National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents.

Canada

A SYSTEMS APPROACH TO
FISHERIES MANAGEMENT

by

Christopher S. Wright

Dipl. Tech., B.C. Institute of Technology, 1974
B.A. (Com.,Hons.), Simon Fraser University, 1977
C.M.A., Society of Management Accountants, 1982
M.A. (Economics), Simon Fraser University, 1985

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY
by Special Arrangements

SIMON FRASER UNIVERSITY
DECEMBER 1991

National Library
of Canada

Acquisitions and
Bibliographic Services Branch

395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale
du Canada

Direction des acquisitions et
des services bibliographiques

395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-78281-1

Canada

APPROVAL

Name: Christopher S. Wright

Degree: Doctor of Philosophy, by Special Arrangements,

Thesis Title: A SYSTEMS APPROACH TO FISHERIES MANAGEMENT

Examining Committee:

Chairman: Dr. Bruce Clayman, Professor, Dept. of Physics
Dean of Graduate Studies

Dr. Parzival Copes, Professor, Dept. of Economics,
Senior Supervisor & Fisheries Economics

Dr. Terence Heaps, Associate Professor, Dept. of Economics,
Mathematical & Resource Economics

Dr. Randall Peterman, Professor, Natural Resource Management,
Population Dynamics & Aquatic Ecology

Dr. Moustafa Abdel Magid, Associate Professor, Faculty of
Business Administration, Accounting Systems & Auditing

Dr. Dennis Maki, Professor, Dept. of Economics,
Labour Economics & Statistics

Dr. Robert Brown, Associate Professor, Dept. of Geography,
Dean of Arts

Dr. Anthony Charles, Associate Professor, Dept. of Finance &
Management Science, St. Mary's University, Nova Scotia,
External Examiner

Date Approved: 9 Dec. 1991

PARTIAL COPYRIGHT LICENSE

I hereby grant to Simon Fraser University the right to lend my thesis, project or extended essay (the title of which is shown below) to users of the Simon Fraser University Library, and to make partial or single copies only for such users or in response to a request from the library of any other university, or other educational institution, on its own behalf or for one of its users. I further agree that permission for multiple copying of this work for scholarly purposes may be granted by me or the Dean of Graduate Studies. It is understood that copying or publication of this work for financial gain shall not be allowed without my written permission.

Title of Thesis/Project/Extended Essay

A Systems Approach to Fisheries Management

Author: ______________________
(signature)

Christopher S. Wright
(name)

Nov 25/91
(date)

\SAR\COPYRITE

ABSTRACT

Fisheries are complex systems with bioeconomic and socio-political facets. *Systems theory* suggests that efforts to manage the individual elements in a system to resolve an extant fisheries problem may provoke even more pernicious problems.

This dissertation seeks to demonstrate that a hierarchical systems approach to fisheries analysis has several advantages, not available in a conventional Cartesian approach. *Developments in fisheries management theory* are reviewed in section 2 to support the following comments.

- My understanding of the history, strengths and weaknesses of the conventional wisdom in fisheries management is a part of what leads me to believe that a new perspective could prove useful in fisheries management.
- The perspectives and associated policies that are a part of the conventional wisdom in fisheries management, have many significant and serious failings.

Von Bertalanffy's general system theory has evolved into numerous variants. This dissertation uses a hierarchical form of systems theory where the Continuum is seen as *the General System* and all other systems are artifacts—envisioned as a means of abstracting *workable bits* from the infinite Continuum. An overview of hierarchical general system concepts and language is given in sections 3 and 4.

Section 5 demonstrates a hierarchical systems approach to fisheries modeling—relatively simple modules are used to form (in a systems sense) a general model. In sections 6 and 7 assemblages of section 5 modules are used to examine several common fisheries management problems. The systems model tends to make apparent many insights that are obscured in a corresponding Cartesian approach model.

In section 8 the insights developed in sections 6 and 7 correlated well with observations from several fisheries. In section 9 the role, scope and limitations of fisheries management are reappraised in terms of the insights in the preceding sections.

Section 10 concludes that, over a wide variety of common fishery situations, the systems approach in this dissertation furnishes useful *a priori* insights that are often obscured by the conventional approach. Also, insights are proffered as to why many of the socioeconomic problems that besiege fisheries appear to be unresolvable.

ACKNOWLEDGMENTS

The author gratefully acknowledges the input, encouragement and guidance of Professor P. Copes. Much of the basic analysis developed in this thesis was first envisioned during discussions and debates in Professor Copes' seminars on fisheries economics and management. Also, Professor Copes has many papers (published and unpublished) that have preceded and demonstrated the need for the type of analysis considered in this thesis.

Much of the mathematical analysis and conceptual development in this dissertation would not have been possible without the patient review and guidance of Professor T. Heaps. His input into this thesis is on a par with that of Professor P. Copes.

I would also like to acknowledge the input, guidance, encouragement and patience of the other members of the supervisory committee, fellow graduate students, friends and relatives.

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX:

LIST OF CHARTS

APPENDIX:

LIST OF TABLES

1. INTRODUCTION

H. Scott Gordon observed, in a 1954 *Journal of Political Economy* article, that while much was known about the biology of the various commercial fish species, little was known about the economic characteristics of the fishing industry. Gordon's article sought to rectify that deficiency by introducing the concept of common property to fisheries analysis. That article changed how fisheries are perceived and laid the foundations of modern fisheries economics. A host of refinements, studies and management techniques followed Gordon's article and made it seem ever more probable that the world's commercial fisheries would soon be rationalized. However, after more than a quarter century since Gordon's article, fisheries management results are still a mixed bag and fisheries rationalization is still an elusive goal.

Fisheries rationalization has failed at specific times and places for a host of specific reasons but, overall, the failures have rarely been due to deficiencies in either knowledge or effort. For example, Canada has one of the best documented fishing industries in the world, and is the source of much of the more important theory and empirical research on fishery management (Cunningham, et al., 1985, p.258). Also Canadian fisheries managers are among the most sophisticated, professional and dedicated in the world. Yet, most Canadian commercial fisheries still exhibit many deep socio-economic problems and some are becoming progressively less stable.

This dissertation contends that much of the problem lies with how fisheries are perceived. Humans cannot know, prove the existence of or understand the meaning of what we believe is an infinite Universe, or any part thereof, except through our finite perceptions.[1] However, in the absence of evidence to the contrary, we tend to accept culturally sanctioned perceptions of the infinite Universe as reality. Thus, any precept or model that changes how we perceive the Universe, changes us and how we relate to the microcosm in which we are embedded. Margenau (1983) formalized in theory the methods by which science filters out and systemizes what (we call) facts and knowledge from the background chatter of our hopes and fears.

Most fisheries management paradigms (e.g. biology, economics and sociology) are dominated like most common Western thought by Cartesian philosophy, as epitomized by the scientific method. This reductionist approach is a powerful and successful way of understanding and manipulating reality. It has supplanted most rival world views over the last 300 years. However, weaknesses in this approach are now being revealed by its inability to effectively portray nonlinear and/or complex systems, such as those found in fisheries.

General System Theory was developed, by biologists, as a means of transcending the failings of the reductionist approach, without losing its strengths.[2] Von Bertalanffy's general system theory has evolved into numerous variants. Also, an array of general system precepts are

---

[1] This concept is well rooted in Western philosophy and is discussed extensively by Quinton (1973) Margenau (1983, pp.27-38) and Mackie (1984, p.54).

[2] Systems theory is more than just a tool for solving problems already defined; it is a conceptual framework within which one might develop new ideas about the world or any portion, thereof (Allen and Star, 1982, p.4). Models created under a systems approach fill the continuum from partial to general equilibrium analysis (i.e. the models are not general because they do not explicitly consider all things but they do explicitly place, in the Cosmos, that which they describe).

used to lend complexity to some reductionist models. However, that is a superficial application of the general system concept. This thesis uses the hierarchical form of general system theory were the Continuum is perceived as the General System and all other systems are artifacts —fabricated to provided a means of abstracting the infinite Continuum into workable bits.

The message of this dissertation is that applying a hierarchical general systems approach to fisheries analysis should provide new and needed ways of perceiving or managing fisheries. An example of how a systems approach to modeling a fishery might be developed is provided for illustrative purposes only—it is only one of many forms that such an approach might take.

2. DEVELOPMENTS IN FISHERIES MANAGEMENT THEORY

In the 300 years prior to the publication of Adam Smith's (1796) magnum opus *An Inquiry into the Nature and Causes of the Wealth of Nations*, western governments followed a mercantile policy of manipulating markets to maximize their nation's holdings of gold. That policy involved governments in market management and intervention (Galbraith, 1987, pp.39-45).[3] Adam Smith (1812, pp.352-355 and 523) argued eloquently for emancipating markets from regulation. His book focused the discipline of economics on market behaviour and encouraged enlightened rulers to be less involved in managing markets. However, Adam Smith (1812, p.545) recognized that government involvement in markets exhibiting substantial externalities can generate benefits or control costs that would otherwise not be internalized by individual decision.

It is now generally accepted that external diseconomies dominate and cause market failures in most unregulated fisheries (Gordon, 1954, pp.136-142; Scott, 1955, p.116; Schaefer, 1957a, pp.670-680; Clark, 1976, pp.27-29; Copes, 1980, pp.125-127; Cunningham et al., 1985, p. 90). In the perfect markets of traditional neoclassical economics competition is a virtuous force—lower prices and greater output increase the consumer surplus by an amount that is greater than or equal to any associated loss in profit.

---

[3] In 1651, the great English philosopher Thomas Hobbes published a treatise on the nature and function of the state in which society was described as a mechanical giant—"Leviathan". "Machines were just beginning to transform social life and weigh heavily on people's minds so it came easily to Hobbes to liken money to a fluid that oiled the joints of his monster, and government to a set of strings and pulleys that moved its limbs into the required positions" (Watson, 1987, p.144).

Enterprises are willing to supply their products to the market on the basis of their marginal cost of production. As a result, an industry supply curve is the sum of the marginal cost curves of all enterprises currently or potentially in a market.

Under perfect competition, markets achieve an equilibrium at the social optimum—where the marginal return to each type of production factor is equal to its marginal social cost. If inputs vary in quality or cost then input rent should be considered. In the absence of price discrimination each input that is of higher quality and/or lower cost than the marginal input (of its type) earns an input rent. The difference between the marginal cost and the average cost of an input is the average input rent attributable to that type of input. The concept of input rent can be divided into the more familiar notions of *Ricardian rent* (owing to the relative richness of a resource; called resource rent in fisheries—Copes, 1972, p.150) and producer surplus (owing to the relative quality of labour, capital, technology and/or entrepreneurial skills employed—Copes, 1972, p.150; Mishan, 1968).

An unregulated fishery is akin to a perfectly competitive market, except the fish being sold are taken from a stock that is a shared resource—used in common, by all who fish it. Fish are seen by fishermen as free goods that can be had for the cost of fishing. In the resulting fishery *free-for-all* the opportunity cost of drawing from the fish resource is not considered in the decision to catch a marginal fish.[4] Because each vessel has equal access to the common stock of fish, the harvest produced by a vessel is a function not only of its inputs and the richness of the stock but also of the total fishing effort in the fishery.[5] Individual vessels supply fish based on their marginal cost (MC) curve. In the long run, fish is supplied only for prices (P) that are greater than or equal to the minimum point of the fishery average cost (AC) curve. However, profit (P=MC > AC) spurs entry—which causes AC to rise until P = MC = AC and all resource rents (i.e. the profits associated with the quality of inputs) are dissipated by rising input rents, increasing costs and/or reductions in sustainable yield. Harden (1968, 1977 and 1986) has examined this process in detail and calls it *the tragedy of the commons.* If the fishing vessels are assumed to be identical or if the input rent is treated as a capitalized cost then the market supply curve (in most fisheries) is the industry average cost curve, the equilibrium forms where the marginal return to each production factor is equal to its average cost and there is no rent in the fishery, except for consumer surplus and input rent (Copes, 1972).

---

[4] The marginal fish of a fishery is not readily definable. Specifically, a fishing enterprise will fish until its marginal cost of fishing is equal to its marginal revenue from fishing. The last fish taken by an enterprise is its marginal fish. However, the concepts of the marginal enterprise and the marginal fish should not be associated—the marginal fish (of the fishery) is likely to be a situation-specific concept rather than a general concept. As a result, the last fish taken by the marginal fishing enterprise is not a workable definition for the fishery's marginal fish the *fishery marginal fish* may be taken by an intra-marginal vessel.

[5] While the total harvest in a fishery is a function of the total fishing effort and the richness of the stock, each vessel's share of the total harvest is related to its fishing effort, relative to total fishing effort.

Resource rent in a fishery is maximized at a relatively low total fishing effort. Increasing effort beyond this level, by definition, causes a decline in resource rent. The initial reductions in resource rent are more than offset by the associated rise in consumer surplus but fishing effort tends to expand past this socially beneficent phase through a socially pernicious phase (where consumer surplus gains are less than the resource rent loss) and possibly into an *ill wind phase* (where due to reductions in the long run harvest there is a dissipation of the resource rent and some consumer surplus).[6] Society will benefit greatly if means are found to convert the fishery *free-for-all* into an orderly exploitation of the fish resource.

The literature in fisheries attributes many fisheries problems to externalities that can vary in mix and importance from one fishery to the next. The following enumeration of common fisheries externalities is not exhaustive and the nature of the externality phenomenon is such that there is some overlap and/or fuzziness in the items listed:

- **Stock thinning.** Fishing down a stock biomass by a given amount reduces density of the stock and increases the effort and cost needed to harvest a similar amount of fish.
- **Growth overfishing.** Harvesting a cohort before it has had time to reach the optimal harvest value.[7] This is a waste of the potential of the cohort.

---

[6] John Heywood (fl. 1497-1580) "An ill winde that bloweth no man to good" (Bartlet, 1951, p.17).

[7] As a fish cohort ages its gross value initially increases because of the growth of individuals and the reduction in the (per unit of weight) fishing and/or handling costs. That gain is offset to some degree by losses due to natural mortality. The optimal time to harvest a cohort is when the net value of the effects is at the maximum. To the extent that a cohort cannot be harvested instantly, there is a trade-off between losses from growth overfishing and those from growth underfishing.

- Growth underfishing. Harvesting a cohort after it has aged past the optimal harvest value. This is a waste of fish.

- Recruitment overfishing. Recruitment to a stock (adding the next generation) is buffered against calamity by, among other things, the high fecundity of fish stocks. Thinning a stock can clear room for potential recruits and enhance recruitment. However the adult portion of a stock can be so reduced by fishing that it is unable to generate sufficient potential recruits to support the desired sustainable harvest.

- Gear conflict. The various items of gear used in fishing can entangle, damage or otherwise impair the effectiveness or efficiency of other gear.

- Interception. A fisherman's effectiveness and efficiency is diminished when a fish is prevented from migrating into the range of his gear because it was caught by a competing fisherman. This externality focuses on when and where fish are taken.

- Crowding. Fishing costs may rise with crowding if the fishing operations get in each other's way.

- Interspecies effects. Fishermen in one fishery can benefit from or be harmed by effects arising from the harvesting down of predator, prey, competing or complementary species in another fishery.[8]

- Habitat damage. Gear can harm the habitat (e.g. a dragging of the sea bottom by trawls, the use of explosives or poison, ghost fishing by lost gear, noise and other pollution).

- Bycatch. Incidental to the harvesting of targeted species, non-targeted species (that are important to other fisheries) may be taken.

- Investment Clash. Fishermen base investment decisions for the next fishing season on their experience in the current season. The investment plans of the other fishermen are not considered. As a result when there is resource rent in a fishery, fishermen tend to overinvest and then barriers to investment exit tend to trap that investment long after all the fishery resource rent has been dissipated. Lags in investment and disinvestment (combined with exit barriers) are a major cause of the poverty found in many fisheries (Copes, 1988a, p.8).

---

[8] Complementarity can take several forms. One form occurs if a predator "Z" prefers species "X" but will switch to species "Y" if the density of "X" falls, then the *welfare* of species "Y" is, to a degree, dependent on the *welfare* of species "X".

Most fishery externalities can be grouped under the common property resource heading, which Gordon (1952) incorporated into the title of his paper. Such externalities are an outcome of a variant the *free rider problem* discussed in many lower level economics texts (Blomqvist et al., 1983. p.600) where an individual in a group is able to internalize all or most benefits from an action that imposes some or all of its costs on all the group's members. While much is made of externalities in fisheries economics, a common property externality is not necessarily sufficient to cause a significant market failure. Markets tend for the most part to be hardy and adaptable. Alchian and Demsetz (1972, pp.779-783 and 794) noted that any group endeavor is subject to a form of common property problem called shirking.[9] They further argue that the problem can be resolved by the group members contracting to a central agent who becomes the owner of the group's residual return and (in the process of maximizing that return) optimizes the trade-off between the shirking losses and monitoring costs. In fisheries, a mismatch often exists between the scale needed to effectively manage the common property resource problem and the scale at which the production unit's common property problem (shirking) is best managed. Specifically, while a fishery central agent is effective only at a scale of the whole fishery (where the fish stock and all inputs to the fishery can be managed) fishing enterprises tend to be best managed by a skipper/owner at a vessel level (where individual inputs can be supervised and conserved). Effective fisheries management requires a bridging of this

---

[9] Shirking occurs when a member of a group evades (in whole or in part) the agreed share of group costs. It might involve one group member not pulling on a rope as enthusiastically as others in the group or it might involve failing to adequately maintain a leased vessel.

gap between the management scale appropriate for the fish resource and the management scale appropriate for fishing enterprises.

Early fisheries management was for the most part the domain of biologists (Gordon, 1954, pp.124-125). Before biologists were involved in managing fisheries (e.g. during the 17th to 19th centuries) fishery regulation focused on excluding foreign vessels from coastal fisheries (Gough, 1988, pp.781-782) and exhaustion of the resource was not seen as a problem. The renowned Dutch jurist "Hugo Grotius (1608) maintained that two critical conditions for property rights on the high seas were missing: exhaustibility and enforceability" (Neher et al., 1989, p.2). In the 1880s Dr. Thomas Huxley, a renowned British biologist, told a London assemblage: "All the great sea fisheries are inexhaustible. ... nothing we can do can seriously affect the numbers of fish" (Simon, 1984, p.14). Salmon, because they are harvested in a *gauntlet fishery*, have long been treated as a special case where protection is needed. In 996 Ethelred II forbade the sale of young salmon in England and William of Orange (1650-1702) passed laws to protect the salmon in Scottish rivers (Simon, 1984, pp.16-18). In Canada's Pacific salmon fisheries, regulation (in the form of limited entry licenses) was enacted in 1889 (MacDonald, 1981, pp.1-7). Stock failures in fisheries on most whale stocks, Peruvian anchoveta, Atlantic halibut, California sardine, various herring stocks and others have made stock collapse an important consideration in fisheries management (Ellis, 1982; Paulik, 1981; Radovich 1981; Pitcher and Hart, 1982, p.344; Simon, 1984, p.24; Cunningham et al., 1985, p.67; Clark, 1985, p.6). Fisheries managers have tended to respond to this problem by seeing stock preservation as the most important fisheries management goal (Pearse, 1982, p.4).

After it became apparent that fisheries had to be managed to preserve the stocks, the stock exploitation level became a responsibility of fisheries managers and a search was made for appropriate management tools. Two relatively distinct approaches have dominated the modeling of fisheries biology—the dynamic pool models focus on individual fish (pieces) and lead to concepts such as the *yield per piece*; the surplus yield models tend to focus on processes of the whole stock and lead to concepts such as the MSY (maximum sustainable yield). The dynamic pool modeling approach founded by Beverton and Holt (1957), models individual fish growth along with the significant inflows and outflows of the pieces in the stock. The complexity and data needs of this approach tend to make it less popular as a fisheries management tool than the surplus yield techniques that blend the stock processes into a single net growth function.

The surplus yield approach has a longer history than dynamic pool approach. In 1920, Pearl and Reed developed the *logistic growth model* which uses a single equation to describe how populations grow. Their model was named in honour of Verhulst after Pearl and Reed found that Verhulst's (1845) *logistique* growth curve was similar to their work. In 1954, Ricker proposed a family of growth curves that departed from the bilateral symmetry of the logistic curve. In 1975, Fox proposed a *generalized stock production function* that included, as special cases, the harvest functions of the logistic, Ricker and *non-self-regulating* models. In 1957, Schaefer introduced the concept of a logistic growth curve to the literature of fisheries economics. He used it as an example of a yield curve for a *self-regulating fish stock* in contrast to the *non-self-regulating fish stock* yield curve, used by Gordon (1954).

Fisheries biologists, working from simple single equation fishery production models, recommended that fisheries be exploited for a maximum sustainable yield (MSY). Graham (1935, p.274) used Russell's 1931 model to show that "it will pay to reduce the fishing rate at any rate so long as the stock will thereby grow in weight sufficiently for the product of the new reduced fishing rate multiplied by the new augmented stock to be no less than the product of the old higher rate and smaller stock." MSY was rapidly accepted as the sole conceptual basis for fisheries management (Pitcher and Hart, 1982, p.353). As a simple physical concept, it was relatively easy to define and enforce, it did not involve any complex socio-economic abstractions and it appeared to maximize the food gained without wasting fishing effort (Cunningham et al., 1985, pp.98-100). However, forces generated by the socio-economic considerations in the fishery caused fishery managers to not heed the advice given by biologists. As a result, the stated MSY policies were rarely enforced, overfishing intensified and the yields continued to decline (Cunningham et al., 1985, pp.344-345).

In the 1950s a Canadian economist, H.S. Gordon, was asked by the federal fisheries authorities to provide an economic analysis of the persistent problem of low income among the Canadian maritime fishermen (Clark, 1985, p.1). Gordon attributed the low income of fishermen and the fishery conservation problem to a process that Harden (1968) later dubbed *the tragedy of the commons*. Gordon's theory initiated fisheries economics and made a seductive promise—solving the commons problem in fisheries will resolve the poverty of fishermen and the inefficiencies of fisheries production (Gordon, 1954, p.134). Gordon recommended that fisheries be managed so as to maximize resource rent. Schaefer (1957a, p.678) called this target the *maximum net economic yield*—it was later simplified to the *maximum economic yield* (MEY). Graham (1935, p.265) mentioned rent maximization, but did not pursue it. In 1911, Warming developed a detailed theoretical model of rent maximization in fisheries. Warming's work anticipated many of the concepts in Gordon's 1954 article but his article (written in Danish) remained obscure and his concepts went unnoticed by fishery managers until they were independently developed by Gordon (Andersen, 1983).

MSY dominated fishery management for decades (Cunningham et al., 1985, pp.98-100) until fisheries managers found that it was hazardous to manage stocks at MSY. At MSY there is no buffer for the effects of an overestimate of MSY or a temporary decline in stock productivity. This problem and a history of government susceptibility to pressure to increase allowed harvests caused the fisheries managers, biologists, economists, politicians, etc. to search for a justifiable exploitation level that was less than MSY. MEY was considered as were biological optimum sustainable yield (BOSY), maximum social yield (MScY), dynamic maximum economic yield (DMEY) and $F_{0.1}$—a MEY proxy (Cunningham et al, 1985, pp.98-100; Anderson, 1977, p.124; Gulland and Boerema, 1973).[10]

---

[10] At $F_{0.1}$ the marginal yield of fishing effort is 10 percent of the marginal yield at very low levels of fishing. Therefore it is a point at which there is little reward from increased fishing effort (Gulland, 1983, p.13).

Fisheries management does not have a currently accepted wisdom on which yield is the appropriate management target. However, it is now generally acknowledged that in a variable and uncertain world managing a fishery at an exploitation rate lower than the MSY rate generates a much more stable situation than does managing for the MSY.

Once a target yield has been set, the managers must find a means of achieving it. Fisheries economists tend to be attracted to taxes as a regulatory device—other regulatory systems are seen as tending to interfere more with the flexibility and other advantages inherent in a competitive economic system. If properly applied, taxes can reduce the total fishing effort applied to a fishery without affecting its cost-efficiency (Anderson, 1977, p.160). Warming (1911) recommended that a flat license tax be applied to each vessel in each fishery. Most books on fishery economics feature taxation, in various forms, as the ideal solution to the common property problem in fisheries (Clark, 1976, pp. 116-122; Anderson, 1977, pp.160-165; Scott, 1979; Crutchfield, 1979; Sinclair, 1979; Cauvin, 1979; Wilen, 1979; Pitcher and Hart, 1982, pp. 369-372; Cunningham et al., 1985, pp.161-165) and then discuss various socio-political and technical reasons why taxes are not used in fisheries. These reasons include: a general sympathy induced for fishermen by their relative poverty, the relative voting power of fishermen, the potential of creating black markets and a lack of management flexibility (e.g. due to the lags that are inherent in any tax system).

The most common form of management in large fisheries involves a government agency which acts as the central agent for each fishery, by supervising how and when privately owned vessels can fish. Most fisheries have implicit and explicit prohibitions against fishing methods and/or gear that excessively damage fish stocks or the environment. In common property gauntlet fisheries (i.e. the Pacific salmon fisheries) traps and weirs are often prohibited—they are seen as being so effective and efficient that they threaten the viability of a stock. Gear restrictions can also be used as a fisheries management tool. In net and trap fisheries the mesh size is often regulated to restrain growth overfishing and keep the fishery's output on a desired *eumetric yield curve* (Cunningham et al., 1985, pp.1152-1158 and Turvey, 1964).[11] The open access equilibrium (OAE) occurs at a bionomic equilibrium. Selectivity regulation (e.g. mesh size) tends to drive-up the cost of fishing—which is why *eumetric* regulation can shift an OAE from a level of over-exploitation to a more desired exploitation level.[12] A *Real time fisheries management* approach (Copes, 1986a, pp.86-90) controls the when, where and how of fishing—it can greatly increase the yields and /or the market values of harvests, in some fisheries (e.g. roe herring fisheries and prawn fisheries).

Government agencies can also control the total fishing effort applied by privately owned vessels fishing in a fishery, by setting the

---

[11] The eumetric yield curve is the upper envelope of the yield curves generated by various regulations. It defines the maximum yield that can be attained (at each level of effort) from adjusting regulations on the fishing gear and/or the minimum size of fish that fishermen may legally retain.

[12] According to Gordon (1954, pp.135-137) the bionomic equilibrium occurs where all the resource rents have been dissipated. A bionomic equilibrium occurs when the fishery system is simultaneously in biological equilibrium and economic equilibrium (Clark, 1976, p.28). In an unregulated fishery, the bionomic equilibrium is called the open access equilibrium. Regulation, by changing the economics of a fishery, can shift the bionomic equilibrium away from the open access equilibrium.

effective length of the fishing season. If the season length is set *ex ante* the control mechanism is called a fishing season; if it is set *ex post* the controlling objective is either a total allowable catch (TAC) or an escapement target. Controlling the season to maintain a desired rate of exploitation conserves the stock but not the resource rent. In terms of a simple Schaefer (1954) model, if the effective season is reduced by the enforcement of a season, a TAC or an escapement target, the efficiency of the inputs in the fishery is reduced and they generate less fishing effort. This causes an upward rotation in the fishing cost curve. If the fishery was at the open access bionomic equilibrium to the right of the maximum sustainable yield (MSY), a moderate reduction in output tends to be followed by the reemergence of profit, that spurs the entry of more fishing inputs, the fishery then shifts along a new cost curve, until another bionomic equilibrium is reached. Thus, fisheries managers are forced to adjust and re-adjust the season until the fishing total cost curve is rotated to where the *season-regulated bionomic equilibrium* (SRBE) corresponds to the target level of stock exploitation. Thus, while gear and season regulation can regulate the fishery yield to a desired level, they cannot be used to conserve the fishery resource rent.

Economists also looked at the idea of using sole ownership of the fishery as an alternative to government regulation. Scott (1955) noted that a scale problem existed between the fishery resource and the many privately owned fishing vessels exploiting it. He asserted that a sole owner operating at the fishery scale, would seek to maximize the fishery resource rent. From the government's perspective, the appeal of a sole owner fisheries proposal lies in its simplicity (i.e. government involvement in fisheries is reduced to that of the enforcer of fishing rights). The only change to the fishery would be in the deeding, to a private interest, of the central agent role with its right to contract with the fishermen and vessel owners on the royalties, fees and season length. Presumably the social benefits of a sole owner fishery policy arise because sole owners have more autonomy from the political process than a government agency and are free to manage in an economically rational fashion. However, sole-ownership fisheries can create many complex sociopolitical problems. Copes (1972, p.161) observed that the social surplus from a fishery consists of consumer surplus, resource rent and producer surplus. The interests of fishery sole owners lies in maximizing the fishery resource rent, regardless of any effects on the other elements of social surplus.

As many products compete with fish and there are many fisheries—in many countries—all competing to sell fish, a sole owner fisheries policy is not likely to generate either a monopoly or oligopoly. What may be created is either a monopsony or oligopsony, with the associated risk of sole owners usurping value from the inputs in their fisheries. Capital and to a lesser extent labour tend to become dedicated if applied to a fishery (Copes, 1988a, pp.7-10). That dedication provides fishery sole owners with an opportunity to extract quasi-rents from fishermen and the owners of vessels. In theory this process of quasi-rent extraction cannot go on indefinitely. However, if there is ongoing immigration into the country, this process of extraction could be spun into a long stream of many short-run tragedies (Sinclair, 1946).

A sole owner fisheries policy is unlikely to ever be widely applied. Fishermen tend to be poor (Copes, 1988a, p.2)—an enrichment of a few sole owners with resource rent and quasi-rent that is (perceived to be) acquired at the expense of many fishermen, is unlikely to gain popular support for a government implementing it. Other problems with a sole ownership fisheries policy involve inter- and/or intra-fishery externalities, social equity, conservation, multi-use fisheries/environments, regional policy and intergenerational equity. Regulating the fishery sole owners, to correct these problems, defeats the purpose of sole ownership and may create for the government or its successors the means to extract quasirent from fishery sole owners. Uncertainty about the agenda of future governments and the information/power asymmetries between the government and potential fishery sole owners may cause the latter to severely discount the net present value of owning a fishery (Akerlof, 1970). Thus fishery sole ownership is not politically viable as a fisheries policy. Also, relief of the chronic poverty observed in many fisheries may be judged to be the second most important political fisheries management goal (Tables 5-1 and 5-2; Copes, 1988a, p.12).[13]

In the late 1950s and early 1960s, limiting entry to the fishery was proposed as a solution that would rationalize the fishery and, in the process, improve fishing incomes (Sinclair, 1960; Copes, 1980). However, this policy only limits the number of individuals or vessels that can legally compete for resource rent in the fishery. Restricting

---

[13] While fishery sole ownership is not viable as a general policy, it may be appropriate for small isolated fisheries, especially when sedentary species are involved.

the use of one or even several out of the many possible fishing inputs cannot prevent a competitive expansion of vessel fishing power through the addition of unrestricted inputs. It is neither administratively possible nor economically desirable to restrict all fishing inputs and innovations (Pearse, 1982, pp.81-83). However, the amount of fishing power that can be reasonably achieved by stuffing inputs into a vessel has short and long-run upper limits. Fishing inputs are not perfectly substitutable and inputs eventually experience diminishing returns to scale. As a result, if limited entry has been strictly enforced after having been applied early in a fishery's development it has met with a modicum of success (Meany, 1982; Copes, 1978a, pp.8-14, and 1986a, pp. 20-24). Limited entry was tried in the British Columbia salmon fishery (a mature fishery) but did not maximize the fishery social surplus and the outcome worsened the lot of many fishermen (Anderson, 1977, pp.177 -204; Pearse, 1982, pp.78-79; Copes, 1980, pp.136-139, 1986a, pp.20-24 and 1988a, p.14; Cunningham et al., 1985, pp.165-169). A major element in the B.C. salmon fishery limited entry program involved vessel buy-backs. However, the buy-back scheme failed because of the *expectations trap*—the program was sold to the fishermen on the basis that it would increase fishing incomes. The anticipation of higher (future) earnings increased license values, which stopped the buy-back program and prevented the fulfillment of the promised higher earnings (Copes, 1980, p.137). While the reasons for the failure of the limited entry program in the B.C. salmon fishery are specific to that fishery, democratic governments usually have difficulty finding the political will required to impose an effective limited entry program on a mature fishery. Also, any gains from limited entry will likely be eroded as innovation increases the effectiveness and efficiency of fishing power. The Gulf St. Vincent prawn fishery and the lobster fisheries in South Australia experienced this problem (Copes, 1986a, pp.20-24 and 1978, pp.10-13). Applying limited entry programs to mature fisheries appears to offer (at best) a modest intermediate-run gain in return for a lot of short-run pain.

In the 1980s the individual quota (IQ) replaced limited entry as the *touted cure-all* for fisheries. However, after being burned by the empty promise and perverse reality of the limited entry solution, many fishery managers have become sceptical of fisheries economists notions in general and IQs in particular. Their caution may be valid. Copes' (1986b) review of IQs indicates that as a fisheries management device they have many serious practical problems. And, IQs may increase deck-hand unemployment during the adjustment phase, preclude using fisheries as *employers of last resort* (Copes, 1986c) and may provide little gain to future fishermen (Copes, 1986b, p.287 and Tullock, 1975).[14]

---

[14] To the extent that a fishing right is transferable, the benefits generated by the right tend to be capitalized in its market value and, thus, are shifted away from those who operate the right. This is demonstrated by noting that the first generation holders of the fishing right could sell their rights and still benefit. Therefore, those who choose to operate the right, earn a normal return on the value that was gifted to them when the government first issued the right.

If a transferable fishing right is inherited, the heirs are benefiting from the original gift of the right to their progenitor. The situation in their fishery determines what sort of return is earned on their inheritance. This is little different from the case where a progenitor sold the right and used the proceeds to buy a farm—in both cases the heirs benefit from the original gifting of the right, not from operating the right.

Fisheries biologists and economists have developed a solid understanding of fisheries. However, as the preceding discussion indicates, they have not developed viable long-run solutions to resolve the socio -economic problems that beset fisheries. The biologists continue to add to an ever greater and more detailed understanding of the characteristics and ecology of fish populations. While such knowledge is of immense value to fisheries managers and economists, fishing is a human activity and, as such, a resolution of its problems (if such a resolution exists) is most likely to originate within the domain of a social science such as economics.[15]

The discipline of fisheries economics has been dominated throughout its short history by a search for a solution to the *commons problem* and with arguments on an appropriate distribution of the resulting surplus (Appendix A).

In a recent paper, Copes (1988a) observed that the linking of the commons to poverty is a chimera. Exploitation of a common property resource (e.g. a fish stock or common pasture) is neither necessary nor sufficient to cause poverty in a community. The *tragedy of the commons* (Harden, 1968) dissipates the resource rent from a common property resource and makes it not available for use in relieving a pre-existing condition of poverty. This failure to relieve poverty was misconstrued by many economists and ecologists (Gordon, 1954, p.132; Harden, 1968 and 1986; Appendix A) as the main cause of that poverty.

---

[15] Economics is the social study of the production, distribution and consumption of wealth (Greenwald & Associates, 1983, p.153).

Copes (1988a, pp.7-10 and 16) attributed the poverty, that persists in many fisheries, to a combination of: low opportunity costs, surplus labour (e.g. resulting from labour shedding caused by enhanced productivity), cycle lags and illusions about their relative fishing abilities. Governments often unwittingly aggravate these problems by implementing assistance programs that have perverse long-run effects (Copes, 1988, p.10). While Gordon (1954, pp.124, 125, 132 and 134) did give passing mention to isolation and illusion as contributing to the poverty observed in many fishing communities, he attributed the role of primary cause to the common property problem. The thinking that led to his error, like that of the biologists (who ignored socio-economic forces when they set MSY as the basis for fishery management) does not withstand close scrutiny. That each error prevailed for a long time as conventional wisdom in fisheries management is of greater import than their occurrence. The presence of deep underlying problems in fisheries management is further evidenced by the observation that one fundamental error replaced another. The delay in exposing these errors and the general intractability of fisheries problems are understandable if fishery managers tend to perceive fisheries in the Cartesian tradition —as things or collections of things. A fishery is a complex nonlinear system and (as discussed in the next section) the make up and behaviour of a system can be radically different from that of things.

3. GENERAL SYSTEM THEORY VS THE CARTESIAN TRADITION

Our concept of *how the world works* imposes implicit constraints on the models we create. The Cartesian scientific paradigm has dominated Western thought over the last three centuries. It is a complex amalgam of many ideas that trace their origin to the teachings of René Descartes (1596-1650).

Orders based on rationalism (derived from the Cartesian paradigm) have supplanted in most areas of the world many established orders who derived power from an appeal to divine right, backed by might. Today,

> "many people in our society, scientists as well as non-scientists, are convinced that the scientific method is the only valid way of understanding the universe. ...Descartes' method is analytic. It consists in breaking up thoughts and problems into pieces and in arranging these in their logical order. This analytic method of reasoning is probably Descartes' greatest contribution to science. It has become an essential characteristic of modern scientific thought and has proved extremely useful in the development of scientific theories and the realization of complex technological projects. ...On the other hand, overemphasis on the Cartesian method has led to the fragmentation that is characteristic of both our general thinking and our academic disciplines, and to the widespread attitude of reductionism in science—the belief that all aspects of complex phenomena can be understood by reducing them to their constituent parts. ...Today although the severe limitations of the Cartesian world view are becoming apparent in all the sciences, Descartes' general method of approaching intellectual problems and his clarity of thought remain immensely valuable." (Capra, 1983, pp.57-62).

The Cartesian view that reality consists of separate parts, joined by local connections (Capra, 1983, p.83) works best with physical things or collections of physical things. A *thing-in-itself* is not dependent on an observer for its existence (Flew, 1971, p.348) and has very specific observable characteristics. It "is a collection of qualities, manifested in a particular definite region of space[/time] and thus containing within it definite shape and size. ...In order to pick out some region of space[/time] as being occupied by a thing. ...there must be a boundary or limit where the thing leaves off and its surroundings begin" (Quinton, 1973, pp.44-45).

The focus and clarity of separation that is essential to understanding, under the Cartesian approach, is lacking in some phenomena. An "integrated whole whose properties cannot [all] be reduced to those of its parts is called a system. Living organisms, societies and ecosystems are all systems" (Capra, 1983, p.43). System phenomena can be best understood in terms of the interrelatedness, interdependence and integration of (what the Cartesian approach would call) the system's elements.

Attempts at modeling complex bioeconomic systems (e.g. fisheries) according to the reductionist approach dictated by the Cartesian paradigm (e.g. Scott's 1955 model of a sole owner fishery) tend to fail because of the model being either intractable or under-specified. When important characteristics of that which is being modeled are not conceptualized in our view of the world then our models will not always track reality. Improving such models requires adjustment to our way of viewing the world. Such adjustments can be difficult to make because, at least initially, they cause a degree of cognitive dissonance.[16] For example fisheries economists are trained in the Cartesian tradition to

---

[16] Cognitive dissonance is a feeling of unease that occurs after information has been acquired that is in conflict with our concept of the world. We deal with this unease by altering our view of the world or denying the data or putting off the problem until more data are gathered (Martindale, 1981).

act as independent objective observers using inductive and deductive reasoning to define absolute truths in the fishery in the form of verifiable relations, axioms and laws. The findings are then used in developing rational management strategies for a fishery. However, based on the following *general system theory* axioms (Johnson et al., 1974, pp.4-9 and 71-73) Cartesianism can be thought of as a subset of system theory where the whole is *defined* as equaling the sum of its parts. If the limitation is not binding, then *any absolute truth* derived from it is illusory, as are the Cartesian ideals of observer independence and objectivity.

- A system is a concept of reality, it is artificial and has no existence outside of our choice to construct and use it to describe the relationships we perceive in the *empirical* world.
- A system is a relative concept—within the bounds of infinity, every system both contains subsystems and is itself a subsystem of a larger system.
- Subsystems may or may not be additive—*the whole is different from the sum of its parts.* As such, the whole may be equal to, greater than or less than the sum of its parts.

In these terms, a fishery is an artificial relativistic concept with possibly nonadditive subunits. Therefore, how a fishery is defined, its subsystems, how it relates to the system of which it is a component and the time scale viewed are all, more or less, choice variables of an observer. Part of the wisdom of the general system approach is that observers can never be independent as they are participants in the creation of the system(s) formed to gather and interpret phenomena that are only assumed but can never be proved to be independent of the observer.

Biologists studying ecosystems have long been aware of a need for a systems approach. Darwin's concept of adaptation is a good example— "Species are not adapted only to physical conditions. Rather, they are adapted to their co-inhabitants, to those on which they feed, from which they must escape, and with which they compete. Adaptation is therefore a relative concept, one that can be understood only by knowing the full range of ecological relations, and one that may change rapidly and subtly as those relations change" (Kingsland, 1988, p.11).

General system theory (as conceived by von Bertalanffy after the Second World War) "was both a point of view and a method. The object was to model the interrelationships between the component parts comprising any sort of system. The word *system* was therefore interpreted very broadly ... so that as a mathematical technique, systems analysis could be applied to fields as different as biology, information theory, economics or sociology" (Kingsland, 1988, p.103). Von Bertalanffy (1968, pp.18-23) listed several approaches that might be encompassed within general system theory: *classical* system theory, computerization and simulation, compartment theory, set theory, graph theory, information theory, net theory, game theory, theory of automatia, cybernetics, decision theory and queuing theory. In his book *Perspectives on General System Theory*, von Bertalanffy (1975, p.167) observed:

> "...there is a great and perhaps puzzling multiplicity of approaches and *trends in general system theory.* This is understandably uncomfortable to those who want a neat formalism, e.g., the textbook writer and the dogmatist. It is, however, quite natural in the history of ideas and of science, particularly in the beginning of a new development. Different models and theories may be apt to render accounts of different aspects and are therefore complementary. On the otherhand, future developments will undoubtedly lead to further unification.."

As noted by von Bertalanffy (1951, p.343) "the central point of system theory is the dynamic view, trying to explain phenomena of order in terms of the interaction of processes, as contrasted with the Cartesian machine theory, which tries to explain it in terms of preestablished structures." Von Bertalanffy integrated previous and concurrent population ecology work by the likes of V. Lotka, W. Thompson, V. Bailey, V. Volterra and A. Nicholson (Kingsland, 1988, pp.103-126).

Conceptualizing very complex biological systems caused ecologists to formulate several general system axioms (Holling, 1984, pp.25-37):

- **Everything is not strongly connected to everything else.** Therefore, an understanding of significant connections is sufficient and there is no need to measure everything.

  Further, the loss of an subassembly does not necessarily destroy the whole. If a lost subassembly was minimally connected, the others can persist, often long enough for self-recovery.

  Also a system can adapt rapidly to change. As long as the same connections, functions or roles are maintained, major changes or substitutions can take place within or between subassemblies.

- **Impacts are not always gradually diluted over time and space.** Changes in one variable can have unexpected impacts on variables at the same place but several connections away. Also, events at one time/place can re-emerge as impacts at distant time/places.

- **Systems are dynamic rather than static.** It is variability and not constancy that contributes to the capacity of a system to persist, self-monitor and self-correct. Policies that reduce variability in space or time should always be questioned.

- **Nature is resilient, not infinitely forgiving.**[17] In many systems shocks are natural. However, some systems do not always return to the predisturbance condition, even after the perturbant is no longer acting. Thus, monitoring the wrong variable may indicate no change, even if a drastic and irreversible change is imminent.

---

[17] Resilience is a property allowing a system to absorb and utilize (or even benefit from) change.

A fishery should be studied and managed as a complex bio-economic and socio-political system. According to the axioms of general system theory, the Cartesian approach of managing the individual elements of a fishery system may cause unexpected, unwanted and sometimes dramatic results. If a fishery is seen as a subsystem within a larger system, the insights and policy instruments formulated will tend to transcend those developed using a Cartesian approach.

Again and again fishery managers using a Cartesian approach have targeted and pursued, often at great cost, desirable partial equilibrium targets only to have a long-run system equilibrium overtake their fishery and move it to the preintervention socio-economic situation or worse. In other words, a reductionist approach in fisheries economics and management often leads to good observations and correct but incomplete conclusions. As a result, management intervention in fisheries has often had inappropriate, ineffective or even perverse long-run results. For example Gordon and most fisheries economists after him correctly noted that a fishery is a commons, correctly concluded that the process Hardin (1968) named *the tragedy of the commons* would dissipate any resource rent, but then rashly attributed the persistent poverty observed in many fisheries to that tragedy. If a hierarchical systems approach is used in fisheries analysis (e.g. all things are connected —nothing is considered in isolation) it is clear that, while an over-expenditure of resources and the associated loss of resource rent is a tragedy, it is neither necessary nor sufficient to cause poverty. At the margin, a reasonable individual directs investment to the enterprise that appears to offer the highest return. Thus, the true tragedy of the commons is that, *in an unmanaged commons, eventually the aver-*

age return to investment reflects the marginal opportunity cost of the marginal investor. If a community is impoverished the cause is not *the tragedy of the commons* but a lack of opportunities or distortions that exaggerate the anticipated return to an investment in a fishery and then trap that investment. A misunderstanding of how the commons problem relates to fishing incomes can result in fruitless decades of misdirected fisheries policy and poverty relief.

A Cartesianist applying general system theory precepts to modeling a fishery will likely bound the fishery as a first step (Holling, 1984, pp.146-154). As discussed in the next section, this bounding depends on an unwarranted reification of the fishery and its subsystems and reification is not consistent with the precepts of general system theory.[18] The reification problem can be avoided in the hierarchical systems approach. That approach can be seen in von Bertalanffy's comments on the importance of hierarchical organization:

> "Problems of realizability appear even apart from the paradoxes connected with infinite sets....a concept or complex of concepts which indubitably is fundamental in the general theory of systems ...[is] that of *hierarchical order*. We presently see the universe as a tremendous hierarchy, from elementary particles to atomic nuclei, to atoms, molecules, high-molecular compounds to the wealth of structures (electron and light microscopic) between molecules and cells (Weiss, 1962b) to cells, organisms and beyond to supra-individual organizations. ...A similar hierarchy is found both on *structures* and in *functions*. In the last resort, structure (i.e.,order of parts) and function (order of processes) may be the very same thing: in the physical world matter dissolves into a play of energies, and in the biological world structures are the expression of a flow of processes. ...A general theory of hierarchic order obviously will be a mainstay of general systems theory. Principles of hierarchic order can be stated in verbal language (Koestler, 1967

---

[18] To reify is to convert an abstraction into a thing (Sykes, 1982, p.875).

> ...); there are semimathematical ideas (Simon, 1965) connected with matrix theory and formulations in terms of mathematical logic (Woodger, 1930-31)." (Von Bertalanffy 1968, pp.27-28).

The idea that there is a General System embracing all of Creation was also expressed by Poincaré:

> "...every generalization implies in some measure the belief in the unity and simplicity of nature. As to the unity [of nature] there can be no difficulty. If the different parts of the universe were not like the members of one body, they would not act on one another, they would know nothing of one another; and we in particular would know only one of these parts. We do not ask, then, if nature is one, but how it is one." (Poincaré, 1946, p.130).

However, the complexities of modeling the Universal System would overload the finite cognitive capacity of humans. Thus, a way is needed to separate the Continuum into logical workable bits, to find the bits relevant to a given fishery and to combine them into a cohesive system. In the Cartesian system, things are used as the logical bits. A focus on things can cause us to lose sight of the whole, to perceive the Continuum as being mechanistic and to fail to appreciate that (as part of this whole) our views of the Continuum, or any part thereof, can never be independent or unbiased. However, this fragmented view of reality may be what gives societies based on a Cartesian philosophy a dynamism and vitality that is often lacking in societies based on a

Holistic philosophy.[19] Specifically, the focus in Cartesian reductionism on the parts of systems leads inexorably to a belief in the individual as existing in an open system where the parts combine to define the whole. The result is a vision of human nature as an unfilled potential and of life as an adventure in self-development. "Humanness, Pico della Mirandola [1487; reprinted 1948] tells us, is not a closed box, but an open door... leading to an open door... leading to an open door. ...Pico...asks us to see ourselves as a grand spectrum of possibilities whose unexplored regions include the godlike as well as the diabolical." Roszak (1975, pp.8-9). Holism's focus on the whole (the interconnectedness of all existence) leads inexorably to a belief that the whole determines the nature of its parts which leads to change being viewed as chaos, which leads to a desire to fit into the existing order and to inertia/stagnation.

Cartesian *reductionism* and Holist *system integrity* can be thought of as extremes of a continuum. A hierarchical general system approach harmonizes these opposing philosophies into a useful balanced view.

---

[19] Holism is derived from the Greek word for whole. "It is a term coined by Gen. J.C. Smuts (1870-1950) to designate the tendency in nature to produce wholes (i.e. bodies or organisms) from the ordered grouping of unit structures" (Burchfield, 1987, p.363). Holism is a religion, a philosophy and a way of life—the *whole* is the focus of attention and individual elements within the *whole* are unimportant except in terms of service to the whole. In contrast, reductionism is based on the assumption that individual things combine to form collectives and that one can understand the *whole* by understanding its parts. Systems theory, combines the virtues of both views, but defines no *whole* (a thing-in-itself) other than the imponderable infinity of the Universal System. Systems theory focuses on holons, which are not related to Holism but instead are defined comprehendible representations of rational subsets of the Universal System. A holon is a subset of a larger holon and contains subsets of smaller holons.

4. APPLYING A HIERARCHICAL GENERAL SYSTEMS APPROACH

The previous chapter defined a system as an integrated whole with properties not reducible to those of its parts. If all things are relative, there is a General System embracing all of Creation. However, the complexities involved in modeling this Universal System are beyond the finite cognitive capacity of humans. A means is needed to separate the Continuum into logical workable bits. The Cartesian approach asserts that *things* exist independently of the observer and make ideal *logical workable bits.* Also, nature is assumed to exist independently of the mind, even though it may bear little resemblance to the world that we perceive directly. Further, experience is considered the ultimate test to confirm or refute physical theories or models (Wallace, 1989, p.112). However, the Cartesian approach has serious problems— the 17th century French philosopher Rene Descartes (after trying to prune away all belief from knowledge to create a germ of pure rational knowledge from which a rational system of knowledge could be derived) concluded that the only thing we can know with absolute certainty is *I think, therefore, I am.* It is still accepted in the philosophy of metaphysics that all knowledge (other than *I think, therefore I am*) is grounded to a greater or lesser degree on faith. Buddhist philosophers reached this conclusion and then noted that we cannot be our thoughts for if we are our thoughts then, between two thoughts, what and where are we? (Wallace, 1989, pp.130-137).

A systems approach transcends the concept of physical things and focuses on the interrelatedness, interdependence and processes within a system and its environment. However, a systems way of viewing existence generates only relative knowledge—if absolutes exist, they are not accessible to human methods of inquiry. Thus, meanings of facts or systems of facts always depend on an imposed context and scale.

4.1 PERCEPTION, REALITY AND THE LIMITS OF LANGUAGE

Language imposes major constraints on our ability to conceptualize systems (e.g. the word *it* implies a *thing-in-itself* and the use of *its*, in the preceding subsection, is not consistent with a systems approach). "Indo-Aryan languages, like the English language...because of their subject-verb-object structure of sentences, tend to overemphasize things and underemphasize processes" (Boulding, 1985a, p.162). This impediment may explain why relativity, which was a well developed Taoist concept in the 3rd century BC (as evidenced by the philosophies of Chuang Tzu ca. 369-286 and Hui Shih fl. 350-260; Fung Yu-Lan, 1966, pp.110-113, 83-87), was not accepted in the West until after the 1905 publication of Einstein's special theory of relativity (Capra, 1983, p.75). Relativity and relatedness are important concepts. A thing that exists only by itself or in itself is (by definition) without meaning to anything else. All of our evidence of an external reality involve transactions—entities have meaning to each other only in encounters. General system theory and ecological systems axioms (see pp.24-26) are both precursors and summaries of another way of speaking of and ultimately perceiving existence. Von Bertalanffy (1968, pp.222-223) quoted Whorf to demonstrate an understanding of the link between language and comprehension: "We cut up and organize the spread and flow of events as we do largely because, through our mother tongue, we are parties of an agreement to do so, not because nature itself is segmented in exactly that way for all to see (Whorf, 1952, p.21)." Von Bertalanffy

(1968, p.237) then stated: "conceptualization is culture bound because it depends on the symbolic systems we apply. These symbolic systems are largely determined by linguistic factors, the structure of the language applied. Technical language, including the symbolism of mathematics, is, in the last resort, an efflorescence of everyday language, and so will not be independent of the structure of the latter. This, of course, does not mean that the content of mathematics is *true* only within a certain culture....But which aspects or perspectives are mathematized depends on the cultural context." This idea that what we perceive as reality is, at least in part, culturally dictated is well known in the discipline of physics—Werner Heisenberg (1962, p.58), an architect of quantum theory, noted that "what we observe is not nature in itself but nature exposed to our methods of questioning." Margenau (1966, p.36) noted that experience is never purely exogenous but, to a degree, is always contingent on the nature and expectations of the individual having an experience. In discussing *systems epistemology*, von Bertalanffy (1975, pp.166-167) asserted:

> "...perception is not a reflection of *real things* (whatever their metaphysical status), and knowledge is not a simple approximation to *truth* or *reality*. It is an interaction between knower and known, and is dependent on a multiplicity of factors of biological, psychological, cultural, linguistic, etc., nature. Physics itself tells us that there are no ultimate entities like corpuscles or waves existing independently of the observer. This leads to a *perspective* philosophy for which physics, fully acknowledging its achievements in its own and related fields, is not a monopolistic way of knowledge. Against reductionism and theories declaring that reality is *nothing but* (a heap of physical particles, genes, reflexes, drives, or whatever the case may be), we see science as one of the *perspectives* that man with his biological, cultural, and linguistic endowment and bondage has created to deal with the universe..."

Margenau (1966 and 1983) developed a model to show how science organizes cognitive experience into structures and how science uses the structures to predict and explain other phenomena. Margenau starts his model with perceptions but makes no projections into reality. This is consistent with Wittgenstein (1975, p.283) who asserted "a phenomenon isn't a symptom of something else: it is the reality."

Margenau's approach asserts that humans impute meaning to perceptions by forming constructs (at ever higher levels) to interpret what the underlying constructs and perceptions mean. This approach avoids the corroboration problems that are inherent in Wittgenstein's (1975, p.286) idea that: "Describing phenomena by means of the hypothesis of a world of material objects is unavoidable in view of its simplicity when compared with the unmanageably complicated phenomenological description." However, even if the *absolute truth* of Cartesianism is not available to us, *relative truths* can be formulated. As Poincaré argued mathematics and the related sciences can often transcend the need for corroboration:

> "... these conventions are the work of the free activity of our mind, which, in this domain, recognizes no obstacle. Here our mind can affirm, since it decrees; but let us understand that while these decrees are imposed upon *our* science, which, without them, would be impossible, they are not imposed upon nature. Are they then arbitrary? No, else were they sterile. Experiment leaves us our freedom of choice, but it guides us by aiding us to discern the easiest way." Poincaré (1946, p. 27-28).

If corroboration is considered desirable then, as Popper (1961, pp.266 -267) noted:

> "... a theory is to be accorded a positive degree of corroboration if it is compatible with the accepted basic statements and if, in addition, a non-empty sub-class of these basic statements is derivable from the theory in conjunction with the other accepted basic statements. ...But the *degree of corroboration* of a theory

> as *the severity of the various tests* to which the hypothesis in question can be, and has been, subjected. But the severity of the *tests*, in its turn, depends upon the *degree of testability*, and thus upon the simplicity of the hypothesis."

However, Popper (1961, p.280) also gave the following caveat

> "Bold ideas, unjustified anticipations, and speculative thought, are our only means for interpreting nature....And we must hazard then to win our prize. Those among us who are unwilling to expose their ideas to the hazard of refutation do not take part in the scientific game. ...The old scientific *epistémé*—of absolutely certain, demonstrable knowledge— has proven to be an idol. The demand for scientific objectivity makes it inevitable that every scientific statement must remain *tentative for ever*. It may indeed be corroborated, but every corroboration is relative to other statements which, again, are tentative. Only in our subjective experiences of conviction, in our subjective faith, can we be *absolutely certain.*"

Margenau's model (summarized in Appendix C) provides the basis of the next subsection.

4.2 THE *MARGENAU CONSTRUCT FIELD MAP*

If Margenau's model (Appendix C) is structured using a hierarchical general system approach, a method of mapping simulation models is implied that is more than a flow chart. Specifically, a *Margenau construct field map*:

- can provide insight into model structure, function, relations, strengths, and weaknesses,
- can be used to highlight any important concepts ignored by a model, and
- can be used to reconcile and compare different models that focus on the same set of phenomena.

Margenau's model starts with the P-plane (Figure C-1, Appendix C) and moves to the left (into the C-field) along lines of correspondence to simple constructs. The left-ward flow in the model continues along construct interconnections that form webs called theories, models or submodels. This is consistent with Poincaré's (1946, p.55) observation "Every conclusion supposes premises; these premises themselves either are self-evident and need no demonstration, or can be established only by relying upon other propositions, and since we can not go back thus to infinity, every deductive science ... must rest on a certain number of undemonstratable axioms." Popper (1961, pp.276-277) also supported this view when he noted that science moves from specific to general theories and indicated that this is necessary because one layer supports another—the more general and complex theories are difficult to test until the underlying and simpler theories are accepted as being reasonably corroborated.

The idealized *Margenau map* illustrated in Chart 4-1 reverses the flow in Margenau's model, and has as its centre point the general system focus. This hub is an unattainable paragon that incorporates the infinity of the general system (e.g. the Continuum, the Universal Set, etc.) into a single equation that is focused on the target phenomenon —in this case a fishery. The scale of function (i.e. nesting of sets) decreases exponentially with the distance from the focus, until (at an infinite distance from the focus) the Margenau P-plane is reached. As one moves from the *P-plane to C-field interface*, individual (single association) constructs are found, then pairs of constructs, then complexes of constructs, then theories, then complexes of theories, then sub-disciplines, then disciplines and so forth until, at the infinite function scale of the focus, all constructs are linked. If one were to orbit the focus, (what we call) the disciplines would appear as pie shaped wedges with fuzzy (semi-permeable) boundaries and sharing the focus in common with all other disciplines. In economic terms, a perfect general equilibrium model would occupy the general system focal point in a *Margenau map*.

It is not possible to map any model in terms of the *Margenau idealized map*. However, the basic principles and land marks of a *Margenau map* are still useful. Von Bertalanffy (1968, p.244), in discussing a process similar to Margenau's model, noted:

> "In a way, progressive de-anthropomorhization is like [Baron von] Muenchhausen pulling himself out of the quagmire on his own pigtail. It is, however, possible because of a unique property of symbolism. A symbolic system, an algorithm, such as that of mathematical physics, wins a life of its own as it were. It becomes a thinking machine, and once the proper instructions are fed in, the machine runs by itself, yielding unexpected results that surpass the initial amount of facts and given rules, and are thus unforeseeable by the limited intellect who originally has created the machine. In this sense, the mechanical chess player can outplay its maker (Ashby, 1952a)." (Von Bertalanffy, 1968, p.244)

There are, from a Cartesianist perspective, several serious problems with the Margenau map idea. For example, Popper (1960, pp.77-78) cited Gomperz (1908), Hayek (1943) and Mannheim (1940) when he noted that:

> "It is not possible for us to observe or to describe a whole piece of the world, or a whole piece of nature; in fact, not even the smallest whole piece may be so described, since all description is necessarily selective. ...the fact that wholes in the sense of totalities cannot be made the object of scientific study, or of any other activity such as control or reconstruction, seems to have escaped the Holists, even those of them who admit that, as a rule, science is selective."

This commentary seeks to defend the Cartesian *reductionist* extreme by focusing on failings in the Holist *system integrity* extreme. The hierarchical general systems approach, epitomized in a Margenau map, fits along the continuum between these two extremes.

4.3 HIERARCHICAL SYSTEMS LANGUAGE AND CONCEPTS

The debate between the protagonists of the Cartesian, holist and system approaches can be obscured and aggravated by language problems. While Shakespeare's powerful prose argues that words are not important —"What's in a name? that which we call a rose by any other name would smell as sweet"—Oxford Dictionary of Quotations, 1980, p.480)—many philosophers have argued that meaningful debate only occurs within the context of a common language. As a result, disparate cultures or disciplines can be isolated by "...real differences in language structure which have a strong influence on attitude and understanding. *The limits of my language*, said the Austrian philosopher Ludwig Wittgenstein, *mean the limits of my world.*" (Watson, 1986, p.246).

Wittgenstein (1953, Sec.109) concerned with the adequacy of language, observed that "...philosophy is a battle against the bewitchment of our intelligence by means of language." [20] Language uses reach out to that which is felt but not yet articulated and captures it for the realm of the sayable. While Wittgenstein (1953) noted "there is indeed the inexpressible...it is the mystical", he also asserted "whereof one cannot speak, thereon one must remain silent" (Oxford Dictionary of quotations, 1980, p.575). Thus, if one does not wish to remain silent on a new concept, often new words must be added to the language or old words modified.

---

[20] Wittgenstein (1958, p.28) felt that there was little need for a highly refined and technical language. In contrast, Bertrand Russell (1956) delivered a blistering attack on *the cult of ordinary language* by declaring that this view "makes philosophy trivial" by encouraging endless dispute over "what silly people mean when they say silly things."

Allen and Star (1982) provide much of the philosophy and language needed in hierarchical systems analysis. In their discussion of hierarchical structures in ecology they use *holons*, a term developed by Koestler to subdivide systems into workable bits.[21] The holon function in systems theory is similar to set theory in mathematics. A holon, as an entity, is both a whole and a part of a whole. For example, in the following nested hierarchy of holons an individual is a part of a family, that is a part of a tribe, that is a part of a nation. Non-nested hierarchies (e.g. living systems) "...exhibit multileveled patterns of organization characterized by many intricate and nonlinear pathways along which signals of information and transaction propagate between all levels, ascending as well as descending" (Capra, 1983, p.282). Instead of defining holons as entities, it is more functional to define them as being "an integration of information from their parts" (Allen and Star, 1982, p.10). As such a holon is "...a two-way window through which the environment influences the parts; through which the parts communicate, as a unit, to the rest of the universe. ...What a holon shall contain is determined by the observer" (Allen and Star, 1982, p. 270).

The nature of holon communication is of interest: "Ordered systems are so, not because of what the components do, but rather because of what they are not allowed to do. ... higher holons in a hierarchy constrain lower holons and provide the context in which the lower holons function. ... [That] constraint is described in terms of quality

---

[21] Koestler (1967, p.343) described the *holon* as having "a dual tendency to preserve and assert its individuality as a quasi-autonomous whole and to function as an integrated part of an existing (or evolving) larger whole."

and quantity of information flow and its consequences. Therefore, the scale of a structure can be defined by the time and space constants whereby it receives and transmits information. ...A signal is a string of energy or matter in transit between communicating entities. ...A scale is the period of time or space over which signals are integrated or smoothed to give message. Transmitted messages have particular meanings; that is they carry particular information for the transmitters, as do received messages for receivers. However, since between message transmission and message reception a message becomes a signal, information in a message transmission is not usually the same as information at reception. ...[For example] the signal may be integrated by the transmitter over periods that are different from those employed by the receiver. In such cases the communicants are differently scaled and in some ways the signal is distorted, but the distorted signal is all that the receiver has and becomes the firm context for any responses the receiver might subsequently make. ... Wimsatt (1980) .... notes that a checkerboard of environmental patches of ten meters on a side, varying between patches discretely from 0°C to 40°C, would kill a *Drosphilia* by either freezing or overheating but would not even activate themoregulatory systems in a cow or a man walking through such an environment. ...[Conversely,] the Milky Way probably behaves so slowly and over such a large space that the life we know will be gone before the galaxy can offer anything significant for it" (Allen and Star, 1982, pp.11-23).

As noted above, the observer chooses what a holon shall contain. However, holons cannot be arbitrary—a system will approximate observed phenomena only if its holons are tied through some logical basis to what is being modeled. Thus, some form of boundary should be apparent between the holons chosen. These boundaries are permeable—hierarchies (by definition) are *nearly-decomposable systems* that "can be broken up (in thought or analysis) into subsystems such that the interactions within the subsystems are relatively strong and numerous compared to the interactions between subsystems" (Allen and Star, 1982, pp.70-72). Hierarchical systems have neither an utmost nor an innermost limit—they are infinitely large and fine in detail. Therefore, neither a *top-down* nor a *bottom-up* approach is appropriate when subdividing a system into subsystems. A system should be modeled by specifying it at some (to the modeler) mid-level of detail and then elaborating both up-level and down-level until the unmodeled levels are at a scale (space/time frame), relative to the modeler, such that they might reasonably be approximated by either functions or parameters. The infinite nature of systems causes another problem. The subdivision of an infinite set makes smaller, but still infinite subsets. For example the set of all whole numbers and the set of all whole even numbers are both infinite, but the latter (as a subset of the former) must be smaller. Defining a subset of a system (a holon) in terms of all possible internal and external transactions would take an infinite number of observations made by infinite types of observers (human and other) over an infinity. As Wittgenstein (1975, p.159) noted:

> "If you say space is infinitely divisible, then strictly speaking that means: space isn't made up of individual things (parts).... in a certain sense, infinite divisibility means that space is indivisible, that *it* is not affected by any division. That it is above such things: *it* doesn't consist of parts."

A more pragmatic approach is to use a human perspective as a relevant system context. Other contexts may be equally valid, but they are not relevant to us unless eventually they affect the system's transactions with us. For instance, birds producing guano after feeding on Peruvian anchoveta is seen as a low value use of that fish stock, but that view might change if it is found that the 90 percent of the guano that is dropped at sea enhances fish larvae survival rates (Paulik, 1971, pp. 56-57 and 68). The need for an infinite number of observations, taken over infinity, can be obviated if the holons are defined as *fuzzy sets* (i.e. characteristics are attributed to holons on the basis of a probability derived from observation and inference). As such, our concept of a system and its holons will become more refined and less fuzzy, as we accumulate observations and experience. Poincaré (1946, p.30) advocated such an approach when he stated that:

> "The method of physical science rests on the induction which makes us expect the repetition of a phenomena when the circumstances under which it first happened are reproduced. If *all* these circumstances could be reproduced at once, this principle could be applied without fear; but that will never happen; some of these circumstances will always be lacking. Are we absolutely sure that they are unimportant? Evidently not. That may be probable, it can not be rigorously certain, Hence the important rôle the notion of probability plays in the physical sciences."

The rules that govern a probabilistic hierarchical system emerge from an understanding of its structure. Allen and Star (1982, p.42) listed the following criteria to distinguish between laws and rules:

Laws are:	Rules are:
a) inexorable,	a) arbitrary,
b) incorporeal, and	b) structure dependent, and
c) universal;	c) local.

In other words, while we can never alter or evade laws of nature, we can always evade or change rules. For example, early fisheries economic models ignored the effects of fishing-vessel input configuration on the output of fishing power (i.e. vessels were assumed to generate a constant amount of fishing power). Using such models, many fisheries economists postulated that limiting entry can prevent the dissipation of resource rent. This rule was viable until fishermen circumvented it by altering the configuration of their vessels

4.4 MODELING A FISHERY

Fishing is a human activity, and should be studied in the context of the relevant human institutions. Stock biology and fisheries microeconomics are relevant but insufficient to the task. As such, a fishery is the business of catching fish.

A fishery's essential subsystems (holons) are by definition those clusters of activities whose absence would preclude a fishery's existence. These holons should include: a fish stock, a fish market, fishing enterprises, a labour market, a capital market, other users of the resource and a government—to mitigate market failure via regulation.

A serious flaw in the Cartesian approach to modeling this type of system emanates from the reductionist belief that *the whole is always the sum of its parts* and that, as such, it can be understood by merely understanding in sufficient detail, a sufficient portion of its parts. This leads to the Cartesian response to model failure of seeking ever greater and more detailed knowledge of the model components. Where the models persistently fail, as in fisheries, the Cartesian approach may form *positive feedback loops*—leading to a model that *eventually spins out of control* or *folds* under the crush of its own detail.

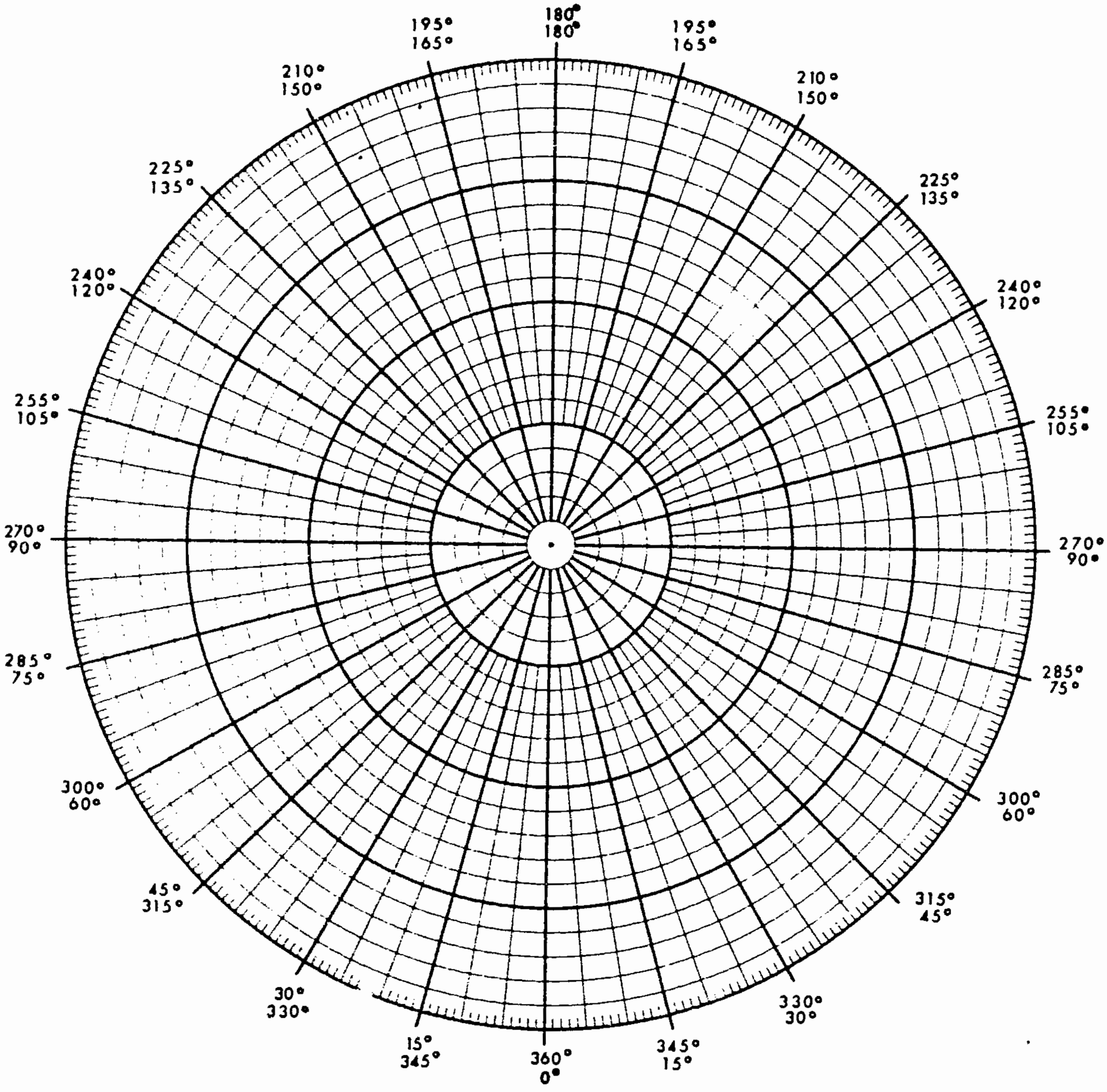
Under the systems approach to building models, if a model with a reasonable level of complexity persists in failing, the assumption is that the model has not been defined with sufficient breadth to capture all relevant influences. Current fisheries models are Cartesian based and tend to be over-burdened with details on stock biology and fisheries microeconomics but the economic and political linkages between the fishery and the society in which it is embedded are rarely considered as an active part of the model. These relations are usually treated as constants or are subsumed in implicit simplifying assumptions underlying the model. Significant harm can arise, if fisheries managers rely on such models without being aware of their deficiencies. An excellent discussion of the role that a systems model can serve is provided by Skolimoswski:

> "Models...are sophisticated cognitive structures. Their purpose is to aid our understanding. Models do not isomorphize the world in a one-to-one way. They are not mirrors, or photographic cameras by which we can capture the world *as it is*. Rather, they are a set of filters through which we apprehend the world and render it in a specific way. No model is accurate or unbiased. All models are in the final analysis metaphors. They are flexible clouds, or at any rate ought to be, and not rigid deterministic boxes. Thus adequate world models must themselves be open-ended, dynamic, behaving like a kaleidoscope, not as a clock." (Skolimoswski, 1973, pp.116-117)

The model outlined in the next chapter is a general model, in the system sense. While it includes all relevant *holons*/subsystems of the fishery and surrounding society, it minimizes the degree of detail expressed in the holons. This is done to highlight the ***macro-behaviour*** in the system and the *conditions required for* ***system equilibrium***. As noted at the start of this section, a systems way of viewing existence generates only relative knowledge—thus, meanings of facts or systems of facts always depend on an imposed context and scale.

It should, also, be remembered that the model illustrated in this diisertation is a prototype that illustrates one of many ways to apply a hierarchical systems approach to the modeling of a fishery. Popper (1961, p.31) distinguished "...sharply between the process of conceiving a new idea and the methods and results of examining it logically." Based on this idea, many of the exercises that are appropriate or even essential to the development of a functioning model of an actual fishery are beyond the scope of the prototype model in this dissertation.

CHART 4-1: An Idealized Margenau Map



5. MODELING A FISHERY AS A SYSTEM

A fishery, as noted previously, is a concept constructed by us as an aid in describing and manipulating phenomena that we perceive to be related. As such, the concept of a fishery is fuzzy and open ended. It can vary with the phenomena under consideration. Further, as a subset/holon of the infinite All, a fishery (or any holon we choose to define from it) is, itself, infinitely complex. Infinity is a concept beyond human cognition. It is, therefore, necessary to create and use finite abstractions of the infinity that is a fishery.

Good models simplify and abstract from reality to show a fragment of Creation on a human scale. As such they are more appropriate, as a means of communicating reality to humans, than more comprehensive representations. For example, Van Gogh's the *Fourteenth of July in Paris* (painted 1886-1888; Courthion, 1977, pp.138-139) abstracts from, simplifies and intensifies a scene to convey the artist's impression and passion in a way rarely achieved in the detail and precision of a photograph. Artists can transcend the problem of *not seeing a forest for the trees* by painting a forest without painting the trees or they can transcend the obverse problem by painting the trees without painting a forest. The model presented in this chapter is a general model, in the sense that it is simple and abstract. That form idealizes the general concept and behaviour of a fishery system and many of the complexities found in specific fisheries are excluded, to avoid muddying this generic model of a fishery as a system. The hierarchical models generated by a systems approach are infinitely adaptable. If the methodology is applied to specific fisheries, the model and subsystems can be adjusted so as to reflect the appropriate scope, scale, resolution or other specifics.

The difference between *a Cartesian/reductionist approach* to modeling and *a systems modeling approach* rest less on technique and more on how techniques are applied and/or results interpreted. In a systems approach boundaries are semi-permeable, not absolute—a large complex system is separated into a system of holons such that the interactions within holons are relatively strong and numerous, when compared to the interactions between holons. Holons (similar to a thing) are a convenient way to apportion the infinite Continuum into patterns of workable bits that enable an individual to order (make sense of) existence. The Cartesian need to reify perception should be resisted with respect to holons. "What we observe is not nature in itself but nature exposed to our methods of questioning" (Heisenberg, 1971, p.58). Thus reification is a delusion that has meaning only as a human convention to describe collections of perceived attributes. Another Cartesian penchant that should be avoided is the projection of a holon into reality. No matter how well a holon represents its *target phenomena* it is not that *target phenomena* nor can it have a one to one correspondence with that *target phenomena*. Given that a model cannot exhaust the full scope of *target phenomena*, it is reasonable and often useful to represent an array of phenomena with contrasting models. However, such an approach will only be accepted by those who have overcome a Cartesian urge to include all phenomena within a single objective unified theory (Wallace, 1989). An individual with a systems perspective finds the notion of differing perspectives (models) for the same phenomena as eminently reasonable. In contrast, an individual with a Cartesian perspective sees the same notion as an anathema or as evidence of fuzzy thinking.

The following subsections develop holons templates that in section 6 are adjusted, modified and assembled to form various systems models of a fishery. If they or their interactions are too simple then important behaviour in a fishery may be missed and the model may not adequately track reality. If the representation is overly complex the model may fail because required data are not available, or the resulting complexity generates chaotic, difficult to understand results or the model collapses under its own weight. It should be noted that the holon concept is used because, like a mathematical set, it can act as a finite portrayal of an infinite entity and/or process. Unless noted otherwise, each of the following subsections should be read as an independent module. As such, each module is its own microcosm and much can be inferred from its nature, structure and limitations.

As noted previously, a systems approach will only generate relative knowledge—thus, the meanings of facts or systems of facts always depend on an imposed context and scale. However, as Poincaré (1946, p. 27-28) noted, the structures within a discipline or a model are valueless if they are arbitrary. Thus, the structures and behaviours within a sub-model holon ideally should never be imposed by the model maker—instead they can and should be deduced from the nature of lower scale holons (e.g. accepted physical, economic and biological axioms) and/or the nature of higher scale holons (e.g. government objectives, vessel owner maximands and equilibrium conditions). A major purpose of model building is to identify the logical limits within a model and to infer the type of behaviour one would observe within a fishery if those limits also hold in the fishery. As the focus in this dissertation is on developing a new approach to fisheries, it is inappropriate to muddy the process by using data from a fishery (i.e. actual data are often a confused tangle of historical effects and/or effects arising from the misapplication of statistics to a profusion of processes that are, at best, poorly understood). At this stage in the development process the focus is on a search for generic behaviours within a generic fishery and parameter values are selected for illustrative purposes only (see Appendix B)—exact values are unimportant. Once the approach is better understood, the application stage can begin and the use of actual data will be appropriate. This way of developing an approach is consistent with that of Popper (1961, p.31) who distinguished sharply between the process of conceiving an idea and the methods of examining logically.

5.1 THE MARKET FOR FISH

The processes and influences subsumed in a fishery revenue to effort curve are infinite in their complexity and variety. However, for illustrative purposes, they are summarized and simplified to those effects discussed in the following subsections. The revenue curve arises from eqns (2) through (5) and is given first because (as the end-product) it is at a higher scale of abstraction than the equations from which it arises:

$$R = q\delta PE(1 - qE/r)/\alpha \qquad (1)$$

R = bioequilibrium revenue
P = landed price of fish
E = total fishing effort
q = catchability coefficient
r = maximum rate of biomass growth
α = 1/environment carrying capacity
δ = portion of M that is retained by fishermen as harvest
M = harvest related fish mortality

The revenue curve is presented before its derivation to provide a context for the discussions in the following subsections.

5.1.1 THE PRICE OF FISH

While the model developed in this section can accommodate elaborate price behaviour, analysis using such behaviour should be deferred until the gains in knowledge from models with a simple price behaviour have been exhausted. Therefore, the landed price of fish (P) is assumed to be unaffected by the average size of the fish taken, the season or the amount of the harvest.

5.1.2 STOCK CHARACTERISTICS

In keeping with the theme of a simple general model of a fishery, the fished stock is assumed to behave according to the Schaefer (1957) model where recruitment, piece growth and natural mortality are blended into a single net growth function:[22]

$$G(X) = rX(1 - \alpha X) \qquad (2)$$

$G(X)$ = annual net natural growth in the stock biomass
X = fish biomass

Equation (2) has to be placed in a time context. The choice is usually between an instantaneous or annual rate and the net growth rate should be matched to an appropriate fishing mortality rate. Annual rates were used to simplify the model relations and calculations—instantaneous rates would complicate the model by unnecessarily emphasizing intra-seasonal effects.

---

[22] "Recruitment: addition of new fish to the vulnerable [fishable] population by growth from among smaller size [younger] categories" (Ricker, 1975, p.5).

5.1.3 THE HARVEST AND FISHING MORTALITY

The harvest (fish taken and retained by fishermen) is assumed to vary with the fishing related mortality. In simple models, the harvest to fishing mortality relation (δ) is a constant fraction, in more complex models it may vary with fishing effort or other factors (Gulland, 1983, pp.67-70). Fishing related mortality includes non-catch fishing mortality—shaker mortality, increased loss to predators, ruptured air bladders, etc. (Ricker, 1976, p.1485)—and varies directly with fishing effort:

$$H = \delta qEX \tag{3}$$

H = harvest, in tonnes
δ = portion of M that is retained by fishermen as harvest
M = harvest related fish mortality (annual rate)
q = catchability coefficient
E = total fishing effort

In equilibrium, eqn (3) divided by δ can be set equal to eqn (2) and the result arranged to define the equilibrium biomass at any given level of fishing effort.

$$\bar{X} = (1 - qE/r)/\alpha \tag{4}$$

$\bar{X}$ = equilibrium fish biomass

The fishery static equilibrium harvest curve is defined by substituting the LHS of eqn (4) into eqn (3). Eqn (3) can now be stated as:

$$\bar{H} = \delta qE(1 - qE/r)/\alpha \tag{5}$$

$\bar{H}$ = Equilibrium harvest (tonnes)

The fishery bioequilibrium revenues are defined by eqn (1), which is eqn (5) multiplied by the fish price per tonne.

5.2 THE FISHING INPUT MARKET

Vessel owners must acquire inputs for their fishing vessels. Both capital and labour tend to be *committed* inputs once applied to a fishery (Copes, 1988a, pp.7-10). This characteristic sorts the inputs that vessel owners can bid on into at least two distinct markets; an entry market with inputs are not yet committed to the fishery and a veteran market containing inputs that are committed to the fishery and are not readily transferable to other employment. The isolation in some fishery dependent communities may impair the employment opportunities of individuals and savings in the community and, thereby, create a third distinct input market. However, this third type of input market is not considered further in this *general* model (i.e. it is a consideration that is *specific* to only some fisheries).

In most input markets, the equilibrium return to an input is the marginal value product for that type of input (Henderson and Quandt, 1980, p.191). The commons problem in most fisheries causes two changes to the process. First, the perceived marginal value product (PMVP) may vary from the actual marginal value product (MVP).[23] When the PMVP of an input rises above the *entry opportunity cost* of that type of input, entry occurs and the *entry opportunity cost* tends to set the return to

---

[23] Resource rent, in a fishery, may generate distortions (a common property resource effect) and cause vessel owners to perceive the marginal product of a fishing input to be much higher than its actual marginal product (see subsection 5.3.5). When economic losses cause effort in a fishery to contract, quasirents (the return to fixed costs) become visible (PMVP is less than the entry opportunity cost) and can create problems similar to those created by resource rent.

that type of input. When the PMVP of an input falls below the *exit opportunity cost* of that type input, exit occurs and the *exit opportunity cost* tends to set the return to that type of input. The return to an input is set by the PMVP only if the PMVP is between the entry and exit opportunity costs of that input. In the ultralong run, returns to fishing inputs will tend toward their entry opportunity cost.

The peculiarities of the capital and labour markets, that are relevant to a fishery, are discussed in the following subsections.

5.2.1 THE CAPITAL MARKET

The nonfishing capital market is assumed to be perfectly competitive. The rate of return to capital is assumed to be constant. Therefore, if an asset's return falls its market value falls at a similar rate. Capital is normally a freely transferable asset but once transformed into a fishing asset, it tends to have little value outside of the fishery. Thus, in terms of an individual investor, fishing capital is *locked into* the fishery until the asset is either fully used up or sold for its market value within the fishery (the net present value—discounted at a normal rate of return—of its future cash flows). By definition, the market value of fishing capital is greater than nil if there is resource rent or quasi-rent in the fishery.

5.2.2 THE LABOUR MARKET

In this model, vessel owners bid for labour in a utility driven labour market. Labour trades off income, offered by employers, against the leisure time that will be lost. Income makes leisure more valued—thus, income and leisure are, also, complements in the labour utility function. In eqn (6) all individuals are assumed to have an identical income/leisure utility functions. While this assumption is not especially realistic, it makes the model more mathematically tractable and it conforms to a common assumption in fisheries economics models—that fishermen are identical.[24]

$$U = Y^{¥}L^{Ç} \tag{6}$$

U = utility
Y = annual income of a fisherman
L = portion of a standard work-time year spent in leisure ($L < 1.0$)
¥,Ç = parameters;
assumed values: ¥ = .8
Ç = .4

The utility function is assumed to be of a Cobb-Douglas form (defined by eqn (6) and shown in Figure 5-1) and is strictly quasiconcave. This assumption is consistent with the idea that if only one input to utility increases the other becomes more binding. If the parameter ¥ and Ç values sum to one, this utility function becomes homogeneous of degree one—constant returns to scale (Silverberg, 1978, pp.84-90). However, that is an elegant, but unnecessary condition—the (Appendix B) values set for ¥ and Ç sum to 1.2 and the utility function has increasing returns to scale. Future analysis might consider the effects of varying the values of ¥ and Ç.

---

[24] It should also be noted that models using consumer surplus as a measure of consumer well-being make similar assumptions (about consumers), for the same reasons (Dixit and Weller, 1979)

5.2.3 THE LABOUR (INCOME TO LEISURE) BUDGET LINES

Each year individuals are endowed with a year of leisure ($L = 1$). Individuals exchange a portion of their leisure endowment for income.

The terms of trade between work and leisure depend on the nature of the employment taken. Fishing earnings can be defined in terms of the opportunity cost of being a fisherman. This opportunity cost is endogenously defined by the interaction of a fisherman's utility function with exogenously defined wages, paid for full and part-time nonfishing employment.

At the time of entry to a fishery, potential fishermen can choose between fishing or full-time nonfishing employment.

$$Y_{FTNF} = (1-L)W_{FTNF} \qquad (7)$$

Y_{FTNF} = annual earnings from full-time nonfishing employment
W_{FTNF} = annual wage potential a fisherman can earn in full-time nonfishing employment

Individuals who enter a fishery tend to become committed to it and are no longer employable in full-time (career) nonfishing work in the short to intermediate run—part of their year is already committed to fishing. As a result, the opportunity wage of a committed fisherman is the temporary (nonfishing) employment wage. This wage generates a budget line that is less than the full-time employment budget line.[25] The maximum utility associated with this budget line is less than the

---

[25] The wages for part-time employment will tend to be significantly less than the wages to full-time employment because fishermen are not always available and the nature of fishing tends to make fishermen less suitable for many types of employment in terms of both skills and temperament.

maximum utility associated with the full-time employment budget line. As a result, rational individuals will not enter a fishery unless, in addition to their part-time wage, they receive a lump sum compensation (τ) that is sufficient to maintain their utility at the point A level. Fishing incomes can also be *topped up* (during the off-season) by earnings from part-time nonfishing employment.

$$Y_{PTNF} = \Phi(1-L) \tag{8}$$

Y_{PTNF} = annual earnings from part-time nonfishing employment

Φ = annual wage potential fishermen can earn in part-time nonfishing employment

Figure 5-1 illustrates, in the income/leisure plane, the income curves generated by eqns (7) and (8), and an appropriate indifference curve (eqn (6)).[26]

5.2.4 THE ENTRY OPPORTUNITY COST OF BEING A FISHERMAN

The income of individuals who choose not to enter the fishery is based on full-time nonfishing employment. In Figure 5-1, an individual engaged in nonfishing full time work maximizes utility by choosing the income leisure combination at point A, where (based on the constrained optimization solution to maximizing eqn (6) subject to eqn (7)) their income equals:

$$Y_A = W_{FTNF}/(1+\text{Ç}/\yen) \tag{9}$$

---

[26] Figure 5-1 illustrates the income/leisure trade-off made by deckhands. The trade-off made by vessel owners is likely similar but is complicated by savings, loans, return on capital assets and lifetime income considerations that are not as prominent in the deckhand situation.

and the leisure equals:

$$L_A = 1/(1+¥/Ç) \qquad (10)$$

Equations (9) and (10) imply that the labour supplied by an individual is infinitely inelastic with respect to the wage. This effect occurs because the annual leisure endowment is assumed to be 100 percent of a work-time year. Thus people can only be made better off by an increase in their wage (the terms of trade for their leisure endowment). This point is more apparent if eqns (9) and (10) are substituted back into eqn (6) to produce:

$$U = [W_{FTNF}/(1+Ç/¥)]^{¥}[1/(1+¥/Ç)]^{Ç} \qquad (6a)$$

where the wage (W_{FTNF}) is the only variable.[27]

---

[27] In terms of eqns (6) to (10), a backward bending labour supply curve is possible if the income equations (eqns (7) and (8)) are nonlinear. This is not possible, given the assumptions of this model. However, the presence of time consuming maintenance tasks (i.e. grooming, health, food preparation, sleeping, etc.) could justify nonlinear income curves. Specifically, as a person's income rises they hire others to perform some maintenance tasks.

These concepts could have been incorporated into the model by assuming that the year is separated into discretionary time (T_d) and a portion spent on maintenance tasks (T_m) and assuming that discretionary time is related to

income (Y) according to: $T_d = 1(1 - e^{-aY})$

then the relationship between Y and L would be: $Y = (T_d - L)W$

which simplifies to: $L = 1 - e^{-aY} - Y/W$

These concepts are likely to be relevant in low income developing nations. However, a backward bending labour supply curve is neither necessary nor within the scope of this discussion. Therefore, the linear income functions of eqns (7) and (8) are used in this model.

5.2.5 THE EXIT OPPORTUNITY COST OF FISHERMEN

Fishing inputs tend to become dedicated to fishing after entering a fishery. The problem is particularly severe for vessel owners—fishing labour tends to be dedicated to fishing, but can move between vessels; fishing capital tends to be dedicated both to fishing and to a vessel.

The dedicated nature of fishing inputs tends to reduce their opportunities for employment outside of the fishery. Thus, the wage required to attract an individual to a fishery (i.e. entry opportunity cost) is often much higher than the wage needed to keep an individual in a fishery (i.e. exit opportunity cost).

The difference between the labour entry opportunity cost and the exit opportunity wage tends to be highest at the time of exit. Individuals who leave a fishery find that, with time, the wages available to them in nonfishing work tend to increase.[28] Therefore, the exit opportunity cost is a complex discounted present value of all post exit earnings, adjusted for risk.

5.2.6 COMBINATIONS OF INCOME AND LEISURE THAT SATISFICE FISHERMEN

When utility is a function of only income and leisure, an individual is indifferent between any of the income-leisure combinations defined by eqn (6) ($U=U_o$). Fishermen are indifferent between *full-time nonfishing work* and *fishing* only when their leisure of:

---

[28] The human capital and work attitudes of fisherman tend to be inappropriate for many nonfishing jobs. Over time, exfishermen can add to their human capital and adjust their work attitudes.

$$L_B = (1-g) \qquad (11)$$

g = fishing season as a fraction of a year

is combined with a fishing income (based on eqns (6) and (11)) of:

$$Y_B = [U_o(1-g)^{-\text{Ç}}]^{1/\text{¥}} \qquad (12)$$

U_o = utility at point A

However, fishermen can (also) work part-time. This reduces the income required from fishing. In Figure 5-1, individuals are indifferent between the situation of part-time work and that of nonfishing full-time work only when they are given sufficient compensation to shift them to point C.[29] Thus, the income at point C equals:

$$Y_F = \tau + \Phi(1-L) \qquad (13)$$

The leisure at point C can be defined by setting the slope of eqn (6) equal to the slope of eqn (13):

$$dY/dL = -(\text{Ç}/\text{¥})(Y/L) = -\Phi \qquad (14)$$

then reorganizing eqn (6) to define income and substituting the RHS of that result into eqn (14), which can then be reorganized to:

$$L_c = [(\text{Ç}/\text{¥})(U_o{}^{1/\text{¥}}\Phi)]^{[1/(\text{Ç}/\text{¥}+1)]} \qquad (15)$$

A similar process can be used to develop:

$$Y_c = [(\text{¥}/\text{Ç})(U_o{}^{1/\text{Ç}}\Phi)]^{[1/(\text{¥}/\text{Ç}+1)]} \qquad (16)$$

The compensation required by a part-time worker to be indifferent to point A is adapted from eqn (13):

$$\tau = Y_c - \Phi(1-L_c) \qquad (17)$$

Figure 5-1 shows how fishermen choose to allocate their year—the fraction of a year to the right of the line labeled g is spent fishing

---

[29] This is called *Hicksian Compensation*—It involves maintaining a constant utility; *Slutsky Compensation* involves maintaining a constant purchasing power (Silverberg, 1978, p.244 and 257-258).

and the fraction of a year to the left of g is spent in either leisure or part-time employment. The *Hicksian Compensation* (τ), required by part-time workers, is by definition the vertical distance between the *part-time income curve* (eqn (8)) and the *compensated part-time income curve* (eqn (13)). Points B and E are on the ray that extends vertically above leisure (L) of .5 of a year. Points B and C are on the indifference curve (eqn (6)) and point E (where: L=g and Y=fishing income) is slightly below the indifference curve. Thus, fishing earnings might be thought of as having a fixed component and a variable component— the fixed element of τ is represented by the vertical distance between points D and E and the variable element ($g\Phi$) is represented by the vertical distance between point D and the X-axis. If the distance between points E and C is separated into horizontal and vertical rays, the horizontal ray represents the time spent (by a fisherman) in part-time nonfishing work and the vertical ray represents the earnings in that employment. As such, eqn (13) can be restated as:

$$Yc = \tau + g\Phi + (1-L-g)\Phi \tag{18}$$

where the first two terms in the RHS of eqn (18) are fishing earnings and the third term is earnings from nonfishing part-time work.

5.2.7 INCOMES AND SATISFACTION IN FISHERIES

The concepts displayed in Figure 5-1 can be used to examine various long and short-run problems in fisheries. It should be remembered that the fishing income equilibrium (point C in Figure 5-1) is a bionomic equilibrium produced by when the biological, economic and regulatory forces, in the fishery, are balanced.

5.2.7.1 INCOMES AND SATISFACTION IN FISHERIES -- LONG RUN (FIGURE 5-1)

At the fishery long-run equilibrium (by definition) the entry opportunity costs of the fishermen are being met. While opportunity cost is usually a pecuniary concept, satisfaction can be derived from many things. Thus, low income fishermen may be just as satisfied with their lot as individuals in high income nonfishing full-time employment. The latter may have more income but less leisure than fishermen. However, the many forces in a fishery can cause hardship by driving the incomes of fishermen even lower than the satisficing level.

Modifying the indifference curve of a fisherman for other factors (e.g. quality of work) may cause a given utility curve to shift down and rotate anti-clockwise from the utility curve of the nonfishermen. This will further reduce the income required to satisfice fishermen.

When part-time employment is available the fishermen will always be at point C. This occurs because any change in their fishing income (i.e. due to a reduction in the fishing season) is offset by increased earnings from part-time nonfishing work. As a result, the fishing compensation premium (τ) tends to be constant.

On the other hand if nonfishing part-time employment is unavailable, the fishermen earnings/leisure equilibrium combination will move along the indifference curve. A reduction in the fishing season will cause point B to shift down the indifference curve toward more leisure and less income. If such work is available, fishermen's incomes tend to be buffered against decreases in the fishing season. The Figure 5-1 analysis can be adapted to the absence of alternative employment (to fishing) by replacing eqn (7) with:

$$Y_{SA} = \textit{Lamda} \qquad (7a)$$

Y_{SA} = social assistance income
Lamda = social assistance payment per annum

This produces a corner solution (of L = 1.00) for the nonfishing individual and fishermen will be indifferent only at income/leisure combinations that generate the same utility as the $\{Y,L\} = \{\textit{Lamda},1\}$ level.

5.2.7.2 INCOMES AND SATISFACTION IN FISHERIES -- SHORT RUN (FIGURE 5-1)

If the government uses subsidies to increase fishing incomes to the average income of people engaged in full-time nonfishing work, the utility of being a fisherman will exceed the equilibrium and entry to the fishery will occur in the form of new vessels and/or inputs to the existing vessels. If the fishery managers are maintaining a TAC, they will respond to an increase in effort by shortening the fishing season which decreases the fishing incomes back to the point C level. In this case the benefit to fishermen from subsidies is always short run, even though the annual cost to maintain the subsidies continues in the long run.

The assumption of a uniform income-leisure indifference curve can be relaxed by having several groups of labour with different relative values for leisure. The annual earnings of fishermen at the bionomic equilibrium (point C in Figure 5-1) are defined by the conditions that satisfice the marginal fisherman. When an open access fishery is managed for a TAC, fishermen with a relatively high preference for income and a relatively low preference for leisure tend to be squeezed out of the fishery by a combination of entry by individuals with the opposite income-leisure preference and the shortening of seasons. In the situation envisioned here, as the fishing power rises, the season is shortened. While this keeps effort, harvest and total revenue in the fishery, annual fishing incomes per fisherman decline as the fishing total costs rise and the number of fishermen increases. Individuals currently in the fishery may find those changes to be unsatisfactory and, if they are unable to offset the adverse effects, they initiate a process of exiting to other work. However, individuals with a relatively high preference for leisure may continue to enter the fishery as the fishing season is shortened and the earnings per day increase (i.e. people with strong leisure preferences may experience a producer surplus from an annual income-leisure combination that is unsatisfactory to people with strong income preferences). It should be noted that effort exiting the fishery under such conditions tends to be that of people whose annual income expectations are relatively high, when compared to those of the people entering the fishery. Thus, in the long run, people who are satisfied with low incomes and high leisure may drive other groups from the fishery. However, in the short to intermediate run, fishing labour tends to be dedicated to the fishery. As a result, until this long-run transit from the fishery is complete people may be trapped in the fishery with incomes they consider to be inadequate.

The above point can be extended to fisheries that are very profitable because they are new.[30] New fisheries tend to generate resource

---

[30] New fisheries refers (in this case) to fisheries that are past the exploration stage but have not yet suffered significant biomass reductions. The high incomes in exploratory fisheries likely includes a risk premium.

rent—this can attract individuals with a high relative preference for income. As the fishery matures, this rent is dissipated but the individuals with a high relative income preference, that were attracted to the fishery, are stranded. Until the long-run transit from the fishery is complete, such individuals will experience much hardship. Attempts by the government to alleviate this hardship, via a subsidy, will fail for the reason previously noted.

5.2.8 INFERENCES DRAWN FROM A UTILITY APPROACH TO FISHERMAN WELL-BEING

The utility approach to fisherman well-being highlights some very interesting ideas.

5.2.8.1 THE TRAGEDY OF THE COMMONS AND POVERTY

Appendix A-1 demonstrates that the belief that *the tragedy of the commons causes poverty* is well entrenched in ecology and in fisheries policy economics and analysis. As Wittgenstein noted (1953, sec.109), the words used in a philosophical discussion should be clearly defined to prevent the discussion from descending into a battle of semantics. *The tragedy of the commons* concept is reviewed thoroughly in Section 2 and Appendix A. Defining poverty is another problem. Boulding (1985b, p.199) says: "Poverty is the inability to sustain a decent human life because of a lack of command over economic goods." Friedman (1976, pp. 255-56) asserts that "...living levels regarded as *poverty* are always judged by any society relative to the general level of living." However, for this discussion poverty does not have to be precisely defined—it is sufficient to note that poverty is an involuntary state and that for each society a boundary demarcates the various states of poverty from those of a decent life. Figure 5-1 shows that if utility is defined by a Cobb-Douglas type function of income and leisure, relative income is a poor measure of poverty. As the number of considerations incorporated in the utility function increases, relative income becomes an increasingly inadequate indicator of the state of poverty. Causation is a Cartesian concept (Capra, 1983, p.85) where the cause—antecedent(s)—is invariably and unconditionally followed by a certain phenomenon—the effect (Sykes, 1982, p.147). Causation is an important idea—if a phenomenon (e.g. poverty) is undesirable and if the theory of its cause is valid then the phenomenon can be eliminated by eliminating its antecedent(s).

