impacts to benthic habitat						
	Resuspension of bottom sediments						
	Erosion of shorelines						
	Contaminant spills and discharges						
	Underwater noise						
	Derelict structures						
	Increased air emissions						
	Release of debris						
Navigation Dredging	Conversion of substrate/habitat						
	Loss of submerged aquatic vegetation						
	Siltation/sedimentation/turbidity						
	Contaminant releases						
	Release of nutrients/eutrophication						
	Entrainment and impingement						
	Underwater blasting/noise						
	Altered hydrological regimes						
	Altered tidal prism						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Altered current patterns						
	Altered temperature regimes						
	Loss of intertidal flats						
	Loss of wetlands						
	Contaminant source exposure						
Offshore Mineral Mining	Loss of benthic habitat types						
	Conversion of substrate/habitat						
	Siltation/sedimentation/turbidity						
	Changes in bottom topography						
	Changes in sediment composition						
	Sediment transport from site (erosion)						
	Impacts to water quality						
	Release of contaminants						
	Change in community structure						
	Changes in water flow						
	Noise impacts						
Petroleum Extraction	Contaminant releases						
	Drilling mud impacts						
	Siltation/sedimentation/turbidity						
	Release of debris						
	Noise impacts						
	Changes in light regimes						
	Habitat conversion						
	Pipeline installation						
Offshore Dredge Material Disposal	Burial/disturbance of benthic habitat						
	Conversion of substrate/habitat						
	Siltation/sedimentation/turbidity						
	Release of contaminants						
	Release of nutrients/eutrophication						
	Altered hydrological regimes						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Altered current patterns						
	Changes in bottom topography						
	Changes in sediment composition						
	Changes in water bathymetry						
Fish Waste Disposal	Introduction of pathogens						
	Release of nutrients/eutrophication						
	Release of biosolids						
	Loss of benthic habitat types						
	Behavioral affects						
Vessel Disposal	Release of contaminants						
	Conversion of substrate/habitat						
	Changes in bathymetry						
	Changes in hydrodynamics						
	Changes in community structure						
	Impacts during deployment						
	Release of debris						
Sewage Discharge Facilities	Release of nutrients/eutrophication						
	Release of contaminants						
	Impacts to submerged aquatic vegetation						
	Reduced dissolved oxygen						
	Siltation/sedimentation/turbidity						
	Impacts to benthic habitat						
	Changes in species composition						
	Trophic level alterations						
	Introduction of pathogens						
	Introduction of harmful algal blooms						
	Bioaccumulation/biomagnification						
	Behavioral avoidance						
	Release of pharmaceuticals						
Industrial	Alteration of water alkalinity						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
Discharge Facilities	Release of metals						
	Release of chlorine compounds						
	Release of pesticides						
	Release of organic compounds						
	Release of petroleum products						
	Release of inorganic compounds						
	Release of organic wastes						
	Introduction of pathogens						
Combined Sewer Overflows	Potential for all of the above effects						
Discharge Facilities	Scouring of substrate						
	Turbidity/sedimentation						
	Alteration of sediment composition						
	Reduced dissolved oxygen						
	Alteration of salinity regimes						
	Alteration of temperature regimes						
	Conversion/loss of habitat						
	Habitat exclusion/avoidance						
	Restrictions to migration						
	Acute toxicity						
	Behavioral changes						
	Cold shock						
	Stunting of growth in fishes						
	Attraction to flow						
	Alteration of community structure						
	Changes in local current patterns						
	Physical/chemical synergies						
	Increased need for dredging						
	Ballast water discharge						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Gas-bubble disease/mortality						
	Release of radioactive wastes						
Intake Facilities	Entrainment/impingement						
	Alteration of hydrological regimes						
	Flow restrictions						
	Construction related impacts						
	Conversion/loss of habitat						
	Seasonal loss of habitat						
	Backwash (cleaning of system)						
	Alteration of community structure						
	Increased need for dredging						
	Ballast water intake						
Cropland, Rangelands, Livestock, and Nursery Operations	Release of nutrients/eutrophication						
	Bank/soil erosion						
	Altered temperature regimes						
	Siltation/sedimentation/turbidity						
	Altered hydrological regimes						
	Entrainment and impingement						
	Impaired fish passage						
	Reduced soil infiltration						
	Release of pesticides						
	Reduced dissolved oxygen						
	Soil compaction						
	Loss/alteration of wetlands						
	Land-use change (post agriculture)						
	Introduction of invasive species						
	Introduction of pathogens						
	Endocrine disruptors						
	Change of community structure						
	Change in species composition						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
Silviculture and Timber Harvest Activities	Reduced soil infiltration						
	Siltation/sedimentation/turbidity						
	Altered hydrological regimes						
	Impaired fish passage						
	Bank/soil erosion						
	Altered temperature regimes						
	Release of pesticides						
	Release of nutrients/eutrophication						
	Reduced dissolved oxygen						
	Loss/alteration of wetlands						
	Soil compaction						
Timber and Paper Mill Processing Activities	Chemical contaminant releases						
	Entrainment and impingement						
	Thermal discharge						
	Reduced dissolved oxygen						
	Conversion of benthic substrate						
	Loss/alteration of wetlands						
	Alteration of light regimes						
Climate Change	Alteration of hydrological regimes						
	Alteration of temperature regimes						
	Changes in dissolved oxygen						
	Nutrient loading/eutrophication						
	Release of contaminants						
	Bank/soil erosion						
	Alteration in salinity						
	Alteration of weather patterns						
	Alteration of alkalinity						
	Changes in community structure						
	Changes in ocean/coastal use						
	Changes in ecosystem structure						

Activity Type	Potential Effects	Habitat Impact Categories					
		Life History/Ecosystem Type					
		Benthic/Demersal Stages			Pelagic Stages		
		Riverine	Estuarine/ Nearshore	Marine/ Offshore	Riverine	Estuarine/ Nearshore	Marine/ Offshore
	Loss of wetlands						
Ocean Noise	Mechanical injury to organisms						
	Impacts to feeding behavior						
	Impacts to spawning behavior						
	Impacts to migration						
	Exclusion of organisms to habitat						
	Changes in community structure						
Atmospheric Deposition	Nutrient loading/eutrophication						
	Mercury loading/bioaccumulation						
	Polychlorinated biphenyls and other contaminants						
	Alteration of ocean alkalinity						
	Alteration of climatic cycle						
Military/ Security Activities	Exclusion of organisms to habitat						
	Noise impacts						
	Chemical releases						
	Impacts to tidal/intertidal habitats						
	Blasting injuries from ordinances						
Natural Disasters and Events	Loss/alteration of habitat						
	Impacts to habitat from debris						
	Impacts to water quality						
	Impacts from emergency response						
	Alteration of hydrological regimes						
	Changes in community composition						
	Underwater landslides						
Electromag-netic Fields	Changes to migration of organisms						
	Behavioral changes						
	Changes in predator/prey relationships						

U.S. Secretary of Commerce
Gina M. Raimondo

Undersecretary of Commerce for Oceans and Atmosphere and
Administrator of National Oceanic and Atmospheric Administration
Richard W. Spinrad

Assistant Administrator for Fisheries
Janet Coit

January 2023

OFFICIAL BUSINESS
National Marine Fisheries Service
Alaska Region, Habitat Conservation Division
P.O. Box 21668 709 W. 9th Street
Juneau, Alaska 99802
www.alaskafisheries.noaa.gov