As it is possible to imagine many situations where *the tragedy of the commons* is neither necessary nor sufficient to cause poverty, it does not seem to be particularly useful to describe the tragedy of the commons as causing poverty. Clearly, further research and analysis is needed to identify conditions for which it is reasonable to attribute poverty in fishing communities to a common property resource problem.

While the common property resource problem observed in many fisheries may not be a cause of poverty, it does tend to dissipate any resource rent and any additional resources directed to subsidize fishing incomes—making them unavailable for use in poverty relief. This is a subtle but an important distinction which, if added to the other ideas discussed in the preceding subsections, can lead to several inferences for fisheries and social policy.

5.2.8.2 INFERENCES FOR FISHERIES AND SOCIAL POLICY

As inferences, the following ideas should be treated cautiously until they are either supported or invalidated by future research.

- Even if, from a microeconomic perspective, poverty is not attributable to the fishery, a fishery can attract poverty to it. For example, in a region of high unemployment, open access fisheries often act as an employer of last resort (Copes, 1986a). Also, as noted previously, individuals with a high preference for leisure relative to income tend to enter fisheries and drive down the bionomic equilibrium earnings of fishermen. The individuals with a high income preference then tend to move from the fishery. This process will tend to lower the average incomes in regions where fisheries are the primary source of income.

- When fisheries are examined from a macroeconomic perspective they may contribute to underemployment.

  On the supply side, an open access fishery attracts inputs until all resource rents are dissipated. This reduces the net amount of goods a society can produce.[31]

  On the demand side, the individuals employed in a fishery tend to be satisficed with lower incomes and demand fewer goods than individuals engaged in full time nonfishing careers.

  These effects can work together to reduce the overall income and standard of living in regions with large fisheries. However, the net effect on the *quality of life* in such regions is less clear.

- A government cannot increase the long-run average (net) income of fishermen. Subsidies directed to reducing their fishing costs and/or subsidies linked with fish yields, generate short-run benefits that are dissipated by the common property resource nature of the fishery or are capitalized in the value of fishing licenses. The end result is a long-run annual expenditure and no benefit.

- Governments can raise fishing incomes in the long run by increasing the entry opportunity cost of fishermen. However, that action (by definition) would also tend to increase the income of people in full-time nonfishing employment. In terms of relative income (not utility) fishermen could still claim relative poverty.

---

[31] In producing a given amount of fish, a rationalized fishery will use less inputs than a biologically managed open access fishery. The freed inputs can be used to produce more goods.

- A government can increase fishing incomes in the long run by increasing short-run exit opportunity cost of fishing (i.e. increase the wage for part-time work via community projects, training programs that increase fishermen's nonfishing human capital, subsidies to employers, etc.).

- A government can raise fishing incomes in the long run by making fishing less enjoyable (e.g. less leisure, rigorous training, onerous side duties). However, fishermen are unlikely to thank the government for their higher incomes and there may be some hardship during the adjustment period.

- If governments want to improve the lot of fishermen, they need a more comprehensive measure of *well-being* than that afforded by relative incomes.

5.2.9 WAGES OR SHARES PAID TO FISHERMEN

A complex relationship likely exists between the short-run opportunity costs of fishermen (Φ) and the amount of part-time nonfishing employment being sought (1-L-g). Specifically, on one hand, as fishermen seek more part-time nonfishing employment the wages for such work will tend to be driven down but, on the other hand, as the length of time that fishermen are available for part-time work increases their value to prospective employers may increase. The model, in the following sections, evades such complications by utilizing only the simple (parameter) short-run opportunity cost behaviour discussed above.

The amount earned by deckhands depends on economics, but the form it takes is based on custom. In a few cases the risk sharing rationale of shares is ignored and labour is paid a flat wage. In the short run, the wage earnings can lie between the earnings defined by eqns (7) and (8); to attract labour to a fishery it has to be equal to, or greater than, the earnings defined in eqn (13); in the very long-run, it will fixed at one fifteenth of the vessel revenues, the deckhand wage is:

$$W_s = R_1/15 - g\Omega \tag{20}$$

W_s = share earnings/deckhand, if a share equals 1/15 of the vessel revenues

5.3 FISHING ENTERPRISES

As noted in chapter 2, a vessel tends to be the optimum scale for private operations in a fishery. Multi-vessel companies can exist if market channels or other features in the fishery (e.g. family or other ties) can minimize shirking and diversion problems. In this model, the decision unit for private fishing enterprises is assumed to be at the vessel level. Any departures from this assumption will be justified in terms of risk/return benefits to the enterprises and/or the structure of the fishery being exploited.

Rational entrepreneurs endeavor to maximize the net present value (NPV) of their firms based on their expectations of the future and a suitable discount rate. Fishing entrepreneurs usually exploit a fish resource in common with other fishing enterprises. As a result, there are few means for them to predict the future in a fishery, other than to assume that the future will be similar to the present.[33]

---

[33] Rational expectations about a future situation (Friedman, 1981, p.230) can be formed only when an individual controls, understands or has other knowledge of the processes leading to that situation. If rational expectations are not viable, individuals must anticipate future situations based on a random walk process (Levy and Sarnat, 1972, pp.492-493) or on adaptive expectations (Friedman, 1981, p.229) or on an assumption that the future will be the same as present. Lane's (1988, p.787) model of investment decision making by fishermen assumed that fishermen extrapolated future conditions from the present conditions.

If the present revenue pattern is expected to persist into future periods and if costs include a discount rate on investment then profit maximization is consistent with maximizing net present value. In most industries, maximizing profits involves minimizing the cost of producing a given level of revenue and then selecting the profit maximizing output from the range of outputs studied. However, the common property resource nature of most fisheries generates some interesting effects at the fishing entrepreneur level.

5.3.1 FISHING ENTERPRISES -- REVENUES

The common property resource nature of most fisheries causes the revenue captured by a vessel to be a function of its output (its fishing effort) and the output of all vessels in the fishery (total effort in the fishery).

$$R_i = R_B E_i / [\sum_{j=1}^{n} E_j] \quad ; \quad \text{where } 1 \le j \le n \tag{21}$$

$R_B = f(\sum_{j=1}^{n} R_i)$ = bionomic equilibrium revenues at a given total fishing effort
j = j^{th} vessel of vessels 1 to n
R_i = revenue of vessel i
E_i = fishing effort of vessel i

In most cases this relation is either unknown to owner/skippers or it is perceived as irrelevant (as it is beyond their individual control). Instead, they tend to assume that the present conditions will persist into the future (section 5.3) and act as though there is a linear relationship between vessel revenue and effort:

$$R_i = E_i(R_o/E_o) \tag{22}$$

$_o$ = value of the preceding variable is prechange value and is viewed as being constant by the owner/skippers

5.3.2 FISHING ENTERPRISES -- EFFORT-PRODUCTION FUNCTION

The linkage between fishery output and inputs is convoluted. Fishing enterprises do not directly produce fish. They acquire inputs, to be combined on a vessel platform to generate fishing power (annual capacity to catch fish). The fishing power is transformed by the portion of the year spent fishing, into fishing effort. The fishing power production function (of a vessel) is assumed to be of *a general Cobb-Douglas form* (Chiang, 1974, pp.407-411). This function exhibits decreasing returns to scale ($n + k < 1$), reflecting (among other things) the limited room on vessel platforms—as fishing inputs are added, their interference with each other tends to increase and increasing the platform size can only partially overcome this effect.

$$f_i = mN^nK^k \tag{23}$$

f_i = fishing power of vessel i
N = crew per vessel—assumed to be a whole number from 1 to 10, inclusive [34]
K = units of capital per vessel
n,k,m = technology parameters

Multiplying the total fishing power in a fishery by the effective length of the fishing season (portion of a year) defines the fishing effort actually applied to the fishery. If all vessels are identical, then:

$$E = gfV \tag{24}$$

V = number of vessels
g = effective season (portion of a year)

Equations (23) and (24) can be combined and adapted to form:

---

[34] The labour input (unlike capital) comes in discrete non-divisible units (called people). At some level (assumed to be 11 crew per vessel), crowding causes the return to additional labour to become negative.

$$E_i = gmN^nK^k \qquad (25)$$

$$E = gmVN^nK^k \qquad (26)$$

E = total fishing effort in the fishery

If vessels vary in input configuration, then:

$$E = gV(\sum_{i=1}^{n} f_i) \qquad (27)$$

f_i = fishing power of the i^{th} vessel

The selection of a unit for fishing power or effort (both use the same unit of measure) is arbitrary—any unit of measure has meaning only in its use as a unit of measure.[35] This quality is frequently overlooked because of the need to use a physical proxy to measure target phenomena. A hazard of using a physical proxy such as a *standard vessel-year* as a unit of measure is that empirical implications may be attributed to it that either are or soon may be meaningless.[36] Defining the *fishing power/effort* unit of measure in terms of the fraction of fishing mortality it imposes on a standard stock under standard conditions has several virtues. First, it is conceptually simple. Second, the values for the unit of power/effort measure and the catchability coefficient are defined as being related artifacts of the model (e.g. the catchability coefficient relates to the unit of effort in the same way as a price index relates to the unit of currency). Third, it is independent

---

[35] Tying a unit of measure to a physical phenomenon either makes calibration easier or makes the taking of measurements easier. A unit of measure is however an artifact created for our purposes and need not have any basis other than its role as a unit of measure.

[36] The concept of a *standard vessel-year* must be clearly defined in terms of the quality and quantity of inputs, technology and fishing time subsumed in the measure (Ricker, 1975, p.18). In the absence of a clear definition, changes in applied technology will severely inflate or deflate the standard vessel-year measure.

of changes in the fishery except those affecting the attributes of the catchability coefficient. Fourth, the fishing power of vessels and the fishing period is explicitly stated—not subsumed in a fuzzy measure, whose accuracy falls far short of its implied precision. In this model the fishing power/effort unit of measure is defined so that the catchability coefficient is 1/10,000th (in this model the stock is assumed to be a standardized stock—the stock characteristics and the fishing conditions do not change).

Catchability coefficient may be a misnomer. The name ***harvesting power index*** may be more appropriate as it refers to that coefficient's primary role—keeping track of the relative effect of a unit of effort on the stock biomass—to be consistent with other fishery models, this dissertation continues to refer to q as the *catchability coefficient*. In terms of equation (2):

$$E = 1 = H/(\delta q X) = .0001/q \quad \text{and} \quad q = .0001 \qquad (28)$$

If instead of being a parameter, the *catchability coefficient* is a function (e.g. varies with fishing effort, stock biomass, season, or other phenomena—see Clark, 1976, pp.235-237) the approach to indexing fishing power/effort used in eq (28) is more involved, but it is still feasible.

5.3.3 FISHING ENTERPRISES — COSTS

The use of fishing inputs results in fixed and variable costs. If vessel labour is paid wages then the following social cost of fishing will also tend to be the private fishing cost observed by a vessel owner/skipper:

$$C_i = b + (\Gamma + g\theta)K + (\tau + g\Phi + g\Omega)N \qquad (29)$$

C_i = fishing annual social cost per vessel
b = annual cost associated with vessel ownership (license fees, moorage, security, etc.)
Γ = annual cost of fishing capital (insurance, interest, depreciation, some types of maintenance, etc.)
θ = annual operating costs of fishing capital (fuel some types of maintenance)
τ = compensated opportunity cost of a deckhand not having a permanent nonfishery job
Φ = annual wage that a deckhand can earn working elsewhere (this is a part time wage that reflects the loss accounted for in τ)
Ω = annual provision costs/deckhand
N = number of fishermen per vessel

If the share system involves the crew sharing 50 percent of the vessel revenue then vessel owner/skippers will observe a private fishing cost of:

$$C_i = b + (\Gamma+g\theta)K + .5R_i(1-1/N) + (\tau+g\Phi+g\Omega) \qquad (30)$$

A share agreement with individual shares of 1/15 of the vessel revenue causes a vessel owner/skipper to perceive a private fishing cost of:

$$C_i = b + (\Gamma+g\theta)K + R_i(N-1)/15 + (\tau+g\Phi+g\Omega) \qquad (31)$$

5.3.4 FISHING ENTERPRISES — RENTS AND INCOMES

The owner/skipper of a vessel will receive rents of:

$$\pi_i = R_i - C_i \qquad (32)$$

π_i = rent received by the owner of the i^{th} vessel

and a net income of:

$$Y_i = (\tau+g\Phi) + (1-L-g)\Phi + \pi_i \qquad (33)$$

Y_i = income received by the owner/skipper the i^{th} vessel

Depending on which of (the above) labour remuneration formulas is used, a deckhand will receive rent per one of the following equations:

$$\pi_{dh} = -0- \tag{34}$$

$$\pi_{dh} = .5R_i/N - (\tau+g\Phi+g\Omega) \tag{35}$$

$$\pi_{dh} = R_i/15 - (\tau+g\Phi+g\Omega) \tag{36}$$

π_{dh} = rent received by a deckhand

and a net income of:

$$Y_{dh} = (\tau+g\Phi) + (1-L-g)\Phi + \pi_{dh} \tag{37}$$

Y_{dh} = income received by a deckhand

5.3.5 FISHING ENTERPRISES -- CONFIGURATION OF VESSEL INPUTS

As discussed in subsection 5.3, it is assumed that vessel owners expect the current conditions in their fishery to persist, predict the return to fishing effort (eqn (22)), and configure their vessels so as to maximize their current profits. If the resource rents available in a fishery increase, a fishery entrepreneur will want to increase his output of fishing effort. This can be accomplished by adding inputs to the current vessel, by adding vessels or by a combination of both. The economics of this choice are illustrated in Figure 5-2 and derived in the following paragraphs. The inferences are presented first to give a context for the discussion of how they were deduced/derived.

In Figure 5-2, the average and marginal cost of expanding fishing effort through the addition of more minimum cost configuration vessels (subsection 5.3.5.1) is a series of discrete points. In that series, the fishing effort per entrepreneur is a multiple (vessels per entrepreneur) times the effort produced by the minimum cost vessel (defined by eqn (29) after substituting in the RHS of eqns (47) and (48)). And, the average and minimum cost is the cost per minimum cost vessel:

$$C_1^* = b/(1-n-k) \tag{38}$$

divided by the effort of that vessel. The lowest cost expansion path for fishing effort is along this series of cost points (where the most cost-effective input configuration is used on each vessel).

In Figure 5-2, the single vessel average cost of fishing effort curve was developed by defining (based on eqns (25) and (43)) the lowest cost combination of inputs that can produce a given fishing effort in a single vessel;

$$N = (E_1/(gm[(k/n)(\tau+g\Phi+g\Omega)/(\Gamma+g\theta)]^{k}))^{(1/(n+k))} \tag{39}$$

$$K = (E_1/(gm[(n/k)(\Gamma+g\theta)/(\tau+g\Phi+g\Omega)]^{n}))^{(1/(n+k))} \tag{40}$$

then the RHS of eqns (39) and (40) were substituted into eqn (29) and the result divided by E_1.

In Figure 5-2, the single vessel marginal cost of fishing effort curve was developed by defining (based on eqns (25), (41), (42), (43) and (57)) the combination of inputs that, at a given amount of vessel effort, yields the most profit (i.e. where the marginal cost of effort is equal to the marginal revenue generated);

$$N = [(E_o/R_o)[(\tau+g\Phi+g\Omega)/(nmg)] \\ [(n/k)(\Gamma+g\theta)/(\tau+g\Phi+g\Omega)]^{k}]^{1/(n+k-1)} \tag{41}$$

$$K = [(E_o/R_o)[(\Gamma+g\theta)/(kmg)][(k/n)(\tau+g\Phi+g\Omega)/(\Gamma+g\theta)]^{n}]^{1/(n+k-1)} \tag{42}$$

then the LHS of eqns (41) and (42), as calculated for various marginal costs ($MC = MR = R_o/E_o$), were substituted into equation (25).

In terms of Figure 5-2, adding vessels is the lowest cost mode of expanding fishing effort. Also, the operating and financial risk facing a fishing firm tends (*ceteris paribus*) to vary inversely with the number of vessels it operates. Specifically, as the number of vessels a firm operates increases, the standard deviation of its earnings will fall from the single vessel average toward the industry average.[37] In *portfolio* theory terms (Levy and Sarnat, 1972, p.485), by diversifying into additional vessels, a fishing firm reduces its *unsystematic risk* (e.g. the risk associated with the catch fluctuations of a single vessel) toward the industry risk.[38] As vessels are discrete nondivisible units, it is (from a financial risk perspective) safer to finance the purchase of a second vessel with a mortgage on it than to mortgage and input-stuff a single vessel. Also the minimum cost vessel will always be competitive in a fishery, whereas, an input stuffed vessel may become nonviable as the resource rent available in the fishery declines. Where there is rapid expansion of a new fishery, the rent decline will tend to be readily apparent and input stuffing of vessels will likely be confined to ephemeral and/or low cost items.

---

[37] This statement is derived from one of the implications of the *central limit theorem*, in statistics (Parsons, 1974, pp.314-322)—as the number of observations in a sample is increased, the standard deviation of the sample mean falls from the *universe* standard deviation toward zero (it will be zero when the number of observations equals the number of items in the *universe*).

[38] The Firm may be able to further reduce risk, by diversifying into nonfishing investments, but that topic is beyond the scope of this discussion.

In terms of configuring physical inputs, the multivessel approach is a more cost-efficient means of expanding effort than is the stuffing of inputs into a single vessel. However, this advantage is offset to a large degree by shirking problems. As noted in section 2, a vessel tends to be the most appropriate scale for managing private fishing enterprises. As the number of vessels being managed increases, the shirking costs increase and make input stuffing a relatively more cost -effective expansion mode. Even if shirking problems can be overcome, another requirement may work against a multivessel enterprise—a class of fishermen is needed, who have the ability to skipper a vessel but do not have the desire to own a vessel.

It is not possible to generalize as to which of the two expansion modes is superior. In some fisheries, expansion by input stuffing will dominate; in some fisheries, expansion will be primarily through the addition of firms (operating single minimum cost vessels) and in some fisheries expansion will tend to be driven by multivessel firms adding minimum cost vessels. However, in most fisheries, expansion will occur via an amalgam of the above ways.

Figure 5-3 illustrates the effect on the average fishing costs of restricting the vessel labour input to whole numbers. The average cost is in Figure 5-3 lies above the Figure 5-2 curve, drops down to touch it as the rounded and unrounded labour values approach and then rises again. As the number of crew rises, the degree of distortion (from the rounding) declines rapidly. As the next subsection shows, great care should be exercised when applying constrained cost minimization techniques to fisheries where one or both inputs tend to be *lumpy*.

5.3.5.1 CONFIGURATION OF VESSEL INPUTS -- MINIMUM COST

The social ideal would be to have the effort in a fishery expand along the minimum cost expansion path. In a static equilibrium analysis, the objective function would be to:

Minimize: $C_i = b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N$ (43)

Subject to: $E_i = gmN^{n}K^{k}$ (25)

$$Z = b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N - \pounds(gmN^{n}K^{k} - E_i) \tag{44}$$

$\pounds$ = Lagrange multiplier

This is a standard *constrained cost minimization* problem and its solution (see Appendix C) yields the following information:

$$K^* = kb/[(\Gamma+g\theta)(1-n-k)] \tag{44a}$$

$$N^* = nb/[(\tau+g\Phi+g\Omega)(1-n-k)] \tag{44b}$$

* = value of the preceding variable is consistent with fishing cost minimization

$$RTS = nK/(kN) = (\tau+g\Phi+g\Omega)/(\Gamma+g\theta) \tag{45}$$

However, the above solution requires that both labour and capital be infinitely divisible. Specifically, the average cost curve in Figure 5-2 is an envelope that is continuous and well behaved (no kinks) only if vessel inputs are infinitely divisible and, hence, will generate an infinite number of production curves that are tangent to the average cost envelope. Figure 5-3 shows that when labour is available only in discrete whole number units, the average cost envelope becomes kinked.

The average cost function in Figure 5-3 was developed by the following (*integer programming*) process. Equation (25) was reorganized to define the capital input:

$$K = [E_i/(gmN^{n})]^{1/k} \tag{46}$$

The RHS side of eqn (44a) was substituted into eqn (43) to produce:

$$C_i = b + (\Gamma+g\theta)[E_i/(gmN^{n})]^{1/k} + (\tau+g\Phi+g\Omega)N \tag{43a}$$

Equation (43a) was then divided by fishing effort to produce:

$$AC_i = [b + (\Gamma+g\theta)[E_i/(gmN^n)]^{1/k} + (\tau+g\Phi+g\Omega)N]/E_i \qquad (47)$$

AC_i = average cost of vessel i fishing effort.
$N = \langle N \rangle$
$\langle\rangle$ = notation for rounding the value inside the brackets to an integer (Abrramowitz and Stegan, 1972, p.146)

The marginal cost function in Figure 5-3 was created by differentiating eqn (43a) with respect to fishing effort to produce:

$$MC_i = (\Gamma+g\theta)E_i^{(1/k-1)}N^{(-n/k)}(gm)^{(-1/k)}/k \qquad (48)$$

MC_i = vessel i marginal cost of effort

The minimum average cost for any given labour input was developed by dividing eqn (25) into eqn (43) to define average cost as a function of the vessel inputs:

$$AC_i = [b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/(gmN^nK^k) \qquad (49)$$

Equation (49) was differentiated with respect to the inputs:[39]

$$\delta AC_i/\delta K = [(\Gamma+g\theta) - k[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/K] /(gmN^nK^k) = -0- \qquad (49a)$$

$$\delta AC_i/\delta N = [(\tau+g\Phi+g\Omega) - n[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/N] /(gmN^nK^k) \neq -0- \qquad (49b)$$

Equation (49a) was reorganized to define the optimal amount of capital (the amount of capital input that minimizes the average cost, of fishing effort, for a given labour input):

$$K^* = [b + (\tau+g\Phi+g\Omega)N]/(\Gamma+g\theta)/(1/k-1) \qquad (50)$$

---

[39] If eqn (49b) is divided into eqn (49a) the result is eqn (45)—the rate of technical substitution. However, labour is not infinitely divisible and eqn (49b) should not be set to zero. Therefore, it is inappropriate to make that division and, hence, to use the RTS (eqn (45)) to define the cost minimizing capital input for a given labour input.

The RHS of eqn (50) was substituted into eqn (49) and the result reorganized to:

$$AC^*_i = [(\Gamma+g\theta)(1/k-1)]^k[b + (\tau+g\Phi+g\Omega)N]^{1-k}/[gmN^n(1-k)] \qquad (51)$$

The optimal labour input is:

N^* = value of <N> that generates the lowest value of AC^*_i in eqn (51) (52)

The socially optimal fishing costs for a fishery as a whole can now be defined:

$$C_i^* = b + (\Gamma+g\theta)K^* + (\tau+g\Phi+g\Omega)N^* \qquad (53)$$

$$C^* = V^*C_i^* \qquad (54)$$

C = total cost of fishing, when all vessels are identical

In Figure 5-2 labour is used in fractional units, therefore, the minimum cost of fishing effort is below and to the left of the equivalent point in Figure 5-3 (where labour is restricted to whole units). Also, the minimum average cost envelope in Figure 5-3 lies above the Figure 5-2 average cost curve everywhere except for those points where the component AC curves of Figure 5-3 are tangent to the Figure 5-2 AC curve.

The labour productivity parameter (*n*) is the only difference between Figures 5-3 and 5-4. In Figure 5-4, *n* has been increased to .40 from .15 (see Appendix B-1). A comparison of Figures 5-3 and 5-4 shows that the global minimum average cost of fishing effort occurs at the minimum cost point of one of the component curves. This appears to be a general feature of cost curves where one input is restricted to an integer. It can, also, be inferred from the relationship between long and short-run cost curves, that are not input restricted.[40] In Figure 5-4, where the labour productivity parameter n has been increased from the Appendix B-1 value of .15 to .40, the global minimum AC occurs at the minimum point of the two fishermen/vessel curve. In Figure 5-3, the global minimum AC occurs at the minimum point of the one fisherman /vessel curve.

At the Figure 5-3 minimum long-run average cost of effort point, vessels generate 98.901 units of fishing power by employing one fisherman and 7.021 units of capital, at a cost of $90,264 (or $912.67 per unit of fishing effort).

5.3.5.2 PERCEIVED OPTIMUM CONFIGURATION OF VESSEL INPUTS IF LABOUR IS PAID A WAGE.

If the vessel owners try to configure their vessels so as to maximize their vessel net income;

$$\pi_i = R_i - C_i \qquad (32)$$

expansion in a fishery will come about through both input stuffing and the addition of vessels. Based on eqns (22), (25) and (29), the vessel

---

[40] This analysis is similar to the relationship between short and long-run production costs. Layard and Walters (1978, p.217) noted that "if for a given output, plant size is optimal SMC = LMC. If plant size is too small SMC > LMC and vice versa." Blomqvist, Wonnacott and Wonnacott (1983, pp.466 -468) provide further insight by noting that, by definition, at the minimum point on the LAC curve all short and long-run economies of scale must be exhausted. That can only occur if the SMC equals the SAC which equals the LAC. If there are long-run economies of scale the LAC curve is tangent to the SAC to the left of the SAC minimum. If there are long-run diseconomies of scale, the LAC curve is tangent to the SAC to the right of the SAC minimum. An integer input restricted LAC curve can have tangencies with an equivalent unrestricted LAC curve only in the diseconomies of scale region. Thus, the minimum point on an integer input restricted LAC curve is above the minimum point on the unrestricted LAC curve (unless, due to an extraordinary coincidence, the two points are equal).

owner observes a profit function of:

$$\pi_i = gmN^{n}K^{k}R_o/E_o - b - (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega)N \tag{55}$$

and adds inputs until the profit maximizing conditions (inferred when the following partial derivatives are set to nil) are met:

$$\delta\pi_i/\delta K = kmN^{n}K^{k-1}gR_o/E_o - (\Gamma+g\theta) = \text{-0-} \tag{55a}$$

$$\delta\pi_i/\delta N = nmN^{n-1}K^{k}gR_o/E_o - (\tau+g\Phi+g\Omega) \neq \text{-0-} \tag{55b}$$

When eqn (55a) is divided by eqn (55b) the result is the rate of technical substitution:

$$RTS = nK/(kN) = (\tau+g\Phi+g\Omega)/(\Gamma+g\theta) \tag{45}$$

However, this division is not appropriate because labour is not infinitely divisible—eqn (55b) does not equal zero. Instead, eqn (55a) is reorganized to define the optimal capital for a given labour input:

$$K^{o} = [gkmR_oN^{n}/E_o/(\Gamma+g\theta)]^{(1/1-k)} \tag{56}$$

^{o} = value of the preceding variable is consistent with vessel profit maximization

The RHS of eqn (56) was substituted into eqn (55) to produce:

$$\pi_i = (\Gamma+g\theta)(1/k - 1)[gmN^{n}(R_o/E_o)/(\Gamma+g\theta)]^{(1/1-k)} - b - (\tau+g\Phi+g\Omega)N \tag{57}$$

However, as previously noted, fractional labour units are not feasible so the optimal labour input must be defined as:

N^{o} = value of <N> that generates the highest value of π_i in eqn (57) (58)

The private optimal fishing costs at the vessel level and for a fishery as a whole can now be defined:

$$C_i^{o} = b + (\Gamma+g\theta)K^{o} + (\tau+g\Phi+g\Omega)N^{o} \tag{59}$$

$$C^{o} = V^{o}C_i^{o} \tag{60}$$

Subject to: $1 \leq N \geq 10$.

5.3.5.3 PERCEIVED OPTIMUM CONFIGURATION OF VESSEL INPUTS IF LABOUR SHARES A PORTION OF VESSEL REVENUE.

If labour shares a flat percentage of vessel gross revenue (e.g. 50 percent), eqns (56) to (61) are still appropriate—a vessel owner will hire deckhands until the sum of the provision costs and the total opportunity cost of the deckhands rises to equal labour's share of the expected vessel revenue. In a world without uncertainty, this type of share agreements leaves fishing labour without a share in any resource rent.

5.3.5.4 PERCEIVED OPTIMUM CONFIGURATION OF VESSEL INPUTS IF THE CREW EACH RECEIVE ONE SHARE OF A FIXED NUMBER OF SHARES OF VESSEL REVENUE.

If the vessel gross revenue is split into a *base* number of shares (e.g. a set number of shares) with each crew receiving one share, then based on eqns (22), (25), (31) and (32) vessel owners observe a profit function of:

$$\pi_i = gmN^{n}K^{k}(R_o/E_o)(\mathrm{Base}+1-N)/\mathrm{Base} - b - (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega) \quad (61)$$

Base = inverse of the revenue share
received by each deckhand.

and will add inputs until the following conditions are met:

$$\delta\pi_i/\delta K = kgmN^{n}K^{k-1}R_o(\mathrm{Base}+1-N)/E_o - \mathrm{Base}(\Gamma+g\theta) = \text{-0-} \quad (61a)$$

$$\delta\pi_i/\delta N = [ngmN^{n}K^{k}R_o/(\mathrm{Base}E_o)][(\mathrm{Base}+1)/N - 1 - 1/n)] \neq \text{-0-} \quad (61b)$$

If labour was infinitely divisible eqn (61b) would equal nil and could be reduced and rearranged to the following constant:

$$N^{\S} = (\mathrm{Base}+1)/(1+1/n) \quad (62)$$

$\S$ = value of the preceding variable
is consistent with fishing vessel profit maximization

and equation (61a) can be reorganized to:

$$K^{\S} = \mathrm{Base}(E_o/R_o)(\Gamma+g\theta)/[kgmN^{n}(\mathrm{Base} + 1 - N)] \quad (63)$$

However, as previously noted, fractional labour units are not feasible so eqn (61b) is reorganized to define the (private) optimal amount of capital to compliment a given amount of labour per vessel:

$$K^{\$} = [kgmN^{n}(R_o/E_o)(Base+1-N)/Base/(\Gamma+g\theta)]^{1/(1-k)} \qquad (64)$$

The RHS of eqn (64) was substituted into eqn (61) to produce:

$$\pi_i = [gmN^{n}(R_o/E_o)(Base+1-N)/Base/(\Gamma+g\theta)]^{1/(1-k)}$$
$$(k^{k/(1-k)}-k^{1/(1-k)})/(\Gamma+g\theta)^{k/(1-k)} - b - (\tau+g\Phi+g\Omega) \qquad (65)$$

As previously noted, fractional labour units are not feasible so the optimal labour input must be defined as:

$$N^{\$} = \text{value of } \langle N \rangle \text{ generating the lowest value in eqn (64)} \qquad (66)$$

The private optimal fishing costs at the vessel level and for a fishery as a whole can now be defined:

$$C_i^{\$} = b + (\Gamma+g\theta)K^{\$} + gmN^{n}K^{k}(R_o/E_o)(N^{\$}-1)/Base + (\tau+g\Phi+g\Omega) \qquad (67)$$

$$C^{\$} = V^{\$}C_i^{\$} \qquad (68)$$

Subject to: $1 \leq N \leq 10$, and
$R_i/15 \geq (\tau+g\Phi+g\Omega)$.

Equations (62) and (63) show that under a share system, with infinitely divisible inputs, a fixed share base and the crew paying the provision costs only the capital input varies as effort in the fishery expands—the labour input per vessel is constant. A more complex pattern emerges when the labour input is restricted to whole units. Equations (64) to (66) are only solvable if the share base is defined. The share base may be an arbitrary parameter (an accident of history) but, in the long run, it more likely adjusts to reflect such things as the private opportunity cost of the inputs (labour, capital, vessel platform, fees), the bargaining power of vessel owners relative to that of the crew, the current technology, and any legal, social or political constraints. This relation is simplified in this model to:

$$\text{Base} \leq R_o/V/(\tau+g\Phi+g\Omega) \qquad (69)$$

which states that the amount paid to a crew member must, in the long-run, at least cover the entry opportunity costs of that crew member.

5.3.6 FISHING ENTERPRISES -- THE EFFECT OF SEASON LENGTH

Fishery managers often use the fishing season length as a control variable. When pondering how the season length affects the behaviour of the vessel owners, it is useful to think of time as a fishing input that enters the vessel profit function via the season length (g).

As noted previously, vessel owners are profit maximizers who seek to configure their vessels to a labour and capital mix that they perceive as optimal. If the fishing season length is changed, the vessel configuration that was perceived as optimal will tend to be perceived as suboptimal for the new season length and vessel owners will seek to reconfigure their vessels. If inputs are lumpy rather than infinitely divisible, this effect may be obscured by regions of relative stability (i.e. instead of being continuous, configuration changes will tend to be less frequent and discrete).

5.3.6.1 FISHING ENTERPRISES -- SEASON LENGTH EFFECTS UNDER OPEN ACCESS

As noted in section 2, in an open access fishery, the equilibrium forms where fishing revenues and costs are equal, and the average cost of effort is minimized, for the given circumstances. These equilibrium conditions are consistent with the analysis in subsection 5.3.5.2. And that analysis can be adapted to provide insight into how vessel owners respond to season reductions, in an open access fishery. However, the additional assumption that labour is infinitely divisible is needed.

Under that assumption, the effort average cost function and eqn (49a) are unchanged:

$$AC_i = [b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/(gmN^{n}K^{k}) \qquad (49)$$

$$\delta AC_i/\delta K = [(\Gamma+g\theta) - k[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/K]/(gmN^{n}K^{k}) = \text{-0-} \qquad (49a)$$

but eqn (49b) is changed to:

$$\delta AC_i/\delta N = [(\tau+g\Phi+g\Omega) - n[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/N]/(gmN^{n}K^{k}) = \text{-0-} \qquad (49c)$$

Equations (49a) and (49c) are the effort average cost minimizing conditions, with respect to labour and capital. They also are the minimizing conditions for the total cost of effort, with respect to the labour and capital inputs. Equations (49a) and (49c) can be reorganized to define (respectively) K and N. When the RHS of those results are substituted (respectively) into eqns (49c) and (49a), the results can be reorganized to:

$$K^{*} = kb/[(\Gamma+g\theta)(1-n-k)] \qquad (44a)$$

$$N^{*} = nb/[(\tau+g\Phi+g\Omega)(1-n-k)] \qquad (44b)$$

$$dK^{*}/dg = -\theta kb(\Gamma+g\theta)^{-2}/(1-n-k) \qquad < \text{-0-} \qquad (49d)$$

$$dN^{*}/dg = -(\Phi+\Omega)nb(\tau+g\Phi+g\Omega)^{-2}/(1-n-k) < \text{-0-} \qquad (49e)$$

Given the assumptions in this subsection, it can be deduced (from eqns (49d) and (49e)) that as the fishing season length declines in an open access fishery, the vessel owners perceive that the optimum amounts of capital and labour increase. Thus, input stuffing is not merely a phenomenon of limited entry, but (at least under these circumstances) can be associated with reductions in the length of the fishing season.

The effect of a change in season length, on the number of vessels in the fishery, can be determined by modifying eqn (26) so the fishing effort is at the constant managed level of E_o.

$$E_o = gmVN^{n}K^{k} \qquad (26a)$$

$$V^{*} = E_o N^{-n}K^{-k}/(gm) \qquad (26b)$$

When the chain rule is used to differentiate eqn (26b) with respect to a change in the season length the result is:

$$dV^{*}/dg = (\delta V/\delta g)(\delta g/\delta g) + (\delta V/\delta N)(\delta N/\delta g) + (\delta V/\delta K)(\delta K/\delta g) \qquad (26d)$$

$$dV^{*}/dg = -E_o N^{-n}K^{-k}/(g^2 m) + E_o N^{-n}K^{-k}(\Phi+\Omega)n^2 b/[gmN(\tau+g\Phi+g\Omega)^2(1-n-k)]$$
$$+ E_o N^{-n}K^{-k}\theta k^2 b/[gmK(\Gamma+g\theta)^2(1-n-k)] \qquad (26e)$$

If the RHS of eqns (44a) and (44b) are substituted into eqn (26e), the result simplifies to:

$$(1/V^{*})dV^{*}/dg = n/[\tau/(\Phi+\Omega) + g] + k/(\Gamma/\theta + g) - 1/g \qquad (26f)$$

Given the parameter values in Appendix B: $(n+k) < 1$, $(n+k)/g < 1/g$, $n/[\tau/(\Phi+\Omega) + g] < n/g$, $k/(\Gamma/\theta + g) < k/g$, and (logically)

$$dV^{*}/dg = n/[\tau/(\Phi+\Omega) + g] + k/(\Gamma/\theta + g) - 1/g < -0- \qquad (26g)$$

Thus, given the conditions described in this subsection, as the season in an open access fishery is reduced, the fishery vessels tend to increase both in fishing power (i.e. input stuffing) and in number. These predictions are corroborated by the simulation results summarized in Table 6-3 (the "Actual MEY" vs the "MEY Harvest" columns).

5.3.6.2 FISHING ENTERPRISES -- SEASON LENGTH EFFECTS UNDER LIMITED ENTRY

In sections 2 and 6, it is noted that limiting entry can create a situation where a fraction of the resource rent is not dissipated. As a result, profits can be important in a limited entry fishery and the analysis in subsection 5.3.5.2 can be adapted to provide some insight into how the vessel owners in such a fishery respond to changes in the length of the fishing season. However, the additional assumption that labour is infinitely divisible is needed. Under that assumption, the vessel profit function and eqn (55a) are unchanged:

$$\pi_i = gmN^nK^kR_o/E_o - b - (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega)N \qquad (55)$$

$$\delta\pi_i/\delta K = kmN^nK^{k-1}gR_o/E_o - (\Gamma+g\theta) = \text{-0-} \qquad (55a)$$

but eqn (55b) is changed to:

$$\delta\pi_i/\delta N = nmN^{n-1}K^kgR_o/E_o - (\tau+g\Phi+g\Omega) = \text{-0-} \qquad (55c)$$

While explicit solutions to K and N can be educed from eqns (55a) and (55c), the resulting functions generate complex differentials with respect to the season length (g). Another way to perform static equilibrium analysis is to note that, at the vessel scale, eqns (55a) and (55c) are the profit maximizing conditions with respect to labour and capital—if those equations are differentiated with respect to g, the following pair of equations result:

$$[\delta^2\pi/(\delta K^2)](\delta K/\delta g) + [\delta^2\pi/(\delta K\delta N)](\delta N/\delta g) + \delta^2\pi/(\delta K\delta g) = \text{-0-}$$
$$[\delta^2\pi/(\delta N\delta K)](\delta K/\delta g) + [\delta^2\pi/(\delta N^2)](\delta N/\delta g) + \delta^2\pi/(\delta N\delta g) = \text{-0-}$$

which can be reorganized to:

$$[\delta^2\pi/(\delta K^2)](\delta K/\delta g) + [\delta^2\pi/(\delta K\delta N)](\delta N/\delta g) = -\delta^2\pi/(\delta K\delta g)$$
$$[\delta^2\pi/(\delta N\delta K)](\delta K/\delta g) + [\delta^2\pi/(\delta N^2)](\delta N/\delta g) = -\delta^2\pi/(\delta N\delta g)$$

and restated as:

$$\pi_{KK}(\delta K/\delta g) + \pi_{KN}(\delta N/\delta g) = -\pi_{Kg}$$
$$\pi_{NK}(\delta K/\delta g) + \pi_{NN}(\delta N/\delta g) = -\pi_{Ng}$$

and reorganized to:

$$\begin{bmatrix} \pi_{KK} & \pi_{KN} \\ \pi_{NK} & \pi_{NN} \end{bmatrix} * \begin{bmatrix} (\delta K/\delta g) \\ (\delta N/\delta g) \end{bmatrix} = \begin{bmatrix} -\pi_{Kg} \\ -\pi_{Ng} \end{bmatrix} \qquad (55d)$$

Both $\delta K/\delta g$ and $\delta K/\delta g$ can be *signed* by using Cramer's Rule on eqn (55d) —see Silverberg (1978, pp.130-34). The first step in this process is to define and *sign* the other elements in eqn (55d):

$$\pi_{KK} = k(k-1)mN^{n}K^{k-2}gR_o/E_o \quad < -0- \;;\; (\text{i.e. } k-1 < -0-) \qquad (55e)$$

$$\pi_{NN} = n(n-1)mN^{n-2}gK^{k}R_o/E_o \quad < -0- \;;\; (\text{i.e. } n-1 < -0-) \qquad (55f)$$

$$\pi_{KN} = \pi_{NK} = nkmN^{n-1}K^{k-1}gR_o/E_o > -0- \;; \qquad (55g)$$

$$\pi_{Kg} = kmN^{n}K^{k-1}R_o/E_o > -0- \qquad (55h)$$

$$\pi_{Ng} = nmN^{n-1}K^{k}R_o/E_o > -0- \qquad (55i)$$

The next step, in this process, is to define and sign the determinant of the first matrix in eqn (55d):

$$|\,D\,| = \begin{bmatrix} \pi_{KK} & \pi_{KN} \\ \pi_{NK} & \pi_{NN} \end{bmatrix} = D = \overset{(-)}{\pi_{KK}} * \overset{(-)}{\pi_{NN}} - \overset{(+)}{(\pi_{NK})^2} \qquad (55j)$$

When the RHS of eqns (55e), (55g) and (55f) are substituted into eqn (55j) the result is positive only when:

$$(k-1)(n-1) > nk \qquad (55k)$$

which can be reorganized to:

$$k + n < 1.00 \qquad (55l)$$

and makes the common sense assertion that the results are dependent on the economies of scale experienced with the inputs. In this case, the restriction is met—the economies of scale are negative ($k+n < 1.00$).

If the determinant D is positive then, based on Cramer's Rule and the above equations:

$$\delta K/\delta g = \begin{bmatrix} -\pi_{Kg} & \pi_{KN} \\ -\pi_{Ng} & \pi_{NN} \end{bmatrix} / \overset{(+)}{D} = \frac{-\overset{(+)}{\pi_{Kg}} * \overset{(-)}{\pi_{NN}}}{D} + \frac{\overset{(+)}{\pi_{Ng}} * \overset{(+)}{\pi_{KN}}}{D} > -0- \qquad (55m)$$

$$\delta N/\delta g = \begin{bmatrix} \pi_{KK} & -\pi_{Kg} \\ \pi_{NK} & -\pi_{Ng} \end{bmatrix} / \overset{(+)}{D} = \frac{-\overset{(+)}{\pi_{Ng}} * \overset{(-)}{\pi_{KK}}}{D} + \frac{\overset{(+)}{\pi_{Kg}} * \overset{(+)}{\pi_{NK}}}{D} > -0- \qquad (55n)$$

Given the assumptions in this subsection, it can be deduced (from eqns (55m) and (55n)) that as the fishing season length declines in an open access fishery, the vessel owners perceive that the optimum amounts of capital and labour decrease increase. Thus, the input stuffing that is associated with limited entry may (at least under these circumstances) be mitigated by reductions in the fishing season length. However, more analysis is needed on the effects of such a policy—on things such as social costs and global efficiency—before season management should be generally adopted as a policy tool in limited entry fisheries.

In a limited entry fishery the vessel numbers are, by definition, fixed. However, for the harvest (R_o/P) to be constant the effort (E_o) must be constant:

$$E_o = gmVN^{n}K^{k} \tag{26a}$$

Given that the vessel owners are changing the configuration of N and K in their vessels in response to changes in the season length, then the fishery managers can only maintain the target harvest if they adjust the number of licensed vessels:

$$V = E_oN^{-n}K^{-k}/(gm) \tag{26b}$$

As noted in the previous subsection:

$$dV/dg = (\delta V/\delta g)(\delta g/\delta g) + (\delta V/\delta N)(\delta N/\delta g) + (\delta V/\delta K)(\delta K/\delta g) = -0- \tag{26d}$$

Based on eqns (55m) and (55n):

$$\delta K/\delta g > -0-$$

$$\delta N/\delta g > -0-$$

and the partial differentials of eqn (26b) show that:

$$\delta V/\delta g = -E_o N^{-n} K^{-k}/(g^2 m) \quad < -0-$$

$$\delta V/\delta N = -nE_o N^{-n-1} K^{-k}/(gm) < -0-$$

$$\delta V/\delta K = -kE_o N^{-n} K^{-k-1}/(gm) < -0-$$

$$dV/dg = \overset{(-)}{(\delta V/\delta g)}\overset{(+)}{(\delta g/\delta g)} + \overset{(-)}{(\delta V/\delta N)}\overset{(+)}{(\delta N/\delta g)} + \overset{(-)}{(\delta V/\delta K)}\overset{(+)}{(\delta K/\delta g)} < -0- \quad (26g)$$

Therefore, given the conditions described in this subsection, as the season in a limited entry fishery is reduced, input stripping will occur and the fishery's vessels will tend to decrease in fishing power and in number. These predictions should be corroborated with further research before being incorporated into fisheries management policies.

5.3.6.3 FISHING ENTERPRISES -- SEASON LENGTH EFFECTS UNDER IQs

In sections 2 and 6, it is noted that under individual quotas the amount that a vessel can earn tends to fixed at its quota. Under such conditions (because increasing revenues is difficult, if not impossible) profit maximizing quota holders will tend to focus on minimizing the average cost of fishing effort. As a result, the analysis in subsection 5.3.6.1 is applicable here and:

$$K^* = kb/[(\Gamma+g\theta)(1-n-k)] \quad (44a)$$

$$N^* = nb/[(\tau+g\Phi+g\Omega)(1-n-k)] \quad (44b)$$

$$E_o = gmVN^n K^k \quad (26a)$$

$$V^* = E_o N^{-n} K^{-k}/(gm) \quad (26b)$$

$$dK^*/dg = -\theta kb(\Gamma+g\theta)^{-2}/(1-n-k) \quad < -0- \quad (49d)$$

$$dN^*/dg = -(\Phi+\Omega)nb(\tau+g\Phi+g\Omega)^{-2}/(1-n-k) \quad < -0- \quad (49e)$$

$$dV^*/dg = n/[\tau/(\Phi+\Omega) + g] + k/(\Gamma/\theta + g) - 1/g < -0- \quad (26g)$$

Given the assumptions in this subsection, it can be deduced (from eqns (49d) (49e) and (26f)) that as the fishing season length declines in an IQ fishery, the amounts of capital and labour perceived as optimal by IQ owners increase and more vessels are needed to take the TAC, at the minimum cost for a given season length. This input stuffing and the increase in vessel numbers may make managing the season length a counter-productive fisheries management tool in IQ fisheries, at least in terms of maximizing resource rents. However, in terms of providing employment or other equity considerations it may prove to be a useful tool.

5.3.7 FISHING ENTERPRISES — VESSEL SUCCESSION AND THE COST OF FISHING

Understanding how fishing costs vary with total fishing effort is essential to good fisheries management. A linear cost/effort function is the simplest assumption, but its use is reasonable only if the configuration of vessels or the mix of vessel configurations is constant across vessels and through time/space. As noted in section 5.3.5, the vessel configuration desired by the owner of a single vessel tends to vary with the resource rent and to vary inversely with total effort.

If fishing effort expands in a fishery by the addition of minimum cost vessels and if the fishing season length is fixed, the predisposition of fisheries economists to assume linear cost of fishing effort curves is appropriate. If effort is expanded in a fishery through the addition of vessels at the (then) perceived optimal configuration (see subsections 5.3.5.2 to 5.3.5.4), the total cost of fishing curve will be neither linear nor time independent. In this case, estimates of the cost function (derived from regression on cost/effort data) tend to be more of an artifact of the data collection process and a fishery's history than a fair depiction of fishing costs. This idea is developed more fully in subsection 6.1.2.

The managers of a fishery can develop an appropriate description of their fishery's total cost function only if the effects of changing vessel configuration, and the forces driving such changes, are understood and factored into the empirical cost/effort data.

The process and outcome of competition between the vessel configurations in a fishery is similar to the process in Darwin's concept of evolution (section 3.0) in that vessel owners adapt their vessels as a response to the effort level in a fishery (competition) as well as to natural factors. As such, fishing vessel adaptation is a relative concept that can be understood only by knowing the full range of bionomic relations. And, the optimum adaptation may change rapidly and subtly as those relations change.

In biology, the change (over time) in an area's biota that arise from changes in the environment is called succession.[41] It is a useful concept for fisheries. In both situations the precursors often assist in bringing about the environmental conditions needed by their successors and succession is dependent on the ability to deny the precursors access to a vital resource. Vessel succession works through interception. Successor configurations intercept sufficient fish (through time

---

[41] The biota is the animal and plant life in a region.

and/or space) to make precursor configurations non-viable.[42] Several dicta can be derived from the vessel succession concept:

i. Vessel succession is based on efficiency at the vessel scale rather than efficiency at the fishery or social scale. Given the common property resource problems inherent in most fisheries, a remarkable coincidence of events and circumstances is necessary for unregulated succession to generate socially efficient vessels (i.e. the minimum cost vessel defined in subsection 5.3.5.1).

ii. Vessel succession is dynamic. In open access fisheries, departures from the minimum cost vessel configuration (see subsection 5.3.5.1) vary directly with the amount of the resource rent and inversely with the amount of effort in a fishery.[43] At a bionomic equilibrium there is no resource rent and only the minimum cost vessel configuration will be present.

iii. Vessel succession is adaptive. The vessel succession path and equilibrium configuration adapt in response to changes precipitated by fisheries managers. For example, if managers reduce the fishing season length or impose limited entry the intent is to either reduce or maintain the level of fishing effort. However, vessel owners respond to the limitations by ***input stuffing***, which offsets to some degree the intent of the management intervention and forces a more intensive manipulation, to which vessel owners respond and so on.

iv. The lowest unit cost fishing effort is produced by the minimum cost vessel configuration that is associated with the maximum fishing season length. As the season is reduced, the vessel configurations adapt and new minimum cost configurations form (see subsection 5.3.6). However, because time is an input, a reduction in the season forces the fishermen to substitute away from the socially optimal vessel configuration to one that is efficient under the shorter fishing season, but that generates fishing effort at a unit cost that is higher than the ***global*** minimum unit cost.

---

[42] In a coho fishery, regulated only for escapement, succession will tend to flow from fixed traps and weirs (fishing in the river) to gill net vessels (fishing in the river mouth) to seine vessels (fishing offshore) to troll vessels (which can profitably fish at lower stock densities) to the ultimate in succession, drift net vessels (intercepting immature coho salmon on the high seas).

[43] The vessel configuration that generates the minimum cost fishing effort is the socially efficient vessel configuration. As many fisheries are widely defined and may encompass many niches, they may sustain several different socially optimal vessel configurations.

5.4 FISHERIES REGULATION

The presence of government and the laws it enforces are so pervasive that many economists either treat them as part of *ceteris paribus* or focus on the effect of a single regulation. Law and government are a vital part of any economy. Roman law was not always fair, equitable, or economically sound but when Rome fell those who had lived under *Pax Romana* found that even bad law was better than no law. If an accepted or enforced system of law is absent "...social interaction is subject only to the laws of nature. There are no property rights and the ultimate arbiter is the physical force of individuals or the coalitions they can form. (Alexander the Great, asked on his deathbed who should inherit his empire, answered: *He who can hold it.*)" (Peltzman, 1976, p.244).

Governments tend to form because a degree of cooperation is more productive than absolute conflict and cooperation is only viable if an arbiter is present to transcend the *prisoner's dilemma* trade problem. Specialization and trade is good for everyone, in the long-run, but specialization and theft may be better for an individual, in the short run. However, as more individuals turn to theft the general standard of living falls because there is less things to steal and more thieves trying to steal. A government enriches society by diverting conflicts to the legal system. It performs this role by using: appeals to common sense, arguments of legitimacy or, if all else fails, the application of an overwhelming superiority in the means of violence. Codified law, legal precedent and enforced custom reinforce the government's efforts to reduce the level of social conflict by creating behaviour norms and discouraging actions that either precipitate or perpetuate conflict.

Governments range from being autocratic to being democratic. The first extreme tends to be changed only by revolution, conquest or collapse and the later extreme can change every few years, if its policy mix is not at least accepted by a plurality of those governed. An increase in individual freedom beyond that afforded by a democracy tends toward anarchy and a revival of the *prisoner's dilemma*. The nature of revolution/conquest makes modeling the situation (before, during and after a revolution) difficult. Revolutions often change the *overclass* and then return to the prerevolution style of government but the event could shift to another style of government. A democratic government is assumed in the analysis in this dissertation—democracy, by providing a path for social evolution, greatly reduces the probability of revolution.

The policies of a government are made effective by bureaus which translate policy into regulations and enforce regulations. The bureaucrats and the government are not a uniform entity—the bureaucrats may or may not sympathize with government policies and they may or may not be adequately controlled by the government. The motivations and limitations of fishery managers are discussed in the next subsection, and the subsection following the next discusses the motivations and limitations of their sponsors (the government).

5.4.1 FISHERIES REGULATION — THE MANAGERS

A bureaucrat acts on behalf of a sponsor and receives a budget to provide services or other benefits to a target group.[44] The established literature on the economic behaviour of bureaucrats (Hayek, 1952; von Mises, pp.47-49; Tullock, 1965, 1975 and 1976; Downs, 1967; Coase, 1969; Niskanen, 1971; Stigler, 1971; Posner, 1974; Peltzman, 1976; Becker, 1983) depicts them as having the same underlying motivation as any rational individual—they act so as to maximize their own utility.

Bureaus provide public goods or mitigate public bads—the nonexclusive nature of the benefits of public goods/services creates particularly severe *agency problems* between bureaus and their sponsors.[45] Specifically, while sponsors want the marginal benefit provided to the target groups to equal the marginal cost of providing it, bureaucrats (according to Niskanen, 1971, pp.36-42) want to maximize the total budget of the bureau during their tenure. If there is a severe information asymmetry favouring the bureau over its sponsor, the bureaucrat is able to offer the bureau services according to *their average social benefit schedule* (the *all or nothing demand curve*; Niskanen, 1971, pp. 24-30) instead of according to the schedule of their marginal cost. If

---

[44] In this discussion, the term bureaucrat means the senior official of a bureau with a separate identifiable budget. This is consistent with the approach used by Niskanen (1971, p.22).

[45] In agency theory, a firm is viewed not as an individual but merely as an overlapping set of contracts among principals and agents, each of whom is assumed to be motivated solely by self interest. Therefore, the behaviour of any multiperson organization is the outcome that brings into equilibrium the relative power, information and (possibly) conflicting interests of the principals and agents (Alchian and Demsetz, 1972; Leibenstein, 1975; Baiman, 1975 and 1982; Jensen and Meckling, 1976; Fama and Jensen, 1982).

its sponsor is particularly uninformed, a bureau's budget may expand to the point where the average social benefit from the bureau's activities is equal to the average cost. This is the maximum budget desired by a bureaucrat. Any further expansion would cause the bureau to run a deficit (i.e. at the higher activity level its costs are greater than its total social benefit). A bureau's budget tends to be less than or equal to the total social benefit that it provides.

While the extremes depicted in the Niskanen view of bureau behaviour are rarely realized it is likely that the budgets of many bureaus are closer to their *all or nothing demand curve* than to their *marginal cost curve.* Tullock (1976) provided the more reasonable argument that bureaucrats attempt to minimize the sum of the flak that they get from their sponsors and target beneficiaries and/or regulated groups.

The following schedule of the objectives of fishery managers was developed from the above discussions on bureaucratic motives and from previous discussions in this dissertation. The synthesis is rational but not adequate. It does not view the bureaucrat as a complete person but is based on the *economic man* concept.[46] As such it should be tempered with the professionalism and idealism observed in most fisheries managers. Another problem is that the attainment of several objectives conflicts with the attainment of other objectives in the list.

TABLE 5-1: <u>The Objectives of Fishery Managers</u>

1. Preserve the fish stock.
2. Ensure that fishermen, shoreworkers, workers in fishery support industries and other users of the resource perceive that their well-being (vis-à-vis incomes, employment and/or allocation of the stock) is enhanced by the actions of the regulatory agency.
3. Minimize the sum of all *flak* received from various groups.
4. Maximize the agency's budget, status and resources.
5. Maximize the gross social wealth produced by the fishery.

The theories and concepts mentioned previously in this subsection were used to arrange the above objectives in what (in my judgement) is their order of importance to fisheries managers. The first two objectives secure the existence of the regulatory agency and the last three directly or indirectly maximize the well-being of the employees of the agency.

---

[46] The *economic man* is the concept of humanity being solely motivated by economic reasons. It was created by economists of the classical school, who were using the (Cartesian) deductive method in an attempt to fashion economics into an exact science known as pure economy (Greenwald et al., 1983, p.152). The approach failed because it assumed that to be rational a person must be objective. It did not appreciate the power of a subjective value to modify objective reasoning. Economists in the Neo-classical school, believing that objectivity was essential to make economic analysis mathematically rigorous, adapted the axioms drawn from the economic man concept to transcend the problem of subjective values. The resulting axioms/corollaries of *rational consumer behaviour* were stated in relative/ordinal terms and hence did not exclude subjective values, as would an absolute/cardinal system. These axioms can be found in many microeconomics textbooks (e.g. Stigler, 1966, pp.46-70; Green, 1976, pp.21-45).

5.4.2 FISHERIES REGULATION — THE GOVERNMENT

Subsection 5.4 discussed the general role of a government, in the economy. This subsection focuses on the government's role as the sponsor of the agency responsible for managing a fishery. The government, in return for paying the budget of the fishery management agency, expects it to manage the fishery so as to meet the government's current policy objectives. Various theories have been developed to explain the behaviour of individuals in government. These theories include:

- Public Interest Theory -- *Regulation* is instituted primarily for the protection and/or benefit of the public at large or some large subclass of the public (Stigler, 1971, p.3). Mitigation of externalities is in this category.
- Enforcement Theory -- *Enforcement* is a necessary part of a social system of property rights and contracts and that system leads rational individuals to negotiate, so that the gain from their actions and actions that affect them is always greater than what is lost (Coase, 1969).
- The Economic Theory -- The coercive power of government can be used to give significant benefit to particular individuals or groups. In such terms, regulation can be viewed as a product whose allocation is governed by supply and demand (Posner, 1974, p.344).
- The Bureaucratic Theory -- Individuals in government service acting so as to maximize their own utility. Tullock (1976) argues that bureaucrats attempt to minimize the sum of flak they receive from consumers on one hand and regulated producers on the other. Niskanen (1971, pp.36-42) asserts that bureaucrats maximize their bureau's total budget during their tenure, subject to constraints imposed by the sponsor organization.

Many supporting examples can be found for each of these theories. However, while some theories explain some of the stated objectives of government and other theories reveal a few hidden agendas of government, none of them can account for the breadth of government behaviour actually observed. Becker's (1983) "Theory of Competition Among Pressure Groups for Political Influence" unifies the theories and provides many useful propositions and corollaries concerning the behaviour of governments and bureaucrats. Individuals with interests in the fishery can be clustered into several interest groups:

- Fishermen
  - vessel owners,
  - deck hands.
- Fish processors
  - managers,
  - shoreworkers,
  - investors.
- Potential fishermen
  - investors,
  - unemployed,
  - underemployed.
- Regulatory bureau employees.
- Taxpayers.
- Consumers
  - domestic,
  - foreign.
- Outfitters and other suppliers to fishermen.
- Beneficiaries of multiplier effects.
- Other (fishery) user groups
  - native food fishermen,
  - sport fishermen,
  - environmentalists,
  - fishermen in related commercial fisheries.

According to Becker (1983), the relative political effectiveness (capacity to benefit or harm politicians) of the groups, or coalitions thereof, determines how well the government fishery policy represents their interests. According to Niskanen (1971), the degree of information asymmetry (between the fishery regulation bureau and its government sponsor) will determine the extent to which government policy is acted upon in the fishery.

The following schedule of the fishery objectives of government was developed from the above discussions on the motives of individuals in government. Many of the objectives are in conflict with each other, especially if a short run time frame is used. Also, the schedule like that used to form the objectives of fisheries managers is based on the *economic man* concept. As such the qualities of integrity and idealism found in many politicians can not be adequately considered.[47]

TABLE 5-2: The Fishery Objectives of Government

1. Preserve the fish stock.
2. Reduce the persistence of poverty in fishery dependent communities.
3. Reduce the nominal rate of unemployment in the region around the fishery.[48]
4. Ensure that the *good* done by the fisheries management agency is attributed to the current government while the *unpleasant aspects* of the fisheries management are attributed either to prior administrations or forces not controllable by the current government.
5. Reduce the need for government subsidies in fishery dependent communities.
6. Ensure that the fishery management agency is cost effective.
7. Maximize the net social wealth produced by the fishery, but not at the cost of increasing the nominal rate of unemployment in the region around the fishery.

The theories and concepts discussed previously in this subsection and the preceding subsection were used to arrange the above objectives in what (in my judgement) is their order of importance to those that form the government. However, in terms of specific governments and/or fisheries, this ordering may appear fuzzy because the level of funding

---

[47] Ibid. note 46.

[48] The nominal rate of unemployment is the percent of employable individuals desiring to be employed but unable to find employment. A real rate of unemployment would take into consideration the effects of *under-employment*.

to attain given objectives may vary with the strength of the economy. Also, a change in government often brings people to power who have new agendas or doctrines on such related issues as privatization, regional equity, social welfare, etc.

There is rarely a consensus on what form or level that management intervention should take in a fishery. Also, the structural and institutional problems in most fisheries make the task of overseeing fisheries management needed, difficult, thankless and politically hazardous. Specifically:

- It takes an individual years to develop a reasonable understanding of both the complex problems (socio-political and bio-economic) involved in fisheries and the sophisticated techniques required to manage a fishery.
- A stock collapse or other harm precipitated by a management failure is often not apparent until years or decades after the culpable policy has been implemented. If the fishery is on a slow-growing long-lived species, recovery from a stock collapse, if it occurs at all, may involve decades.
- Changes in the harvest trend of a fishery are often due to changes in climate or other factors not directly related to management actions in the fishery.
- An asymmetry exists between the cost and value patterns of information. The cost of acquiring information on the characteristics of fish stocks tends to rise exponentially with both its timeliness and quality. However, the value of that information depends on the nature and degree of management intervention in the fishery.

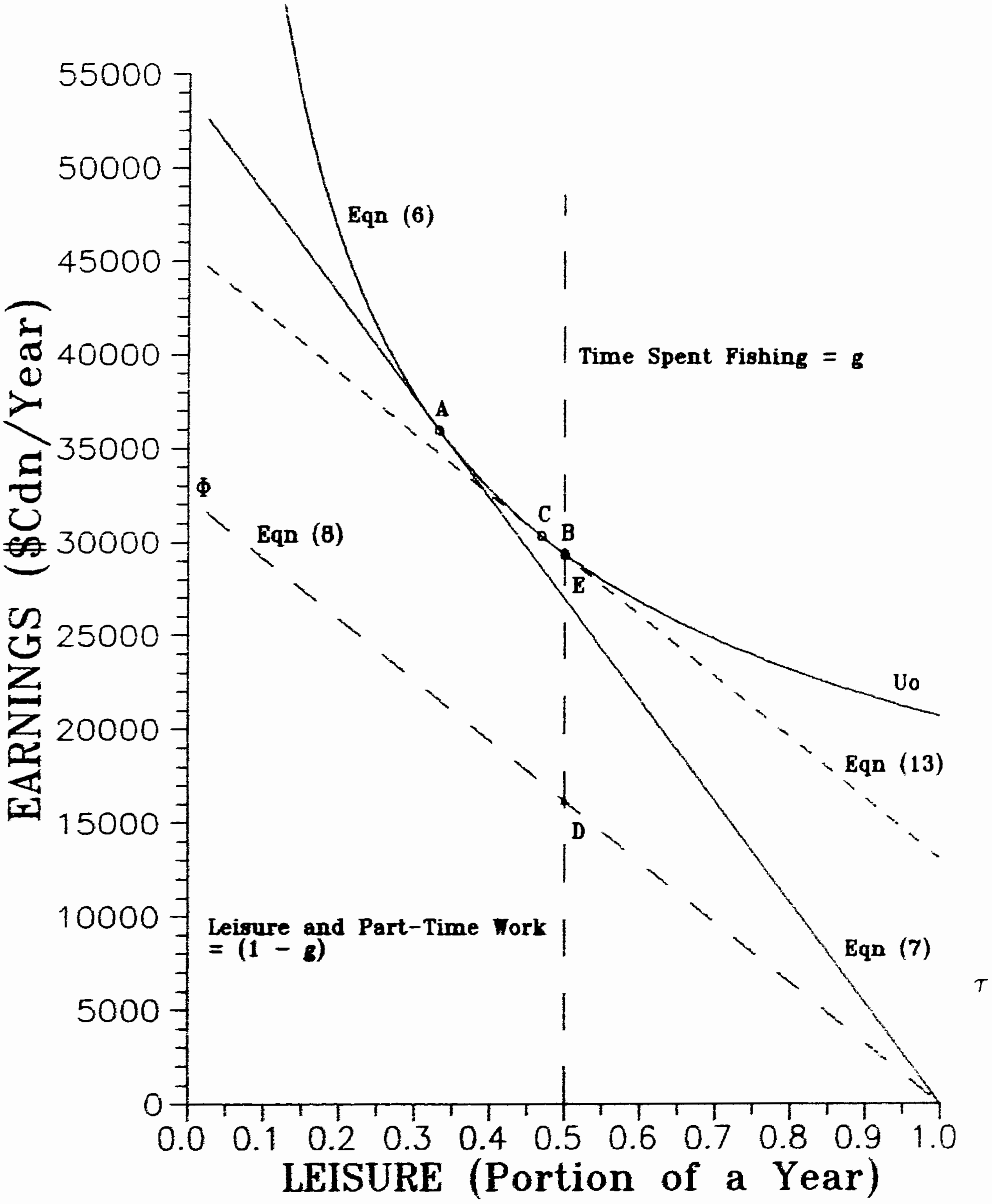
These and other problems mean that the people employed by a fisheries management agency are often better informed and more experienced in fisheries than the politicians to whom they report. As a result, politicians (to a large extent) have to choose between relying on the professionalism and integrity of their fisheries managers or invoking costly control devices—internal audit, multiple agencies and/or zero based budgeting.[49]

The discussions in this subsection developed the modules that, in following sections, are assembled into hierarchical system models of a fishery. Also, the tone and the context is set for the examination of fisheries management policies and procedures featured in the following sections.

---

[49] Large corporations developed the *zero-based budget* to control service centres (personnel, legal services, internal audit). This technique works by shifting the targeted service centre away from its *all or nothing demand curve* and toward its *marginal cost curve*. This is done by having each service centre manager formally define the benefits and costs associated with a progression of service levels from the minimum absolutely essential level to the *blue skies* maximum. Decreasing the increment between service levels increases the cost of the process but provides a closer match between the budgeted costs and the service centre's actual supply curve. There are several reasons for this match. The margins for fudging are reduced and more cross-checks are available to the individual reviewing the service centre's budget and subsequent performance.

FIGURE 5-1: Income/Leisure Trade-offs and Opportunity Costs in a Fishery



]

FIGURE 5-2: Cost of Fishing Effort at the Entrepreneur Level (labour and capital are infinitely divisible)

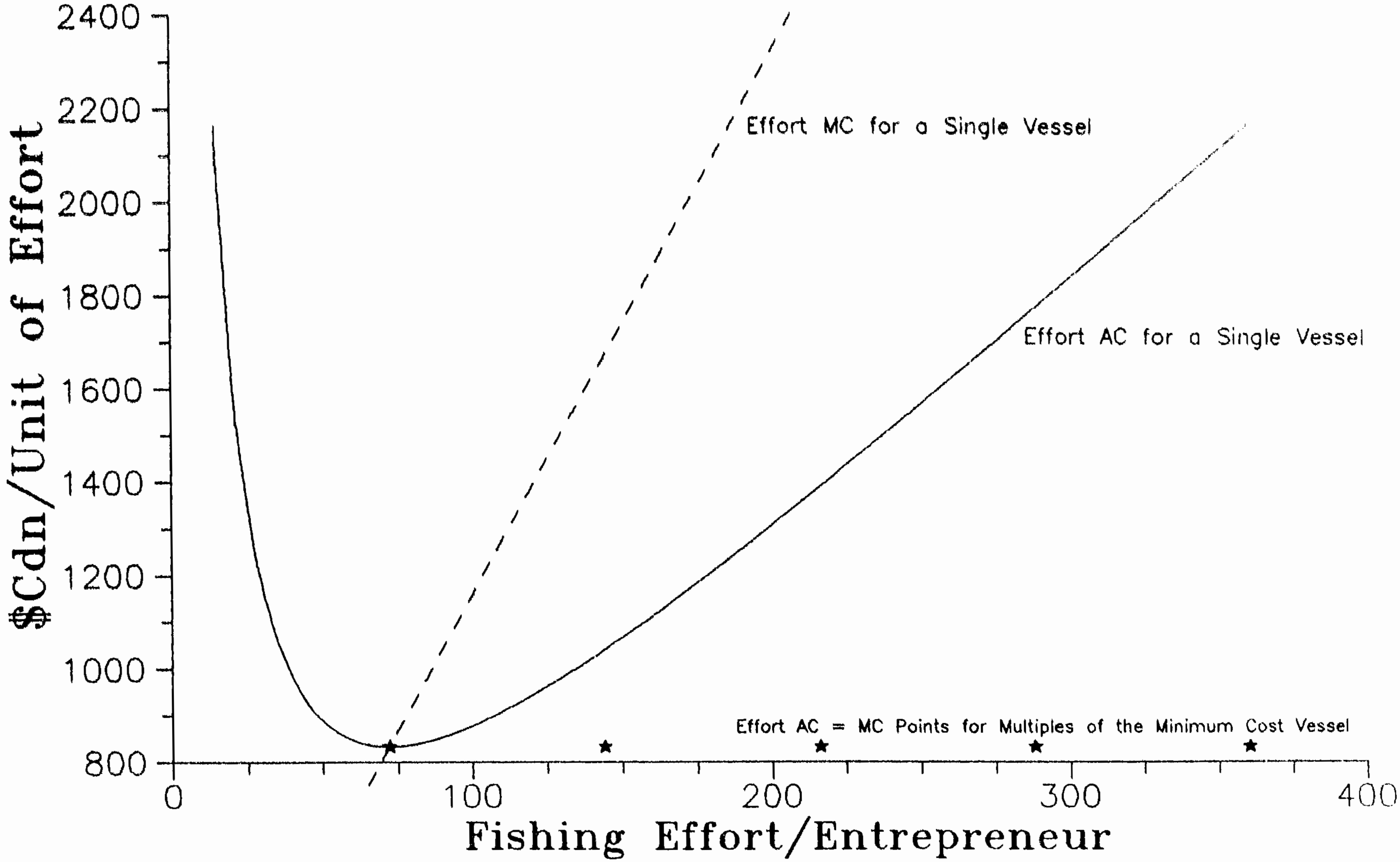


FIGURE 5–3: Cost of Fishing Effort at the Entrepreneur Level (when labour is restricted to whole numbers)

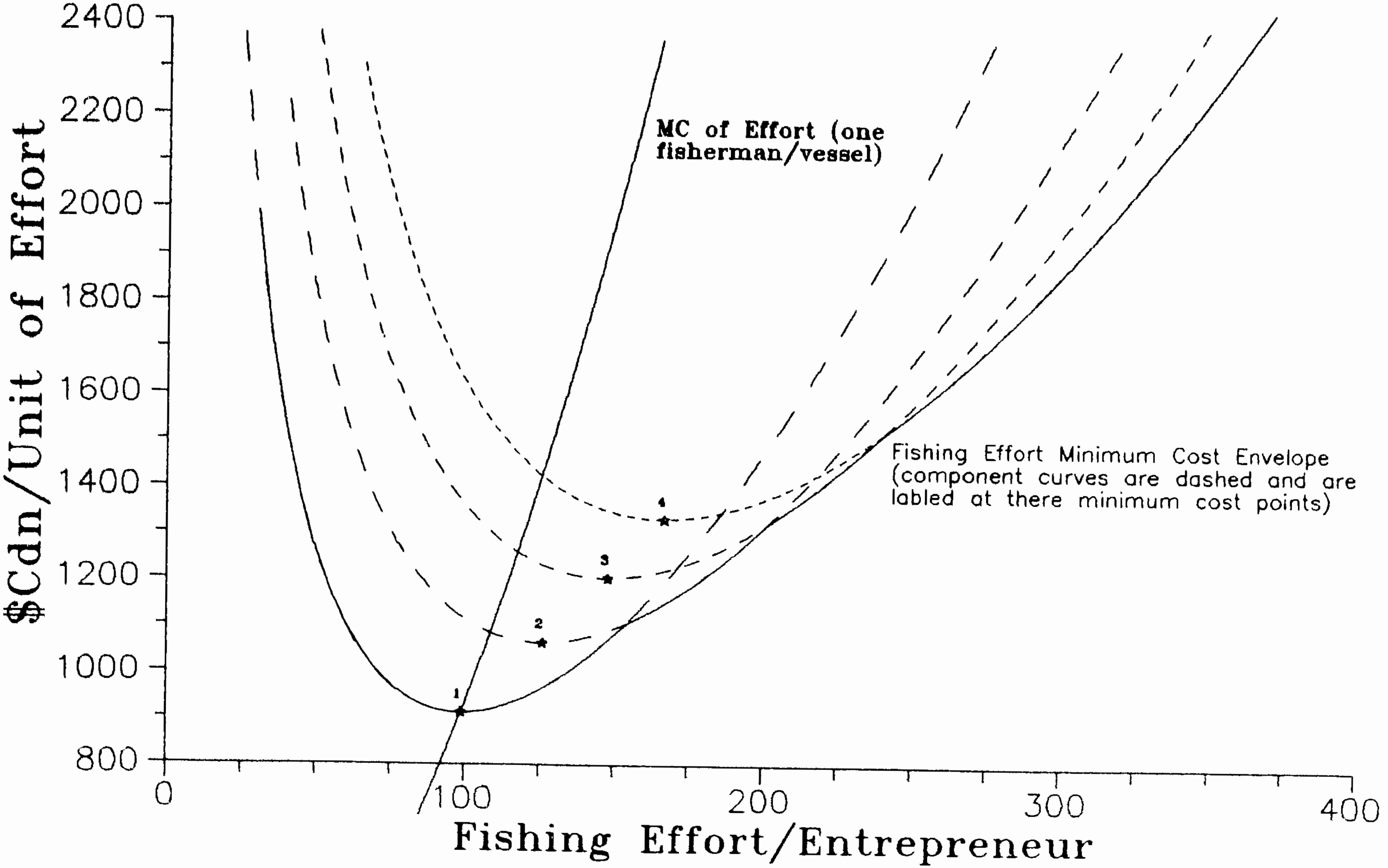
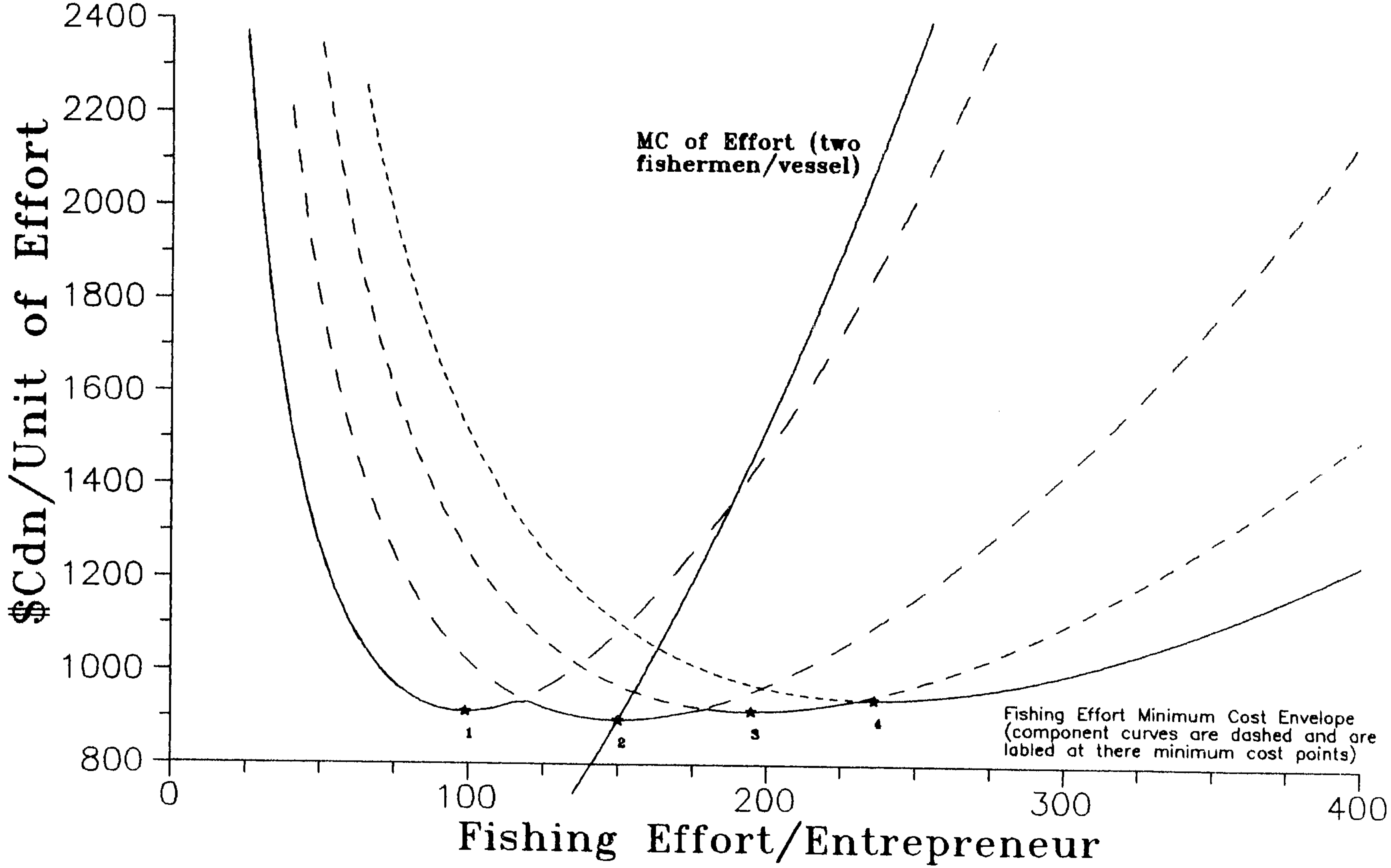


FIGURE 5-4: *Cost of Fishing Effort at the Entrepreneur Level (labour restricted to whole numbers and n is .4)*



6. MANAGING A FISHERY SYSTEM

In this section various policies and practises of fisheries management are reviewed, modeled and evaluated in terms of their ability to attain desired policy objectives (subsections 5.4 to 5.4.2).

The needs of fisheries management are too broad and complex to be encompassed within one discipline (e.g. biology, economics, sociology, anthropology or political science). As a result, fisheries management has evolved into a practice that draws theories and/or techniques from many disciplines. This multi-discipline approach is reflected in many of the modules developed in section 5. However, developing a hierarchical systems model of a fishery is more than a mere lumping together of the section 5 modules. The model maker has to choose an appropriate variation of each module and then has to weave them into an internally logical and consistent system. As von Bertalanffy (1968, p.244) and Margenau (1966 and 1983) note, building a model should be an iterative *boot-strap* process where a model builder forms, learns from what is formed, adjusts what is formed, learns from what is formed, etc.

As noted earlier, under a hierarchical systems perspective, much of the nature, form and function of any given holon is constrained by the nature, form and function of *its* higher and lower scale holons. In theory, models using this approach extend toward infinity in the micro and macro-scales. In practice, however, there are upper and lower limits on what holon scales are meaningful to human model builders/users. As a result, in Chart 6-1 (a Margenau map of a fishery), the holons at comprehendible scales are embodied by functions, the holons at subliminal scales represented by parameters (and/or black boxes) and the holons at "super-liminal" scales are framed as rules, maximands and/or black boxes.

Ideally, a Margenau map should be given for each variant of each type fishery. However, Margenau maps are difficult to draw and remarkable changes, to such a map, can arise from what appears (a priori) to be a minor change to a minor holon. In recognition of these problems, only two example maps are provided in this section. Charts 6-1 and 6-2 represent fisheries where the function and the methods of the fishery managers are well established—they are discussed after several less sophisticated forms of fisheries management are considered.

This dissertation is focused on the management policy scale—its goal is not to find *the ideal fishery management policy*—rather, there is an examination of how an idealized fishery system adjusts to or is altered by various management themes. While the importance of performing exhaustive sensitivity analysis at all scales is recognized, there is also recognition that performing sensitivity analysis at more than one scale at a time, generates model results that tend to be unmanageably complex and confusing. In an effort to avoid this problem, this dissertation focuses its sensitivity analysis at a policy scale—it is hoped that the results arising from this preliminary study will demonstrate that a hierarchical systems approach to fisheries modeling is sufficiently fruitful to warrant future studies that will (in time and over a number of studies) perform exhaustive sensitivity analysis, at and across all scales in hierarchical systems models.

6.1 THE FORMS OF FISHERIES MANAGEMENT

The "first evidence for economically significant use of aquatic resources occurs in Africa. At caves at the Klasies River in South Africa (dated apparently just at the outer limits of carbon-14 dating and thus reported as anywhere between 50,000 and 80,000 years old), remains of seals, marine birds, fish and shellfish occur in an economy still centered largely on land-based hunting" (Cohen, 1977, p.100). However the practise of fisheries management has developed only over the last one hundred years. During almost all of the time that humans have exploited fish stocks, predation by humans was either not a significant factor in the viability of the exploited stocks or there were other stocks available. Fisheries management was not established until its necessity became apparent. The growing power of fisheries technology has provoked an escalating need for ever more sophisticated fisheries management techniques. As a result, fisheries management has become a dynamic craft with few absolutes and what is considered as the current conventional wisdom can be dramatically thrust into disrepute by new precepts or changes in a fishery.

While the following subsections review fisheries management techniques in terms of various traditional approaches to managing fisheries, it is important to remember that in practise fisheries management is more of a collage of overlapping sets than a series of independent sets.

6.1.1 LAISSEZ FAIRE

A fishery exploits a common property resource—the benefits of a harvest method accrue to the individual using it but many of the associated costs affect all who exploit the fishery. As a result, a group exploiting a fishery can benefit, as a whole, if control is exercised over those methods of harvest that are highly effective but socially inefficient (e.g. poisons, explosives or weirs with no escapement).

During most of humanity's tenure on this planet, our numbers and our technology were limited. Under those conditions, a *laissez faire* approach to fisheries management was appropriate because the how, who, when or where of fishing was irrelevant to the potential harvest. As our numbers and the sophistication of our technology grew, so did the importance of the detrimental effects of fishing on potential harvests and/or the environment. All human cultures reach a point where growth forces them to either maintain their population at a low density via infanticide, ritual war or other means (Cohen, 1977) or to develop the means to intensively control and exploit the resources in their environment. Cultures which chose the former path usually found themselves crowded-out and either overwhelmed or pushed aside by the tide of the cultures which chose the latter path (Cohen, 1977, p.55).

Economic models of *laissez faire* fisheries tend to be impractical or irrelevant (i.e. many fishing methods are used and their effects on the stock are insignificant—when compared to the processes of population dynamics and/or the effects of environmental change) or pointless (i.e. the fishery is in transition—either to extinction or to a form of active management).

6.1.2 MANAGING FISHING GEAR AND METHOD

Restricting the gear and/or method used to harvest fish is one of the oldest methods of managing fisheries. Gear restrictions were first introduced to the Fraser river (British Columbia, Canada) salmon fishery in 1890 (MacDonald, 1981, pp.1-7). Gear regulations and economic pressures act together and tend to cause the formation of norms in the fishing methods applied to a fishery. The presence of such norms makes predicting the cost and behaviour patterns practical and, hence, makes modeling the fishery workable.

As fishing effort expands in the fishery, the sustainable (yield) revenues will expand along a path described by equation (1). Fisheries economic analysis tends to focus on this sustainable yield. However, Clark (1976, pp.179-209), Anderson (1977, pp.26-27), Copes (1978a, pp. 25-27) and Cunningham (1985, pp.30-33) noted that the short run yields recorded in annual surveys may be greater or less than the sustainable yield if they include a drawing down or a drawing up of stock biomass. While a yield is always a function of the fishing effort and the fished biomass, a sustainable yield is by definition a special case where the associated biomass is constant and (as a result) can be substituted out of the yield function, leaving yield defined in terms of effort alone. In most situations, the fishery is not in equilibrium. Thus, a yield curve fitted directly to annual yield to effort data tends to be a meaningless artifact of the fishery's history and/or the regression process.

Ideally, a fishery yield function should incorporate biomass information along with the annual yield/effort data. However, a detailed sequence of annual biomass information is rarely available. Therefore, methods are needed to derive a long-run yield/effort function from the annual yield/effort data that is available in most fisheries. Copes (1978a, p.36) suggested that long run yield curves could be generated via an inspection of plotted data (by judging a *fit* from the assumed relationship between the short run catch pattern and long run yields). Copes noted that while the results of his method are less precise than yield/effort curves fitted via regression, they may be more accurate.

The precision of Copes' approach to fitting a yield/effort curve can be enhanced by a formalizing of his intuitive approach in a mathematical model. Cook (1983, pp.131-132) developed such an approach by assuming a linear catchability coefficient (q), reorganizing eqn (3) to define the biomass (X) and substituting the result into a short-run yield function. Cook's method is an elegant way of using yield effort data to impute a short-run yield/effort function. A major weakness of her method is its need to assume a relationship between q and X.

In Cook's (1983) model the biomass effect on yield is subsumed in the catch per unit effort. The biomass effect is stated explicitly in the following equations. In terms of the model in subsection 5.1, the biomass at the start of a given period is defined by:[50]

$$X_t = X_{t-1} + G_B(X_{t-1}) + G_R(X_{t-j}) - H_{t-1}/\delta \qquad (70)$$

---

[50] Use of the average annual biomass would be more accurate but would, also, be unnecessarily complex in this illustrative model.

X = stock biomass
t = period t
$t-j$ = period $t-j$

In eqn (70) growth has been separated into biomass growth (RHS, second term) and recruitment growth (RHS, third term).[51] Equation (70) can be simplified for illustrative purposes by assuming that j equals one.

$$X_t = X_{t-1} + G(X_{t-1}) - H_{t-1}/\delta \qquad (71)$$

In the absence of fishing, the stock biomass (based on equation (4)) will tend toward:

$$\bar{X}_{Hcap} = 1/a \qquad (72)$$

$\bar{X}_{Hcap}$ = carrying capacity biomass

The short run yield function can be defined by substituting the RHS of eqns (2) and (3) into eqn (71) and the result into eqn (3).

$$H_t = q\delta E_t X_{t-1}[1 + r(1-aX_{t-1}) - qE_{t-1}] \qquad (73)$$

When eqn (73) is multiplied by the price of fish (P; subsection 5.1.1) the result is the short run revenue/effort function.

$$R_t = q\delta P E_t X_{t-1}[1 + r(1-aX_{t-1}) - qE_{t-1}] \qquad (74)$$

In the revenue vs current fishing effort plane, eqn (74) produces a revenue ray that emanates from the origin, rises with the current period fishing effort and is logically limited to:

$$R_t \leq PX_t \qquad (75)$$

The only equilibrium point ($\bar{R}$) on the short-run revenue ray (eqn (74)) occurs where it intersects the long-run revenue curve (eqn (1)). The harvest associated with a point (on the short-run revenue ray) to the left of the equilibrium revenue leaves residual growth which increases

---

[51] Equation (70) also assumes *knife-edge* recruitment. If recruitment occurs over several years, a recruitment growth term may be needed for each of those years.

the stock biomass and rotates the short-run revenue ray upward for the next period. Conversely, the harvests associated with a point (on the short-run revenue ray) to the right of the equilibrium revenue draws down the stock biomass and rotates the short-run revenue ray downward for the next period.

In a fishery where effort is expanding or contracting, the short-run revenue ray cannot persist from one period to the next. Therefore, the nature of these rays must be inferred from observed shifts in the yield/effort relation. These shifts are illustrated in Figure 6-1.[52]

The fishery depicted in Figure 6-1 starts with one vessel. It and all vessels entering the fishery are assumed to be of the (Figure 5-3) minimum fishing cost configuration. Large rents tend to be earned in a fishery in its early years and that rent attracts vessel entry. Little is known about the exact entry response, so many fisheries economists assume that annual vessel/capital/effort entry in a fishery occurs in a linear response to the previous year's absolute profit (R-C) (Clark, 1976, p.118). However, an investment response function that is linear with respect to absolute earnings implies that potential investors are very knowledgeable about the fishery and/or have a bizarre investment preference. A potential investor is unlikely to know both the size of

---

[52] Figure 6-1, assumes that all the vessels in the fishery are of the same size/power, that new vessels enter (at the start of each year) according to eqn (76), that a vessel has a 10 year useful life and that a fishermen has a 40 year working life (after entering a fishery). While these assumptions are somewhat arbitrary, they or similar assumptions are needed to impose a comprehendible order on the expansion of fishing effort. Also, vessels and capital can be divided into fractions of a unit, but fishing labour (deck-hands and skippers) is assumed to be restricted to whole units.

the potential fishery and the investment plans of the other potential investors. As a result, investment in a fishery is more likely to vary with a measure of return on cost than with the absolute profit earned in the fishery.[53] The eqn (76) exponential relationship between entry and profitability in a fishery is inferred from the following line of logic. If risk in a fishery is perceived as high but constant then, as the return/cost (R/C) rises, the value that investors place on a fishery investment rises proportionally. However, in an open access fishery the cost of acquiring a vessel is constant and the common property resource problem infers that the market clearing mechanism (of entry dissipating all of the resource rent) is not apparent to an investor. Investments are not like consumption goods (satiation occurs in terms of all investments rather than at the specific good level) and fishery investment is not like other investments (a new vessel owner tends to change jobs to become the skipper of his/her vessel). Therefore, when R/C is just above 1.00 entry to the fishery is slow, but as R/C rises the number of people willing to change their occupation rises exponentially rather than in a linear form.[54] The entry of fishing capacity to the fishery is assumed to follow:

$$\mathit{ln}(V_{tnew}) = \mathit{ln}(v) + R_{t-1} - C_{t-1} \tag{76}$$

subject to: $R_{t-1}/C_{t-1} \geq 1.00$

---

[53] Return on assets would be a better measure, but it is not as available as the return/cost ratio.

[54] This assumes that the risk preference distribution in a population is log normally distributed around a mean that is to the *risk averse* side of *risk neutral* and is skewed toward the *risk preference* side where the utility of risk is perceived (respectively) as negative, zero and positive for risk averse individuals, risk neutral individuals and risk loving individuals (Van Horne, 1974, pp.23-26).

V_{tnew} = number of new vessels added to the fishery in period t
v = new vessels when R/C = 1.0. In Figures 6-1 to 6-8 v = 1.35
t-1 = period before period t
C = total fishing costs (eqn (77))

The short-run revenue (eqn (74)) includes an initial fishing down of the stock biomass and, therefore, is greater than the sustainable revenue (eqn (1)). As a result, fishing effort expands well beyond the long-run open access equilibrium (at point A). Eventually, the stock density declines past the level where the value generated by the CPUE (catch per unit of effort) is greater than or equal to the cost of the effort. At that point, effort in the fishery has reached a maximum and begins declining.

The asymmetry that tends to exist in fisheries between the input entry and exit costs (see subsection 5.2) means that the time frame is important to what costs are relevant to the fishing effort maxima. If short-run revenues dip below the fishing total cost curve the entry of new vessels (fishing capacity) will cease.[55]

$$C = [b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]V \qquad (77)$$

In the short and intermediate run, effort will not decline because the fishermen still replace vessels except when a vessel and its skipper/owner both retire at the same time.[56] However vessel skipper/owners do

---

[55] This first occurs in Figure 6-1 to 6-3 the year before point B. The lag of a year occurs because fishermen are assumed to base their current years fishing effort on the previous year's results. Each of the marked points in Figures 6-1 to 6-3 represents one year.

[56] Figures 6-1 to 6-5 assume that vessels wear out on a 10 year cycle and fishermen retire (in the absence of duress) after 40 years, in the fishery.

not replace expended vessels unless the short-run revenues cover both the capital total cost and labour variable cost.[57]

$$C = [b + (\Gamma+g\theta)K + (g\Phi+g\Omega)N]V \qquad (78)$$

As vessels wear out, fishing effort slowly declines and fishermen from expended vessels withdraw from the fishery, into part-time nonfishing employment. In the short run, fishing vessels may be *mothballed* if the short-run revenues do not recover the variable costs of fishing.[58]

$$C = [b + (\Gamma-r_c+g\theta)K + (g\Phi+g\Omega)N]V \qquad (79)$$

r_c = portion of the annual cost of fishing capital that is fixed with respect to fishing

The possibility of mothballing vessels creates a problem for the model —if all vessels and inputs in the fishery are exactly alike, then all vessels will simultaneously leave the fishery if the average vessel is not earning enough to recover its short-run variable costs. The model must be modified to eliminate this absurd outcome. Copes (1972, p.152) noted that some fishery inputs earn *producer surplus* because, in their fishery, they are superior inputs. Explicitly incorporating producer surplus in the model at this point would raise needless complications. For example, what is the relation between the producer surplus and the total fishing effort—is the producer surplus of a vessel consistent or does it vary with the amount of input employed, does total and/or

---

[57] This first occurs in Figure 6-1 to 6-3 the year before point C. If fishermen based the current year investment and operating decisions on an average of the returns to their inputs of the preceding three years (instead of on the preceding year) then points B, C, and D would shift to the left. Also, the slope between points C and D would be less severe in Figures 6-2 and 6-3.

[58] This first occurs in Figure 6-1 to 6-3 the year before point D.

individual producer surplus vary with the biomass? These complications are avoided by implicitly including producer surplus via an assumption that the number of vessels not *mothballed* when short-run revenues are less than the short-run variable costs, is equal to:

$$(V - V_{mothballed}) = V_{active} = V(P\delta qEX/C) \qquad (80)$$

subject to: $P\delta qEX/C < 1.00$

where the numerator is the price of fish multiplied by eqn (3) and the LHS of eqn (79) is the denominator.[59] As the conditions improve in the fishery the *mothballed* vessels are assumed to slowly return to fishing —eqn (80) continues to define the number of active vessels. The time spent *mothballed* is not deducted from a vessel's 40 year life span.

Points B, C and D (Figure 6-1) were identified through iterative calculation. The open access equilibrium (point A) was delineated by using eqns (1), (23a) and (51) to calculate the number of vessels at point A:

$$V_A = [r/(q\delta PmN^{n}K^{k})](1-[a/(q\delta PmN^{n}K^{k})][b+(\Gamma+g\theta)K+(\tau+g\Phi+g\Omega)N]) \qquad (81)$$

N = fishermen/vessel per eqn (51)
K = capital/vessel per eqn (50)

then substituting that result into eqn (23a) and substituting that result into eqn (1).

---

[59] Owner/skippers might consider responding to the losses by reducing the time spent fishing—to reduce costs. However, this approach is not a viable solution. Based on eqn (32), reducing the time spent fishing will (in the short run) cause a greater reduction in revenue than in costs ($d\pi/dg > 0$). Also, based on Figure 5-1, fishermen can only maintain a constant utility if their total income is determined by eqn (18). If the time spent fishing is reduced, eqn (18) only holds if the fishing wages ($[\tau+g\Phi]/g$) rise as g falls. That scenario is neither possible in the short-run (see eqn (74)) nor is it perceived as possible by vessel owner/skippers (see eqn (22)).

After passing points B, C and D the short-run revenue path (Figure 6-1) goes into a damped cycle of expansion and contraction that is focused on the open access equilibrium at point A. At the open access equilibrium (Figure 6-1) there are 87 vessels, each earning $88,339 by using 1 fishermen and 7.0205 units of capital to generate 98.901 units of fishing effort (g is .50 of a year). Due to rounding, the fishing costs at point A ($90,264) are slightly higher than revenues.

Figure 6-2 describes the fishery (Figure 6-1) in terms of a phase plane diagram. The short-run harvest is given by eqn (73) and the sustainable harvest is given by eqn (2). The biomass, below which there is no entry of new harvest capacity, is defined by multiplying eqn (3) by the price of fish, settling the RHS of the result equal to eqn (77) and reorganizing the result to:

$$X^{*} = V[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N]/(P\delta qgmN^{\eta}K^{\kappa}) \qquad (82)$$

The biomass below which some capacity will exit, is defined by similar process but eqn (78) is used in place of eqn (77):

$$X^{**} = V[b + (\Gamma+g\theta)K + (g\Phi+g\Omega)N]/(P\delta qgmN^{\eta}K^{\kappa}) \qquad (83)$$

The biomass below which worn harvest capacity is not replaced, is defined by a similar process but eqn (79) is used in place of eqn (78):

$$X^{***} = V[b + (\Gamma-r_c+g\theta)K + (g\Phi+g\Omega)N]/(P\delta qgmN^{\eta}K^{\kappa}) \qquad (84)$$

Points B, C and D are lagged from their limiting biomass because fishermen are assumed to base their current operation on their experience last year.

Figure 6-3 describes the fishery (Figure 6-1) in terms of stock flows. The short-run ending biomass is defined by eqn (71) and the sustainable biomass is defined by eqn (4). The sustainable effort is defined by a combination of eqns (1), (24), (26), (49), (50), (51) and (52). The results of eqns (82) to (84) are also shown in Figure 6-3. Point E (Figure 6-3) is the first short-run ending biomass after the slope of the sustainable biomass curve becomes tangent with the sustainable effort. Before point E, the absolute value of the slope of short-run ending biomass curve varies (at a decreasing rate) with the stock biomass; after that point the slope is approximately constant until point B.

In this nonstochastic model, increasing the rate of effort expansion (parameter v, in eqn(76)) does not appear to cause a significant decrease in the minimum stock density. This observation would change significantly if the model was stochastic or if fishermen were assumed to be sufficiently optimistic, stubborn and/or desperate to persist at fishing even after incurring a string of significant losses.

This subsection indicates that, for most fisheries, managing the type of fishing gear (alone) cannot produce a socially optimum outcome nor can it conserve a fish stock. This model, also, displays a potential cause of short-run poverty in a fishery. Specifically, fisheries tend to experience a rapid expansion in fishing effort (when profitable) and then adjust to subsequent economic loses via the slow painful process of attrition. The model indicates that more government intervention is desirable (in most fisheries) for a combination of biological, economic, social and political reasons. This model, is consistent with the findings of simpler dynamic models such as Clark's (1974, pp. 196-198) dynamics of a *zero cost nonlinear fishery.*

6.1.3 MANAGING THE AMOUNT HARVESTED

In fisheries that are not managed for the amount harvested, there is a tendency for stocks to be fished too hard by too much effort.[60] A fishery, under such pressure, produces less fish and the stock may be reduced to a level where its inherent resilience to natural shocks is grievously impaired.[61] As noted in sections 5.4.1 and 5.4.2, for both fisheries managers and the government, the objective of preserving the fish stock takes precedence over all other fishery objectives.

Fisheries managers can control the amount harvested in a fishery either directly, by enforcing a total allowable catch (TAC), or indirectly, by managing the length of the fishing season. The end effect of both approaches is the same. However, a TAC automatically adjusts the season length (via the harvest) when the fishing effort changes. As a result, less management involvement is needed during the adjustment phase from the unmanaged to the target biomass with a TAC, than with a preset fishing season length.[62]

When they were assigned the responsibility of managing the amount harvested, the fisheries managers had to chose an appropriate harvest

---

[60] In many fisheries, fishing costs are low relative to the MSY revenues. Where the reverse is true, the fishing effort may be to the left of MSY and management of the harvest may still be desirable but it is not imperative.

[61] Resilience is a property allowing a system to absorb and utilize (or even benefit from) change.

[62] When a fishery is managed using a preset season length, an accurate and timely measure of the harvest is still required to ensure that the fishery is not excessively damaged by an incorrect length of season. Also, reductions in the fishing season are politically more acceptable if the season length is set by a TAC rather than by *ad hoc* bureaucratic decisions.

level. The Margenau Map illustrated in Chart 6-1 treats that choice as a black box. As a result, that map applies to all the harvest choices examined in the following subsections. Table 6-3 shows effect of these management targets, on a selection of fisheries variables.

The initial harvest level of choice was maximum sustainable yield (MSY). Fisheries economics and management experience have discredited MSY (as a management target see section 2). However, it is consistent with the discussion in this subsection (and with the early history of season management) to portray the use of MSY as a harvest target.[63]

After selecting MSY as the target harvest, fishery managers would have to estimate the MSY harvest. In many fisheries, yield/effort data are the only data available in a long enough and sufficiently reliable series for use in regression analysis. However, Copes (1978a, pp.25-27) noted that, because of changes in the stock biomass, the short-run yield to effort is greater than the long-run value when fishing effort increases and is less than that value when fishing effort declines. As a result, a simple regression of yield and effort data tends to generate precise but incorrect estimates of the sustainable yield to effort relation (see, also, Roff and Fairbairn, 1980).[64]

---

[63] Any TAC level could be used in the following analysis—the specific outcome might change but the general effects would remain the same.

[64] Even though the dangers inherent in this type of regression analysis are recognized by many theoreticians and practitioners, many examples can be found of such regressions or regression that involve a simple mechanical time related adjustment—for example: Russell, 1931, p.20; Schaefer, 1954, 1957a and 1970; Pella and Tomlinson, 1969; Fox, 1970, pp.85-89; Ricker, 1975, pp.324-325; Anderson, 1977, pp.188-194; Pitcher and Hart, 1982, pp. 229-230; Gulland, 1983, pp.71-72).

The following example gives a feel for the serious problem that a precise but inaccurate yield/effort estimate can create for fisheries managers. If the Figure 6-1 harvests are regressed against the associated effort (using eqn (5) and correcting for first order autocorrelation) for years 3 to 30 (28 years) of the Figure 6-1 data, the result of:

$$H_t\hat{} = 4.2800E(1-.000082030E) + .85493\epsilon_{t-1} \qquad (85)$$

$$(49.520) \qquad (145.42) \qquad (14.105)$$

$H\hat{}_t$ = estimated harvest for period t
ϵ_{t-1} = period t-1 error = $H\hat{}_{t-1} - H_{t-1}$
$q\delta/a$ = 4.2800
q/r = .000082030

is extremely precise (R^2 = 99.84 percent and LM Statistic = .1509E-16) but not very accurate. It estimates that MSY effort (i.e. $dH/dE = 0$, $E = .5r/q$) is 6,095 units, MSY is 13,044 tonnes and MSY revenue is $26.1 million, when the actual values (as derived from the list of parameter values in Appendix B-1) are respectively 5,000 units, 8,000 tonnes and $16 million. In this example, the estimated MSY is over 160 percent of actual MSY and the estimated E_{MSY} is 122 percent of actual E_{MSY}. If the 13,044 tonne estimate of MSY were used as the TAC, the annual harvest would be like an annuity—comprised of the annual natural growth and a drawing down of the biomass. Eventually, the biomass falls to a point where the harvest revenues are below the total fishing costs and the harvest begins a damped cycle around the open access equilibrium.

MSY can, also, be guesstimated by working back from yield/effort data to approximate the catchability coefficient and population parameters. (This approach has its own problems, but they are likely to be less material than the problem discussed above). For example, if there is a linear catchability coefficient, eqn (3) can be reorganized to define the biomass. The LHS of the result can then be substituted into eqn (73) to produce:[65]

$$H_t = E_t[CPUE_{t-1} + rCPUE_{t-1}(1 - (a/\delta)CPUE_{t-1}/q) - qH_{t-1}] \qquad (86)$$

$CPUE_{t-1}$ = catch per unit effort in the period t-1; $CPUE_{t-1} = H_{t-1}/E_{t-1}$

which defines the current harvest in terms of current effort and past

---

[65] The transformation of eqn (3) to define the CPUE is likely to result in an error in the specification of the disturbance term (Kementa, 1971, pp. 400-402). In order to satisfy the OLS assumptions of a homoskedastic disturbance term with a zero mean, eqn (3) should be transformed to:

$$X = H/(\delta qE) + \epsilon_X \qquad (a)$$

However, if the error term (ϵ_H) in eqn (3) is assumed to be a fixed percent of the harvest then eqn (3) becomes:

$$H = \delta qXE(1+\epsilon_H) \qquad (b)$$

which reorganizes to:

$$X = H/[\delta qE(1+\epsilon_H)] \qquad (c)$$

When eqns (a) and (b) are set equal, the result can be reorganized to:

$$\epsilon_X = H/(1+1/\epsilon_H) \qquad (d)$$

The error terms defined by eqns (b) and (d) are heteroskedastic. If eqn (b) were *logged* to eliminate the heteroskedasticity, the result could not be substituted into eqn (73). If the error term in eqn (b) were made additive then eqn (d) would still be heteroskedastic but would become:

$$\epsilon_X = -\epsilon_H/(\delta qE) \qquad (e)$$

Uhler (1980) has a more complete discussion of this problem and a Monte Carlo simulation of its effects. Other references that might be of interest are Ludwig and Varah (1979) and Ludwig and Walters (1981 and 1982).

yield effort data.[66] Regressing eqn (86) against the yield/effort data for years 2-30 of the data shown in Figure 6-1 generates a result of:

$$H_t = E_t(\mathit{CPUE}_{t-1})[1 + a[1-b(\mathit{CPUE}_{t-1})] - cE_{t-1}] \tag{87}$$

$R^2 = 100.0\bar{0}$ percent[67]; LM Statistic = 14.422

Parameters		tstat
$a = r$	$= .20016$	8,115.1
$b = \alpha/(\delta q)$	$= .31245$	19,309.
$c = q$	$= .000020014$	7,490.2
RHO	$= .92001$	127.56

$$\hat{r} = .20016 \approx r = .20$$
$$b(c) = (\alpha/\delta)\hat{} = .000006253 \approx \alpha/\delta = .0000062$$
$$c = \hat{q} = .000020014 \approx q = .00002$$

$$E_{MSY}\hat{} = .5r/q = 5{,}000.\bar{5}0 \approx 5{,}000$$
$$MSY\hat{} = 8{,}002 \text{ tonnes} \approx 8{,}000 \text{ tonnes}$$
$$R_{MSY}\hat{} = \$16.0 \text{ million}$$
$$X_{MSY} = \text{not estimated; } \alpha \text{ and } \delta \text{ cannot be separated}$$

---

[66] The use of a lagged dependent variable (CPUE = H/E) creates the problem of autocorrelation in the error terms. This problem is aggravated by the heteroskedasticity problem, discussed in the previous note. "Unfortunately, it is not the case that the problem of simultaneous violation of two assumptions of the CLR model [autocorrelated errors and a lagged dependent variable as a regressor] can be treated as two separate problems. The interaction of these two problems produces new problems." (Kennedy, 1985, p.118). Further research is needed on how to best specify the error terms in eqn (87) so as to minimize the above problems in a *nonlinear regression.*

[67] The regression package used to estimate eqn (87) (an intrinsically nonlinear equation) estimates "nonlinear equations by a maximum likelihood procedure. It is assumed that the errors are additive and normally distributed. (White, et al., 1990, p.125).

Kmenta (1971, p.444) notes that "if the regression disturbance is normally distributed, nonlinear least squares estimators [R^2] are the same as maximum likelihood estimators." However, Kmenta (1971, p.465), also, commented that "the assumption of normality of the disturbance term is not always crucial." Kmenta (1971, pp.465-466) then warned that the trial and error method used in nonlinear regression can lodge in a local maxima rather than finding the global maxima. White, et al. (1990, p.131) also noted that this could be a problem and recommended that nonlinear regression should be run several times (with different starting values) to ensure that a global maxima had been achieved. Additional information on nonlinear regression can be found in Maddala (1977, pp.174-181).

This technique generates reasonable guesstimates of the values of the parameters in a fishery. It is rife with assumptions (e.g. a catchability coefficient that is constant with respect to the stock density and total fishing effort, recruitment and harvesting that occur evenly throughout the year, no significant interstock effects, etc.), but the process of generating these explicit assumptions should warn managers to not place undue reliance on the results of the analysis and to seek corroborative evidence from other sources.

Figure 6-4 illustrates what happens when fisheries managers use a TAC to control the fishery from its inception. A TAC policy terminates the fishing season when the harvest reaches the MSY (point F_h). As the fishing effort needed to attain the allowed harvest moves to the right of point F_h, the portion of the harvest that is due to a fishing down of the stock biomass decreases and the fishery moves toward point G at a decreasing rate.

In Figure 6-4 fishing costs rise rapidly to the right of point F_c because, as the fishing season (g) is progressively reduced to enforce the TAC more inputs (vessels, labour and capital) are required to generate a given amount of fishing effort. The full effect of the changing fishing season length is obscured in Figure 6-4 because fishing effort (the X-axis) is a function of both fishing power and the length of the fishing season. In Figure 6-5, the TAC mechanism is more apparent because the effort axis is changed to fishing power axis (which is independent of the fishing season length). A comparison of Figures 6-4 and 6-5 shows that a TAC works by adjusting the length of the fishing season to make less efficient the conversion of vessel fishing power into fishing effort. If the season length is shortened to maintain the harvest as fishing power is increased, the cost of fishing power (Figure 6-5) rotates downward because a reduction in the season length reduces the annual cost of fishing power. However, the cost of fishing effort curve (Figure 6-4) rises because the reductions in the fishing power costs are more than offset by increases in the amount of fishing power needed to produce a unit of fishing effort (e.g. $E = g(FP)$). In the long run, reductions in the season length drive the fishing costs up to the total revenues (point H in Figure 6-5) and an open access equilibrium managed for MSY is achieved.[68] In effect, TAC or season length regulation restrains the fishery effort and may convert a *self-regulating* fish stock into an *administered non-self-regulating* fish stock.[69] Such policies attain the biological goal (of conserving fish stocks) by accommodating, not alleviating, the tragedy of the commons.

The need to manage the amount of fish harvested tends to be more apparent in mature fisheries than in developing fisheries. Thus, fisheries managers are usually called upon not to prevent a problem but to ameliorate a well-established problem that is threatening to escalate

---

[68] In theory, the fishery approaches point H but (because of the fishing down of the stock biomass) never reaches it. In the simulation at the end of 200 years a three year cycle is apparent where the number of vessels in the fishery was 229 ±1, fishing power was 50,926.8 units (+.40% or -.45%), the season was .09818 of a year (+.45% or -.40%) and effort is 5,000 units. Please note that 1/229 is .44 percent. This cycle is due to the specification of whole vessel entry and exit in eqn (76).

[69] Marshall (1938, pp.166-7) offered this definition for *self-regulating* and *non-self-regulating* fish stocks; "Among the renewable resources there are...two types with fundamental differences, those for which the rate of renewal is dependent on the amount of resource which is left unharvested, and those where such dependence does not exist, or is negligible."

to a catastrophe. There are several means by which a transition can be effected from the unmanaged open access equilibrium to an open access equilibrium managed to MSY.

One approach is for managers to set a transition TAC that is less than the target TAC and less than the current catch (assuming the current effort is to the right of the effort at the target TAC). In Figure 6-6, the initial TAC is set at 3,000 tonnes (down from the point A sustainable yield of 3,483 tonnes) until the biomass surpasses 100,000 tonnes, at which point the TAC is reset at 8,000 tonnes.[70] The number of vessels at point A (87 vessels) was defined by eqn (81), and eqns (23a), (1), (5) and (4) were used to set the associated fishing effort (8,604 units), sustainable revenue ($7.685 million), sustainable yield (3,483 tonnes) and stock biomass (27,920 tonnes). The 3,000 tonne TAC, in Figure 6-6, causes the short-run revenues to fall to point I from point A, to move across from point I to point J and then (back) to a point to the right of point I. The short-run revenues then jump to $16 million and, after a short movement to the left, move on to point H. After a 3,000 tonne TAC is set, fishing power costs decrease, but they are initially above the short-run revenues.[71] Immediately before point J, the cost of fishing power falls below the short-run revenue and remains below until the long-run managed open access equilibrium (manag-

---

[70] Figure 6-6 has the same assumptions as Figure 6-1 except for the inclusion of the assumptions approximating the equilibrium conditions at point A, that the initial vessels (year 0) are replaced on a ten year straight-line basis and that the initial fishermen retire on a 40 year straight-line basis.

[71] Please note that the cost of fishing effort (fishing power costs/g) is rising throughout this process.

ed for MSY; point H) is approached. The harvest (TAC) based transition from points A to H is marked by initial loses in the fishery, followed by large profits that eventually fade to, what to fishing are, normal returns. The closer the transition TAC is to the unmanaged open access equilibrium, the lower will be these initial loses. However, the time required to get the biomass to the target TAC varies with the depth of the initial cut in harvest. Another point in favour of the approach is that it is simple to administer and enforce.

A transition from the unmanaged open access equilibrium to a managed open access equilibrium can also be effected by setting the fishing season so that the harvest per annual (starting) biomass tonne is always at the MSY rate.

$$g_t = (H_{MSY}/X_{MSY})/(\delta q f_t) \qquad (88)$$

f = fishing power

In Figure 6-7, where this effect of this approach is illustrated, the initial losses experienced by fishermen (from points A to I to J) from this process are larger than the initial losses in Figure 6-6. However fishermen do experience transitional gains shortly after point J that are larger than those depicted in Figure 6-6. The net surplus generated in the transition from points I to H in Figure 6-7 is, in nominal terms (i.e. a discount rate of nil), 5.80 percent larger than the corresponding Figure 6-6 surplus ($703.825 million vs. $665.255 million). When a social discount of five percent is included in the analysis the net present value of the Figure 6-7 surplus is 18.77 percent more than the Figure 6-6 value ($68.398 million vs. $57.591 million).[72]

The major problem with this method of controlling fishing effort is that both the harvest and stock density must be measured each year. This problem can be resolved by substituting the LHS of eqn (23) into eqn (88) and simplifying the result to:

$$g_t = E_{MSY}/f_t \tag{88}$$

The transition from points A to H depicted in Figure 6-8 was managed with eqn (88) and is identical to the transition shown in Figure 6-7. While the simplicity of eqn (88) is desirable, managing fishing effort directly has other virtues. It is conservative, in that damage to the stock and fishery from either errors in estimating E_{MSY} or from exogenous shocks are much less than the damage from corresponding problems with a MSY TAC control system.[73]

Controlling fishing effort in a fishery by managing the length of the season may be used to maintain the stock density at a target level (This, attains the first objective of fisheries management—preserving the stock). It may, also, dramatically increase the period over which fishermen earn above normal returns. However, eventually, the incomes

---

[72] In its Guidelines for Benefit-Cost Analysis, the government of the province of British Columbia recommends a (general) social discount of 10 percent (Loose, 1977, p.84). However, Heaps and Pratt (1989, p.22) demonstrated that the social discount rate is between 3 and 7 percent and recommended that a conservative discount rate of 4 to 5 percent be used in evaluating social investment.

[73] When a TAC is set too high the result is similar to an annuity (the harvest consists of an increasing draw down of biomass and a declining annual growth). This problem can persist for many years before becoming apparent to the managers. If the E_{TAC} is set too high, the damage is limited in amount and duration because of the harvest being defined by equation (3).

in the fishery tend to stabilize at a normal long run condition of below normal incomes (section 5.2.2) and the government may be pressured to raise fishing incomes. Also, while managing the fishing season can conserve a stock, it wastes fishing inputs—in Figure 6-5, the fishing fleet at the managed (MSY) open access equilibrium (point H) is nearly three times more powerful than the fleet at the unmanaged open access equilibrium (point A). Further, as the length of the season decreases the fishery becomes more difficult to manage (i.e. if g is 0.50, a one day error in the opening is one half of a percent of the season but if g is .05, that one day error is five percent of the season).

If vessel input configurations adjust slowly, a transitory form of producer surplus may arise as a side effect of using season length to manage the total fishing effort.[74] As noted in subsections 5.3.6 to 5.3.6.3, as the season length is reduced, the configuration of vessel inputs that generates the minimum average cost fishing effort changes. If there are delays in changing the configuration of some vessels, the vessels that are changed to the new (minimum cost) configuration will generate a producer surplus because, for the shorter season, they are more cost effective than the unchanged vessels. For example, at point H (in the fishery depicted in Figure 6-8) a vessel configuration of 1.00 fisherman and 9.8117 units of capital will generate the lowest cost of effort (i.e. .09818*222.388 units of power, at 21.834 units of

---

[74] Copes (1972, p.150) defined *producer surplus* as being the return to an input (labour, capital, technology or entrepreneurial skills) that is due to it being of lower cost and/or higher quality than similar inputs similarly employed. In contrast, *Ricardian rent* is due to the relative richness of the resource being exploited (see, also, Mishan, 1968).

effort/vessel, costing \$69,852/vessel; \$3,199.23/unit of effort). If one of the 229 vessels active in the fishery at point A changes its configuration to what was appropriate for point A (the unmanaged open access equilibrium), then:

- the fishing season will increase from .09818 to .09823 of a year (5000/(197.802+228*222.388))
- four vessels will retire (unchanged from Figure 6-8),
- the one vessel that changed to the point A minimum cost configuration (1 fisherman and 7.0205 units of capital) earned revenues of \$62,174 by generating 197.802 units of fishing effort, at a cost of \$62,902, for a net loss of 728, and
- the 228 unchanged vessels will each earn revenues of \$69,902 by generating 21.845 units of fishing effort, at a cost of \$69,856 for a net gain per vessel of \$46 and a producer surplus of \$774.[75]

This producer surplus is transient. It will fade as the configuration of the other vessels is changed. The amount of the transient producer surplus is relatively small because the average cost of fishing effort curve (Figure 5-2) is relatively flat around the minimum cost point. Season generated transient producer surplus assumes greater import in subsection 6.1.5

6.1.4 MANAGING FOR ECONOMIC YIELD (MEY AND $F_{0.1}$)

While managing fishing seasons (to control the effort in fisheries) conserves fish stocks, it does not conserve the resource rent nor does it address the mature fishery problem of average fishing incomes

---

[75] As g decreases the fishing power generated by the minimum (fishing) cost vessel configuration could increase or it could decrease, depending on the parameter values. In this example that fishing power varies inversely with g because the optimal amount of labour (as defined by eqn (51) is unchanged or varies with g and (given $\Phi + \Omega > \theta$) the optimal amount of capital as defined by eqn (50) varies with g. Thus, as g declines, the effort associated with the minimum fishing cost vessel configuration (eqn (23)) must decline.

being lower than the average income accruing to individuals in equivalent nonfishing employment.

The discipline of fisheries economics has predicated from its inception (Gordon, 1954, p.142), that fisheries should be managed so as to maximize the surplus generated. Fisheries economists recognize that (in theory) there are three surpluses (resource rent, consumer surplus and producer surplus; Turvey, 1964; Copes, 1972), but they have tended to focus the concept of maximum economic yield (MEY) on maximizing the resource rent.

Fisheries economists, to provide simple illustrative examples of MEY and other concepts, tend to subsume many complex aspects of the fishing cost curve into simple linear functions. However, as the following example shows, the fuzzy thinking that can arise from the use of simple linear functions can be hazardous. In the fishery depicted in Figure 6-1, a vessel with the minimum fishing cost input configuration involves a capital input of:

$$K^* = [b + (\tau+g\Phi+g\Omega)N]/(\Gamma+g\theta)/(1/k-1) \qquad (50)$$

a labour input of:

$$N^* = \langle N\rangle^* \qquad (52)$$

N^* = value of $\langle N\rangle$ that generate
the lowest value of eqn (51)

incurs an annual cost of:

$$C_1^* = b + (\Gamma+g\theta)K^* + (\tau+g\Phi+g\Omega)N^* \qquad (53)$$

and generates the following fishing effort:

$$E_1 = gmN^nK^k \qquad (23)$$

This complex system of equations shows that the cost of fishing effort is a complex function of the parameters in this model.

$$C/E = f(g,m,n,k,b,\tau,\Phi,\Omega,\Gamma,\theta) \tag{89}$$

The decision to define the cost of fishing effort as a linear function of fishing effort involves an implicit assumption that the relations expressed in eqns (49), (50), (51) (38) and (23) are constant throughout the relevant range of fishing effort/operations in a fishery. When the parameters values listed in Appendix B-1 are substituted into the above equations and g is assumed to be .5 and the RHS of eqns (50) and (52) are substituted into eqn (23) then N^* is 1 unit, K^* is 7.0205 units, C_i is \$90,264 and E_i is 98.901 units. The cost of fishing effort (expressed as an over simplified linear function of effort) would then be:

$$C = 0 + \$912.669E \tag{90}$$

The fisheries economists would then define the MEY by differentiating eqns (1) and (90) with respect to fishing effort, setting the differentials equal and reorganizing the result to:

$$E_{MEY} = .5r[1 - 912.67a/(q\delta P)]/q \tag{91}$$

When the Appendix B-1 parameter values are substituted into eqns (91), (4), (1) and (90): E_{MEY} is 4,286.98 units, V_{MEY} is <43.346>, X_{MEY} is 114,260 tonnes, R_{MEY} is \$15,674,626, C_{MEY} is \$3,912,595 and π_{MEY} is \$11,762,032. When this MEY forecast is contrasted with the (unmanaged) open access equilibrium results (point A, in Figure 6-8, see the last part of subsection 6.1.3) it is easy to see why governments are interested in the concept of MEY. However, implementing the MEY fisheries policies has proved to be difficult.

When the time value of money is considered then the MEY becomes a DMEY (Dynamic Maximum Economic Yield). The above analysis can be considered as the special case of the DMEY where the social discount rate is nil and the open access equilibrium is the special case of the DMEY where there is an infinite social discount rate. A more complete discussion of DMEY is available in Clark (1976, pp.68-86) and Cunningham, et al. (1985, pp.111-119).

6.1.4.1 CONTROLLING SEASONS TO MANAGE FOR MEY

The harvest can be set at the MEY level by managing the length of the fishing season—a decrease in g causes the cost of fishing effort curve to rise.[76] However, the use of this management tool frustrates the rent maximization intent of the MEY policy—even though it attains the physical target of a harvest at the MEY tonnage. Figure 6-9 shows how an MEY harvest can be attained without achieving MEY.

There are no significant differences in focus between the transitions in Figures 6-8 and 6-9. The Figure 6-9 focus on MEY (as opposed to the Figure 6-8 focus on MSY) does cause the revenue reduction from point A to I to be deeper, the cut in fishing power from point A to J to be deeper and the managed open access equilibrium at point L is at a lower fishing power and a lower revenue than the equivalent at point H, but these differences are not substantial.[77]

---

[76] Clark (1976, pp.32-33) shows that the managers of the Peruvian open access anchovy fishery were forced to impose ever shorter fishing seasons (i.e. from 1959 to 1965 the season varied between 298 and 265 days; from 1966 to 1973 the seasons were, respectively, 190, 170, 167, 162, 180, 89, 89 and 27 days).

[77] Similar to point H (see note 64), in theory, the fishery approaches point L but (because of stock effects) never reaches it. In the simulation at the end of 200 years a three year cycle is apparent where the number of vessels in the fishery was 226 ± 1, fishing power was 50,567.98 units (+.41% or -.46%), the season was .084775 of a year (+.46% or -.41%) and effort is 4,286.98 units. Please note that 1/226 is .44 percent.

Eventually, it would become apparent that the transition depicted in Figure 6-9 was not to MEY. As noted previously, in fisheries economics MEY in practise represents the combination of outputs and inputs point where the resource rent is maximized (point K in Figure 6-9). If fisheries economists waited until the (Figure 6-9) transition to point L is complete before re-examining the fishery they would find that the eqn (90) cost curve was no longer relevant to the fishery. The change in g (.500000 of a year at point A to .084775 at point L) dramatically increases the observed cost of fishing effort. If the exercise in subsection 6.1.4 is redone for the values observed at point L then N^* is 1, K^* is 9.9950 units, C_i is \$69,225, f_i is 223.833 units and E_i is 19.053 units. This changes the cost of fishing effort, expressed as an over simplified linear function of fishing effort, to:

$$C = 0 + \$3,633E \tag{92}$$

An unthinking fisheries economist might respond to the information in eqn (92) by asserting that the MEY had shifted and might estimate this new value by differentiating eqns (1) and (90) with respect to effort, setting the differentials equal and reorganizing that result to:

$$E_{MEY} = .5r[1 - 3,633\alpha/(q\delta P)]/q \tag{93}$$

When the Appendix B-1 parameter values are substituted into eqns (93), (4) (1) and (92): E_{MEY} is 2,161.72 units, X_{MEY} is 156,765.6 tonnes, R_{MEY} is \$10,844,262, C_{MEY} is \$7,853,524 and π_{MEY} is \$2,990,738. Figure 6-10 shows what happens if the fisheries managers shift from the managed open access equilibrium at point L (in Figures 6-10 to 6-11) to the, eqn (93) defined, MEY effort. The result is a relatively small intermediate-run gain, in return for a considerable amount of short and long-run pain. In the long run (point M, Figure 6-10), the revenue and cost curves shift to a common interior point and the resource rent is fully dissipated. Fisheries managers can also generate this interior solution by setting a 3,000 tonne transitional TAC and when the biomass rises to 156,765.6 tonnes, setting the TAC to 5,422.133 tonnes ($10,844,262/$2,000 per tonne). The result of this TAC driven transition, shown in Figure 6-11, is similar to the transition shown in Figure 6-10. The wild swings in fishing power observed in Figure 6-9 are also present in Figure 6-10 but are less obvious, because a TAC forces fishing revenues to be constant. In nominal terms (i.e. a nil discount rate) the Figure 6-9 transition from points I to H results in a social loss of $(6,887 million) and that transition in Figure 6-10 results in a $63.318 million surplus. When a social discount of five percent is included in the analysis the net present value of the Figure 6-9 loss rises to $19.362 million and the Figure 6-10 surplus changes to a loss of $(.107) million.

A further idea of what is happening can be developed by extending a ray in Figure 6-10 from the origin to point K and marking the point of tangency between that ray and the sustainable revenue curve. When a horizontal line is extended from point M (the new managed open access equilibrium) to the Y axis it will pass through the point of tangency.

If the fisheries economists are persistent they could assume that the cost of fishing effort had changed again and re-estimate the MEY. The revenues at that managed open access equilibrium can be defined by drawing a ray in Figure 6-10 from the origin to the intersection of the sustainable revenue curve and the point M horizontal and finding the tangency between that ray and the sustainable ray curve. While in theory this process of estimating and re-estimating MEY could go on *ad infinitum*, sooner or later the fisheries managers will lose confidence in the process.

A comparison of Figures 6-6 to 6-11 shows that the cost curve for fishing power has a constant slope in a fishery where seasons are managed. When the management TAC or effort target is changed the cost of fishing power curve shifts so that it intersects the unmanaged cost of fishing power curve at the fishing effort associated with the management target. This match-up does not occur in Figure 6-5. In that case, the harvest is managed from the fishery's inception and the management efforts are affected by effect of the fishing down of the biomass. The fishing down of the biomass occurs at a diminishing rate, as the fishery moves toward point H. In Figure 6-6, the fishing down effect was insignificant because the biomass was not allowed to rise significantly past the biomass associated with the target TAC (e.g. thus, there was little fishing down of the biomass).

6.1.4.2 CONTROLLING SEASONS TO MANAGE FOR $F_{0.1}$

Fisheries biologists, recognizing that it is difficult to formulate a practical operating definition for MEY, have proposed that $F_{0.1}$ be used as a proxy (Gulland and Boerema, 1973, pp.331-332). Saetersdal (1987, p.12) noted that Canada had adopted a $F_{0.1}$ TAC policy for its Atlantic fisheries by 1976/77. $F_{0.1}$ is associated with optimal yields and resource rent conservation in government of Canada studies (Fisheries and Oceans, 1978, p.2, 1983, p.2; Munro and McCorquodale, 1981, pp.38-39; Campbell, 1981, p.29; Fargo et al., 1988, p.109; Harris, 1990, p.96). At $F_{0.1}$, the marginal yield to fishing effort is 10 percent of the marginal yield at very low levels of fishing (at or near the origin). Thus, $F_{0.1}$ is a point at which there is little (social) reward from increased fishing effort (Gulland, 1983, p.13). When eqn (1) is differentiated with respect to effort the result is:

$$dR/dE = q\delta P(1-2qE/r)/\alpha \qquad (94)$$

The marginal yield at $F_{0.1}$ can be calculated by setting the effort in eqn (1) equal to nil and multiplying the result by 10 percent.

$$dR/dE \text{ at } F_{0.1} = .10q\delta P/\alpha \qquad (95)$$

When the RHS of eqns (94) and (95) are set equal the result can be reorganized to:

$$E_{F0.1} = .45r/q \qquad (96)$$

When the parameter values listed in Appendix B-1 are substituted into eqn (96) the effort at $F_{0.1}$ is 4,500 units, which is reasonably close to the E_{MEY} of 4,286.98 units estimated with eqn (91). However, this simple method of guesstimating E_{MEY} still leaves a problem. MEY is not just a yield, both yield and cost have to be controlled to attain MEY. Specifically, season management maintains a fishery at the target harvest or effort by shifting the open access equilibrium from its unmanaged point to the targeted value—the target yield is attained but all the resource rent is dissipated, by increased fishing costs (see Table 6-3). Another problem can occur with $F_{0.1}$. In terms of Figure 6-2, the $F_{0.1}$ stock level is to the right of the MSY stock level. The $F_{0.1}$ harvest amount can also be generated by a lower stock density that is to the left of the MSY level. If only harvest data are available there is no means to identify which of the two stock densities has been attained. This is a problem, because the $F_{0.1}$ point is a stable equilibrium and the other point is an unstable equilibrium.

In summary, while the $F_{0.1}$ harvest may be a reasonable approximation for the MEY harvest, it works by dissipating all of the resource rent—thus is not an approximation of MEY. The misconception that $F_{0.1}$ is a good approximation for MEY is widespread and is best epitomized by the following incorrect assertion:

> "It is important to notice that $F_{0.1}$ is a sensible but arbitrary biological reference point. It offers an approximate solution to the problem of how best to maximize the profitability of the fishery without the necessity of constructing a complex and sophisticated economic model..." (Harris, 1990, p.96).

6.1.4.3 USING TAXES TO MANAGE FOR MEY

If attaining MEY is defined as managing a fishery so as to maximize the resource rent then the only way to achieve MEY in open access fisheries is through taxation. Taxes shift the open access equilibrium to the MEY point by either reducing the private revenue (i.e. if the tax is a royalty) or by increasing the private cost of fishing (i.e. if the tax is a licence fee). However, taxes will not directly affect the fishery social revenue and cost. Taxes transfer resource rent to the government and are perceived, by fishermen, as either a cost or a revenue reduction.

If the tax is in the form of a royalty per tonne of fish then in the fishery depicted in Figure 6-9 (at point A), the royalty should be set at $1,500.8/tonne ([15.674,622 revenue - 3,912,595 costs]/7,837.31 harvest tonnes). However, in a mature fishery, the shock from suddenly imposing a royalty can generate severe oscillations in fishing power. These oscillations eventually damp to the target yield/effort—if all the fishing vessels do not leave the fishery after the initial shock.

In an over exploited fishery, Clark's (1976, pp.116-122) dynamic tax approach would recommend using maximum royalty tax to drive effort out of the fishery until a point was attained on the optimum trajectory to the target effort/biomass point and a minimum royalty (nil) would be applied until the target was reached. The economic shock and dislocation that would ensue from such a royalty policy are unacceptable to most politicians. A staged phase-in of the royalty would be much less disruptive to the fishery. In a mature fishery a small tax will have a large effect, therefore, as effort leaves, the stock biomass increases and the royalty has to be increased to maintain the pressure to reduce effort. A phased-in royalty takes longer to attain the target yield/effort but minimizes the disruption to the fishery.

In the fishery depicted in Figure 6-12, the royalty was phased-in at 50 percent for the first decade, 75 percent for the next decade and 100 percent, there after.

The Figure 6-12 damped revenue cycle (around point K) collapses if a TAC is used to limit the harvest to the MEY level (Figure 6-13). Thus, Royalties and season management should be use in concert—a royalty for gross management and season management for fine tuning.

Licence fees, if applied per vessel, are seen by vessel owners as an increase in vessel fixed costs (similar in nature to parameter b). Owner/skippers respond to this change in private cost by modifying the configuration of inputs in their vessels. The minimum private cost of effort configuration of vessel inputs will, with vessel licence fees, be described by:

$$N^* = \langle N^* \rangle \qquad (51a)$$

a capital input of:

$$K^* = [b + FEE + (\tau+g\Phi+g\Omega)N]/(\Gamma+g\theta)/(1/k-1) \qquad (97)$$

FEE = fishery tax as a vessel annual licence fee

and will incur an annual cost of:

$$C_1^* = b + FEE + (\Gamma+g\theta)K^* + (\tau+g\Phi+g\Omega)N^* \qquad (98)$$

For example, if the fishery managers translate a \$1,470.72/tonne royalty to a \$271,351 (\$1,500.77*7,837.31 tonnes/43.346 vessels) fee per vessel then the vessel configuration of choice for owner/skippers shifts to 4 fishermen and 58.510 (± 1 %) units of capital.[78] As shown in Figure 6-14 the true MEY cannot be attained via vessel licence fees alone. Also, Figure 6-14 indicates that the fishery adjustment to vessel licence fees is convoluted and difficult to predict. Taxing all of the fishing inputs (labour, capital and the vessel platform) will minimize but not eliminate this distortion (e.g. vessel owners will look for inputs that are difficult to identify and/or tax).

While royalty taxes can generate MEY, it might be more prudent to use a tax mix so that less benefit accrues to the avoidance of any one tax. Ideally, the tax on inputs should be set at or near the marginal value of the input expense as a deduction from income tax—so any gain from input tax avoidance (i.e. nondisclosure of an input) tends to be offset by an income tax exemption loss). However, the MEY produced by

---

[78] The shock from license fees could severely disrupt the fishery and drive out too much fishing power. In the fishery shown in Figure 6-14, this disruption is controlled by phasing the license fee in at 25 percent for the first decade, 50 percent for the next decade and 100 percent, there after.

taxes does not increase the incomes of fishermen. Further, the adjustment path from an open access fishery to a tax induced MEY may involve substantial loss to fishermen in the open access fishery. The resource rent generated by a fishery tax policy will not benefit the government image—it is received by the nation as a whole and is not focused on a small group. The transitional losses from such a tax policy are focused on a small vocal group who can promote an image of poor hard working small businessmen being unfairly set upon by an uncaring government. Thus, as noted subsection 5.4.2, the government tends to be more interested in raising the average incomes of fishermen than in maximizing the resource rent generated by fisheries. One way of resolving the problem is to use the funds generated by the royalty tax to subsidize the fishermen who withdraw from the fishery. However, Figure 5-1 indicates that the problem of how much compensation is fair is complicated. Specifically, if a fishery is in economic difficulty, the fishermen who sell their vessels are often forced to do so by circumstance and any willing buyers tend to deeply discount the vessel price—as an offset to the low earnings, and to maintain their utility at the entry level). Thus, when a fishery is in difficulty, the current *fair market value* may not be a *fair* exit compensation for the exiting fishermen.

The committed nature of fishing inputs can create another problem with fishery taxes—a government that is unscrupulous, uncaring or incompetent may set taxes that extract the quasirents from the owners of fishing inputs, along with the resource rents. Arnason (1989, p.222) considered a related problem when he noted that the optimal tax is not the same for all firms. This is a problem only if the government in-tends to extract the producer surplus (see Copes 1972) along with the resource rent.[79]

Heaps and Helliwell (1985, pp.437-440) noted that various other problems can plague fishery tax schemes. For example, seasonal variations in stock biomass density, lags and other problems tend to make the impact of taxes unpredictable. As a result, the use of taxes for management control is questionable. Taxes may be useful, however, as a means of collecting revenue for the government or one of many elements in a fisheries management control program.

6.1.5 LIMITING ENTRY

Limited entry was touted by a number of fisheries economists as a fishery *cure-all*. In theory, it eliminates excessive effort in fisheries, generates large amounts of resource rent and creates the potential of increasing the incomes of fishermen—by allowing them to earn a significant share of the resource rent. The reality of limited entry programs has shown these exhortations to be overly optimistic.[80] Also, the effectiveness of many limited entry programs was reduced because some governments lacked the political will to rationalize their fisheries after implementing limited entry. The number of vessels licensed often exceeded the number active in the prelicence fishery, vessel im-

---

[79] As resource rent is due to the relative richness of a resource, the government is on relatively sound moral ground if it decrees a fishery to be a public resource and taxes away the resource rent. Producer surplus arises because some producers are more skilled, efficient and/or effective than the marginal producer. A tax extracting all producer surplus is economically inefficient and its moral basis, if any, would be Byzantine.

[80] See discussions by Fraser, 1977; McKellar, 1977; Sinclair, 1978; Pearse and Wilen, 1979; Crutchfield, 1979; Copes, 1980; Pearse, 1981; Munro 1987.

provements further expanded fishing effort, vessel buy-back programs were poorly thought out, taxes and licence fees tended to be nominal—often less than the value and/or cost of the government goods/services provided to the fishery.[81] Generally, limited entry has proven to be a qualified success, in terms of generating resource rent and increasing fishing incomes. Often, the second and more important part of this qualified success was usurped by the benefits being capitalized in the value of the transferable licences. Only the first generation of fishermen benefit from a transferable licence program—succeeding generations must buy or inherit licences.

Given the current wisdom on limited entry programs it is remarkable that such programs work at all, even poorly. Pearse's (1982, p.83) remarks are typical, if "one or more inputs in the fishing process are restricted, the capacity of the fleet can continue to expand by adding other, unrestricted inputs. As a result, this technique has consistently failed to achieve the desired results." Pearse further emphasized his judgement by observing that restricting every fishing input and innovation is administratively neither possible nor desirable.

---

[81] A fishery is exploited in a rational manner if the net social benefits arising from the exploitation are maximized. The exact meaning of fisheries rationalization may also be affected by time horizon and/or allocation concerns. Copes (1972) provides an excellent discussion of the components of the social surplus and the relative importance of each component to different groups associated with the fishery.

The diminished success that tends to occur in limited entry fisheries is attained because fishing inputs are not perfectly substitutable, most fishing inputs eventually experience diminishing returns to scale and the amount of fishing power that can sensibly be generated by the stuffing of inputs into a vessel has limits. A rational vessel owner will only add an input if its marginal private cost is less than its (perceived) private marginal revenue. In open access fisheries, effort expands through the addition of vessels. In limited entry fisheries, expansion occurs through the addition of inputs to the limited number of licensed vessels. The intent of limited entry programs is to reduce the amount of resource rent being dissipated. The occurrence of resource rent causes distribution to be an issue between vessel owner/skippers and their deckhands. A share payment fishery system is a good way of exploring this issue. In a limited entry fishery with each vessel crew member being paid a share of their vessel's gross revenue the expansion of fishing effort is limited by eqns (64) to (69), (23) and (29).

$$K^{\S} = [\mathrm{Base}(\Gamma+g\theta)(E_o/R_o)/(\mathrm{base}+1-N)]^{1-k} \qquad (64)$$

$$\pi_i = [gmN^{n}(R_o/E_o)(\mathrm{Base}+1-N)/\mathrm{Base}]^{2}/(\Gamma+g\theta) - b -$$
$$(\Gamma+g\theta)[gmN^{n}(R_o/E_o)(\mathrm{Base}+1-N)/\mathrm{Base}]^{1-k} - (\tau+g\Phi+g\Omega) \qquad (65)$$

$N^{\S}$ = value of <N> that generates
the highest value in eqn (65) (66)

$$C_i = b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N \qquad (29)$$

$$C_i^{\S} = b + (\Gamma+g\theta)K^{\S} + gmN^{n}K^{k}(R_o/E_o)(N^{\S}-1)/\mathrm{Base} + (\tau+g\Phi+g\Omega) \qquad (67)$$

$$C^{\S} = V^{\S}C_i^{\S} \qquad (68)$$

$$E_i = gmN^{n}K^{k} \qquad (23)$$

$$\mathrm{Base} \le R_o/V/(\tau+g\Phi+g\Omega) \qquad (69)$$

Equations (64) and (66) define the vessel input configuration desired by profit maximizing vessel owners, eqn (29) is the associated social fishing cost per vessel and eqn (67) is the associated private fishing cost per vessel.[82] The social cost of fishing effort may lie above the private cost of fishing effort—by definition the social cost includes the opportunity cost of all inputs, whereas, the private cost replaces the opportunity cost of deckhand labour with the deckhand share of the vessel revenues.

In limited entry fisheries, managers can control both the number of vessels and (via season length) the amount harvested. For example, if the vessels in the fishery depicted in Figure 6-4 are limited to 87 (the number at point A), the fishing season can be manipulated to regulate (via eqns (64), (64) and (23)) the amount of fishing effort.[83] Figure 6-15 shows the *short-run equilibrium* fishing efforts, revenues and costs that are possible with 87 vessels. In Figure 6-16, total revenues and costs in the fishery are shown as a function of the associ-

---

[82] In an open access fishery, profits are dissipated by vessel entry and the limits described by the eqns (64) and (66) are not meaningful. In the very long-run changes in technology change the parameter values in eqns (64) and (66).

[83] The number of licences to issue is always a major problem. McKellar (1977, p.25) noted that "almost irrespective of the objective of the management program adopting licence limitation as a means of control, the most crucial and difficult issue confronting administrators is that of how to allocate licences. Equally important is the issue of how many licences should be available, but this problem has usually been side stepped in solving the allocation problem by freezing the number of vessel licences at a particular time."

ated fishing power.[84]

In Figures 6-15 to 6-16, the fishing effort must be less than or equal to the effort at point B. At that point the fishing season is at its maximum of .5000 of a year and decreases as the *short-run equilibrium effort* is decreased. The maximum total effort willingly generated by vessel owner/skippers occurs at point D. However, that and all the other points on the private cost of fishing effort curve are unstable in the long run. As evidenced by the social cost being above the private cost the vessel deckhands are being paid less than their long-run opportunity costs. Ignoring this problem for the moment, the fishery resource rent is maximized at the fishing effort associated with point A, which lies between the MEY and MSY efforts. That point, however, is of little interest to the fishery managers. The relatively flat slope of the social cost of fishing effort in limited entry fisheries mean that losses in resource rent, produced by decreasing the effort, tend to be more than offset by gains in stock conservation and stability. Therefore, the current conventional wisdom is to manage fish stocks at efforts that are significantly less than the MSY effort. The following figures assume that the fishery is being managed for the MEY harvest level.[85]

---

[84] The private cost of fishing effort lies below the associated social cost. This indicates that (in this example) when the number of vessels is limited to 87, the vessel owners are (in the short to intermediate run) able to extract quasirent from deckhands. This idea is discussed in more detail later in this subsection.

[85] Where MEY is the harvest level at point K in Figure 6-12.

After choosing the target harvest level the fishery managers must choose the number of vessels to have in the fishery. When the fishery total revenue, share base and crew per vessel are constant, the number of vessels operating in the fishery has a profound effect on the allocation of revenues between vessel owner/skippers and crew. If all vessels are identical then the annual fishing wage per deckhand is:

$$W_s := R_o/V/\text{Base} \tag{99}$$

However, in this model, the Base is, in the long run, a variable:

$$\text{Base} \leq R_o/V/(\tau+g\Phi+g\Omega) \tag{69}$$

Based on Figure 6-15, a limited entry program can reduce the amount of resource rent being dissipated and substantially increase fishing incomes. When there is resource rent in a fishery and it is in the form of private profits and there is a share agreement, the weak inequality in eqn (69) is accurate. However, Figure 6-15 shows only the short-run effect. Tullock (1975), in describing the long-run effect of a government bestowed benefit coined the phrase *transitional gains trap*—where a benefit conferred to an individual as a transferable right becomes capitalized as the price of the right. Tullock, further, observed that individuals granted benefits in the form of nontransferable rights are ingenious at finding ways of converting those rights into transferable rights. The sale of transferable licences enables the seller to usurp the estimated present value of all future benefits arising from a limited entry program. This causes limited entry to fail its objective of benefiting all fishermen—not just the current generation. If the resource in a fishery becomes capitalized in the amounts paid for vessel licenses then the private profit falls to nil (the resource rent becomes a normal return to capital invested in the vessel licenses) and the weak inequality in eqn (69) becomes an equality.

The ability of the deckhands to share in the resource rent varies with the bargaining power of their union (if any) compared to that of the vessel owner association (if any). If the union is relatively weak most the resource rent will tend to be capitalized (in form of license values) and in the short to intermediate-run the vessel owners may be able to extract and capitalize quasi-rents from their crews (i.e. the difference between the entry and exit opportunity costs). This model assumes that a monopsony exists and that share negotiations will tend toward long-run agreements that cover private fishing costs first and then share any profit/loss.[86] While, the dynamics of this process tend to be difficult to model, the long-run equilibrium conditions can be identified by incorporating the following observations and assumptions into the model:

- If the fishery is managed for an MEY harvest level then the fishing season is defined by:

  $$g = E_{MEY}/(mVN^{\alpha}K^{k}) \qquad (100)$$

- In the long run the share base will adjust to:

  $$Base = R_{MEY}/V/(\tau+g\Phi+g\Omega) \qquad (101)$$

- The vessel owner/skipper share of resource rent is capitalized into (vessel) license values and vessel owner/skippers observe a profit function of:

  $$\pi_i = gmN^{\alpha}K^{k}(R_{MEY}/E_{MEY})(Base+1-N)/Base - b - t$$
  $$- (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega) \qquad (102)$$

---

[86] The annual cost of vessel licenses, including the opportunity cost of the capital tied up in the license is part of the private cost of fishing and would be deducted from gross revenues as a part of determining the private profit.

t = annual cost of a limited entry licence

- If adjusted for a varying share base and crew, the capital desired by vessel owners/skippers becomes:

$$d\pi_i/dK = kgmN^{a}K^{k-1}R_{MEY}(Base+1-N)/E_{MEY} - Base(\Gamma+g\theta) = -0- \quad (102a)$$

which can be reorganized to:

$$K^{\S} = [Base(\Gamma+g\theta)(E_{MEY}/R_{MEY})/(base+1-N)]^{1-k} \quad (103)$$

- When the RHS of eqn (103) is substituted into eqn (102) the result is:

$$\pi_i = [gmN^{a}(R_{MEY}/E_{MEY})(Base+1-N)/Base]^{2}/(\Gamma+g\theta) - b - t$$

$$(\Gamma+g\theta)[gmN^{a}(R_{MEY}/E_{MEY})(Base+1-N)/Base]^{1-k} - (\tau+g\Phi+g\Omega) \quad (104)$$

and the vessel owners/skippers desire a labour input of:

$N^{\S}$ = value of <N> that generates
the highest value in eqn (104) (66)

- The annual cost of a vessel license is assumed (in the long-run) to equal the resource rent and is defined by:

$$t = (R_{MEY}/V)(base+1-N)/base - b - (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega) \quad (*105)$$

Figure 6-17 was produced using an iterative process to solve eqns (99) to (107). It shows that the degree of resource rent dissipation varies with the number of licensed vessels. In the example the loss of resource rent is lowest at 15 vessels and there is no resource rent at 227 vessels. When there are more than 226 vessels a long-run equilibrium is not possible but inferences can be made about the intermediate -run situation by altering eqns (101), (102), (104) and (105) to reflect the exit opportunity cost of labour. The short-run situation is much more complex because the crew, while dedicated to the fishery are (unlike fishing capital) not dedicated to a particular vessel. In Figure 6-17, as the number of licensed vessels is increased the long-run number of fishermen per vessel declines and the social cost of fishing curve shifts down and rotates to a shallower slope. The social cost of fishing cure in Figure 6-17 lies (for the most part) above its equivalent in Figure 6.9.

Limited entry can generate resource rents but if the limit is not set at a relatively low number of vessels a large portion of potential resource rent will still be dissipated. Capitalization of the present value of the expected future undissipated rents, in the market value of the vessel licenses, causes another problem. The annual cost of the capital invested in the license (actual or implicit—opportunity cost) enters into the private cost function and reduces the private profit being shared. Vessel owners then receive their private costs (including the annual cost of a license) plus a share in the private profit. That share may then be capitalized into the licence's market value and so forth, until the private profit is reduced to nil. Unwary entrants to the fishery may assume that the appreciation in license values will continue and base what they are willing to pay for a vessel license on the annual income plus appreciation. However, when the undissipated resource rent is fully capitalized, the license values cease to appreciate, the unwary investors experience capital losses and may go bankrupt. During the transition to a stable situation, the deckhands may experience falling incomes even though fishing revenues are constant. However, their complaints can be met with the incontrovertible argument that the returns to the vessel owner/skippers time and investment are also lower than normal. And fishermen will, as a common interest group, turn to governments for assistance to their *depressed and distressed industry*.

The idea of season generated transient producer surplus, introduced in subsection 6.1.3, is more important in limited entry fisheries. In Figure 6-17, at 75 vessels, each vessel will earn revenues of $208,995 by combining 2 crew and 23.549 units of capital to generate 335.229 units of fishing power at a social cost of $132,409 and a private cost of $208,995 (the annual cost of a vessel license is $208,995 - 132,202 = $76,586). Vessel owner/skippers and crew earn their opportunity cost. If one vessel returned to the Figure 6-8, point A vessel configuration of 1 crew and 7.0205 units of capital generating 197.802 units of effort, the fishing season would be .17145 of a year (4286.98 /[197.802 + 74*335.229]). Under these conditions the unchanged vessels each earn $210,143 ($15,674,626*335.229/[197.802 + 74*335.229]) at a social cost of $132,943 and private cost of $209,529 (132,943+76,586) for a private net gain of $614. The changed vessel will earn $123,994 at a social cost of $67,889 and a private cost of $144,475 ($67,889 + $76,586) for a private net loss of $(20,481). The transient producer surplus, in this example, is $21,095 per unchanged vessel. Subsection 5.6.3.2 indicates that when the number of vessels is limited and a TAC holds the harvest constant then season length reductions may mitigate the amount of capital stuffing. However, before this effect is used as a management tool, further research is needed on its social efficiency and costs.

In specific fisheries, these observations have to be tempered by local features—variations on share agreements, additional limitations on the vessels (e.g. length, engine power), alternate forms of input stuffing (e.g. spotter planes, packing/supply vessels, multiple shifts per vessel). While limited entry conserves some of the resource rent those benefits are soon capitalized as vessel license values and provide no further benefit to individuals fishing. Overall, limited entry programs may serve neither the long-run interests of the fishermen nor those of the government.

6.1.6 INDIVIDUAL QUOTAS (IQs or ITQs)[87]

Recognizing that the property rights granted to vessel owners by limited entry were seriously flawed, some fisheries economists started searching for a less impaired fishing right. The primary problem with limited entry regulation is that it only restricts access to a fishery commons. It cannot address the fishery common property resource problem that still exists for the individuals licensed to fish. Individual quotas were developed to resolve this common property resource problem by granting to each quota holder the harvest rights to a pre-specified amount of fish. In theory (Arnason, 1989, pp.236-237; Clark et al., 1989, pp.137-138), this approach promotes efficiency and substantially reduces the need for government involvement in fisheries. A quota sets the amount harvested by a fishing enterprise. The *rule of capture* is, however, still active in an IQ fishery—but the prize contended for by each fishing enterprises is changed from "the amount of fish taken" to "the mix of particular pieces (individual fish) taken". Copes (1986b), in discussing the strengths and weaknesses of IQs, noted:

---

[87] ITQs are a class of IQs where part of the quota right is a right to transfer the quota, in whole or in part, to another individual.

> "When they are assured of their quota—so it is held—fishermen can take their time, spreading their effort optimally across the entire season and using the most economical configurations of equipment and manpower in the process. ...As a further advantage operators will find little need to fish in bad weather or under other dangerous circumstances in order to keep up their share of the catch." (Copes, 1986b, p.280).

The market solution associated with ITQs is a good match for our culture—we tend to have more faith in *the level playing field of a fair market* than in the fairness/judgement of a bureaucrat. However, IQs are not without problems. Copes (1986b) identified a host of situations where (per the policy objectives in Table 5-2) an IQ management system will either fail or be grievously flawed. However, as discussed below, the successes of IQs may produce as much harm as the failures.

IQs can be allocated either in terms of absolute tonnages of fish or as a fraction of an annually set TAC. Clark, et al. (1989, p.143) provides a good discussion of the issues involved in these approaches. The model in this section assumes that the individual quota is a fixed percentage of an annually set TAC. A vessel's share of the harvest and the associated revenue is assumed to be determined by that vessel's effort as a ratio of the total effort in the fishery. This is consistent with eqns (3) and (21). Chart 6-2 is a Margenau map of an IQ fishery—except for a few major differences in the fishery management and the fishing enterprise behaviour, it is very similar to Chart 6-1.

While any revenue and effort pair can be used to set a TAC, R_{MEY} and E_{MEY} are used in the following example—MEY is consistent with the resource rent maximizing goal of IQs.

When an individual quota management system works as it should, it transforms the fishery objective function to:

$$\text{Maximize: } \pi_i = Q_i R_{MEY}(Base+1-N)/Base - b - (\Gamma+g\theta)K - (\tau+g\Phi+g\Omega) \quad (106)$$

$$\text{Subject to: } Q_i E_{MEY} = gmN^n K^k \quad (107)$$

Q_i = the fraction of the TAC owned by vessel i, as an individual quota

Equation (107) can be reorganized to:

$$K = (Q_i E_{MEY} N^{-n}/g/m)^{1/k} \quad (108)$$

When the RHS of eqn (108) is substituted into eqn (106) vessel profits can be expressed as a function of the labour input alone:

$$\pi_i = Q_i R_{MEY}(Base+1-N)/Base - b - (\Gamma+g\theta)[Q_i E_{MEY} N^{-n}/(gm)]^{1/k} - (\tau+g\Phi+g\Omega) \quad (109)$$

If the harvest quota per vessel (Q_i) is given, the desired labour input per vessel is defined as:

N = value of <N> that generates
the highest value in eqn (109) (110)

and eqn (108) defines the desired capital input. However, this result will tend to be a short-run local optimum that relates only to the Q_i specified. Further, the above equations assume that the fishing season length is at the maximum value (.50 of a year per Appendix B).[88]

---

[88] There may be some set of unusual circumstances were fishing enterprises may be able to maximize their profits by taking less than their assigned quota. However, those circumstances would be extremely difficult to model because both the actual harvest and the actual effort in the fishery would simultaneously vary from their target values. These problems are not resolved here, but are reserved for future study.

The transition from a limited entry fishery to a fishery with IQs tends to be convoluted and the adjustment path is likely to be dependent on accidents of history, culture and politics. One thing is certain—many of the management tools and much of the thinking that were useful in limited entry fisheries will be inappropriate in IQ fisheries. For example, as the management focus changes in a fishery so does the most suitable graphic presentation: in open access fisheries yield /effort graphs are appropriate, in limited entry fisheries yield/fishing power graphs are appropriate and in IQ fisheries both effort and fishing power are irrelevant to the fishery managers. In IQ fisheries, the size and number of quotas issued are relevant, for the X-axis. The assumption in this model that of the all fishing vessels are identical simplifies the analysis. Under this assumption, the number of vessels in a fishery is an appropriate value for the X-axis because:

$$Q_i = 1/V \qquad (111)$$

Also, that assumption changes eqn (101) to:

$$\text{Base} = Q_i R_{MEY}/(\tau+g\Phi+g\Omega) \qquad (112)$$

Figure 6-18 was formed with the assumption in mind that adjusting the configuration of vessel inputs is easier than adjusting the share base. Under that assumption, the season length used in eqn (112)—the share base—is the limited entry equilibrium season length even though the actual season length increases under IQs (e.g. change in the share base is assumed to lag the change in season length). Equations (108) to (111) along with (29) and (69) can be solved to create Figure 6-18. In that figure the total private cost is:

$$C_p = Q_1 R_{MEY}(N-1)/\text{base} + b + (\Gamma + g\theta)K + t + (\tau + g\Phi + g\Omega) \qquad (113)$$

t = annual cost of a limited entry licence

and, in most cases, the difference between total revenue and the total private cost is due the reduction in fishing costs—the longer fishing season gives rise to more efficient vessel configurations. Where there are deckhands involved, the vessel owner/skippers can gain a quasirent windfall from their crew. Specifically, the share base carried over from the limited entry fishery was negotiated in terms of the reduced season length in that fishery. It is commonly suggested that under an IQ management program the season length does not have to be reduced to manage the harvest (Pearse, 1982, p.84; Fraser and Jones, 1989, p.279; Scott, 1989, p.28)—as a result, the season length should rise to its natural length. If the fishing labour market was perfect, the fishing incomes of the deckhands would rise, to compensate for the additional time spent fishing (Figure 5-1). However, initially, IQs only increase the vessel net income—vessel gross income is unchanged, as is the old share base. Thus, in terms of Figure 5-1, there is a short-run decline in the well-being of fishermen—the decrease in their leisure time is not compensated by an increase in income.

In the short run all rents (both real and quasi) are captured by the quota/vessel owners and tend to be capitalized in the market price of the quota. This situation is depicted in Figures 6-17 and 6-18. The discontinuities in those figures arise because fishing labour is lumpy (discrete) rather than continuous.

In the intermediate run the share base will adjust to reflect the entry opportunity cost of deckhands and the value of quota will adjust to fully capitalize all resource rents. Figure 6-19 depicts this ideal but during the adjustment period the IQ may be overvalued (e.g. if the afore mentioned quasirent windfall and/or other unrealistic expectations are capitalized). Also, if the quota is transferable a reduction of vessels may generate a surplus of deckhands and reduce their earnings from their entry opportunity cost to their exit opportunity cost. In the very long run, such difficulties are either resolved or settle into some form of a cyclical pattern.

If the quota is transferable and combinable, in whole or in part, then, in the long run, vessel owner/skippers will choose that combination of capital, labour and quota which maximizes vessel profits. That configuration was identified via the following process. When the RHS of eqn (112) is substituted into eqn (109) the result defines the vessel profit exclusively in terms of the labour input:

$$\pi_i = Q_iR_{MEY} - b - (\tau+g\Phi+g\Omega)N - (\Gamma+g\theta)[Q_iE_{MEY}N^{-n}/g/m]^{1/k} \qquad (114)$$

Equation (114) was differentiated with respect to the quota (Q_i):

$$d\pi_i/dQ_i = R_{MEY}-(1/k)(\Gamma+g\theta)[E_{MEY}N^{-n}/g/m]^{1/k}Q_i^{1/k(1-k)} = -0- \qquad (114a)$$

Equation (114a) can be reorganized to:

$$Q_i^* = ([kR_{MEY}/(\Gamma+g\theta)]^k[gmN^n/E_{MEY}])^{1/(1-k)} \qquad (115)$$

As noted previously, labour is not infinitely divisible. As a result, vessel optimal quotas (eqn (115)) can be calculated for a spread of integer labour inputs. Each vessel local optimal quota and its associated labour input can be substituted into eqn (114), the set that generates the highest profit generates the vessel global optimum and the vessel optimum capital input can then be calculated by using the following modified form of eqn (108).

$$K = [Q_i E_{MEY} N^{-\alpha}/g/m]^{1/k} \qquad (116)$$

The results of the above calculations are given, along with other analysis, in part I of Table 6-2. From this perspective of maximizing the per vessel resource rent, an optimal vessel uses six fishermen and 89.789 units of capital to produce 631.47 units of fishing power at a cost of $605,983 to take 7.36 percent of the TAC_{MEY}. However eqn (114) does not consider the opportunity cost of the ITQ. In the long run eqn (114) becomes:

$$\pi_i = Q_i R_{MEY} - b - (\tau+g\Phi+g\Omega)N - (\Gamma+g\theta)[Q_i E_{MEY} N^{-\alpha}/g/m]^{1/k} - t \qquad (117)$$

t = annual cost of the capital tied -up in the value of the ITQ

where private profit likely falls to nil and all resource rent is capitalized in the market value of ITQs. It is likely that a host of complex, interacting factors are involved in determining the market value of t (especially in the short run). In this model, these factors are ignored and it is assumed that the long-run value of the ITQs reflects the maximum annual rent they can earn. Under this assumption eqn (114) becomes:

$$\sum_{i=1}^{n} \pi_i = R_{MEY} - [b+(\tau+g\Phi+g\Omega)N + (\Gamma+g\theta)(Q_i E_{MEY} N^{-\alpha}/g/m)^{1/k}]/Q_i \qquad (118)$$

$$d(\Sigma\pi_i)/dQ_i = [b+(\tau+g\Phi+g\Omega)N]Q_i^{-2} -$$

$$(1/k-1)[(\Gamma+g\theta)(E_{MEY} N^{-\alpha}/g/m)^{1/k}]/Q_i^{-(2-1/k)} = -0- \qquad (118a)$$

After both sides of eqn (118a) are multiplied by Q^2, the result can be reorganized to:

$$Q_i^* = (gmK^{\alpha}/E_{MEY})([b+(\tau+g\Phi+g\Omega)N]/[(1/k-1)(\Gamma+g\theta)])^k \qquad (119)$$

Socially optimal quotas (eqn (119)) can be calculated for a spread of integer labour inputs. Each local social optimal quota and its associated labour input can be substituted into eqn (118), the set that generates the highest profit generates the social global optimum and the social optimum capital input can be calculated by using eqn (116).

The results of the above calculations are given, along with other analysis, in part II of Table 6-2. From this perspective of maximizing the total resource rent, optimal vessels use one fisherman and 7.0205 units of capital to produce 197.80 units of fishing power at a cost of $90,256 to take 2.31 percent of the TAC_{MEY}. This results in a true MEY and not just the same harvest as MEY.

Both the vessel optimum and the social optimum are (long-run) attractors in the fishery system.[89] Their relative strength depends on the market for quota. As the ITQ market approaches the ideal of a perfectly competitive market the social optimum becomes more dominant and in the limit it is the only stable attractor. The market imperfections needed for the vessel optimum to dominate the fishery in the very long run are unlikely to be met. However, the influence of that attractor could cause significant capital losses and hardship, in the intermediate to long run.

---

[89] In systems, an attractor is defined as whatever the system tends to settle down to (Stewart, 1989, p.109).

ITQs appear to avoid the input stuffing problems that marred the success of limited entry programs. However, in a mature limited entry fishery (where input stuffing is established) the gain in long-run efficiency appears to occur at the short to intermediate-run expense of the owners of the *stuffed inputs.* Where the quota is awarded to vessel owners on the basis of past harvests, the owners of vessel capital are well compensated for their losses by the value of that quota. However, deckhands are at a decided disadvantage. As shown previously, a limited entry fishery with a managed TAC tends to favour vessels that are larger and have more crew than the vessels that will be optimal in an ITQ fishery. In the resulting shakedown of vessel numbers and size the number of deckhands will exceed the demand and their fishing earnings will tend to fall, until the market clears. In a worst case scenario, the total annual earnings of deckhands could fall to their exit opportunity cost. In terms of eqns (9) through (10) and Figure 5-1, their incomes could fall to:[90]

$$Y = \Phi/(1+\text{Ç}/\Psi) \tag{120}$$

and their leisure could fall to:[91]

$$L = 1/(1+\Psi/\text{Ç}) \tag{121}$$

---

[90] As mentioned in subsection 5.2.2, an excess of deckhand supply over demand may impose a ***double whammy*** on deckhands. Specifically, just as deckhands are seeking more part-time employment, both the surplus and the increase in the fishing season (decreases the period available for part-time work) could act in concert and potentiate the fall in their exit opportunity costs.

[91] A decrease in leisure may appear to be contradictory, however, the form of eqn (6) causes the utility curve to change shape as it shifts down. A utility curve could have other mathematical forms and display other behaviour but these other forms were dismissed (see note 26) as being unnecessarily complex.

When the parameter values given in Appendix B-1 are substituted into eqns (120), (121) and (6) the result is an income of $20,000, leisure of .3333 of a year and a utility of 1,778. The effect of these changes on the well-being of deckhands can be inferred from Table 6-1.

<u>TABLE 6-1</u>: Comparison of Fishermen's Exit Opportunity Cost Income with Points on Figure 5-1

	Fishermen's Exit Opportunity Cost	Fishermen's Satisficing Income[92]	Full-time Nonfishing Employment
Figure 5-1 Point	na	Point C	Point A
Optimum Income	$20,000	$28,114	$33,333
Leisure (in years)	.3333	.4686	.3333
Total Utility	1,778	2,676	2,676

In a worst case transition scenario Table 6-1 shows that the deckhands will work longer for a lower income. In the ultra long run (e.g. several generations), as the number of deckhands declines, the incomes of the remaining deckhands will increase, as will their leisure until the Figure 5-1 point C conditions are reestablished. A deckhand union will have to be exceptionally strong to soften these transition problems. However, once the transition is complete a moderately powerful union may be able to appropriate part of the resource rent for itself and/or its members. While the game theory and agency theory involved in such an analysis exceeds the scope of this study, it raises an interesting issue—at some point during the transit to ITQs from the limited entry fishery the ITQs will tend to be overvalued. Quota buyers will pay too

---

[92] To satisfice (Greenwald and Associates, 1983, p.409) is to resolve an issue to a point sufficient to engender satisfaction but not necessarily to the optimum outcome.

much for quota: if they cannot differentiate between resource rent and quasirent from their crew, if they cannot identify the transitional producer surplus (e.g. the rent arising from a vessel configuration that allows them to be the first at a denser fish concentration), if they assume that the quota prices will continue to rise (e.g. a speculative premium is added to the price). In a world of perfect markets and information these problems will not occur but, in this imperfect world, there will tend to be much confusion and/or injury during the transition to ITQs from either a mature open access fishery or a limited entry fishery.

The next chapter uses the insights developed in chapters four through six to assess how a shift to individual quotas may affect fisheries in the long run. The effects of IQ management are considered in isolation because using of complementary policy instruments in conjunction with an IQ would contradict one of the most touted IQs gains—the reduction of government involvement in the fishery.

FIGURE 6-1: Revenue and Costs in a Fishery Regulated Only for Gear Type

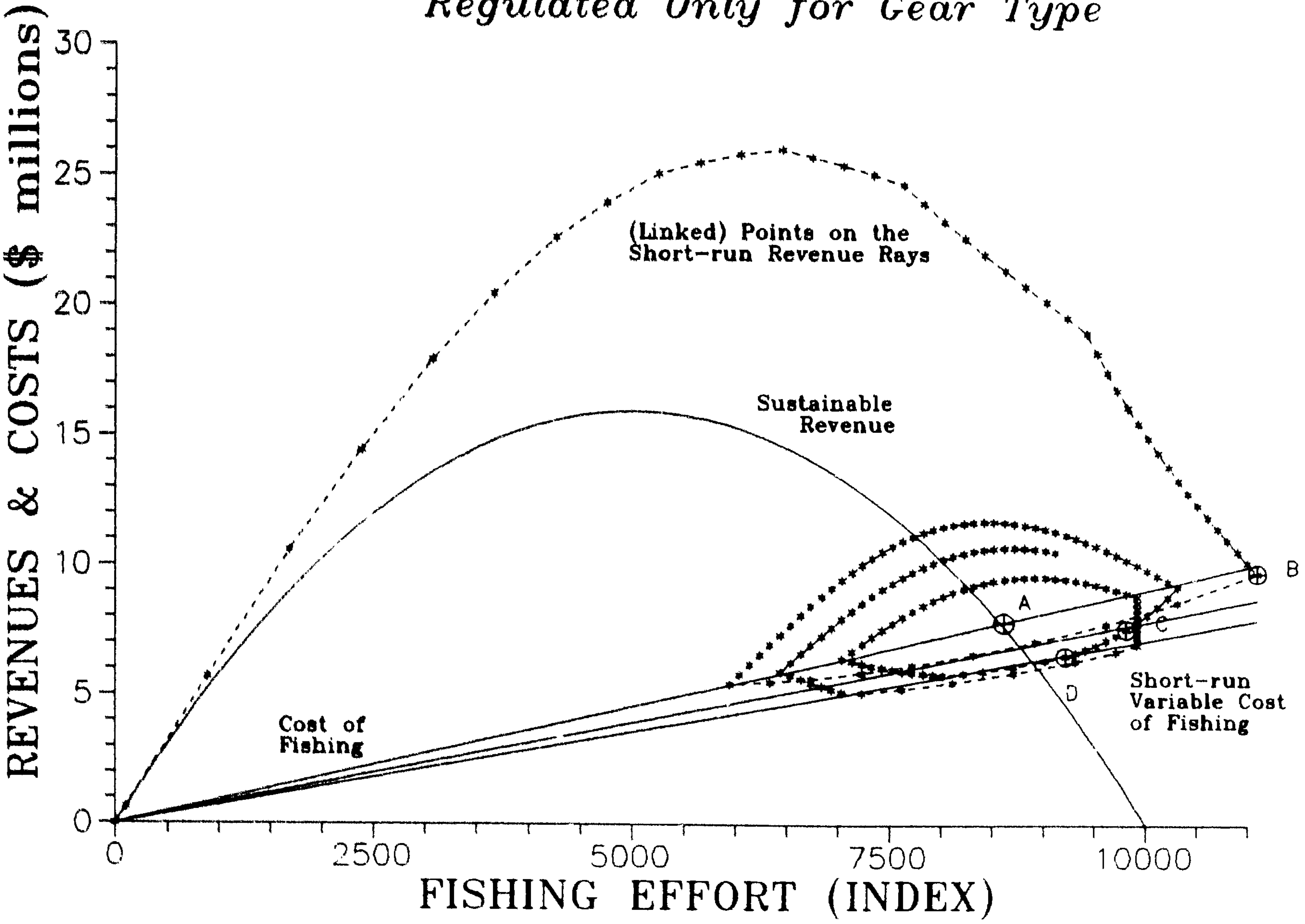


FIGURE 6-2: *Phase Plane Diagram for the Fishery System Depicted in Figure 6-1*

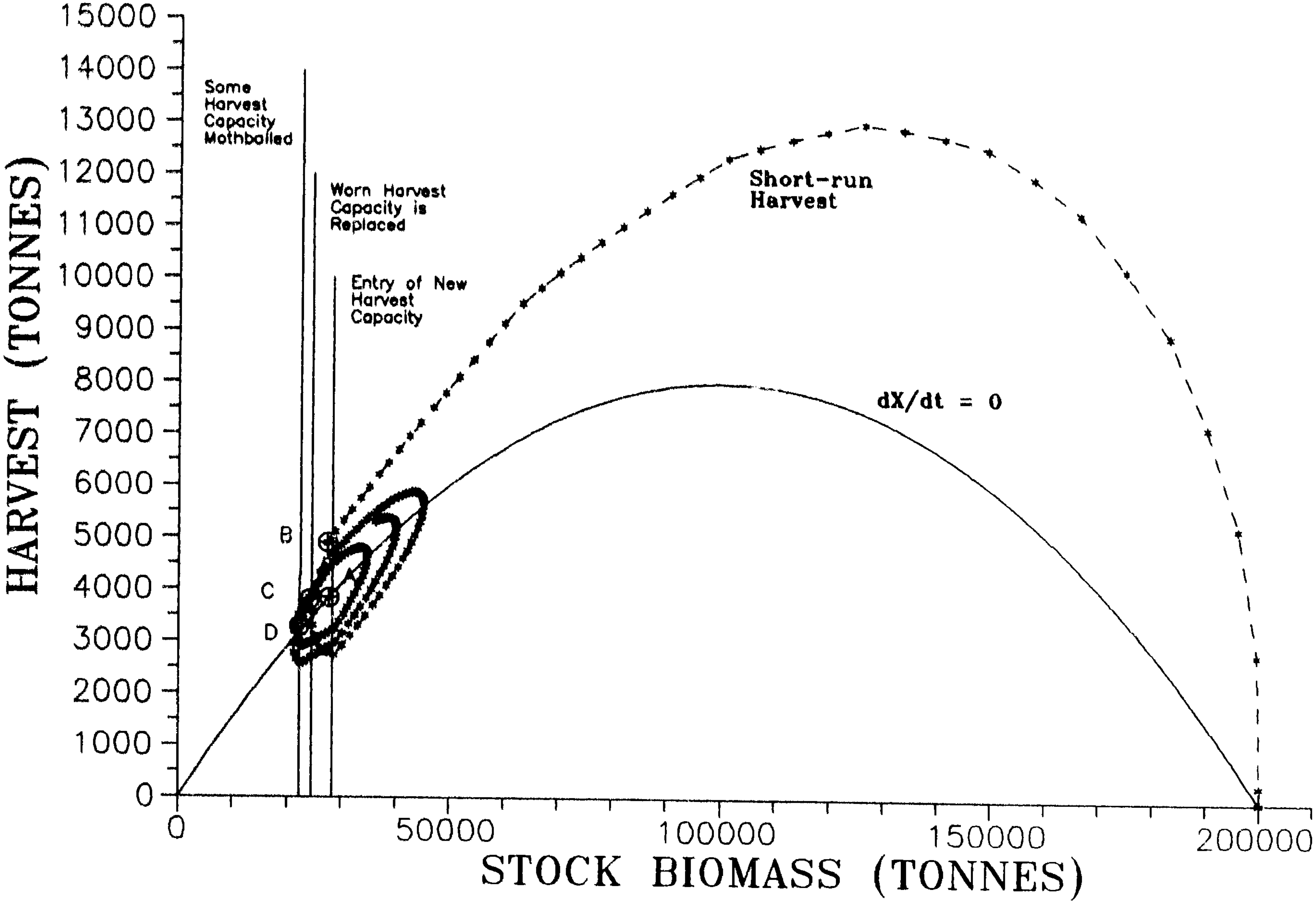


FIGURE 6–3: Vessel Stock (effort) vs Biomass Stock (tonnes) for the Fishery System Depicted in Figure 6–1

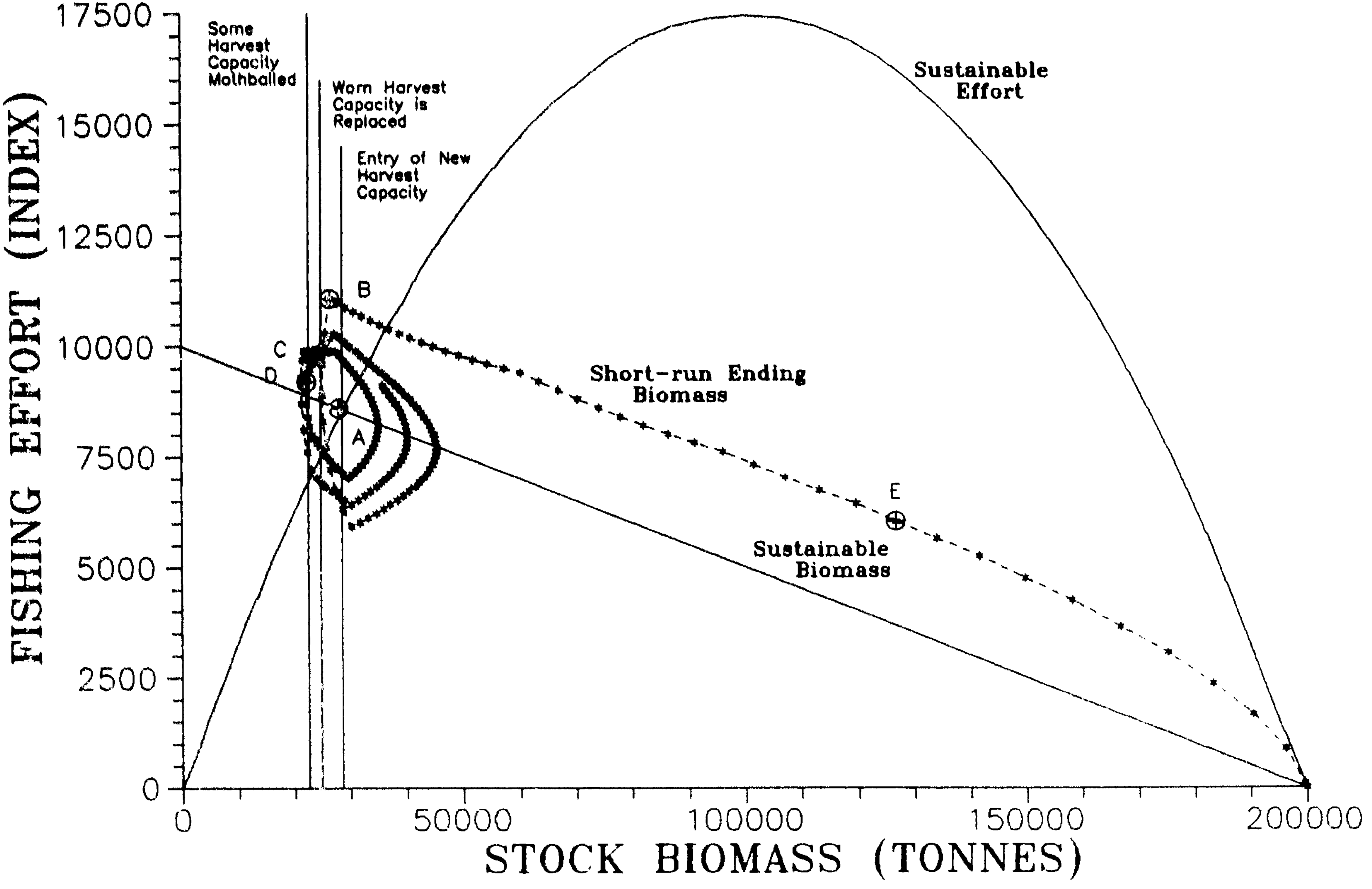


FIGURE 6-4: Revenue and Costs vs Fishing Effort in a Fishery Regulated for the Season Length

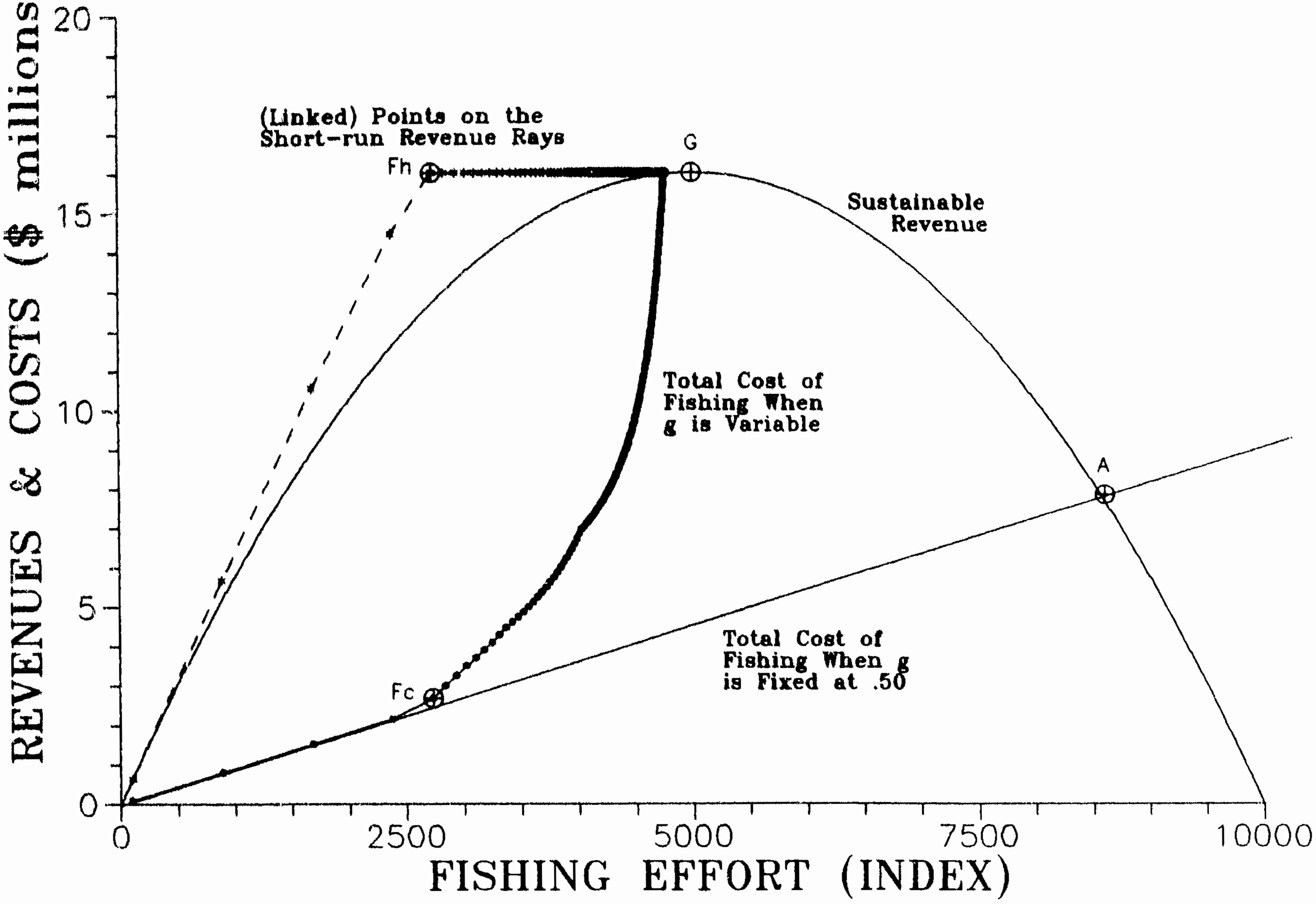


FIGURE 6–5: Revenue and Costs vs Fishing Power in a Fishery Regulated for the Season Length

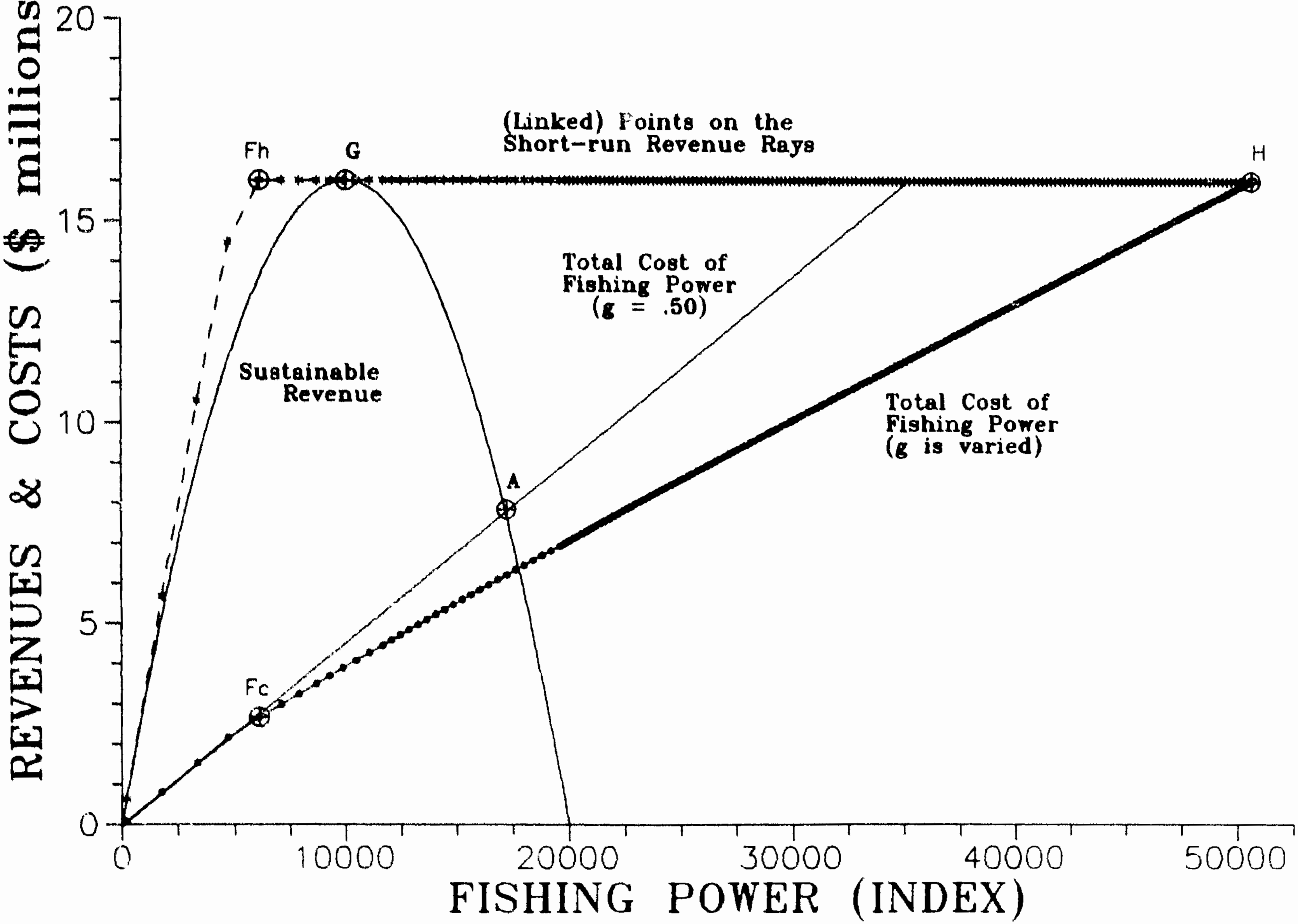


FIGURE 6-6: Transition (Using a TAC) from an Unmanaged to a Managed Open Access Equilibrium

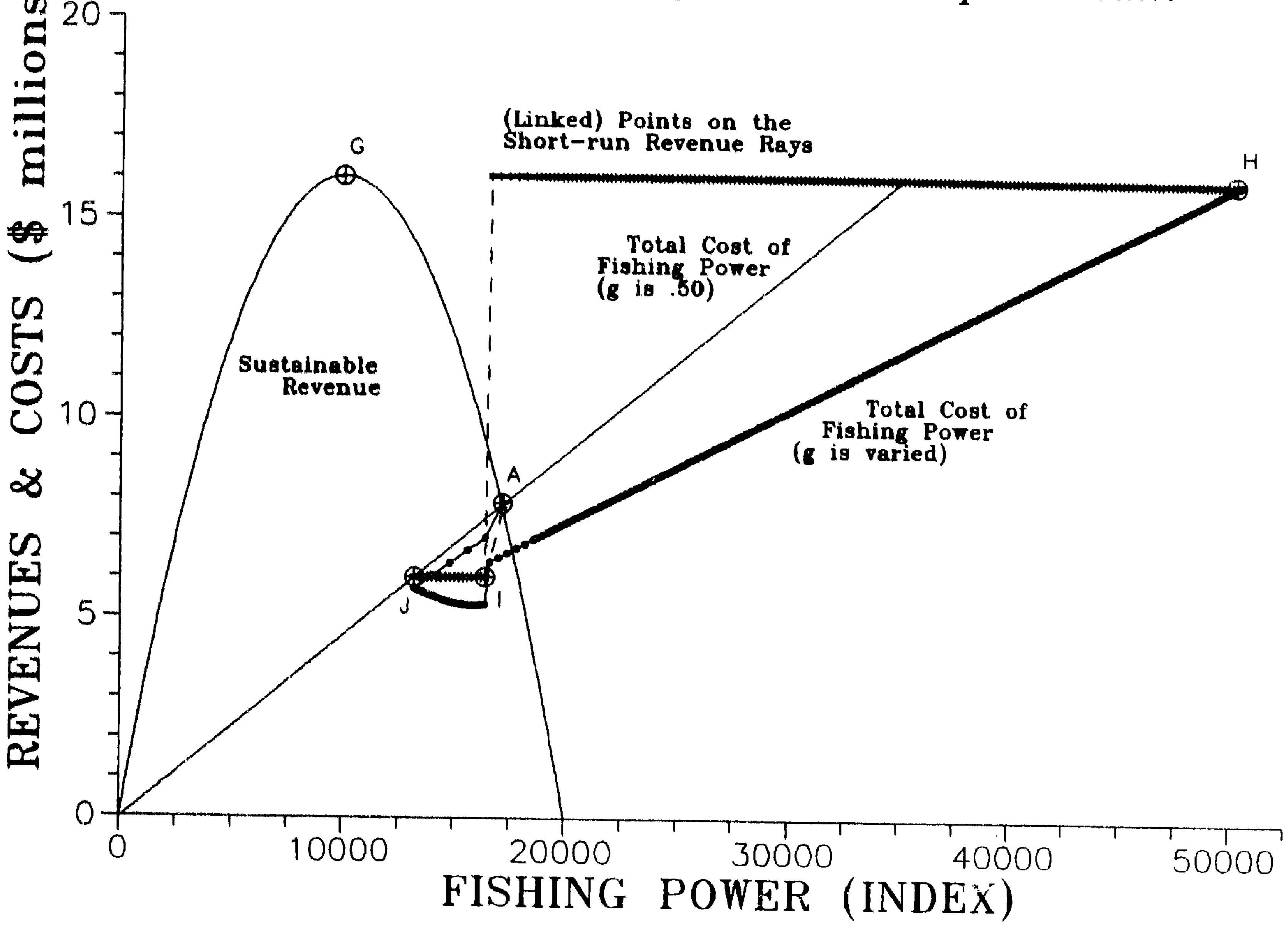


FIGURE 6-7: Transition (Using Harvest/Biomass Tonne) from an Unmanaged to a Managed Open Access Equilibrium

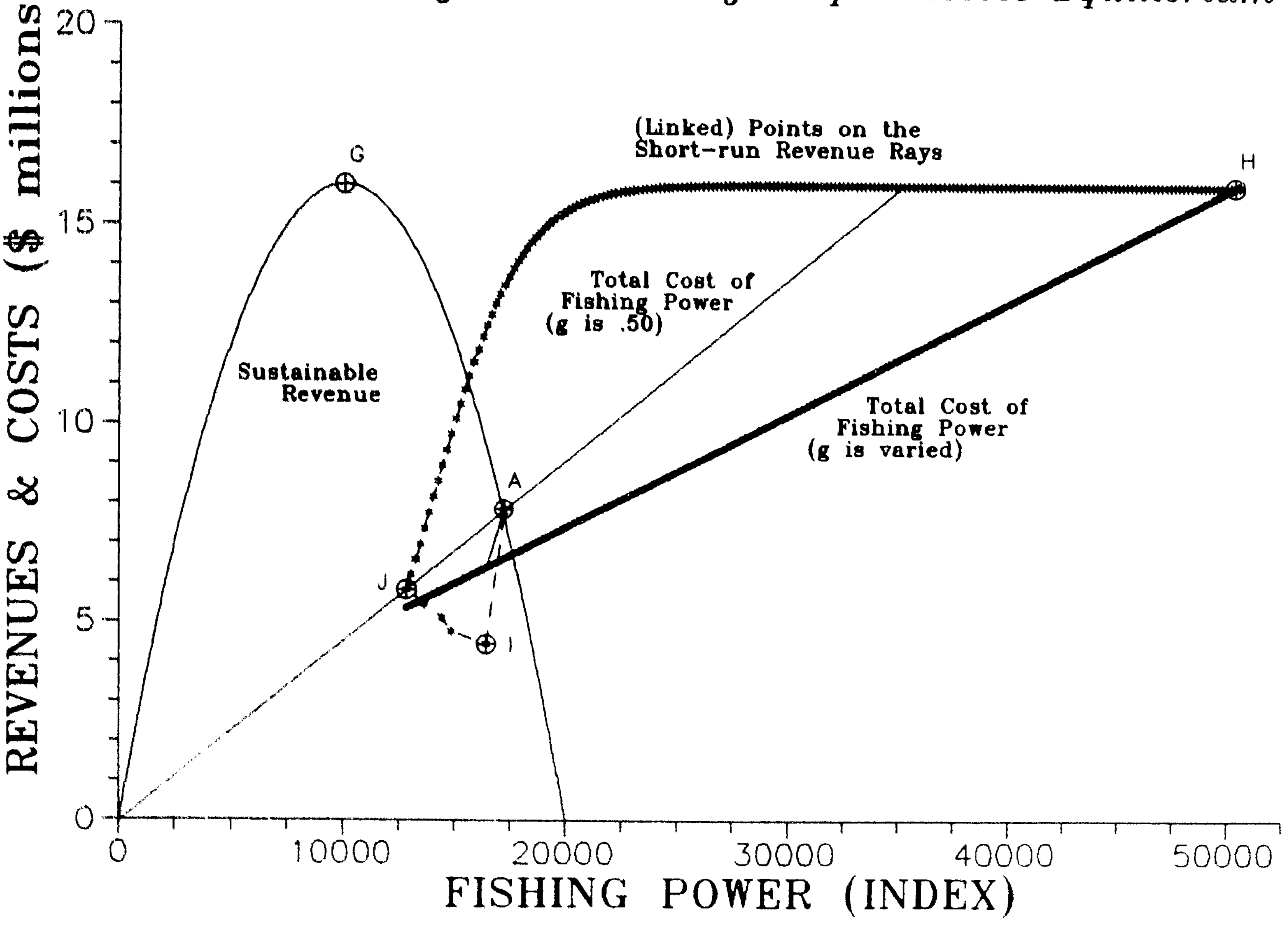


FIGURE 6-8: *Transition (Using Effort) from an Unmanaged to a Managed Open Access Equilibrium*

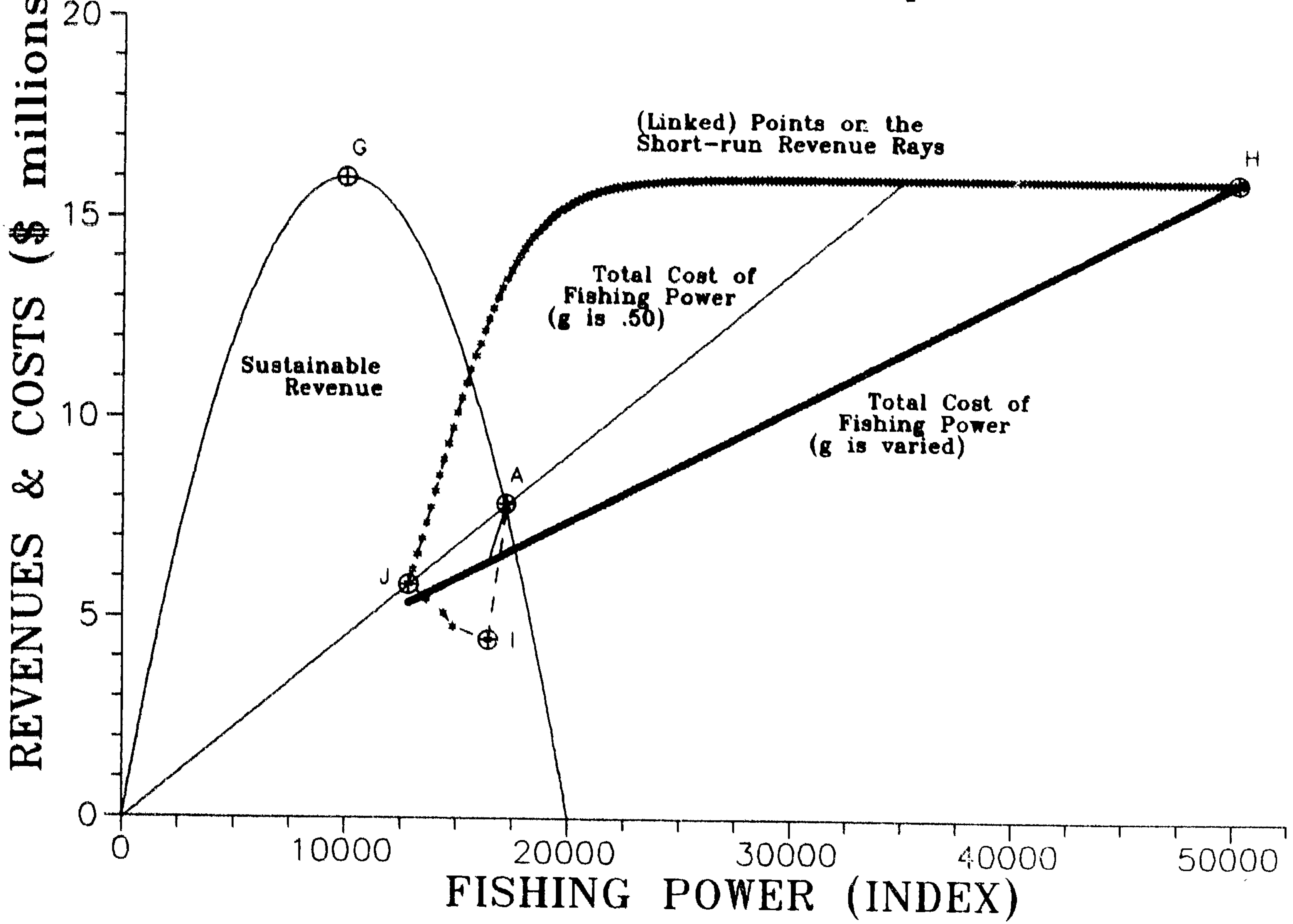


FIGURE 6–9: Transition (Using MEY and Effort) from an Umanaged to a Managed Open Access Equilibrium

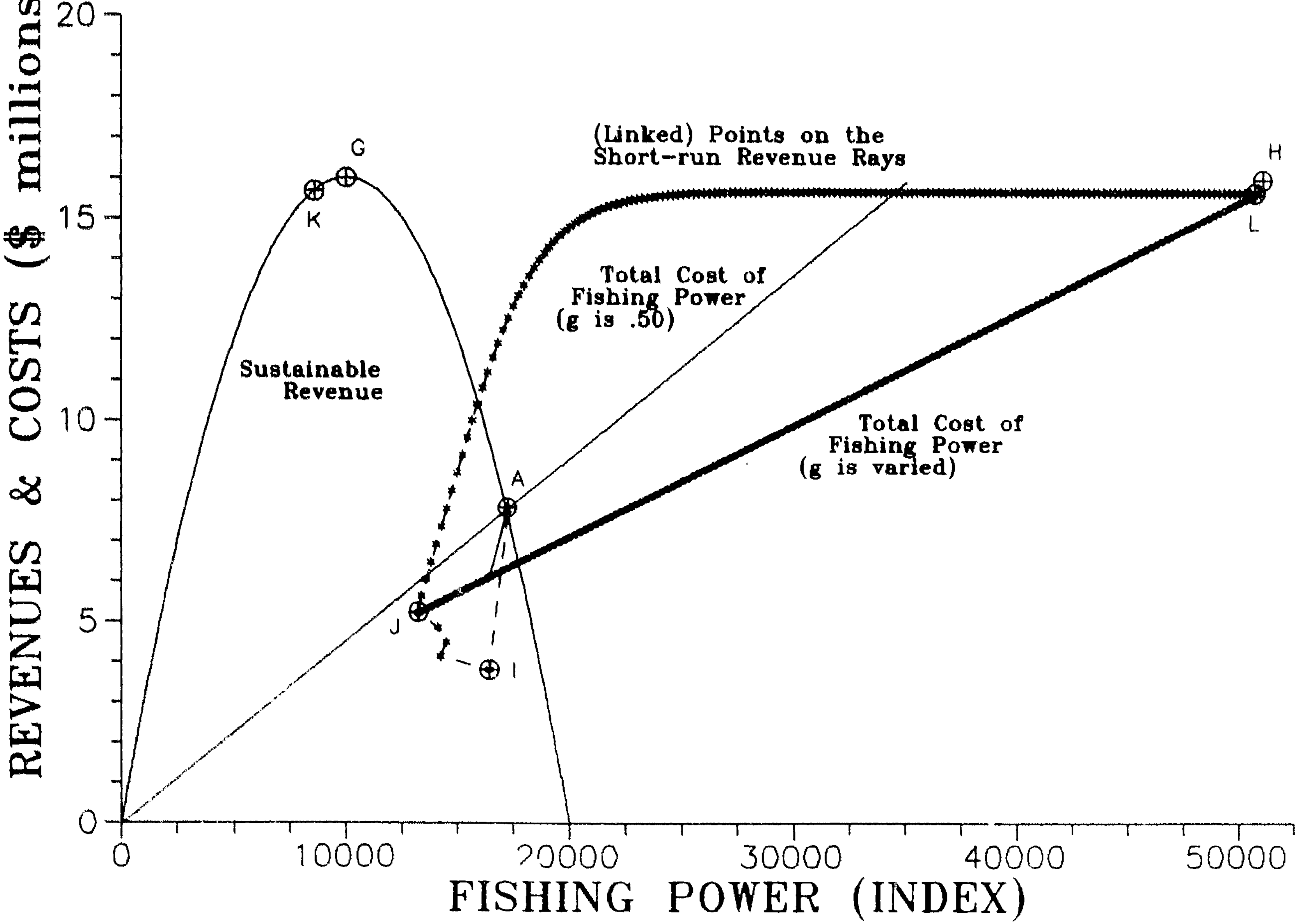


FIGURE 6–10: Transition from a Managed Open Access Equilibrium to One that has a Lower Amount of Fishing Effort

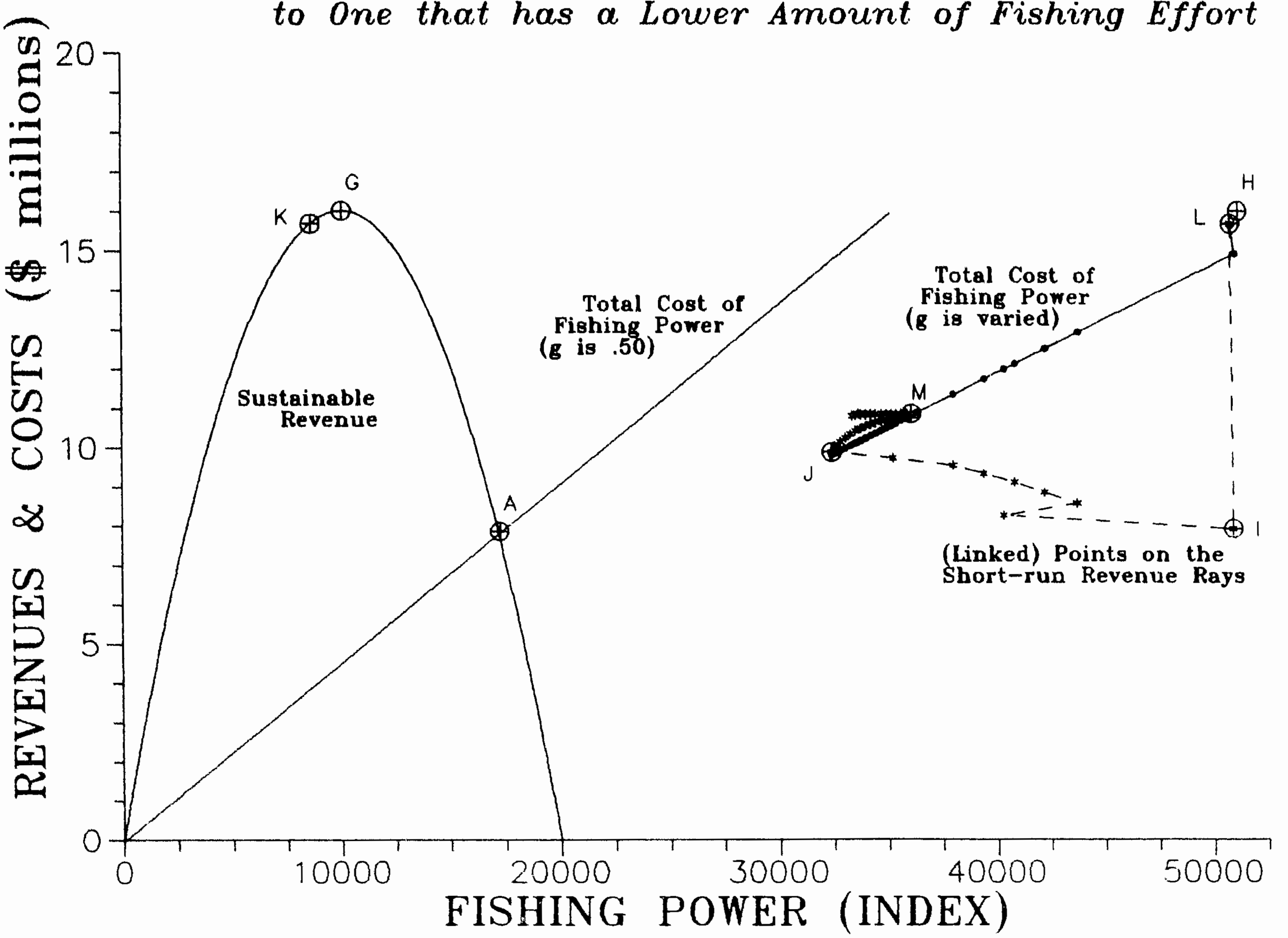


FIGURE 6-11: Transition from a Managed Open Access Equilibrium to One that has a Lower TAC

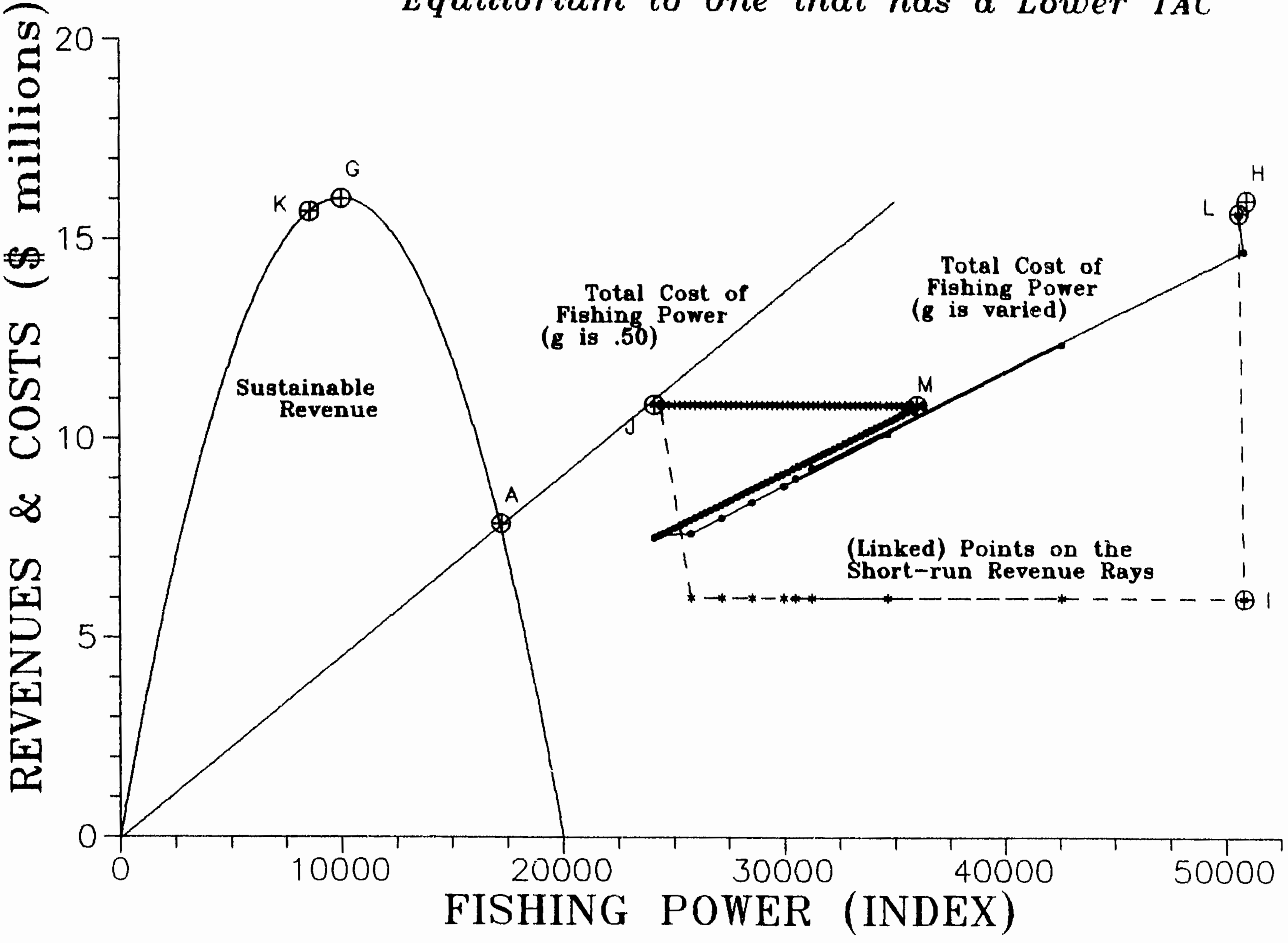


FIGURE 6–12: Transition (Using a Royalty Tax) to MEY from an Open Acess Equilibrium

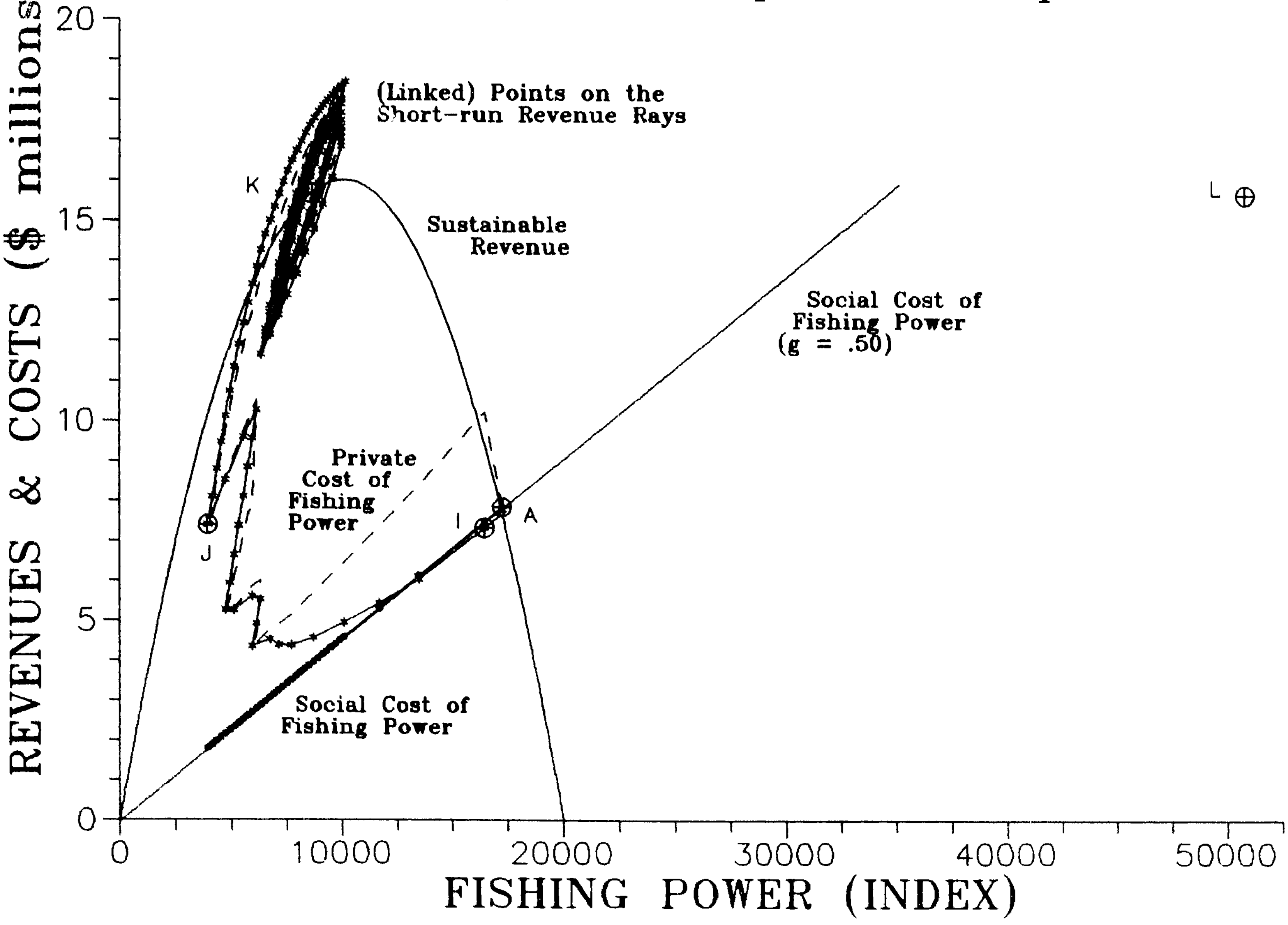


FIGURE 6–13: Transition to MEY (Using a Royalty Tax and a TAC Managed Season) from an Open Access Equilbrium

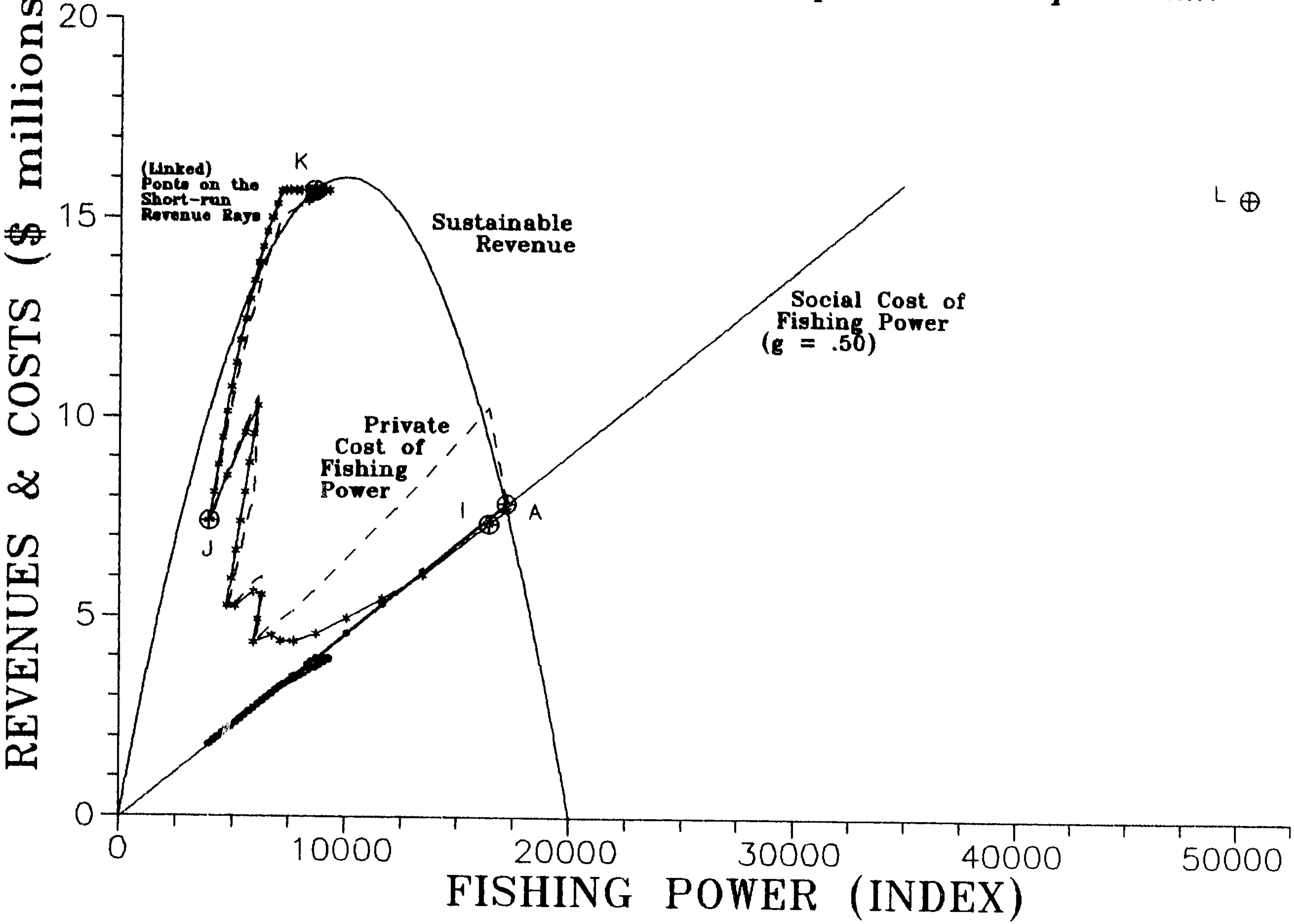


FIGURE 6–14: Transition to an MEY Harvest (Using Fees and a TAC Managed Season) from an Open Access Equilbrium

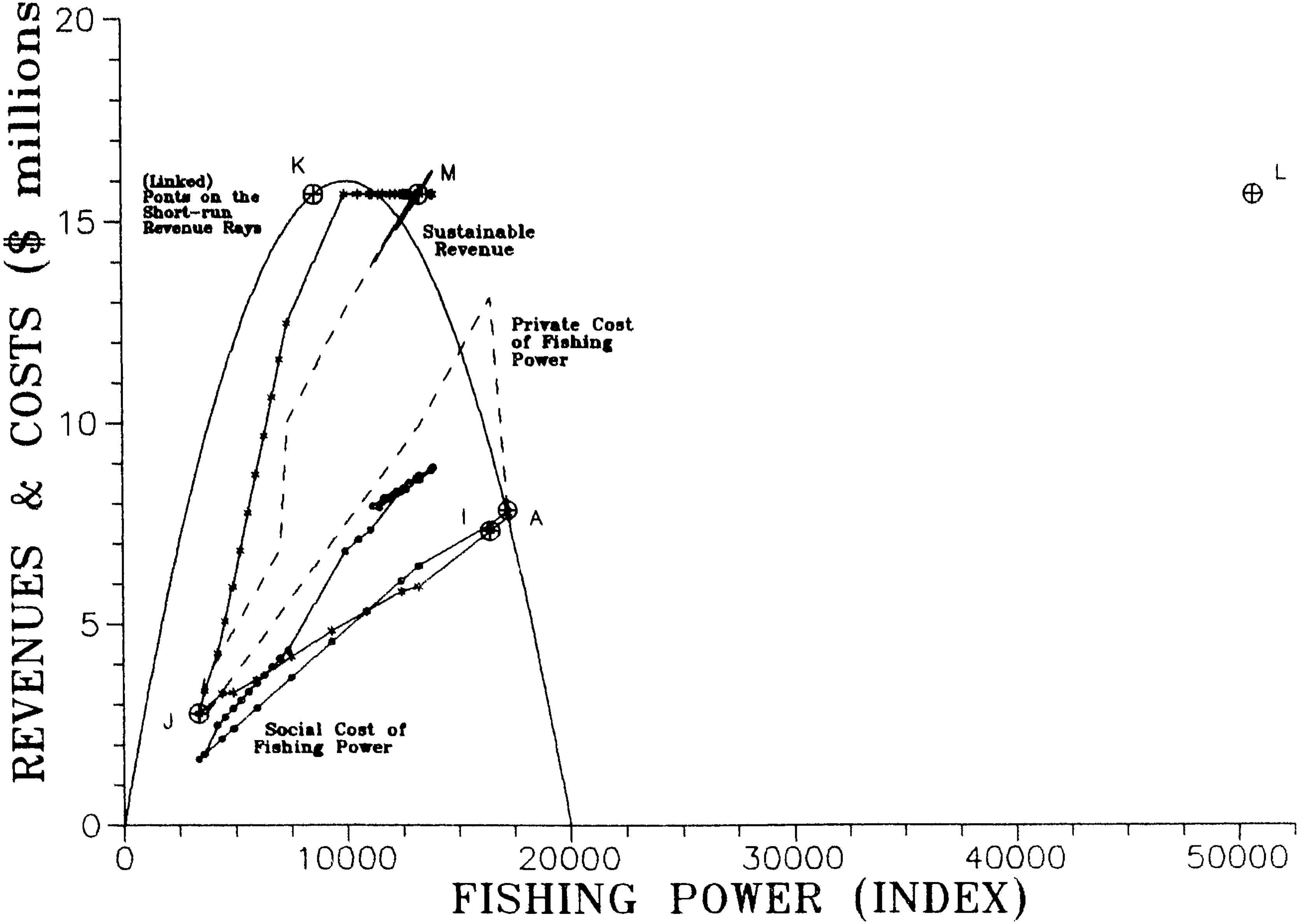


FIGURE 6-15: *Revenue and Costs in a Fishery with Season Management, Entry Limited to 87 Vessels and a Share Base of 15*

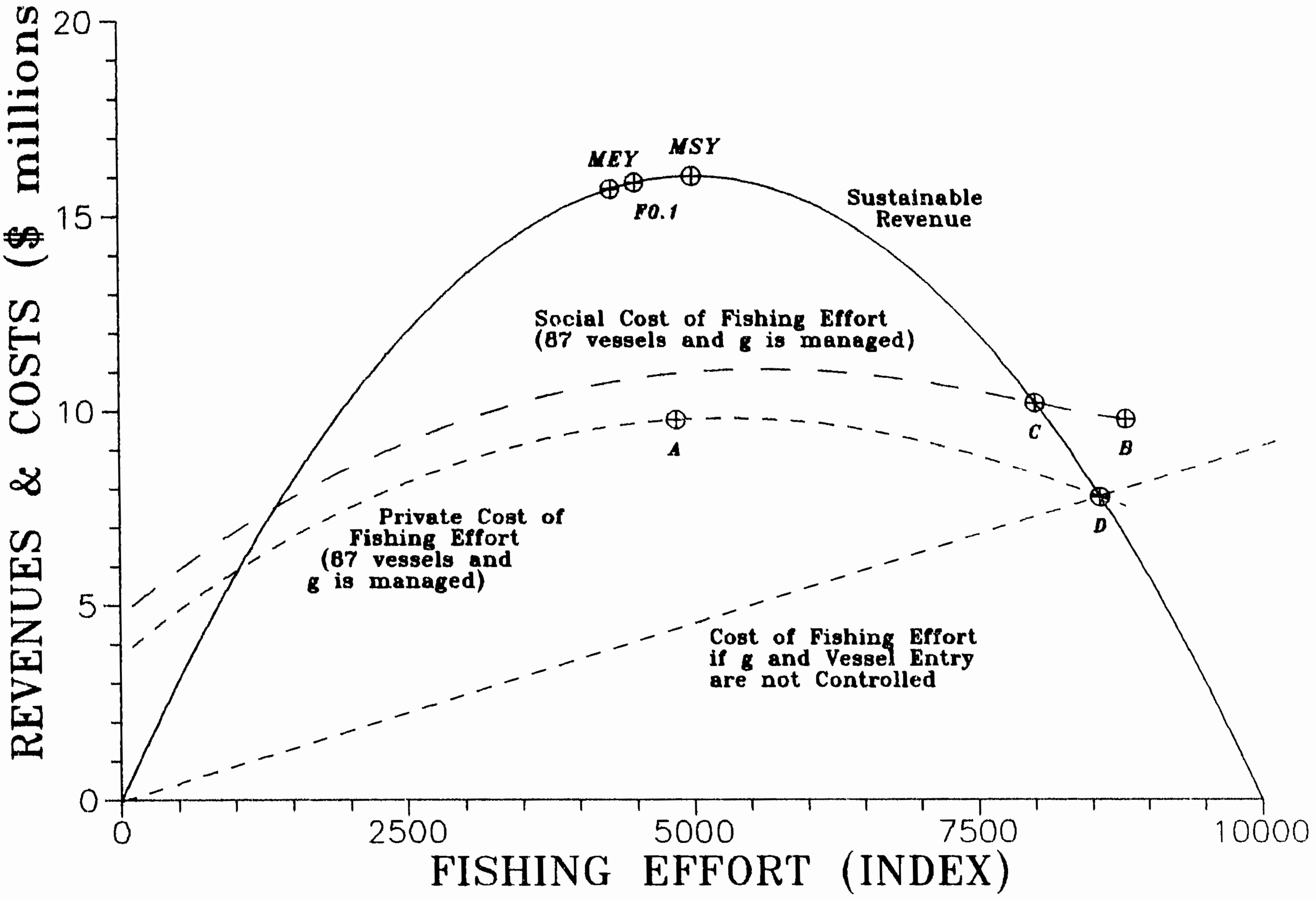


FIGURE 6-16: Revenue and Costs in a Fishery with Season Management, Entry Limited to 87 Vessels and a Share Base of 15

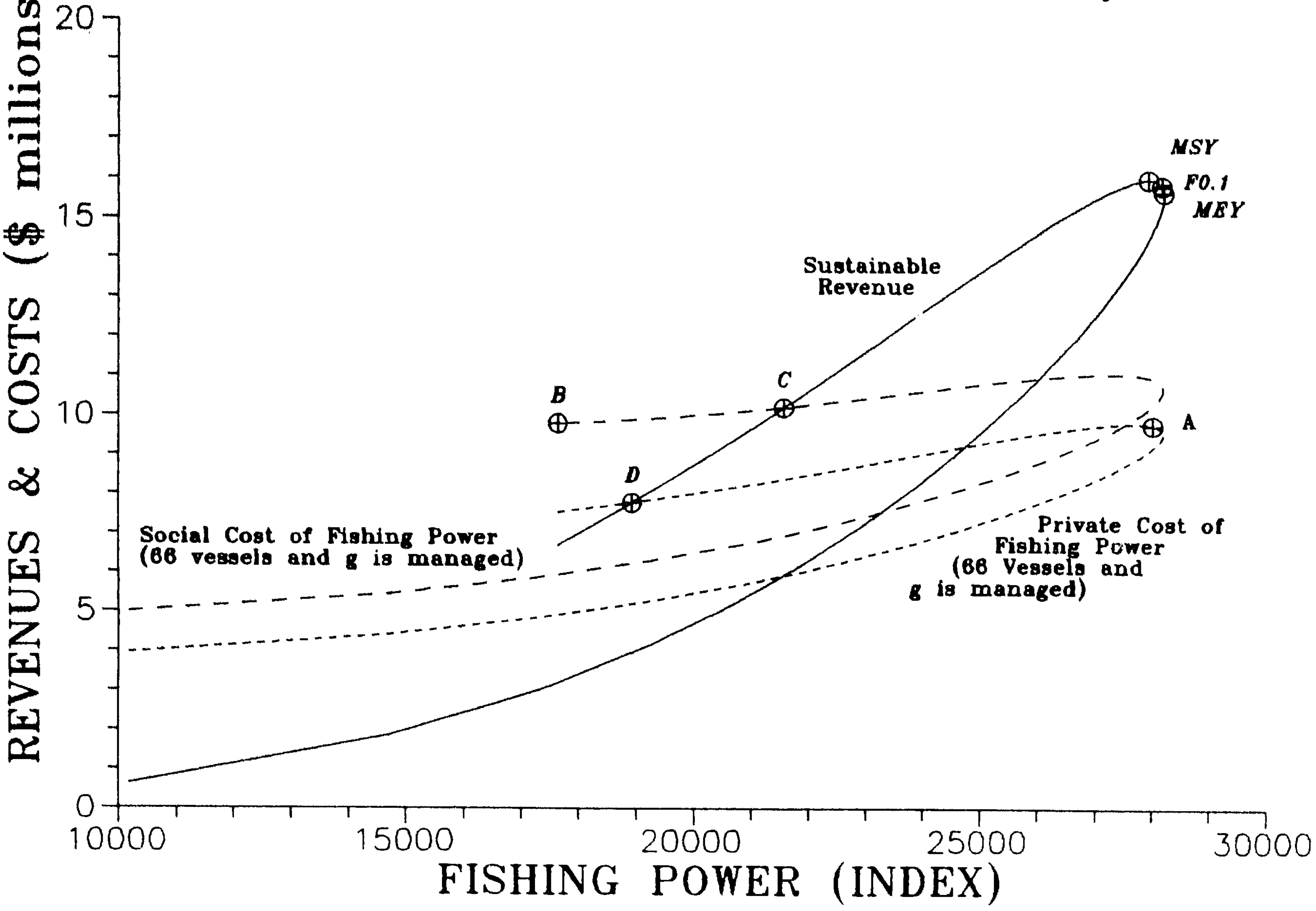


FIGURE 6-17: Long-run Revenue and Costs for a Spread of Vessel Limits in a Limited Entry Fishery

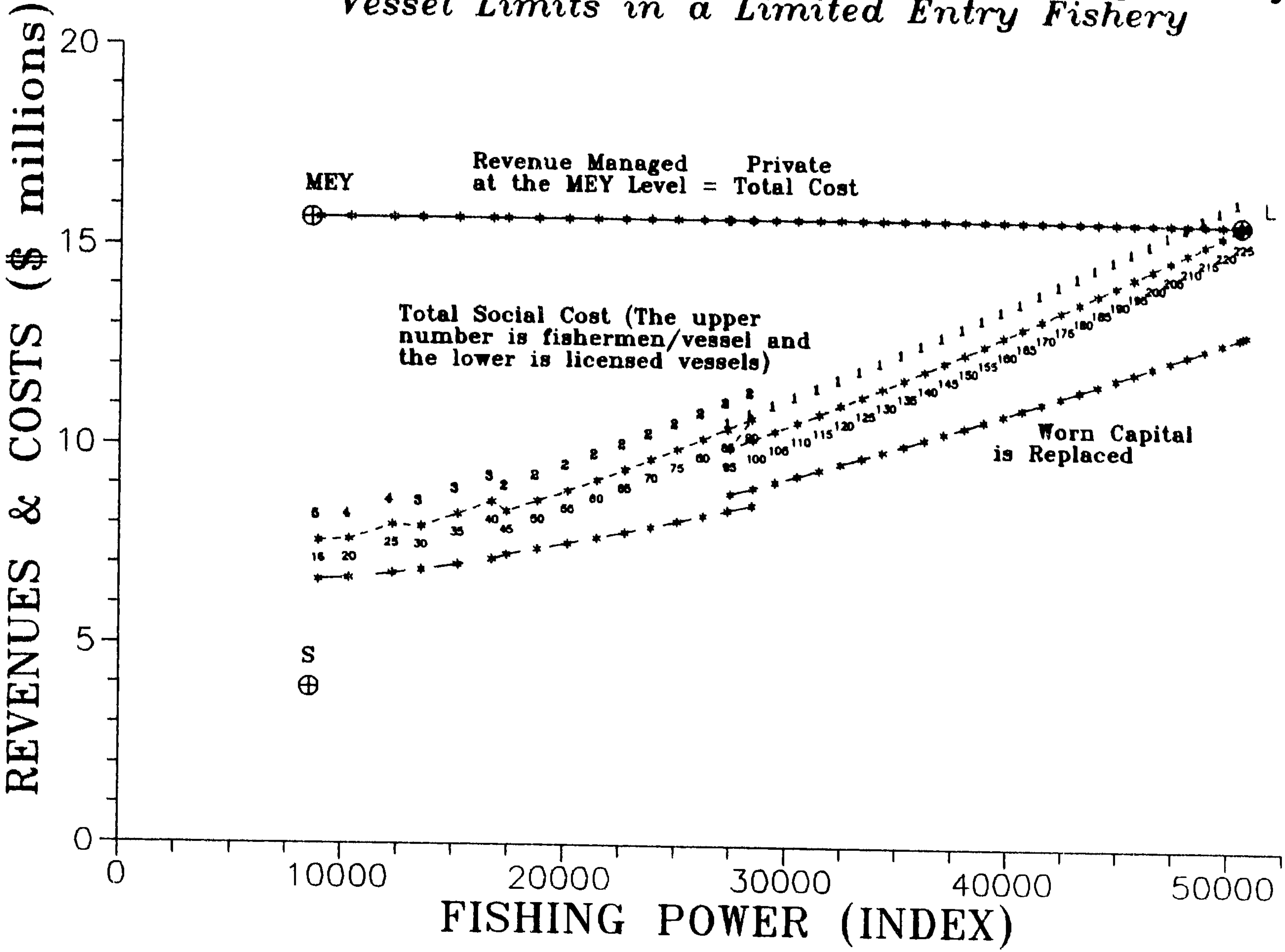


FIGURE 6–18: *Short–run Revenue and Costs in a Fishery with IQs (Share Base Unchanged from Limited Entry)*

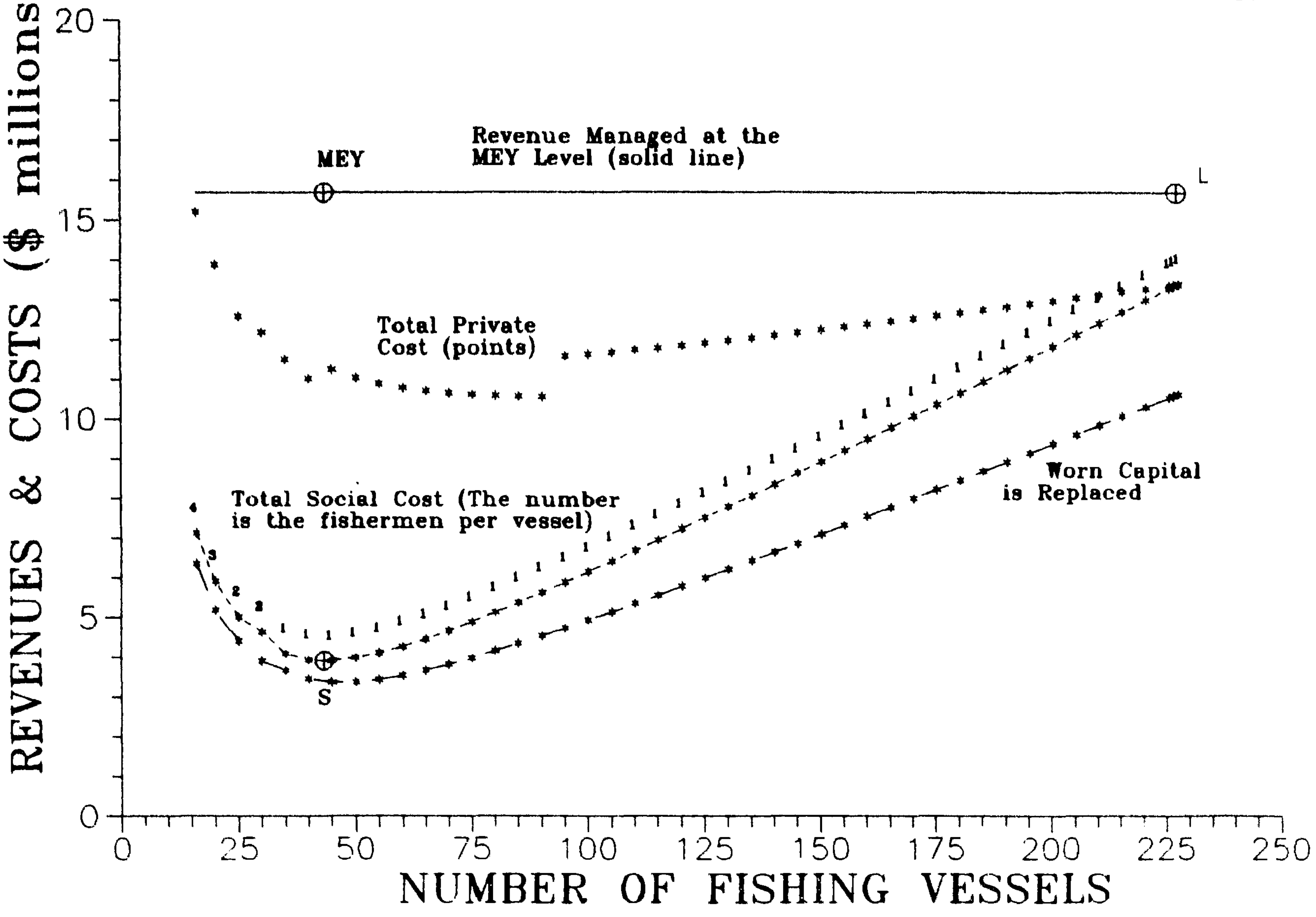


FIGURE 6–19: *Intermediate–run Revenue and Costs in a Fishery with IQs (Share Base Reflects Crew Entry Opportunity Cost)*

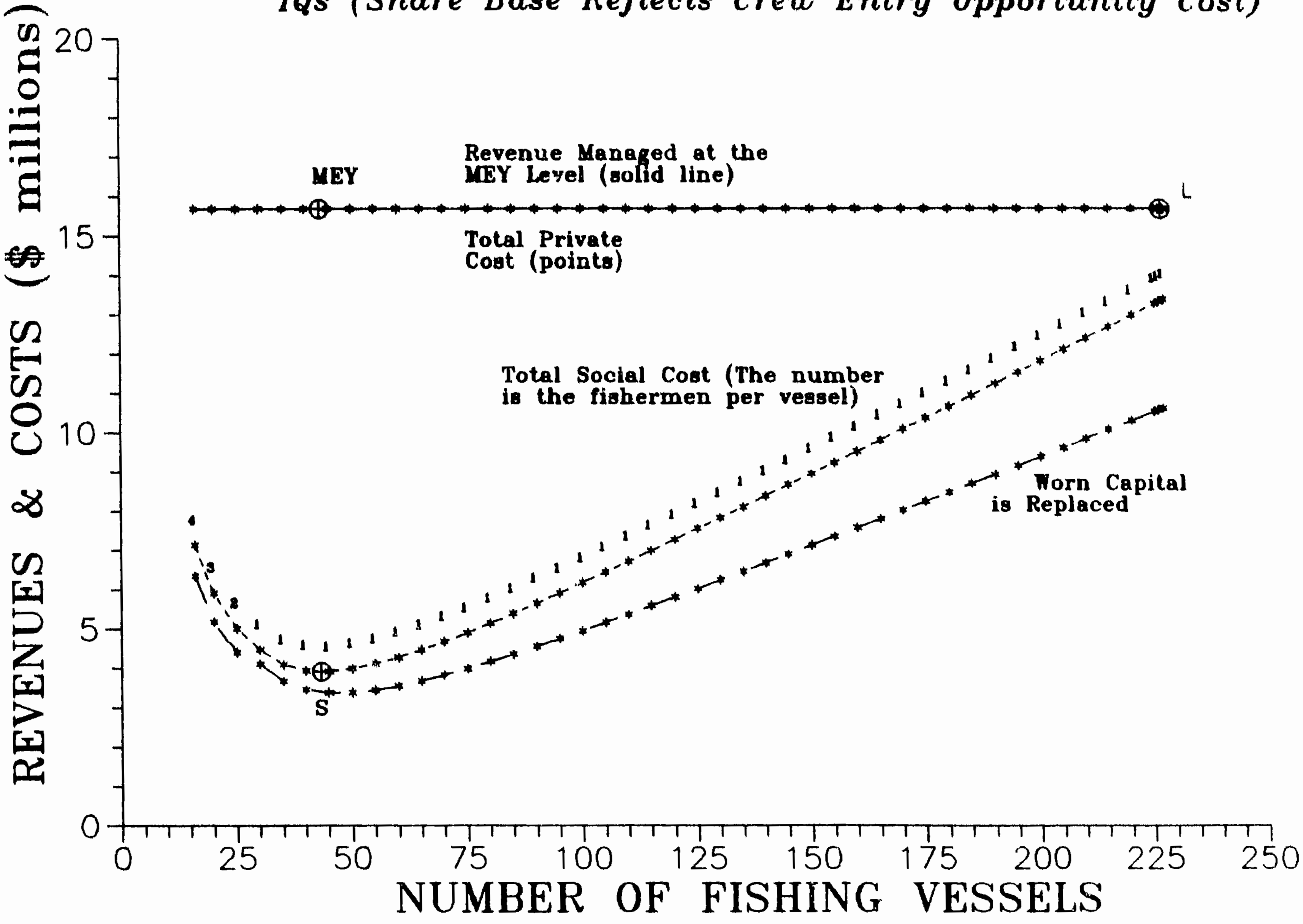
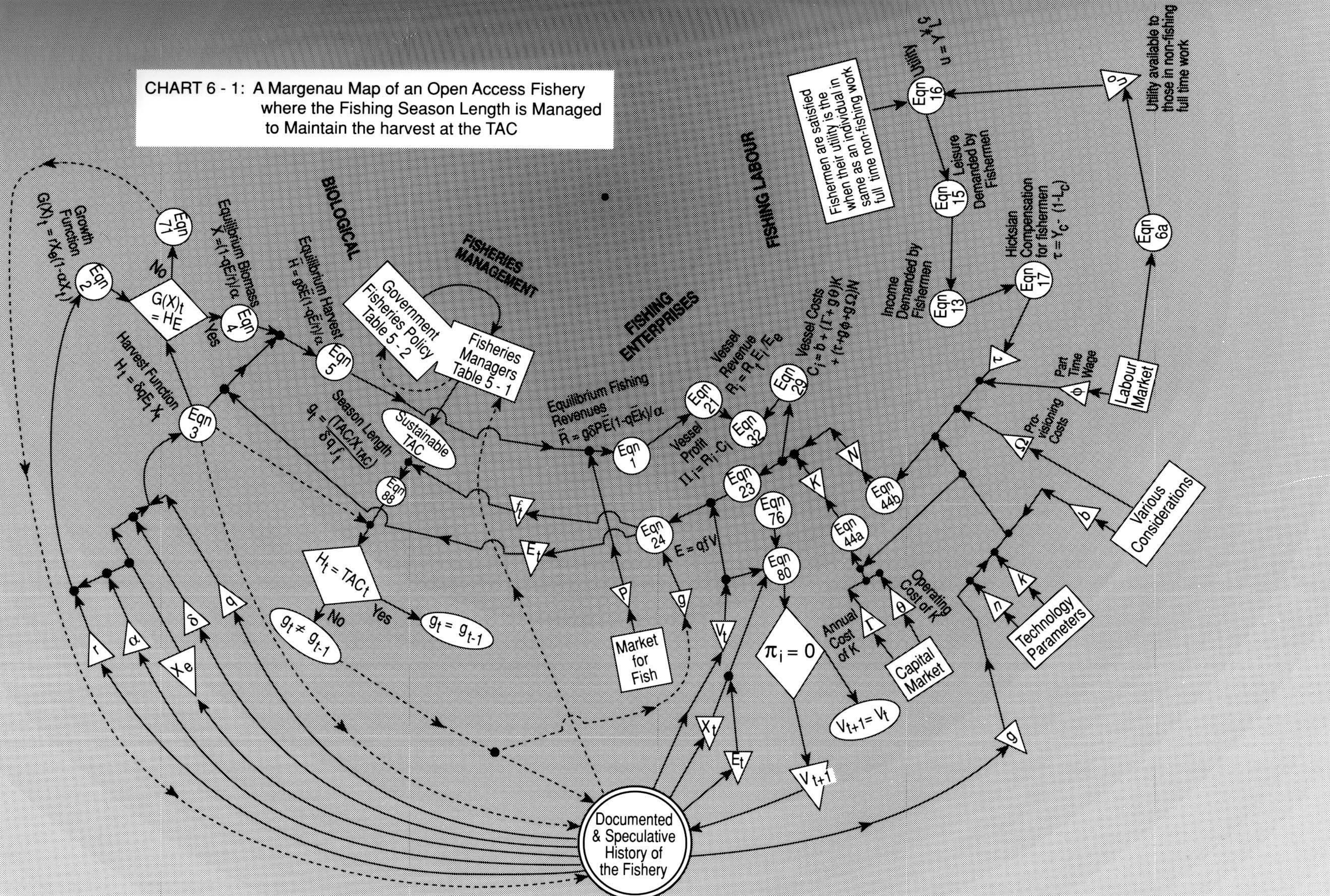


CHART 6 - 1: A Margenau Map of an Open Access Fishery where the Fishing Season Length is Managed to Maintain the harvest at the TAC



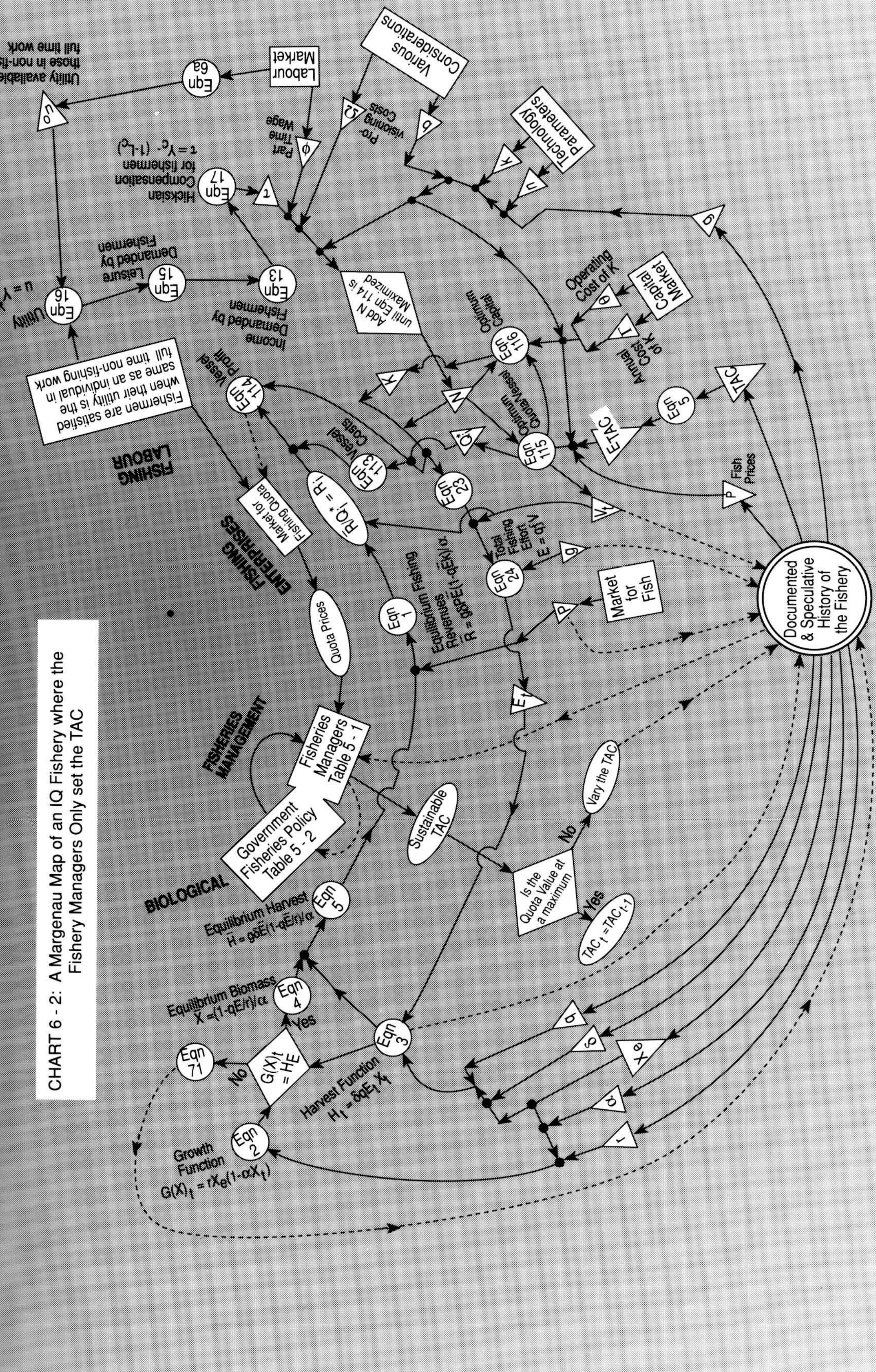


CHART 6 - 2: A Margenau Map of an IQ Fishery where the Fishery Managers Only set the TAC

CHART 6 - 3: Key to the Shapes and Lines Used in Charts 6 - 1 and 6 - 2

ITEM	APPEARANCE	DESCRIPTION OF ITEM
1	⟶	Message flow
2	⇠	Feedback
3	─●─→ ↑	Joining of information into a message flow
4	○	Construct represented by an equation
5	△	Parameter
6	▽	Variable
7	◇	Decision
8	⬭	Local Outcome
9	□	Black box process
10	◎	Information storage; releases lagged to t - n

TABLE 6-2: Resource Rent Maximization in a Fishery with ITQs

FISHING VESSEL				SHARE	SOCIAL	RESOURCE RENT $000			% OF NORMAL	POWER
N	Q_i	E	No.	BASE	COST	TOTAL	PER V	PER Q_i%	RETURN ON Qi MARKET VALUE	PER VESSEL
I. Maximize Resource Rent per Vessel										
1	4.87%	59.381	20.53	26.628	$6,690,689	8,984	437.6	89.8	76.4%	417.62
2	5.72	69.681	17.50	31.247	7,014,265	8,660	495.0	86.6	73.6	490.06
3	6.28	76.516	15.93	34.312	7,334,591	8,340	523.4	83.4	70.9	538.12
4	6.71	81.768	14.91	36.667	7,643,342	8,031	538.7	80.3	68.3	575.06
5	7.06	86.089	14.16	38.605	7,941,096	7,734	546.1	77.3	65.8	605.45
6	7.36	89.789	13.58	40.264	8,229,246	7,445	548.3	74.5	63.3	631.47
7	7.63	93.040	13.10	41.722	8,509,073	7,166	546.9	71.7	60.9	654.33
8	7.87	95.952	12.71	43.028	8,781,635	6,893	542.5	68.9	58.6	674.81
9	8.09	98.596	12.36	44.213	9,047,792	6,627	535.9	66.3	56.3	693.40
10	8.29	101.022	12.07	45.301	9,308,246	6,366	527.5	63.7	54.1	710.47
II. Maximize Total Resource Rent										
1	2.31%	7.021	43.35	12.612	$3,912,607	11,762	271.4	117.6	100.0%	197.80
2	2.94	10.451	33.99	16.085	4,567,016	11,108	326.8	111.1	94.4	252.27
3	3.45	13.882	28.96	18.880	5,168,371	10,506	362.8	105.1	89.3	296.09
4	3.90	17.313	25.67	21.296	5,714,223	9,960	388.0	99.6	84.7	333.99
5	4.29	20.744	23.30	23.460	6,215,215	9,459	405.9	94.6	80.4	367.92
6	4.65	24.175	21.49	25.437	6,680,135	8,994	418.5	89.9	76.5	398.93
7	4.99	27.605	20.05	27.269	7,115,507	8,559	426.9	85.6	72.8	427.67
8	5.30	31.036	18.86	28.985	7,526,196	8,148	432.0	81.5	69.3	454.59
9	5.60	34.467	17.86	30.605	7,915,902	7,759	434.3	77.6	66.0	479.98
10	5.88	37.898	17.01	32.142	8,287,503	7,387	434.3	73.9	62.8	504.10

III. VALUES COMMON TO ALL POINTS IN THE ABOVE TABLES

- Total Revenue.......... $15,674,626
- Total Private Cost..... $15,674,626
- Opportunity Cost of Q_i..... $117.62 per % point

- Total Fishing Power ...... 8,573.95 units
- Total Fishing Season .... .50000 of a year
- Total Fishing Effort ..... 4,286.98 units

- Total Harvest .... 7,837 tonnes
- Total Stock Biomass ..... 114,260 tonnes

TABLE 6-3: Effect of Fisheries Policy Targets on a Selection of Variables, at Equilibrium, in Various Forms of the Simulation Model

VARIABLE TYPE AND NAME	VALUE IF THE FISHERY MANAGED FOR AN EQUILIBRIUM AT THE				
	OAE	MSY	Actual MEY	MEY Harvest	F0.1 Harvest
BIOLOGICAL: (tonnes)					
• Biomass	27,920	100,000	114,260	114,260	110,000
• Harvest	3,483	8,000	7,837	7,837	7,920
SEASON:					
• Percent of a Year	50.0000%	9.8180%	50.0000%	8.4775%	8.7707%
ECONOMIC: (millions)					
• Revenues	$7.685	$16.000	$15.675	$15.675	$15.840
• Costs	7.685	16.000	3.913	15.675	15.840
• Resource Rent	$.000	$.000	$11.762	$.000	$.000
VESSELS:					
• Total Effort	8,604	5,000	4,287	4,287	4,500
• Total Fishing Power	17,208	50,927	8,574	50,569	51,307
• Number	87	229	43.346	226	229
PER VESSEL:					
• Catch (tonnes)	40.03	34.93	180.81	34.68	34.59
• Effort	98.90	21.83	98.90	18.97	19.65
• Fishing Power	197.79	222.39	197.80	223.76	224.05
• Capital	7.0205	9.8117	7.0205	9.9950	9.9464
• Labour	1	1	1	1	1
• Revenues	$88,333	$69,869	$361,616	$69,357	$69,170
• Costs	88,333	69,869	90,264	69,357	69,170
• Resource Rent	$0	$0	$271,352	$0	$0
PER UNIT EFFORT					
• Catch (tonnes)	.405	1.600	1.828	1.828	1.760
• Revenue	$893	$3,200	$3,656	$3,656	$3,520
• Cost	$893	$3,200	$913	$3,656	$3,520
• Resource Rent	$0	$0	$2,744	$0	$0
PER UNIT FISHING POWER					
• Catch (tonnes)	.202	.157	.914	.155	.154
• Revenue	$447	$314	$1,828	$310	$309
• Cost	447	314	456	310	309
• Resource Rent	$0	$0	$1,372	$0	$0

7.0 IQs - A VIABLE FISHERIES POLICY OR A GERMINATING FAILURE

Fisheries tend to suffer from a pernicious version of *Peer's Law —the solution to the problem changes the problem* (Lyall, 1986). A review of why past fisheries solutions have tended to be less successful than forecasted may provide insight into the problems that may emanate from using IQs. Fisheries economists instead of agonizing over details of applying IQs or allocating the forecasted gains should look closely at what can go wrong when IQs or ITQs are imposed on fisheries.

As Rettig (1989, p.61) noted "rights based fishery management, if it can be designed to reduce public expenditures, is likely to attract a great deal of interest from financially strapped government agencies." Individuals extolling IQs often refer to the savings that will arise from reduced fisheries management. Pearse (1982, p.84) proposed that IQs be adopted or improved in all of Canada's west coast developed commercial fisheries, other than the salmon and roe-herring fisheries. Pearse asserted that an IQ approach would free "...the regulatory authorities from many of the problems associated with regulating fishing activity." Pearse qualified his comment by noting that "some controls on fishing would obviously still be required for ... biological reasons." Pearse then qualified this qualification by stating that "with the total catch controlled by licenses, most of the restrictions on vessels, gear and fishing time that are now used to prevent overfishing would become unnecessary." After more qualifications, Pearse asserted that "as a means for regulating the catch and promoting fleet rationalization, licensing individual fishermen's quotas holds more promise than any of the other approaches..."

Other individuals are even more enthusiastic with their praise of the virtues of IQs. Scott (1989, pp.29-30) stated, with caveats, that "...there is no doubt that if the individual quotas exist, their owners can at some cost contract with each other to coordinate them, to perform what are now regarded as government functions. ... [fishermen] would stop racing, cooperate with enforcers and choose their own gear, time and place to fish." Various types of socio-political resistance were considered by Scott (1989, pp.29-33) to be major obstacles to the adoption of IQs. Scott (1989, p.28) did not see any major problem with the market for ITQs replacing the activities of public-harvesting regulators with respect to controlling the time of fishing and/or gear (type or selectivity).[93] The adoption of ITQs has changed the focus of New Zealand's fisheries enforcement. The "new role of the enforcement authorities is not so much policing fishermen as monitoring, following product flow, seeking to establish a paper trail from the fishing vessel to retail disposal. Enforcement activity now takes place more on land than at sea—which is more cost effective—and is carried out by people who are more auditors than game wardens" (Clark et al., 1989, p.137). Arnason (1989) noted that the data available to fisheries managers tends to be less than adequate for the calculation of an optimal level of management controls (i.e. tax rates, TACs or ITQs). Arnason (1989, p.236) then stated that "it appears that there exists a certain variant of the individual transferable quota system, namely the perma-

---

[93] Scott (1989, p.28) did make an indirect caveat on gear control by stating that "because the catch is the unit of property, the authorities must concern themselves with gear, net type and so on only in connection with the long-run selective management of the stock.

nent share quota system, that allows the fisheries manager, under certain conditions, to determine the optimal total quota with a minimal collection of information.[94] In this system, the fisheries manager is essentially only required to monitor the quota market and to adjust the total quotas until the current total quota market value is maximized. This is referred to as minimum information management." Clark et. al (1989, p.134) expressed a related idea when (in their review of the New Zealand ITQ experience) they noted "another benefit of quota transferability as regards catch levels involves the adjustment of TACs. A trading flow has been established which enables the Crown to sell or purchase quota to adjust the TAC: this may be achieved with minimum administrative costs, at a price reflecting the social benefits of the adjustment."

The amount of literature on *what may go right* with IQs tends to utterly overshadow the literature on *what may go wrong* with IQs. This unbridled enthusiasm should be of great concern. IQs (transferable or not) will dramatically alter complex systems, on which depend both the livelihood of fishermen and a portion of the wealth of the nation. It, therefore, behooves us to act with great caution. We should express in fair measure, to ourselves and other interested parties, our ignorance as to how a given fishery system will ultimately respond to the imposition of IQs.

---

[94] Under a permanent share quota system the quota holder's rights are restricted to a fixed percentage of an annually set TAC. Those rights may or may not be transferable, however, in this discussion the rights are assumed to be transferable.

IQs will so profoundly alter fisheries that it is unsafe to routinely extrapolate experience and traditions from *nonIQ* fisheries into the management of IQ fisheries. Further, managers will not be able to afford the luxury of passively responding only after changes to their fishery become apparent—rights and privileges, once established, tend to be difficult/costly to extinguish, in whole or in part. Therefore, managers will need to actively monitor/test their fishery to determine how it is changing. Their management should then be adapted to induce or re-enforce desired change, to deflect or blunt undesired change and to give advance warning of undesired changes that appear to be inevitable.

Copes made an excellent start on fulfilling this need in his 1986 paper: *A Critical Review of the Individual Quota as a Device in Fisheries Management.* Copes (1986b, pp.281-295) discussed 14 ways in which IQs can go wrong. The following summary of those problems was adapted from that paper.[95]

- Quota Busting -- quotas are exceeded on a persistent and widespread basis.
- Data Fouling -- under-reporting of catches taken.
- Residual Catch Management -- many salmon stocks are managed on the basis of escapement and the residual stock cannot be easily allocated via IQs.

---

[95] Pearse (1982, p.84) mentioned three of these problems as qualifications to his recommendation that a "quota system be adopted or improved in all of the developed [west coast Canadian] commercial fisheries other than salmon and roe herring."

- Unstable Stocks -- In these stocks, the TAC cannot be determined with any reasonable level of certainty at the beginning of the season. Uncertainty over the TAC defeats the purpose of IQs—the fishermen will tend to race to catch fish to avoid losing quota, if the TAC is reduced.

- Short-lived Species -- such species tend to be non-self-regulating with respect to recruitment. A TAC is meaningless.

- Flash Fisheries -- roe herring, to meet the standards of Japanese markets, need to be harvested within a period of hours. Such a fishery cannot wait for unlucky or unskilled quota holders.

- Real Time Management -- This defeats the purpose of IQs because it requires that the fishery managers set the when, where and how of fishing.

- High Grading -- fishermen sort their catch, to retain higher value pieces (individual fish) and throw back lower value pieces. Discarded fish tend to have a low survival rate. As a result fish is wasted and the TAC (based on landings) is exceeded by the catch even though the landed fish equals the TAC.

- Multi-Species Fisheries -- an undifferentiated quota encourages high grading and/or a race for the high value species. A differentiated quota causes a by-catch problem.

- Seasonal Variations -- If a fishery experiences a significant intra-seasonal decline in CPUE, IQs reduce but do not eliminate the race for fish. Fishermen trade-off gains from a higher CPUE early in the season with gains from a higher price later in the season.

- Spacial Distribution of Effort -- If several fishing grounds (with varying CPUEs and/or fishing costs) are aggregated under a single quota regime, some grounds will be over-exploited, while others will be under-exploited. Resource rent will be lost and the situation appears to be inherently unstable.

- TAC Setting -- TACs are set to attain an optimal harvest. If some fishermen are unwilling or unable to take all of their quota and are unwilling or unable to sell or rent the unused quota then (assuming that quota busting is avoided) the optimal harvest is not attained.

- Transitional Gains Trap -- IQs can attain their efficiency objective only if they are transferable. If an individual can sell the right to a stream of benefits, that individual can capture the present value of all future benefits, in the market value of that stream (Tullock, 1975). If an objective of ITQs is to increase fishing incomes that objective will be frustrated, for future generations of fishermen.

- Industry Acceptance -- Approval and cooperation of the fishing industry is an important element of any program of fisheries reform. The independent nature of fishermen, their faith in their fishing abilities/luck, along with fear that quota ownership will become concentrated in a few hands will work against the acceptance of ITQs.

This study will expand on a few of these problems and introduce a few other problems associated with IQs. What becomes apparent from reviewing the above problems is that, like previous fisheries management solutions, IQs can transform but not eliminate the fishery common property resource problem. *Fine-tuning* specific IQ programs can eliminate some fishery specific problems but the general problem of common property remains, albeit in a new and unfamiliar form.

7.1 THE SELECTIVITY EXTERNALITY

IQs control and guaranty the amount of fish a specific fisherman can catch. If all fishermen are law abiding and if all fish are equal, IQ regulation should eliminate the common property resource problem. However, all fishermen are not law abiding and all fish are not equal. In those realities, lie the form that the fishery common property resource problem can take in IQ fisheries.

Muse and Schelle (1989, p.109), after reviewing the histories of 12 IQ programs in various areas of the world, noted that "the harvest rights contained in the individual quotas will not necessarily produce the same results as sole ownership of the stocks. In particular, the holder will have an incentive to conserve his individual quota and devote it to its most valuable use, but the holder will have fewer incentives with respect to conserving stocks. ...The quota holder who engages in illegal dumping, highgrading, under-reporting, smuggling, or misreporting may be negatively impacting the stocks for his own short term gain. The cost of such actions in terms of reduced harvests in the future may be spread over all holders of individual quota." It could be argued that these actions are immoral and laws can be passed to limit any losses to the enforcement costs. However, this study will show how moral, law abiding fishermen can wreak similar havoc in an IQ fishery. In such a situation, the immorality (if any) resides in the situation rather than in the individuals trapped within the situation.

A fisherman may be expected to seek personal gain through pursuing the higher value and/or lower cost fish with no (or little) regard for any costs that are imposed on the users of the stock as a whole. After all, the fisherman owns not the stock but a share of the current TAC. As with any tragedy of the commons, the benefits of such actions acrue to a fisherman and the costs are shared by all fishermen fishing the stock. Selectivity tends to be a significant problem only in an IQ fishery—the race for fish that occurs in open access or limited entry fisheries tends to prevent the individual fishermen from seeing selectivity as an optimizing behaviour. IQs limit the amount of fish that a fisherman can harvest, shifting the fishing enterprise profit maximizing behaviour away from catch quantity to quality (i.e. selecting the pieces to harvest and land, the timing of the harvest, the location to harvest and the harvest gear type). And, by guarantying the amount of fish that a fishing enterprises can try to harvest, IQs afford fishermen the time needed to engage in such selectivity.

It is difficult to regulate against most variations of selectivity and maintain the free market intent of IQs. Further, such regulation would tend to be seen by most fishermen as an unacceptable intrusion into their business affairs and would tend to be unenforceable.

7.1.1 THE EFFECT OF THE SELECTIVITY EXTERNALITY

Much of the management of a fishery is based on a historical data set. Selectivity alters the established patterns in a fishery and can make the historical yield/effort data sets used by many fishery managers even less reliable. Further, selectivity is a complex syndrome of fishing behaviours and strategies whose elements vary in both absolute and relative intensity. Thus, data biases induced by the various forms of selectivity may be neither constant nor predictable, over time. The data fouling produced by selectivity will persist far into the future and data, even as it is gathered, will tend to corrupt and unreliable for management purposes. Further, there is no reason to believe that the biases will ever converge to a constant or predictable form.

The amorphous nature of the biases generated by selectivity precludes the possibility of identifying and offsetting error patterns in the corrupted data. There is little reason to believe that the results from models using this type of corrupted data will be of use in managing a fishery.[96]

---

[96] In discussing the current problems in the Canadian east coast northern cod fishery, Harris (1990, p.3 and 44-45) placed much of the blame for the problems on unreliable data. This study indicates that the DFO scientists' cry of *mea culpa* in the Harris report (1990, pp.44-45) may have been precipitous—the reasons why the northern cod fishery data were unreliable are more important than assigning blame to those gathered and used that data.

The use of a dynamic pool model (Pitcher and Hart, 1982, pp.250-292; Holling, 1984; Clark, 1985, pp.127-136; Cunningham et al., 1985, p.153) can, in theory, solve these problems by including such elements as the yield per recruit (Gulland, 1983, pp.147-162), gear selectivity (Gulland, 1983, pp.117-130) and cohort analysis (Ricker, 1975, pp.193-202; Pitcher and Hart, 1982, pp.180, 273, 283 and 374-377; Gulland, 1983, pp.105-117). However, such detailed models would tend to either collapse under the weight of their data needs (Pitcher and Hart, 1982, p.251; Gulland, 1983, pp.70-74; Holling, 1984, pp.57-69) or they would be so complex as to defy comprehension (Holling, 1984, pp.60-64). Also the fishery under consideration is likely to be in transition, from an open access or limited entry fishery to an IQ fishery, which tends to complicate the situation by at least one order of magnitude.

It is convenient for modeling purposes to separate the selectivity syndrome into various types—piece selectivity, timing selectivity, stock selectivity, spacial selectivity, etc. This classification, like the analysis in the following subsections, is an abstraction. The analysis is intended to provide insight into a few of the many interrelated selectivity effects that might occur in an IQ fishery. In actual fisheries, selectivity generated changes to fishery parameters will tend to vary over time/space in complex and unpredictable ways.

In the following subsections the analysis imposes an order on the selectivity bias. This is not a depiction of reality, but is a way of gaining insight into how selectivity biases may affect a fishery. This approach can be likened to the separation of a complex physical motion into ordinal vectors—while the results are not additive they indicate the nature of the effects each factor will have on the system and may provide insight on how combinations of factors will affect the system.

7.2 HOW A TAC IS SELECTED

As noted in Tables 5-1 and 5-2, the foremost fisheries objective of fisheries managers and their government sponsors is to preserve the stock. Thus, the TAC is set first and foremost to either be a sustainable yield or as part of a TAC series that is intended to converge on a sustainable yield.

The set of acceptable sustainable yields is defined by the use of one or more bionomic models. The choice of which yield in that set to make the TAC depends on conservation, socioeconomic and political considerations. As noted in section 2.0, the use of MSY as a TAC has been largely discredited. The use of MEY (as the TAC) has been accepted in theory but tends to rejected in practise due to the practical problems involved in its calculation. Canadian fishery managers tend (as noted in subsection 6.1.4.2) to favour $F_{0.1}$ (the biologists' proxy for MEY) as a TAC—it can be calculated from yield/effort data and bypasses the need for fishing effort cost data. Even though this supposed strength can be a serious failing (subsection 6.1.4.2), $F_{0.1}$ is widely accepted in Canada as a good practical choice for a TAC (Fo'c'sle, 1988, p.22; Harris, 1990, pp.2, 9 and 96).

As shown in subsection 6.1.4.2, fishing effort at $F_{0.1}$ is defined by:

$$E_{F0.1} = .45r/q \qquad (96)$$

When the parameter values specified in Appendix B are substituted into eqns (96), (4), (5) and (1) then at $F_{0.1}$: 4,500 units of fishing effort are applied on a starting fish stock of 110,000 tonnes to yield a harvest of 7,920 tonnes that is worth $15,840,000. If we assume that, in this ITQ fishery, the fishermen operate the most efficient vessels (1 fisherman and 7.205 units of capital generating 98.901 units of effort when the season is .50 years) then the cost of fishing effort can be determined from eqn (90):

$$C = 0 + \$912.669E \tag{90}$$

7.3 PIECE SELECTIVITY

Piece selectivity occurs when fishermen select which pieces they will land as part of their quota.

Pre-harvest piece selection occurs when fishermen alter their gear selectivity to maximize the net value of their harvest. Eumetric yield management is a regulated form of pre-harvest piece selectivity. Attained through the setting of a size limit or restrictions on fishing gear, it can be used as an effort management device in open access or limited entry fisheries. Please note, a virtue under one management regime can become a vice under another regime.

Gear choice and/or eumetric yield management can adversely affect a fishery through a reduction in δ (the landed portion of the harvest related fishing mortality; equation (3), subsection 5.1; Ricker, 1976, p.1485; Argue, et al., 1983, pp.38-41 and 62-63).[97] Please note, what was considered to be a virtue under conventional fisheries wisdom may prove to be less virtuous than originally believed. In summary, while the amount of fish landed is never less than the amount of fish taken from a stock, the amount of fish removed from a stock can be much more than the amount of fish landed. This can greatly reduce the sustainable yields and makes the historical yield/effort data, for management purposes, even less reliable.

Post harvest piece selectivity occurs when fishermen sort their catch to retain the highest value selection of pieces and discard the rest. This externality is discussed by NRA (1983, pp.23-24) and Copes (1986b, pp.284-285) as a high grading problem. Like pre-harvest piece selectivity, it adversely affects a fishery through a reduction in δ.

7.3.1 THE EFFECT OF PIECE SELECTIVITY

The following analysis assumes that piece selectivity occurs suddenly in what was a stable ITQ fishery and that the only effect is a simple one time reduction in δ. While the assumptions are not realistic, the model is tractable and the insights it generates will provide a starting point for more realistic models.

The effect on the yield/effort curve of a change in δ is not made immediately obvious when eqn (5) is differentiated with respect to δ.

---

[97] Specifically, a fraction of the fish that pass through a selective gear will be harmed by the gear and are either killed or suffer a reduction in growth. While the relation between this harm and the selectivity of the fishing gear is likely to be very complex, the harm will likely vary directly with the number of exposures to the gear.

$$\bar{H} = \delta qE(1 - qE/r)/a \quad (5)$$

$$dH/d\delta = qE(1-qE/r)/a \quad (122)$$

However, from eqn (122) it is obvious that:

$$dH/d\delta = qE(1-qE/r)/a > -0- \text{ for all } E < r/q = E_{MAX} \quad (123)$$

E_{MAX} = the effort at which, in the long run the biomass and the harvest fall to nil

and that for any given sustainable level of fishing effort the associated sustainable harvest will decline as δ declines.

This reduction in the sustainable yield is undesirable and, even worse, it can set the stage for disaster in the fishery. This disaster would happen in several stages. If the TAC was set at the $F_{0.1}$ yield; and if the fishermen suddenly started to practise pre and post-harvest selectivity; and if that selectivity caused significant decline in δ; and if the fishery managers did not notice that decline, then the TAC (the old $F_{0.1}$ yield) would be above the new $F_{0.1}$ yield. The harm caused by this problem would depend on whether or not the TAC exceeded the new MSY yield. If the TAC was less than the new MSY the stock would be fished harder than intended but the TAC would be sustainable. If, however, the TAC were greater than the new MSY the TAC would not be sustainable and the yields would eventually collapse.

In the example analysis, the sudden advent of both pre and post-harvest selectivity causes a 25 percent decline in δ (from .80 to .60) the TAC of 7,920 tonnes (the old $F_{0.1}$ yield) would be in excess of the new $F_{0.1}$ sustainable yield of 5,940 tonnes (eqns (96) and (5)) and it would be in excess of the new MSY yield of 6,000 tonnes (5,000 units of effort per subsection 6.1.3 and eqn (5)).

Figure 7-1, shows that the effect of this over-fishing would not be immediately obvious.[98] There is an annuity effect that maintains a constant harvest until the stock in essence collapses. This analogy to financial instruments is reasonable—in a well managed, stable fishery management's objective is to set a TAC that exactly offsets the annual growth in the stock. In such a fishery, the harvest is the same as an interest coupon clipped from a bond—the capital in the form of the fish stock, is not diminished and continues to earn a constant return. The TAC in Figure 7-1 was unwittingly set in excess of the sustainable landed yield. This is analogous to an annuity. An annuity is a financial instrument that yields from an initial lump sum investment a preset number of annual payments. The payments are a changing mix of interest and capital, designed such that as the last payment is made all of the initial capital invested has been withdrawn. The interest rate is constant for most financial annuities. In the case of the *fishery annuity* shown in Figure 7-1, the stock growth rate (eqn (2) divided by the biomass) tends to rise as the stock biomass declines. This extends the *period* of the annuity by slowing the rate of decline of the stock biomass. Figure 7-2 indexes the change in several key variables in the fishery shown in Figure 7-1. It indicates that a constant harvest with a declining CPUE (e.g. increasing total effort) are good indicators of an *annuity situation* occurring in a fishery.

---

[98] In Figures 7-1 and 7-3, $F_{0.1}$ is identified by points $F_{0.1h}$ ($F_{0.1}$ fishing revenues) and $F_{0.1c}$ ($F_{0.1}$ fishing costs).

When an ITQ fishery is in an annuity situation the fishermen will notice that ever more fishing effort is needed to harvest their quota. However, at least initially, this problem might be attributed to: bad weather, a series of weak year classes, temporarily high natural mortality, poor feed conditions and/or the fishermen not working as hard as they did previously. Eventually, the over-fishing but not its cause will become obvious and quotas will be slashed in an futile attempt to re-establish the former productivity of the stock. The attempt will be futile, because, until the problem of the increased nonlanded fishing related mortality is resolved, the former harvest levels are outside of the envelope of attainable harvests.

In this example, the current recruitment to the fishable stock is dependent on the ending biomass of the previous year.[99] Where current recruitment depends on what the biomass level was, in a year, several years prior to the current year, the *period* (number of installments) of the annuity will tend to be several years longer—there are several years of pre-recruit cohorts *in the pipeline*). Also, the period during which the harvest is less than the official TAC but still greater than nil will be greatly extended. During this last stage (when the harvest is less than the official TAC) fishermen will abandon piece selectivity and, by taking any fish they can harvest, they will accelerate the stock collapse.

---

[99] In this model, recruitment, growth and mortality are blended into a single parameter (r)—see subsection 5.1.2.

7.4 TIME SELECTIVITY (WITHIN A GIVEN SEASON)

In some open access and limited entry fisheries, many regulations are set to maximize the yield per recruit (Ricker, 1975, pp.235-264; Pitcher and Hart, 1982, chapter 8; Gulland, 1983, pp.147-162 and 177; Copes, 1986a, pp.51-54).[100] As noted earlier (subsection 7.0), reduced management costs are touted as a major benefit of IQs. The idea is that the current complex management practises and procedures found in many fisheries can be replaced with a TAC, IQs (based on the TAC) and a program of enforcement to ensure compliance with the IQs.

Another touted benefit of IQs is that fishermen can choose when, where and how to fish. However, this benefit can also create problems. As noted by Copes (1986b, p.286), in some IQ fisheries, fishermen will choose when to fish by trading-off the gain from the higher CPUE early in the season with the gain from higher prices later in the season. If the timing of fishing is changed by the imposition of IQs, the current estimate of the biomass growth rate may no longer be appropriate (e.g. if it was based on historical data, gathered before the imposition of IQs).[101]

---

[100] The yield per recruit is maximized when the harvest strategy optimizes the trade-off between the growth of individuals in each cohort with the losses to natural mortality. If the fish are harvested at too small a size, growth over-fishing occurs. If the fish are harvested at too large a size, growth under-fishing occurs. The age at which fish are recruited to the fishable stock is usually the vital factor and is often controlled by regulations on fishing gear.

[101] In Canadian's west coast sablefish fishery there is substantial cohort information, but the basic management tool is a TAC with a desired harvest rate of $F_{0.1}$ (Saunders and McFarlane, 1990, pp.127-149 and 131).

The piece selection discussed in subsections 7.3 and 7.3.1, also, has a time dimension. Fish piece weight and growth rates vary with age (Ricker, 1975, pp.210-219; Pitcher and Hart, 1982, pp.134-147 and p. 305). If before the imposition of ITQs in a fishery, the harvest timing and the age of first capture were managed to optimize yields then departures from that management regime will tend to reduce the growth parameter r (eqns (2) and (5)). The reduction will tend to be significant if the biomass growth (eqn (2)) is highly dependent on the growth of individual fish or if recruitment is greatly affected by the average biomass, or if fecundity varies with piece size.

7.4.1 THE EFFECT OF TIME SELECTIVITY

The following analysis assumes that the ITQ generated time selectivity occurs suddenly in what was a stable fishery and that the only effect is a simple one time reduction in r. While the assumptions are not realistic, the model is tractable and the insights generated will provide a starting point for more realistic models.

The effect on sustainable harvests of changes in r is immediately obvious, when eqn (5) is differentiated with respect to r.

$$dH/dr = \delta q^2E^2/r^2/\alpha > -0- \qquad (124)$$

It is obvious, from eqn (124) that the sustainable harvest (at a given effort) declines as r declines. Changes in r also affect $E_{F0.1}$. When eqn (96) is differentiated with respect to r, the result:

$$d(E_{F0.1})/dr = .45/q > -0- \qquad (125)$$

shows that the $F_{0.1}$ effort declines as r declines.

As shown in subsection 7.2, if the parameter values in Appendix B are substituted into eqns (96), (4), (5) and (1), then at $F_{0.1}$: 4,500 units of effort are applied on a starting fish stock of 110,000 tonnes to yield a harvest of 7,920 tonnes and worth $15,840,000. If we assume that in this ITQ fishery fishermen operate the most efficient vessels (one fisherman and 7.205 units of capital, to generate 98.901 units of effort when the season is .5000 years) then the cost of fishing effort can be defined by eqn (90):

$$C = 0 + \$912.669E \tag{90}$$

The TAC in this fishery would be the $F_{0.1}$ sustainable yield. If, however, all of the fishermen suddenly started practising time selectivity and if their actions caused r to decline by 25 percent (from .2 to .15) the $F_{0.1}$ fishing effort, per eqn (96), would fall to 3,375 and the official TAC of 7,920 tonnes will be in excess of the actual $F_{0.1}$ sustainable yield of 5,940 tonnes.[102]

Figure 7-3, indicates that the effect of this over-fishing would not be immediately obvious. As in the piece selectivity case, there is an annuity effect that maintains a constant harvest until the stock in essence collapses.

---

[102] The $F_{0.1}$ fishing effort is changed by time selectivity, because the growth function is changed. This change in the growth function, also, changes the efforts associated with other potential TAC targets (MEY, MSY, Social Optimum, etc.).

7.5 STOCK SELECTIVITY

In open access and limited entry fisheries, the fishermen have to scramble—if they fail to take a fish it is soon lost to another fisherman. This causes fishermen to take fish however, wherever and whenever they have the chance. IQs give fishermen the opportunity to consider where to harvest the fish that will makeup their quota. This is an important benefit, if the CPUE and/or cost of fishing effort varies significantly across the region from which their IQ may be drawn. However, problems can arise if the TAC (upon which the IQs are based) encompasses but does not consider several stocks or substocks.[103]

"Managing fish on the basis of stocks offers protection against over fishing. For example, if all the cod in Atlantic Canada were managed as a single stock, with one overall quota, trawlers would concentrate their efforts on the most accessible fish. This would likely overfish that area and underfish others. Identifying separate stocks allows fisheries managers to match the fishing effort to the size and distribution of the resource" (Fo'c'sle, 1988, p.10). IQs can interfere with this matching process. If a region, containing several substocks of varying productivity and/or fishing cost patterns, has IQs which are based on the average character of the region as a whole then the most profitable substock attracts too much fishing effort until it is sufficiently depleted that the next most profitable stock attracts

---

[103] "... a fish stock is something like a community or tribe. A few of its members mingle with members of other groups or even join them for good, but most stay with their own. A fish population is considered a separate stock when it can be fished without affecting other populations of the same species" (Fo'c'sle, 1988, p.10).

too much effort. If the fishery managers are unaware of the problem of overfishing and depletion could continue to move from substock to substock until the substocks collapse or the system bifurcates to a lower level of harvest.[104]

7.5.1 THE EFFECT OF STOCK SELECTIVITY[105]

The following analysis assumes that the ITQ generated spacial selectivity occurs suddenly in what was a stable fishery. The fishery is assumed to occur in a region that has n substocks, with no migration between substocks. The substocks are equally productive but have different cost of effort curves. The inverse of the environment holding capacity (α) was multiplied by n to create α_n and n substocks that are each $1/n^{th}$ of the stock in previous examples. In subsection 5.3.2, the parameter q was shown to be a *harvest calibration coefficient* that is used to scale the LHS of eqn (3) so that a unit of fishing effort harvests $\delta/10{,}000^{th}$ of the stock biomass. If the substock j biomass (X_j) is substituted into eqn (3) the parameter q must be replaced with q_n ($q*n$). If this is not done then the amount of fishing effort which in a previous example could harvest the entire stock is needed to harvest any one substock—that is $1/n^{th}$ of the size of the stock (the combined

---

[104] Bifurcation occurs in a system when, instead of moving towards the pre-change equilibrium, it moves toward a new equilibrium and a new set of dynamics (Prigogine and Stengers, 1984, pp.160-170).

[105] Both Warming (1911) and Gordon (1954) examined the problem of managing two fish stocks. In those examples the biological productivity of one stock was higher than that of the other stock and the cost of fishing was the same for both stocks. In this multistock analysis the substocks are assumed to be equally productive, but the cost of fishing each stock is assumed to be different. This approach simplifies the problem and makes it easier to extend a multistock analysis to the management of an ITQ fishery.

substocks).[106] These assumptions make the sum of the $\cap$ substock *sustainable yield to effort* curves equivalent to the *sustainable yield* to *effort* curves in the previous examples.

The different fishing costs were considered by changing eqn (29) to:

$$C_{ij} = \S_j[b + (\Gamma+g\theta)K + (\tau+g\Phi+g\Omega)N] \tag{126}$$

C_{ij} = cost of fishing effort, by vessel i, on substock j
j = subscript for substock j
$\S_j$ = cost scaler for substock j

The monotonic change in the vessel fishing cost means that the optimum vessel configuration is the same for all substocks—which means that, in either an IQ or an open access fishery, eqn (90) resolves to:[107]

$$C_{ij} = c_{ij}E_{ij} \tag{127}$$

c_{ij} = unit cost of fishing effort on substock j, by vessel i

These simplifying assumptions are unlikely to be found in actual fisheries. However, the model is tractable and the insights generated will provide a starting point for more realistic models.

In a TAC managed open access fishery, based on eqns (3) and (21), the short-run (nonequilibrium) harvest of vessel i, in this (multiple

---

[106] Another way to resolve this problem is to redefine E (the unit of fishing effort). However, that approach needs adjustments to parameters m, *n* and *k*, in eqn (26).

[107] The input stuffing that tends to occur in a limited entry fishery will invalidate the use of eqn (127) in place of eqn (126). In an open access fishery, if there is a binding TAC, then (per subsection 6.1.3) the fishery managers will be forced to reduce the season length (g) until the cost of fishing effort rises to a level where the open access equilibrium moves to the TAC. This changes the parameter values of c_{ij} but will not invalidate the use of eqn (127) in place of eqn (126). The TAC in an open access fishery is nonbinding and, thus, is irrelevant.

substock) fishery, equals:

$$H_i = \sum_{j=1}^{n} \delta q_s E_{ij} X_j \tag{128}$$

Subject to:

$$TAC \geq \sum_{j=1}^{n} \sum_{i=1}^{v} \delta q_s E_{ij} X_j \tag{129}$$

V = vessels in the fishery
TAC = Total Allowable Catch

It is assumed that the TAC is based on the five substocks as an undifferentiated whole. Per subsection 7.2, the official $F_{0.1}$ TAC is 7,920 tonnes. Based on eqns (127) and (128) the short-run profit to vessel i from fishing stock j, is:

$$\pi_{ij} = (\delta q_s P X_j - c_{ij}) E_{ij} \tag{130}$$

The marginal profit to vessel i, from fishing stock j, is:

$$d\pi_{ij}/dE_{ij} = \delta q_s P X_j - c_{ij} \tag{131}$$

And the profit to vessel i from stock j is maximized when:

$$d\pi_{ij}/dE_{ij} = \delta q_s P X_j - c_{ij} = \text{-}0\text{-} \tag{131a}$$

This condition also defines the open access equilibrium (i.e. fishing profits are nil) and eqn (131a) can be reorganized to define the biomass of stock j (X_j) at that equilibrium:

$$X_j = c_{ij}/(\delta q_s P) \tag{132}$$

When the subscript j is changed to the subscript 1, eqn (132) becomes:

$$X_1 = c_{i1}/(\delta q_s P) \tag{133}$$

Rational vessel owners will allocate fishing effort between the stocks such that:

$$d\pi_{ij}/dE_{ij} = d\pi_{i1}/dE_{i1} \tag{134}$$

$$(\delta q_s P X_j - c_{ij}) = (\delta q_s P X_1 - c_{i1}) \tag{134a}$$

and eqn (134a) can be reorganized to:

$$X_j = X_1 + [c_{ij} - c_{i1}]/(\delta q_s P) \tag{135}$$

However, at the open access equilibrium, eqn (132) can be divided into eqn (133) to show that the biomass ratio between substocks will be:

$$X_1/X_j = c_{i1}/c_{ij} \qquad (136)$$

When the RHS of eqn (135) is substituted into eqn (136) the result can be reorganized to eqn (133).

When IQs are instituted in a fishery the quota owned by a fishing enterprise tends to be the prime determinant of the gross fishing revenue of that enterprise.[108] Thus, at the enterprise level, revenue is not the control variable—minimizing the total cost of achieving their IQ is the new control focus. In an IQ fishery, with a TAC encompassing several substocks, the quota owners' maximand is:

$$\text{Minimize } C_i = \sum_{j=1}^{n} c_{ij}E_{ij} \qquad (137)$$

$$\text{Subject to: } TAC \geq \delta q_s[(\sum_{j=1}^{n} \sum_{i=1}^{v} E_{ij}X_j)] \qquad (138)$$

$$\text{and} \quad Q_i(TAC) \geq \delta q_s[(\sum_{j=1}^{n} E_{ij}X_j)] \qquad (139)$$

$$\text{and} \quad E_{ij} > -0- \text{ for all substocks that are fished} \qquad (140)$$

Q_i = quota of vessel i, as
a percent of the TAC

The constraints defined by eqns (138) and (140) are binding at a fishery scale but are not apparent to an entrepreneur at the vessel scale. Equations (137) and (139) give the following Kuhn-Tucker conditions:

$$Z = \sum_{j=1}^{n} c_{ij}E_j + £_i[Qi(TAC) - \delta q_s \sum_{j=1}^{n}(E_{ij}X_j)] \qquad (141)$$

---

[108] Under the simplifying assumption that fish prices per tonne are invariant over both time and piece size, the legal revenues of a quota holder are a function of the lesser of what he harvests or his quota (in tonnes).

$$(dZ/dE_{i1})E_{i1} = (c_{i1} - \pounds_i \delta q_s X_1)E_{i1} = \text{-0-} \tag{141a}$$

$$(dZ/dE_{ij})E_{ij} = (c_{ij} - \pounds_i \delta q_s X_j)E_{ij} = \text{-0-} \tag{141b}$$

$$dZ/d\pounds_i = Q_i(TAC) - \delta q_s\Big(\sum_{j=1}^{n} E_{ij}X_j\Big) = \text{-0-} \tag{141c}$$

Given the constraint in eqn (140), eqns (141a) and (141b) can be simplified to:

$$c_{i1} = \pounds_i \delta q_s X_1 \tag{142}$$

$$c_{ij} = \pounds_i \delta q_s X_j \tag{143}$$

When eqn (142) is divided by eqn (143) the result can be restated as:

$$X_1/X_j = c_{i1}/c_{ij} \tag{136}$$

which is the same (substock) biomass ratio in the open access case and it can be reorganized to:

$$X_j = (c_{ij}/c_{i1})X_1 \tag{144}$$

Equation (144) is the ratio of substock biomasses where fishermen will not adjust the allocation of effort between substocks. Potential bionomic equilibria can be found by adapting eqn (2) to define the growth function of the combined stocks.

$$G(X) = \sum_{j=1}^{n} G(X_j) = \sum_{j=1}^{n} rX_j - a_s r X_j^2 \tag{145}$$

and then substituting the RHS of eqn (144) into eqn (145):

$$G(X) = \sum_{j=1}^{n} r c_{ij} X_1/c_{i1} - a_s r(c_{ij}X_1/c_{i1})^2 \tag{146}$$

At a biological equilibrium, the fishing related mortality ($H/\delta = TAC/\delta$) is equal to the RHS of eqn (146). That result can be reorganized into the following quadratic equation:

$$a_s r\Big[\sum_{1=j}^{n}(c_{ij})^2/c_{i1}^2\Big]X_1^2 - r\Big[\sum_{1=j}^{n}(c_{ij})/c_{i1}\Big]X_1 + (TAC)/\delta = \text{-0-} \tag{147}$$

The dynamics of this system of stocks can be inferred from the harvest related mortality (H/δ), eqns (146) and (133). Specifically, in terms of Figure 7-6, for a given X_1, if:

a) $H/\delta <$ eqn (146), the stock biomass will increase,
b) $H/\delta >$ eqn (146), the stock biomass will decrease,
c) $H/\delta =$ eqn (146), the stock biomass will not change,
d) $H/\delta < TAC/\delta$, the harvest will increase,
e) $H/\delta > TAC/\delta$, the harvest will decrease, and
f) $H/\delta = TAC/\delta$, the harvest will not change;

Further, for a given TAC, if X_1 is less than the minimum root produced by eqn (147), the TAC is not binding and the fishery will behave like an open access fishery. Under those conditions,

if: g) $X_1 <$ eqn (133), effort will eventually withdraw from the fishery until $H/\delta =$ eqn (146) and $X_1 =$ eqn (133). Which is the open access equilibrium.

Tables 7-4 and 7-5 and Figures 7-5 and 7-6, show the results of a simulation of the above equations, using two stocks that are identical except that the cost of fishing effort for the second stock is one and a half times those of the first stock. Thus, for eqn (127)

$$C_i = c_{ij}E_{ij} \tag{127}$$

c_{ij} = unit cost of fishing effort on substock j
where: c_1 = \$ 912.669
c_2 = 1,369.003

Based on eqns (138) and (139), the open access equilibrium biomass is:

- 14,260 tonnes for substock 1,
- 21,391 tonnes for substock 2, and
- 35,651 tonnes for the aggregate stock.

Based on eqn (136), when both stocks are being harvested, the biomass ratio stock 1/stock 2 is $c_1/c_2 = 2/3$. Equation (147) can be simplified to:

$$(3.25a_s r)X_1^2 - (2.5r)X_1 + (TAC)/\delta \tag{147a}$$

from which the following two roots can be derived (using the quadratic formula):

$$X_1 = 38{,}462 \pm [6.25 - .0008125(TAC)]^{.5}(15{,}385) \tag{148}$$

Equation (145) is only applicable when $c_1/c_2 = 2/3$, when X_1 is greater than $2/(3\alpha_s) = 66{,}667$ tonnes then only stock one is harvested ($j \leq 1$), and eqn (147) can be simplified to:

$$\alpha_s r X_1^2 - rX_1 + (TAC)/\delta = -0- \qquad (147b)$$

from which the following two roots can be derived (using the quadratic formula):

$$X_1 = 50{,}000 \pm [1 - .00025(TAC)]^{.5}(50{,}000) \qquad (149)$$

If eqn (138) is used to define the biological equilibrium biomass of each stock, eqn (4) can be adapted to define the effort devoted to each stock:

$$E_j = (r/q_s)(1 - \alpha_s X_j) \qquad (150)$$

and eqn (3) can be adapted to:

$$H_j = \delta q_s E_j X_j \qquad (151)$$

Equation (127) can then be used to define the cost of fishing effort in each fishery.

Figure 7-5 and Table 7-4 show that (in an IQ fishery) a $TAC_{F0.1}$ that is based on the average characteristics of several substocks can exceed the actual MSY. This creates the annuity type of situation discussed in previous sections and can severely deplete a fishery before being discovered. However, problems arise even if the TAC is based on data from the individual substocks. Equation (91) can be modified to determine the MEY effort for each of the substocks:

$$E_{MEYsj} = .5r[1 - c_{sj}\alpha_s/(q_s\delta P)]/q_s \qquad (152)$$

When eqns (152), (4) and (3) are used to establish the optimal harvest for the two substocks the result is:

TABLE 7-1: MEY if Each Substock is Managed Separately

E_{MEYj}	X_{MEYj}	H_{MEYj}	R_{MEYj}	C_{MEYj}	π_{MEYj}
2,143.49	57,130	3,919	$7,837,312	$1,956,296	$5,881,016
1,965.23	60,695	3,817	7,633,951	2,690,410	4,943,541
4,108.72	117,826	7,736	$15,471,263	$4,646,706	$10,824,557

which sets the TAC at 7,736 tonnes which is 44 tonnes above the actual MSY harvest of 7,692 tonnes (Table 7-4). The fishery managers have to either set a separate IQ for each substock or use the actual MEY harvest of 7,428 tonnes (Table 7-4). Again, the reason for the problem is that IQs grant rights to a specific amount of fish but not to specific fish. As a result, if the TAC in a multi-substock IQ fishery is set by adding the individual MSYs, MEYs or $F_{0.1}$s of the fished substocks in a region, the TAC does adjust for the stock selectivity externality and will result the fishery being overexploited—possibly to a collapse.

In this model, the harvest from a substock is a function of the substock's beginning biomass and the effort applied to it. An analysis of the dynamics of this fishery would be possible only if assumptions were made concerning rates of recruitment, piece growth and mortality. Those assumptions would tend to be specific to different fisheries and would greatly complicate the analysis. The two stocks, in the system, also complicate the system dynamics because a phase diagram will only be meaningful if it has at least four dimensions (Stewart, 1989, pp.93 -94).[109] When a system is too complex to analyze using a dynamic perspective, a reasonable alternative approach is to focus on its long-

---

[109] There are two state variables (X_j) and two control variables (E_j).

term behaviour. This approach ignores the infinite number of possible transients (i.e. short-run movement in the system) and concentrates on the possible attractors (i.e. points the system can settle down to) in the system (Stewart, 1989, pp.108-110). Several types of attractors are possible in an n-space phase diagram—strange attractors, stable limit cycles and single points. The first two will have to await a detailed mathematical study of the multi-substock problem. This analysis focuses on stable points. Phase diagrams exhibit three types of non-singular behaviour—sources, sinks and saddle points. A *source* is a single point, from which all nearby points move away. In economics, a source is called an unstable equilibrium. Such points are identified (in this model) via inspection. A *sink* is a locality where a flow line degenerates to a single point, toward which all nearby points flow. In economics, such a point is called a *stable equilibrium.* In this model, eqn (133) identifies such points. A saddle point occurs at the intersection of two flow lines called separatrices. One separatrix flows toward the saddle point and the other flows away from it. Nearby flows move at first toward a saddle point and then shear away from it. In economics, a saddle point is called an unstable equilibrium. Equation (148) is used to identify such points.

As noted previously a multisubstock fishery has j state variables (X_j) and j control variables (E_j). However, over a fishing season the control and state variables are linked in that fishermen, for economic reasons, will adjust their allocation of effort between the substocks until the following ratio holds:

$$X_j = (c_{1j}/c_{11})X_1 \qquad (144)$$

After one fishing period the state variable of substock j is described by:

$$X_{jt+1} = X_{jt} + G(X_{jt}) - q_s X_{jt} E_{jt} \qquad (153)$$

As the stock (state) variables change in the fishery, if the substocks change from the ratio described by eqn (144) individual fishermen find that they can decrease the cost of attaining their quota by changing the allocation of their effort between substocks. This adjustment acts in the same way as arbitrage does in financial markets—it eliminates the gain from stock switching by *correcting* the substock biomass ratio to the profit satisficing ratio of eqn (144). Thus the ratio described by eqn (144) tends to persist across periods, which only occurs if:

$$(1/X_j)(dX_j/dt) = (1/X_1)(dX_1/dt) \qquad (154)$$

$$G(X_j)/X_j - q_s E_j = G(X_1)/X_1 - q_s E_1 \qquad (154a)$$

$$E_j = \sum_{i=1}^{v} E_{ij}$$

If the RHS of eqn (146) is substituted into eqn (154a), the result can be simplified to:

$$E_j = E_1 + (r/q_s) a_s X1(c_{ij}/c_{i1} - 1) \qquad (155)$$

Equation (155) is a problem in that the effort on the jth substock is expressed as a function of two variables (E_1 and X_1). However, where the TAC is binding the following relation can be imputed:

$$TAC = \delta q_s [\sum_{j=1}^{n} (E_{ij} X_j)] \qquad (138a)$$

If eqn (138a) is restricted to the first substock (e.g. TAC is $TACc_{i1}$) and if the RHS of eqn (144) is substituted into it, that result can be reorganized to:

$$\sum_{j=1}^{n} E_j = TACc_{i1}/(\delta q_s X_1 \sum_{j=1}^{n} c_{ij}) \qquad (156)$$

The change in the biomass of all the stocks can be defined by:

$$dX/dt = \sum_{j=1}^{n} [rX_j - a_\varepsilon rX_j^2 - q_s X_j E_j] \qquad (157)$$

When the RHS of eqn (144) is substituted into eqn (157) the result is:

$$dX/dt = \sum_{j=1}^{n} [r(c_{1j}/c_{11})X_1 - a_s r(c_{1j}/c_{11})^2 X_1^2 - q_s(c_{1j}/c_{11})X_1 E_j] \qquad (158)$$

When the RHS of eqn (156) is substituted into eqn (158) the result can be simplified and reorganized to:

$$dX/dt = (rX_1/c_{11})[\sum_{j=1}^{n}(c_{1j})] - a_s(X_1/c_{11}^2)[\sum_{j=1}^{n}(c_{1j}^2)] - TAC/\delta \qquad (159)$$

Based on eqn (154) the change in biomass of stock 1 is:

$$dX_1/dt = (dX/dt)[c_{11}/(\sum_{j=1}^{n} c_{1j})] \qquad (160)$$

the biomass change for each substock can be defined by:

$$dX/dt = (dX_1/dt)(c_{11}/c_{1j}) \qquad (161)$$

and the equilibria can be identified by setting eqn (159) equal to nil to produce the (previously defined) quadratic equation:

$$a_s r[\sum_{1=j}^{n}(c_{1j})^2/c_{11}^2]X_1^2 - r[\sum_{1=j}^{n}(c_{1j})/c_{11}]X_1 + (TAC)/\delta = -0- \qquad (147)$$

When the subscript j in eqn (157) is set to 1 it can be reorganized to define, for a given biomass X_1, the total effort directed at stock 1:

$$E_1 = [r(1 - a_s X_1) - (dX_1/dt)/X_1]/q \qquad (162)$$

and the effort directed at the other substocks can then be defined by eqn (155).

In the illustrative example of two substocks and given the parameter values specified in Appendix B, eqn (147) is simplified and can be solved by eqns (148) or (149).

Figure 7-6 was created using eqns (148), (149), (138) and (133). It is a stock phase plane illustrating how the total harvest is related to the biomass of stock one (i.e. the biomass of the other substock is conform to eqn (144) and can, therefore, be reasonably subsumed in X_1).[110]

Figure 7-6 shows that when the TAC equals the actual MSY of 7,692 tonnes (Table 7-4), it is possible but unlikely that the fishery will eventually reach an unstable equilibrium. If the TAC is below the MSY, there are two possible equilibriums. In a mathematical sense, the one to the right of MSY is stable, while the one to the left of MSY is unstable (e.g. shifts up and/or to the left from that point start a flow to the open access equilibrium, while shifts down and/or to the right start a flow to the stable TAC equilibrium).[111] The stable TAC equilibrium is a local sink, with a resilience that varies inversely with its the points vertical distance from MSY. Specifically, if the TAC is at MSY the TAC equilibrium is unstable, as the TAC is decreased below MSY the stable TAC equilibrium becomes increasingly resilient until it becomes a global sink (when the TAC is less than the open access equilibrium harvest). In this sense, the MSY yield might be thought of as a hurdle—if harvests persistently exceed the MSY then (in the absence

---

[110] In the two dimensional space of Figure 7-6, a large number of substock biomass combinations could generate a given point, within the envelope of feasible harvests. However, an equilibrium is generated only by the eqn (138) ratio of substock biomass combinations.

[111] At any point to the right of the unstable TAC equilibrium, the TAC constraint acts as an upper limit and (assuming that quota holders are profit maximizers) it is reasonable to assume that the TAC is also the lower limit on harvest. At any point to the left of the unstable TAC equilibrium, the TAC constraint acts only as an upper limit on the harvest. The behaviour in the fishery when the TAC is only upwardly binding is that of an open access fishery and effectively the only binding constraint in the fishery is the open access equilibrium.

of any buffering influence) the fishery moves into an unstable region and is drawn to the open access equilibrium.

It can be argued that this example oversimplifies the multi-stock problem, but the problem does exist. Fish densities and costs tend to be heterogeneous both between fishing grounds and within a given fishing ground. Even if the stocks are managed separately, IQs will make that management more difficult. A system of IQs achieves its maximum benefits only if fishermen are free to choose when and where to fish. That freedom makes efforts to control the amount of fish taken from a stock both difficult and costly. In the absence of such controls, less scrupulous fishermen can freely take quota from any stock and claim it was from another stock.

7.6 LOCATIONAL SELECTIVITY

Locational effects within a fishery tend to be ignored in fisheries models. The practise has been to treat "fish populations as though they were uniform. ... This is a necessary simplification in order to make the models workable" (Gulland, 1983, p.21). Stewart (1989, p.273) observed that "biologists have tended to look at averaged quantities, asking how the averages relate to each other. This is a bit like the thermodynamic approach to a gas: emphasize averages such as temperature and pressure. It works pretty well for gases, and rather badly for populations." Stewart explained that, in populations, change occurs at the level of the individual not to the population as a whole.

Gulland (1983, p.21) also observed that fish populations are not uniform; "feeding may be better in one part of the range, resulting in better growth; fishing is not distributed uniformly, so that some fish are exposed to a greater intensity of fishing than others. Within a small area there may be sufficient and rapid mixing so that over a period it is reasonable to suppose that individuals are exposed to something approaching average conditions of feeding, or fishing intensity, and differences within the area can be [safely] ignored." Defining an appropriate stock, as Gulland went on to note, can be a matter of some importance. "Briefly, a group of fish can be treated as a unit stock if possible differences within the group and interchanges with other groups can be ignored without making the conclusions reached depart from reality to an unacceptable extent (Gulland, 1983, pp.21-22).

Fishery models also tend to assume that fishing mortality occurs uniformly through the stock. The definition of catchability coefficient—the fraction of a fish stock which is caught by a defined unit of fishing effort (Ricker, 1975, p.2)—is meaningful only if all fishing effort is applied uniformly to a fish stock. Thus, these models have no space dimension and fisheries are assumed to behave as though they occur in a single point in space.

A geographer (Abler, et al., 1971) would tend to see a fishery as a rich n-space topology. Along with the three dimensions of space and the dimension of time, fisheries are rich arrays of currents, upwellings, bottom types, communities of species, human communities, migratory species, climates and so forth (see Thomson, 1981). A model that encompassed such a view of the fishery would tend to collapse from the weight of data requirements and/or be so complex as to confound rather than edify.

At issue in fishery models is not whether variation exists across a fishery (for such variation does exists) but, rather, whether ignoring that variation significantly biases the model. A related question is: if there are significant intra-fishery locational effects, is it reasonable to manage the fishery as though those effects do not exist? In the fresh water fisheries of the Canadian Prairies distance between fisheries and markets appears to be a significant factor. Gislason, et al. (1982, pp.177-179 and 192) observed a trend toward a concentration of Lake Winnipeg fishing quota licenses in the south basin of the lake —even though actual yields/license tended to be higher in the channel and north channel of the lake. Gislason, et al. (1982, p.178) further noted that the "shift of fishing pressure from the North Basin to the South Basin is inconsistent with the increased pollution in the South Basin relative to the North Basin." A higher CPUE in the northern part of Lake Winnipeg, relative to the south, was first recorded in 1877 (Howard, 1975, pp.32-33). In their analysis of transportation costs in freshwater fisheries Gislason et al. (1982, pp.269-285) found that the transportation cost (raw fish in and product out) averaged 30 percent of the total conversion costs and 12 percent of gross revenues. Transportation is costly for British Columbia freezer plants—salmon lose an average of around 2.5 percent in round weight while in transit to the plants and packer vessels, crew and ice costs represent five to eight percent of their finished product's wholesale value (The [B.C.] Select Committee on Agriculture, 1979). Thus, location affects local fishing output—via increased fishing costs or decreased landed price. The net effect of location on a fishery's total yield is less clear.

Clark (1976, pp.325-333) examined locational effects, in fishing, using a model where the cost of fishing varied with the distance from the shore and where recruitment was constant but where the fish stocks tend to diffuse (migrate) from sites of high density to sites of lower density. Clark's model generates some very interesting results but its assumption that recruitment is constant over time and space restricts the analysis to those stocks that are non-self-regulating (in terms of the fished portion of a stock). McGlade and Allen (1986, pp.1194-1198) developed a model for predicting fishing behaviour when there are many discontinuous fish aggregations across a two dimensional fishery.

The following analysis is kept at a reasonably tractable level by expanding the fishery model to a single spacial dimension. Rather than portraying a fishery in the typical single point fashion, the model is in the tradition of *line-land* (Abbott, 1952, pp.53-64).

7.6.1 A ONE-DIMENSIONAL LOCATIONAL MODEL OF A FISHERY

There is little fisheries tradition to draw upon in developing a model of the locational aspects of fishing. Imagination and a willingness to accept an unfamiliar perspective of familiar concepts is needed.

Imagine a fishing ground that is a 100 kilometer south/north line along which the environment is uniform. Fishermen approach the fishery from the south and can choose to fish at any point along the line. The cost of fishing is assumed to be constant throughout the fishery. The distance related costs are treated as a reduction in the price of the fish—defined as its net value at the point of capture. The value of the fish at the point of capture is assumed to vary according to:[112]

$$P_i = P - sK_i - t_r \tag{163}$$

P_i = price for fish at point i
P = maximum price for fish/tonne
s = \$.015 per tonne per metre
K_i = distance from point i to the south end of the fishery
t_r = royalty/tonne on fish

Surplus yield models (such as the Schaefer logistic growth model, used to develop eqns (1) through (5)) assume that recruitment to the stock and the growth of stock pieces are on average both a function of the same average biomass. In this uni-dimensional fishery, recruitment is assumed to be a function of the stock biomass (many fish species have a planktonic larval stage) and the growth of an individual piece is assumed to depend on the species biomass in its immediate vicinity.

The number of potential recruits is likely to vary with the stock and the stock biomass. Based on the discussion in Appendix G, the following function was selected:

$$\text{Recruits}_p = a(1 - e^{-bX}) \tag{164}$$

Recruits_p = potential recruits (in tonnes/ metre)
X = stock total biomass (it is the integral of X_i over the length of the fishery
X_i = point i biomass density

The rate of piece growth in a given location will likely vary inversely with the stock local density—based on the discussions in Appendix G the following function was selected:

---

[112] Distance related costs are difficult to define. They can be thought of as the combination of transportation, steaming time, lost fishing time, reduction in fish quality and other sacrifices that minimize the distance related reduction in net ex-vessel fish prices. All of this detail is subsumed in the parameter *s*.

$$r_i = (1-gX_i)r \tag{165}$$

r_i = growth rate at location i
X_i = biomass density at location i
r = maximum growth rate
g = a parameter

The discussion in Appendix G indicates that the following growth function may be more realistic.[113]

$$r_i = [1-g(e^{hX_i} - 1)r \tag{166}$$

h = a parameter

However, it was discarded because its complexity is not needed for the purpose of this analysis (e.g. an illustration of the basic concept of location selectivity.

$$\text{Growth}_i = rX_i(1 - gX_i) \tag{167}$$

It is reasonable to assume that the rate of recruit survival and the piece growth rate are related (e.g. when the stock biomass is low, food is relatively abundant and cannibalism is reduced), therefore:

$$\text{Recruits}_i = a(1 - e^{-bX})(1 - gX_i) \tag{168}$$

Recruits_i = point i recruits (tonnes/metre)

and the biomass at point i is described by:

$$X_{(t+1)i} = X_i + [a(1 - e^{-bX}) + rX_i](1 - gX_i) - H_i/\delta \tag{169}$$

X_i = point i biomass (tonnes/metre)
H_i = point i harvest (tonnes/metre)
a = .10
b = .00001
g = .50
r = .15

When there is no fishing then an equilibrium will form at:

---

[113] Storebakken and Austreng (1987a and 1987b) found that (for salmonids) the relationship between feed availability and the piece growth rate is significantly nonlinear.

$$X_i = 1/g \qquad (170)$$

When the parameter values given for eqn (169) are substituted into eqn (170) the mean biomass in this unfished fishery is 2.0 tonnes in each one metre column, in the 100 km fishery, for a total unfished biomass of 200,000 tonnes.

If the fishery is either an open access fishery or has ITQs, the cost of fishing can be described by eqn (127):

$$C = cE \qquad (171)$$

$$c = 912.669$$

Equation (3) can still be used, but the catchability coefficient has to be re-scaled to reflect the use of X_i in the place of X.

$$H_i = \delta q E_i X_i \qquad (172)$$

$$q = q^{*}100{,}000 = 2.0 \text{ and is constant}$$

7.6.1.1 A ONE-DIMENSIONAL OPEN ACCESS FISHERY

Under conditions of open access, the equilibrium biomass (at any given point along the fishery line) is defined by multiplying the LHS of eqn (172) by the LHS of eqn (163) and setting that result equal to the LHS of eqn (127):

$$\bar{X}_i = \min\{c/[\delta q(P - sK_i - t_r)],\ 1/g\} \qquad (173)$$

$$i \leq 100{,}000 \text{ meters}$$

The equilibrium biomass of the entire stock is found by integrating eqn (173) over the length of the active fishery—at high transportation costs (s) not all of the potential fishery (100,000 kilometres) will be fished. The active zone in the fishery can be defined by setting eqn (170) equal to eqn (173) and reorganizing the result to:

$$K_{max} = \min\{[P - cg/(\delta q) - t_r]/s,\ 100{,}000\} \qquad (174)$$

The density in the inactive (not fished) zone is defined by eqn (170).

$$X = [c/(s\delta q)](\int_{0}^{K_{max}} ln[P - sK_i - t_r]) + (100{,}000 - K_{max})/g \qquad (175)$$

$$\bar{X} = [c/(s\delta q)][ln(P - s0 - t_r) - ln(P - sK_{max} - t_r) \qquad (175a)$$

$$\bar{X} = [c/(s\delta q)]ln[(P - t_r)/(P - sK_{max} - t_r)] \qquad (175b)$$

If the parameter values set for this example are substituted into eqn (175a), the result is:

$$\bar{X} = 57{,}378.28 \text{ tonnes} \qquad (175c)$$

If the parameter values set for this example are substituted into eqn (174), the result is:

$$K_{max} = \min\{114319,\ 100000\} = 100{,}000 \qquad (175d)$$

Based on eqn (169) the equilibrium harvest is defined by:

$$\bar{H}_i = \delta[a(1 - e^{-bX}) + rX_i](1 - gX_i) \qquad (176)$$

When the RHS of eqn (173) is substituted into eqn (176) the result is:

$$\bar{H}_i = \delta[a(1 - e^{-bX}) + (rc/\delta q)/(P - sK_i - t_r)]$$
$$(1 - gc/[\delta q(P - sK_i - t_r)]) \qquad (177)$$

Equation (177) defines the equilibrium harvest at point i. The fishing effort associated with that harvest can be defined by reorganizing eqn (172) to:

$$\bar{E}_i = H_i/(\delta q X_i) \qquad (178)$$

and substituting in the values produced by eqns (173) and (177). Table 7-5 and Figure 7-7 show how the local variables $\bar{P}_i$, $\bar{X}_i$, $\bar{H}_i$ and $\bar{E}_i$ vary as the distance from the home port (e.g. K_i equals nil) is increased. In Figure 7-7 as the distance from home port increases P_i decreases at a constant rate, X_i increases exponentially until the unfished biomass of 2 tonnes/metre is reached and E_i decreases slowly at first and then decreases at an increasing rate. The effect of distance on H_i is more complex: As the distance to home port increases at first the increased stock density (needed to offset the higher transportation cost of sK_i) leads to a higher H_i, even though E_i is decreasing. As X_i increases, the effect slows until, eventually, the H_i that is sustainable by the X_i is less than the previous H_i and the local harvest decreases exponentially.

The equilibrium harvest can be defined for the fishery as a whole by expanding eqn (176) to:

$$\bar{H}_i = a\delta(1-e^{-bX}) - ag\delta X_i(1 - e^{-bX}) + r\delta X_i - rg\delta X_i^2 \tag{176a}$$

and integrating that result over $0 \le i \le K_{max}$ to produce:

$$\begin{aligned} H = \; & a\delta(1 - e^{-bX})(K_{max} - gX) + r\delta X \\ & - rg(c/q)^2 K_{max}/[\delta(P-t_r)(P-sK_{max}-t_r)] \end{aligned} \tag{179}$$

The local fishing effort can be defined by substituting the RHS of eqn (176a) into eqn (178) and simplifying the result to:

$$E_i = a(1-e^{-bX})/(qX_i) - ag(1-e^{-bX})/q + r/q - rX_i/q \tag{180}$$

When eqn (180) is integrated over $0 \le i \le K_{max}$ the result is:

$$\begin{aligned} E = \; & a\delta K_{max}(P-.5sK_{max}-t_r)(1-e^{-bX})/c \\ & - agK_{max}(1-e^{-bX})/q + rg(K_{max} - X)/q \end{aligned} \tag{181}$$

The gross fishing revenue (R_c) can be defined by multiplying eqn (179) by the price per tonne:

$$R_c = PH \tag{182}$$

The total cost of fishing effort is defined by eqn (171)

$$C = cE \tag{171}$$

$$c = 912.669$$

and the cost of transporting fish is defined by subtracting eqn (171) from eqn (182):[114]

$$\text{Transportation Costs} = H(P\text{-}tr) - cE \tag{183}$$

In terms of the revenue/effort plane, Figure 7-8, eqns (182) and (181) produce a single equilibrium point. The curve in Figure 7-8 was generated by varying the unit fishing costs (c). This curve looks like a fisheries yield/effort curve and a yield/effort relation can be fitted to the data. When regression analysis is used to fit the Schaefer logistic yield curve to the data in Table 7-6 the result is:

$$R_t\hat{} = \underset{(30.393)}{4{,}591.3}E(1 - \underset{(268.14)}{.000075462}E) \tag{184}$$

$R\hat{}_t$ = estimated revenue (\$,000s)
$q\delta P/a$ = 4,591.3
q/r = .000075462

R^2 = 99.98 %
LM Statistic = 1.0889
Rho = 1.0432 (35.364)

If the Schaefer form was appropriate for the curve in Figure 7-8, then the $F_{0.1}$ effort is 5,963.3 units:

$$E_{F0.1} = .45r/q \tag{96}$$

which generates \$15,058,529 in revenue (when substituted back into eqn (184)). Based on Table 7-6, if the cost of fishing effort is \$912.669,

---

[114] This assertion can be proven by reorganizing eqn (173) to: $sK_i = (P\text{-}t_r) - c/(\delta_i X_i)$ then multiply that result by the local harvest: $sK_i H_i = (P\text{-}t_r)H_i - cH_i/(\delta_i X_i)$ then substituting in the RHS of eqn (178) to produce: $sK_i H_i = (P\text{-}t_r)H_i - cE_i$ which, if integrated over $0 \leq i \leq K_{max}$, resolves to eqn (183).

This result is consistent with the conventional wisdom that resource rents are dissipated in open access fisheries. Specifically, if all the resource rent is dissipated in an open access fishery as a whole and if fishermen rationally allocate their effort across that fishery then (in the long run) there can be no resource rent at any local in that fishery.

fishery managers will observe an average cost of fishing (effort plus transportation costs) of $1,510.38/unit of effort (912.669 + 5372300 /8988.13 units of effort). Thus based the Schaefer curve in Figure 7-6 (at $F_{0.1}$) the fishery should generate a rent of $6,051,680 (15058529 - 5963.3*1510.38).

The MEY, generated from the Figure 7-8, information is at 4,446.2 units of effort:

$$E_{MEY} = .5r[1 - (\text{unit cost of effort})\alpha/(q\delta P)]/q \quad (91)$$

$$E_{MEY} = .5[1 - 1510.38/4,591.3]/.000075462 \quad (91a)$$

generating $13,564,605 in revenue and a rent of $6,849,153 (13564605 - 4446.2*1510.38). Based on this information the managers of the fishery (or their political masters) might seek to create this MEY by applying a royalty of $1,009.86/tonne (2000*6849153/13564605). There is a problem, however—even though the curve in Figure 7-8 look like a Schaefer yield/effort curve, the actual yield relation is more complicated (see eqns (179) and (181)) and is influenced by royalty taxes. The effect on the fishery of various levels of royalty taxes/(subsidies) is examined in Table 7-7 and illustrated in Figure 7-9. In this example, if a royalty of $1,009.86/tonne is applied to the fishery, the equilibrium effort is considerably lower than what eqns (184) and (91) might lead a policy maker to believe (2,888.4 units instead of 4,446.2 units). Also, the total royalty ($3.923 million) is considerably less than the forecast instead ($6.849 million). Table 7-7 shows that when distances are an important factor in a fishery, royalty taxes are not neutral—as the royalty is increased, the actively fished portion of the fishery tends to decline (when the royalty is $1,009.86 per tonne, only 47 percent of the fishery is fished). If the aim of the fishery managers is to maximize the royalty collected, per Table 7-7, a royalty rate of \$867.53 is optimal—an equilibrium forms at 3,943.8 units of fishing effort and the total royalty is \$4.077 million.

7.6.1.2 A ONE-DIMENSIONAL IQ FISHERY

An important implicit assumption in most IQ models is an absence of intrastock locational effects. It is reasonable to assume that each owner of an IQ will seek to maximize the returns on that IQ by fishing where the contribution margin on their fishing effort is highest.

$$\pi_i = P_iH_i - cE_i \tag{185}$$

When the RHS of eqns (163) and (172) are substituted into eqn (185):

$$\pi_i = [(P-sK_i-t_r)\delta qX_i - c]E_i \tag{185a}$$

The contribution margin per unit effort for point i is defined by:

$$\pi_i/E_i = CM_i = (P-sK_i-t_r)\delta qX_i - c \tag{186}$$

This concentration of effort at the high contribution point draws down the biomass at that point, which reduces the contribution generated at that point, which causes the effort to diffuse out into the next richest locations, which draws down the biomass in those locations, which reduces their contribution margins and causes further diffusion of the effort until the contribution margin (on fishing effort) is equalized across the fished zone of the fishery.

If the contribution margins for points i and $_o$ are set equal, the result can be reorganized to give the biomass at point i as a function of the biomass at point $_o$:

$$CM_i = CM_o = (P-t_r)\delta qX_o - c \tag{186a}$$

i = area i
q = a constant, so q_o is q
$_o$ = the south end of the fishery

$$X_i = X_o(P-t_r)/(P-sK_i-t_r) \qquad (187)$$

At high transportation costs all of the fishery (100,000 metres) may not be actively fished. The active zone, in the fishery, can be defined by setting eqn (170) equal to eqn (187) and reorganizing that result to:

$$K_{max} = \min\{(P-t_r)(1-gX_o)/s,\ 100{,}000\} \qquad (188)$$

The inactive zone is the region from K_{max} to 100,000 metres, and the density in that unfished zone is defined by eqn (170).

The equilibrium biomass of the entire stock is found by integrating eqn (187) over the active portion of the fishery, integrating eqn (170) over the inactive portion of the fishery and adding the results:

$$\bar{X} = (100{,}000 - K_{max})/g - (X_o/s)(P-t_r)\Big(\Big[_{0}^{K_{max}}\ ln[P-sK_i-t_r]\Big) \qquad (189)$$

$$X = (100{,}000-K_{max})/g + (X_o/s)(P-t_r)ln[(P-t_r)/(P-sK_{max}-t_r)] \qquad (190)$$

The total biomass in the inactive and active zones of the fishery are defined (respectively) by the first and the second terms in the RHS of eqn (190). Thus:

$$\bar{X}_A = (X_o/s)(P-t_r)ln[(P-t_r)/(P-sK_{max}-t_r)] \qquad (191)$$

X_A = sustainable biomass in the part of the fishery that is actively fished

The sustainable harvest at any given point in the fishery can be defined by eqn (176a).[115] If the RHS of eqn (187) is substituted into eqn (176a) the result is:

---

[115] Equations (176) and (176a) contain only biological information and are independent of the economic and/or technological aspects of the fishery.

$$\bar{H}_i = a\delta(1 - e^{-bX}) - a\delta g(1 - e^{-bX})X_o(P-t_r)/(P-sK_i-t_r) + r\delta X_o(P-t_r)/(P-sK_i-t_r) - r\delta X_o^2(P-t_r)^2(P-sK_i-t_r)^{-2} \tag{192}$$

If eqn (192) is integrated over $0 \leq i \leq K_{max}$, in a fishery with a TAC, the result is both the harvest and the TAC:

$$H = TAC = a\delta(1 - e^{-bX})(K_{max} - gX_A) + r\delta X_A - rg\delta X_o^2(P-t_r)K_{max}/(P-sK_{max}-t_r) \tag{193}$$

Equation (180) defines the fishing effort at a given point in the fishery. This equation can be used in either an open access fishery or an IQ fishery because it is derived from eqns (176a), (176), (178) and (169) which contain only biological and/or technological information—the management structure of the fishery is not subsumed in any part of that relation.

$$E_i = a(1-e^{-bX})/(qX_i) - ag(1-e^{-bX})/q + r/q - rgX_i/q \tag{180}$$

If the RHS of eqn (187) is substituted into eqn (180), the result can be integrated over $0 \leq i \leq K_{max}$, to produce:

$$E = aK_{max}(P-.5sK_{max}-t_r)(1-e^{-bX})/[qX_o(P-t_r)] - agK_{max}(1-e^{-bX})/q + r(K_{max} - gX_A)/q \tag{194}$$

The key variables of K_{max}, X, TAC, and E are defined, respectively, by eqns (188), (190), (193) and (194). When all of the fishery is actively fished then eqn (188) is at its limiting value. If because of a high s value, only part of the fishery is actively fished then eqn (188) is (by definition) below its limiting value.

The above system of equations can be implicitly solved for the X_o which generates a given TAC. The equation systems can then be used to explicitly define the TAC that is sustained by a give X_o. It is, also, possible to work backwards (graphically) to find the X_o that generates a desired TAC. Per eqn (185a), the *fishing effort* contribution margin is constant throughout the fishery.

$$CM_i = CM_o = (P-t_r)\delta q X_o - c \qquad (186a)$$

Therefore, the total profit in the fishery is defined by:

$$\pi = CM_o E \qquad (195)$$

Also, the minimum value of X_o can be defined by setting eqn (185a) to nil and reorganizing the result to:

$$X_o = c/[\delta q(P-t_r)] \qquad (196)$$

Table 7-8 and Figure 7-10, show how an IQ affects behaviour in a single-spacial-dimension fishery. In the example, the resource rent is maximized at $5.716 million by a TAC of 6,192 tonnes (an X_o of .76168) and a fishing effort of 3,748.7 units. This is a considerable improvement over the maximum resource rent produced by an open access fishery controlled by a royalty ($4.077 million per Table 7-7). However, while the IQ fishery conserves the resource ground rent (i.e. resource rent available at any actively fished point in a fishery) it dissipates all of the resource locational rent (i.e. resource rent arising because of a location specific factor). As the next subsection shows, the efforts of a sole owner to maximize the total resource rent (ground rent plus locational rent) result in a much different fishery than a IQ fishery.

7.6.1.3 A ONE-DIMENSIONAL SOLE-OWNER FISHERY

A fishery sole owner wants to maximize the total sustainable resource rent of the fishery.

$$\pi = R - cE \qquad (197)$$

R = the fishery total revenue

If eqn (197) is defined as the profit for point i and the RHS of eqns (178) and (176) are substituted into it, the result is:

$$\pi_i = [P_i - c/(\delta q X_i)][\delta(a(1-e^{-bX})+rX_i)(1-gX_i)] \tag{198}$$

Mathematically, to maximize the total resource rent at each point in a fishery, eqn (198) should be differentiated with respect to the local biomass and that differential should be set equal to nil:

$$d\pi_i/dX_i = r\delta P_i + ca(1-e^{-bX})/(qX_i^2) - ag\delta(1-e^{-bX})P_i - 2rg\delta P_i X_i + rcg/q = -0- \tag{199}$$

which can be reorganized to the following cubic equation:

$$X_i^3 - .5[1/g - a(1-e^{-bX})/r + c/(q\delta P_i)]X_i^2 - .5ca(1-e^{-bX})/(rg\delta P_i q) = -0- \tag{200}$$

Some useful information can be inferred from eqn (200), when it is reorganized to:

$$P_i = -c[a(1-e^{-bX})X_i^{-2} + rg]/[q\delta(r - ag(1-e^{-bX}) - 2rgX_i)] \tag{201}$$

When the RHS of eqn (163) is substituted into eqn (201) the result can be restated as:

$$K_i = (P - t_r)/s + c[a(1-e^{-bX})X_i^{-2} + rg] /[sq\delta(r - ag(1-e^{-bX}) - 2rgX_i)] \tag{202}$$

At the boundary between he fished and unfished zones, in the fishery, the local biomass density, by definition, must be:

$$X_{Kmax} = 1/g \tag{203}$$

When the RHS of eqn (203) is substituted into eqn (202) the result can be simplified to:

$$Kmax = [P - t_r - cg/(\delta q)]/s \tag{204}$$

which reconciles to eqn (173).

Table 7-9 was created by setting the distance from the home port in the first column and using eqn (202) in an iterative process to set the X_i associated with K_i. Equations (163), (176) and (178) were used to define P_i, H_i and E_i. The total biomass, harvest, effort revenues, costs in the fishery was estimated by using a weighted variant of the Trapezoidal rule (Press, et al, 1987, p.105). Key variables from Table 7-9 are shown in Table 7-10 in the form of index values and are graphed, as a function of distance, in Figure 7-11.

The total biomass is a variable in eqn (202) but is not available until the calculations are complete. The problem was solved by using a guesstimate of the total biomass as a *seed* biomass value to start the calculations, then substituting the resulting estimated total biomass figure for the seed value and recalculating. This process was continued until the *seed* total biomass resulted in an estimated total biomass that was within 1 kg of the seed value.

The following contrast between the resource rent maximizing conditions in the sole-owner and IQ fisheries, was developed from Tables 7-8 and 7-9.

ITEM	RESOURCE RENT MAXIMIZING AMOUNT		PERCENT DIFFERENCE
	IQ FISHERY	SOLE-OWNER FISHERY	
Resource Rent	$5,715,700	$7,921,500	38.6 %
Harvest (tonnes)	6,192	9,886	59.7
Biomass (tonnes)	132,932	119,450	(10.1)
Effort (units)	3,749	5,289	41.6

The reason why resource rent is still dissipated in an IQ fishery is made apparent by the profit-to-location curve, in Figure 7-11. The resource rent at the edge of an active fishery should be thought of as the *fishery resource rent*—it is available at all points in the fishery. The greater amount of resource rent that is potentially available at other locations in the fishery is location-specific and, therefore, should be thought of as the *location resource rent.* An IQ management program conserves the fishery resource rent, but is unable to prevent IQ holders from competing away any location resource rents. In Figure 7-11, the resource rent at 100 km from port is 5.7 percent of the resource rent potential at the port. When IQ holders attempt to acquire this locational resource rent they tend to dissipate it by overfishing the most valuable areas in the fishery and underfishing other areas.

There are mathematical reasons to believe that maximizing the resource rent at each point in the fishery will not necessarily maximize the fishery resource rent. Specifically, recruitment varies with the stock biomass (see eqn (164)) and the stock biomass is the integral of all the point biomasses. As mentioned previously, the explicit consideration of all the net gains and losses in the fishery from changes to the standing stock (Xi) at all points, in the fishery, is not a viable way to solve the sole owner's maximand. A more workable approach is to subsume all of these implicit opportunity costs into a single explicit *shadow value* and to assume that this *shadow value* is constant, across the entire fishery.[116] Under this approach eqn (199) becomes:

$$\text{lambda} + d\pi_i/dX_i = r\delta P_i + ca(1-e^{-bX})/(qX_i^2) - ag\delta(1-e^{-bX})P_i$$

$$- 2rg\delta P_i X_i + rcg/q + \text{lambda} = -0- \qquad (205)$$

---

[116] Clark (1976, p.104) noted that "the term *shadow price* refers to the fact that the asset's value is not its direct sale value but the value imputed from its future productivity".

lambda = opportunity cost to the total fishery of drawing down the biomass at point i.

which can be reorganized to:

$$P_i = -c[a(1-e^{-bX})X_i^{-2} + rg + q(\mathrm{lambda})/c]/[q\delta(r - ag(1-e^{-bX}) - 2rgX_i] \tag{206}$$

When the RHS of eqn (163) is substituted into eqn (206) the result can be restated as:

$$K_i = (P - t_r)/s + c[a(1-e^{-bX})X_i^{-2} + rg + q(\mathrm{lambda})/c]/[sq\delta(r - ag(1-e^{-bX}) - 2rgX_i] \tag{207}$$

When the RHS of eqn (203) is substituted into eqn (207) the result is:

$$K_{max} = (P-t_r)/s - (cg + q(\mathrm{lambda})/[r + ag(1-e^{-bX})])/(s\delta q) \tag{208}$$

When eqn (208) is differentiated with respect to lambda, the result is

$$dK_{max}/d\mathrm{lambda} = -q(\mathrm{lambda})/(s\delta q[r+ag(1-e^{-bX})]) < -0- \tag{209}$$

shows that size of the fished zone varies inversely with lambda. Thus, the maximum value of lambda occurs when eqn (208) is set to nil. Under those conditions no fishing occurs, the biomass rises to its maximum value of:

$$X = 100000/g \tag{210}$$

and eqn (208) can be restated as:

$$\mathrm{lambda}_{max} = [\delta(P-t_r) - cg/q][r + ag(1-e^{-b100000/g})] \tag{211}$$

Table 7-11 was created by setting the distance from the home port in the first column and using eqn (207) in an iterative process to set the X_i associated with K_i. Equations (163), (176) and (178) were used to define P_i, H_i and E_i. The total biomass, harvest, effort revenues, costs in the fishery was estimated by using a weighted variant of the Trapezoidal rule (Press, et al, 1987, p.105). Key variables from Table

7-11 are shown in the bottom half of the table as index values and are graphed, as a function of lambda, in Figure 7-12. The resource rent is maximzed at $7.944 million when lambda is 8. This is a minor but significant improvement (.28 percent) over the $7.922 million of resource rent generated if lambda is set at nil (e.g. with different parameters and/or a smaller fishery the improvement could be much larger). Table 7-12 restates the Table 7-10 index, except the indexed results are for when lambda is equal to 8.

7.6.1.4 OPTIMAL TAXES, SUBSIDIES AND MANAGEMENT IN A ONE-DIMENSIONAL FISHERY

As discussed in section 2, allocating fisheries to a sole private owner is not politically viable, as a fisheries policy. As a result, governments are interested in finding policy instruments (i.e. taxes, subsidies, etc.) that can make the other forms of fisheries management as efficient as management by a sole owner.

Table 7-13, an open access situation, was created by using eqns (175b), (179) and (181) along with the following reorganization of eqn (174):

$$s^* = [P - tr - c^*g/(\delta q)]/K_{max} \tag{212}$$

s^* = the cost of transporting fish that will generate a fished zone of 0 to K_{max} metres. When a subsidy is applied, the value of s^* is substituted for the value of s in the analysis—the fishermen see s^* as the cost of transporting fish.

to define the key variables for a range royalty levels. The following equations were developed to define other key variables:

$$s_{sub} = (1 - s^*/s) \tag{213}$$

s_{sub} = subsidy (as a percent of s) required to reduce the cost of transporting from s to s^*.

$$\text{Total Subsidy} = s_{sub}[(P-tr)H - cE]/[1000(1-s_{sub})] \tag{214}$$

$$\text{Resource Rent} = (tr^*H - s_{sub}[(P-tr)H - cE]/[1000(1-s_{sub})] \tag{215}$$

The fished zone area was varied by altering K_{max}. The highest resource rent was generated by a royalty of $1,372.89/tonne, a transportation subsidy of 77.21 percent (of s) and a K_{max} of 100,000 metres. However, this maximum resource rent of $6,178 million (per Table 7-13) is only 77.8 percent of the $7,944 million generated by the best sole-owner solution (Table 7-11). Figure 7-13 illustrates the key variables of Table 7-13.

Table 7-14, an IQ situation, was created with eqns (186), (186a), (188), (190), (191), (193), (194) and (195), along with the following reorganization of eqn (188):

$$X_o = [1-s100000/(P-t_r)]/g \tag{216}$$

The following equations were developed to define other key variables:

$$s^* = s(1-s_{sub}) \tag{217}$$

$$\text{TCOST} = s_{gross}H = [(P-t_r)H - cE - \pi]/(1-s_{sub}) \tag{218}$$

TCOST = fishery total unsubsidized transportation costs.

$$\text{TRANSPORT}_{sub} = s_{sub}{*}\text{TCOST} \tag{219}$$

TRANSPORT_{sub} = total transportation subsidy

Royalties were found to be neutral in terms of generating net resource rent. In the analysis the royalty was varied from $500/kg to a subsidy of $500/kg—while the net share of the resource rent, between the government and the IQ holders varied, the net amount of net resource rent was unchanged (e.g. the transportation subsidy adjusted to buffer the effects of a royalty/subsidy on the IQ holders). The highest resource rent was generated by a transportation subsidy of 27.31 percent (of *s*) and a K_{max} of 100,000 metres. Please note, this maximum resource rent of $6,178 million (per Table 7-14) is the same maximum resource rent as the open access fishery in Table 7-13. In this model, the maximum amount of resource rent that can be generated by government regulation management of the fishery is less than the maximum amount of rent that can be achieved under sole ownership. This is consistent with the Muse and Schelle (1989, p.109) observation that the harvest rights contained in the individual quotas will not necessarily produce the same results as sole ownership of the stocks. In conditions described in this subsection, even a subsidized IQ fishery does not mimic the sole-owner result. Figure 7-14 illustrates the key variables of Table 7-14.

FIGURE 7-1: ITQ Fishery Revenue and Costs, if Managers are Unaware of a Fall in the Amount of the Harvest Mortality that is Landed

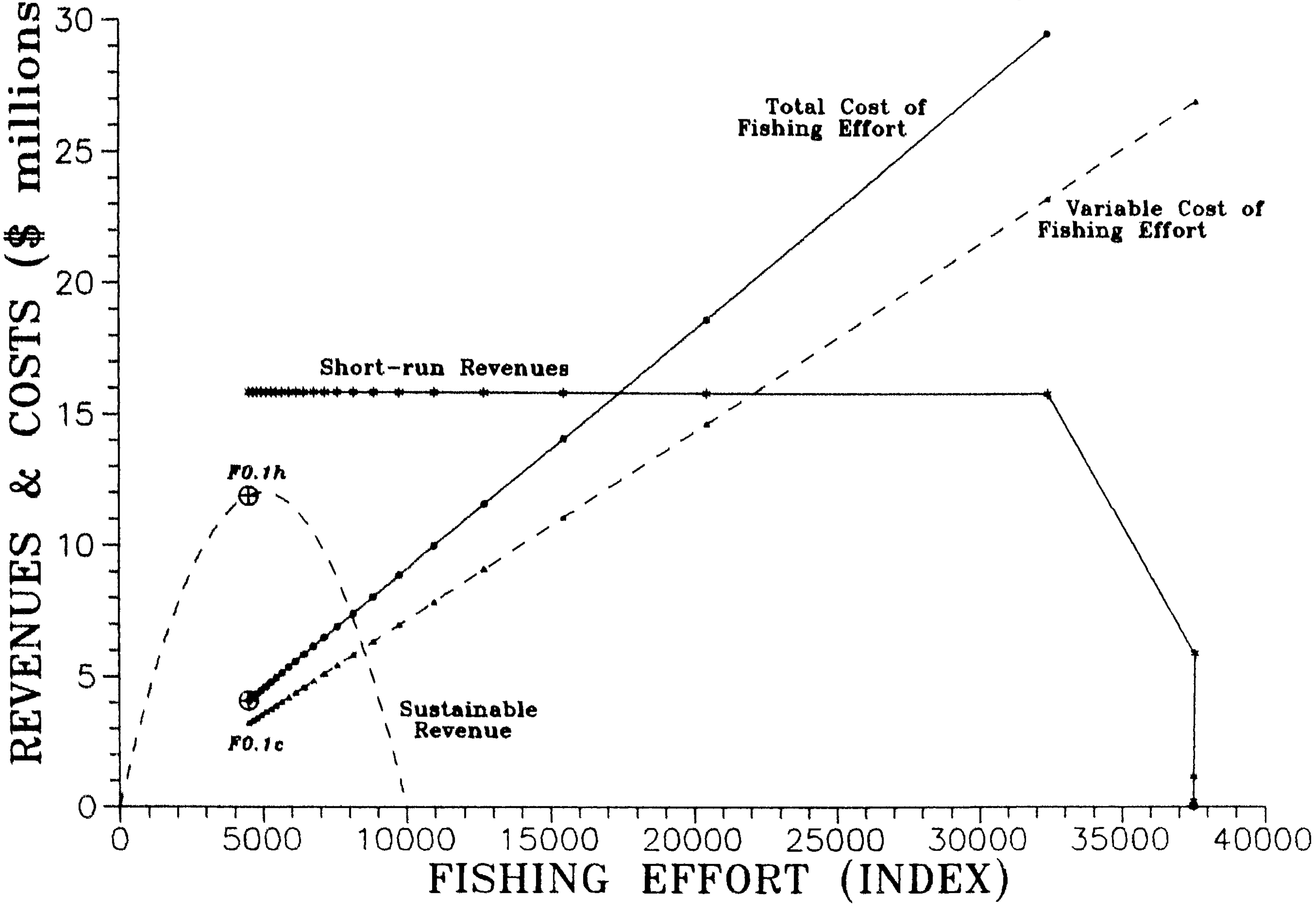


FIGURE 7–2: Index of Changes in Key Variables in the Fishery Depicted in Figure 7–1

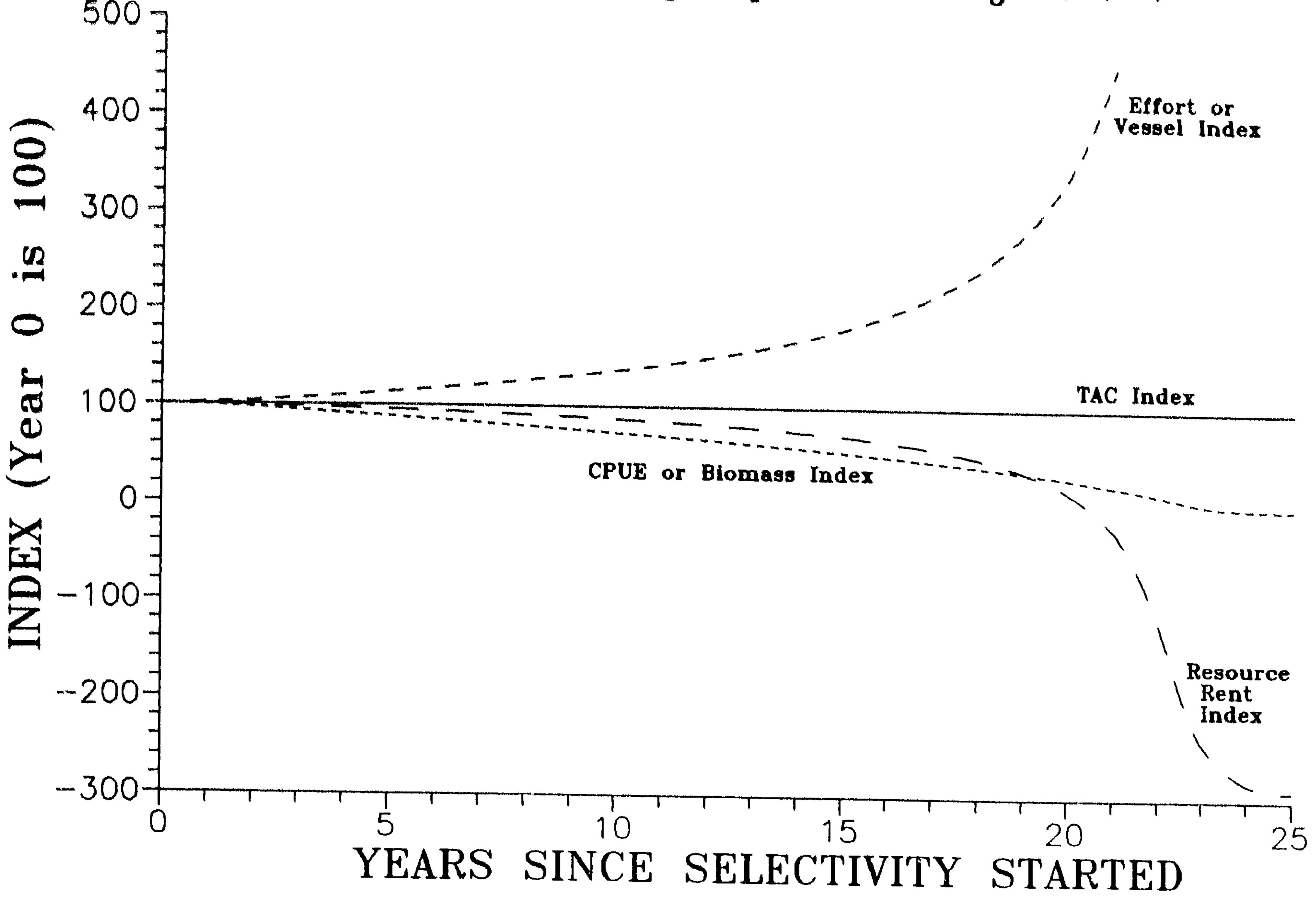


FIGURE 7-3: ITQ Fishery Revenue and Costs, If Managers are Unaware of a Fall in the Growth Rate of the Stock

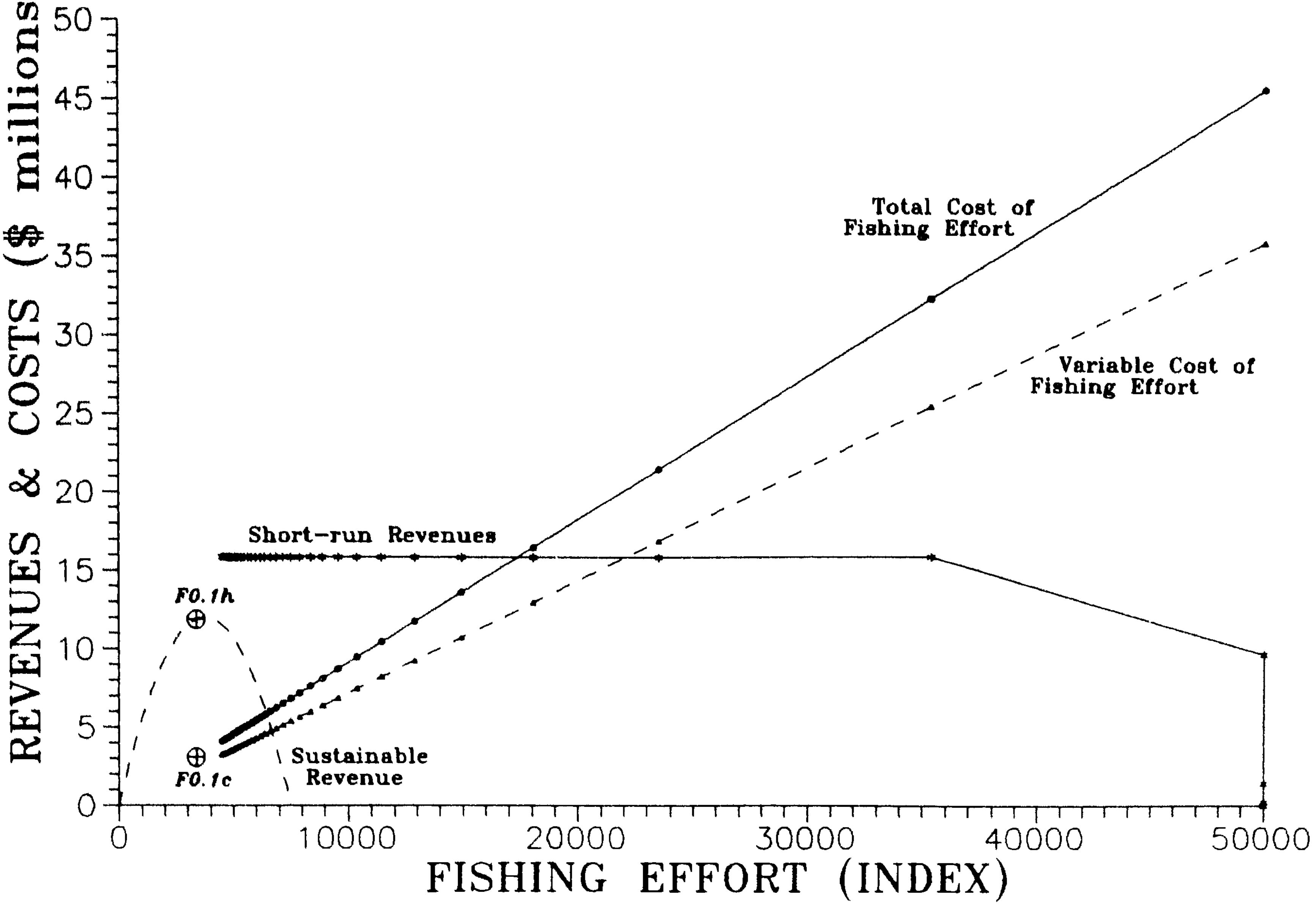


FIGURE 7-4: Index of Changes in Key Variables in the Fishery Depicted in Figure 7-3

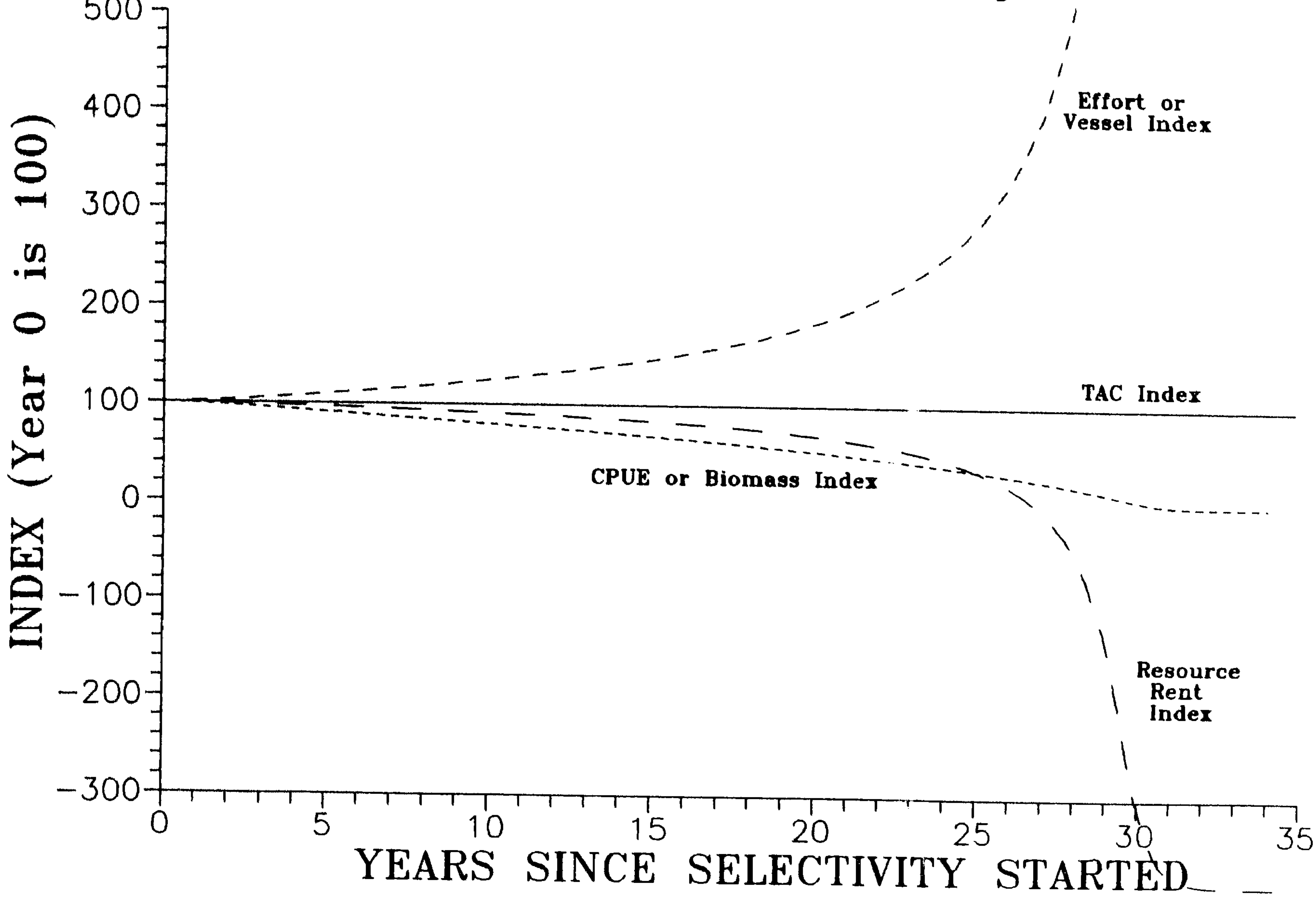


FIGURE 7–5: Revenue and Costs in an ITQ Fishery Encompasing Two Fish Sub–stocks with Different Effort Costs

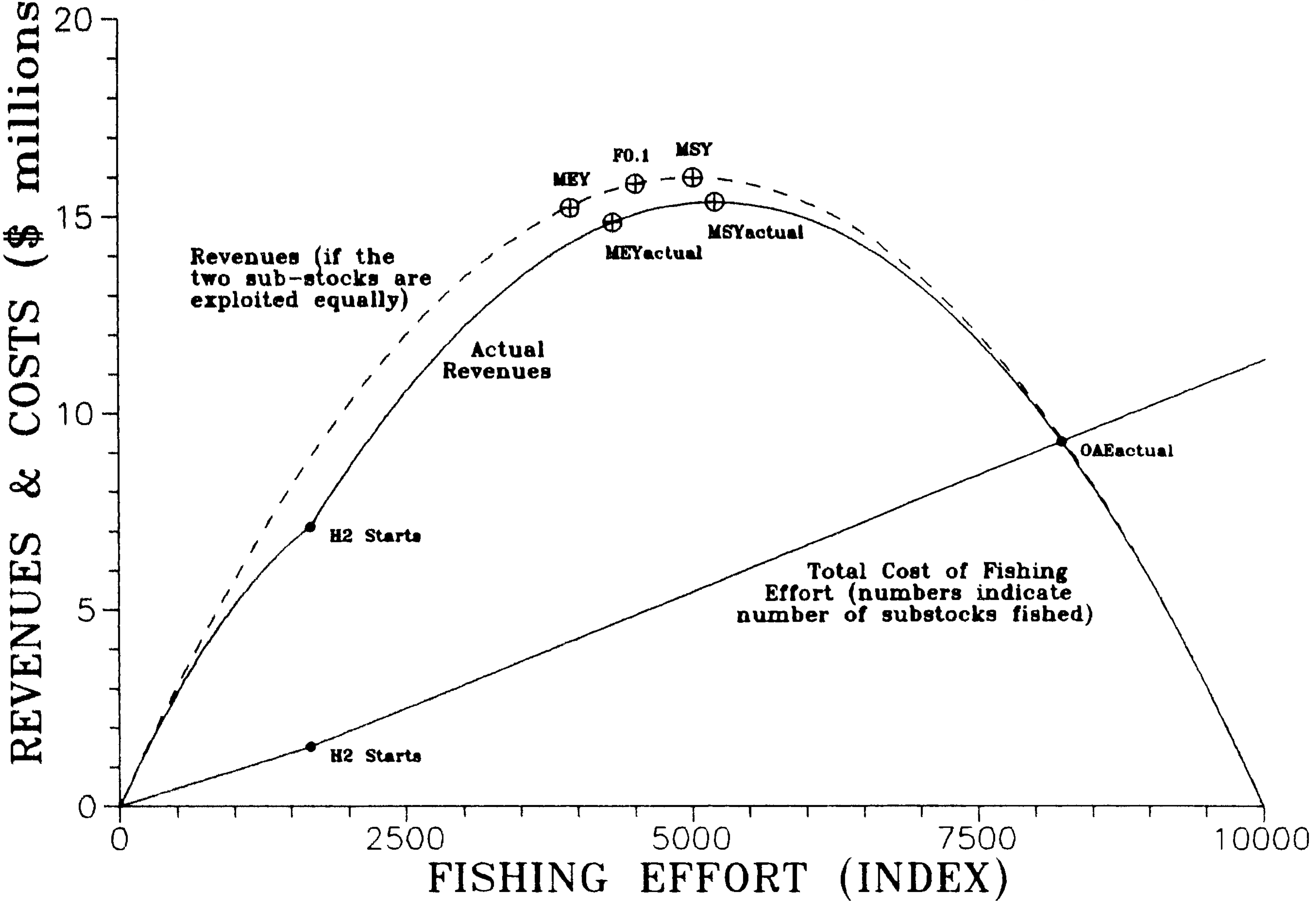


FIGURE 7-6: Phase Plane Diagram for the Fishery System Depicted in Figure 7-5 (for a TAC set at 6,000 tonnes/annum)

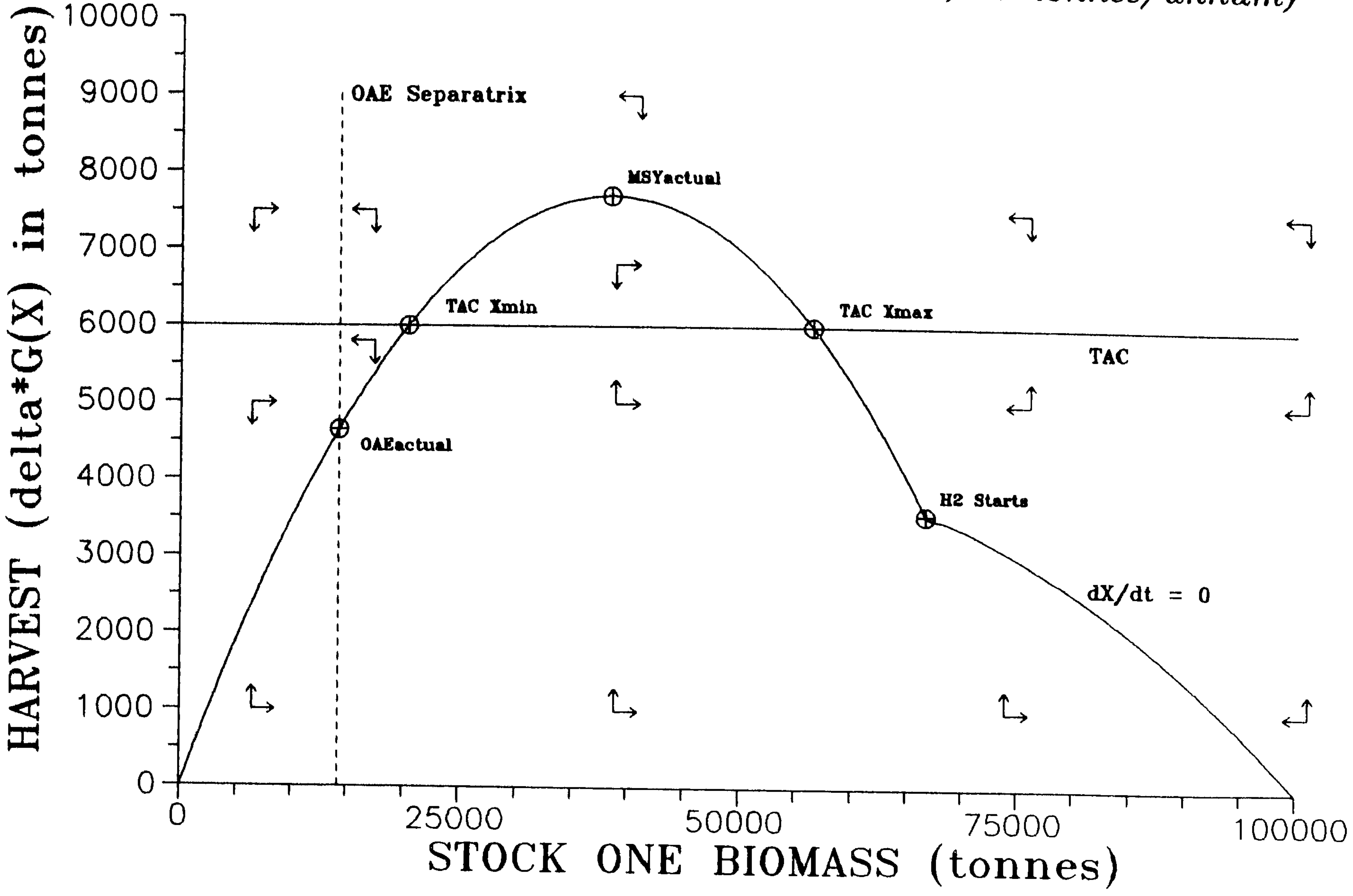


FIGURE 7-7: Index of How the Key Variables in a Fishery with a Single Spacial Dimension Vary with the Distance from Home Port

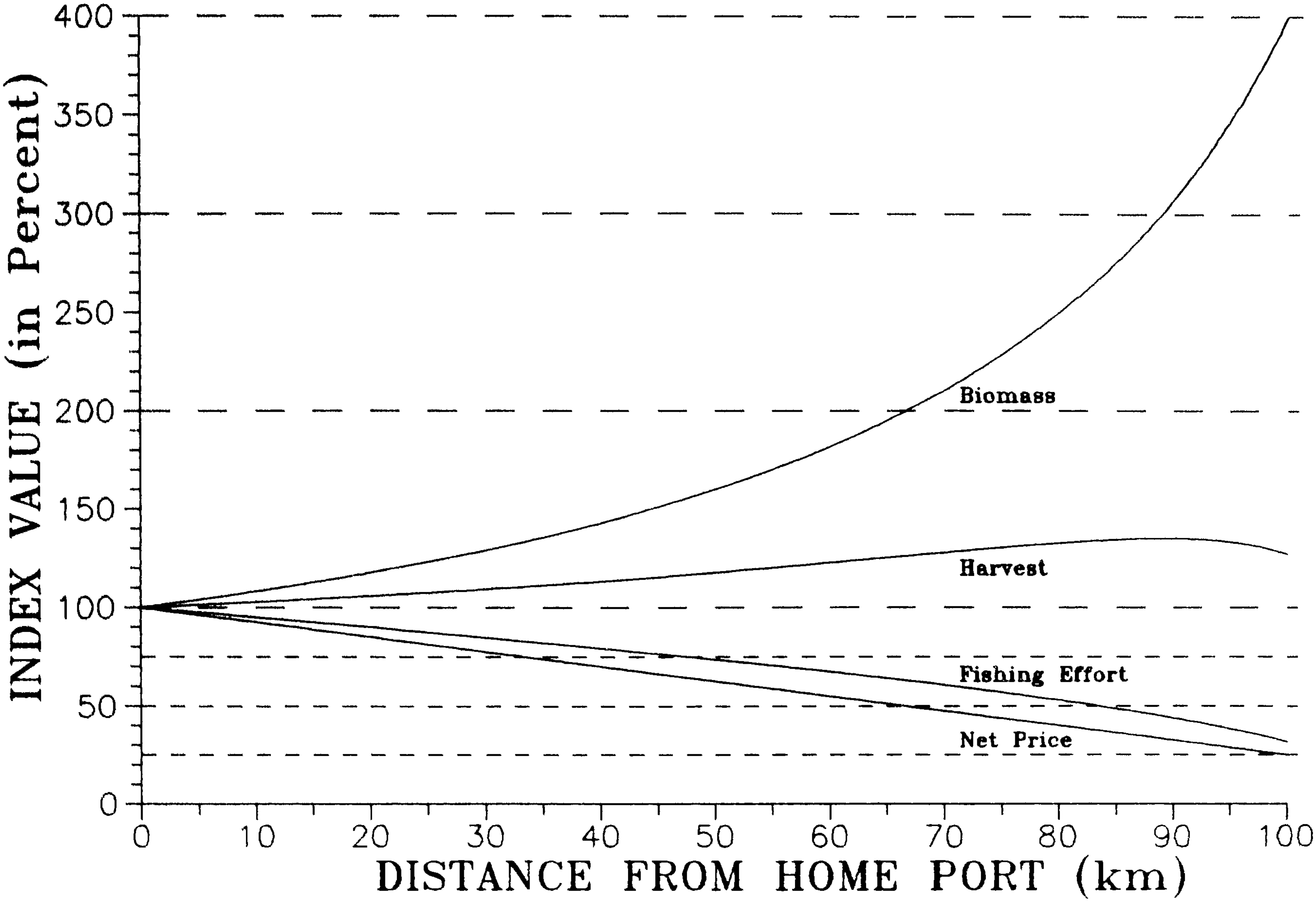


FIGURE 7–8: Equilibirum Revenue and Costs in a One Spacial Dimension Fishery, when the Unit Cost of Fishing Effort is Varied

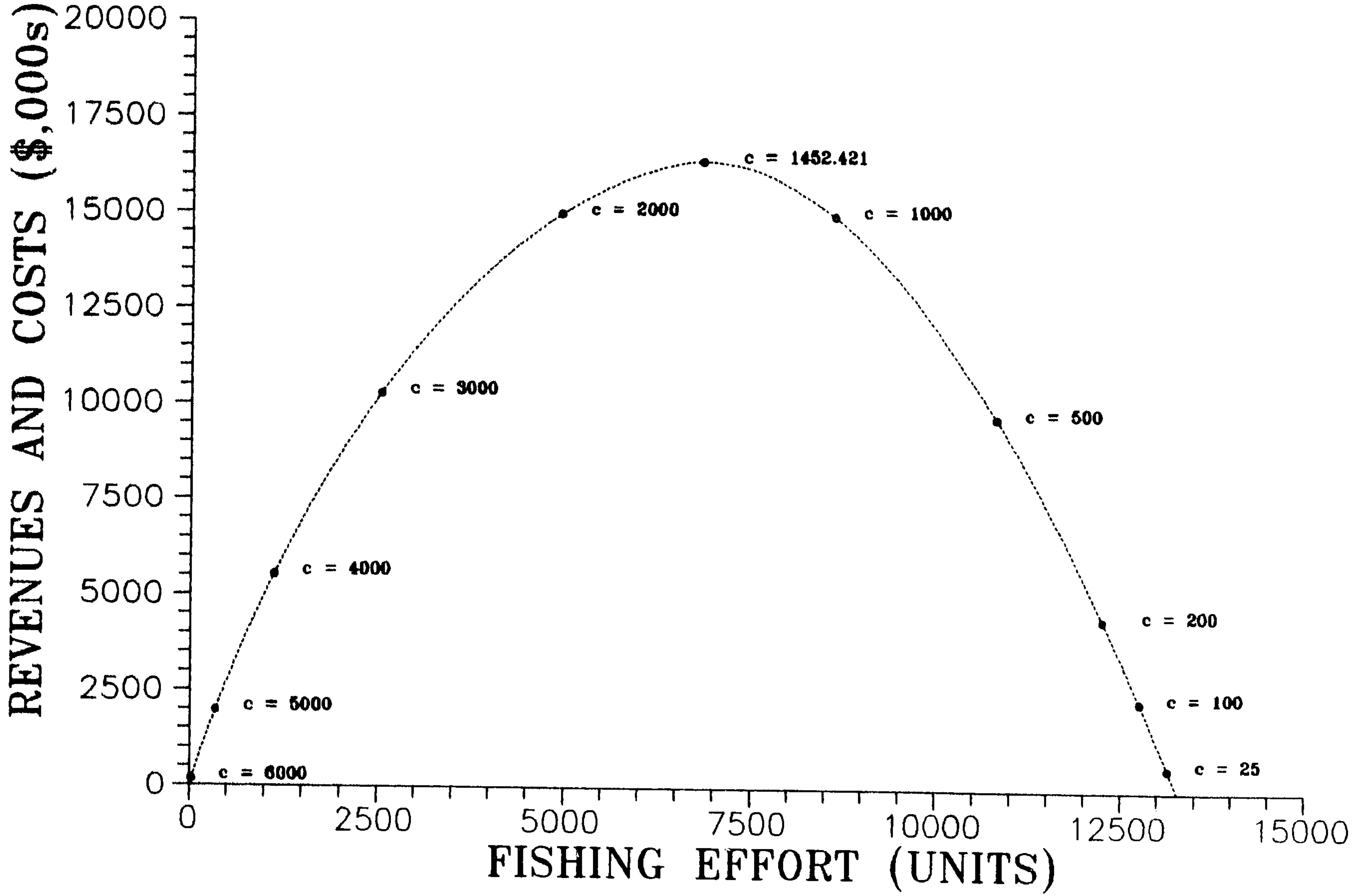


FIGURE 7–9: *Effort, Revenues and Costs in a One Spacial Dimension Fishery as Fishing Effort is Controlled with a Royalty*

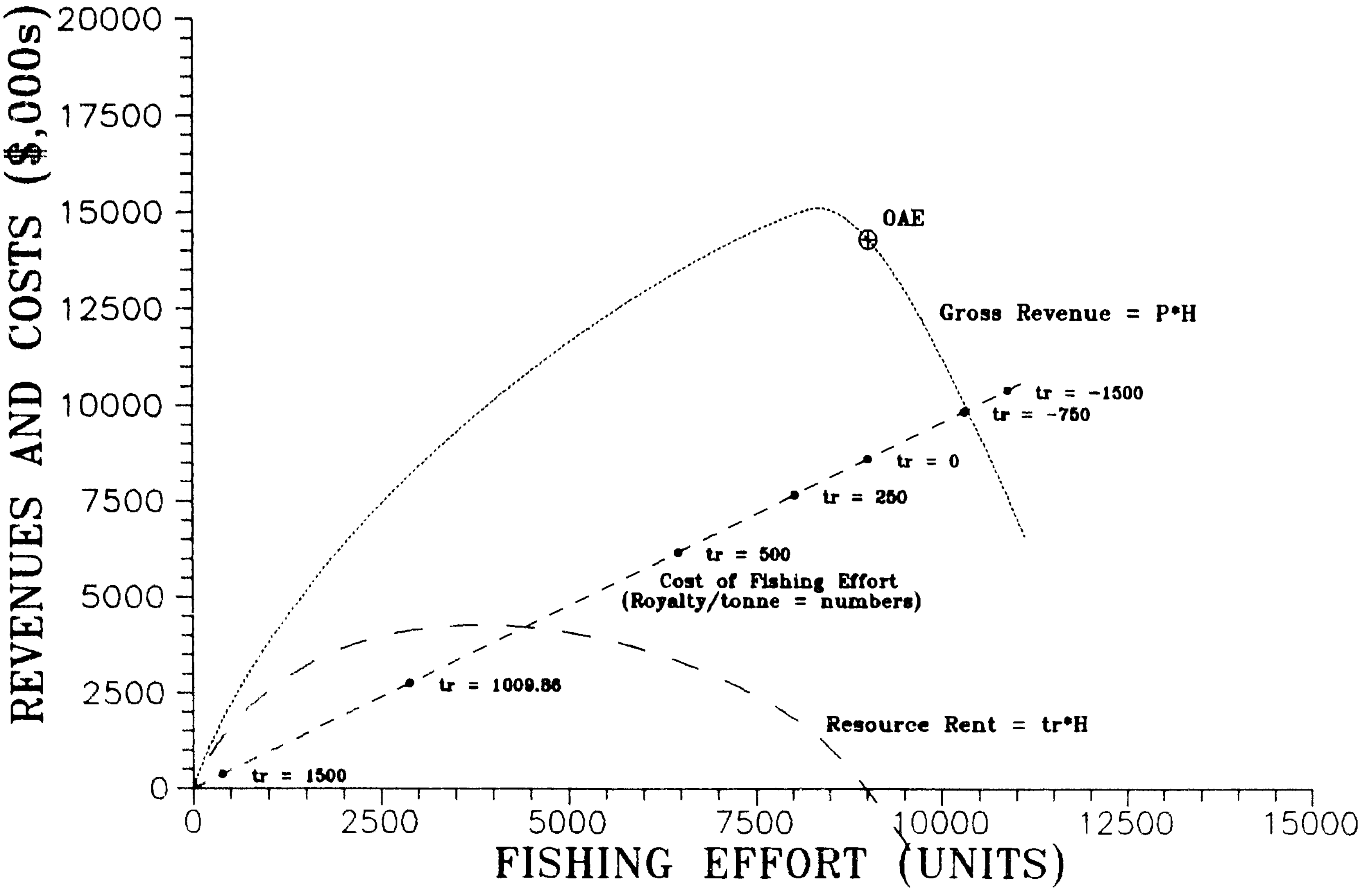


FIGURE 7-10: *Effort, Revenues and Costs in a One Spacial Dimension IQ Fishery with Fishing Effort Controlled by a TAC*

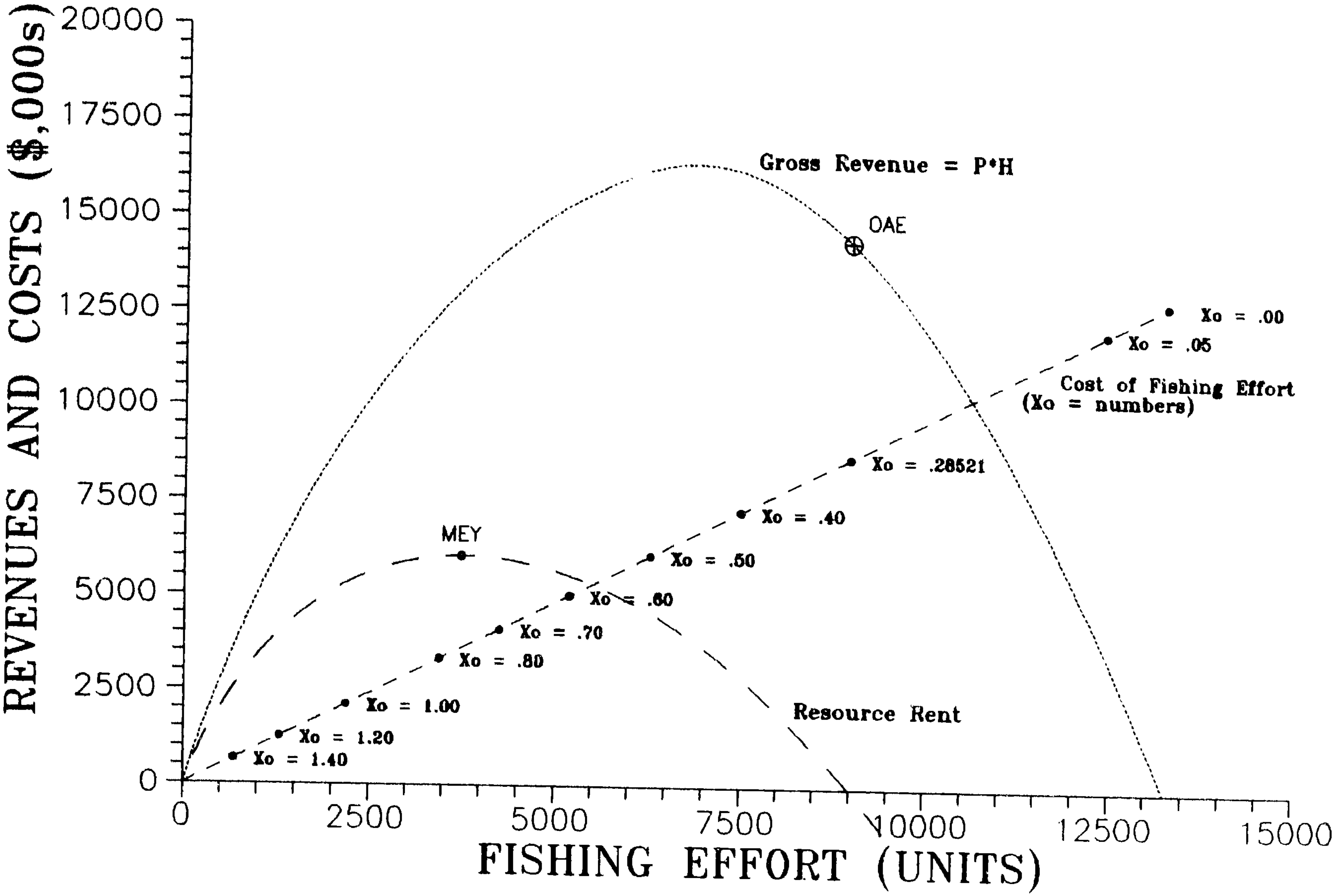


Figure 7-11: Index of How the Key Variables in a Sole Owner Fishery vary with the Distance from Port if Xi is Optimized in Isolation

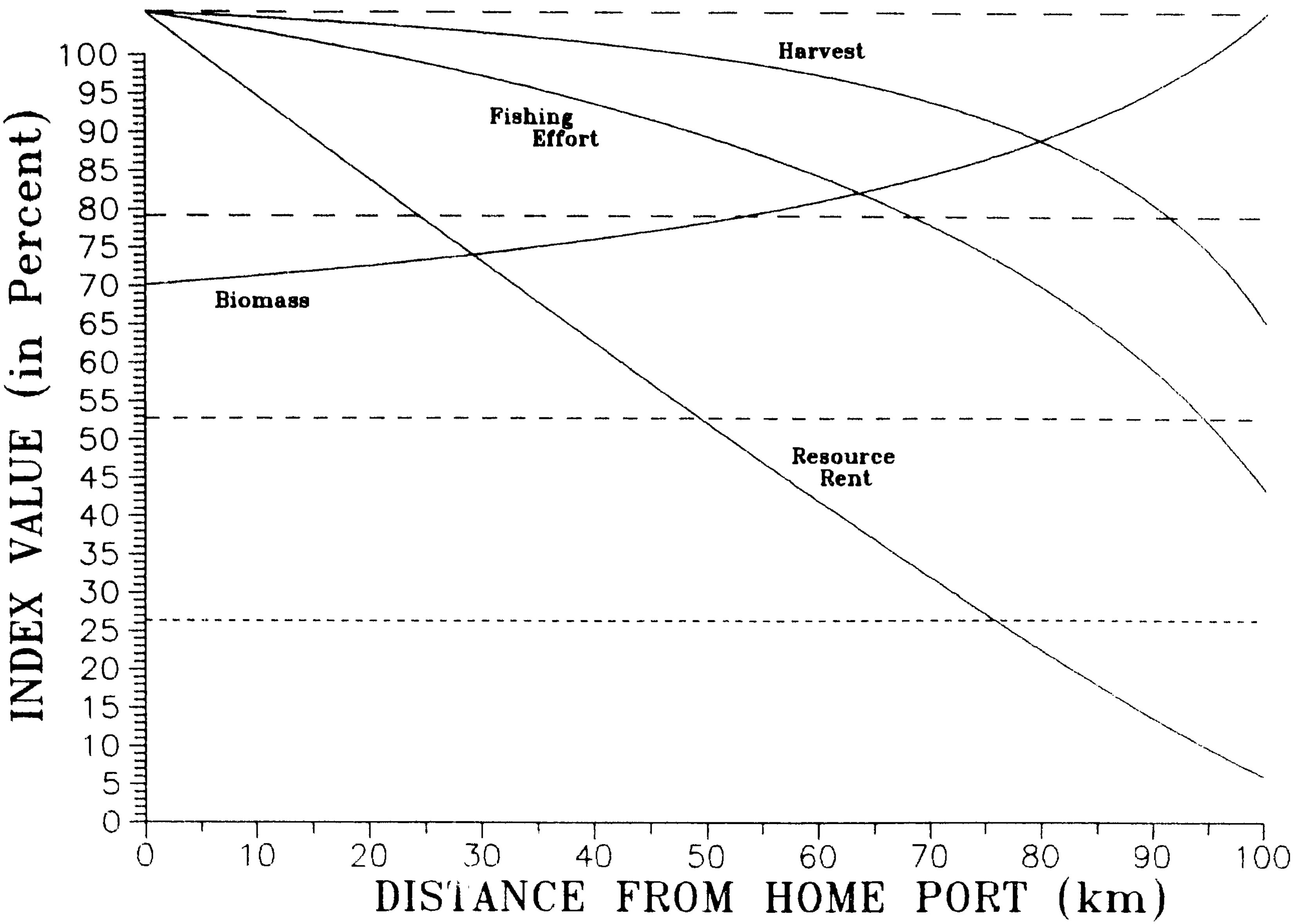


Figure 7–12: *Index of How the Key Variables in a Sole Owner Fishery vary with Changes to the Local Biomass Level Externality (Lambda)*

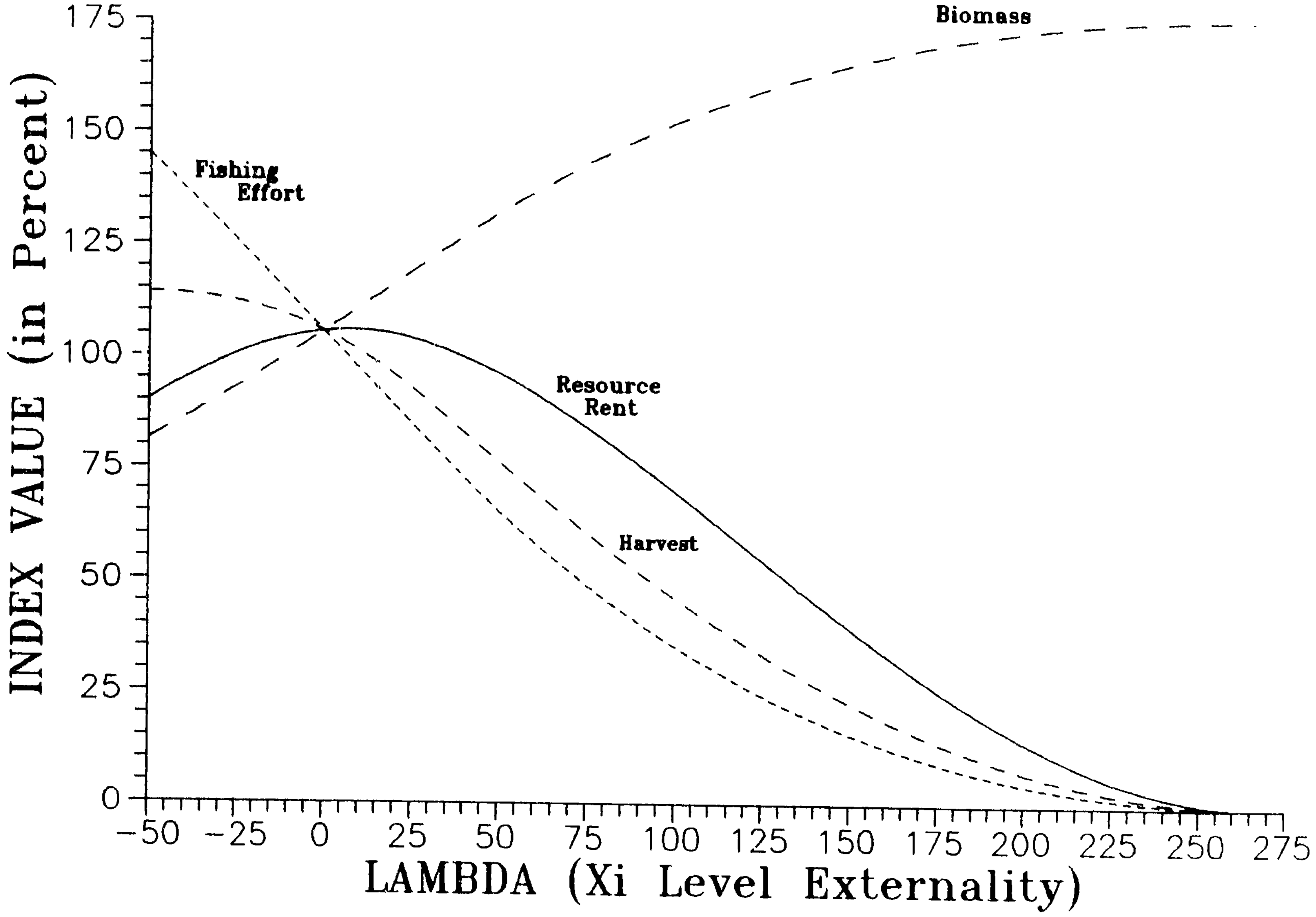


FIGURE 7-14: Effects of Managing an IQ Fishery (One Spacial Dimension) with a Per Tonne Royalty/(Subsidy) and a Subsidy on Transportation

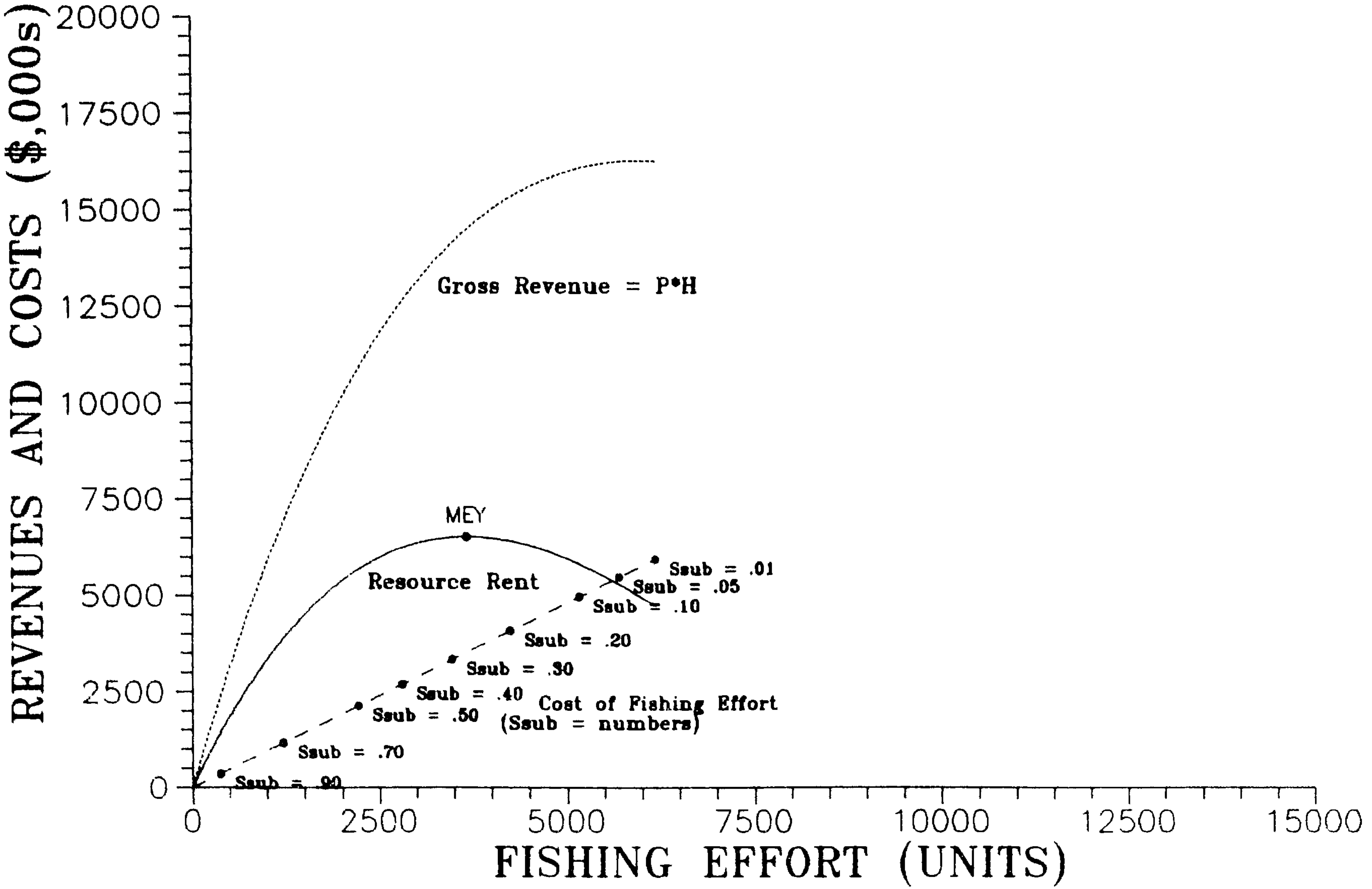


FIGURE 7-13: Effects of Managing an Open Access Fishery (One Spacial Dimension) with a TAC, a Per Tonne Royalty/(Subsidy) and a Subsidy on Transportation Costs

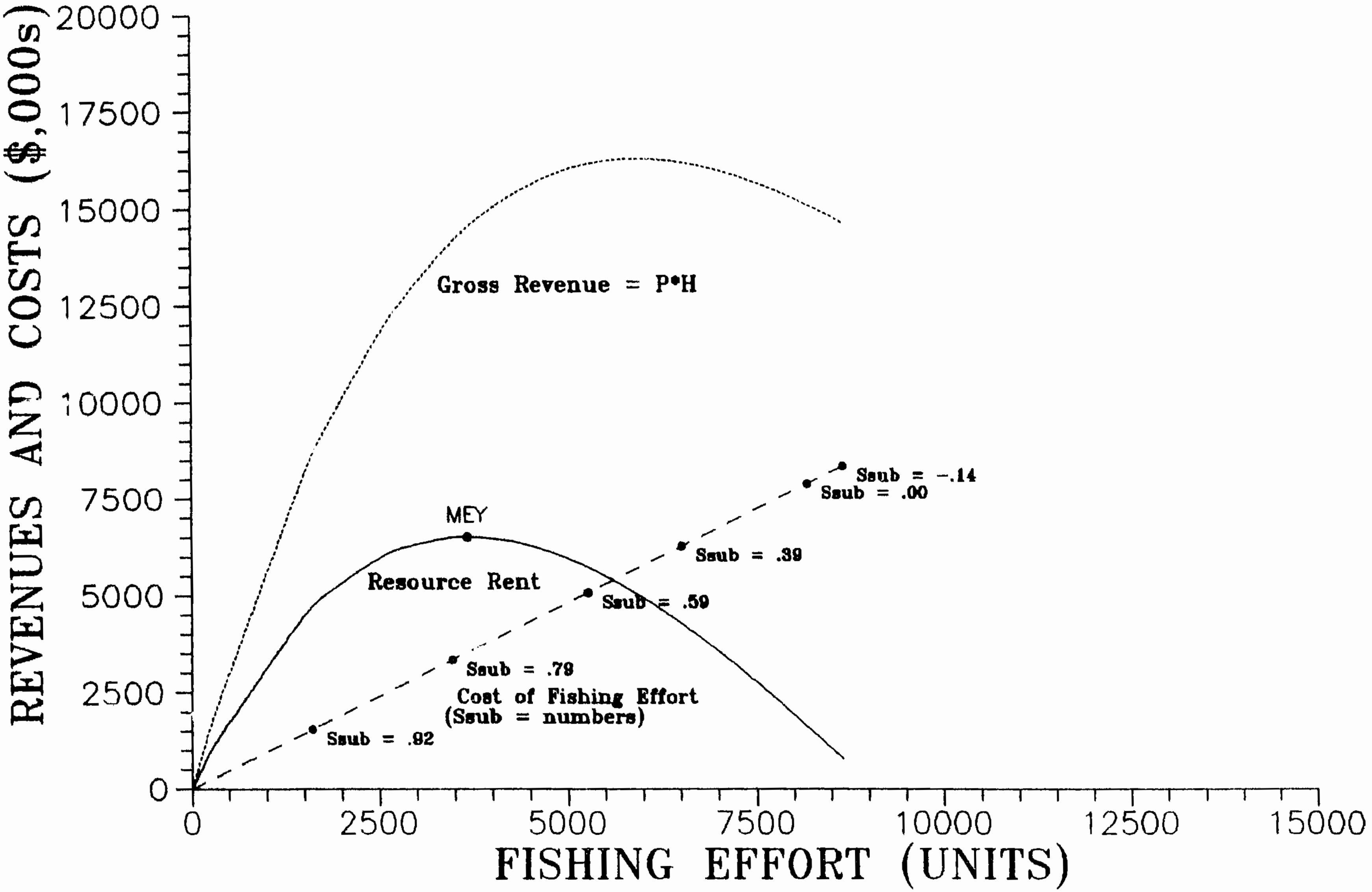


TABLE 7-2: Changes in Key Variables in an ITQ Fishery, If Managers are Unaware of a Fall in the Amount of the Harvest Mortality that is Landed

YEARS SINCE SELECTIVITY STARTED	FISHING VESSELS		STARTING BIOMASS (tonnes)	HARVEST (tonnes)	FISH. MORT. UNLANDED (tonnes)	GROWTH (tonnes	ENDING BIOMASS (tonnes)	SHORT-RUN REVENUES $,000,000	VALUES IN $,000,000s			RESOURCE RENT INDEX
									FISHING COSTS		RESOURCE	
	Number	Effort							total	Variable	RENT	
0	45.500	4,500	110,000	7,920	1,980	9,900	110,000	$15.840	$4.107	$3.234	$11.733	100.00
1	45.500	4,500	110,000	7,920	5,280	9,900	106,700	15.840	4.107	3.234	11.733	100.00
2	46.907	4,639	106,700	7,920	5,280	9,955	103,455	15.840	4.234	3.334	11.606	98.92
3	48.379	4,785	103,455	7,920	5,280	9,988	100,243	15.840	4.367	3.438	11.473	97.79
4	49.929	4,938	100,243	7,920	5,280	10,000	97,043	15.840	4.507	3.549	11.333	96.59
5	51.575	5,101	97,043	7,920	5,280	9,991	93,834	15.840	4.655	3.666	11.185	95.33
6	53.339	5,275	93,834	7,920	5,280	9,962	90,596	15.840	4.815	3.791	11.025	93.97
7	55.245	5,464	90,596	7,920	5,280	9,912	87,308	15.840	4.987	3.926	10.853	92.50
8	57.326	5,670	87,308	7,920	5,280	9,839	83,947	15.840	5.174	4.074	10.666	90.90
9	59.621	5,897	83,947	7,920	5,280	9,742	80,489	15.840	5.382	4.237	10.458	89.14
10	62.183	6,150	80,489	7,920	5,280	9,619	76,908	15.840	5.613	4.419	10.227	87.17
11	65.078	6,436	76,908	7,920	5,280	9,467	73,175	15.840	5.874	4.625	9.966	84.94
12	68.398	6,765	73,175	7,920	5,280	9,280	69,256	15.840	6.174	4.861	9.666	82.38
13	72.269	7,147	69,256	7,920	5,280	9,055	65,110	15.840	6.523	5.136	9.317	79.41
14	76.870	7,602	65,110	7,920	5,280	8,783	60,693	15.840	6.939	5.463	8.901	75.87
15	82.464	8,156	60,693	7,920	5,280	8,455	55,948	15.840	7.444	5.861	8.396	71.56
16	89.458	8,847	55,948	7,920	5,280	8,059	50,808	15.840	8.075	6.358	7.765	66.18
17	98.509	9,743	50,808	7,920	5,280	7,580	45,188	15.840	8.892	7.001	6.948	59.22
18	110.761	10,954	45,188	7,920	5,280	6,996	38,983	15.840	9.998	7.872	5.842	49.79
19	128.389	12,698	38,983	7,920	5,280	6,277	32,060	15.840	11.589	9.125	4.251	36.23
20	156.113	15,440	32,060	7,920	5,280	5,384	24,244	15.840	14.091	11.095	1.749	14.90
21	206.440	20,417	24,244	7,920	5,280	4,261	15,306	15.840	18.634	14.672	(2.794)	(23.81)
22	327.006	32,341	15,306	7,920	5,280	2,827	4,932	15.840	29.517	23.241	(13.677)	(116.57)
23	379.168	37,500	4,932	2,959	1,973	962	962	5.919	34.225	26.948	(28.306)	(241.25)
24	379.168	37,500	962	577	385	192	192	1.155	34.225	26.948	(33.071)	(281.86)
25	379.168	37,500	192	115	77	38	38	.230	34.225	26.948	(33.995)	(289.74)
26	379.168	37,500	38	23	15	8	8	.046	34.225	26.948	(34.179)	(291.31)
27	379.168	37,500	8	5	3	2	2	.009	34.225	26.948	(34.216)	(291.62)
28	379.168	37,500	2	1	1	0	0	.002	34.225	26.948	(34.223)	(291.69)
29	379.168	37,500	0	0	0	0	0	.000	34.225	26.948	(34.225)	(291.70)

TABLE 7-3: Changes in Key Variables in an ITQ Fishery, If Managers are Unaware of a Fall in the Growth Rate of the Stock Biomass

YEARS SINCE SELECTIVITY STARTED	FISHING VESSELS		STARTING BIOMASS (tonnes)	HARVEST (tonnes)	FISH. MORT. UNLANDED (tonnes)	GROWTH (tonnes	ENDING BIOMASS (tonnes)	SHORT-RUN REVENUES $,000,000	VALUES IN $,000,000s			RESOURCE RENT INDEX
									FISHING COSTS		RESOURCE RENT	
	Number	Effort							total	Variable		
0	46.000	4,500	110,000	7,920	1,980	9,900	110,000	$15.340	$4.107	$3.234	$11.733	100.00
1	45.500	4,500	110,000	7,920	1,980	7,425	107,525	15.840	4.107	3.234	11.733	100.00
2	46.547	4,604	107,525	7,920	1,980	7,458	105,083	15.840	4.202	3.308	11.638	99.19
3	47.629	4,711	105,083	7,920	1,980	7,481	102,663	15.840	4.299	3.385	11.541	98.36
4	48.752	4,822	102,663	7,920	1,980	7,495	100,258	15.840	4.401	3.465	11.439	97.50
5	49.921	4,937	100,258	7,920	1,980	7,500	97,858	15.840	4.506	3.548	11.334	96.60
6	51.146	5,058	97,858	7,920	1,980	7,497	95,454	15.840	4.617	3.635	11.223	95.66
7	52.434	5,186	95,454	7,920	1,980	7,485	93,039	15.840	4.733	3.727	11.107	94.67
8	53.795	5,320	93,039	7,920	1,980	7,464	90,603	15.840	4.856	3.823	10.984	93.62
9	55.241	5,463	90,603	7,920	1,980	7,434	88,136	15.840	4.986	3.926	10.854	92.51
10	56.787	5,616	88,136	7,920	1,980	7,394	85,631	15.840	5.126	4.036	10.714	91.32
11	58.449	5,781	85,631	7,920	1,980	7,345	83,076	15.840	5.276	4.154	10.564	90.04
12	60.246	5,958	83,076	7,920	1,980	7,285	80,461	15.840	5.438	4.282	10.402	88.66
13	62.204	6,152	80,461	7,920	1,980	7,214	77,775	15.840	5.615	4.421	10.225	87.15
14	64.353	6,365	77,775	7,920	1,980	7,130	75,004	15.840	5.809	4.574	10.031	85.50
15	66.730	6,600	75,004	7,920	1,980	7,031	72,136	15.840	6.023	4.743	9.817	83.67
16	69.383	6,862	72,136	7,920	1,980	6,918	69,153	15.840	6.263	4.931	9.577	81.63
17	72.376	7,158	69,153	7,920	1,980	6,786	66,040	15.840	6.533	5.144	9.307	79.32
18	75.788	7,495	66,040	7,920	1,980	6,635	62,775	15.840	6.841	5.386	8.999	76.70
19	79.730	7,885	62,775	7,920	1,980	6,461	59,335	15.840	7.197	5.667	8.643	73.67
20	84.351	8,342	59,335	7,920	1,980	6,260	55,695	15.840	7.614	5.995	8.226	70.11
21	89.864	8,888	55,695	7,920	1,980	6,028	51,823	15.840	8.112	6.387	7.728	65.87
22	96.579	9,552	51,823	7,920	1,980	5,759	47,682	15.840	8.718	6.864	7.122	60.70
23	104.966	10,381	47,682	7,920	1,980	5,447	43,229	15.840	9.475	7.460	6.365	54.25
24	115.778	11,451	43,229	7,920	1,980	5,083	38,412	15.840	10.451	8.229	5.389	45.93
25	130.298	12,887	38,412	7,920	1,980	4,655	33,167	15.840	11.761	9.260	4.079	34.76
26	150.902	14,924	33,167	7,920	1,980	4,158	27,417	15.840	13.621	10.725	2.219	18.91
27	182.548	18,054	27,417	7,920	1,980	3,549	21,066	15.840	16.478	12.974	(.638)	(5.43)
28	237.584	23,497	21,066	7,920	1,980	2,827	13,993	15.840	21.445	16.886	(5.605)	(47.77)
29	357.669	35,374	13,993	7,920	1,980	1,952	6,046	15.840	32.285	25.420	(16.445)	(140.16)
30	505.557	50,000	6,046	4,836	1,209	879	879	9.673	45.634	35.931	(35.961)	(306.49)
31	505.557	50,000	879	704	176	131	131	1.407	45.634	35.931	(44.227)	(376.94)
32	505.557	50,000	131	105	26	20	20	.210	45.634	35.931	(45.424)	(387.14)
33	505.557	50,000	20	16	4	3	3	.031	45.634	35.931	(45.602)	(388.67)
34	505.557	50,000	3	2	1	0	0	.005	45.634	35.931	(45.629)	(388.89)
35	505.557	50,000	0	0	0	0	0	.001	45.634	35.931	(45.633)	(388.93)

TABLE 7-4: Changes in the Key Variables of an ITQ Fishery that Encompasses Two Fish Substocks with Different Costs

	FISHERY	TOTAL STOCK (SUBSTOCK 1 AND 2)					SUBSTOCK 1				
	TAC tonnes	REVENUES Millions	BIOMASS tonnes	EFFORT	COSTS Millions	Rents Millions	BIOMASS tonnes	EFFORT	REVENUES Millions	COSTS Millions	Rents Millions
	0	.000	200,000	0	.000	0	100,000	0	.000	.000	.000
	100	.200	199,371	31	.029	.171	99,371	31	.200	.029	.171
	250	.500	198,412	79	.072	.428	98,412	79	.500	.072	.428
	500	1.000	196,771	161	.147	.853	96,771	161	1.000	.147	.853
	1,000	2.000	193,301	335	.306	1.694	93,301	335	2.000	.306	1.694
	1,250	2.500	191,458	427	.390	2.110	91,458	427	2.500	.390	2.110
	1,500	3.000	189,528	524	.478	2.522	89,528	524	3.000	.478	2.522
	2,000	4.000	185,355	732	.668	3.332	85,355	732	4.000	.668	3.332
	2,500	5.000	180,619	969	.884	4.116	80,619	969	5.000	.884	4.116
	3,000	6.000	175,000	1,250	1.141	4.859	75,000	1,250	6.000	1.141	4.859
	3,500	7.000	167,678	1,616	1.475	5.525	67,678	1,616	7.000	1.475	5.525
	4,000	8.000	162,774	1,861	1.752	6.248	65,110	1,745	7.269	1.592	5.677
	4,500	9.000	158,099	2,095	2.029	6.971	63,240	1,838	7.439	1.677	5.762
	5,000	10.000	153,042	2,348	2.329	7.671	61,217	1,939	7.597	1.770	5.828
	5,500	11.000	147,488	2,626	2.659	8.341	58,995	2,050	7.741	1.871	5.870
	6,000	12.000	141,256	2,937	3.029	8.971	56,503	2,175	7.865	1.985	5.880
	6,500	13.000	134,012	3,299	3.458	9.542	53,605	2,320	7.958	2.117	5.841
	7,000	14.000	125,002	3,750	3.993	10.007	50,001	2,500	8.000	2.282	5.718
	7,200	14.400	120,481	3,976	4.261	10.139	48,192	2,590	7.990	2.364	5.625
	7,300	14.600	117,870	4,106	4.416	10.184	47,168	2,643	7.974	2.412	5.562
	7,400	14.800	114,899	4,255	4.592	10.208	45,960	2,702	7.948	2.466	5.482
actual MEY	7,427.93	14.856	113,981	4,301	4.647	10.209	45,593	2,720	7.938	2.483	5.455
	7,500	15.000	111,359	4,432	4.802	10.198	44,543	2,773	7.905	2.531	5.374
	7,600	15.200	106,688	4,666	5.079	10.121	42,675	2,866	7.828	2.616	5.212
actual MSY	7,692.31	15.385	96,155	5,192	5.704	9.681	38,462	3,077	7.574	2.808	4.766
	7,600	15.200	85,622	5,719	6.329	8.871	34,249	3,288	7.206	3.000	4.206
	7,500	15.000	80,951	5,952	6.606	8.394	32,381	3,381	7.007	3.086	3.921
	7,400	14.800	77,411	6,129	6.816	7.984	30,964	3,452	6.840	3.150	3.690
	7,200	14.400	71,829	6,409	7.147	7.253	28,732	3,563	6.553	3.252	3.300
	7,000	14.000	67,308	6,635	7.415	6.585	26,923	3,654	6.296	3.335	2.961
	6,500	13.000	58,298	7,085	7.950	5.050	23,319	3,834	5.722	3.499	2.223
	6,000	12.000	51,054	7,447	8.380	3.620	20,421	3,979	5.200	3.631	1.569
	5,500	11.000	44,822	7,759	8.749	2.251	17,929	4,104	4.709	3.745	.963
	5,000	10.000	39,268	8,037	9.079	.921	15,707	4,215	4.237	3.847	.390
actual OAY	4,646.72	9.293	35,651	8,217	9.293	.000	14,260	4,287	3.913	3.913	(.000)
	4,500	9.000	34,211	8,289	9.379	(.379)	13,684	4,316	3.780	3.939	(.159)
	4,000	8.000	29,536	8,523	9.656	(1.656)	11,814	4,409	3.334	4.024	(.690)
	3,500	7.000	25,168	8,742	9.915	(2.915)	10,067	4,497	2.897	4.104	(1.207)
	3,000	6.000	21,055	8,947	10.159	(4.159)	8,422	4,579	2.468	4.179	(1.711)
	2,500	5.000	17,155	9,142	10.391	(5.391)	6.862	4,657	2.045	4.250	(2.205)
	2,000	4.000	13,438	9,328	10.611	(6.611)	5,375	4,731	1.628	4.318	(2.690)
	1,500	3.000	9,882	9,506	10.822	(7.822)	3,953	4,802	1.215	4.383	(3.168)
	1,250	2.500	8,158	9,592	10.924	(8.424)	3,263	4,837	1.010	4.414	(3.404)
	1,000	2.000	6,466	9,677	11.025	(9.025)	2,587	4,871	.806	4.445	(3.639)
	500	1.000	3,176	9,841	11.220	(10.220)	1,271	4,936	.401	4.505	(4.104)
	250	.500	1,574	9,921	11.315	(10.815)	630	4,969	.200	4.535	(4.334)
	100	.200	626	9,969	11.371	(11.171)	250	4,987	.080	4.552	(4.472)
	0	.000	0	10,000	11.408	(11.408)	0	5,000	.000	4.563	(4.563)

TABLE 7-5: Index of How the Key Variables in a Fishery with a Single Spacial Dimension Vary with the Distance from Home Port

KILOMETERS FROM i TO HOME PORT	AT LOCATION i IN THE FISHERY					
	NET PRICE $/tonne	BIOMASS tonnes/m	HARVEST tonnes/m	EFFORT units	REVENUE $/m	COSTS $/m
When i = 0	2000	.28521	.05745	.12589	$114.90	$114.90
km To Port	INDEX	INDEX	INDEX	INDEX	INDEX	INDEX
.0	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.5	98.1	101.9	100.7	98.8	98.8	98.8
5.0	96.3	103.9	101.3	97.5	97.5	97.5
7.5	94.4	106.0	102.0	96.3	96.3	96.3
10.0	92.5	108.1	102.7	95.0	95.0	95.0
12.5	90.6	110.3	103.5	93.8	93.8	93.8
15.0	88.8	112.7	104.2	92.5	92.5	92.5
17.5	86.9	115.1	105.0	91.2	91.2	91.2
20.0	85.0	117.6	105.8	89.9	89.9	89.9
22.5	83.1	120.3	106.6	88.6	88.6	88.6
25.0	81.3	123.1	107.5	87.3	87.3	87.3
27.5	79.4	126.0	108.4	86.0	86.0	86.0
30.0	77.5	129.0	109.3	84.7	84.7	84.7
32.5	75.6	132.2	110.2	83.4	83.4	83.4
35.0	73.8	135.6	111.2	82.0	82.0	82.0
37.5	71.9	139.1	112.2	80.6	80.6	80.6
40.0	70.0	142.9	113.2	79.2	79.2	79.2
42.5	68.1	146.8	114.3	77.8	77.8	77.8
45.0	66.3	150.9	115.3	76.4	76.4	76.4
47.5	64.4	155.3	116.5	75.0	75.0	75.0
50.0	62.5	160.0	117.6	73.5	73.5	73.5
52.5	60.6	164.9	118.8	72.0	72.0	72.0
55.0	58.8	170.2	120.0	70.5	70.5	70.5
57.5	56.9	175.8	121.2	69.0	69.0	69.0
60.0	55.0	181.8	122.5	67.4	67.4	67.4
62.5	53.1	188.2	123.8	65.8	65.8	65.8
65.0	51.3	195.1	125.1	64.1	64.1	64.1
67.5	49.4	202.5	126.4	62.4	62.4	62.4
70.0	47.5	210.5	127.7	60.7	60.7	60.7
72.5	45.6	219.2	129.0	58.9	58.9	58.9
75.0	43.8	228.6	130.2	57.0	57.0	57.0
77.5	41.9	238.8	131.4	55.0	55.0	55.0
80.0	40.0	250.0	132.6	53.0	53.0	53.0
82.5	38.1	262.3	133.5	50.9	50.9	50.9
85.0	36.3	275.9	134.3	48.7	48.7	48.7
87.5	34.4	290.9	134.8	46.3	46.3	46.3
90.0	32.5	307.7	134.9	43.8	43.8	43.8
92.5	30.6	326.5	134.4	41.2	41.2	41.2
95.0	28.8	347.8	133.2	38.3	38.3	38.3
97.5	26.9	372.1	130.8	35.2	35.2	35.2
100.0	25.0	400.0	126.9	31.7	31.7	31.7

TABLE 7-6: The Effect of Changes in the Unit Cost of Fishing Effort on the Key Variables in a Fishery with One Spacial Dimension

UNIT COST OF EFFORT	ACTIVE ZONE KILOMETRES	BIOMASS tonnes	HARVEST tonnes	EFFORT Units	REVENUE $ 000s	COSTS ($ 000s)	
						EFFORT	TRANSPORT
0	100.000	0	.0	13,276.20	.0	.0	.0
25	100.000	1,444	285.7	13,144.73	571.4	328.6	242.8
50	100.000	2,888	565.2	13,014.14	1,130.3	650.7	479.6
75	100.000	4,332	838.5	12,884.45	1,677.0	966.3	710.7
100	100.000	5,776	1,105.7	12,755.65	2,211.5	1,275.6	935.9
200	100.000	11,552	2,114.9	12,249.09	4,229.9	2,449.8	1,780.1
300	100.000	17,329	3,031.1	11,755.87	6,062.1	3,526.8	2,535.3
400	100.000	23,105	3,857.3	11,275.30	7,714.6	4,510.1	3,204.5
500	100.000	28,881	4,596.8	10,806.77	9,193.6	5,403.4	3,790.2
750	100.000	43,322	6,083.6	9,684.22	12,167.3	7,263.2	4,904.1
912.669	100.000	52,718	6,787.7	8,988.13	13,575.5	8,203.2	5,372.3
1,000	100.000	57,762	7,084.1	8,624.68	14,168.2	8,624.7	5,543.5
1,250	100.000	72,203	7,630.9	7,620.68	15,261.9	9,525.9	5,736.0
1,452.421	100.000	83,895	7,760.4	6,843.93	15,520.7	9,940.3	5,580.4
1,500	100.000	86,643	7,751.6	6,665.67	15,503.2	9,998.5	5,504.7
1,750	96.875	100,800	7,508.4	5,763.37	15,016.9	10,085.9	4,931.0
2,000	91.667	113,596	7,102.8	4,951.51	14,205.7	9,903.0	4,302.7
2,250	86.458	125,087	6,604.2	4,231.99	13,208.4	9,522.0	3,686.5
2,500	81.250	135,417	6,049.3	3,597.20	12,098.6	8,993.0	3,105.6
2,750	76.042	144,705	5,464.2	3,038.36	10,928.5	8,355.5	2,573.0
3,000	70.833	153,044	4,868.2	2,547.13	9,736.5	7,641.4	2,095.1
3,250	65.625	160,514	4,275.8	2,116.09	8,551.7	6,877.3	1,674.4
3,500	60.417	167,182	3,698.2	1,738.83	7,396.4	6,085.9	1,310.5
3,750	55.208	173,106	3,144.3	1,409.85	6,288.5	5,286.9	1,001.6
4,000	50.000	178,334	2,621.1	1,124.45	5,242.1	4,497.8	744.3
4,250	44.792	182,911	2,134.4	878.61	4,268.9	3,734.1	534.8
4,500	39.583	186,875	1,689.3	668.87	3,378.5	3,009.9	368.6
4,750	34.375	190,260	1,289.6	492.26	2,579.2	2,338.2	240.9
5,000	29.167	193,096	938.9	346.19	1,877.7	1,730.9	146.8
5,250	23.958	195,411	640.1	228.39	1,280.2	1,199.0	81.1
5,500	18.750	197,230	395.8	136.88	791.6	752.9	38.8
5,750	13.542	198,576	208.3	69.92	416.6	402.1	14.5
6,000	8.333	199,468	79.5	25.95	159.1	155.7	3.4
6,250	3.125	199,926	11.3	3.58	22.5	22.4	.2
6,300	2.083	199,967	5.0	1.58	10.0	10.0	.1
6,350	1.042	199,992	1.3	.39	2.5	2.5	.0
6,375	.521	199,998	.3	.10	.6	.6	.0
6,399.999	.000	200,000	.0	.00	0	0	0

TABLE 7-7: The Effect of Changes in a Per Tonne Royalty/(Subsidy) on the Key Variables in a Fishery with One Spacial Dimension

ROYALTY PER TONNE	ACTIVE ZONNE km	BIOMASS tonnes	HARVEST tonnes	EFFORT Units	REVENUE $ 000s	COSTS ($ 000s) EFFORT	COSTS ($ 000s) TRANSPORT	ROYALTIES $ 000s
(2,000.00)	100.000	17,873	3,141.9	11,083.2	6,283.8	10,115.3	2,452.4	(6,283.8)
(1,750.00)	100.000	19,426	3,374.9	10,972.9	6,749.9	10,014.6	2,641.4	(5,906.1)
(1,500.00)	100.000	21,281	3,645.2	10,843.5	7,290.3	9,896.5	2,861.6	(5,467.8)
(1,250.00)	100.000	23,541	3,962.1	10,689.3	7,924.3	9,755.8	3,121.2	(4,952.7)
(1,000.00)	100.000	26,359	4,338.6	10,502.2	8,677.2	9,585.0	3,430.9	(4,338.6)
(750.00)	100.000	29,983	4,791.8	10,269.5	9,583.7	9,372.7	3,804.9	(3,593.9)
(500.00)	100.000	34,845	5,344.1	9,970.9	10,688.2	9,100.2	4,260.1	(2,672.1)
(250.00)	100.000	41,778	6,017.7	9,569.6	12,035.4	8,733.9	4,806.0	(1,504.4)
(200.00)	100.000	43,547	6,167.3	9,471.5	12,334.6	8,644.4	4,923.7	(1,233.5)
(100.00)	100.000	47,640	6,477.1	9,250.7	12,954.1	8,442.9	5,159.0	(647.7)
.00	100.000	52,718	6,787.7	8,988.1	13,575.5	8,203.2	5,372.3	.0
100.00	100.000	59,253	7,058.6	8,667.0	14,117.1	7,910.1	5,501.2	705.9
125.00	100.000	61,204	7,109.3	8,574.5	14,218.5	7,825.7	5,504.2	888.7
150.00	100.000	63,317	7,147.6	8,475.9	14,295.2	7,735.7	5,487.4	1,072.1
174.28	100.000	65,548	7,168.7	8,373.6	14,337.4	7,642.3	5,445.8	1,249.6
200.00	100.000	68,137	7,167.1	8,257.0	14,334.3	7,535.9	5,364.9	1,433.4
250.00	97.653	73,683	7,093.3	8,005.4	14,186.6	7,306.3	5,106.9	1,773.3
300.00	94.319	79,247	6,992.0	7,728.9	13,983.9	7,054.0	4,832.4	2,097.6
400.00	87.653	90,275	6,729.2	7,117.7	13,458.4	6,496.1	4,270.7	2,691.7
500.00	80.986	101,154	6,395.5	6,450.5	12,790.9	5,887.2	3,706.0	3,197.7
600.00	74.319	111,864	6,000.2	5,749.9	12,000.4	5,247.7	3,152.6	3,600.1
700.00	67.653	122,379	5,551.6	5,034.7	11,103.2	4,595.0	2,622.0	3,886.1
800.00	60.986	132,668	5,056.7	4,321.2	10,113.4	3,943.8	2,124.2	4,045.4
867.53	56.484	139,470	4,699.4	3,847.4	9,398.9	3,511.4	1,810.6	4,076.9
900.00	54.319	142,693	4,521.7	3,623.1	9,043.4	3,306.7	1,667.1	4,069.5
1,000.00	47.653	152,402	3,952.2	2,952.6	7,904.4	2,694.7	1,257.5	3,952.2
1,009.86	46.995	153,340	3,894.4	2,888.4	7,788.8	2,636.1	1,219.9	3,932.8
1,100.00	40.986	161,728	3,353.9	2,320.4	6,707.9	2,117.8	900.8	3,689.3
1,200.00	34.319	170,583	2,733.1	1,736.8	5,466.2	1,585.1	601.3	3,279.7
1,300.00	27.653	178,838	2,098.1	1,212.2	4,196.2	1,106.3	362.3	2,727.5
1,400.00	20.986	186,309	1,462.3	758.0	2,924.5	691.8	185.6	2,047.2
1,500.00	14.319	192,710	850.6	388.6	1,701.3	354.6	70.7	1,276.0
1,600.00	7.653	197,557	318.1	124.8	636.2	113.9	13.4	509.0
1,700.00	.986	199,951	7.4	2.4	14.9	2.2	.0	12.7
1,710.00	.319	199,995	.81318	.25696	1.62637	.23452	.00131	1.39054
1,714.70	.006	200,000	.00030	.00009	.00060	.00009	.00000	.00051
1,714.72	.005	200,000	.00018	.00006	.00036	.00005	.00000	.00031
1,714.74	.003	200,000	.00009	.00003	.00019	.00003	.00000	.00016
1,714.76	.002	200,000	.00003	.00001	.00007	.00001	.00000	.00006
1,714.78	.001	200,000	.00000	.00000	.00001	.00000	.00000	.00001
1,714.80	.000	200,000	.00000	.00000	.00000	.00000	.00000	.00000

TABLE 7-8: The Effect of CHanges in I_o on the Key Variables in an IQ Fishery, with One Spacial Dimension

BIOMASS AT POINT o	ACTIVE ZONE km	CHi	BIOMASS tonnes	HARVEST tonnes	EFFORT Units	REVENUE $ 000s	COSTS ($ 000s) EFFORT	COSTS ($ 000s) TRANSPORT	RENT $ 000s
.00	100.000	($913)	0	0	13,276.2	$.0	$12,116.8	$.0	($12,116.8)
.01	100.000	(881)	1,848	365	13,108.1	729.1	11,963.3	309.7	(11,543.9)
.02	100.000	(849)	3,697	719	12,941.4	1,438.0	11,811.2	609.7	(10,983.0)
.03	100.000	(817)	5,545	1,063	12,776.2	2,126.8	11,660.4	900.3	(10,433.9)
.04	100.000	(785)	7,394	1,398	12,612.4	2,795.8	11,511.0	1,181.4	(9,896.6)
.05	100.000	(753)	9,242	1,723	12,450.1	3,445.2	11,362.8	1,453.2	(9,370.8)
.10	100.000	(593)	18,484	3,203	11,658.8	6,406.8	10,640.6	2,676.0	(6,909.8)
.15	100.000	(433)	27,726	4,456	10,899.5	8,911.4	9,947.7	3,679.6	(4,715.9)
.20	100.000	(273)	36,968	5,492	10,169.9	10,983.0	9,281.8	4,474.3	(2,773.0)
.25	100.000	(113)	46,210	6,322	9,467.5	12,643.0	8,640.7	5,069.0	(1,066.7)
.28521	100.000	0	52,718	6,788	8,988.1	13,575.5	8,203.2	5,372.3	.0
.30	100.000	47	55,452	6,955	8,790.3	13,910.6	8,022.6	5,471.9	416.1
.35	100.000	207	64,694	7,401	8,136.3	14,802.8	7,425.7	5,690.2	1,686.9
.40	100.000	367	73,936	7,667	7,503.6	15,334.9	6,848.3	5,730.2	2,756.3
.45	100.000	527	83,178	7,760	6,890.7	15,520.4	6,289.0	5,597.8	3,633.7
.4525	100.000	535	83,640	7,760	6,860.6	15,520.8	6,261.4	5,586.7	3,672.7
.50	100.000	687	92,420	7,686	6,296.1	15,371.7	5,746.2	5,298.0	4,327.5
.55	96.667	847	101,339	7,495	5,729.1	14,989.2	5,228.7	4,906.0	4,854.6
.60	93.333	1,007	109,651	7,245	5,201.0	14,489.8	4,746.8	4,503.9	5,239.1
.65	90.000	1,167	117,407	6,951	4,711.5	13,902.8	4,300.1	4,102.8	5,499.9
.70	86.667	1,327	124,650	6,625	4,259.1	13,250.9	3,887.1	3,710.6	5,653.2
.75	83.333	1,487	131,416	6,276	3,841.5	12,552.3	3,506.0	3,332.7	5,713.6
.76168	82.555	1,525	132,932	6,192	3,748.7	12,384.0	3,421.4	3,247.0	5,715.7
.80	80.000	1,647	137,738	5,911	3,456.5	11,821.6	3,154.6	2,973.0	5,694.0
.85	76.667	1,807	143,642	5,535	3,101.7	11,070.7	2,830.8	2,634.1	5,605.8
.90	73.333	1,967	149,154	5,155	2,775.0	10,309.4	2,532.6	2,317.4	5,459.3
.95	70.000	2,127	154,296	4,773	2,474.3	9,545.8	2,258.2	2,023.9	5,263.6
1.00	66.667	2,287	159,056	4,393	2,197.8	8,786.9	2,005.9	1,753.9	5,027.1
1.05	63.333	2,447	163,563	4,019	1,943.8	8,038.6	1,774.1	1,507.4	4,757.2
1.10	60.000	2,607	167,683	3,653	1,710.8	7,305.9	1,561.4	1,283.8	4,460.6
1.15	56.667	2,767	171,519	3,297	1,497.4	6,593.1	1,366.6	1,082.7	4,143.8
1.20	53.333	2,927	175,065	2,952	1,302.3	5,904.1	1,188.6	903.2	3,812.3
1.25	50.000	3,087	178,334	2,621	1,124.4	5,242.1	1,026.2	744.3	3,471.5
1.30	46.667	3,247	181,336	2,305	962.8	4,610.2	878.7	605.0	3,126.5
1.35	43.333	3,407	184,081	2,005	816.4	4,010.9	745.1	484.1	2,781.7
1.40	40.000	3,567	186,579	1,723	684.4	3,446.5	624.6	380.4	2,441.5
1.45	36.667	3,727	188,840	1,460	566.1	2,919.2	516.6	292.7	2,109.9
1.50	33.333	3,887	190,879	1,215	460.7	2,430.9	420.4	219.6	1,790.8
1.55	30.000	4,047	192,678	992	367.6	1,983.1	335.5	159.8	1,487.8
1.60	26.667	4,207	194,271	789	286.2	1,577.6	261.2	112.1	1,204.3
1.65	23.333	4,367	195,655	608	216.1	1,215.7	197.2	74.9	943.6
1.70	20.000	4,527	196,838	449	156.5	898.7	142.9	47.1	708.7
1.75	16.667	4,687	197,826	314	107.2	627.8	97.9	27.2	502.7
1.80	13.333	4,847	198,620	202	67.7	404.0	61.8	13.9	328.3
1.85	10.000	5,007	199,231	114	37.6	228.5	34.3	5.8	188.3
1.90	6.667	5,167	199,661	51	16.5	102.1	15.1	1.7	85.3
1.95	3.333	5,327	199,916	13	4.1	25.6	3.7	.2	21.7
2.00	.000	5,487	200,000	0	.0	.0	.0	.0	.0

TABLE 7-9: The Effect of Distance from Port on the Key Variables in a Sole-Owner Fishery, with One Spacial Dimension

DESIRED	REQUIRED	AT LOCATION i IN THE FISHERY								TOTAL
K_t	X_t	K_i	P_i	H_i	Value	EFFORT	REVENUE	COSTS	PROFIT	BIOMASS
(km to port)	(tonnes)	km eqn(202)	$/tonne eqn(163)	tonnes eqn(175)	of eqn(200)	Units eqn(177)	$\$/M^3$	$\$/M^3$	$\$/M^3$	119,449.81
										TOTAL
100,000	1.55681	100,000	500.00	.06720	.0000	.02698	33.60	24.62	8.98	HARVEST
99,000	1.53882	99,000	515.00	.06930	.0000	.02815	35.69	25.69	10.00	9,885.90
98,000	1.52175	98,000	530.00	.07125	.0000	.02926	37.76	26.71	11.06	
97,000	1.50554	97,000	545.00	.07307	.0000	.03033	39.82	27.68	12.14	TOTAL
96,000	1.49012	96,000	560.00	.07476	.0000	.03135	41.86	28.62	13.25	EFFORT
95,000	1.47543	95,000	575.00	.07633	.0000	.03233	43.89	29.51	14.38	5,288.72
94,000	1.46141	94,000	590.00	.07781	.0000	.03328	45.91	30.37	15.54	
93,000	1.44802	93,000	605.00	.07919	.0000	.03418	47.91	31.19	16.71	TOTAL
92,000	1.43522	92,000	620.00	.08048	.0000	.03505	49.90	31.99	17.91	REVENUE
91,000	1.42296	91,000	635.00	.08170	.0000	.03588	51.88	32.75	19.13	$12,748,371
90,000	1.41120	90,000	650.00	.08284	.0000	.03669	53.85	33.49	20.36	
89,000	1.39992	89,000	665.00	.08392	.0000	.03747	55.81	34.19	21.61	TOTAL COST
88,000	1.38909	88,000	680.00	.08496	.0000	.03822	57.76	34.88	22.88	OF EFFORT
87,000	1.37868	87,000	695.00	.08590	.0000	.03894	59.70	35.54	24.16	$4,826,847
86,000	1.36865	86,000	710.00	.08681	.0000	.03964	61.64	36.18	25.46	
85,000	1.35900	85,000	725.00	.08768	.0000	.04032	63.57	36.80	26.76	TOTAL
84,000	1.34970	84,000	740.00	.08850	.0000	.04098	65.49	37.40	28.09	PROFIT
83,000	1.34072	83,000	755.00	.08927	.0000	.04162	67.40	37.98	29.42	$7,921,524
82,000	1.33206	82,000	770.00	.09001	.0000	.04223	69.31	38.55	30.76	
81,000	1.32369	81,000	785.00	.09072	.0000	.04283	71.21	39.09	32.12	-.00
80,000	1.31560	80,000	800.00	.09139	.0000	.04341	73.11	39.62	33.49	
79,000	1.30777	79,000	815.00	.09203	.0000	.04398	75.00	40.14	34.86	THEORETICAL
78,000	1.30019	78,000	830.00	.09263	.0000	.04453	76.89	40.64	36.25	K_{max}
77,000	1.29285	77,000	845.00	.09322	.0000	.04506	78.77	41.13	37.64	116,319.40
76,000	1.28573	76,000	860.00	.09377	.0000	.04558	80.65	41.60	39.04	
75,000	1.27883	75,000	875.00	.09431	.0000	.04609	82.52	42.07	40.45	
74,000	1.27214	74,000	890.00	.09482	.0000	.04658	84.39	42.52	41.87	
73,000	1.26564	73,000	905.00	.09531	.0000	.04706	86.25	42.95	43.30	
72,000	1.25933	72,000	920.00	.09577	.0000	.04753	88.11	43.38	44.73	
71,000	1.25320	71,000	935.00	.09622	.0000	.04799	89.97	43.80	46.17	
70,000	1.24723	70,000	950.00	.09666	.0000	.04843	91.82	44.20	47.62	
69,000	1.24143	69,000	965.00	.09707	.0000	.04887	93.67	44.60	49.07	
68,000	1.23579	68,000	980.00	.09747	.0000	.04929	95.52	44.99	50.53	
67,000	1.23029	67,000	995.00	.09785	.0000	.04971	97.36	45.37	51.99	
66,000	1.22494	66,000	1,010.00	.09822	.0000	.05012	99.20	45.74	53.46	
65,000	1.21972	65,000	1,025.00	.09858	.0000	.05051	101.04	46.10	54.94	
64,000	1.21464	64,000	1,040.00	.09892	.0000	.05090	102.88	46.45	56.42	
63,000	1.20968	63,000	1,055.00	.09925	.0000	.05128	104.71	46.80	57.91	
62,000	1.20485	62,000	1,070.00	.09957	.0000	.05165	106.54	47.14	59.40	
61,000	1.20013	61,000	1,085.00	.09988	.0000	.05201	108.37	47.47	60.90	
60,000	1.19552	60,000	1,100.00	.10017	.0000	.05237	110.19	47.80	62.40	
59,000	1.19102	59,000	1,115.00	.10046	.0000	.05272	112.01	48.11	63.90	
58,000	1.18663	58,000	1,130.00	.10074	.0000	.05306	113.84	48.43	65.41	
57,000	1.18234	57,000	1,145.00	.10101	.0000	.05339	115.65	48.73	66.92	
56,000	1.17816	56,000	1,160.00	.10127	.0000	.05372	117.47	49.03	68.44	
55,000	1.17404	55,000	1,175.00	.10152	.0000	.05404	119.28	49.32	69.96	
54,000	1.17003	54,000	1,190.00	.10176	.0000	.05436	121.10	49.61	71.49	
53,000	1.16610	53,000	1,205.00	.10200	.0000	.05467	122.91	49.89	73.01	

TABLE 7-9: The Effect of Distance from Port on the Key Variables in a Sole-Owner Fishery, with One Spacial Dimension

52,000	1.16226	52,000	1,220.00	.10223	.0000	.05497	124.72	50.17	74.55
51,000	1.15850	51,000	1,235.00	.10245	.0000	.05527	126.52	50.44	76.08
50,000	1.15482	50,000	1,250.00	.10266	.0000	.05556	128.33	50.71	77.62
49,000	1.15121	49,000	1,265.00	.10287	.0000	.05585	130.13	50.97	79.16
48,000	1.14768	48,000	1,280.00	.10307	.0000	.05613	131.93	51.23	80.70
47,000	1.14422	47,000	1,295.00	.10327	.0000	.05641	133.73	51.48	82.25
46,000	1.14083	46,000	1,310.00	.10346	.0000	.05668	135.53	51.73	83.80
45,000	1.13750	45,000	1,325.00	.10365	.0000	.05695	137.33	51.97	85.36
44,000	1.13424	44,000	1,340.00	.10383	.0000	.05721	139.13	52.21	86.91
43,000	1.13105	43,000	1,355.00	.10400	.0000	.05747	140.92	52.45	88.47
42,000	1.12791	42,000	1,370.00	.10417	.0000	.05772	142.72	52.68	90.03
41,000	1.12483	41,000	1,385.00	.10434	.0000	.05797	144.51	52.91	91.60
40,000	1.12191	40,000	1,400.00	.10450	.0000	.05822	146.30	53.14	93.16
39,000	1.11885	39,000	1,415.00	.10466	.0000	.05846	148.09	53.36	94.73
38,000	1.11594	38,000	1,430.00	.10481	.0000	.05870	149.88	53.57	96.30
37,000	1.11308	37,000	1,445.00	.10496	.0000	.05893	151.66	53.79	97.88
36,000	1.11027	36,000	1,460.00	.10510	.0000	.05916	153.45	54.00	99.45
35,000	1.10751	35,000	1,475.00	.10524	.0000	.05939	155.23	54.20	101.03
34,000	1.10480	34,000	1,490.00	.10538	.0000	.05961	157.02	54.41	102.61
33,000	1.10214	33,000	1,505.00	.10551	.0000	.05983	158.80	54.61	104.19
32,000	1.09952	32,000	1,520.00	.10565	.0000	.06005	160.58	54.81	105.77
31,000	1.09695	31,000	1,535.00	.10577	.0000	.06027	162.36	55.00	107.36
30,000	1.09442	30,000	1,550.00	.10590	.0000	.06048	164.14	55.19	108.95
29,000	1.09194	29,000	1,565.00	.10602	.0000	.06068	165.92	55.38	110.54
28,000	1.08949	28,000	1,580.00	.10614	.0000	.06089	167.70	55.57	112.13
27,000	1.08708	27,000	1,595.00	.10625	.0000	.06109	169.47	55.75	113.72
26,000	1.08472	26,000	1,610.00	.10637	.0000	.06129	171.25	55.93	115.31
25,000	1.08239	25,000	1,625.00	.10648	.0000	.06148	173.02	56.11	116.91
24,000	1.08009	24,000	1,640.00	.10658	.0000	.06168	174.80	56.29	118.51
23,000	1.07784	23,000	1,655.00	.10669	.0000	.06187	176.57	56.46	120.11
22,000	1.07562	22,000	1,670.00	.10679	.0000	.06205	178.34	56.63	121.71
21,000	1.07343	21,000	1,685.00	.10689	.0000	.06224	180.12	56.80	123.31
20,000	1.07127	20,000	1,700.00	.10699	.0000	.06242	181.89	56.97	124.92
19,000	1.06915	19,000	1,715.00	.10709	.0000	.06260	183.66	57.13	126.52
18,000	1.06706	18,000	1,730.00	.10718	.0000	.06278	185.43	57.30	128.13
17,000	1.06501	17,000	1,745.00	.10727	.0000	.06295	187.19	57.46	129.74
16,000	1.06298	16,000	1,760.00	.10736	.0000	.06313	188.96	57.61	131.35
15,000	1.06098	15,000	1,775.00	.10745	.0000	.06330	190.73	57.77	132.96
14,000	1.05901	14,000	1,790.00	.10754	.0000	.06347	192.49	57.92	134.57
13,000	1.05707	13,000	1,805.00	.10762	.0000	.06363	194.26	58.08	136.18
12,000	1.05516	12,000	1,820.00	.10771	.0000	.06380	196.03	58.23	137.80
11,000	1.05327	11,000	1,835.00	.10779	.0000	.06396	197.79	58.37	139.42
10,000	1.05142	10,000	1,850.00	.10787	.0000	.06412	199.55	58.52	141.03
9,000	1.04958	9,000	1,865.00	.10794	.0000	.06428	201.32	58.66	142.65
8,000	1.04777	8,000	1,880.00	.10802	.0000	.06443	203.08	58.81	144.27
7,000	1.04599	7,000	1,895.00	.10810	.0000	.06459	204.84	58.95	145.89
6,000	1.04423	6,000	1,910.00	.10817	.0000	.06474	206.60	59.09	147.51
5,000	1.04250	5,000	1,925.00	.10824	.0000	.06489	208.36	59.23	149.14
4,000	1.04079	4,000	1,940.00	.10831	.0000	.06504	210.12	59.36	150.76
3,000	1.03910	3,000	1,955.00	.10838	.0000	.06519	211.88	59.50	152.39
2,000	1.03743	2,000	1,970.00	.10845	.0000	.06533	213.64	59.63	154.01
1,000	1.03579	1,000	1,985.00	.10851	.0000	.06548	215.40	59.76	155.64
0	1.03416	(.00)	2,000.00	.10858	.0000	.06562	217.16	59.89	157.27

TABLE 7-10: Index of How the Key Variables in a Sole-Owner Fishery with a Single Spacial Dimension Vary with the Distance from Port

DISTANCE TO PORT	RES. RENT $/tonne	BIOMASS tonnes/m	HARVEST tonnes/m	EFFORT units	REVENUE $/m	COSTS $/m
0 km	100.0%	66.4%	100.0%	100.0%	100.0%	100.0%
2	97.9%	66.6%	99.9%	99.6%	98.4%	99.6%
4	95.9%	66.9%	99.8%	99.1%	96.8%	99.1%
6	93.8%	67.1%	99.6%	98.7%	95.1%	98.7%
8	91.7%	67.3%	99.5%	98.2%	93.5%	98.2%
10	89.7%	67.5%	99.3%	97.7%	91.9%	97.7%
12	87.6%	67.8%	99.2%	97.2%	90.3%	97.2%
14	85.6%	68.0%	99.0%	96.7%	88.6%	96.7%
16	83.5%	68.3%	98.9%	96.2%	87.0%	96.2%
18	81.5%	68.5%	98.7%	95.7%	85.4%	95.7%
20	79.4%	68.8%	98.5%	95.1%	83.8%	95.1%
22	77.4%	69.1%	98.4%	94.6%	82.1%	94.6%
24	75.4%	69.4%	98.2%	94.0%	80.5%	94.0%
26	73.3%	69.7%	98.0%	93.4%	78.9%	93.4%
28	71.3%	70.0%	97.8%	92.8%	77.2%	92.8%
30	69.3%	70.3%	97.5%	92.2%	75.6%	92.2%
32	67.3%	70.6%	97.3%	91.5%	73.9%	91.5%
34	65.2%	71.0%	97.1%	90.8%	72.3%	90.8%
36	63.2%	71.3%	96.8%	90.2%	70.7%	90.2%
38	61.2%	71.7%	96.5%	89.5%	69.0%	89.5%
40	59.2%	72.1%	96.2%	88.7%	67.4%	88.7%
42	57.2%	72.5%	95.9%	88.0%	65.7%	88.0%
44	55.3%	72.9%	95.6%	87.2%	64.1%	87.2%
46	53.3%	73.3%	95.3%	86.4%	62.4%	86.4%
48	51.3%	73.7%	94.9%	85.5%	60.8%	85.5%
50	49.4%	74.2%	94.6%	84.7%	59.1%	84.7%
52	47.4%	74.7%	94.1%	83.8%	57.4%	83.8%
54	45.5%	75.2%	93.7%	82.8%	55.8%	82.8%
56	43.5%	75.7%	93.3%	81.9%	54.1%	81.9%
58	41.6%	76.2%	92.8%	80.9%	52.4%	80.9%
60	39.7%	76.8%	92.3%	79.8%	50.7%	79.8%
62	37.8%	77.4%	91.7%	78.7%	49.1%	78.7%
64	35.9%	78.0%	91.1%	77.6%	47.4%	77.6%
66	34.0%	78.7%	90.5%	76.4%	45.7%	76.4%
68	32.1%	79.4%	89.8%	75.1%	44.0%	75.1%
70	30.3%	80.1%	89.0%	73.8%	42.3%	73.8%
72	28.4%	80.9%	88.2%	72.4%	40.6%	72.4%
74	26.6%	81.7%	87.3%	71.0%	38.9%	71.0%
76	24.8%	82.6%	86.4%	69.5%	37.1%	69.5%
78	23.0%	83.5%	85.3%	67.9%	35.4%	67.9%
80	21.3%	84.5%	84.2%	66.2%	33.7%	66.2%
82	19.6%	85.6%	82.9%	64.4%	31.9%	64.4%
84	17.9%	86.7%	81.5%	62.4%	30.2%	62.4%
86	16.2%	87.9%	80.0%	60.4%	28.4%	60.4%
88	14.5%	89.2%	78.2%	58.2%	26.6%	58.2%
90	12.9%	90.6%	76.3%	55.9%	24.8%	55.9%
94	9.9%	93.9%	71.7%	50.7%	21.1%	50.7%
96	8.4%	95.7%	68.8%	47.8%	19.3%	47.8%
98	7.0%	97.7%	65.6%	44.6%	17.4%	44.6%
100	5.7%	100.0%	61.9%	41.1%	15.5%	41.1%

TABLE 7-11: Index of How the Key Variables in a Sole-Owner Fishery with a Single Spacial Dimension Vary with Changes to the Local Biomass Externality

VALUE OF lambda	BIOMASS tonnes	HARVEST tonnes	EFFORT units	TOTAL REVENUE	TOTAL COSTS	RESOURCE RENT
(50)	92,124.7	10,693.0	7,264.1	$13,391,778	$6,629,720	$6,762,058
(20)	107,980.8	10,431.2	6,096.5	13,218,003	5,564,071	7,653,933
(10)	113,634.7	10,199.4	5,694.9	13,021,647	5,197,540	7,824,107
0	119,449.8	9,885.9	5,288.7	12,748,371	4,826,847	7,921,525
5	122,413.4	9,697.1	5,084.2	12,581,699	4,640,189	7,941,510
7	123,608.7	9,615.4	5,002.2	12,509,279	4,565,309	7,943,971
8	124,208.4	9,573.2	4,961.1	12,471,838	4,527,827	7,944,011
9	124,809.5	9,530.1	4,920.0	12,433,568	4,490,317	7,943,250
10	125,412.0	9,486.2	4,878.9	12,394,441	4,452,778	7,941,663
15	128,444.0	9,252.7	4,672.8	12,186,217	4,264,699	7,921,518
20	131,508.0	8,996.4	4,466.1	11,956,686	4,076,031	7,880,655
50	149,570.8	7,140.0	3,266.5	10,206,571	2,981,220	7,225,351
75	162,037.1	5,655.2	2,441.3	8,548,736	2,228,057	6,320,679
100	172,294.5	4,316.2	1,766.9	6,854,172	1,612,633	5,241,539
125	180,642.0	3,139.7	1,223.9	5,210,723	1,117,027	4,093,696
150	187,290.6	2,138.5	796.6	3,693,607	727,013	2,966,595
175	192,410.4	1,321.1	471.6	2,366,448	430,442	1,936,006
200	196,133.4	694.6	238.3	1,286,699	217,479	1,069,220
225	198,565.4	265.4	87.7	507,179	80,042	427,137
250	199,800.1	38.0	12.1	74,793	11,067	63,725
265.084	200,000.0	.0	.0	.00	.00	.00
(50)	77.12%	108.16%	137.35%	105.05%	137.35%	85.363%
(20)	90.40%	105.52%	115.27%	103.68%	115.27%	96.622%
(10)	95.13%	103.17%	107.68%	102.14%	107.68%	98.770%
0	100.00%	100.00%	100.00%	100.00%	100.00%	100.000%
5	102.48%	98.09%	96.13%	98.69%	96.13%	100.252%
7	103.48%	97.26%	94.58%	98.12%	94.58%	100.283%
8	103.98%	96.84%	93.81%	97.83%	93.81%	100.284%
9	104.49%	96.40%	93.03%	97.53%	93.03%	100.274%
10	104.99%	95.96%	92.25%	97.22%	92.25%	100.254%
15	107.53%	93.60%	88.35%	95.59%	88.35%	100.000%
20	110.09%	91.00%	84.44%	93.79%	84.44%	99.484%
50	125.22%	72.22%	61.76%	80.06%	61.76%	91.212%
75	135.65%	57.20%	46.16%	67.06%	46.16%	79.791%
100	144.24%	43.66%	33.41%	53.77%	33.41%	66.168%
125	151.23%	31.76%	23.14%	40.87%	23.14%	51.678%
150	156.79%	21.63%	15.06%	28.97%	15.06%	37.450%
175	161.08%	13.36%	8.92%	18.56%	8.92%	24.440%
200	164.20%	7.03%	4.51%	10.09%	4.51%	13.498%
225	166.23%	2.68%	1.66%	3.98%	1.66%	5.392%
250	167.27%	.38%	.23%	.59%	.23%	.804%
265.084	167.43%	.00%	.00%	.00%	.00%	.000%

TABLE 7-12: Restatement of Table 7-10, but Lambda is 8 Instead of Nil

DISTANCE TO PORT	RES. RENT $/tonne	BIOMASS tonnes/m	HARVEST tonnes/m	EFFORT units	REVENUE $/m	COSTS $/m
0 km	100.0%	63.7%	100.0%	100.0%	100.0%	100.0%
2	97.9%	63.9%	99.8%	99.5%	98.4%	99.5%
4	95.9%	64.2%	99.7%	99.0%	96.7%	99.0%
6	93.8%	64.4%	99.5%	98.5%	95.0%	98.5%
8	91.7%	64.6%	99.4%	97.9%	93.4%	97.9%
10	89.7%	64.9%	99.2%	97.4%	91.7%	97.4%
12	87.6%	65.1%	99.0%	96.8%	90.1%	96.8%
14	85.5%	65.4%	98.8%	96.3%	88.4%	96.3%
16	83.5%	65.7%	98.6%	95.7%	86.8%	95.7%
18	81.4%	66.0%	98.4%	95.1%	85.1%	95.1%
20	79.4%	66.2%	98.2%	94.4%	83.4%	94.4%
22	77.3%	66.5%	97.9%	93.8%	81.8%	93.8%
24	75.3%	66.8%	97.7%	93.1%	80.1%	93.1%
26	73.3%	67.1%	97.4%	92.5%	78.4%	92.5%
28	71.2%	67.5%	97.2%	91.8%	76.8%	91.8%
30	69.2%	67.8%	96.9%	91.1%	75.1%	91.1%
32	67.2%	68.2%	96.6%	90.3%	73.4%	90.3%
34	65.2%	68.5%	96.3%	89.6%	71.7%	89.6%
36	63.2%	68.9%	96.0%	88.8%	70.1%	88.8%
38	61.1%	69.3%	95.6%	88.0%	68.4%	88.0%
40	59.1%	69.7%	95.3%	87.1%	66.7%	87.1%
42	57.2%	70.1%	94.9%	86.3%	65.0%	86.3%
44	55.2%	70.5%	94.5%	85.4%	63.3%	85.4%
46	53.2%	71.0%	94.0%	84.4%	61.6%	84.4%
48	51.2%	71.4%	93.6%	83.5%	59.9%	83.5%
50	49.2%	71.9%	93.1%	82.5%	58.2%	82.5%
52	47.3%	72.4%	92.6%	81.5%	56.5%	81.5%
54	45.3%	73.0%	92.0%	80.4%	54.8%	80.4%
56	43.4%	73.5%	91.5%	79.3%	53.0%	79.3%
58	41.5%	74.1%	90.8%	78.1%	51.3%	78.1%
60	39.5%	74.7%	90.2%	76.9%	49.6%	76.9%
62	37.6%	75.4%	89.5%	75.6%	47.9%	75.6%
64	35.7%	76.0%	88.7%	74.3%	46.1%	74.3%
66	33.8%	76.7%	87.9%	72.9%	44.4%	72.9%
68	32.0%	77.5%	87.0%	71.5%	42.6%	71.5%
70	30.1%	78.3%	86.0%	70.0%	40.8%	70.0%
72	28.3%	79.1%	84.9%	68.4%	39.1%	68.4%
74	26.4%	80.0%	83.8%	66.7%	37.3%	66.7%
76	24.6%	81.0%	82.5%	65.0%	35.5%	65.0%
78	22.8%	82.0%	81.2%	63.1%	33.7%	63.1%
80	21.1%	83.0%	79.7%	61.2%	31.9%	61.2%
84	17.6%	85.4%	76.2%	56.8%	28.2%	56.8%
86	15.9%	86.7%	74.1%	54.5%	26.3%	54.5%
88	14.3%	88.2%	71.9%	51.9%	24.4%	51.9%
90	12.7%	89.7%	69.3%	49.2%	22.5%	49.2%
94	9.6%	93.2%	63.1%	43.1%	18.6%	43.1%
96	8.1%	95.3%	59.4%	39.7%	16.6%	39.7%
98	6.7%	97.5%	55.0%	36.0%	14.6%	36.0%
100	5.4%	100.0%	50.0%	31.9%	12.5%	31.9%
Port value	$158.12	1.05936	.10819	.06383	$216.37	$58.25

TABLE 7-13: The Key Variables in a One Spacial Dimension Open Access Fishery, with an Optimum Royalty and a Subsidy on Transportation Costs

ROYALTY PER TONNE	PERCENT SUBSIDY Percent	BIOMASS tonnes	TAC HARVEST tonnes	EFFORT Units	GROSS REVENUE $ 000s	FISHING COSTS		GROSS ROYALTIES $ 000s	TOTAL SUBSIDY $ 000s	RESOURCE RENT $ 000s
						EFFORT $ 000s	TRANSPORT $ 000s			
.00	(14.32)	64,789	6,931.2	8,654.2	13,862.3	7,898.4	5,963.9	.0	(747.0)	747.0
25.00	(12.65)	65,323	6,956.7	8,602.6	13,913.5	7,851.3	5,888.3	173.9	(661.3)	835.3
50.00	(10.99)	65,867	6,982.3	8,550.2	13,964.7	7,803.5	5,812.1	349.1	(575.3)	924.4
75.00	(9.32)	66,422	7,008.0	8,497.1	14,016.0	7,755.0	5,735.4	525.6	(488.9)	1014.5
100.00	(7.65)	66,989	7,033.7	8,443.3	14,067.3	7,705.9	5,658.1	703.4	(402.2)	1105.6
125.00	(5.99)	67,567	7,059.4	8,388.6	14,118.7	7,656.1	5,580.2	882.4	(315.2)	1197.6
150.00	(4.32)	68,157	7,085.0	8,333.2	14,170.1	7,605.5	5,501.8	1,062.8	(227.8)	1290.6
200.00	(.99)	69,375	7,136.3	8,219.9	14,272.7	7,502.1	5,343.4	1,427.3	(52.2)	1479.4
214.80	.00	69,746	7,151.5	8,185.7	14,303.0	7,470.8	5,296.0	1,536.1	.0	1536.1
250.00	2.35	70,646	7,187.4	8,103.1	14,374.9	7,395.5	5,182.5	1,796.9	124.6	1672.3
300.00	5.68	71,974	7,238.2	7,982.7	14,476.3	7,285.5	5,019.4	2,171.5	302.3	1869.1
400.00	12.35	74,818	7,337.8	7,729.8	14,675.6	7,054.7	4,685.7	2,935.1	660.1	2275.1
500.00	19.01	77,947	7,433.2	7,459.2	14,866.5	6,807.8	4,342.1	3,716.6	1,019.4	2697.2
600.00	25.68	81,409	7,521.8	7,168.4	15,043.5	6,542.4	3,988.1	4,513.1	1,378.1	3135.0
700.00	32.35	85,265	7,599.5	6,854.2	15,198.9	6,255.6	3,623.7	5,319.6	1,732.6	3587.0
800.00	39.01	89,595	7,660.6	6,512.8	15,321.3	5,944.0	3,248.7	6,128.5	2,078.3	4050.2
867.53	43.52	92,837	7,688.6	6,264.5	15,377.2	5,717.4	2,989.7	6,670.1	2,303.3	4366.8
900.00	45.68	94,500	7,697.0	6,139.3	15,394.0	5,603.1	2,863.5	6,927.3	2,408.1	4519.2
1,000.00	52.35	100,114	7,696.0	5,727.3	15,391.9	5,227.1	2,468.8	7,696.0	2,712.1	4983.9
1,009.86	53.00	100,713	7,693.2	5,684.3	15,386.4	5,187.9	2,429.5	7,769.1	2,740.1	5028.9
1,100.00	59.01	106,623	7,638.3	5,268.4	15,276.5	4,808.3	2,066.1	8,402.1	2,974.9	5427.2
1,200.00	65.68	114,284	7,493.0	4,751.0	14,986.0	4,336.1	1,658.3	8,991.6	3,173.6	5818.0
1,300.00	72.35	123,473	7,208.7	4,158.8	14,417.4	3,795.6	1,250.5	9,371.3	3,271.6	6099.8
1,372.89	77.21	131,451	6,864.4	3,666.6	13,728.8	3,346.4	958.4	9,424.1	3,246.2	6177.8
1,400.00	79.01	134,764	6,694.7	3,467.5	13,389.3	3,164.7	852.1	9,372.5	3,208.3	6164.3
1,500.00	85.68	149,087	5,778.3	2,638.7	11,556.6	2,408.2	480.9	8,667.5	2,877.7	5789.7
1,600.00	92.35	168,079	4,096.0	1,606.4	8,192.0	1,466.2	172.2	6,553.6	2,078.5	4475.1
1,700.00	99.01	194,987	753.7	243.6	1,507.3	222.3	3.8	1,281.2	378.7	902.5
1,710.00	99.68	198,339	254.5	80.4	508.9	73.4	.4	435.1	127.4	307.7
1,714.70	99.99	199,968	4.9	1.5	9.9	1.4	.0	8.4	2.5	6.0
1,714.72	100.00	199,975	3.8	1.2	7.7	1.1	.0	6.6	1.9	4.7
1,714.74	100.00	199,982	2.8	.9	5.5	.8	.0	4.7	1.4	3.4
1,714.76	100.00	199,989	1.7	.5	3.4	.5	.0	2.9	.8	2.0
1,714.78	100.00	199,996	.6	.2	1.2	.2	.0	1.0	.3	.7
1,714.79	100.00	200,000	.1	.0	.1	.0	.0	.1	.0	.1

TABLE 7-14: The Key Variables in a One Spacial Dimension IQ Fishery with an Optimal Royalty and a Subsidy on Transportation Costs

TRANSPORT SUBSIDY PERCENT	BIOMASS AT POINT •	ACTIVE ZONE	CHi	BIOMASS tonnes	TAC HARVEST tonnes	EFFORT Units	GROSS REVENUE $ 000s	COSTS ($ 000s) EFFORT	COSTS ($ 000s) TRANSPORT	TRANSPORT SUBSIDY $ 000s	PRIVATE PROFIT $ 000s	RESOURCE RENT $ 000s
.00	.50	100.0	687	92,420	7,686	6,296.1	15,371.7	5,746.2	5,298.0	.00	4327.49	4,327.488
2.50	.54	100.0	807	96,583	7,702	5,984.6	15,403.8	5,462.0	5,241.3	131.03	4,831.6	4,700.517
5.00	.58	100.0	927	100,597	7,694	5,692.6	15,387.5	5,195.4	5,171.8	258.59	5,278.9	5,020.323
7.50	.61	100.0	1,047	104,476	7,664	5,417.7	15,328.0	4,944.5	5,091.2	381.84	5,674.1	5,292.261
10.00	.65	100.0	1,167	108,230	7,615	5,157.9	15,229.4	4,707.5	5,001.1	500.11	6,021.0	5,520.872
12.50	.69	100.0	1,287	111,869	7,548	4,911.6	15,095.6	4,482.7	4,902.9	612.86	6,322.9	5,710.039
15.00	.73	100.0	1,407	115,401	7,465	4,677.5	14,929.7	4,269.0	4,797.6	719.64	6,582.8	5,863.116
17.50	.76	100.0	1,527	118,833	7,367	4,454.3	14,734.5	4,065.3	4,686.3	820.10	6,803.1	5,983.020
20.00	.80	100.0	1,647	122,172	7,256	4,240.9	14,512.5	3,870.6	4,569.6	913.93	6,986.2	6,072.306
22.50	.84	100.0	1,767	125,424	7,133	4,036.7	14,265.8	3,684.1	4,448.4	1,000.90	7,134.1	6,133.226
25.00	.88	100.0	1,887	128,594	6,998	3,840.7	13,996.3	3,505.2	4,323.2	1,080.81	7,248.6	6,167.778
27.31	.91	100.0	1,998	131,455	6,864	3,666.3	13,728.4	3,346.1	4,204.4	1,148.23	7,326.0	6,177.810
27.50	.91	100.0	2,007	131,688	6,853	3,652.2	13,705.6	3,333.3	4,194.6	1,153.50	7,331.2	6,177.740
30.00	.95	100.0	2,127	134,708	6,698	3,470.8	13,395.3	3,167.7	4,062.9	1,218.86	7,383.6	6,164.706
32.50	.99	100.0	2,247	137,660	6,533	3,295.9	13,066.7	3,008.0	3,928.5	1,276.78	7,406.9	6,130.109
35.00	1.03	100.0	2,367	140,547	6,361	3,126.9	12,721.0	2,853.8	3,791.9	1,327.18	7,402.4	6,075.242
37.50	1.06	100.0	2,487	143,372	6,180	2,963.5	12,359.4	2,704.7	3,653.4	1,370.01	7,371.3	6,001.279
40.00	1.10	100.0	2,607	146,138	5,991	2,805.4	11,982.8	2,560.4	3,513.1	1,405.24	7,314.5	5,909.285
42.50	1.14	100.0	2,727	148,848	5,796	2,652.1	11,592.0	2,420.5	3,371.3	1,432.82	7,233.1	5,800.234
45.00	1.18	100.0	2,847	151,505	5,594	2,503.3	11,188.1	2,284.7	3,228.3	1,452.76	7,127.8	5,675.017
47.50	1.21	100.0	2,967	154,111	5,386	2,358.8	10,771.6	2,152.8	3,084.3	1,465.03	6,999.5	5,534.451
50.00	1.25	100.0	3,087	156,668	5,172	2,218.4	10,343.3	2,024.7	2,939.3	1,469.65	6,848.9	5,379.289
52.50	1.29	100.0	3,207	159,178	4,952	2,081.7	9,983.7	1,899.9	2,793.6	1,466.63	6,676.9	5,210.225
55.00	1.33	100.0	3,327	161,644	4,727	1,948.7	9,453.6	1,778.5	2,647.2	1,455.98	6,483.9	5,027.901
57.50	1.36	100.0	3,447	164,067	4,497	1,819.0	8,993.4	1,660.1	2,500.4	1,437.72	6,270.6	4,832.911
60.00	1.40	100.0	3,567	166,448	4,262	1,692.5	8,523.7	1,544.7	2,353.2	1,411.89	6,037.7	4,625.810
62.50	1.44	100.0	3,687	168,790	4,022	1,569.1	8,044.8	1,432.0	2,205.6	1,378.51	5,785.6	4,407.110
65.00	1.48	100.0	3,807	171,094	3,779	1,448.5	7,557.2	1,322.0	2,057.9	1,337.62	5,514.9	4,177.292
67.50	1.51	100.0	3,927	173,361	3,531	1,330.7	7,061.3	1,214.5	1,910.0	1,289.25	5,226.1	3,936.804
70.00	1.55	100.0	4,047	175,592	3,279	1,215.5	6,557.5	1,109.3	1,762.1	1,233.45	4,919.5	3,686.065
72.50	1.59	100.0	4,167	177,790	3,023	1,102.8	6,046.1	1,006.5	1,614.1	1,170.25	4,595.7	3,425.468
75.00	1.63	100.0	4,287	179,954	2,764	992.5	5,527.5	985.8	1,466.3	1,099.70	4,255.1	3,155.381
77.50	1.66	100.0	4,407	182,087	2,501	884.4	5,001.9	807.2	1,318.5	1,021.84	3,898.0	2,876.153
80.00	1.70	100.0	4,527	184,188	2,235	778.6	4,469.6	710.6	1,170.9	936.72	3,524.8	2,588.108
82.50	1.74	100.0	4,647	186,260	1,965	674.8	3,930.9	615.9	1,023.5	844.38	3,135.9	2,291.555
85.00	1.78	100.0	4,767	188,303	1,693	573.0	3,386.1	523.0	876.3	744.88	2,731.7	1,986.785
87.50	1.81	100.0	4,887	190,317	1,418	473.1	2,835.3	431.8	729.4	638.25	2,312.3	1,674.072
90.00	1.85	100.0	5,007	192,385	1,139	375.1	2,278.8	342.3	582.8	524.55	1,878.2	1,353.676
92.50	1.89	100.0	5,127	194,266	858	278.8	1,716.9	254.5	436.6	403.83	1,429.7	1,025.843
95.00	1.93	100.0	5,247	196,202	575	184.3	1,149.6	168.2	290.7	276.13	966.9	690.807
97.50	1.96	100.0	5,367	198,113	289	91.3	577.3	83.6	145.1	141.50	490.3	348.789
98.00	1.97	100.0	5,391	198,492	231	73.0	462.2	66.6	116.1	113.75	393.3	279.566
99.00	1.99	100.0	5,439	199,248	116	36.4	231.5	33.2	58.0	57.42	197.7	140.315
99.50	1.99	100.0	5,463	199,625	58	18.1	115.8	16.6	29.0	28.85	99.1	70.290
99.75	2.00	100.0	5,475	199,812	29	9.1	57.9	8.3	14.5	14.46	49.6	35.178
99.90	2.00	100.0	5,483	199,925	12	3.6	23.2	3.3	5.8	5.79	19.9	14.079
99.95	2.00	100.0	5,485	199,962	6	1.8	11.6	1.7	2.9	2.90	9.9	7.041
99.97	2.00	100.0	5,486	199,977	3	1.1	7.0	1.0	1.7	1.74	6.0	4.225
99.99	2.00	100.0	5,487	199,992	1	.4	2.3	.3	.6	.58	2.0	1.400

8.0 PARALLELS BETWEEN THE SYSTEMS APPROACH MODEL AND ACTUAL FISHERIES

As noted in section 5, the difference between *a systems modeling approach* and *a Cartesian/reductionist approach* rests less on technique and more on how techniques are applied and results interpreted. It is inconsistent with a systems approach to speak of a model as being correct or accurate. However, in pragmatic terms, the merit of using a systems approach to model fisheries is revealed by the quality of the parallels that can be drawn between actual fisheries and the prognostications, assumptions and caveats of the systems model. This section compares several of the more significant insights developed in previous sections with observations from several fisheries. A general overview and summary is given in section 10.

This section identifies and examines a selection of the parallels between actual fisheries and the systems (general) fishery model highlighted in the earlier sections of this dissertation. In most of the following subsections, British Columbia's sablefish fishery is reviewed (along with experiences from other fisheries) and conclusions are drawn about potential contributions that a systems approach can make to the discipline of fisheries management. The last subsection in this section provides a review of and a (systems) context for the meanings that are often attributed to the value of fishing rights.

8.1 THE BRITISH COLUMBIA SABLEFISH FISHERY

Sablefish (***Anoplopoma fimbra***) is also called ***Alaska blackcod, blackcod, coalfish, coalcod*** or ***black cod*** and may be *incorrectly* called ***bluecod, bluefish, candlefish, skil-fish*** or ***skil*** (Lamb and Edgell, 1986, p.124). Bell et al. (1986, p.1) state that:

> "The present minimum size limit for the Canadian fishery is 55 cm FL [fork length], equivalent to about 1.8 kg round weight (McFarlane and Beamish, 1983[c]). Sablefish are exploited for their economic yield of edible flesh, and in earlier times also for the yield of vitamins A and D from their livers. The firm, white, oily (*moist*) flesh commands a high price from the restaurant and ethnic trades and the smoked product has a high commercial value."

Eschmeyer et al. (1983, p.154) note that sablefish:

- are: "An elongate fish with 2 dorsal fins. Anal fin similar to and opposite 2nd dorsal fin. Scales small weakly ctenoid",[117]
- young (< 15 cm) tend to be found in shallow waters and are blue-black above and white below,
- adults (30-61 cm) are often greenish with faint stripes on the back and are found on mud at moderate depths (305-914-1839 m),
- can attain a length of 102 cm and a weight of 57 kg, but a maximum length of < 76 cm and weight of < 11 kg is more common, and
- range from Japan and the Bering Sea to central Baja California.

"The oldest age determined to date for sablefish is 55 yr, however, the majority of [commercial trap caught fish] fish range from 4 to 35 yr" (McFarlane and Beamish, 1983a, p.69).

8.1.1 THE BRITISH COLUMBIA SABLEFISH FISHERY -- A BRIEF HISTORY

Sablefish have been fished commercially by North Americans since the late 1800s (Ketchen and Forrester, 1954). However, Table 8-1 shows that the fishery was lightly exploited until foreign fleets arrived in the late 1960s. In the Canadian fishery: longline was the primary gear until 1970, trawling was important from the mid 1960s until the early 1970s and traps have been the dominant gear, since their introduction to the Canadian fishery in 1973.

---

[117] Ctenoid is a greek word meaning like a comb.

In the late 1970s, *distant water fishing nations* took most of the sablefish harvest off the Pacific coast of Canada.[118] A TAC was imposed in 1978—one year after Canada declared a 200 mile EEZ (exclusive economic zone; Copes, 1978b, pp.157-158) around its coasts. However, the annual TACs have always been significantly exceeded by the actual reported landings (Tables 8-2 and 8-4). During Canada's phase-out of foreign harvests of sablefish (1977, 1978 and 1979) Canadian observers on foreign vessels (fishing the Canadian Pacific EEZ) gained valuable information on the sablefish stocks (e.g. stock size, location, age structure), gears and fishing methods (Selsby et al., 1977; Selsby et al., 1977a; Selsby and Matthews, 1978; Thomas, 1978; Osterman, 1978; Osterman, 1978a; Leaman, et al., 1980; Leaman, et al., 1981).

"Licence limitation was contemplated in 1978 to ensure that the fleet did not overexpand [DFO estimated that the sablefish stock could accommodate 10 to 15 specialized vessels] but,...it was left too late. A year later the Japanese market for sablefish burgeoned, and triggered a stampede into the fishery....The Minister finally restricted further entry in October 1979, but by then 47 vessels had to be grandfathered in. ...Sablefish (*K*) licences ... can be transferred with the vessel, but the foot-for-foot rule applies if the licence is replaced. ... With three or four times the needed capacity licensed to fish the stocks, the sablefish fishery is now in serious trouble. Only half of the licensed vessels engaged in the fishery in 1981, yet the fishing

---

[118] Warner (1983) provides a good general discussion/history of the distant water fishing fleets.

pressure forced an early closure." (Pearse, 1982, pp.125-126).

Table 8-3 shows that limited entry was not a binding constraint in B.C.'s sablefish fishery until the late 1980s—during the early to mid 1980s roughly half of the licensed vessels were not active in the fishery and over a quarter of the licensed vessels were not active in any fishery. In 1988, all but two of the licensed vessels were active in the sablefish fishery.

"The Department of Fisheries and Oceans (DFO) made an attempt to establish an individual transferable quota (ITQ) system for the sablefish fishery in 1986. This attempt failed mainly because of lack of acceptance among the fishermen. ...Allocation of the TAC into ITQs ... has been done largely on the basis of historical catch performance. In 1986, too many sablefish fishermen felt that this would leave them too low a share of the TAC, relative to what they felt entitled to or relative to what they felt able to catch within the existing system of a seasonal open fishery." (Longva, 1990, p.4). It is interesting to note that the number of inactive K-licenses declined rapidly after 1986. At least some of the perceived return to fishing effort in the late 1980s was in terms of increasing (or at least maintaining) the present value of the IQ allocations, that fishermen expected DFO to impose sooner or later.

By the late 1980s the B.C. sablefish fishery was in deep trouble. Table 8-4 and Figure 8-1 show that, while the effective fishing effort had remained relatively constant from 1978 to 1989, the fishing season was being reduced exponentially in a lagged attempt to offset the exponentially increasing fishing power (see eqns (23) through (26)). In 1988 and 1989, DFO tried to spread the fishing season over the year by having each fisherman elect to fish only one of a few short openings. This innovation increased the amount of the harvest that could be sold in the fresh market and reduced vessel crowding and gear conflicts. The increased price of the yield likely led (*ceteris paribus*) to increases in fishing power applied to the fishery. Also, the many short seasons decreased the management options available to DFO (e.g. they could not equitably adjust the fishing season to maintain the TAC). The 1988 and 1989 harvests (respectively 5,771.3 and 5,349.0 tonnes) significantly exceeded what Saunders and McFarlane (1990, p.132) had called the high risk sustainable yield of 5,000 tonnes and the expected (long-run) sustainable yield of 4,000 tonnes.

In November of 1989, DFO submitted an ITQ discussion paper to all sablefish licence holders (Chamut, 1989). An overwhelming majority of the licence holders approved of the ITQ plan and it was instituted, on a two year trial basis, for the 1990 fishing season.[119] Under the ITQ plan (per: Chamut, 1989 and Longva, 1990):

- The TAC will be set annually (4668.5 tonnes for 1990).
- The TAC will be allocated 91.25 % to K-Licences (4,260 tonnes for trap and longline) and 8.75 % to T-licences (408.5 tonnes for the trawler incidental catch).

---

[119] After the two year trial period, the minister of fisheries will consult with the sablefish industry and fishery managers and will decide whether to discontinue or make permanent the sablefish ITQs (Chamut, 1989, p.4).

- The K-licence quotas will be allocated to a licence based:
  - 70 % on the weighted average of the best annual catch performance during 1987 to 1989 associated with that license, and
  - 30 % on the *relative* length of the vessel associated with that license (e.g. the vessel length as a fraction of the summed lengths of all the vessels).
- After the two year trial period, ITQs will be transferable in whole or in part. During the trial period, only the total quota can be transferred (and only to a K-licensed vessel).
- The fishing season would not be restricted and K-licence holders would be able to retain (as part of their ITQ) any sablefish they catch incidentally in other fisheries.
- Sablefish landings are to be monitored with mandatory logbooks, sales slips, limited landing ports, dockside observers and a check-in/out system. The monitoring costs will be recovered via a royalty charged on the weight of the catch (in 1989 the royalty was expected to be $.02/pound).
- In the absence of a reduced season and with the assurance that they will have an opportunity to catch a fixed share of the TAC, K-licence holders will want to reduce the fishing power of their vessels and will be encouraged to keep incidental catches of such valuable species as rockfish and lingcod.

Thus, while B.C.'s sablefish fishery has a relative long history, the period of intense exploitation is comparatively recent. Also, data on that period is readily available and is of relatively high quality. Further, the fishery has in recent history evolved from an open access international fishery, through a limited entry phase, to the current ITQs. Thus, the B.C. sablefish fishery is a good fishery to look for parallels between it and the model in this dissertation.

8.1.2 B.C. SABLEFISH -- HOW SUSTAINABLE YIELD IS DETERMINED

In 1985 DFO biologists (McFarlane et al., 1985, pp.164-165) observed that:

- "Accurate landings and effort statistics for the Canadian trap fishery were unavailable until 1977....The change from Canadian rectangular traps to Korean conical traps around 1978 further complicated the situation in that the change-over was so complete that we have very little information to standardize the two types of traps."

- "For previous stock assessments, Canadian scientists used two methods to estimate MSY (Westrheim 1980). The first method involves a regression of LPUE (landings per unit effort) on the average fishing effort over a number of preceding years (K), which ideally should be equal to the average length of time an individual of a year class is vulnerable to the fishery (Gulland 1961); the second is a dynamic, stochastic version of a Schaefer model (Schnute, 1977). Using Gulland's (1961) linear regression model, estimates of MSY using landings-per-10-hachi and landings-per-boat-day ranged between 3,200 and 4,100 tonne/yr.[120] The results generated by the modified Schaefer model produced estimates ranging from 5,200 to 6,200 tonne/yr."

- "Because some of the assumptions of the surplus production model have not been met, alternative models are now being applied. ... [cohort] analysis suggests that the stock will experience a rapid increase in biomass over the next few years due to the entry of the large 1977 year-class and the slightly above average 1978, and possibly 1979, year classes. Yield per recruit calculations over a range of fishing mortality [has indicated that]....Y/R is maximized at F_{max} = [F=] 1.212 and $F_{0.1}$ [occurs where F=] 0.205."

When making yield recommendations, the DFO biologists frequently refer back to the 1985 study (Saunders, 1986, p.30; Saunders, et al., 1988, pp.108-109; Saunders and McFarlane, 1990, p.131). In 1988, DFO biologists noted that the:

> "F levels of 0.205 and 0.1025. ...correspond to the $F_{0.1}$ and the $F_{0.05}$ levels from yield per recruit analysis (McFarlane et al. 1985). While $F_{0.1}$ is assumed to be conservative for most species, it is not known if it is conservative for a long-lived species with low recruitment. It is likely that the acceptable catch is somewhere between the two." (Saunders, et al., 1988, p.109).

---

[120] Hatchi is a Japanese word for a skate (Leaman, et al., 1981, p.4).

In 1990, DFO biologists stated that for sablefish:

> "Risk in the yield options below is a function of the uncertainty regarding recruitment. There exists a strong possibility that the high-risk level may interfere with the future yield....Given a commitment to an $F_{0.1}$ approach, the following levels are appropriate. ...The high risk level [5,000 t] is the mid-point between the F levels assuming high recruitment and high natural mortality. The low risk level [2,900 t] is the mid-point between the F levels assuming average recruitment and low natural mortality. The [expected] sustainable level [4,000 t] is the mid-point between the high and low risk levels." (Saunders and McFarlane, 1990, pp.131-132).

Table 8-4 shows that, since the 1978 inception of an annual TAC, the reported sablefish landings have always been significantly greater than the set TAC. DFO responded to this problem by setting shorter and shorter seasons. Figure 6-5 and subsections 6.1.3, 6.1.4.1 and 6.1.4.2 predict that while managing the fishing season can conserve the stock and control the effective fishing effort, it does so by increasing the cost of the effective fishing effort and dissipating all (or at least most) of the resource rent. The end result is a season of mere days or hours that encourages (or at least accommodates) vast amounts of fishing power. This effect is dramatically illustrated in Figure 8-1—from 1978-1989 the effective effort stayed relatively constant even as the fishing season effective length was progressively reduced from 365 to 14 days (3.8 percent of a year) and the fishing power increased over

30 fold.[121]

These points indicate that B.C.'s sablefish fleet is approaching maximum effectiveness and that, at a social level, efficiency is being lost. This comment, however, is not the same as the remark by Saunders and McFarlane (1990, p.132): "Barring any major innovations the [B.C. sablefish] fleet should be approaching a level of maximum efficiency."

8.1.3 B.C. SABLEFISH -- IS PIECE SELECTIVITY A LIKELY PROBLEM?

Subsection 7.3 discussed the problem that *high grading* can create for an IQ fishery. This problem occurs when the TAC is based on weight landed and the price per unit weight is not uniform across all pieces in the catch. Figure 8-2 and Tables 8-5 and 8-6 clearly show that the price/kg of sablefish rises (at a decreasing rate) with piece weight. The Figure 8-2 curve (based on Table 8-6) indicates (in the absence of handling costs) that an IQ holder who discards four 0.50 kg fish worth \$2.82 (4fish*.50kg*60%*\$2.35; where \$2.35 is the maximum price/kg, in Table 8-6) and catches a 2 kg fish worth \$4.14 (1*2*88%* 2.35) is 46.7 percent better off, than if he kept the smaller pieces. However, both choices reduce the IQ holders quota by 2 kg. Thus, there is a strong

---

[121] The use of 365 days as a base may overstate the degree of reduction in the effective fishing season. When the entire year is available to fish, people tend to not fish if the weather is bad or if stock concentrations are low. However, the following concerns should, also, be considered:

- **The "CPUE was examined by month and [was] found to be significantly higher in winter months (November-February) than in summer months" (Saunders and McFarlane, 1990, p.129).**
- **A benefit of ITQs is that "...operators would be under less pressure to overload their boats and fish or travel in poor weather conditions. If the weather turns bad fishermen can stop fishing and take shelter until conditions improve." (Chamut, 1989, p.2).**

incentive for piece selectivity in the B.C. sablefish fishery.

If the survival rate for the discarded pieces is high then, piece selectivity is unlikely to create a major problem in the sablefish IQ fishery. Given the nature of trawl fisheries, the survival rate of the trawl caught discards is likely to be low. However, the trawl quota is a *trawl commons* TAC (any trawl vessel can participate on a *catch-as-catch-can* basis until the trawl TAC is used-up). This type of TAC does not encourage high grading. Trap gear does kill a portion of the catch prior to the trap being raised. In a study on escape mechanisms to reduce ghost fishing of lost trap gear, Scarsbrook et al. (1988, p.159) observed that the mortality imposed by a trap increased exponentially with the soak time (5 percent at 10 days, 28 percent at 14 days and 51 percent at 15 days). Given that the commercial trap soak times tend to be less than two days (Beamish, et al. 1980, p.3) and that sablefish are relatively hardy, the trap discard mortality is likely to be relatively low.[122] As longlines are harder on the fish, the discard mortality associated with that gear is likely to be relatively high.

---

[122] "Because it has no swim bladder, sablefish can be brought to the surface in good physiological condition unlike most deep living fishes" (Sullivan and Smith, 1982, p.1013).

8.1.4 B.C. SABLEFISH -- IS TIME SELECTIVITY A LIKELY PROBLEM?

Table 8-6 shows that, in 1989, sablefish prices tended to be significantly lower in the summer months than in the winter months. Also, Saunders and McFarlane (1990, p.129) noted that in the sablefish trap fishery the CPUE was significantly higher in winter months (November-February) than in summer months. These factors would tend to concentrate fishing effort in the winter months. Mason, et al. (1983, p.139) show that approximately 90 percent of mature sablefish females spawn between the last week of January and the first week of March.

McFarlane and Beamish (1986, p.194) noted that, at present, it is "unlikely that fluctuations in fecundity as observed for some other species (Ware 1984) cause strong fluctuations in year-class abundance. Sablefish are long lived and extremely fecund and the adult population has not been seriously depleted." It can be inferred, from these comments, that (in terms of recruitment) the sablefish stock is currently in a *non-self-regulating state*, but at some point of biomass reduction and/or a shift toward a *younger age class structure* the stock could switch to a *self-regulating state.*[123] McFarlane and Beamish (1983b, p. 129) noted that for juvenile sablefish "growth is greatly reduced during winter months." Therefore, if effort in the sablefish fishery is focused on the winter months, seasonal growth overfishing should not be a problem. McFarlane and Beamish (1983a p.71) show that, due to the release of gonadal products, the piece weight of adult sablefish falls by approximately 15 percent after the winter spawning. The price/kg of sablefish (Table 8-6) implies that quality of (and/or the demand for) sablefish is greater in the winter than in the late spring and summer. McFarlane and Beamish (1983a, p.71) also show that the growth rate is much greater for younger fish than for older fish—thus, growth over-

---

[123] The concept of renewable resources being *self-regulating* or *non-self-regulating* was discussed by Marshall (1938, pp.166-167):

> "Among the renewable resources there are ... two types with fundamental differences, those for which the rate of renewal is dependent on the amount of resource which is left unharvested to perpetuate itself, and those where such dependence does not exist, or is negligible."

Schaefer (1957b, p.672) postulated that populations of sea fish are a *self-regulating* resource and, as such:

> "The annual rate of renewal of the resource [the equilibrium harvest] is a function both of the physical environment, which is presumably constant, on the average, over the long run, and of the magnitude of the standing crop, or population, of the resource, which is being diminished by the rate of harvesting."

Another approach is to treat *self-regulating* and *non-self-regulating* as the extremes of a continuum. While some stocks of fish have yield to effort functions which initially create the illusion of being *non-self-regulating*, all fish stocks become *self-regulating* beyond some level of fishing effort. However, for a few stocks a coincidence of the piece growth function, stock fecundity, presence of refuges, market prices, fishing costs and/or the current state of technology makes it impractical to harvest at, or beyond, that level of effort. This continuum concept is important in that it raise the possibility that minor changes in one or more of the listed coincidental factors can cause such a stock tc shift to a *self-regulating* state.

fishing is unlikely to become a problem before recruitment overfishing becomes a significant problem.

E.1.5 B.C. SABLEFISH -- IS STOCK SELECTIVITY A LIKELY PROBLEM?

Beamish et al. (1980, p.iii) noted that:

> "The sizes of mature fish of similar ages are extremely variable [in sablefish] and it appears that some coastal areas contain stocks of slow-growing individuals."

Beamish and McFarlane (1983a, p.181) inferred that:

> Adult Sablefish are, for the most part, resident but a few are highly migratory. As a result, "there is interbreeding throughout the range and that sablefish off the west coast of North America belong to one [genetic] population. However, the difference in migratory behaviour between releases off the Queen Charlotte Islands and Vancouver Island and the relatively large number of fish that remained in the immediate release area after five years indicate that the population is composed of several subpopulation or stocks."

McFarlane and Beamish (1983a, pp.62-63) note that:

> "Sablefish are also present on sea mounts. ... A research Survey conducted in 1979 in the Gulf of Alaska seamounts indicated that sablefish were abundant on all seamounts surveyed (NOAA, 1979)."

McFarlane and Beamish (1986, pp.191-192) note that:

> There is "no extensive migration [of spawning sablefish] although localized movements occur. Thus, it is probable that most sablefish spawn on local areas throughout the continental slope. ...In the laboratory, sablefish eggs reared at a temperature of 4°C and a salinity of 34 % hatched in an average time of 15 days. ... Neutral buoyancy measurements of eggs incubated at 4°C indicated that eggs would float freely [be dispersed by currents] at salinities of approximately 32 ppt at fertilization ... and 33.25 ppt after 80 h. Just prior to hatching (2 to 3 days) egg density increased, indicating that eggs in the ocean would sink, corroborating the interpretation of Mason et al. (1983) that during late embryonic development the eggs sink in the water volume. Hatching probably occurs at depth and it is likely that the early development of yolk sac larvae takes place below the relatively more dynamic upper waters, since no early yolk sac larvae were captured in the upper water column (Mason et al. 1083)....it is unknown at what point yolk sac larvae move up in the water column, however since some larvae were found in the surface waters at 7-8 mm (Kendall and Clark 1982; Shaw et al. 1983) it is likely that migration towards the surface begins in the late yolk utilization stage [approximately 20 days]."

These observations indicate that while stock selectivity may be a problem from a piece growth perspective, it is unlikely to cause major problems in the area of recruitment.

8.1.6 B.C. SABLEFISH -- IS LOCATIONAL SELECTIVITY A LIKELY PROBLEM?

Locational selectivity will be a problem if the return to fishing varies with some element of spatial location. This variation could be caused by factors such as stock densities, fishing costs, weather, sea floor features, currents etc.

Studies on the bathymetric distribution of sablefish have produced conflicting results. Studies from the mid 1960s and prior indicated that both biomass density and piece size varied strongly with depth. Kennedy and Pletcher (1968, pp.6-7) noted that:

> "A striking increase of fish size with depth is evident....Other investigators (Phillips, 1954; Shubnikov, 1963; Heyamoto and Alton, 1965; and Kibizaki, 1965) have reported a similar relationship between size and depth. ...Considering that catch per tow of all sablefish increases with depth and that the proportion of marketable sablefish among those caught also increases with depth, it is evident that abundance of marketable sablefish must increase dramatically with depth. ...That the best commercial catches are made at considerable depth is confirmed by Subnikov (1963), Heyamoto and Alton (1965) and Kibizaki (1965). In fact they, all either specify or imply that the best depth range for taking sablefish commercially is 200 to 450 fms [365.8 to 823.0 m]. Heyamoto and Alton report taking minor quantities of sablefish as deep as 650 fms [1,188.7 m]."

These conclusions appear to be in conflict with those of McFarlane and Beamish (1983a, pp.63-64) who state:

> "...sablefish were abundant between 400-1830 m. There was no apparent trend between total catch and depth range. Catches were consistently high between 400-800 m. Catches increased in deeper waters (>800 m) during the summer months and fall, probably a reflection of cessation of spawning (Mason et al. [1983]...). Similarly, CPUE varied without trend in relation to either depth or season. ...No change in the size distribution of trawl-caught

> sablefish was apparent in the Bering Sea between 200 and 900 m (Kulikov, 1965). No size segregation by depth interval in the commercial [trap] catch has been observed in the Canadian zone."

One explanation for the discrepancies is that, based on Table 8-7, the earlier work overlapped into the zone of juvenile fish. Specifically:

> "Adult sablefish are abundant along the entire westcoast of British Columbia at depths exceeding 200m....Juvenile sablefish are generally located in shallow inshore waters <200 m." (Mcfarlane and Beamish, 1983a, p.62).
>
> The majority of the 1977 year class juveniles began to move offshore and recruit to the adult population in 1981 at mean lengths of 52.7 and 56.0 cm for males and females, respectively (McFarlane and Beamish, 1983b, p.128).

Based on these observations it is reasonable to deduce that any differences in the bathymetric distribution of adult sablefish are minor and unlikely to contribute to a locational selectivity problem.

Spatial locational selectivity appears to have been a problem, to a degree—Hart (1973, p.457) cites Bell and Pruter (1958) and Larkin and Ricker (1964) to state that:

> "It appears that off the southern part of British Columbia where trawlers and longliners combine in exploitation of sablefish, the stock is being definitely overfished. Elsewhere further from market the fishery is in better condition."

8.1.7 B.C. SABLEFISH -- IS GENOTYPE SELECTIVITY A LIKELY PROBLEM?

Understanding the genotype concept requires that other concepts be understood.

> In ecology "...competitive exclusion...[is] the key to the structure of whole communities. Gause [1936; Gause and Witt 1935] identified the dynamic process as competition and mutual aid (symbiosis). The competitive principle that no two species could occupy the same niche was therefore the explanation of community structure, in that the best-adapted species were those that occupied the principle available niches. ...With Gause's interpretation of the niche as a unit structure over which species fought for possession, its dimensions shrank immediately to fit only one species. The niche became a place uniquely belonging to a given species, a place where it alone could enjoy full advantage as a

> competitor....the competitive exclusion principle, as it was renamed by Garrett Hardin in 1960....[is] potentially tautological ...[and] still prompts occasional protests that the principle is not useful [i.e. Gould's (1989, p.236) comments on fitness]. The problem occurs when one tries to define the niche in terms of the ecological requirements of species." (Kingsland, 1988, p.158-159).

> In "the *adaptive peak* [genetic landscape] concept of Wright (1932). ...peaks represent genotypes associated with suites of morphological characteristics that have high fitness. The genotypes that underlie *valley morphologies*, on the other hand, are unsuccessful. ...The landscape as well as the genotype may shift through time." (Stanley, 1979, pp.24-25).

> "... the *phenotype*, the individual as it appears, is the product of the effect of the environment on its *genotype*, its hereditary constitution. (Spurr and Barnes, 1980, p.4).

A niche is unlikely to be homogeneous over space and time. Thus, a niche should be thought of as a dynamic fuzzy concept, rather than a fixed static concept.[124] A species that has some diversity in both its phenotypes and genotypes is more resilient and, therefore, more likely to persist in this dynamic and uncertain world than a species that has no diversity. Ni (1978, p.2) notes that:

---

[124] In his paper on *Fuzzy Sets*, Lofti (1965) quoted Jan Christiaan Smuts: "...round every luminous point in experience, there is a gradual shading off into haziness and obscurity. A Concept is not merely its clear luminous centre, but embraces a surrounding sphere of meaning or influence of smaller or larger dimensions, in which the luminosity trails off and grows fainter until it disappears. The [use of] hard and abrupt contours make reality inexplicable, not only in the case of causation, but in all cases of relations between things, qualities, and ideas."

A person with a systems perspective will tend to be very comfortable with the fuzzy set concept. Whereas, a person with a Cartesianist/reductionist perspective will see the issue as one of the problem being under-specified. The difference between the two concepts is important. Specifically, while an under-specified problem can be correctly specified, a systems perspective indicates that an infinite number of specifications are needed to remove the fuzzyness from the solutions to most problems.

> "fish populations exhibit both common properties (homogeneity) and variability (heterogeneity). The variability of fish populations depends upon genetic constituents as well as environmental factors."

Intelligent management of a fishery requires a sound knowledge of the dynamics of the population that is being exploited. There is reason to believe that a population's characteristics (i.e. growth rates, fecundity, age/size at maturity, natural mortality rates) are part of its *life history strategy* (e.g. they are inter-related and co-evolved —Ni, 1978, p.ii; Roff, 1984, pp.989-991). As a result, there is also reason to believe that a change in mortality is only the first of many changes that a change in the exploitation rate inflicts on the characteristics of a stock. A clear understanding of *life history strategy* is required before these effects can be discussed. Begon and Mortimer (1986, pp.156) note that:

> "...by increasing its current reproductive effort (or by reproducing at all) an individual is likely to decrease its survivorship and/or its rate of growth, and therefore decrease its potential for reproduction in the future. ... the strategy adopted by an animal or a plant is a compromise allocation of [limited] energy to the various aspects of its life history, each of which contributes to total fitness [of the individual or its progeny]. The result is a co-adapted *suite* of characteristics which natural selection has favoured."

MacArthur and Wilson (1967) classify organisms by the main processes that control their populations:

- *R-strategists* tend to be short-lived species with high fecundity —they rely for their persistence on the ability to colonize new habitats and increase rapidly to make use of short-lived resources. After disasters *wipe-out* adult populations in unpredictable environments, their progeny are able to rapidly occupy/ reoccupy the niche. (Pitcher and Hart, 1982, pp.83-84).

- *K-strategists* tend to be long-lived slow growing species and in stable environments they survive long enough to crowd-out shorter lived competing species. (Pitcher and Hart, 1982, pp.83-84).

Like many longer lived demersal fish species, sablefish appear to have combined the two strategies. Specifically:

- adults grow relatively slowly and live in stable but nutrient poor deep water,
- larvae hatch in nutrient poor but relatively safe deep water that occasionally has enough nutrient density to foster large recruitments to the juvenile stock, and
- juveniles grow rapidly and live in nutrient rich but unpredictable shallow coastal waters.

Under such conditions, a long-lived slow growing genotype producing progeny over many seasons is more likely to produce progeny during one or more of the ideal recruitment years. In contrast, a short-lived fast growing genotype is less likely to survive long enough to produce progeny during the infrequent good years and will tend to be less represented in the population. Given that the pattern of these conditions is uncertain, a populations is more resilient if it is diverse in both phenotypes (e.g. short-run response) and genotypes (e.g. intermediate-run response).

Table 8-8 and Figure 8-3 show how the fecundity of sablefish varies with length. Mason (1984, p.2) estimated ($R^2 = 62.4\%$) the relation to be:[125]

---

[125] In fitting his curve to the data, Mason (1984, p.2) suggested that the last two data points be dropped because they did not fit eqn (220). The fork length, associated with both of the dropped points, was over 90 cm.

I was unable to duplicate Mason's results with either a nonlinear regression specification or a linearized form of eqn (220). It is possible that the regression algorithms used by Shazam (White, 1987) are different from those of the regression package used by Mason.

$$F = 0.73(FL)^{2.94} \tag{220}$$

F = fecundity in thousands of eggs per piece
FL = fork length in cm

Mason's function is displayed in Figure 8-3 with a dashed line. Using Mason's data a better fit (R^2 = 67.1%; $\bar{R}^2$ = 66.4%; Appendix E-5) was generated using the following exponential equation:[126]

$$F = (\underset{(29.4)}{10106} * e^{\underset{(9.99)}{.041282} FL})e^{\epsilon} \tag{221}$$

ϵ = log normally distributed error term that is more consistent with the error structure indicated in Table 8-8.

Equation (221) is illustrated in Figure 8-3 by a solid line. The point of Figure 8-3 is not the maximum likelihood relation but the distribution of the error. Instead of representing a statistical error that, distribution may portray an important characteristic of the population —it may be a measure of the population diversity in terms of fecundity. This concept should cause us to think of a population character-

---

[126] Four data points where dropped because their associated fork length was under 60 cm. In the first few seasons after recruitment to the adult population the fecundity of fish tends to be highly variable. The effect of this change can be seen by comparing the regression results in Appendix E-5 with the regression results using the complete data set (Appendix E-4).

istic as the fuzzy set around a regression line.[127] An individual fish tending to a *K-strategy* would likely be in the lower bound of the distribution around the regression line and an individual fish tending to an *R-strategy* would likely be in the upper bound. As the fishing mortality intensifies, the long-lived strategy of *K-strategy* individuals will be frustrated and their numbers will tend to decline, within the population. This will cause the regression line to shift-up and terminate at a smaller fork length. Thus, as fishing pressure increases on a long-lived stock the stock fecundity is likely to increase. However, the resilience of the stock (to long periods of low recruitment) will tend to decline and it will be at more risk of catastrophic failure.

It is difficult to find evidence of the above scenario. However, if it is viable, then age should affect fecundity in two ways:

1) Via piece growth. In Figure 8-3, larger fish tend to be more fecund and older fish tend to be larger than younger fish).
2) Via life-strategy. Fish that grow quickly tend to devote more energy (in a given year) to production and release of gonadal products than slower growing species. In fish, the natural mortality rate tends to vary with fecundity. Thus, at a given fork length, fecundity should vary inversely with age.

---

[127] While most actuaries are unfamiliar with the concept of fuzzy sets (per se), they do seek to make the mortality functions for human populations more precise by more precisely specifying each population Specifically, by separating the general population into categories (e.g. male/female, smoker /nonsmoker, married/single, etc.) the mortalities for each group can be made more precise than the summed mortality. (Jordan, 1952).

An important point about a fuzzy set is: while its fuzzyness may appear to be stochastic, it is often due to potentially deterministic factors rather than due to a stochastic process. A user of a fuzzy function has to choose between the cost of using fuzzy information and the cost of reducing that fuzzyness through a better and more complete specification. Systems theory informs us that an infinite amount of information is needed to completely specify any real problem.

These predictions were tested by regressing the following equation, on the data in Table 8-8 (see Appendices E-6 and F-5):

$$F = [a(e^{bFL})(AGE)^{c}]e^{\varepsilon} \tag{222}$$

The result of the regression was:[128]

$R^2 = 70.09\ \%$; $\bar{R}^2 = 68.82\ \%$

$a = 2.4459$ T-stat = 7.6891
$b = .047208$ T-stat = 10.040
$c = -0.22438$ T-stat = -2.3580

As predicted, once the indirect *growth effects* of age are disentangled from the direct effect, the fecundity varies inversely with age (e.g. parameter c is negative). This finding supports the thesis that fecundity varies with the piece growth rate. The second part of the thesis, is difficult to prove other than by inference—a low piece growth rate combined with a low fecundity is maladaptive for an individual (and/or its progeny) unless it induces a long life.

8.1.8 B.C. SABLEFISH -- IS COHORT SELECTIVITY A LIKELY PROBLEM?[129]

The age structure of the sablefish population and the interaction between cohorts appear to be important:

---

[128] There was no age given for data point 5. Therefore, the regression of eqn (222) generates its superior statistics with one less degree of freedom than that of the regression of eqn (221).

[129] The most reliable method of determining age-specific mortality, growth and fecundity for a population with overlapping generations is to follow the fate of a cohort (e.g. a group of individuals, all born during the same time interval). Cohort analysis has been applied to many fisheries. It is particularly applicable in fisheries that have some or all of the following features:

- a large number of age groups in the fishery,
- a long series of age composition data, and
- a complex and variable fishery (i.e. F varies with both age and year).

> "The importance of a large number of age groups for sablefish is unknown. It is possible that the ability to live to older ages permits sablefish to survive in an environment where food may be scarce and where recruitment is limited for extended periods." (McFarlane and Beamish, 1983a, p.78).

> "In contrast to mature individuals, actively growing juveniles are found in inshore waters, where food resources are greater. In the offshore waters, after maturation, growth is reduced. It is probable that most energy, surplus to maintenance requirements is used for reproduction. The extension of the reproductive life probably is an adaptation to surviving in the deeper offshore areas, particularly in times of unfavourable environmental conditions. It appears that under conditions of limited recruitment the stability of the populations may depend on maintenance of the age structure in the population. It also appears that the success of any year-class is dependent on its ability to move into areas of high productivity." (McFarlane and Beamish, 1983a, p.78).

> "The interaction of a strong year-class with succeeding year-classes may be a key parameter in determining the age structure of the stock. Direct competition and cannibalism are probably equally important in determining year-class strength." (McFarlane and Beamish, 1983a, p.78).

Managing a fishery on the basis of maintaining an average fishing mortality can create another form of year-class interaction. As noted above, part of the sablefish life-history-strategy involves infrequent very large recruitments. When such a recruitment occurs, in a constant fishing mortality fishery, the fishing pressure on the weaker cohorts increases. As such, a *mixed cohort fishery problem* is akin to the *mixed stock fishery problem* (Ricker, 1975, pp.303-307; Pitcher and Hart, 1982, p.192; Pearse, 1982, pp.13 and 51). The reduction of the older, weaker cohorts that can periodically occur in a mixed cohort fisheries is a problem because older fish tend to be larger fish (Table 8-8) and (per Figure 8-3) larger fish tend to be more fecund. In the sablefish fishery, a periodic reduction in the fecundity of the stock could combine with environmental cycles to generate infrequent but catastrophic stock crashes.

The sablefish population profiles, in Tables 8-9 and 8-10, show a disturbing decline in the absolute numbers of older fish. A profile of the percent of the population that each age category represents, is of little value in terms of understanding changes in the sablefish population structure—the effect of periodic large recruitments would tend to swamp out the effect under consideration. In Figure 8-4, the annual population for each age in Table 8-9 is indexed to the 1979 number for that age category. Figure 8-5 does the same for Table 8-10 except that 1977 is the index year. Both figures make it apparent that the numbers of fish in the middle of the age distribution are declining relatively quickly whereas the extremes (young and old) are either declining relatively slowly or are increasing in abundance.

One explanation for the Figures 8-4 and 8-5 observations is that, both landings and fishing intensity have been increasing (Table 8-4) and the middle aged fish tend to suffer the brunt of the fishing mortality—for various reasons younger and older fish in the stock may not be as vulnerable to the fishing gear used in the fishery. This contention is supported by the distribution of the fishing mortality rates, listed in Table 8-11.[130] In Table 8-11, the fishing mortality rates (F values) tend to be highest for middle aged fish. Figure 8-6 shows the average fishing mortality, by age, for the period 1977 to 1986.

It is tempting fit the scattering of points in Figure 8-6 with a curve of the form of either a Ricker or Schaefer curve (Ricker, 1975, pp.281-282; Clark, 1976, pp.15 and 215). In statistical terms, the fit should be excellent—especially if the error term is specified to have a log normal distribution. However, there is no reason to believe that there is a simple relationship between fish age and fishing mortality. Logically, a fish's probability of becoming part of the fishing mortality is a function of:

- The length of the fish, which (in turn) is a function of its age, gender, genetics, and nutritional history.
- Its age and any age-behaviour patterns.
- The gear mix in use in the fishery—different types of gear have different selectivity profiles (Gulland, 1983, pp.117-130).

---

[130] The age related mortality rates (F) for 1977 to 1986 were calculated from Table 8-9 using the same VPA (virtual population analysis) assumption made by Saunders and McFarlane, 1990, p.139 that the natural mortality rate was constant at $M = .10$. The rates for 1987 were taken from Saunders and McFarlane (1990, p.139). However, they are the unweighted averages for the 1977 to 1986 F values (see Table 8-9). The following equation shows how the F value can be used to define fishing mortality for a cohort (Gulland, 1983, p.105):

$N_{t+1} = N_t[e^{-(F_t+M)}]$; where: N = population numbers
t = period t
F = fishing mortality rate
M = natural mortality rate
Z = total mortality rate = $F + M$

- The numbers and vulnerability of other fish. When there are relatively large numbers of more vulnerable fish, then the TAC will more likely be filled with those fish, than with less vulnerable fish. When, there are relatively few fish that are more vulnerable, the less vulnerable fish will likely make up higher percentage of the catch than in the preceding situation.

Thus, all that should be inferred from Figure 8-6 is that historically middle-aged sablefish are more vulnerable to being harvested than the younger or older fish. If this is actually happening, the managers of the sablefish fishery may be in double jeopardy. First, managing for a constant average fishing mortality could decimate the middle-aged fish during a period of high recruitment. Second, a recruitment overfishing problem may not become apparent until the numbers of older/larger fish are reduced by natural mortality. These problems could lead to a cycle in the stock's fecundity. Specifically, if the stock fecundity is low during one of the infrequent occurrences of good to excellent recruitment conditions the future yields of the stock may be reduced. On the other hand if a strong cohort is at the most vulnerable age, managing for a constant average fishing mortality results in a harvest that is less than what could be safely taken.

8.1.9 B.C. SABLEFISH -- IS GEAR SELECTIVITY A LIKELY PROBLEM?

The length selectivity of a gear and the relative density of fish of each given length can be estimated by comparing catches from several fishing trials, providing assumptions are made concerning the form of the selection curve (Gulland, 1983, pp.117-130). The observed piece size selectivity profile of a given gear type can be attributed to one of several mutually exclusive fishable-stock recruitment patterns:

1) All sizes of fish in the stock are equally vulnerable.
2) Knife-edge recruitment—fish below a given size are not vulnerable and all fish above that size are equally vulnerable.

3) Vulnerability increases, at a linear rate, to a maximum.

4) Vulnerability increases, at a decreasing rate, toward a maximum.

5) Vulnerability increases, in a *logistic pattern*, toward a maximum.

6) Vulnerability increases, by one of methods (2) through (5), to a maximum and then declines toward nil.

Based on the discussion in the previous section (Figure 8-6), the most likely size selectivity pattern in the sablefish fishery is embodied in assumption (6). Gulland (1983, p.125) provided the following selectivity curve for gill nets:

$$C(L) = qD(L)[e^{-.5(\ln L-\ln L^{*})^{2}/\ln\sigma^{2}}] \tag{223}$$

C(L) = percent of the fish, taken by a gear set, that are of length L
L = fork length in cm
L^{*} = length at which selectivity is greatest
q = fishing power of gear for length L^{*} fish
D(L) = density, relative to the gear, of length L fish
σ = catchability standard deviation

Equation (223) gives a skewed selectivity distribution. Equation (20) can be expanded to:

$$\ln C(L) = \ln q + \ln D(L) + [\ln L^{*}(\ln L) - .5\ln^{2}L^{*} - .5\ln^{2}L]/\ln\sigma^{2} \tag{224}$$

which is of the linear form:

$$\ln C_{L} = a + b\ln L + c\ln^{2}L + \ln D(L) \tag{225}$$

$a = \ln q - .5\ln^{2}L^{*}/\ln\sigma^{2}$
$b = \ln L^{*}/\ln\sigma^{2}$
$c = -.5/\ln\sigma^{2}$
$\ln D(L) = \sum_{i=r}^{\infty} d_i D_i$
D_i = a dummy variable that equals 1 for L = i and 0 for all other values of L
r = minimum vulnerable length
∞ = maximum vulnerable length

The eqn (225) parameters can be manipulated to estimate the following gear selectivity and population parameters:

$$ln\sigma^2 = -.5/c \qquad (226)$$

$$lnL^{\bullet} = -.5b/c \qquad (227)$$

$$lnq = a + .25b^2/c \qquad (228)$$

$$L^{\bullet} = e^{-.5b/c} \qquad (229)$$

$$q = e^{(a-.25b^2/c)} \qquad (230)$$

$$\sigma^2 = e^{-.5/c} \qquad (231)$$

$$D = d \qquad (232)$$

However, for this analysis, what is of interest is the distribution of the gear size selectivity. That is captured by setting the gear power and the density parameters in eqn (223) to unity. The selectivity profiles of several gear types can be made comparable by setting the area under each distribution to 1.00. The data used in the following analysis is from Beamish, et al. (1980). In that study, piece length was measured to the nearest centimetre. As a result, it is not appropriate to use parameters derived from that data to form a continuous distribution with eqn (233). Instead, eqn (233) is used to develop a gear selectivity histogram for the potential range of sablefish lengths. A scaling factor is found to set the area of that histogram to 1.00 and the RHS of eqn (232) is multiplied by that scaling factor to produce:

$$GSI_L = (1/Z)e^{-.5(lnL-lnL^{\bullet})^2/ln\sigma^2} \qquad (233)$$

Z = scaling factor for the gear under consideration.

Regressions were not performed with the data in Tables 8-13, 8-14 and 8-15 (respectively: trawl, longline and trap)—to make the results from each sample comparable, the regression was performed on the percent that each piece length represented in the sample.[131] A summary of the regression results and the parameter values is given in Table 8-12 along with the appropriate Z parameter values. The Z parameter values were estimated using the following equation:[132]

$$1/Z = ab(4\pi \ln b)^{.5} \qquad (234)$$

π = pi

Figure 8-7 shows the gear selectivity profiles that result if the parameters from Table 8-12 are substituted into eqn (233). As expected the profiles are *log-normal-like* distributions. Each selectivity profile is the harvest that would occur if only the associated gear type was used in the fishery and if all lengths were equally represented in the population. Figure 8-7 indicates that the trawl harvest focuses on smaller pieces and that the harvest profiles of the longline and trap gears greatly overlap. However, the longline gear profile has more of a positive skew and a slightly higher mode than the trap gear profile. Saunders and McFarlane (1990, pp.127 and 143) found a similar pattern and noted:

---

[131] The original data from Beamish, et al., (1980, pp.18-21, 111-130 and 136-163) and Leaman, et al. (1981, pp.38-51) was separated into several convenient samples. The purpose of this process was to use the effect described in the *central limit theorem* (Kmenta, 1971, p.107) to reduce the statistical error and increase the accuracy of the parameters estimated for eqn (233).

[132] T. Heaps (Department of Econonics, Simon Fraser University) developed eqn (234). The results of eqn (234) were verified by using CC4 (Meredith, 1989) to integrate eqn (233) over the piece length interval 10 to 150 cm (see Appendix D-1) and by using simulation.

> "The trap and longline components appear to have similar selectivity patterns. Histograms of the proportion of the catch by weight categories for the two gear types, in 1987 and 1988, are...similar, [but] the longline fishery catches a slightly higher percentage of large fish than the trap fishery."

The profile of the three gears are not additive, because they are not equally represented in the harvest. The selectively profile, for the fishery as a whole, was estimated by multiplying the gear profiles by their percentage of the 1989 harvest. The result (Figure 8-8) confirms that the fishing selectivity tends to focused on mid-sized fish. Specifically, in Figure 8-8, the cumulative catch profile is:

PIECE LENGTH CM	CUMULATIVE % OF CATCH	INCREMENTAL % OF CATCH	LENGTH RANGE CM	% OF OBSERVED RANGE (19-120 CM)
62 to 63	7.9 %	7.9 %	2	2.0 %
61 to 64	15.7	7.8	4	3.9
60 to 65	23.3	7.6	6	5.9
59 to 66	30.7	7.4	8	7.8
58 to 67	37.7	7.0	10	9.8
57 to 68	44.3	6.6	12	11.8
56 to 69	50.5	6.2	14	13.7
55 to 70	56.2	5.7	16	15.7
54 to 71	61.4	5.2	18	17.6
53 to 72	66.1	4.7	20	19.6

In terms of fisheries management, what this section shows is that (for sablefish) the selectivity profile of trawl gear poses a significant interception threat to the other gears. Specifically, the trawl harvests younger fish and if the trawl TAC were greatly increased it would likely significantly reduce the amount of fish growing into the selectivity range of the other gears. In trading-off the catch of the various gear types, fishery managers should consider the shadow value of the fish taken—would the harvested fish have grown larger, become more valuable or cheaper to catch, if it had not been caught.[133] This is necessary because a tonne of fish taken by a gear is not always the same as a tonne of fish taken by another gear type.

Problems can arise even when quota is transferred from a gear type that selects for younger fish to one that selects for older fish. An example of such a problem may be occurring in New Zealand. Specifically, one of the benefits attributed to the shift from limited entry to ITQs was that:

> "Some fishermen have switched from trawl to longline gear to increase the value of their catch (e.g. snapper caught on longline gear sometimes commands a price several times higher than the price of trawl caught snapper)" (Macgillivary, 1990, p.9).

While this switch has both short and long-run benefits, it may refocus the fleet effort on age-classes that have already suffered losses and passed through the trawl fishery. In a slow growing fish like snapper, it may be decades before the benefits from reduced trawl mortality are passed through to the longline fishery. Thus, in the intermediate run, a shift of effort from trawl to longline gear could fish down the age-classes favoured in the longline selectivity profile. If some of the effort then switches back to trawling, a costly cycle of switching between the two gears could result.

---

[133] Helgason (1989) provides an excellent discussion of the concept of basing quotas on shadow value rather than weight.

8.1.10 B.C. SABLEFISH -- IS GENDER SELECTIVITY A LIKELY PROBLEM?

Sexual dimorphism has often been observed in the growth rates of sablefish (Kennedy and Pletcher, 1968, pp.20-21; Beamish and Chilton, 1982, p.285; McFarlane and Beamish, 1983a, p.70). Beamish and Chilton, 1983, p.285) developed the following von Bertalanffy parameter values for West Coast Queen Charlotte Island sablefish:

$$L_t = L_\infty(1-e^{-K(t-t_o)}) \qquad (235)$$

L = fork length
t = age t
∞ = age infinity
K = growth rate
t_o = starting age
for males: L_∞ = 65.5 cm
t_o = .14
K = .47

for females: L_∞ = 80.8 cm
t_o = -3.51
K = .16

The growth curves produced by eqn (235) and these parameters are shown in Figure 8-9. Female sablefish grow both faster and larger than male sablefish. If gear selectivity is based only on piece length, the age selectivity profiles for sablefish should differ between the genders. However, it is possible that the gear selectivity (by piece length) is not the same for each gender. Equation (225) was regressed against the disaggregated (male and female) sablefish longline catch data in Table 8-14. The resulting eqn (233) parameter values generated the curves in Figure 8-10. In that figure, the longline catch profiles appear to be significantly different for male and female sablefish. Both curves in Figure 8-10 appear to be reasonably normal, however, if combined into a single distribution (as in Figure 8-7) the result is a curve that is significantly skewed to the right.

If eqns (233) and (235) are multiplied the result is the longline (gender specific) age selectivity profiles illustrated in Figure 8-11. The profiles indicate that both genders are most susceptible to longline gear at about four to five years of age.[134] While females rapidly grow to lengths that are not very susceptible to the gear, males remain relatively susceptible to the gear all their lives.

Fishing appears to disturb the natural ratio between genders in a sablefish stock. McFarlane and Beamish (1983b, p.131) noted that while trawl caught samples of juvenile sablefish indicated a 1:1 male/female ratio, the ratio among adults was 1:1.5 normally and 1:3 during spawning. McFarlane and Beamish (1983a, p.66) suggest "it is probable that the sex ratio of the stock is equal and the bias towards females is a reflection of the fishery selecting larger fish." While this statement is rational in the short run, it is not possible in the long run (e.g. the gender *favoured* in the harvest should decline in numbers while the other group should be relatively more common in the older age groups, which have lived through many fishing seasons). Given the selectivity profiles in Figure 8-11, it is possible that in the older age-classes the females are much more common than males and (as a result) they are more frequently caught, even though they are not as susceptible to the gear as males of the same age.

Sexual dimorphism in the sablefish growth and fishing mortalities makes good management of the stock more difficult. First, the optimal

---

[134] "Mean ages at maturity were 4.8 for males and 5.1 for females indicating that fifty percent of males and females spawned for the first time at age 5." (McFarlane and Beamish, 1983a, p.64).

gender ratio needs to be considered in the manager's strategy. Second, a failure to separate cohort data, by gender, will grossly impair any associated cohort analysis. Also, the use of three gear types in the fishery makes it virtually impossible to interpolate gender effects into the data. The cohort tables published by McFarlane, et al. (1985, p.178) was separated by cohort only. Therefore, the forward simulation model used by McFarlane, et al. (1985, p.165) to project the sablefish biomass and yield from 1977-2020AD is suspect, as is any yield per recruit model or are recommendations arising from their model.

8.1.12 THE B.C. SABLEFISH FISHERY AND THE SYSTEMS MODEL -- A SUMMARY

Subsection 8.1.1, Table 8-4 and Figure 8-1 show that, while the effort in the sablefish fishery remained relatively constant from 1978 to 1989, the fishing season was being reduced exponentially in a lagged attempt to offset the exponentially increasing fishing power. This is consistent with systems inferences, discussed in subsections (6.1.3 to 6.1.4.2), that: *Managing fishing effort by controlling the fishing season can cause the season to decline toward a very short period.*

The selectivity syndrome of problems arises from the reality that not all fish pieces are alike (e.g. in terms of value and/or harvesting costs per unit of weight). The review of B.C.'s sablefish fishery indicated that the selectivity problems examined in the systems model (piece, time, stock and location) were either irrelevant or just minor problems in that particular fishery. However, the cohort nature of the sablefish stock revealed several other potentially serious selectivity problems. Those problems include: genotype, cohort, gear and gender selectivity—many act by making unreliable the historical information upon which fisheries managers rely. Many of these effects are subtle and compound so that when the problems become apparent, the damage to the fishery is massive and difficult to reverse.

Subsection 8.1.1 and Table 8-3 show that during the early to mid 1980s, roughly half the K-licensed vessels were not active in the B.C. sablefish fishery and over a quarter of those vessels were not active in any fishery. In 1986, DFO tried to implement ITQs in the sablefish fishery. Even though the attempt failed, it was not without effect—by 1988, all but two of the licensed vessels were active in the sablefish fishery. This behaviour implies that a fishing licence can have value, even when there is no resource rent in a fishery. The implications of this concept are discussed in more detail in the next subsection.

8.2 THE MEANING OF THE MARKET VALUE OF A FISHING RIGHT

Many economists and fisheries managers have asserted that when a fishing right is trading at a positive market value, there must be resource rent in the associated fishery. A few fishery managers have expanded on this basic assertion to state that *the fair market value* of the right to fish is fair compensation for any fishermen who are forced to leave the fishery. A sample of views on the fair value of fishing rights is provided below:

> "Last year, fishermen suffered overall losses of $70M -- further losses at least equal in size are projected for 1984. In one twelve month period, from '82 to '83, the market value of licensed vessels declined from $570M to $300M. ... Right now, at the very moment when some fishermen find themselves deeply in debt, the value of their boats and licences have hit bottom. For these fishermen, the buy-back will offer a way out of the fishery, without suffering the loss of their homes or personal bankruptcy. For those not deeply in debt, but who simply want to retire from the fisheries, the buy-back will offer a chance

> to sell their vessel at a fair price -- one not based narrowly on the currently depressed value of fishing assets." (De Bané and Austin, 1984, pp.5 and 9).
>
> "...the market value of all quota shares equals the present value of expected future operating profits in the fishery....it is vitally important for the profitability of the fishing firms to forecast [the amount of] future total quotas accurately. Thus appealing to the principle of rational expectations, industry expectations of *Q* [future quotas] may well be reasonably accurate." (Arnason, 1989, p.233)
>
> "A resource rental is an annual payment per tonne of ITQ. ... During the 1987/88 season, $12.5 million was generated by resource rentals....The biggest increase in government costs associated with ITQs was the buyback of quota in stressed fisheries. ...When ITQs were introduced, the government recognized that quota holders would be given preferential access to a public resource from which they would gain an economic benefit. This benefit could either be taxed away by the government or left in the fishery to be capitalized in the value of the ITQ. ...When ITQs were implemented, the exact level of future resource rentals was not clear, although the New Zealand government stated its intention to capture resource rent. However, the practical problems associated with defining and measuring resource rent proved to be significant. No specific formula was established to adjust resource rentals. Instead, adjustments were based mainly on the value of the ITQ and measures of industrial viability." (Macgillivary, 1990, pp.6, 10, 12 and 17).

The above ideas and their underlying thesis (that the *fair market value* of a fishing licence or ITQ is the present value of the future rents arising from the rights associated with the licence or ITQ) are based on the heroic assumptions that markets behave as though everyone is rational, that perfect costless information is readily available to all, that the future is certain (or the uncertainty is quantifiable) and that there are no entry or exit barriers. As a rule, fisheries do not even come close to meeting these assumptions. For Example:

1) Not all fishing inputs are of equal quality and/or cost. This leads to an intramarginal rent that Copes (1972) called producer surplus. An individual who has expectations of earning a producer surplus may be willing to pay a positive value for fishing rights, even if there is no resource rent.

2) Information in fisheries is neither perfect nor costless. Also, many fishermen have unrealistic expectations of their future earnings in the fishery. Under these conditions a person will tend to pay more for fishing rights than the present value of those rights.

3) The future in a fishery is very uncertain—even in a bad year some fishermen do very well either through effect (1) or via blind luck. Also, many fishermen, prospectors and gamblers are neither risk averse nor risk neutral—they love risk and are willing to pay a large premium for a chance to *strike it rich*.

4) Once capital and labour are invested in a fishery, they tend to become dedicated to the fishery (i.e. they would earn much less if forced into other occupations). This creates a quasi-rent situation where (in the short to intermediate run) individuals in a fishery are willing to pay (to stay in the fishery) up to the net present value of the returns on their sunk costs. This might be thought of as mitigating the personal loss arising from becoming trapped in the fishery.

All these factors contribute to fishing rights having a positive market value, even if there is no resource rent. As a result, buy-back schemes can become much more costly as the cut moves from the marginal fishermen and deeper into the intramarginal fishermen. This effect is consistent with the discussions in subsections 5.2.7 through 5.2.8.

FIGURE 8-1: Index of Season Length, Fishing Effort and Fishing Power in the B.C. Sablefish Fishery

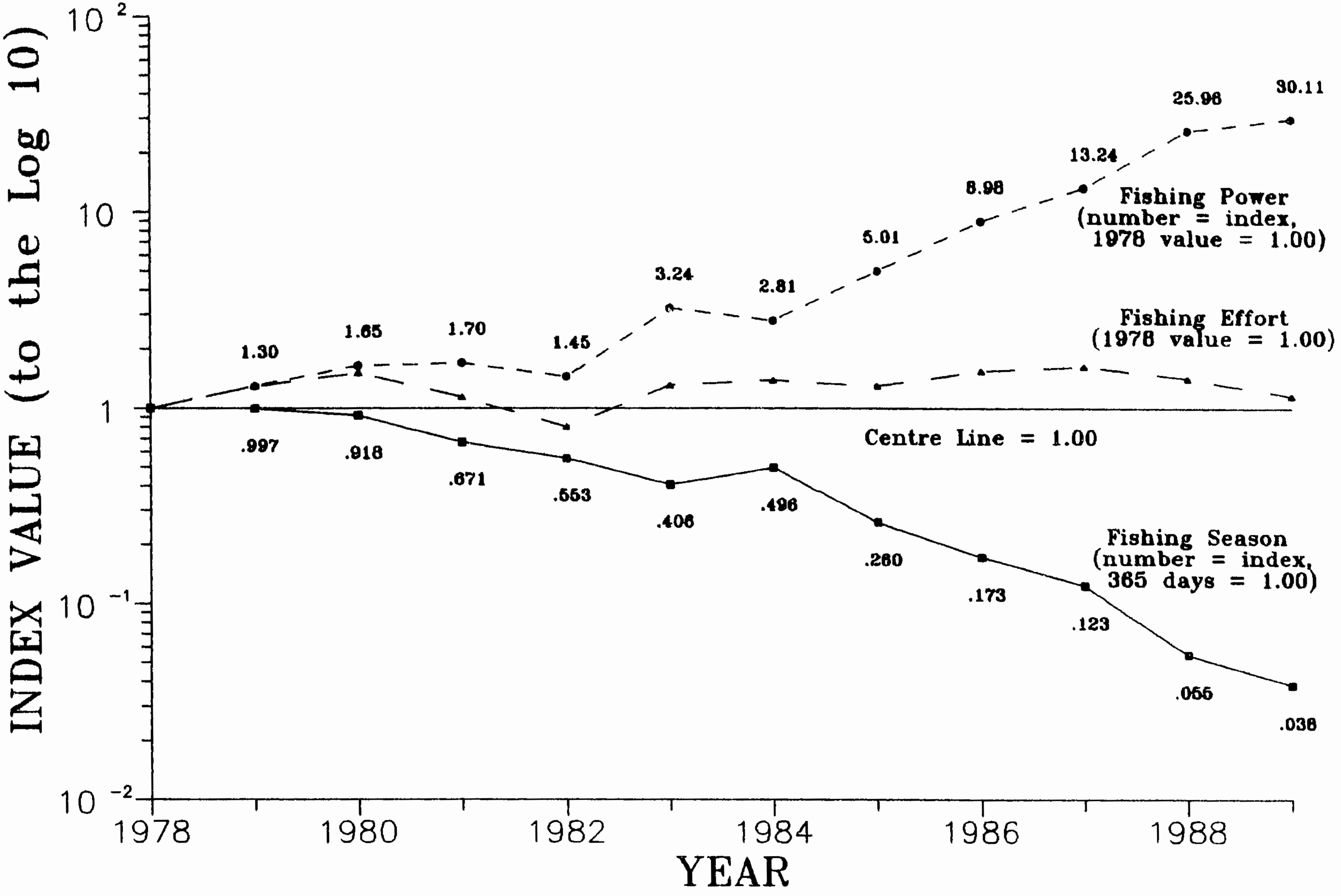


FIGURE 8-2: Index of the Price per Kilogram of Sablefish (the maximum price in each series is 1.00)

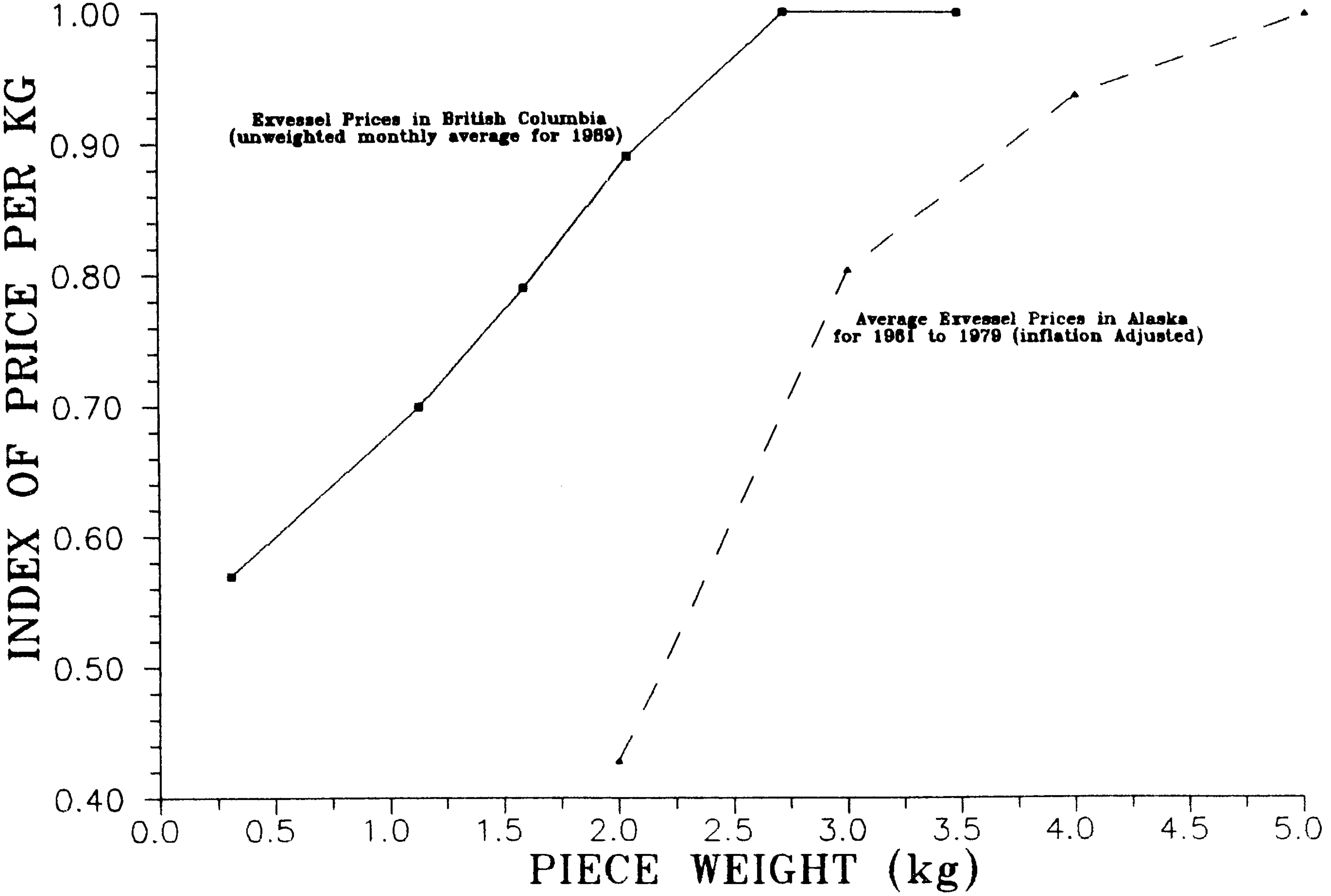


FIGURE 8–3: Fecundity of Sablefish in Relation to Length (sample drawn from B.C. waters in Feb/1981)

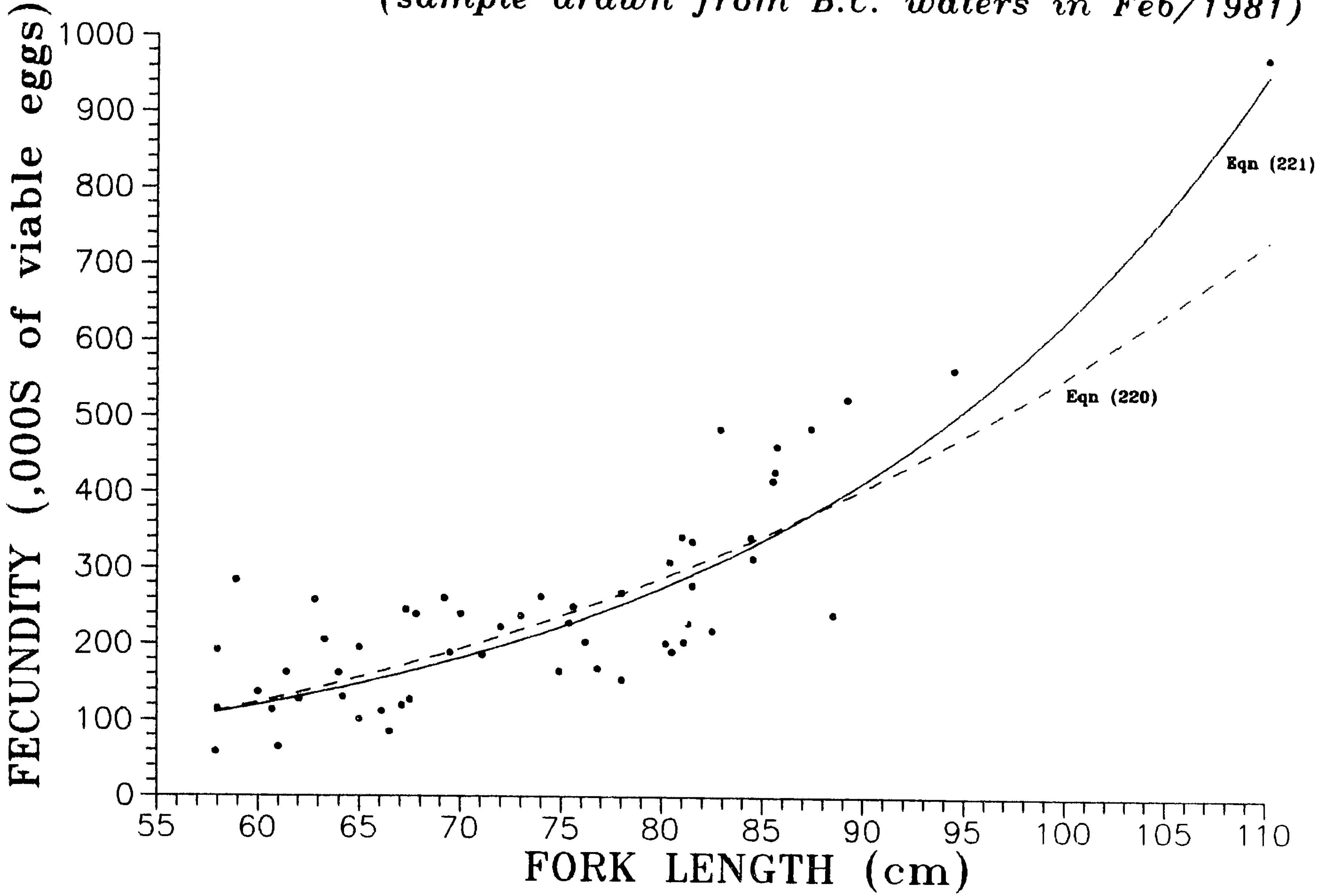


FIGURE 8–4: B.C. Sablefish Population Profile Indexed to the Profile of the 1979 Population

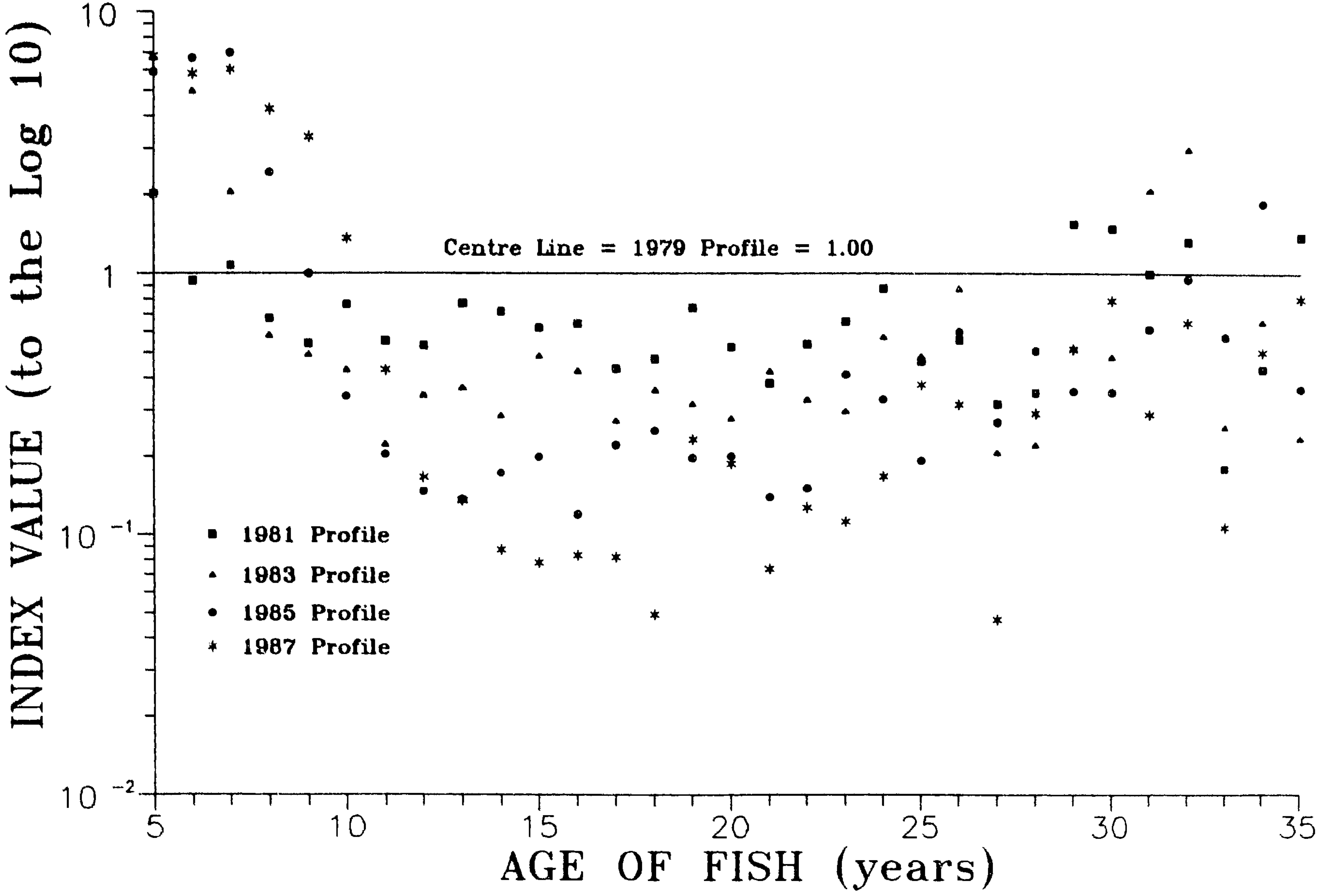


FIGURE 8–5: B.C. Sablefish Population Profile Indexed to the Profile of the 1977 Population

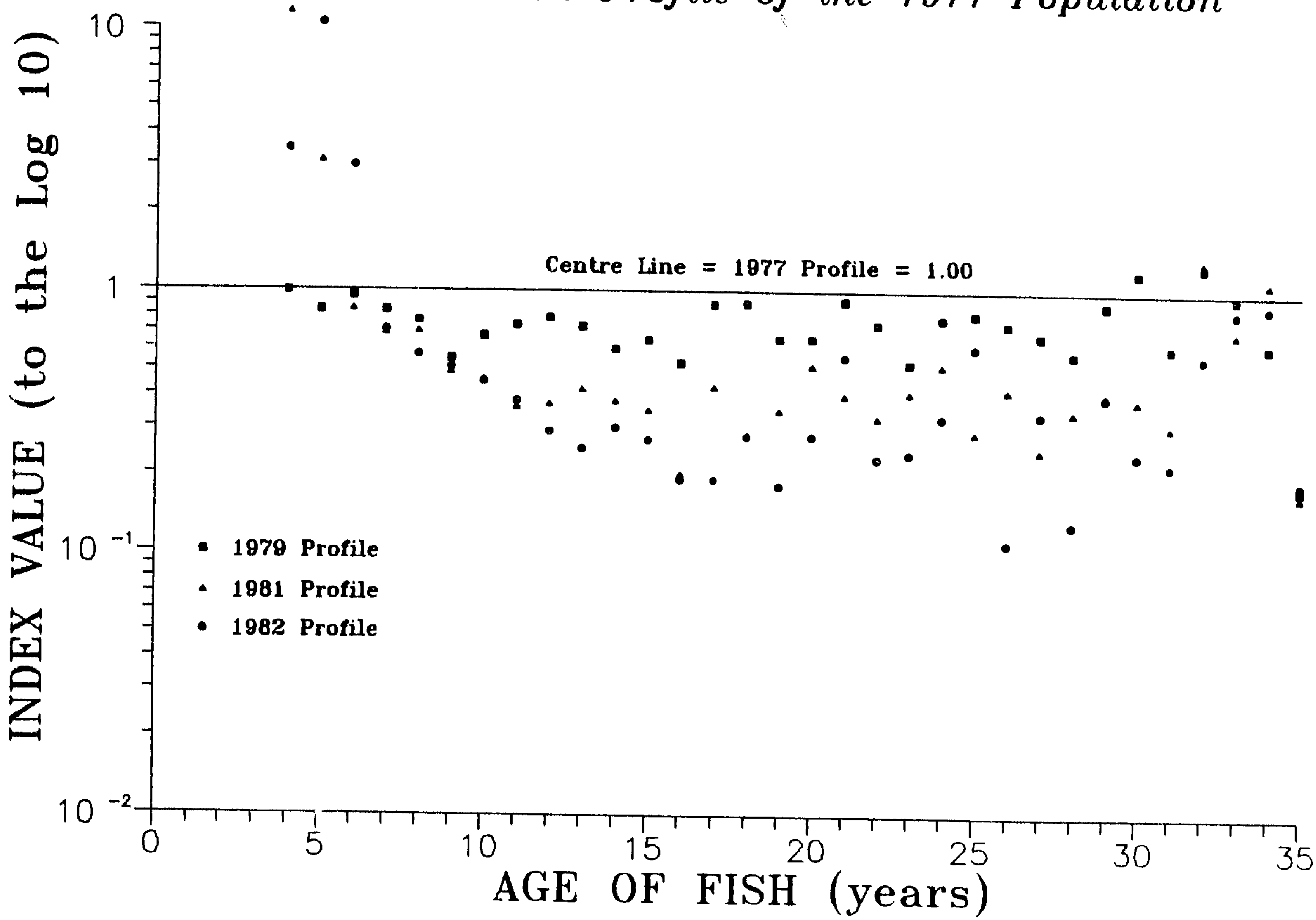


FIGURE 8-6: Average Fishing Mortality (1977 to 1986) vs Age

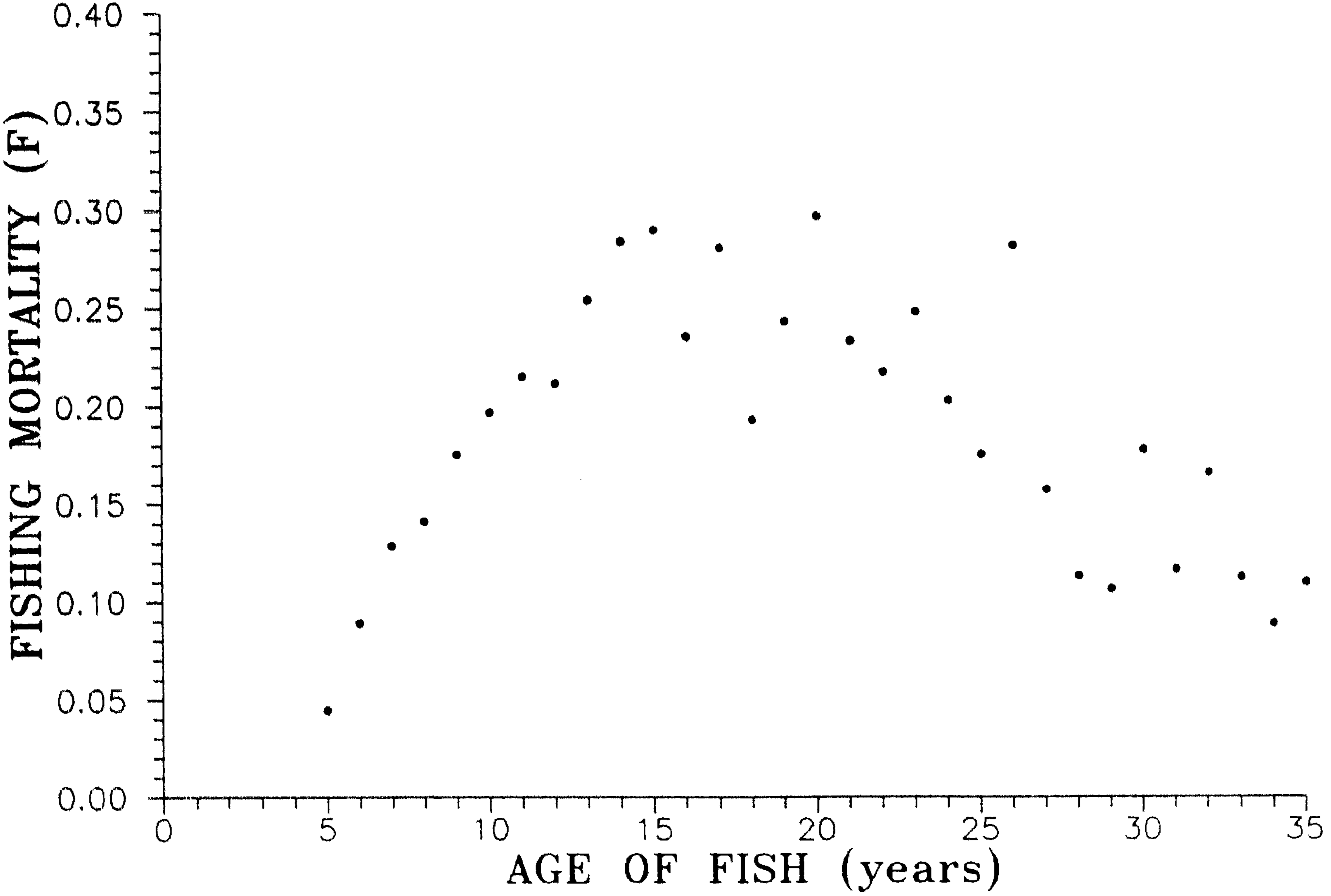


FIGURE 8-7: *Gear Selectivity Distributions*
(area under each curve = 100)

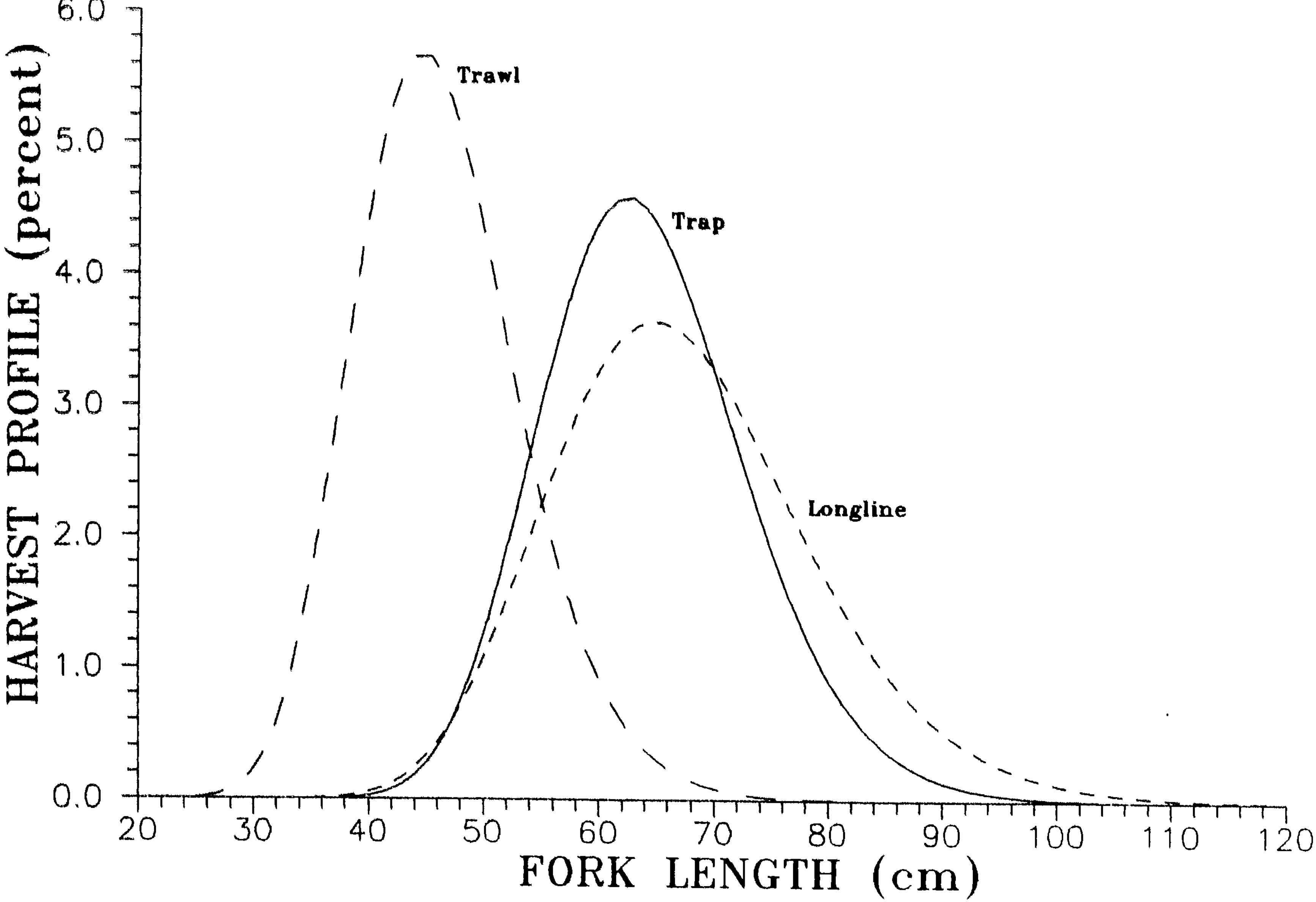


FIGURE 8-8: Envelope of Gear Selectivity Distributions Weighted by Their Share of the 1989 Harvest (area under the selectivity envelope = 100)

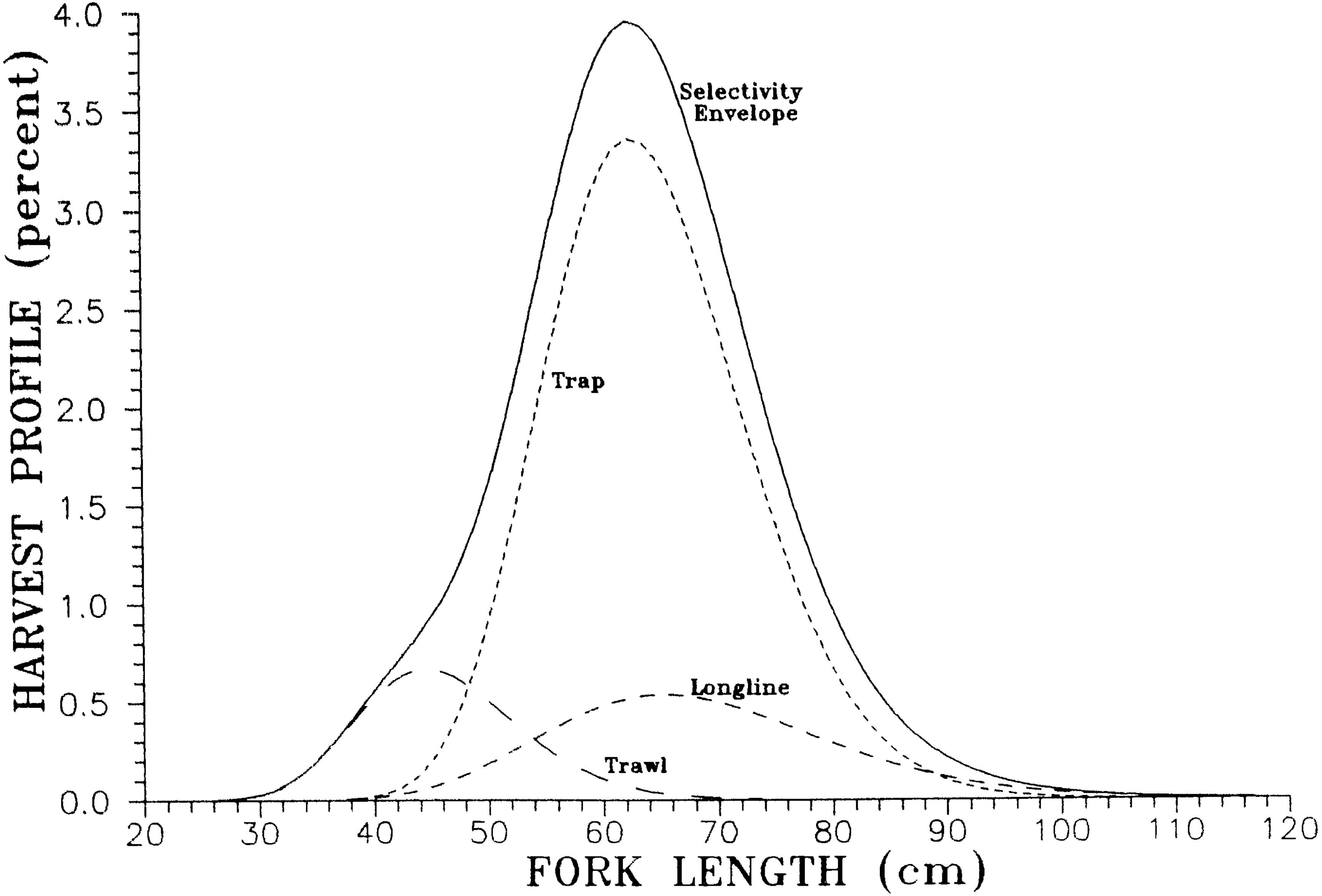


FIGURE 8-9: Growth Functions for West Coast QCI Sablefish

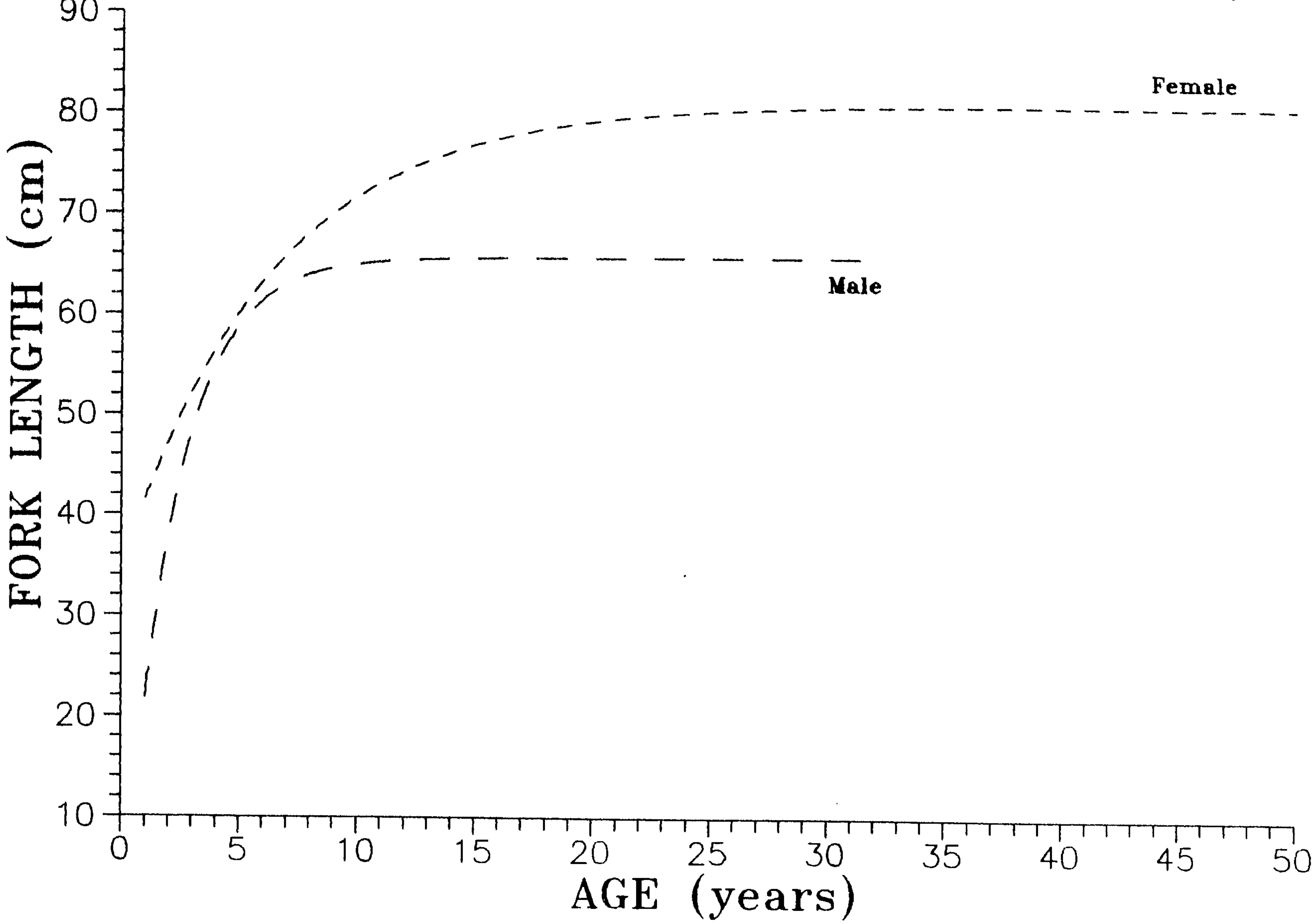


FIGURE 8–10: Effect of Gender on the Longline Gear Profile (area under each curve = 100)

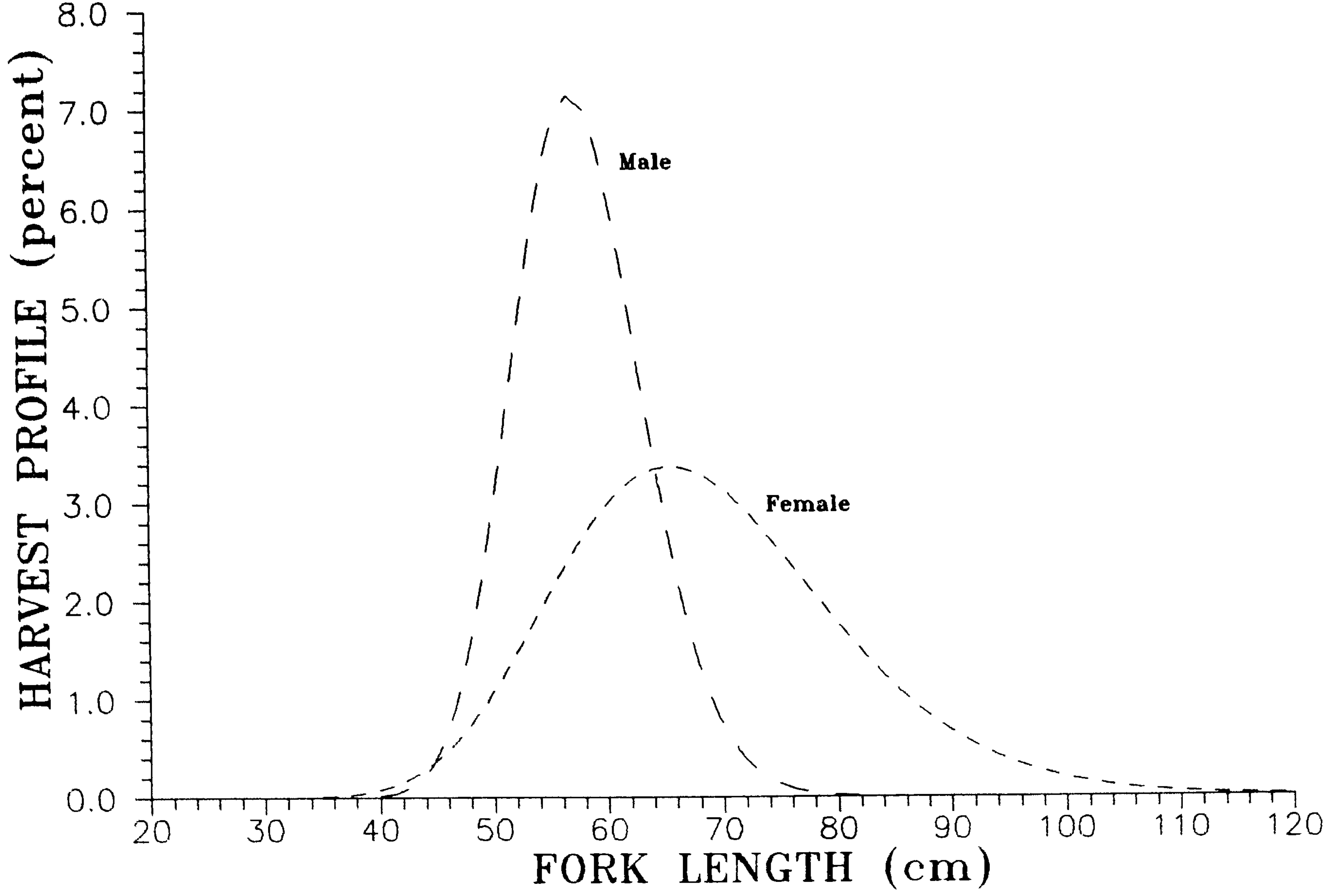


FIGURE 8–11: Estimated Effect of Gender and Age on the Longline Gear Selectivity Profile

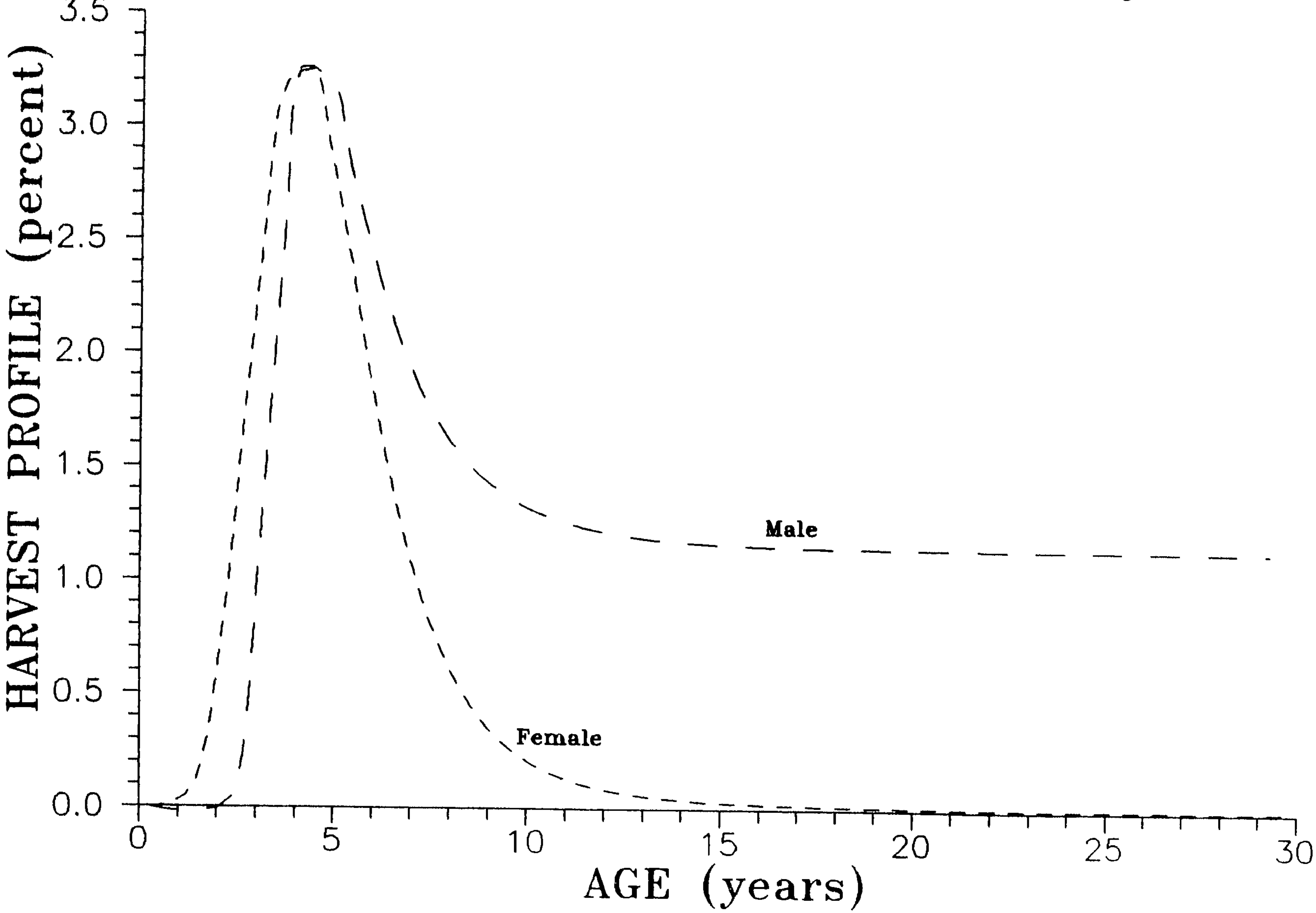


TABLE 8-1: British Columbia Sablefish Landings 1951 to 1989*

	REPORTED LANDINGS (tonnes)			CANADIAN REPORTED LANDINGS				CANADIAN REPORTED DISCARDS
YEAR	TOTAL	FOREIGN	CANADIAN	LONGLINE	TRAP	TRAWL	OTHER	
1951	796.4	-0-	796.4	97.0%	-0-	2.9%	.1%	-0-
1952	487.8	-0-	487.8	92.9%	-0-	7.0%	.1%	-0-
1953	344.7	-0-	344.7	97.4%	-0-	2.3%	.3%	-0-
1954	458.7	-0-	458.7	94.2%	-0-	5.8%	-0-	-0-
1955	373.8	-0-	373.8	96.0%	.1%	3.9%	-0-	-0-
1956	209.9	-0-	209.9	82.3%	-0-	17.7%	-0-	-0-
1957	512.7	-0-	512.7	90.8%	-0-	9.2%	-0-	-0-
1958	285.0	-0-	285.0	58.6%	.1%	41.3%	-0-	-0-
1959	356.2	-0-	356.2	83.7%	.2%	16.1%	-0-	-0-
1960	488.2	-0-	488.2	86.7%	-0-	13.3%	-0-	-0-
1961	419.3	-0-	419.3	76.6%	-0-	23.4%	-0-	-0-
1962	392.5	-0-	392.5	70.8%	-0-	29.0%	.3%	-0-
1963	287.4	-0-	287.4	77.3%	-0-	22.6%	.1%	-0-
1964	482.7	83	399.7	68.7%	-0-	31.3%	-	-0-
1965	547.4	92	455.4	42.4%	-0-	57.5%	.1%	-0-
1966	904.6	269	635.6	51.2%	-0-	48.7%	-	-0-
1967	1,645.9	1,254	391.9	64.5%	-0-	35.4%	-	-0-
1968	2,918.4	2,455	463.4	63.1%	-0-	33.7%	3.3%	-0-
1969	5,074.1	4,763	311.1	52.2%	-0-	47.6%	.2%	-0-
1970	5,505.1	5,246	259.1	54.8%	-0-	45.0%	.2%	-0-
1971	3,523.4	3,211	312.4	39.4%	-0-	60.6%	-0-	-0-
1972	5,906.1	4,818	1,088.1	36.7%	-0-	63.3%	-0-	-0-
1973	3,986.2	3,038	948.2	12.6%	78.7%	8.7%	-0-	-0-
1974	4,778.9	4,287	491.9	8.4%	66.5%	24.8%	.4%	-0-
1975	7,410.8	6,506	904.8	16.8%	51.9%	31.2%	.1%	-0-
1976	7,073.9	6,302	771.9	11.6%	39.3%	49.1%	-	-0-
1977	5,264.2	4,179	1,085.2	7.1%	19.8%	72.5%	.6%	1.1%
1978	4,182.9	3,353	829.9	6.9%	76.5%	15.7%	.9%	43.1%
1979	4,384.5	2,348	2,036.5	13.6%	72.5%	13.6%	.3%	102.6%
1980	4,404.0	606	3,798.0	6.6%	84.5%	8.8%	.1%	39.6%
1981	3,888.0	-0-	3,888.0	9.8%	84.2%	6.0%	-0-	8.9%
1982	3,996.4	-0-	3,996.4	6.8%	86.5%	6.2%	.5%	-0-
1983	4,414.6	-0-	4,414.6	10.3%	83.2%	6.2%	.4%	-0-
1984	3,827.1	-0-	3,827.1	9.5%	85.6%	4.9%	-0-	-0-
1985	4,192.6	-0-	4,192.6	10.9%	83.5%	5.6%	-0-	-0-
1986	4,667.0	-0-	4,667.0	18.1%	70.2%	11.6%	-0-	-0-
1987	4,583.3	-0-	4,583.3	24.7%	66.4%	8.9%	-	-0-
1988	5,771.3	-0-	5,771.3	22.1%	66.8%	11.0%	.1%	-0-
1989	5,349.0	-0-	5,349.0	14.9%	73.4%	11.8%	-0-	-0-

* Developed from:

• McFarlane, Shaw and Tyler (1985, Tables 5.1.2 to 5.1.4, pp.167-170),
~ Saunders (1986, Table 5.2, p.32),
• Saunders and McFarlane (1990, Table 5.1 to 5.2, pp.133-134), and
~ a *Fax* from Barry Ackerman (1990).

TABLE 8-2: Contrast of the British Columbia Sablefish TAC with the Reported Harvest (1978 to 1989)*

	TAC (tonnes)				
	GRAND	CANADIAN QUOTA			FOREIGN
YEAR	TOTAL	SUBTOTAL	K-LICENCE	TRAWL	QUOTA
1978	3,500	1,300	1,300	na	2,200
1979	3,500	2,500	2,500	na	1,000
1980	3,500	3,300	3,300	na	200
1981	3,500	3,500	3,500	na	-0-
1982	3,500	3,500	3,500	na	-0-
1983	3,500	3,500	3,500	na	-0-
1984	3,810	3,810	3,500	310	-0-
1985	4,000	4,000	3,650	350	-0-
1986	4,000	4,000	3,650	350	-0-
1987	4,100	4,100	3,740	360	-0-
1988	4,400	4,400	4,015	385	-0-
1989	4,400	4,400	4,015	385	-0-

	REPORTED HARVEST (tonnes)						
	GRAND	K-LICENCE			OTHER		
YEAR	TOTAL	SUBTOTAL	LONGLINE	TRAP	FOREIGN	TRAWL	OTHER
1978	3,873	692	57	635	3,043	130	8
1979	4,379	1,754	277	1,477	2,343	276	6
1980	4,399	3,460	249	3,211	601	335	3
1981	3,888	3,655	380	3,275	-0-	233	-0-
1982	3,996	3,730	272	3,458	-0-	248	18
1983	4,415	4,125	453	3,672	-0-	274	16
1984	3,827	3,640	365	3,275	-0-	187	-0-
1985	4,193	3,960	458	3,501	-0-	233	-0-
1986	4,667	4,124	847	3,277	-0-	543	-0-
1987	4,583	4,176	1,133	3,043	-0-	407	0
1988	5,771	5,131	1,274	3,857	-0-	637	3
1989	5,349	4,720	795	3,925	-0-	629	-0-

* Adapted from:
- Masaki Sakai (1986, pp.10-11),
- Ackerman (1990), and
- Table 8-1.

TABLE 8-3: Compositon of the British Columbia Sablefish Fleet*

LICENCED VESSELS:	1981	1982	1983	1984	1985	1986	1987	1988	1989
Trap - Active	15	15	14	13	17	19	18	27	31
- Inactive	12	14	16	18	14	6	6	1	0
Total	27	29	30	31	31	25	24	28	31
Longline - Active	11	7	8	7	10	20	21.5	19	17
- Inactive	9	11	9	9	4	0	0	0	0
Total	20	18	17	16	14	20	21.5	19	17
Undeclared - Inactive	-	-	-	-	2	2	1.5	-	-
Grand Total	47	47	47	47	47	47	47	47	48
Active Vessels:	26	22	22	20	27	39	39.5	46	48
Inactive Vessels:									
- Did Not Fish	11	15	14	15	-	-	-	-	0
- Other Species	12	9	10	12	-	-	-	-	0
Total	23	24	24	27	18	6	7.5	1	0

* Adapted from: Masaki Saki (1986, pp.5, 13-16 and 33-34), Pearse (1982, p.125), Tyler and McFarlane (1985, p.163), Chamut (1989, p.1) and Tyler and Fargo (1990, p.127).

TABLE 8-4: Fishing Season Length, Fishing Effort and Fishing Power in the the British Columbia Sablefish Fishery**

YEAR	EFFECTIVE FISHING DAYS	% OF YEAR	HARVEST TONNES	TAC TONNES	HARVEST /TAC	CPUE IN kg/TRAP	TRAP FISHING EFFORT	POWER
1978	365	100.0%	3,873	3,500	110.7%	18.9	205	205
1979	364	99.7%	4,379	3,500	125.1%	16.5	265	266
1980	335	91.8%	4,399	3,500	125.7%	14.2	310	338
1981	245	67.1%	3,888	3,500	111.1%	16.6	234	349
1982	202	55.3%	3,996	3,500	114.2%	24.3	164	297
1983	148	40.5%	4,415	3,500	126.1%	16.4	269	664
1984	181	49.6%	3,827	3,500	109.3%	13.4	286	576
1985	95	26.0%	4,193	4,000	104.8%	15.7	267	1,026
1986	63	17.3%	4,667	4,000	116.7%	14.7	317	1,839
1987	45	12.3%	4,583	4,100	111.8%	13.7	335	2,714
1988	20	5.5%	5,771	4,400	131.2%	19.8	291	5,320
1989	14	3.8%	5,349	4,400	121.6%	22.6	237	6,171

** Adapted from: Masaki Sakai (1986, pp.10-11), Ackerman (1990), Table 8-1 and Saunders and McFarlane (1990, Table 5.3, p.136).

TABLE 8-5: Alaskan Prices per Kg for Various Piece Weights (in US dollars and developed from 1961-1979 inflation indexed price data)*

ROUND WEIGHT CATEGORIES (in kilograms)	MEAN WEIGHT (kg)	PRICE PER Kg ($/kg)	PRICE INDEX $1.23/kg = 100 %
> 1.34	1.00	$.00	.0%
1.34 to 2.66	2.00	$.48	42.9%
2.67 to 3.33	3.00	$.90	80.4%
3.34 to 4.66	4.00	$1.05	93.8%
> 4.66	5.00	$1.12	100.0%

* Adapted from Terry et al. (1983, p.15)

TABLE 8-6: Canadian Prices per Kg for Various Piece Weights (in Canadian nominal dollars for the 1989 British Columbia fishing season)**

ROUND WEIGHT CATEGORIES (in pounds)	AVERAGE EXVESSELL PRICE RECEIVED 1989 OPENING (in $/Kg)							
	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT
> 2.00	$1.48	$.89	$1.59	$1.21	$1.26	--	$1.50	$1.45
2.00 - 3.00	1.98	1.89	1.82	1.49	1.38	1.32	1.49	1.70
3.00 - 4.00	2.18	2.18	2.10	1.78	1.61	1.52	1.70	1.87
4.00 - 5.00	2.38	2.36	2.31	2.04	1.88	1.79	1.91	2.05
5.00 - 7.00	2.58	2.63	2.52	2.25	2.16	2.04	2.18	2.40
> 7.00	2.58	2.63	2.52	2.25	2.15	2.04	2.18	2.45
Monthly: μ	$2.20	$2.10	$2.14	$1.84	$1.74	$1.74	$1.83	$1.99
σ/μ	.19	.31	.18	.23	.22	.18	.17	.20
index	100.0%	95.4%	97.6%	83.6%	79.2%	79.3%	83.2%	90.4%

MEAN WEIGHT (kg)	PRICE PER Kg ($/kg)	σ/μ	PRICE INDEX $3.484/kg = 100 %
.309	$1.34	.18	57.0%
1.134	1.63	.15	69.5%
1.588	1.87	.14	79.5%
2.041	2.09	.11	88.9%
2.722	2.35	.09	99.8%
3.484	2.35	.09	100.0%

** Adapted from Longva (1990, p.9).

TABLE 8-7: Size Distribution of Sablefish, Taken by Trawl, from Three Depths, in the Gulf of Alaska, During August of 1967*

PIECE LENGTH (cm)	HAUL DEPTH (translated from fathoms to metres)		
	SHALLOW 95.1 to 146.3 m	MEDIUM 144.5 to 256.0 m	DEEP 435.3 to 460.9 m
28	6	-	-
30	20	-	-
32	32	-	-
34	32	-	-
36	9	5	-
38	2	5	-
40	3	4	-
42	1	13	-
44	-	70	7
46	-	85	26
48	-	63	63
50	-	48	33
52	-	41	26
54	-	27	24
56	-	13	16
58	-	14	32
60	-	9	22
62	-	13	27
64	-	9	18
66	-	2	13
68	-	-	7
70	-	-	7
72	-	-	3
74	-	-	7
76	-	-	-
78	-	-	-
80	-	-	-
82	-	-	-
TOTAL	105	421	331
MEAN	32.78	49.11	55.23
MODE	35.0	51.0	59.0
MINIMUM	28	36	44
MAXIMUM	42	66	74

* Adapted from Kennedy and Pletcher (1968, p.7).

TABLE 8-8: Fecundity of Sablefish in Relation to Length (Sample Drawn From B.C. Waters in Feb/1981)*

PIECE FORK LENGTH (cm)	EST. AGE yrs	EST. VIABLE EGGS ,000s	EST. ERROR ON FECUNDITY	
			No. ,000s	Percent
57.9	22	58.2	± 4.6	± 7.9%
58.0	5	191.8	± 5.1	± 2.7%
58.0	6	114.7	± 3.8	± 3.3%
58.9	15	283.9	± 6.4	± 2.3%
60.0	-	136.9	± 9.3	± 6.8%
60.7	5	113.7	± 2.3	± 2.0%
61.0	28	64.5	± 1.7	± 2.6%
61.4	7	162.4	± 2.1	± 1.3%
62.0	7	127.9	± 6.6	± 5.2%
75.6	15	250.2	± 3.6	± 1.4%
63.3	6	205.7	± 6.4	± 3.1%
64.0	11	161.8	± 3.7	± 2.3%
64.2	6	130.8	± 1.9	± 1.5%
65.0	26	101.3	± 2.6	± 2.6%
65.0	8	195.2	± 9.3	± 4.8%
66.1	15	112.0	± 2.5	± 2.2%
66.5	11	85.7	± 2.7	± 3.1%
67.1	12	119.5	± 6.2	± 5.2%
67.3	18	245.2	± 3.0	± 1.2%
67.5	7	127.3	± 2.7	± 2.1%
67.8	17	239.6	± 9.0	± 3.8%
69.2	12	260.7	± 8.0	± 3.1%
69.5	5	188.9	± 6.6	± 3.5%
70.0	14	240.4	± 6.6	± 2.7%
71.1	20	186.0	± 9.7	± 5.2%
72.0	8	223.1	± 7.1	± 3.2%
73.0	20	238.0	± 9.1	± 3.8%
74.0	13	263.0	± 1.1	± .4%
74.9	15	165.0	± 8.8	± 5.3%
75.4	11	228.5	± 8.9	± 3.9%
76.2	21	203.6	± 2.5	± 1.2%
76.8	12	168.7	±10.2	± 6.0%
62.8	6	257.8	± 6.1	± 2.4%
78.0	17	268.5	± 5.8	± 2.2%
78.0	16	154.3	± 3.6	± 2.3%
80.2	15	202.4	±10.5	± 5.2%
80.4	22	308.9	±19.8	± 6.4%
80.5	23	191.4	± 6.7	± 3.5%
81.0	8	342.4	±13.4	± 3.9%
81.1	11	203.9	± 6.0	± 2.9%
81.3	21	228.4	±10.9	± 4.8%
81.5	13	278.0	± 9.0	± 3.2%
81.5	13	336.2	± 6.2	± 1.8%
82.5	43	218.7	±10.0	± 4.6%
82.9	14	485.0	±12.8	± 2.6%
84.4	11	341.6	± 4.4	± 1.3%
84.5	18	313.8	± 5.6	± 1.8%
85.5	32	416.7	± 8.3	± 2.0%
85.6	15	429.0	± 9.6	± 2.2%
85.7	11	462.2	±22.0	± 4.8%
87.4	9	486.2	± 7.4	± 1.5%
88.5	15	240.6	± 6.9	± 2.9%
89.2	21	524.4	±10.6	± 2.0%
94.5	20	563.6	±15.8	± 2.8%
110.2	34	977.0	±16.4	± 1.7%

* Adapted from Mason (1984, pp.5-6).

TABLE 8-9: Vitual Population Analysis of B.C. Sablefish (1979-1987)*

	NUMBERS-AT-AGE FOR B.C. SABLEFISH (1,000s of pieces)									
AGE	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
5	408.790	416.445	825.994	2,301.011	2,740.794	3,068.677	2,404.654	2,624.286	2,773.391	
6	389.366	368.498	365.657	709.477	1,944.802	2,379.917	2,591.525	2,087.780	2,255.150	2,411.070
7	284.974	350.977	306.797	308.531	586.708	1,438.837	1,981.424	2,157.600	1,709.330	1,864.917
8	420.537	254.765	284.801	245.745	245.081	449.406	1,026.361	1,522.823	1,784.247	1,358.120
9	363.881	379.094	197.326	242.692	179.756	185.228	364.421	703.729	1,205.900	1,403.538
10	396.582	325.367	303.243	157.316	171.092	129.547	135.040	247.051	540.851	911.400
11	458.731	340.761	254.025	246.033	102.999	103.231	93.880	100.938	196.959	400.672
12	467.306	390.904	248.482	199.823	161.460	68.252	68.693	69.036	77.949	143.022
13	367.526	394.315	283.481	180.159	135.443	98.853	50.265	58.012	49.736	57.171
14	386.999	294.959	277.592	221.451	111.818	88.791	67.067	41.567	33.895	35.048
15	330.737	288.352	205.786	212.629	161.046	59.566	65.998	43.697	25.884	23.179
16	318.243	252.478	205.246	144.434	136.096	100.875	38.082	49.164	26.599	17.525
17	368.985	230.815	160.370	150.957	101.679	96.617	81.936	30.582	30.414	18.932
18	319.820	245.552	151.348	113.033	115.237	55.018	80.440	71.169	15.870	20.799
19	240.042	216.994	177.880	110.454	76.739	79.076	47.443	67.866	55.984	11.875
20	289.828	146.907	152.237	134.439	81.381	41.063	58.186	40.428	54.287	39.848
21	240.852	197.849	92.221	117.001	102.628	46.079	33.620	47.254	17.856	36.390
22	261.992	141.870	141.143	60.019	86.926	70.052	39.560	27.802	33.271	12.837
23	150.628	163.462	98.979	106.673	45.124	59.058	62.057	34.357	16.924	24.160
24	150.941	71.243	132.549	66.666	86.623	24.069	49.995	54.932	25.282	11.926
25	107.403	75.876	49.704	103.482	51.985	64.602	20.672	43.886	40.424	18.729
26	95.607	66.952	53.416	36.084	83.982	42.990	57.218	17.441	30.267	30.552
27	135.919	56.140	43.120	37.604	28.153	69.450	36.633	50.251	6.388	20.698
28	119.285	103.758	41.776	33.140	26.502	22.369	60.320	31.801	34.745	4.925
29	53.734	88.493	83.298	29.442	27.818	20.847	19.061	53.389	27.600	28.164
30	50.664	42.983	75.408	70.515	24.347	21.025	17.765	15.870	39.936	22.372
31	29.301	34.383	29.329	62.782	61.247	20.921	17.916	14.691	8.464	30.183
32	18.698	18.813	24.818	24.750	56.110	53.181	17.828	14.816	12.149	6.793
33	82.159	13.045	14.666	17.702	21.259	46.401	47.075	14.743	8.730	9.274
34	21.850	66.676	9.406	11.537	14.358	18.116	40.743	41.311	10.960	7.076
35	42.130	17.889	58.499	6.720	9.904	11.993	15.286	35.388	33.823	9.063
It	7,373.5	6,056.6	5,348.6	6,462.3	7,779.1	9,034.1	9,691.2	10,413.7	11,183.3	8,990.3
Ht	1,054	993	665	847	1,111	909	1,018	1,019	1,164	5,771
Ht/It	14.30%	16.39%	12.43%	13.11%	14.28%	10.06%	10.51%	9.78%	10.41%	64.19%
F	.268	.290	.243	.227	.253	.194	.209	.209	.202	

* Adapted from Saunders and McFarlane (1990, Table 5.5, p.138)

TABLE 8-10: Vitual Population Analysis of B.C. Sablefish (1977-1982)*

	NUMBERS-AT-AGE FOR B.C. SABLEFISH (in 1,000s)					
AGE	1977	1978	1979	1980	1981	1982
4	716	681	708	2,479	8,231	2,465
5	684	647	575	630	2,131	7,142
6	616	615	583	497	525	1,844
7	606	540	508	501	416	430
8	589	536	453	427	415	333
9	706	514	391	374	347	357
10	633	619	427	311	293	283
11	623	555	458	318	223	235
12	564	531	443	356	209	166
13	568	447	415	329	237	141
14	575	461	343	302	219	171
15	580	449	379	223	202	156
16	628	475	330	267	124	122
17	402	451	357	216	174	75
18	435	327	390	226	121	122
19	424	300	278	280	148	75
20	387	305	254	171	201	110
21	270	266	248	157	107	150
22	283	186	212	150	94	64
23	245	199	131	145	101	58
24	193	147	152	63	101	64
25	122	141	100	89	35	75
26	151	107	113	57	63	17
27	122	90	83	66	30	41
28	128	89	74	53	45	17
29	73	101	66	44	30	29
30	70	65	84	52	27	17
31	77	47	48	55	24	17
32	30	42	38	32	40	17
33	34	15	33	28	24	29
34	19	23	12	23	21	17
35	89	13	16	9	15	17
Xt	11,642	9,984	8,702	8,930	14,973	14,856
Ht^	2,339	1,990	2,251	2,188	2,582	
Ht/Xt	20.1%	19.9%	25.9%	24.5%	17.2%	
F	.273	.272	.362	.474	.543	

* Adapted from McFarlane, et al (1985, Table 5.1.12, p.178)

TABLE 8-11: B.C. Sablefish Fishing Mortality Rates "F" (1979-1987)*

	ANNUAL AND AVERAGE ESTIMATES OF "F" FOR B.C. SABLEFISH										
AGE	1979	1980	1981	1982	1983	1984	1985	1986	1987	μ F	σ/μ F
5	.004	.030	.052	.068	.041	.069	.041	.052	.040	.045	.476
6	.004	.083	.070	.090	.201	.083	.083	.100	.090	.089	.605
7	.012	.109	.122	.130	.167	.238	.163	.090	.130	.129	.509
8	.004	.155	.060	.213	.180	.110	.277	.133	.140	.142	.608
9	.012	.123	.127	.250	.228	.216	.289	.163	.180	.176	.503
10	.052	.148	.109	.324	.405	.222	.191	.127	.200	.197	.595
11	.060	.216	.140	.321	.312	.307	.207	.158	.220	.215	.437
12	.070	.221	.222	.289	.391	.206	.069	.228	.210	.212	.501
13	.120	.251	.147	.377	.322	.288	.090	.437	.250	.254	.495
14	.194	.260	.167	.219	.530	.197	.328	.374	.280	.283	.432
15	.170	.240	.254	.346	.368	.347	.194	.396	.290	.290	.295
16	.221	.354	.207	.251	.243	.108	.119	.380	.240	.235	.413
17	.307	.322	.250	.170	.514	.083	.041	.556	.280	.280	.664
18	.288	.222	.215	.287	.277	.048	.070	.140	.190	.193	.499
19	.391	.254	.180	.205	.525	.207	.060	.123	.240	.243	.614
20	.282	.366	.163	.170	.469	.100	.108	.717	.300	.297	.720
21	.429	.238	.330	.197	.282	.053	.090	.251	.230	.234	.524
22	.372	.260	.180	.185	.287	.021	.041	.396	.220	.218	.637
23	.649	.110	.295	.108	.528	.067	.022	.207	.250	.248	.921
24	.588	.260	.148	.149	.193	.052	.030	.207	.200	.203	.852
25	.373	.251	.220	.109	.090	.021	.070	.272	.180	.176	.689
26	.432	.340	.251	.148	.090	.060	.030	.904	.280	.282	1.023
27	.170	.196	.163	.250	.130	.041	.041	.269	.160	.158	.539
28	.199	.120	.250	.075	.140	.060	.022	.042	.110	.113	.703
29	.123	.060	.067	.090	.180	.060	.083	.190	.110	.107	.494
30	.288	.282	.083	.041	.052	.060	.090	.529	.180	.178	.976
31	.343	.226	.070	.012	.041	.060	.090	.090	.120	.117	.955
32	.260	.149	.238	.052	.090	.022	.090	.429	.170	.166	.816
33	.109	.227	.140	.109	.060	.030	.031	.197	.110	.113	.646
34	.100	.031	.236	.053	.080	.070	.041	.100	.090	.089	.730
35	.110	.110	.110	.110	.110	.110	.110	.110	.090	.110	.000
μ	.217	.200	.170	.174	.243	.117	.104	.270	.186	.187	.609
σ/μ	.792	.457	.435	.567	.654	.792	.791	.750	.375	.370	.347
Wtd μ F	.268	.290	.243	.227	.253	.194	.209	.209	.202	.337	

* Adapted from Saunders and McFarlane
(1990, Tables 5.5 and 5.6, pp.138-139)

TABLE 8-12: B.C. Sablefish Gear Selectivity Parameters*

PARAMETER	GEAR TYPE						LONGLINE GEAR			
	TRAWL		LONGLINE		TRAP		MALE		FEMALE	
	VALUE	T-stat	VALUE	T-stat	VALUE	T-stat	VALUE	T-stat	VALUE	T-stat
I. REGRESSION RESULTS										
R^2	94.67 %		93.44 %		94.16 %		95.00 %		93.11 %	
R^2	93.04 %		92.35 %		93.85 %		94.30 %		91.78 %	
Durbin-Watson	1.8265		2.2378		2.0409		2.3300		2.1817	
Log of the Likelihood Function	-89.62		-138.38		-118.41		-77.79		-87.85	
LM Test for Residual Normality	.4132	with Φ = 2	84.5501	with Φ = 2	49.4157	with Φ = 2	5.8087	with Φ = 2	225.616	with Φ = 2
II. REGRESSION PARAMETERS										
a	-294.94	-23.864	-312.27	-32.602	-448.58	-50.314	-850.51	-41.522	-272.66	-32.310
b	156.620	24.236	150.36	32.155	217.71	50.497	422.24	41.534	131.17	31.908
c	-20.625	-24.435	-18.020	-31.594	-26.329	-50.622	-52.259	-41.543	-15.691	-31.418
III. Eqn(233) PARAMETERS										
$L^* = e^{-.5b/c}$	44.561		64.847		62.453		56.819		65.352	
$q = e^{(a-.25b^2/c)}$	10.927		3.988		4.357		10.904		4.354	
$\sigma^2 = e^{-.5/c}$	1.0245		1.0281		1.0192		1.0096		1.0324	
Z	17.5894		27.4367		21.7949		13.9880		29.7217	
IV. CENTRAL TENDENCY (N = 100,000 pieces)										
Arithmetic Mean	46.44		67.23		64.03		57.75		68.16	
Geometric Mean	45.87		66.34		63.45		57.49		67.11	
Median	52.50		73.50		65.00		52.50		77.00	
Mode = L^*	44.56		64.85		62.45		56.82		65.35	

* Developed from Appendicies E-7, E-8 and E-9 and based on data adapted from Tables 8-13, 8-14 and 8-15.

TABLE 8-13: B.C. Sablefish Trawl Catch Data (1979)*

PIECE LENGTH IN CM.	SABLEFISH TRAWL SAMPLE CATCHES BY TRAWL SET REFERENCE NUMBERS					
	1-25	26-50	51-76	77-101	102-126	TOTAL
19	0	0	1	0	0	1
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	1	0	0	0	1
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	1	0	0	0	0	1
27	0	2	0	0	0	2
28	0	7	0	0	0	7
29	3	0	0	0	0	3
30	5	0	0	0	0	5
31	0	0	0	0	0	0
32	0	0	0	0	0	0
33	1	2	0	0	1	4
34	1	0	0	0	0	1
35	3	7	0	0	0	10
36	13	5	1	0	0	19
37	33	24	9	6	4	76
38	58	40	9	11	7	125
39	80	87	44	27	30	268
40	113	176	75	62	113	539
41	196	252	122	124	144	838
42	312	377	219	212	268	1,388
43	373	456	328	296	303	1,756
44	381	410	354	310	254	1,709
45	305	394	407	365	231	1,702
46	210	293	365	349	190	1,407
47	129	199	320	251	121	1,020
48	85	141	203	178	82	689
49	43	84	131	107	36	401
50	33	45	98	82	21	279
51	12	19	49	50	16	146
52	4	12	22	29	5	72
53	5	9	12	24	4	54
54	3	5	9	10	1	28
55	2	1	4	6	2	15
56	2	0	6	0	0	8
57	1	0	2	0	0	3
58	0	0	1	1	0	2
59	0	0	1	0	0	1
60	0	0	0	0	0	0

TABLE 8-13: B.C. Sablefish Trawl Catch Data (1979)*

61	0	0	0	0	0	0
62	0	0	0	0	0	0
63	0	0	0	1	0	1
64	0	0	1	0	0	1
65	0	0	0	0	0	0
66	0	0	0	0	0	0
67	0	2	0	0	0	2
68	0	0	0	0	1	1
69	0	0	0	0	0	0
70	1	0	0	0	0	1
71	0	0	0	0	1	1
72	0	0	0	0	0	0
73	0	0	0	0	2	2
74	0	0	0	0	1	1
75	0	0	0	1	1	2
76	0	0	0	0	0	0
77	0	0	0	0	0	0
78	0	0	0	0	0	0
79	0	0	0	0	0	0
80	0	0	0	0	0	0
81	0	0	0	0	0	0
82	0	0	0	0	0	0
83	0	1	0	0	0	1
TOTAL	2,408	3,051	2,793	2,502	1,839	12,593

* Adapted from McFarlane, et al (1985, Table 5.1.12, p.178)

TABLE 8-14: B.C. Sablefish Longline Catch Data (1979)*

PIECE LENGTH IN CM.	B.C. TOTAL	SABLEFISH LONGLINE CATCH									
		MALE					FEMALE				
		AREA 5.2	AREA 5.3	AREA 5.4	AREA 5.5	MALE SUBTOTAL	AREA 5.2	AREA 5.3	AREA 5.4	AREA 5.5	FEMALE SUBTOTAL
38	1	0	0	0	0	0	1	0	0	0	1
39	0	0	0	0	0	0	0	0	0	0	0
40	14	2	1	1	0	4	3	2	0	5	10
41	18	1	0	4	3	8	0	1	7	2	10
42	43	5	1	11	6	23	5	0	9	6	20
43	55	5	4	9	6	24	4	3	17	7	31
44	93	11	7	11	20	49	10	4	21	9	44
45	161	16	18	16	20	70	19	21	30	21	91
46	234	24	24	27	42	117	36	14	37	30	117
47	314	38	45	42	39	164	47	26	43	34	150
48	373	46	45	45	35	171	55	35	74	38	202
49	396	40	50	60	48	198	60	29	68	41	198
50	365	64	43	46	47	200	55	33	49	28	165
51	413	84	29	78	70	261	55	22	50	25	152
52	444	81	44	88	96	309	55	21	37	22	135
53	550	109	51	114	129	403	43	30	45	29	147
54	516	127	51	96	109	383	36	29	46	22	133
55	652	146	68	148	168	530	45	17	36	24	122
56	731	172	61	144	228	605	38	23	44	21	126
57	830	171	84	202	250	707	41	16	41	25	123
58	977	206	82	225	332	845	30	31	49	22	132
59	1,084	196	111	253	380	940	46	23	41	34	144
60	1,147	203	108	265	432	1,008	43	20	45	31	139
61	1,254	226	122	294	451	1,093	46	27	56	32	161
62	1,246	213	132	258	463	1,066	54	23	57	46	180
63	1,286	149	143	249	469	1,010	75	44	98	59	276
64	1,153	133	131	227	408	899	54	36	91	73	254
65	1,063	132	105	167	341	745	74	59	97	88	318
66	996	98	104	140	280	622	93	68	118	95	374
67	932	84	89	123	223	519	88	79	111	135	413
68	787	54	79	91	155	379	90	83	123	112	408
69	710	41	48	77	96	262	86	95	133	134	448
70	634	24	34	49	64	171	122	94	146	101	463
71	607	11	18	29	43	101	97	97	175	137	506
72	528	11	21	32	31	95	92	103	158	80	433
73	510	7	9	15	12	43	102	89	174	102	467
74	478	4	9	13	11	37	87	93	160	101	441
75	382	3	6	5	13	27	87	67	120	81	355
76	338	2	1	13	6	22	67	60	119	70	316
77	288	1	0	6	4	11	50	61	100	66	277
78	253	0	1	4	1	6	57	50	88	52	247
79	225	0	1	5	1	7	41	57	87	33	218
80	169	1	0	0	1	2	29	33	63	42	167
81	128	0	0	2	0	2	32	26	44	24	126
82	97	0	0	0	0	0	22	14	47	14	97
83	91	0	0	1	1	2	11	11	49	18	89

TABLE 8-14: B.C. Sablefish Longline Catch Data (1979)*

84	71	0	0	2	0	2	15	12	33	9	69
85	52	0	0	2	0	2	9	5	30	6	50
86	57	0	0	0	0	0	8	13	25	11	57
87	39	0	0	1	0	1	7	5	18	8	38
88	27	0	0	0	0	0	5	2	16	4	27
89	24	0	0	0	0	0	7	4	12	1	24
90	12	0	0	0	0	0	0	4	7	1	12
91	12	0	0	0	0	0	2	2	7	1	12
92	3	0	0	0	0	0	0	0	3	0	3
93	8	0	0	0	0	0	1	0	6	1	8
94	4	0	0	0	0	0	1	1	2	0	4
95	7	0	0	0	0	0	2	2	3	0	7
96	1	0	0	0	0	0	0	1	0	0	1
97	4	0	0	0	0	0	0	2	2	0	4
98	0	0	0	0	0	0	0	0	0	0	0
99	1	0	0	0	0	0	0	0	1	0	1
100	0	0	0	0	0	0	0	0	0	0	0
101	1	0	0	0	0	0	0	0	1	0	1
102	0	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0	0
110	1	0	0	0	0	0	0	0	1	0	1
111	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0
114	2	0	0	0	0	0	0	0	2	0	2
115	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0	0
120	1	0	0	0	0	0	0	0	1	0	1
TOTAL	23,893	2,941	1,980	3,690	5,534	14,145	2,340	1,822	3,373	2,213	9,748
HATCHI	23,696	2,399	1,983	5,355	2,111	11,848	2,399	1,983	5,355	2,111	11,848
HOOKS	577,194	71,838	52,049	128,625	36,085	288,597	71,838	52,049	128,625	36,085	288,597
C/10 HATCHI	5.848	7.110	5.492	4.341	18.088	7.163	5.657	5.053	3.968	7.233	4.937
C/1000 HOOKS	24.009	23.745	20.923	18.073	105.818	29.408	18.893	19.253	16.521	42.316	20.266

---

* Adapted from Leaman, et al. (1981, pp.16, 26-29 and 38-51).

TABLE 8-15: B.C. Sablefish Trap Catch Data (1979)*

PIECE LENGTH IN CM.	B.C. TOTAL	CATCH PER 1000 TRAP SOAKS (KOREAN CONICAL TRAPS)											
		W. COAST QCI						W. COAST VANCOUVER ISLAND					
		SET NUMBERS						SET NUMBERS					
		1-6	7-12	13-18	19-24	25-30	AREA SUBTOTAL	1-6	7-12	13-18	19,22 24-27	28,29,36 32-34	AREA SUBTOTAL
41	4	0	2	1	1	0	4	0	0	0	0	0	0
42	7	1	1	3	1	0	6	2	1	0	1	0	4
43	8	3	1	2	1	0	7	2	0	2	0	1	5
44	22	10	2	4	3	1	20	0	0	6	3	0	9
45	27	8	4	7	3	1	23	2	1	7	12	0	22
46	20	1	1	5	5	0	12	4	5	16	13	4	42
47	41	4	7	6	7	0	24	5	8	36	31	6	86
48	55	5	4	11	2	2	24	8	23	68	49	8	156
49	51	6	2	4	5	0	17	11	12	81	56	9	169
50	89	7	5	4	5	1	22	20	60	141	99	17	337
51	80	6	2	3	3	1	15	23	66	113	94	27	323
52	106	7	2	5	6	1	21	47	73	154	119	33	426
53	123	13	4	4	5	4	30	43	117	129	140	37	466
54	129	6	5	7	6	4	28	53	121	162	132	36	504
55	136	6	7	11	10	5	39	65	108	121	140	53	487
56	135	13	9	11	9	11	53	51	93	113	107	44	408
57	177	14	16	20	28	17	95	64	92	117	95	41	409
58	206	24	25	40	23	16	128	87	72	92	87	51	389
59	234	22	31	48	39	26	166	79	70	81	68	44	342
60	328	42	49	58	61	47	257	60	65	85	83	63	356
61	277	24	45	57	45	49	220	70	39	67	53	58	287
62	360	36	73	67	70	60	306	69	43	62	52	44	270
63	389	43	81	63	77	64	328	66	43	69	63	65	306
64	395	44	73	85	81	52	335	86	35	70	44	64	299
65	383	32	66	81	97	49	325	54	50	68	59	57	288
66	395	35	91	79	92	46	343	45	42	66	57	52	262
67	336	37	74	66	65	46	288	37	42	43	60	59	241
68	348	39	80	71	69	44	303	43	35	56	47	44	225
69	321	42	57	65	76	40	280	46	34	31	43	53	207
70	337	41	62	68	80	39	290	47	37	37	52	64	237
71	259	42	50	48	49	33	222	27	39	31	39	49	185
72	258	56	52	35	63	15	221	39	34	23	37	51	184
73	236	41	55	35	54	19	204	29	23	33	29	45	159
74	206	39	42	46	38	16	181	26	21	26	19	32	124
75	175	34	38	25	40	13	150	22	21	19	31	33	126
76	150	35	20	22	36	16	129	15	24	16	29	23	107
77	145	21	26	25	31	21	124	15	18	18	27	29	107
78	115	23	11	19	34	12	99	11	15	16	15	22	79
79	82	8	15	13	28	6	70	11	8	11	14	16	60
80	74	10	9	12	22	8	61	11	11	5	16	21	64
81	61	14	8	7	15	6	50	9	18	5	10	13	55
82	44	6	5	11	9	4	35	10	7	3	13	12	45
83	39	4	7	7	8	5	31	5	6	6	7	16	40

84	36	5	4	7	13	1	30	7	9	3	6	6	31
85	25	4	4	6	5	4	23	2	4	0	0	6	12
86	19	2	5	0	6	2	15	3	3	0	6	6	18
87	11	1	3	2	2	1	9	3	3	0	2	1	9
88	14	0	2	2	7	0	11	3	4	2	2	4	15
89	5	0	1	1	2	0	4	1	1	2	0	1	5
90	12	1	0	0	8	1	10	2	4	0	0	4	10
91	3	1	0	0	1	0	2	1	0	1	0	2	4
92	3	0	0	0	2	0	2	2	0	0	1	3	6
93	3	0	1	0	2	0	3	1	0	0	0	1	2
94	2	0	0	0	1	0	1	1	0	0	2	0	3
95	2	0	0	1	0	1	2	0	0	0	0	0	0
96	2	0	0	0	1	1	2	0	0	0	0	0	0
97	0	0	0	0	0	0	0	1	0	0	0	0	1
98	0	0	0	0	0	0	0	0	0	0	0	0	0
99	1	1	0	0	0	0	1	0	0	0	0	0	0
100	1	1	0	0	0	0	1	0	0	0	0	0	0
TOTAL	14,715	920	1,239	1,280	1,452	811	5,702	1,446	1,660	2,313	2,164	1,430	9,013
TRAP: NUMBER	1,157	117	116	116	115	114	578	115	114	115	124	111	579
SOAK HRS	32,328	2,924	3,027	3,150	4,274	2,394	15,769	2,113	3,925	2,534	4,710	3,279	16,559
C/1000 SOAK HRS	455.2	314.6	409.3	406.3	339.7	338.8	361.6	684.5	422.9	913.0	459.5	436.2	544.3

* Adapted from Beamish, et al. (1980, pp.18-21 and 111-130)

9.0 REAPPRAISING THE ROLE, SCOPE AND LIMITATIONS OF FISHERIES MANAGEMENT

The economic, socio-political and legal roles played by the fisheries managers are poorly defined in the preceding sections.[135] In the Margenau maps in Charts 6-1 and 6-2, the roles of the fishery managers and their sponsors (the government) are displayed as the output from overlapping *black boxes*—while Tables 5-1 and 5-2 may provide some insight into how those black boxes work but it is not sufficient to model that output as either a *module* or as a *role set*.[136]

The traditional model of the firm is insufficient for the task of examining the concept of a role set at either a market scale or at an individual scale.[137] Alternative models have been developed to examine role sets within firms:

- The *Structure of Organizations* "examines the ways in which stable, consistent, reliable, predictable patterns of behaviour become established in organizations" (Finch et al., 1976, p.15; Williamson, 1964, 1967 and 1975; Downs, 1967, p.143 Jackson, p. 22). However, Abdel-khalik (1989, p.39) concluded that the focus of Williamson's *Structure of Organizations Approach* is on the firm—which is at too low a scale to encompass the market institution function(s) of a role and is at too high a scale to capture the interactions between individuals.

---

[135] A role is a social prescription of some, but not all, of the premises that enter into an individual's choices of behaviour (see Simon, 1975, pp. 93-98).

[136] A role "...has, as defined by the society, community and organization, certain *rights*, *duties* and *obligations* that compose both the costs and rewards of participation [in that role]" (Scott and Mitchell, 1972, p.204).

[137] In the *Traditional Theory of the Firm*, all individuals in a firm act to maximize the wealth of the firm's owners. Reasonable economists understand that this black box view of firms is not how firms work. However, this assumption allows economists to focus on market behaviour without having to factor-in the impossible level of detail of the inner workings of all firms active or potentially active in a market. This theory is not particularly useful for examining roles or the actions of individuals.

- *Agency Theory* is derived from the Alchian and Demsetz theory of the firm. Agency costs, in particular, bear a close relationship to the problems of shirking and monitoring of team production (Jensen and Meckling, 1976, p.309).

  Agency Theory replaces the traditional assumption of firm behaviour with the assumption that all individuals associated with the firm (owners, employees, customers, etc.) enter into contracts with the firm based on maximizing their own self interest. The structure of the firm in this theory is that of a central agent who delegates authority to lower levels of management on the basis of employment contracts. The theory then allows for cheating on the part of either party to the agreement.

  The purpose of the theory is to identify conditions and techniques that optimize the trade-off between the costs of shirking and those of enforcement. As such, it a good way of looking at the role of fisheries managers.

- The *Social Institution Approach* is epitomized by Akerlof's (1970) paper *The Market for Lemons.* The basic idea is that it is in the long-run interests of all in a market to prevent the market from failing. As a result, markets and organizations will tend to evolve institutions and/or roles to mitigate the frequency and severity of market failures (Alchian and Demsetz, 1972). While the this approach can provide much insight into the general socio-political role of fisheries management, its (time and structure) scale is too grand to be of much use in examining the role of a fisheries manager. However the basic ideas of this approach are encompassed, at a lower scale, in Agency Theory.

In each of these models, the role or function of fisheries management can be defined by the answers to the following questions:

- Who do they manage the fishery for?
- Who are they accountable to?
- Who rewards them and on what basis?

A major problem in answering these questions is that in many societies it is unclear who owns the fishery and/or the rights to the actual or potential benefits arising from the fishery and any related resources. Even when a government has a clearly stated policy of state ownership, the common property resource nature of exploitation in most fisheries may provoke confusion and conflict over the title to and/or the nature of property rights in the fishery (Copes 1986a, pp.31-37 and 203-211).

It is neither appropriate nor within the scope of this dissertation to discuss who owns or should own the fishery and/or the benefits that arise or could arise from it—ownership is a socio-political rite shaped by the history, customs, perceptions and other forces that (for members of a society) legitimize freedoms, boundaries, obligations, etc. (Boulding, 1985, pp.120-122). Thus, fisheries management policies should be settled by debate within the domain of a society's political process.

9.1 WHAT ROLE AND RESPONSIBILITIES SHOULD FISHERIES MANAGERS FILL?

A description of what should be involved in fisheries management depends to a large extent on the interests of who is doing the defining. Fisheries management in Canada has shifted its emphasis from maximizing yields to ensuring the best use of society's resources. In a 1976 policy statement the Canada's Fisheries and Marine Service (1976, p.53) observed that:

> "The guiding principle in fishery management no longer would be maximization of the crop sustainable over time but the best use of society's resources. *Best use* is defined by the sum of net social benefits (personal income, occupational opportunity, consumer satisfaction and so on) derived from the fisheries and the industries linked to them."

However, the Fisheries Council of Canada very wisely noted that:

> "It is not enough to say that the fisheries will be managed for the greatest benefit of those in the industry and for Canada. We must know what it means in operational terms." (Pearse, 1982, p.37).

As noted in Tables 5-1 and 5-2, fisheries managers and their political sponsors have multiple and conflicting goals. Fisheries managers are usually more informed and experienced, in fishery matters, than their political masters. However, the allocation of the fishery resource between the contending user groups is ultimately a political rather than technical choice—the advice of fisheries managers is only one of many factors in a political decision. The expertise of fishery managers may also be used to help reconcile the losers to their new circumstances.

Fisheries managers should not make fisheries policy—they should only advise the participants engaged in the political policy setting process and, once policies are set, they should implement them. This function has three perils: first, positive feed back loops may form as fishery managers deliberately or inadvertently seek to provide their political masters with information that is more politically palatable than technically sound; second, fisheries managers may have responsibilities foisted on them that should be made within a political arena; third, the fishery managers may be *captured* by a powerful stakeholder group and, as a result, provide information, decisions and enforcement that are biased in favour of the interests of that group.

9.2 THE FIDUCIARY ROLE OF FISHERIES MANAGERS

Fishery managers implement policies that arise from the political arena and supply much of the information that the fishery stakeholders need to make informed choices. These roles place fishery managers in a fiduciary capacity with respect to fishery stakeholders. These roles require independent, objective and trustworthy fishery managers. However, as noted in section 3.0 and subsections 5.4 to 5.4.2, fisheries managers and their political sponsors are part of the fisheries system they manage and, from a hierarchical general systems perspective, independence and objectivity are illusions. As civil servants, fisheries managers may have another problem—a duty of obedience to (the lawful commands of) those who form the government, at a given point in time.

Fisheries managers, as individuals, may exhibit a high degree of professionalism, idealism and integrity but their focus tends to be on the mechanics of managing fish stocks and fisheries management appears to be unable to come to terms with even the most basic elements of its fiduciary role.

9.2.1 THE FIDUCIARY ROLE OF FISHERIES MANAGERS -- NATIVE INDIAN FISHERIES

An example of fiduciary failure in fisheries can be found in the history of the Canadian Pacific salmon fishery. Regulations were used to create a *commercial* salmon fishery by first restricting where the native Indian's could sell their salmon harvest and then by a gradual process of isolating, limiting and excluding the native Indian harvest from the commercial harvest:

> The Fisheries Act of 1889, gave B.C. canneries a monopsony with respect to Indian fishermen. That act "provided that from 1889 forward, Indians could no longer sell fish or own fishing licences. If they wanted to catch fish for anything other than their own food... they would have to use licences owned by the fishing companies and sell fish to those companies. White fishermen, of course, could apply for their own licences. The canneries were assured a captive labour market of Indian fishermen who were paid five cents a fish, and a growing population of semi-independent white fishermen who were paid ten cents a fish. It was not until 1923 that Indians were allowed to apply for fishing licences as a white man could." (Glavin, 1990, p.21).
>
> "...as the commercial fishery expanded, competition for raw material with the tribal fishery in the region became more acute. ... Fishery authorities...acted to reduce fishing pressure by prohibiting weirs and traps. Where Indians resisted and continued to use these devices, [the devices] were dynamited." (Copes, 1988b, p.10).
>
> "In 1894 the permission of the Department was required for Indians to engage in the fishery" (Pearse, 1982, p.176).
>
> "In 1910 regulations were enacted to require that Indians obtain a permit, "under which the Department could fix the area and time that fishing activities could be undertaken" (Pearse, 1982, p.176).
>
> In 1912, the government of Canada wanted to increase its presence in the northern part of B.C. and issued a number of licences to "independent white fishermen" to induce them to settle in there (MacDonald, 1981, pp.1-7).

> After WW I, wherever practical, the salmon fishery was used to provide employment to returning servicemen (MacDonald, 1981, pp.1-7).
>
> "The Allied Tribes of British Columbia, was formed in 1915 in an unsuccessful attempt to force a judicial decision on land claims by the British Privy Council. Following the government's rejection of the Allied Tribes' land claims in 1927, the organization folded" (Dyck, 1988, p.1457)—"its leadership [was] severely disillusioned, not only by the failure of their appeal but also by the introduction in the Indian Act of a section making it an offense to solicit funds for the purpose of pursuing a land claims case (Canada 1927)" (Kew, 1990, p.166).
>
> "In 1931, following the model of an Alaska organization, the Native Brotherhood of British Columbia was formed ...and directed to all lawful means by which Indian welfare might be enhanced" (Kew, 1990, p.166). "That organization's main concern was to defend the native peoples' lands and fishing and hunting rights against the encroachments of white settlers, miners, and loggers" (Cook, 1987, p.437).
>
> "...with other racial minorities in British Columbian, Indians were denied the provincial franchise until 1949. The federal franchise had been available to Indians who were war veterans (and their wives) and to those who chose to waive tax exemptions extended under the Indian Act, but it was not until 1960 that this right was extended without restriction to registered or status Indians." (Kew, 1990, p.162; Stearns, 1990, p.261).
>
> In 1982, Pearse (pp.179-180) found the legal framework for Indian fisheries was alarmingly ambiguous and incoherent. ...The resulting uncertainty about the legal foundation for Indian fisheries has left the Indians in an unacceptable position and the Department unable to properly manage the resources."

This heritage of injustice contributes greatly to the current strife between Indians and fisheries regulatory authorities. However, at the B.C. provincial court level, recent judgements have been less than favourable toward the (Canadian) Department of Fisheries and Oceans and the commercial fishing interests. Specifically:

- In April, 1989, Judge Terry Shupe accepted the defense that the Lillooet's traditional fisheries law has never been surrendered to Ottawa and acquitted two Indians charged with fishing without a permit and fishing during season closures (Glavin, 1989a).
- In May, 1989, Judge Cunliffe Barnett "blasted the federal government for being unfair and insincere in its dealings with native Indian fishermen" and, "in a written decision dismissing three fishing charges against 37-year-old Shuswap Indian Ernie Archie,

said that the federal fisheries department used its own statistics to obscure the facts related to a controversial closure imposed on the upriver Indian fishery last summer." Judge Barnett, also, said that: "If the government of some Eastern European country had produced such material we would call it propaganda." (Glavin, 1989b; also, Canadian Press, 1989).

- In June, 1989, Judge Terry Shupe when dismissing charges of illegal fishing and illegal possession of fish against nine Lillooet Indians observed that: DFO "infringed the defendants's aboriginal rights by unlawfully giving priority to American commercial fishing, over Indian fishing, on July 13 and 14, 1988. ...That is not just. It clearly conflicts with the spirit of the Sparrow decision, and steps must be taken to correct that imbalance, no matter how difficult so doing may be." (Glavin, 1989b; also, Hume, 1991).
- In June, 1990, Judge Cunliffe Barnett dismissed charges against four Indians and stated "In my opinion the licensing regime which DFO followed still in 1989 was obviously and utterly inconsistent with the proper recognition of aboriginal fishing rights....It is not suggested that the Department of Fisheries and Oceans cannot require IFF (Indian food fishery) participants to be licensed. It is, however, suggested that the particular licences which DFO requires IFF participants to obtain are offensive." The licenses restricted the Indian fishermen to take salmon for food only, for their families only. The licences also prohibited Indians from fishing during optimum times of the season and as a result the Indian fishery took less than four per cent of the catch in 1990, despite the alleged priority placed by Ottawa on Indian Fisheries over and above all other fisheries. (Glavin, 1990).

If this trend in court decisions continues, the people at DFO may experience even more legal difficulties in the future. Specifically, the transfer of access to salmon still occurs, albeit in a more subtle and (perhaps) unintentional guise. Specifically, it is now well known that the salmonid enhancement program (SEP) tends to increase large commercially exploited salmon runs at the expense of the smaller runs, that are often exploited by Indians and/or sports fishermen (Pearse, 1982, pp.51-52). Although this transfer appears to lack the underlying intent needed to prove a charge of *fraudulent preference*, DFO may have difficulty defending itself against a charge of *negligent preference*—they continued and expanded enhancement programs, even when they knew or should have known of the detrimental effects of the programs on the weaker stocks utilized by Indians.

9.2.2 THE FIDUCIARY ROLE OF FISHERIES MANAGERS -- PROVISION OF INFORMATION

In terms of Canadian society as a whole a even more serious issue arises from SEP. The reports released by DFO do not provide sufficient information for an independent party to evaluate the performance of SEP, in terms of the net marginal benefit to society.

The Lake Enrichment Program (LEP) exemplifies the problem. LEP is intended to increase the abundance of sockeye salmon, by nutrient enrichment of oligotrophic (nutrient poor) rearing lakes. After initial LEP trials on Great Central Lake (Vancouver Island) were adjudged to be successful, LEP was swung into a full production mode on 15 lakes. The stellar performance of LEP appears to have been a fortuitous offset to the remarkably ruinous results obtained by most other types of enhancement projects. Based on Pearse's (1982, p.50) figures, LEP represented over 62 percent of the anticipated net national income benefits of Phase I of SEP. When the effects of LEP are excluded, Pearse's estimate of average B/C ratio for SEP falls from the inclusive average of 1.3:1 to a dismal 0.17:1. The target B/C ratio for Phase I of SEP was 1.5:1. The unseemly haste with which LEP was shifted into production mode has resulted in much data that is of little or no value— either to science or for assessing the value of LEP, to society.[138]

---

[138] Peterman (1990, p.10) observed that: "While LEP appears to work in most of the cases in which complete adult data exist, its current production mode precludes gathering the data required to further improve its performance by identifying the range of conditions in which it is successful, and the causes of failures."

Many of the problems with SEP arise because management decisions are being made by comparing the average gross social benefits to the average project costs. Niskanen (1971) postulated that bureaucrats in the process of seeking to maximize their budgets will spend beyond the social optimum of marginal cost equals the marginal benefit and if not controlled they will continue to spend until the average cost of their bureau equals the average benefit. This concept is consistent with DFO not providing their sponsor with sufficient information to determine if the scale of any given SEP project was appropriate.

9.3 CONCLUSION

Further research is needed to define the functional role of fisheries management. In particular, forming fishery policy should not be part of the fisheries management function. Also, an effort should be made to strengthen accountability and external controls over the fisheries management function. Further, the expectations that society has of fisheries managers appear to be:

- too great, in terms of resolving complex intractable social issues, and
- too little, in terms of accounting for both the resources entrusted to their care and the accuracy of the information they input to the political arena.

10.0 CONCLUSIONS AND SUMMARY

After examining the Cartesian paradigm that underlies much of the traditional fisheries management and analysis, this dissertation concludes that the development of an alternative fisheries approach would provide useful insights into fisheries. The summary of fishery management history (section 2) shows that neither neglect nor ignorance is behind the failure to resolve the many serious problems besetting many fisheries. A lesson that can be drawn from that history is that fisheries tend to exhibit a pernicious variant of *Peer's Law—the solution to the problem changes the problem* (Lyall, 1986). Specifically, many of the attempts to resolve a fishery problem merely alter the form of that problem or evoke a host of problems that were previously inconsequential.

From a general system perspective, the Cartesian approach is an extreme where *the whole* is limited to being *the sum of its parts.* This may work well with things or simple linear systems, however, fisheries are complex systems with bio-economic and socio-political facets. *Systems theory* contends that attempts to manage individual elements in a nonlinear system may induce unexpected, unwanted and dramatic results. If the fisheries Peer's Law situation arises from the Cartesian paradigm that underlies much of the traditional fisheries management and analysis, then insights arising from an alternative fisheries approach will be worth pursuing.

Developing a new paradigm for fisheries is beyond the scope of a dissertation—it is a major endeavor involving decades of effort, research, analysis and testing. What this dissertation seeks to achieve is only the first and most elementary steps of this process—to determine if developing an alternative approach to perceiving fisheries is sufficiently feasible and useful to warrant the associated development and implementation costs.

Holism is rejected as a possible approach, because from a general system perspective, it is an extreme where only the whole is of meaning (e.g. *a whole* is seen as being indivisible—from a Holist perspective, *the parts of the whole* is a meaningless concept).

Cartesian *reductionism* and Holist *system integrity* are shown to be extremes of a continuum of world views. A *hierarchical general system approach* harmonizes these opposing views into a more balanced view —as such it encompasses the Cartesianist and Holist views, as special cases.[139] In the Cartesian perspective, the whole is always equal to the sum of its parts and the whole is always equal or superior to any of its parts. In a Holist perspective, wholes are inseparable and are always superior to mere fragments. Thus, in terms of Cartesian logic a *hierarchical general system approach* (which has Cartesian and Holists views as special limiting cases) offers a range of analytical options that is superior to those extremes. However, in a *hierarchical general system* view a whole may be equal to, greater than or less than the sum of itsparts. Based on this *hierarchical general system* precept, there may be a few circumstances where either a Cartesian or Holist approach

---

[139] General system theory has evolved into a wide variety of forms and applications. *Hierarchical general system approach* is a very general form of the theory in that it uses general system theory as its underlying paradigm.

is superior to a *hierarchical general system approach.*

The value of a new approach to fisheries tends to be concentrated in the change in attitudes, perspectives and language that it creates. As the Austrian philosopher Wittgenstein noted "*The limits of my language ...mean the limits of my world*" (Watson, 1986, p.246). However, this change evolves over decades, if ever—thus, it is not feasible to directly value the change at this time. Instead the *hierarchical systems approach* is used to develop various modules (Section 5), that are then assembled into simple models (Sections 6 and 7), that are applied to examining several common fisheries management problems. An approach that focuses on the nature and behaviour of systems is, by its nature, difficult to demonstrate. This problem is further complicated by the Cartesianist history of Western culture—system approach findings tend to be more accepted if they are cast in a Cartesianist context. As our culture evolves away from a Cartesianist past toward a systems orientation, a systems context may evolve for presenting findings. However, having been raised and educated in a Cartesianist culture, I am not sure that I could understand such a context.

A *Hierarchical General System Approach*, by its very nature, precludes a definitive proof of its superiority over other approaches—definitive proofs tends to be a feature of the Cartesian view. What I offer as corroboration of the relative merits of a *Hierarchical General System Approach* is a few of the more significant insights (into the nature and problems of fisheries systems) that use of a *Hierarchical General System Approach* has given to me. Many of these insights can be independently derived from or validated by cleverly crafted Cartesian models, However, they tend to be more apparent in a *hierarchical systems* model (i.e. they often form necessary constraints or other important model structures). However, these insights may be specific to the models and the conditions contemplated by those models—more research is required to determine if they have a general application.

- If a model with a reasonable level of complexity persists in failing, the model may not have been defined with sufficient breadth to capture all relevant influences. Many fisheries models are overburdened with minute details on stock biology and fisheries microeconomics but the economic and political linkages between the fishery and the society in which it is embedded are rarely considered as an active part of the model.

- Models of the effect of a new fishing regulations need to consider the many margins along which fishermen can respond. Models that considers only a single margin is too limited to be of much value.

- When a TAC is held constant, controlling fishing effort by reducing the fishing season length alters the optimum vessel configuration, causes the cost of fishing effort to rise and may encourage:

  - Input stuffing and an increase in the number of vessels in either an open access fishery or an IQ fishery.

  - Input stripping and a decrease in the number vessels in a limited entry fishery.

- Because of the dedicated nature of most fishing inputs, the *exit opportunity cost* of a fishing input can be less than the *entry opportunity cost* associated with a new input.

- If utility is defined by a Cobb-Douglas type function of income and leisure, relative income is a poor measure of poverty. For example, a fisherman with less income and more leisure than *normal*, may be equally satisfied with his lot as an individual in a *normal* job. As the number of considerations in the utility function increase, relative income becomes an increasingly inadequate indicator of the state of poverty.

- As it is possible to imagine many situations where *the tragedy of the commons* is neither necessary nor sufficient to cause poverty, it does not seem to be particularly useful to describe the tragedy of the commons as causing poverty. Clearly, further research and analysis is needed to identify the conditions under which it is reasonable to attribute poverty in fishing communities to a common property resource problem.

- The policies of a government are made effective by bureaus (the fishery managers) which translate policy into regulation and enforce regulations. The bureaucrats and the government are not a uniform entity—the bureaucrats may or may not sympathize with government policies and they may or may not be adequately controlled by the government. The individuals employed by a fisheries management agency are usually more informed and experienced in fisheries than the politician to whom they report.

- The common property resource problem in fisheries is so pervasive that attempts to resolve it via regulation and/or changes to the structure of fisheries tend to only cause a change in the form that this problem takes. As a result, the apparent successes of many management programs dissolve as the common property resource problem becomes manifest in its new form.

- While the season length can be varied to manage for a harvest at an MEY or an $F_{0.1}$ level, the process works by dissipating all of the resource rent—thus, neither result is a valid approximation of MEY. The misconception that $F_{0.1}$ is a good approximation for MEY is widespread.

- If vessel licence fees are seen by vessel owners as an increase in vessel fixed costs, they will respond to this change in the private cost of effort by modifying the configuration of inputs in their vessels. Thus, vessel licence fees may not be neutral with respect to the cost-efficiency of fishing effort.

- The input stuffing problem in a limited entry fishery may not dissipate all of the resource rent. The amount of fishing power that can sensibly be generated by the stuffing of inputs into a vessel has limits—fishing inputs are not perfectly substitutable, most fishing inputs eventual have diminishing returns to scale and a vessel owner will only add an input if its marginal private cost is less than its private marginal revenue.

- IQs appear to avoid the input stuffing problems that marred the success of limited entry programs. However, in a mature limited entry fishery, the gain in long-run efficiency appears to occur at the short to intermediate-run expense of the owners of the *stuffed inputs*. Where the quota is awarded to vessel owners on the basis of past harvests, the owners of vessel capital may be well compensated for their losses by the value of their quota. However, deckhands may be at a decided disadvantage.

- IQs or ITQs will dramatically alter complex systems on which depend both the livelihood of fishermen and a portion of the wealth of the nation. It, therefore, behooves us to act with great caution. We should express in fair measure, to ourselves and other interested parties, our ignorance as to how a given fishery system will ultimately respond to the imposition of IQs.

- IQs will so profoundly alter fisheries that it is likely unsafe to routinely extrapolate experience and traditions from *nonIQ* fisheries into the management of IQ fisheries.

- Selectivity will likely cause significant problems in IQ fisheries. Selectivity occurs when individual fishermen seek personal gain by pursuing fish that (on a per unit weight basis) have a higher value and/or lower cost, with no (or little) regard for any costs that are imposed on the users of the stock as a whole—each fisherman owns not the stock but a share of the current TAC. Selectivity tends to be a significant problem only in an IQ fishery—the race for fish that occurs in open access or limited entry fisheries tends to prevent the individual fishermen from seeing selectivity as an optimizing behaviour. IQs limit the amount of fish that a fisherman can harvest and shift the profit maximizing behaviour of a fishing enterprise away from catch quantity to quality. And, by guarantying the amount of fish that a fishing enterprise can try to harvest, IQs afford fishermen the time needed to engage in selectivity.

- Selectivity is a complex syndrome of fishing strategies and behaviours whose elements vary in both absolute and relative intensity. Thus, data biases induced by the various forms of selectivity may be neither constant nor predictable. The data fouling caused by selectivity will persist far into the future and data, even as it is gathered, will tend to corrupt and unreliable for management purposes. Further, there is no reason to believe that the biases will ever converge to a constant or predictable form.

- When distances are an important factor in a fishery, selectivity causes:

  - Royalty taxes to not be neutral—as a royalty tax is increased, the actively fished portion of a fishery tends to decline (the sustainable yield tends to vary with the amount of the fishery that is actively fished).

  - An IQ fishery to be less economically efficient than a sole-owner fishery.

- When the selectivity syndrome concepts were contrasted with empirical data from an actual fishery, another four possible forms of selectivity became apparent.

- The thesis that the *fair market value* of a fishing right is the present value of the future rents arising from that right is based on the heroic assumptions that markets behave as though everyone is rational, that perfect costless information is available to all, that the future is certain (or the uncertainty is quantifiable) and that there are no entry or exit barriers. As a rule, fisheries do not even come close to meeting these assumptions and fishing rights may have a positive market value even when there is no resource rent in the fishery.

- Ownership is a sociopolitical rite shaped by history, customs, perceptions and other forces that (to the members of a society) legitimize freedoms, boundaries, obligations, etc. (Boulding, 1985, pp. 120-122). Thus, fisheries management policies should be settled by informed debate within the domain of a society's political process.

- Fishery managers implement policies that arise within the political arena and supply much of the information that fishery stakeholders need (to make informed choices). These roles place fishery managers in a fiduciary capacity with respect to the fishery stakeholders.

- Their fiduciary role requires fisheries managers to be independent, objective and trustworthy. However, the fishery managers and their political sponsors are part of the fisheries systems they manage—from a hierarchical general systems perspective, independence and objectivity are illusions. Fisheries managers may have a further problem—as civil servants, they owe a duty of obedience to (the lawful commands of) those who form the government at a given point in time.

- The current role of fisheries managers appears to expect:

  - too much, in terms of resolving complex intractable social issues, and

  - too little, in terms of accounting for both the resources entrusted to their care and the accuracy of the information they input to the political arena.

While many of the above insights are not restricted to a *hierarchical general system approach*, I hope to have demonstrated that they can be made *more plain* by such an approach. The *making plain* of such insights is a strength of *a hierarchical systems approach* to modeling.

Many fisheries economists have displayed an obsessive concern with the relief of poverty. This concern is more of a historical accident than an inherent feature of fisheries economics. Its roots go back to Scott Gordon's seminal article on fisheries economics. While Gordon was careful to make various caveats, he clearly linked the persistent poverty observed in many fishing communities with the common property resource problem:

> "...most of the problems associated with the words *conservation* or *depletion* or *overexploitation* in the fishery are, in reality, manifestations of the fact that the natural resources of the sea yield no economic rent." (Gordon, 1954, p.124).

> "A.G. Huntsman, reporting in 1944 on the work of the Fisheries Research Board of Canada, defined the problem of fisheries depletion in economic terms: *Where the take in proportion to the effort fails to yield a satisfactory living to the fisherman.*" (Gordon, 1954, p.125).

> "In point of fact, fishermen typically earn less than most others, even in much less hazardous occupations or in those requiring less skill. There is no effective reason why the competition among fishermen described above must stop at the point where opportunity incomes are yielded." (Gordon, 1954, p.132).

> "That the plight of fishermen and the inefficiency of fisheries production stems from the common property nature of the resources of the sea is further corroborated by the fact that one finds similar patterns of exploitation and similar problems in other cases of open resources." (Gordon, 1954, p.134).

Gordon's (1954, p.134) theory that poverty in fisheries was attributable, for the most part, to a market failure was greeted with considerable enthusiasm and has been frequently reiterated. The following examples are grouped according to the discipline of the authors.

Mathematical Bioeconomists:

> "In the 1950s a Canadian economist, H.S. Gordon, was asked by federal fisheries authorities to provide an economic analysis of the persistent problem of low income among Canada's maritime fishermen. Gordon's theory of the common *property fishery* (Gordon, 1954), which has since become a classic, not only explained the low income of fishermen, but also clarified in economic terms the so-called overfishing problem..." (Clark, 1985, p.1).

Economists:

> "We begin with a paradox. We have some of the world's most valuable fish resources, they are capable of yielding great economic and social benefits; yet many commercial fishermen and fishing companies are near bankruptcy, sport fishermen and Indians are preoccupied with declining opportunities to fish, and the fisheries are a heavy burden on Canadian Taxpayers.
>
> ...The central economic problem of the commercial fisheries is the chronic overcapacity of the fleets.
>
> ...All of these effects—stock depletion, poor economic performance and instability—result from treating the resource (the fish) as common property until they are caught, and are normal whenever resources are treated this way. It is *The Tragedy of the Commons.*" (Pearse, 1982, pp.3 and 75-76).

> "It is one of the great ironies of the French Revolution that the *égalité*, which really meant equal distribution of estates among children and the abolition of primogeniture along with other hallmarks of aristocracy, is a sure recipe for the equality of misery if the surplus population that will inevitably result cannot be exported. ...If we privatize the commons, we create an upper class who owns and administers it. It will be administered well. There will be no overgrazing. The boundary between the well-managed private property and the ill-managed public estate will stand out sharply." (Boulding, 1977, pp.285-286).

> "Sometimes advertising expenditures only have the effect of raising the costs of the entire industry, since one firm's advertising campaign causes other firms to increase their advertising. The total market for the industry's product may not increase in response to the increased advertising, and the effects on the sales of individual firms may be small, since the effects of the advertising may cancel out. However, once every firm has increased its advertising expenditures, no single firm can reduce them to their former size without losing sales." (Mansfield, 1975, p.37).

> "Gordon (1954) developed the economic theory of common property resources. ...Gordon pointed out that this open-access equilibrium dissipates the wealth (or rent) that the fishery could potentially generate....The result has been that excessive effort is used in the fishery, fish stocks may be dramatically reduced and fishermen tend to remain poor with incomes little more than their opportunity incomes." (Heaps and Helliwell, 1985, p.430).

Ecologists:

> "There-in is the tragedy. Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all." (Hardin, 1968).

> "(As Leo Durocher says, *Nice guys finish last.*) ...*it takes only one less than everybody* to ruin a system of voluntary restraint. In a crowded world of less than perfect human beings—and we will never know any other—mutual ruin is inevitable in the commons. This is the core of the tragedy of the commons." (Hardin, 1977, p.265).

> "...the system of the commons ends in disaster even if every member understands the situation completely. This gives new meaning to the ancient idea of tragedy, which (to the Greeks) was a disaster that even foreknowledge could not prevent. The tragedy of the commons is a logical consequence of the rules of the game (*to each according to his needs*) coupled with inescapable human nature (some people, at least, are both competitive and envious)." (Hardin, 1986, p.93).

> "Each individual herdsman who wishes to optimize his strategy will add a head of cattle to his herd, and this leads necessarily [to over-grazing and] to disaster for the community as a whole." (Muhsam, 1977, p.36).

> "Claims to the seabed treasure, more than any other conflict, might have been the issue that stirred Malta's U.N. Ambassador to call for a law for the sea....Pardo characterized the sea bed as ***the common heritage of mankind***, an idea which became a magnet for contention in drafting the Law of the sea.
>
> The common heritage concept has a background, often overlooked. Commons have been known on land throughout history. The urge to overuse land inspires a comment on man's essential nature in Garret Hardin's *The Tragedy of the Commons*. In brief, the tragedy Hardin describes is villagers' use of common grazing lands. Because these lands were both common to all and free, each man tried to outdo the next in his use of them. Neighbor raced his flocks against neighbor. Eventually, the commons, overgrazed, were useless to all." (Simon, 1985, p.100).

Fisheries Policy Analysts:

> "The unlimited access of fishermen to resource stocks in commercial fisheries leads to excessive capacity, low average fishermen incomes, and difficult and expensive regulation and enforcement" (Morehouse and Hession, 1972)

> "In an open-access, free-for-all fishery, competing fishermen try to catch all the fish available to them, regardless of the consequences. Unless they are checked, the usual consequence is a collapse of the fishery: That is, resource extinction in the commercial sense, repeating in a fishery context *the tragedy of the commons*" (Fisheries and Marine Service, 1976, p.39)

> "A considerable amount has been written about the economic waste that is generated when fisheries are managed under open access conditions. ...Standard analysis shows that in fisheries operated under these conditions all potential economic rent is dissipated and that the average fisherman, depending on his ability to gain alternative employment, will earn less than he would in other occupations requiring similar skills" (Sinclair, 1977, pp.5-6).

> "It is no mystic movement that induced the notion of *too many fishermen chasing too few fish with too little return*....The reason for this lies mainly in the common property nature of this resource" (Sinclair, 1978, p.8).

> "In 1954, Scott Gordon gave the first theoretical explanation of why common property fisheries, where free access exists, develop excess inflows of labour and capital so that economic returns are below those in other industries" (Fisheries and Oceans, 1985, p.5).

The Phrase *The Tragedy of the Commons* was coined by Garrett Hardin in 1968. Earlier philosophers had commented on the problems associated with a commons:

> "What is common to the greatest number gets the least amount of care. Men pay most attention to what is there own: they care less for what is common." (Aristotle, Politics Book II, chapter three).

> "It will serve to illustrate the subject, if we compare the relation subsisting between the cases of two countries, in one of which the constitution of society is such as to throw the burden of a family entirely on the parents, and in the other such that the children maintain themselves at a very early age, with that subsisting between the parallel cases of inclosed grounds and commons ....If a person puts more cattle into his own field, the amount of the subsistence which they consume is all deducted from that which was at the command, of his original stock; and if before, there was no more than a sufficiency if pasture, he reaps no benefits from the additional cattle, what is gained in one way being lost in another. But if he puts more cattle on a common, the food they consume forms a deduction which is shared between all the cattle, as well that of others as his own, in proportion to their number, and only a small part of it is taken from his own cattle. In an inclosed pasture there is a point of saturation ...beyond which no prudent man will add to his stock." (Lloyd, 1833).

> "That the plight of fishermen and the inefficiency of fisheries production stems from the common property nature of the resources of the sea is further corroborated by the fact that one finds similar patterns of exploitation and similar problems in other cases of open resources." (Gordon, 1954, p.134).

> "There-in is the tragedy. Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all." (Hardin, 1968).

The philosopher A.N. Whitehead observed that: "We give credit not to the first man to have an idea, but to the first one who takes it seriously." Taking an idea seriously involves worrying it like a bulldog might a bone. However, receiving credit for this effort also requires the good fortune of getting the attention and interest of your peers.

On this basis credit for the concept of *the tragedy of the commons* should go to Garrett Hardin (1968) and favourable mentions might go to Lloyd (1833) and Gordon (1954).

DESCRIPTION OF PARAMETER OR VARIABLE	SYMBOL & VALUE	
4.1 BIOLOGICAL - STOCK AND HARVEST		
• stock fecundity	r	.20
• inverse of carrying capacity	α	.000005
• substock α (for subsection 7.4.1)	α_s	.000010
• fish biomass (tonnes)	X	variable
• harvest/harvest related mortality	δ	.800000
• catchability coefficient	q	.000020
• substock q (for subsection 7.4.1)	q_s	.000040
• harvest (tonnes)	H	variable
• equilibrium harvest at effort E	H_E	variable
• fishing effort	E	variable
• fishing effort of vessel i	E_i	variable
4.2 MARKET		
• price (tonne)	P	\$2,000
• revenue	R	variable
• revenue of vessel i	R_i	variable
4.3 FISHING ENTERPRISES - REVENUE AND PRODUCTION		
• scaling parameter	m	100.00
• labour exponent	n	.15
• capital exponent	k	.35
• fishing power per vessel	f	variable
• fishing power of vessel i	f_i	variable
• labour input per vessel	N	variable
• capital input per vessel	K	variable
• number of vessels	V	variable
• fraction of year when fishing is allowed:		
- unmanaged	g, g_{max}	.50
- managed	g	variable
4.4 CAPITAL MARKET		
• return to capital	r_c	\$1,000

DESCRIPTION OF PARAMETER OR VARIABLE	SYMBOL & VALUE
4.5 LABOUR MARKET	
• income exponent	¥ .80
• leisure exponent	Ç .40
• deckhand opportunity cost:	
- nonfishing full time earnings (365 days)	W_{FTNF} \$50,000
- nonfishing part-time earnings (365 days)	Φ \$30,000
• deckhand annual opportunity wage and leisure:	
- nonfishing full time - earnings	Y_A \$33,333
- leisure	L_A .333
- utility	U_o 2,675.81
- fishing and part time - earnings	Y_C \$28,114
- leisure	L_C .469
- utility	U_o 2,675.81
- compensation	τ \$12,172
• share earnings per deckhand:	
• labour support costs (provisions)	Ω \$3,000
- total labour share is fixed at 50%	$W_{S/N}$ variable
- each share is 1/15	W_S variable
4.6 FISHING ENTERPRISES - COSTS	
• annual fixed cost of vessel ownership	b \$30,000
• annual cost of vessel capital	Γ \$2,000
• annual operating cost of fishing capital	θ \$5,000
• labour support costs (provisions)	Ω \$3,000
• annual social cost of fishing per vessel	C_1 variable
• scaler for fishing costs - substock 1	$\S_1$ 1.00
- substock 2	$\S_2$ 1.50
• cost of fishing effort - substock 1	c_1 \$ 912.669
- substock 2	c_2 \$1,369.003
• rent received by a vessel owner/skipper	π_1 variable
• income received by a vessel owner/skipper	Y_1 variable
• rent received by a deckhand	π_{dh} variable
• income received by a deckhand	Y_{dh} variable

APPENDIX C: Henry Margenau's Structure Of Science

Margenau (1966 and 1983) examines how cognitive experience is organized into a structure by science and how science uses that structure to predict and explain phenomena.

C.1 MARGENAU CONSIDERS THE NATURE OF EXPERIENCE, NOT REALITY

In keeping with general system theory, Margenau (1966, p.26) states that experience defies simple classification—it is not a collage of discrete packets but a continuum that can be divided only in ways that are arbitrary and unstable.

Margenau's model is neutral with respect to the *true nature* of reality and has human cognitive experience as its outer envelope/boundary. The purest form of human experience is exogenously induced sensation. Such sensation is raw data (meaningless incoherent and unorganized because it has no context). Margenau calls this boundary the P-plane (P is for protocol, perception or primary; Margenau, 1983, p.5). It is the raw input from which science develops concepts.

C.2 HUMANS CONSTRUCT CONCEPTS TO ORGANIZE AND GIVE MEANING TO PERCEPTION

"Concepts are the results of human processes of abstraction, sifting, reasoning; they emerge at the end of a long chain of activity in which man feels himself intelligently involved and responsible" (Margenau, 1983, p.5). "Concepts *correspond* to protocol data but are not identical with them" (Margenau, 1966, p.28). Constructs are the means by which humans impute meaning to perception. For example, if we see a flash of green eyes and a blur of fur we are likely to visualize a cat; in medieval Europe, those sensory stimuli might cause a peasant to visualize a demon. Individuals visualize that which is consistent with how they conceive of the *real* world.

Concepts exist in discrete packages that are represented in Margenau's model as circles suspended in the C-field (C is for concept) by rules of correspondence with protocols in the P-plane. "In most sciences the rules of correspondence are largely procedures of measurement [such] ... operational definitions are the most important rules of correspondence in science, for they allow numbers to be attributed to P-experiences and make the reasoning about scientific constructs qualitative" (Margenau, 1966, p.29).

Near the P-plan the concepts are solitary and not very useful except to explain isolated protocols. However, these concepts are discrete abstractions of phenomena that can be manipulated and interconnected by humans in the reasoning process. Logical or mathematical relations between constructs (interconnections) are depicted in the Margenau model by single lines between circles.

C2.3 THEORIES ARISE FROM DEDUCTIVE REASONING

In some cases deductive reasoning can infer a third construct from the nature and interconnections of two other constructs. Thus not all constructs have or need correspondence (double lines) with protocols in the P-plane. A theory is formed when a complex of constructs (circles) can be interconnected in a web of logical and mathematical relations.

Theories can never be proven absolutely true. A theory can be confirmed via three ways of empirical confirmation. Specifically, there is confirmation when the theory:

1) acknowledges, encompasses or disproves the *known* correspondences between theory constructs and protocols in the P-plane,

2) makes accurate predictions of unknown correspondences between theory constructs and protocols in the P-plane, or

3) outlives contending theories that are falsified via ways (1) and (2).

Theories which have sustained several or many such successful circuits of empirical confirmation are promising candidates for scientific acceptance (Margenau, 1966, p.32). However, all theories are flawed—one or more of the ways of empirical confirmation will not be complete and /or will disclose anomalies in either the theory constructs or observed protocols.

Where "several scientific theories are successfully confirmed yet contradictory in their constructed contents....we are forced to fall back on other regulative principles .... [that are] often collected in a single phrase, such as economy of thought, Occam's Razor, or verifiability" (Margenau, 1966, p.32).[140] These principles include:

- *Logical Fertility* -- An idea entailing many consequences is better than a sterile one having few.

- *Extensibility* -- Theories should be *extensible* to as large a P-domain as possible.

- *Multiple Connectivity* -- One hopes and looks for connections between a theory under consideration and other theories which account for a wholly different group of P-experiences.

- *Simplicity* -- A model should by easy to use and understand.

---

[140] William Ockham's (c 1280-1349) dictum "Multiplicity ought not be posited without necessity" has become known as *Ockham's Razor* (Encyclopaedia Britannica, 1967, Vol. 16, p.858).

- *Elegance* -- A model's concepts should be sweeping, spirited and magnificent rather than ugly, cumbersome and paltry.

C.4 SCIENCES MAY BE CLASSIFIED AS DESCRIPTIVE AND EXPLANATORY

"A purely descriptive science hardy exists; it would aim at a record of P-experiences. Old-style botany, zoology, and geography come close to this type. But many modern sciences are descriptive—comparative in the sense that their practitioners make careful observations and then correlate their findings. ...In terms of the diagram, [such] correlations are linkages between the P-facts, such as are indicated by dashed lines within or near the P-domain. They, too, form rudimentary scientific theories and may be regarded as slight excursions into the C-field. ... Reasoning in correlational sciences is largely inductive, the conclusions are subject to probabilities." (Margenau, 1966, p.30).

In "explanatory sciences, wherever the C-field is extensive, deductive reasoning is possible. Constructs far to the left [within Figure B-1] are abstract, general and powerful. Propositions involving them function as premises from which other propositions, theorems, and laws of lesser range can be deduced." (Margenau, 1966, p.30). The deductive inferences of an explanatory sciences are never probable—if their premises are true then they are true.

"It may be said that the entire business of explanatory science is to make deductive reasoning possible, to open up for man's use the pleasing resources of deductive logic." Indeed, the course of scientific history seems to indicate that inductive theory is usually a forerunner of deductive theory. (Margenau, 1966, pp.30-31).

C.5 WHAT IS THE P-PLANE?

Margenau recognizes that while it is useful to separate the concepts of endogenous constructs and exogenous perceptions, a clear boundary cannot be formed between them. "Perceptory experience shades off continuously into the realm of concepts. ...[and] every protocol experience ...already contains an admixture of constructional elements." (Margenau, 1966, p.33). Thus, much of what we perceive as experience is not exogenous to the system of constructs accepted by the observer. Further, this blending of the exogenous and endogenous elements of experience alters each, making it difficult to unscramble the result.

Automatic recording devices cannot solve the problem because "an automatic record, unseen by man, is not a measurement, is not an observation and does not count as a protocol experience in physics. Only when it enters someone's consciousness does it become one" (Margenau, 1966, p.36). Thus, experience is never purely exogenous but is always, to a degree, contingent on the nature and expectations of the individual having the experience.

This "natural ambiguity of contingent protocol experiences breeds a variety of different sciences, permitting what goes as a construct in one to be viewed as a protocol in another, and vice versa" (Margenau, 1966, p.35). In some cases, one discipline may generate some or all of the constructs used as protocols by another discipline.

Margenau (1966, p.38) notes that the economist's protocol data (i.e. "feelings and general observations about what people buy and sell, what profits they make and what losses they incur, how much one pays for specific commodities) "are translated into objective constructs by very specific operational definitions which make these protocol facts objective, meaningful, quantifiable, and subject to logic and mathematics.

Reification is, at best, hazardous.[141] The Buddhist centrists claim that the tendency of the human mind to assume the existence of independent things, from what are in fact nonentities, lies at the root of a broad range of unnecessary conflicts and miseries (Wallace, 1989, pp.110, 121 and 153). However, even if reification is a delusion, Western science has always found the creation of identities to be a useful way to manipulate reality.

An apparent difference between *hard sciences* and *soft sciences* is the nature of the *real identities* each postulate. The identities postulated by hard sciences are assumed to not be self-aware. As a result, change in hard sciences tend to be driven by changes to the interpretation of protocols. Probability/chance is another source of change in inductive based hard sciences. Soft sciences (such as social sciences) often deal with (what they postulate are) self aware identities with choice.[142] As a result, the soft sciences have to contend with changes in what they study as well as dealing with chance and paradigm changes. In the humanities, there is often a feedback loop between the discipline and what they are studying.[143] Thus, the soft sciences are almost always in a state of flux where even the rate of change (in what is observed) is variable and to a degree dependent on developments in the discipline.

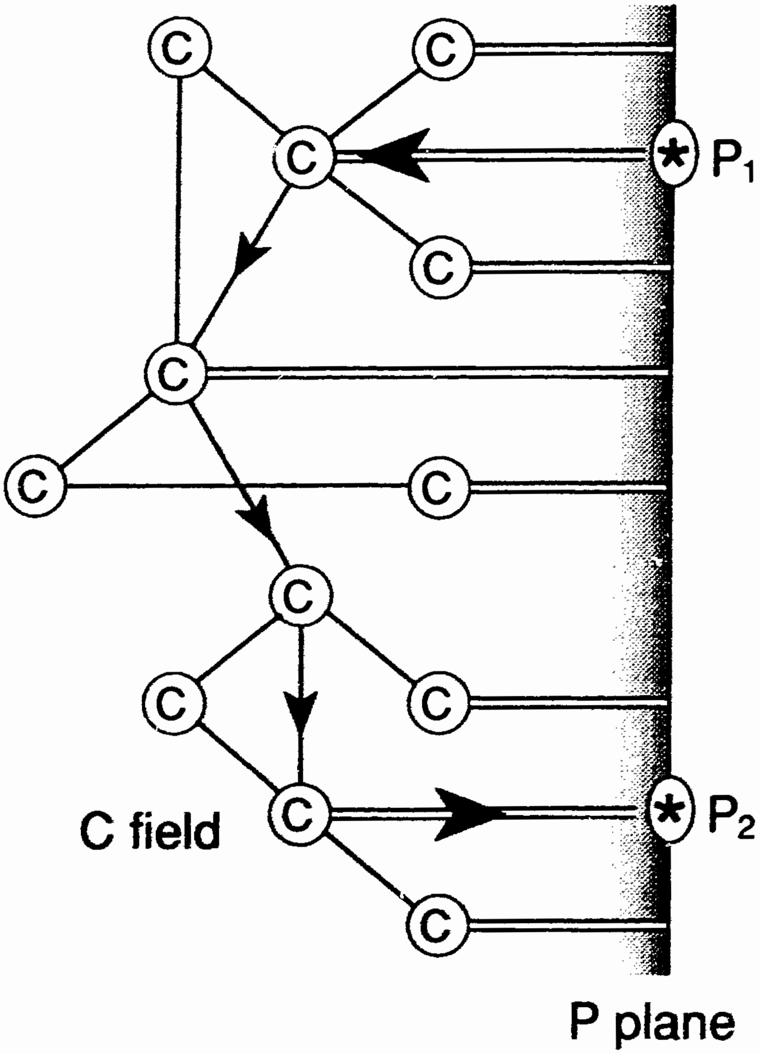
---

[141] Reification is a mental process whereby perceptions and constructs are assumed to be caused by an identity that is assumed to exist in reality.

[142] The concept and effects of choice (free or otherwise) are poorly defined in science (Margenau, 1983, pp.207-214).

[143] In such cases Peer's Law often applies -- "The solution to the problem changes the problem" (Lyall, 1986).

CHART C - 1: A Portrayal of Margenau's Model *



* Adapted from Margenau (1963, p.16)

APPENDIX D: Results of Intergration Analysis Using CC4 and Calculaus Calculator (Meredith, 1990 and 1991)

The command programs are given first and then the results.

```
*** Input Window ***

a=(44.561, 64.847, 62.453, 56.819, 65.352)
b=(√(1.0245), √(1.0281), √(1.0192), √(1.0096),
  √(1.0324))
x=a*b*sqrt(4*pi*ln(b))
L0=ln(a)
c=ln(b^2)
f(L)=exp(-(ln(L)-L0)^2/2/c)
z=in(f(L),L=10,150)
f(exp(L0))
window(0,150,0,10)
graph(f(L),L)
```

```
*** Variables ***

ANS[1] = 1  ANS[2] = 1  ANS[3] = 1  ANS[4] = 1  ANS[5] = 1

 A[1] = 44.561  A[2] = 64.847  A[3] = 62.453  A[4] = 56.819
                A[5] = 65.352

 B[1] = 1.012175874  B[2] = 1.0139526616  B[3] = 1.0095543571
                     B[4] = 1.004788535   B[5] = 1.0160708637

 X[1] = 17.589382558  X[2] = 27.436889532  X[3] = 21.794927815
                      X[4] = 13.988000732  X[5] = 29.721732575

L0[1] = 3.796859037  L0[2] = 4.1720306491  L0[3] = 4.1344142739
                     L0[4] = 4.0398707768  L0[5] = 4.179788044

 C[1] = .0242046887  C[2] = .027712438568   C[3] = .01901800584
                     C[4] = .0095542128088  C[5] = .0031886188864

 F[1] = .0242046887  F[2] = .027712438568  F[3] = .01901800584
                     F[4] = .0095542128088 F[5] = .031886188864

 Z[1] = 17.589408526  Z[2] = 27.436876927  Z[3] = 21.7949457
                      Z[4] = 13.988002205  Z[5] = 29.721624685
```

```
*** Input Window ***

a1=44.561  a2=64.847  a3=62.453

b1=√(1.0245)  b2=√(1.0281)  b3=√(1.0192)

L01=ln(a1)  L02=ln(a2)  L03=ln(a3)

c1=ln(b1^2)  c2=ln(b2^2)  c3=ln(b3^2)

h1=629*100/5349  h2=795*100/5349  h3=3925*100/5349

z1=a1*b1*√(4*pi*ln(b1))
z2=a2*b2*√(4*pi*ln(b2))
z3=a3*b3*√(4*pi*ln(b3))

f1(Ltrawl)=exp(-.5*(ln(Ltrawl)-L01)^2/c1)/z1
f2(LLL)=exp(-.5*(ln(LLL)-L02)^2/c2)/z2
f3(Ltrap)=exp(-.5*(ln(Ltrap)-L03)^2/c3)/z3

da=in(f1(Ltrawl),Ltrawl=61.5,63.5)*h1 + in(f2(L
LL),LLL=61.5,63.5)*h2 + in(f3(Ltrap),Ltrap=61.
5,63.5)*h3
db=in(f1(Ltrawl),Ltrawl=60.5,64.5)*h1 + in(f2(L
LL),LLL=60.5,64.5)*h2 + in(f3(Ltrap),Ltrap=60.
5,64.5)*h3
dc=in(f1(Ltrawl),Ltrawl=59.5,65.5)*h1 + in(f2(L
LL),LLL=59.5,65.5)*h2 + in(f3(Ltrap),Ltrap=59.
5,65.5)*h3
dd=in(f1(Ltrawl),Ltrawl=58.5,66.5)*h1 + in(f2(L
LL),LLL=58.5,66.5)*h2 + in(f3(Ltrap),Ltrap=58.
5,66.5)*h3
de=in(f1(Ltrawl),Ltrawl=57.5,67.5)*h1 + in(f2(L
LL),LLL=57.5,67.5)*h2 + in(f3(Ltrap),Ltrap=57.
5,67.5)*h3
df=in(f1(Ltrawl),Ltrawl=56.5,68.5)*h1 + in(f2(L
LL),LLL=56.5,68.5)*h2 + in(f3(Ltrap),Ltrap=56.
5,68.5)*h3
dg=in(f1(Ltrawl),Ltrawl=55.5,69.5)*h1 + in(f2(L
LL),LLL=55.5,69.5)*h2 + in(f3(Ltrap),Ltrap=55.
5,69.5)*h3
dh=in(f1(Ltrawl),Ltrawl=54.5,70.5)*h1 + in(f2(L
LL),LLL=54.5,70.5)*h2 + in(f3(Ltrap),Ltrap=54.
5,70.5)*h3
di=in(f1(Ltrawl),Ltrawl=53.5,71.5)*h1 + in(f2(L
LL),LLL=53.5,71.5)*h2 + in(f3(Ltrap),Ltrap=53.
5,71.5)*h3
dj=in(f1(Ltrawl),Ltrawl=52.5,72.5)*h1 + in(f2(L
LL),LLL=52.5,72.5)*h2 + in(f3(Ltrap),Ltrap=52.
5,72.5)*h3
```

```
window(20,120,0,4)
graph(f1(Ltrawl)*h1,Ltrawl)
graph(f2(LLL)*h2,LLL)
graph(f3(Ltrap)*h3,Ltrap)
```

```
*** Variables ***

A1 = 44.561  A2 = 64.847  A3 = 62.453

B1 = 1.012175874  B2 = 1.0139526616  B3 = 1.0095543571

L01 = 3.796859037  L02 = 4.1720306491  L03 = 4.1344142739

C1 = .0242046887  C2 = .027712438568  C3 = .01901800584

H1 = 11.759207328  H2 = 14.862591139  H3 = 73.378201533

Z1 = 17.589382558  Z2 = 27.436889532  Z3 = 21.794927815

DA =  7.900514258
DB = 15.707138737
DC = 23.329605815
DD = 30.684709681
DE = 37.699366928
DF = 44.313145484
DG = 50.480102759
DH = 56.169817919
DI = 61.3675573
DJ = 66.073544306
```

APPENDIX E: Results of Statistical Analysis Using Shazam (White, 1987)

The Shazam command programs for the following analysis are given in Appendix F.

APPENDIX B-1: Shazam Regression Results for Eqn (85) on Figure 6-1

```
 UNIT  6 IS NOW ASSIGNED TO: OP.DAT
     SAMPLE 1 30
     READ  YEAR  HARVEST  EFFORT
   3 VARIABLES AND       30 OBSERVATIONS STARTING AT OBS       1

    NL 1 /NCOEF=2 LIST RSTAT AUTO BEG=3
    EQ HARVEST = A*EFFORT*(1-B*EFFORT)
    COEF A 4.4  B .00007
   2 VARIABLES IN  1 EQUATIONS WITH  2 COEFFICIENTS
WITH    1 AUTOREGRESSIVE COEFFICIENTS
       28 OBSERVATIONS
..ALGORITHM USES NUMERIC DERIVATIVES

REQUIRED MEMORY IS PAR=    7 CURRENT PAR=  260
    END

COEFFICIENT STARTING VALUES
A          4.4000      B          0.70000E-04  RHO       0.00000E+00
     100 MAXIMUM ITERATIONS, CONVERGENCE = 0.000010

INITIAL STATISTICS :
TIME =       3.840 SEC.   ITER. NO.      0   FUNCT. EVALUATIONS     4
LOG-LIKELIHOOD FUNCTION=   -269.5521
COEFFICIENTS
   4.400000      0.7000000E-04  0.0000000E+00
GRADIENT
   23.04657      -2100448.      -26.86384

INTERMEDIATE STATISTICS :
TIME =       7.740 SEC.   ITER. NO.     15   FUNCT. EVALUATIONS    91
LOG-LIKELIHOOD FUNCTION=   -164.1634
COEFFICIENTS
   4.278901      0.8201884E-04  0.8550854
GRADIENT
  0.2295169E-01  -45804.33      0.1628861
```

```
FINAL STATISTICS :

TIME =    9.170 SEC.   ITER. NO.    20   FUNCT. EVALUATIONS   124 EXIT CODE  1
LOG-LIKELIHOOD FUNCTION=   -164.1632
COEFFICIENTS
   4.280012       0.8203041E-04  0.8549346
GRADIENT
 -0.3090457E-07 -0.3608288E-02  0.2344791E-07

MAXIMUM LIKELIHOOD ESTIMATE OF SIGMA-SQUARED =   7245.0
GTRANSPOSE*INVERSE(H)*G (LM) STATISTIC  -  =  0.15093E-16

      COEFFICIENT   ST. ERROR   T-RATIO
A         4.2800    0.86429E-01  49.520
B        0.82030E-04 0.56411E-06  145.42
RHO      0.85493    0.60611E-01  14.105

    OBS.  OBSERVED     PREDICTED  CALCULATED
     NO.   VALUE         VALUE     RESIDUAL
      3   5276.1       5276.1      0.00000E+00                *
      4   7227.0       7388.1          -161.16       *        I
      5   8982.3       9006.3          -24.001               *I
      6   102[illegible]5.  10243.           1.7642                *
      7   113[illegible].   11240.           92.637                I    *
      8   11997.       11962.           35.644                I *
      9   12546.       12439.           107.49                I     *
     10   12759.       12764.          -4.7985                *
     11   12914.       12862.           52.325                I  *
     12   13012.       12895.           116.58                I      *
     13   12863.       12910.          -47.033             *  I
     14   12704.       12707.          -2.2588                *
     15   12532.       12486.           46.622                I  *
     16   12344.       12245.           99.527                I     *
     17   11986.       12103.          -117.40         *      I
     18   11648.       11737.          -88.218           *    I
     19   11326.       11384.          -58.027             *  I
     20   11014.       11041.          -26.217              * I
     21   10710.       10702.           7.6786                *
     22   10409.       10365.           43.953                I  *
     23   10112.       10029.           82.913                I    *
     24   9814.9       9690.1           124.77                I      *
     25   9518.1       9348.4           169.71                I         *
     26   9125.6       9242.2          -116.64         *      I
     27   8760.0       8866.1          -106.07          *     I
     28   8417.2       8511.9          -94.681          *     I
     29   8093.9       8176.2          -82.287           *    I
     30   7787.4       7856.2          -68.786            *   I
DURBIN-WATSON = 1.2648     VON NEUMANN RATIO = 1.3116     RHO =  0.36444
RESIDUAL SUM =  -16.772       RESIDUAL VARIANCE =   7245.0
SUM OF ABSOLUTE ERRORS=   1980.0
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9984
RUNS TEST:    10 RUNS,    14 POSITIVE,    14 NEGATIVE, NORMAL STATISTIC =   -1.9258
END
```

APPENDIX E-2: Shazam Regression Results for Eqn (87) on Figure 6-1

```
UNIT  6 IS NOW ASSIGNED TO: OP.DAT
     SAMPLE 1 30
     READ  YEAR  HARVEST  EFFORT
   3 VARIABLES AND       30 OBSERVATIONS STARTING AT OBS       1

    GENR LCPUE=(LAG(HARVEST)/LAG(EFFORT))
..NOTE.LAG VALUE IN UNDEFINED OBSERVATIONS SET TO ZERO
..NOTE.LAG VALUE IN UNDEFINED OBSERVATIONS SET TO ZERO
...WARNING...ILLEGAL DIV  IN OBS.    1, VALUE REPLACED BY ZERO    0.00000E+00
    GENR LEFFORT=LAG(EFFORT)
..NOTE.LAG VALUE IN UNDEFINED OBSERVATIONS SET TO ZERO

    NL 1 /NCOEF=3 LIST RSTAT BEG=2 AUTO
    EQ HARVEST = EFFORT*LCPUE*(1 + A*(1-B*LCPUE) - C*LEFFORT)
    COEF A .2101  B .2501  C .000031
   4 VARIABLES IN  1 EQUATIONS WITH  3 COEFFICIENTS
WITH   1 AUTOREGRESSIVE COEFFICIENTS
        29 OBSERVATIONS
..ALGORITHM USES NUMERIC DERIVATIVES

REQUIRED MEMORY IS PAR=    9 CURRENT PAR=  260
    END

COEFFICIENT STARTING VALUES
A         0.21010       B         0.25010      C         0.31000E-04
RHO       0.00000E+00
      100 MAXIMUM ITERATIONS, CONVERGENCE = 0.000010

INITIAL STATISTICS :
TIME =       4.060 SEC.   ITER. NO.     0   FUNCT. EVALUATIONS     5
LOG-LIKELIHOOD FUNCTION=   -226.8336
COEFFICIENTS
  0.2101000      0.2501000      0.3100000E-04  0.0000000E+00
GRADIENT
  -286.7940       135.5321       3630868.      -28.18424

INTERMEDIATE STATISTICS :
TIME =      10.430 SEC.   ITER. NO.    15   FUNCT. EVALUATIONS   105
LOG-LIKELIHOOD FUNCTION=   -13.52988
COEFFICIENTS
  0.1947722      0.3140953      0.1958838E-04  0.9353228
GRADIENT
   10464.23      -12255.82     -0.2333231E+09   19.23126
TIME =      20.870 SEC.   ITER. NO.    30   FUNCT. EVALUATIONS   270
LOG-LIKELIHOOD FUNCTION=    67.48374
COEFFICIENTS
  0.2001498      0.3124579      0.2001290E-04  0.91947[illegible]4
GRADIENT
  -329318.8       278093.4      0.3388143E+10  -29.48339
```

```
FINAL STATISTICS :
TIME =   23.500 SEC.   ITER. NO.    34   FUNCT. EVALUATIONS   312 EXIT CODE  1
LOG-LIKELIHOOD FUNCTION=    67.64828
COEFFICIENTS
  0.2001568      0.3124496      0.2001367E-04  0.9200146
GRADIENT
  -355450.5      215692.2       0.3433910E+10  -25.80783

MAXIMUM LIKELIHOOD ESTIMATE OF SIGMA-SQUARED =  0.55128E-03
GTRANSPOSE*INVERSE(H)*G (LM) STATISTIC  -  =   14.422

      COEFFICIENT   ST. ERROR   T-RATIO
A        0.20016    0.24665E-04  8115.1
B        0.31245    0.16182E-04  19309.
C        0.20014E-04 0.26720E-08  7490.2
RHO      0.92001    0.72113E-02  127.58

   OBS.   OBSERVED     PREDICTED   CALCULATED
    NO.    VALUE        VALUE       RESIDUAL
      2   2842.7       2842.7       0.00000E+00                *
      3   5276.1       5276.1      -0.36242E-02               *I
      4   7227.0       7227.0      -0.14990E-01             *  I
      5   8982.3       8982.2       0.50496E-01                I          *
      6   10245.       10244.       0.14140E-01                I  *
      7   11332.       11332.       0.59267E-01                I            *
      8   11997.       11997.       0.16001E-01                I  *
      9   12546.       12546.       0.41474E-01                I        *
     10   12759.       12759.       0.39158E-01                I       *
     11   12914.       12914.      -0.17670E-01            *   I
     12   13012.       13012.       0.46258E-01                I         *
     13   12863.       12863.       0.16712E-01                I   *
     14   12704.       12704.       0.10924E-01                I *
     15   12532.       12532.      -0.15166E-01             *  I
     16   12344.       12344.       0.25229E-01                I    *
     17   11986.       11986.       0.17795E-01                I   *
     18   11648.       11648.      -0.73531E-02              * I
     19   11326.       11326.       0.65927E-02                I*
     20   11014.       11014.       0.43237E-02                I*
     21   10710.       10710.      -0.90023E-02              * I
     22   10409.       10409.       0.18887E-01                I   *
     23   10112.       10112.       0.55255E-02                I*
     24   9814.9       9814.8       0.10994E-01                I *
     25   9518.1       9518.1       0.68711E-02                I*
     26   9125.6       9125.6       0.15383E-01                I  *
     27   8760.0       8760.0      -0.76456E-02              * I
     28   8417.2       8417.2       0.78645E-02                I *
     29   8093.9       8093.9      -0.19181E-01            *   I
     30   7787.4       7787.4       0.21591E-01                I    *
DURBIN-WATSON = 1.6360    VON NEUMANN RATIO = 1.6945    RHO =  0.17244
RESIDUAL SUM =  0.34086      RESIDUAL VARIANCE =  0.55128E-03
SUM OF ABSOLUTE ERRORS=  0.53012    R-SQUARE BETWEEN OBSERVED AND PREDICTED = 1.0000
RUNS TEST:    15 RUNS,    21 POSITIVE,    8 NEGATIVE, NORMAL STATISTIC =    1.1533
END
```

APPENDIX E-3: Shazam Regression Results for Eqn (154) on Figure 7-6

```
UNIT  6 IS NOW ASSIGNED TO: OP.DAT
     SAMPLE 1 42
     READ  EFFORT        HARVEST
   2 VARIABLES AND       42 OBSERVATIONS STARTING AT OBS       1

    NL 1 /NCOEF=2 LIST RSTAT
    EQ HARVEST = A*EFFORT*(1-B*EFFORT)
    COEF A 6000 B .0002
   2 VARIABLES IN  1 EQUATIONS WITH  2 COEFFICIENTS
        42 OBSERVATIONS

REQUIRED MEMORY IS PAR=    8 CURRENT PAR=  231

COEFFICIENT STARTING VALUES
A          6000.0       B          0.20000E-03
      100 MAXIMUM ITERATIONS, CONVERGENCE = 0.000010

INITIAL STATISTICS :

TIME =       3.240 SEC.   ITER. NO.     0   FUNCT. EVALUATIONS     1
LOG-LIKELIHOOD FUNCTION=   -717.5075
COEFFICIENTS
   6000.000      0.2000000E-03
GRADIENT
  0.5423200E-02   878247.1

INTERMEDIATE STATISTICS :

TIME =       9.340 SEC.   ITER. NO.    15   FUNCT. EVALUATIONS    38
LOG-LIKELIHOOD FUNCTION=   -528.9695
COEFFICIENTS
   4859.868      0.1496577E-03
GRADIENT
  0.1843488E-04  -1849.743

FINAL STATISTICS :

TIME =       9.610 SEC.   ITER. NO.    16   FUNCT. EVALUATIONS    39
LOG-LIKELIHOOD FUNCTION=   -528.9695
COEFFICIENTS
   4859.867      0.1496577E-03
GRADIENT
  0.7295184E-07   26.71524

MAXIMUM LIKELIHOOD ESTIMATE OF SIGMA-SQUARED =  0.50931E+10
GTRANSPOSE*INVERSE(H)*G (LM) STATISTIC  -  =  0.13249E-10
```

```
      COEFFICIENT    ST. ERROR   T-RATIO
A         4859.9      12.725      381.90
B        0.14966E-03 0.11648E-06  1284.8
    OBS.   OBSERVED    PREDICTED  CALCULATED
     NO.    VALUE       VALUE      RESIDUAL
      1   0.00000E+00  0.00000E+00  0.00000E+00                *
      2    440.94       340.19       100.75                    *
      3    44763.       35002.       9761.0                    I*
      4   0.16467E+06  0.13233E+06   32348.                    I *
      5   0.35394E+06  0.29179E+06   62151.                    I   *
      6   0.60659E+06  0.51262E+06   93973.                    I      *
      7   0.91707E+06  0.79348E+06  0.12358E+06                I        *
      8   0.12795E+07  0.11322E+07  0.14730E+06                I         *
      9   0.16876E+07  0.15253E+07  0.16222E+06                I          *
     10   0.21351E+07  0.19689E+07  0.16619E+06                I           *
     11   0.26166E+07  0.24583E+07  0.15825E+06                I          *
     12   0.31250E+07  0.29870E+07  0.13802E+06                I         *
     13   0.36539E+07  0.35475E+07  0.10640E+06                I      *
     14   0.41971E+07  0.41316E+07   65517.                    I    *
     15   0.47476E+07  0.47290E+07   18616.                    I*
     16   0.52980E+07  0.53276E+07 -29571.                   * I
     17   0.58412E+07  0.59139E+07 -72749.                *    I
     18   0.63695E+07  0.64722E+07 -0.10277E+06         *      I
     19   0.68742E+07  0.69841E+07 -0.10998E+06        *       I
     20   0.73356E+07  0.74241E+07 -88488.               *     I
     21   0.76931E+07  0.77549E+07 -61821.                 *   I
     22   0.79410E+07  0.79771E+07 -36052.                  *  I
     23   0.80824E+07  0.80952E+07 -12806.                    *I
     24   0.81202E+07  0.81135E+07   6655.6                    *
     25   0.80570E+07  0.80355E+07   21442.                    I *
     26   0.78952E+07  0.78641E+07   31018.                    I *
     27   0.76368E+07  0.76016E+07   35216.                    I *
     28   0.72839E+07  0.72497E+07   34201.                    I *
     29   0.68378E+07  0.68092E+07   28531.                    I *
     30   0.62998E+07  0.62807E+07   19137.                    I*
     31   0.56710E+07  0.56637E+07   7301.9                    I*
     32   0.49519E+07  0.49572E+07 -5245.0                     *
     33   0.41428E+07  0.41592E+07 -16301.                    *I
     34   0.32438E+07  0.32671E+07 -23342.                   * I
     35   0.22542E+07  0.22774E+07 -23160.                   * I
     36   0.11734E+07  0.11855E+07 -12136.                    *I
     37   0.88878E+06  0.89595E+06 -7168.1                    *I
     38   0.59836E+06  0.59956E+06 -1193.5                     *
     39   0.30211E+06  0.29625E+06   5862.6                    *
     40   0.12155E+06  0.11093E+06   10618.                    I*
     41    60892.       48548.       12346.                    I*
     42    6099.8      -7803.7       13903.                    I*

DURBIN-WATSON = 0.0870    VON NEUMAN RATIO = 0.0891    RHO =  0.95694
RESIDUAL SUM =  0.90787E+06  RESIDUAL VARIANCE =  0.50931E+10
SUM OF ABSOLUTE ERRORS=  0.21134E+07 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9996
RUNS TEST:     5 RUNS,   27 POSITIVE,   15 NEGATIVE, NORMAL STATISTIC =   -5.2120
END
```

APPENDIX E-4: Shazam Regression Results for Eqn (221) on Figure 8-3

```
    SAMPLE 1 55
    GENR LEGGS=LOG(EGGS)
    GENR LPL=LOG(PL)

NAME        N  MEAN         ST. DEV      VARIANCE      MINIMUM      MAXIMUM
PL          55  73.938        10.859       117.93        57.900       110.20
EGGS        55 0.25137E+06  0.15338E+06  0.23526E+11   58200.       0.97700E+06
LPL         55  4.2929       0.14398      0.20731E-01   4.0587        4.7023
LEGGS       55  12.289       0.54027      0.29189       10.972        13.792

   OLS LEGGS  PL / LIST BEG=1
...NOTE..SAMPLE RANGE SET TO:    1,    55

 R-SQUARE =   0.6239      R-SQUARE ADJUSTED =   0.6168
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.11186
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.33445
SUM OF SQUARED ERRORS-SSE=   5.9286
MEAN OF DEPENDENT VARIABLE =   12.289
LOG OF THE LIKELIHOOD FUNCTION = -16.7840

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.11593
   (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -2.1548
 SCHWARZ(1978) CRITERION-LOG SC =  -2.0818
MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.11608
 HANNAN AND QUINN(1979) CRITERION -HQ=  0.11924
 RICE (1984) CRITERION-RICE=  0.11625
 SHIBATA (1981) CRITERION-SHIBATA=  0.11563
 SCHWARTZ (1978) CRITERION-SC=  0.12470
 AKAIKE (1974)INFORMATION CRITERION-AIC=  0.11592

                      ANALYSIS OF VARIANCE - FROM MEAN
                      SS           DF           MS               F
REGRESSION         9.8336          1.        9.8336            87.910
ERROR              5.9286          53.      0.11186
TOTAL              15.762          54.      0.29189

                      ANALYSIS OF VARIANCE - FROM ZERO
                      SS           DF           MS               F
REGRESSION         8315.4          2.        4157.7          37168.645
ERROR              5.9286          53.      0.11186
TOTAL              8321.3          55.       151.30


VARIABLE    ESTIMATED   STANDARD   T-RATIO     PARTIAL STANDARDIZED ELASTICITY
  NAME     COEFFICIENT   ERROR       53 DF       CORR.  COEFFICIENT  AT MEANS

PL        0.39296E-01 0.41911E-02   9.3761     0.7899  0.78986      0.23644
CONSTANT   9.3831      0.31315      29.964     0.9717  0.00000E+00  0.76356
```

APPENDIX E-4: Shazam Regression Results for Eqn (221) on Figure 8-3

```
OBS. OBSERVED   PREDICTED  CALCULATED
 NO.  VALUE       VALUE     RESIDUAL
  1   10.972     11.658    -0.68671       *         I
  2   12.164     11.662     0.50193                 I       *
  3   11.650     11.662    -0.12208E-01             *
  4   12.556     11.698     0.85873                 I            *
  5   11.827     11.741     0.86130E-01             I*
  6   11.641     11.768    -0.12706               * I
  7   11.074     11.780    -0.70575      *          I
  8   11.998     11.796     0.20193                 I  *
  9   11.759     11.819    -0.60464E-01            *I
 10   12.430     12.354     0.76119E-01             I*
 11   12.234     11.871     0.36362                 I    *
 12   11.994     11.898     0.96056E-01             I*
 13   11.781     11.906    -0.12450               * I
 14   11.526     11.937    -0.41152           *     I
 15   12.182     11.937     0.24442                 I   *
 16   11.626     11.981    -0.35433            *    I
 17   11.359     11.996    -0.63769       *         I
 18   11.691     12.020    -0.32881            *    I
 19   12.410     12.028     0.38209                 I     *
 20   11.754     12.036    -0.28130             *   I
 21   12.387     12.047     0.33934                 I    *
 22   12.471     12.102     0.36872                 I     *
 23   12.149     12.114     0.34783E-01             I*
 24   12.390     12.134     0.25622                 I   *
 25   12.134     12.177    -0.43562E-01            *I
 26   12.315     12.212     0.10295                 I *
 27   12.380     12.252     0.12830                 I *
 28   12.480     12.291     0.18889                 I  *
 29   12.014     12.326    -0.31269            *    I
 30   12.339     12.346    -0.67460E-02             *
 31   12.224     12.377    -0.15356               * I
 32   12.036     12.401    -0.36517            *    I
 33   12.460     11.851     0.60903                 I        *
 34   12.501     12.448     0.52399E-01             I*
 35   11.947     12.448    -0.50155          *      I
 36   12.218     12.535    -0.31666            *    I
 37   12.641     12.543     0.98254E-01             I*
 38   12.162     12.546    -0.38433           *     I
 39   12.744     12.566     0.17764                 I  *
 40   12.225     12.570    -0.34464            *    I
 41   12.339     12.578    -0.23903             *   I
 42   12.535     12.586    -0.50368E-01            *I
 43   12.725     12.586     0.13972                 I *
 44   12.295     12.625    -0.32958            *    I
 45   13.092     12.641     0.45115                 I      *
 46   12.741     12.700     0.41692E-01             I*
 47   12.657     12.704    -0.47122E-01            *I
 48   12.940     12.743     0.19719                 I  *
 49   12.969     12.747     0.22235                 I  *
```

```
      50    13.044        12.751      0.29296                     I   *
      51    13.094        12.818      0.27678                     I   *
      52    12.391        12.861     -0.46993             *         I
      53    13.170        12.888      0.28168                     I   *
      54    13.242        13.097      0.14550                     I *
      55    13.792        13.714      0.78696E-01                 I*

 DURBIN-WATSON = 2.1061    VON NEUMANN RATIO = 2.1451    RHO = -0.09344
 RESIDUAL SUM = -0.10694E-12  RESIDUAL VARIANCE =  0.11186
 SUM OF ABSOLUTE ERRORS=   14.591
 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.6239
 RUNS TEST:   30 RUNS,   30 POSITIVE,   25 NEGATIVE, NORMAL STATISTIC =    0.4742
 COEFFICIENT OF SKEWNESS =  -0.0953 WITH STANDARD DEVIATION OF 0.3217
 COEFFICIENT OF EXCESS KURTOSIS =  -0.0950 WITH STANDARD DEVIATION OF 0.6335

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
 OBSERVED  2.0  8.0 15.0 22.0  7.0  1.0
 EXPECTED  1.3  7.5 18.8 18.8  7.5  1.3
 CHI-SQUARE =    1.8753 WITH  2 DEGREES OF FREEDOM
   STOP
```

APPENDIX 8-5: Shazam Regression Results for Eqn (221) on Figure 8-3
(data on pieces smaller than 60.0 cm excluded)

```
 UNIT  6 IS NOW ASSIGNED TO: OP.DAT
     SAMPLE 1 55

    GENR LEGGS=LOG(EGGS)
    GENR LPL=LOG(PL)

 NAME        N   MEAN        ST. DEV      VARIANCE     MINIMUM      MAXIMUM
 PL          55   73.938      10.859       117.93       57.900       110.20
 EGGS        55  0.25137E+06  0.15338E+06  0.23526E+11  58200.       0.97700E+06
 LPL         55   4.2929     0.14398      0.20731E-01  4.0587        4.7023
 LEGGS       55   12.289     0.54027      0.29189      10.972        13.792

 OLS ESTIMATION
      51 OBSERVATIONS     DEPENDENT VARIABLE = LEGGS
 ...NOTE..SAMPLE RANGE SET TO:    5,   55

  R-SQUARE =   0.6705     R-SQUARE ADJUSTED =   0.6638
 VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.90572E-01
 STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.30095
 SUM OF SQUARED ERRORS-SSE=   4.4380
 MEAN OF DEPENDENT VARIABLE =   12.324
 LOG OF THE LIKELIHOOD FUNCTION = -10.1047

 MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
  AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.94124E-01
    (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
  AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -2.3632
  SCHWARZ(1978) CRITERION-LOG SC =  -2.2874
 MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
  CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.94269E-01
  HANNAN AND QUINN(1979) CRITERION -HQ=  0.96885E-01
  RICE (1984) CRITERION-RICE=  0.94426E-01
  SHIBATA (1981) CRITERION-SHIBATA=  0.93845E-01
  SCHWARTZ (1978) CRITERION-SC=  0.10153
  AKAIKE (1974)INFORMATION CRITERION-AIC=  0.94120E-01

                      ANALYSIS OF VARIANCE - FROM MEAN
                       SS           DF            MS                  F
 REGRESSION          9.0306          1.         9.0306               99.706
 ERROR               4.4380         49.        0.90572E-01
 TOTAL               13.469         50.        0.26937

                      ANALYSIS OF VARIANCE - FROM ZERO
                       SS           DF            MS                  F
 REGRESSION          7755.1          2.         3877.6             42811.898
 ERROR               4.4380         49.        0.90572E-01
 TOTAL               7759.6         51.         152.15

 VARIABLE    ESTIMATED   STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
   NAME     COEFFICIENT    ERROR      49 DF     CORR.  COEFFICIENT  AT MEANS

 PL        0.41282E-01 0.41343E-02   9.9853    0.8188  0.81883       0.25180
 CONSTANT   9.2209      0.31363      29.401    0.9728  0.00000E+00  0.74820
```

APPENDIX E-5: Shazam Regression Results for Eqn (221) on Figure 8-3
(data on pieces smaller than 60.0 cm excluded)

```
OBS.  OBSERVED  PREDICTED CALCULATED
 NO.   VALUE      VALUE    RESIDUAL
   5  11.827    11.698     0.12923                 I *
   6  11.641    11.727    -0.85352E-01            *I
   7  11.074    11.739    -0.66463      *          I
   8  11.998    11.756     0.24225                 I   *
   9  11.759    11.780    -0.21333E-01             *
  10  12.430    12.342     0.88246E-01             I*
  11  12.234    11.834     0.40017                 I      *
  12  11.994    11.863     0.13122                 I *
  13  11.781    11.871    -0.89732E-01            *I
  14  11.526    11.904    -0.37834           *     I
  15  12.182    11.904     0.27760                 I    *
  16  11.626    11.950    -0.32334            *    I
  17  11.359    11.966    -0.60750       *         I
  18  11.691    11.991    -0.29980            *    I
  19  12.410    11.999     0.41070                 I      *
  20  11.754    12.007    -0.25309             *   I
  21  12.387    12.020     0.36695                 I     *
  22  12.471    12.078     0.39356                 I      *
  23  12.149    12.090     0.59022E-01             I*
  24  12.390    12.111     0.27947                 I    *
  25  12.134    12.156    -0.22500E-01             *
  26  12.315    12.193     0.12222                 I *
  27  12.380    12.234     0.14559                 I *
  28  12.480    12.276     0.20419                 I  *
  29  12.014    12.313    -0.29917            *    I
  30  12.339    12.334     0.57775E-02             *
  31  12.224    12.367    -0.14263               * I
  32  12.036    12.391    -0.35543           *     I
  33  12.460    11.813     0.64658                 I          *
  34  12.501    12.441     0.59759E-01             I*
  35  11.947    12.441    -0.49419         *       I
  36  12.218    12.532    -0.31367            *    I
  37  12.641    12.540     0.10085                 I *
  38  12.162    12.544    -0.38193           *     I
  39  12.744    12.565     0.17904                 I  *
  40  12.225    12.569    -0.34344           *     I
  41  12.339    12.577    -0.23822             *   I
  42  12.535    12.585    -0.49957E-01            *I
  43  12.725    12.585     0.14013                 I *
  44  12.295    12.627    -0.33116           *     I
  45  13.092    12.643     0.44878                 I      *
  46  12.741    12.705     0.36345E-01             I*
  47  12.657    12.709    -0.52668E-01            *I
  48  12.940    12.750     0.18966                 I  *
  49  12.969    12.755     0.21462                 I   *
  50  13.044    12.759     0.28504                 I    *
  51  13.094    12.829     0.26548                 I   *
  52  12.391    12.874    -0.48342         *       I
  53  13.170    12.903     0.26681                 I   *
  54  13.242    13.122     0.12010                 I *
```

APPENDIX B-5: Shazam Regression Results for Eqn (221) on Figure 8-3
(data on pieces smaller than 60.0 cm excluded)

```
     55    13.792        13.770       0.22119E-01                  *

   DURBIN-WATSON = 2.1554    VON NEUMANN RATIO = 2.1986    RHO = -0.07967
   RESIDUAL SUM = -0.75502E-13  RESIDUAL VARIANCE =  0.90572E-01
   SUM OF ABSOLUTE ERRORS=   12.463
   R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.6705
   RUNS TEST:   29 RUNS,   29 POSITIVE,   22 NEGATIVE, NORMAL STATISTIC =    0.8597
   COEFFICIENT OF SKEWNESS =  -0.2001 WITH STANDARD DEVIATION OF 0.3335
   COEFFICIENT OF EXCESS KURTOSIS =  -0.5390 WITH STANDARD DEVIATION OF 0.6559

       GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
   OBSERVED  2.0  9.0 11.0 23.0  5.0  1.0
   EXPECTED  1.2  6.9 17.4 17.4  6.9  1.2
   CHI-SQUARE =    5.9366 WITH  2 DEGREES OF FREEDOM
      STOP
```

APPENDIX E-6: Shazam Regression Results for Eqn (222)
(data on pieces smaller than 60.0 cm excluded)

```
UNIT  6 IS NOW ASSIGNED TO: OP.DAT
     SAMPLE 1 54
       READ      NUM      PL     EGGS     AGE
   4 VARIABLES AND       54 OBSERVATIONS STARTING AT OBS       1

    GENR LAGE=LOG(AGE)
    GENR LEGGS=LOG(EGGS)
    GENR LPL=LOG(PL)
    GENR PLAGE=(PL/AGE)
    GENR LPLAGE=LOG(PLAGE)

    OLS LEGGS  PL LAGE    /BEG=5 MAX

REQUIRED MEMORY IS PAR=    7 CURRENT PAR=  223
OLS ESTIMATION
      50 OBSERVATIONS     DEPENDENT VARIABLE = LEGGS
...NOTE..SAMPLE RANGE SET TO:    5,   54

 R-SQUARE =   0.7009     R-SQUARE ADJUSTED =   0.6882
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.84098E-01
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.29000
SUM OF SQUARED ERRORS-SSE=   3.9526
MEAN OF DEPENDENT VARIABLE =   5.4263
LOG OF THE LIKELIHOOD FUNCTION = -7.50566

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.89144E-01
   (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -2.4177
 SCHWARZ(1978) CRITERION-LOG SC =  -2.3029
MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.89466E-01
 HANNAN AND QUINN(1979) CRITERION -HQ=  0.93111E-01
 RICE (1984) CRITERION-RICE=  0.89852E-01
 SHIBATA (1981) CRITERION-SHIBATA=  0.88538E-01
 SCHWARTZ (1978) CRITERION-SC=  0.99966E-01
 AKAIKE (1974)INFORMATION CRITERION-AIC=  0.89131E-01

                      ANALYSIS OF VARIANCE - FROM MEAN
                       SS          DF           MS                F
REGRESSION         9.2639           2.        4.6320             55.078
ERROR              3.9526          47.       0.84098E-01
TOTAL              13.217          49.       0.26972

                      ANALYSIS OF VARIANCE - FROM ZERO
                       SS          DF           MS                F
REGRESSION         1481.5           3.        493.84           5872.161
ERROR              3.9526          47.       0.84098E-01
TOTAL              1485.5          50.        29.709


VARIABLE    ESTIMATED   STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
  NAME     COEFFICIENT   ERROR      47 DF      CORR.  COEFFICIENT  AT MEANS
```

APPENDIX E-6: Shazam Regression Results for Eqn (222)

(data on pieces smaller than 60.0 cm excluded)

```
PL        0.47208E-01 0.47020E-02   10.040      0.8258  0.92409      0.65663
LAGE     -0.22438     0.95157E-01  -2.3580     -0.3253 -0.21703     -0.10738
CONSTANT  2.4459      0.31811       7.6891      0.7464  0.00000E+00  0.45075

VARIANCE-COVARIANCE MATRIX OF COEFFICIENTS
PL        0.22108E-04
LAGE     -0.22321E-03  0.90548E-02
CONSTANT -0.10890E-02 -0.66671E-02  0.10119
              PL           LAGE          CONSTANT

CORRELATION MATRIX OF COEFFICIENTS
PL        1.00000
LAGE     -0.49887       1.0000
CONSTANT -0.72810      -0.22026       1.0000
              PL           LAGE          CONSTANT

  OBS.  OBSERVED    PREDICTED  CALCULATED
   NO.   VALUE       VALUE      RESIDUAL
    5   4.7336      4.9503     -0.21676                *   I
    6   4.1667      4.5779     -0.41126             *      I
    7   5.0901      4.9079      0.18220                    I  *
    8   4.8512      4.9362     -0.84963E-01               *I
    9   5.5223      5.4072      0.11505                    I *
   10   5.3264      5.0322      0.29427                    I    *
   11   5.0864      4.9292      0.15717                    I  *
   12   4.8737      5.0746     -0.20097                 *  I
   13   4.6181      4.7834     -0.16530                 *  I
   14   5.2740      5.0479      0.22617                    I   *
   15   4.7185      4.9587     -0.24023                *   I
   16   4.4509      5.0472     -0.59636          *         I
   17   4.7833      5.0560     -0.27269               *    I
   18   5.5021      4.9745      0.52760                    I        *
   19   4.8465      5.1958     -0.34929              *     I
   20   5.4790      5.0109      0.46807                    I       *
   21   5.5634      5.1551      0.40822                    I      *
   22   5.2412      5.3657     -0.12453                  * I
   23   5.4823      5.1583      0.32398                    I     *
   24   5.2257      5.1302      0.95524E-01                I *
   25   5.4076      5.3783      0.29311E-01                I*
   26   5.4723      5.2199      0.25235                    I   *
   27   5.5722      5.3638      0.20837                    I   *
   28   5.1059      5.3742     -0.26822               *    I
   29   5.4315      5.4674     -0.35825E-01               *I
   30   5.3162      5.3600     -0.43878E-01               *I
   31   5.1281      5.5139     -0.38581             *      I
   32   5.5522      5.0085      0.54364                    I        *
   33   5.5929      5.4924      0.10043                    I *
   34   5.0389      5.5060     -0.46713            *       I
   35   5.3102      5.6244     -0.31412               *    I
   36   5.7330      5.5479      0.18515                    I  *
   37   5.2544      5.5426     -0.28825               *    I
   38   5.8360      5.8032      0.32799E-01                I*
```

APPENDIX E-6: Shazam Regression Results for Eqn (222)

(data on pieces smaller than 60.0 cm excluded)

```
39   5.3176       5.7364    -0.41882            *      I
40   5.4311       5.6068    -0.16970                *  I
41   5.6276       5.7178    -0.90224E-01             * I
42   5.8177       5.7178     0.99861E-01               I *
43   5.3877       5.4966    -0.10894                 * I
44   6.1841       5.7673     0.41684                   I     *
45   5.8336       5.8922    -0.58592E-01              *I
46   5.7488       5.7865    -0.37694E-01              *I
47   6.0324       5.7046     0.32781                   I    *
48   6.0615       5.8793     0.18217                   I  *
49   6.1360       5.9536     0.18240                   I  *
50   6.1866       6.0789     0.10774                   I *
51   5.4831       6.0162    -0.53306          *        I
52   6.2623       5.9737     0.28852                   I   *
53   6.3343       6.2349     0.99456E-01               I *
54   6.8845       6.8570     0.27497E-01               *

DURBIN-WATSON = 2.1456    VON NEUMANN RATIO = 2.1894    RHO = -0.07886
RESIDUAL SUM = -0.64688E-13  RESIDUAL VARIANCE =  0.84098E-01
SUM OF ABSOLUTE ERRORS=   11.765
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.7009
RUNS TEST:   26 RUNS,   26 POSITIVE,   24 NEGATIVE, NORMAL STATISTIC =    0.0114
COEFFICIENT OF SKEWNESS =  -0.1007 WITH STANDARD DEVIATION OF 0.3366
COEFFICIENT OF EXCESS KURTOSIS =  -0.6758 WITH STANDARD DEVIATION OF 0.6619

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS -  6 GROUPS
OBSERVED  1.0  7.0 16.0 18.0  8.0  0.0
EXPECTED  1.1  6.8 17.1 17.1  6.8  1.1
CHI-SQUARE =    1.4948 WITH  1 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =    1.1828 WITH  2 DEGREES OF FREEDOM
   STOP
```

APPENDIX E-7: Shazam Regression Results on Trawl Data for Eqn (225)

```
UNIT 6 IS NOW ASSIGNED TO: OP.DAT
         SAMPLE 1 129
         READ  NUMBER   PL   PERCENT
  3 VARIABLES AND       129 OBSERVATIONS STARTING AT OBS        1

         GENR LPL=LOG(PL)
         GENR LPL2=LPL**2
         GENR LPER=LOG(PERCENT)
         GENR D19=(PL.EQ.19)
         GENR D22=(PL.EQ.22)
         GENR D26=(PL.EQ.26)
         GENR D27=(PL.EQ.27)
         GENR D28=(PL.EQ.28)
         GENR D29=(PL.EQ.29)
         GENR D30=(PL.EQ.30)
         GENR D33=(PL.EQ.33)
         GENR D34=(PL.EQ.34)
         GENR D35=(PL.EQ.35)
         GENR D36=(PL.EQ.36)
         GENR D37=(PL.EQ.37)
         GENR D38=(PL.EQ.38)
         GENR D39=(PL.EQ.39)
         GENR D40=(PL.EQ.40)
         GENR D41=(PL.EQ.41)
         GENR D42=(PL.EQ.42)
         GENR D43=(PL.EQ.43)
         GENR D44=(PL.EQ.44)
         GENR D45=(PL.EQ.45)
         GENR D46=(PL.EQ.46)
         GENR D47=(PL.EQ.47)
         GENR D48=(PL.EQ.48)
         GENR D49=(PL.EQ.49)
         GENR D50=(PL.EQ.50)
         GENR D51=(PL.EQ.51)
         GENR D52=(PL.EQ.52)
         GENR D53=(PL.EQ.53)
         GENR D54=(PL.EQ.54)
         GENR D55=(PL.EQ.55)
         GENR D56=(PL.EQ.56)
         GENR D57=(PL.EQ.57)
         GENR D58=(PL.EQ.58)
         GENR D59=(PL.EQ.59)
         GENR D63=(PL.EQ.63)
         GENR D64=(PL.EQ.64)
         GENR D67=(PL.EQ.67)
         GENR D68=(PL.EQ.68)
         GENR D70=(PL.EQ.70)
         GENR D71=(PL.EQ.71)
         GENR D73=(PL.EQ.73)
         GENR D74=(PL.EQ.74)
         GENR D75=(PL.EQ.75)
         GENR D83=(PL.EQ.83)

 OLS LPER LPL LPL2 &
```

APPENDIX E-7: Shazam Regression Results on Travl Data for Eqn (225)

```
;                  (D19  D22  D26  D27  D28 D29 D30 D33 D34 D35 &
;                   D36  D37  D38  D39  D40 D41 D42 D43 D44 D45 &
;                   D46  D47  D48  D49  D50 D51 D52 D53 D54 D55 &
;                   D56  D57  D58  D59  D63 D64 D67 D68 D70 D71 &
;                   D73  D74  D75  D83) /LIST LM

REQUIRED MEMORY IS PAR=   63 CURRENT PAR=  240
FOR MAXIMUM EFFICIENCY USE AT LEAST PAR=   111
OLS ESTIMATION
     129 OBSERVATIONS     DEPENDENT VARIABLE = LPER
...NOTE..SAMPLE RANGE SET TO:    1,  129

**** STEPWISE REGRESSION ****
***PARAMETERS FOR STEPWISE REGRESSION:   PE=0.050000 AND  PX=0.050000.


-----------------------------------------------------------------
¦**** STEPPING SEQUENCE ****¦               ¦     ¦      ¦           ¦
¦      ¦        ¦           ¦               ¦     ¦      ¦           ¦
¦ STEP ¦VARIABLE¦           ¦               ¦D.F. ¦ D.F. ¦           ¦
¦NUMBER¦ LABEL  ¦ STATUS    ¦       F-VALUE ¦NUM. ¦ DEN. ¦F-PROBABILITY¦
¦-----------------------------------------------------------------¦
¦    0 ¦LPL2    ¦FORCED IN ¦        4.2682 ¦   1 ¦   127¦   0.040877¦
¦    0 ¦LPL     ¦FORCED IN ¦       83.5846 ¦   1 ¦   126¦   0.000000¦
¦    1 ¦D33     ¦STEPPED IN¦       12.2285 ¦   1 ¦   125¦   0.000655¦
¦    2 ¦D36     ¦STEPPED IN¦        9.3949 ¦   1 ¦   124¦   0.002677¦
¦    3 ¦D55     ¦STEPPED IN¦        9.4399 ¦   1 ¦   123¦   0.002621¦
¦    4 ¦D19     ¦STEPPED IN¦        8.8740 ¦   1 ¦   122¦   0.003498¦
¦    5 ¦D54     ¦STEPPED IN¦        9.1062 ¦   1 ¦   121¦   0.003114¦
¦    6 ¦D58     ¦STEPPED IN¦        9.0869 ¦   1 ¦   120¦   0.003142¦
¦    7 ¦D57     ¦STEPPED IN¦        9.0124 ¦   1 ¦   119¦   0.003268¦
¦    8 ¦D37     ¦STEPPED IN¦        9.3617 ¦   1 ¦   118¦   0.002743¦
¦    9 ¦D34     ¦STEPPED IN¦        9.6468 ¦   1 ¦   117¦   0.002380¦
¦   10 ¦D35     ¦STEPPED IN¦       10.4039 ¦   1 ¦   116¦   0.001634¦
¦   11 ¦D38     ¦STEPPED IN¦       11.8782 ¦   1 ¦   115¦   0.000794¦
¦   12 ¦D53     ¦STEPPED IN¦       12.0993 ¦   1 ¦   114¦   0.000797¦
¦   13 ¦D52     ¦STEPPED IN¦       14.4607 ¦   1 ¦   113¦   0.000233¦
¦   14 ¦D56     ¦STEPPED IN¦       12.6154 ¦   1 ¦   112¦   0.000792¦
¦   15 ¦D59     ¦STEPPED IN¦       13.0202 ¦   1 ¦   111¦   0.000464¦
¦   16 ¦D51     ¦STEPPED IN¦       10.7423 ¦   1 ¦   110¦   0.001402¦
¦   17 ¦D22     ¦STEPPED IN¦       11.5952 ¦   1 ¦   109¦   0.000927¦
¦   18 ¦D83     ¦STEPPED IN¦       13.1667 ¦   1 ¦   108¦   0.000716¦
¦   19 ¦D39     ¦STEPPED IN¦       10.5423 ¦   1 ¦   107¦   0.001558¦
¦   20 ¦D63     ¦STEPPED IN¦       10.9641 ¦   1 ¦   106¦   0.001271¦
¦   21 ¦D64     ¦STEPPED IN¦       11.9219 ¦   1 ¦   105¦   0.000801¦
¦   22 ¦D50     ¦STEPPED IN¦       13.6105 ¦   1 ¦   104¦   0.000696¦
¦   23 ¦D49     ¦STEPPED IN¦       10.0152 ¦   1 ¦   103¦   0.002042¦
¦   24 ¦D40     ¦STEPPED IN¦        6.1322 ¦   1 ¦   102¦   0.014920¦
¦   25 ¦D67     ¦STEPPED IN¦        4.7532 ¦   1 ¦   101¦   0.031566¦
¦   26 ¦D68     ¦STEPPED IN¦        5.4037 ¦   1 ¦   100¦   0.022117¦
¦   27 ¦D48     ¦STEPPED IN¦        4.9518 ¦   1 ¦    99¦   0.028332¦
¦   28 ¦D70     ¦STEPPED IN¦        5.1988 ¦   1 ¦    98¦   0.024769¦
¦*SUMMARY FOR POTENTIAL VARIABLES NOT ENTERED INTO THE REG. EQUATION*¦
¦      ¦D26     ¦IF ENTERED¦        0.8223 ¦   1 ¦    97¦   0.366743¦
¦      ¦D27     ¦IF ENTERED¦        0.0180 ¦   1 ¦    97¦   0.893512¦
```

```
|      |D28     |IF ENTERED|     1.3679 |  1 |   97|    0.245043|
|      |D29     |IF ENTERED|     1.7036 |  1 |   97|    0.194905|
|      |D30     |IF ENTERED|     2.0029 |  1 |   97|    0.160201|
|      |D41     |IF ENTERED|     2.8162 |  1 |   97|    0.096534|
|      |D42     |IF ENTERED|     0.0885 |  1 |   97|    0.766781|
|      |D43     |IF ENTERED|     1.3668 |  1 |   97|    0.245235|
|      |D44     |IF ENTERED|     0.8961 |  1 |   97|    0.346187|
|      |D45     |IF ENTERED|     0.7995 |  1 |   97|    0.373464|
|      |D46     |IF ENTERED|     0.0081 |  1 |   97|    0.928287|
|      |D47     |IF ENTERED|     1.7156 |  1 |   97|    0.193349|
|      |D71     |IF ENTERED|     2.7414 |  1 |   97|    0.101014|
|      |D73     |IF ENTERED|     0.6819 |  1 |   97|    0.410952|
|      |D74     |IF ENTERED|     0.0002 |  1 |   97|    0.989162|
|      |D75     |IF ENTERED|     0.1866 |  1 |   97|    0.666755|
|**** END OF STEPPING SEQUENCE ****  |    |     |            |
----------------------------------------------------------------------

 R-SQUARE =   0.9467     R-SQUARE ADJUSTED =   0.9304
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.30926
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.55611
SUM OF SQUARED ERRORS-SSE=   30.307
MEAN OF DEPENDENT VARIABLE = -0.13542
LOG OF THE LIKELIHOOD FUNCTION = -89.6201

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.38358
   (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC = -0.96780
 SCHWARZ(1978) CRITERION-LOG SC = -0.28056
MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.40709
 HANNAN AND QUINN(1979) CRITERION -HQ=  0.50230
 RICE (1984) CRITERION-RICE=  0.45235
 SHIBATA (1981) CRITERION-SHIBATA=  0.34786
 SCHWARTZ (1978) CRITERION-SC=  0.75536
 AKAIKE (1974)INFORMATION CRITERION-AIC=  0.37992

                   ANALYSIS OF VARIANCE - FROM MEAN
                  SS           DF           MS              F
REGRESSION      538.53         30.        17.951          58.046
ERROR           30.307         98.       0.30926
TOTAL           568.84        128.        4.4441

                   ANALYSIS OF VARIANCE - FROM ZERO
                  SS           DF           MS              F
REGRESSION      540.90         31.        17.448          56.420
ERROR           30.307         98.       0.30926
TOTAL           571.21        129.        4.4280


VARIABLE   ESTIMATED  STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
  NAME    COEFFICIENT  ERROR      98 DF      CORR.  COEFFICIENT  AT MEANS

LFL        156.62     6.4622     24.236    0.9258  17.584       -4418.3
```

```
LPL2      -20.625     0.84406      -24.435   -0.9268   -17.473      2231.3
D19        9.2686     0.87836       10.552    0.7293   0.38710    -0.53056
D22        4.4699     0.73619       6.0717    0.5228   0.18669    -0.25587
D33       -3.4687     0.35037      -9.9003   -0.7071  -0.24896     0.59568
D34       -4.0547     0.57072      -7.1045   -0.5831  -0.16934     0.23210
D35       -2.9674     0.41072      -7.2250   -0.5895  -0.17458     0.33973
D36       -3.3711     0.33968      -9.9242   -0.7080  -0.24195     0.57891
D37       -2.4823     0.26997      -9.1947   -0.6805  -0.22817     0.71046
D38       -2.2243     0.26832      -8.2898   -0.6420  -0.20446     0.63663
D39       -1.3736     0.26721      -5.1407   -0.4609  -0.12626     0.39315
D40      -0.75137     0.26650      -2.8194   -0.2739 -0.69065E-01  0.21505
D48      -0.63330     0.26747      -2.3677   -0.2326 -0.58212E-01  0.18126
D49       -1.1551     0.26803      -4.3097   -0.3992  -0.10618     0.33061
D50       -1.4645     0.26868      -5.4508   -0.4823  -0.13462     0.41917
D51       -2.0292     0.26944      -7.5312   -0.6055  -0.18652     0.58078
D52       -2.7267     0.27032      -10.087   -0.7137  -0.25063     0.78041
D53       -2.8134     0.27135      -10.368   -0.7233  -0.25861     0.80525
D54       -3.4036     0.27254      -12.489   -0.7837  -0.31286     0.97416
D55       -3.7779     0.27391      -13.793   -0.8124  -0.34726      1.0813
D56       -3.3300     0.41069      -8.1084   -0.6337  -0.19592     0.38124
D57       -4.0443     0.41189      -9.8190   -0.7042  -0.23794     0.46302
D58       -4.2324     0.41326      -10.242   -0.7190  -0.24901     0.48455
D59       -4.0932     0.57157      -7.1614   -0.5861  -0.17095     0.23431
D63       -3.1397     0.57757      -5.4360   -0.4813  -0.13113     0.17972
D64       -3.0150     0.57949      -5.2028   -0.4652  -0.12592     0.17259
D67       -1.6815     0.58641      -2.8675   -0.2782 -0.70228E-01 0.96253E-01
D68       -1.6284     0.58911      -2.7642   -0.2689 -0.68011E-01 0.93215E-01
D70       -1.3570     0.59517      -2.2801   -0.2244 -0.56677E-01 0.77680E-01
D83        2.1737     0.65635       3.3118    0.3173  0.90786E-01 -0.12443
CONSTANT  -294.94      12.359      -23.864   -0.9237  0.00000E+00   2177.9

    OBS.  OBSERVED     PREDICTED  CALCULATED
     NO.    VALUE        VALUE     RESIDUAL
      1   -3.3242      -3.3242    0.39790E-12                 *
      2   -3.4112      -3.4112    0.39790E-12                 *
      3   -3.1701      -3.5930    0.42294                     I   *
      4   -2.7181      -2.7837    0.65567E-01                 I*
      5   -1.4740      -2.0593    0.58530                     I    *
      6   -2.0794      -1.4121    -0.66731              *     I
      7   -1.5702     -0.83512    -0.73510             *      I
      8   -3.1701      -2.9357    -0.23443                  * I
      9   -2.7181      -2.9357    0.21755                     I *
     10   -2.9188      -2.9357    0.16881E-01                 *
     11   -3.1701      -3.1701    0.28422E-12                 *
     12   -2.0794      -1.7767    -0.30270                 *  I
     13   -1.4740      -1.7767    0.30270                     I  *
     14  -0.61619      -1.9161     1.2999                     I           *
     15   -1.8079      -1.9161    0.10821                     I*
     16   -3.3242      -1.9161     -1.4081        *           I
     17   0.31481     -0.80166     1.1165                     I         *
     18  -0.23953     -0.80166    0.56213                     I    *
     19   -1.1332     -0.80166    -0.33154                 *  I
     20   -1.4271     -0.80166    -0.62546              *     I
     21   -1.5233     -0.80166    -0.72160             *      I
```

```
22  0.87921       -0.35383    1.2330                    I          *
23  0.27079       -0.35383    0.62462                   I     *
24  -1.1332       -0.35383    -0.77938             *      I
25  -0.82098      -0.35383    -0.46715                *   I
26  -0.96496      -0.35383    -0.61113              *     I
27  1.2006        0.65361     0.54695                   I    *
28  1.0480        0.65361     0.39441                   I   *
29  0.45426       0.65361     -0.19936                  * I
30  0.76035E-01   0.65361     -0.57758               *    I
31  0.48919       0.65361     -0.16442                   *I
32  1.5461        1.4019      0.14420                   I*
33  1.7525        1.4019      0.35063                   I  *
34  0.98768       1.4019      -0.41419                *   I
35  0.90745       1.4019      -0.49442                *   I
36  1.8156        1.4019      0.41377                   I   *
37  2.0968        2.2507      -0.15386                   *I
38  2.1114        2.2507      -0.13923                   *I
39  1.4743        2.2507      -0.77635             *      I
40  1.6006        2.2507      -0.65005              *     I
41  2.0580        2.2507      -0.19269                  * I
42  2.5616        2.3215      0.24016                   I *
43  2.5142        2.3215      0.19275                   I *
44  2.0594        2.3215      -0.26210                  * I
45  2.1369        2.3215      -0.18459                  * I
46  2.6792        2.3215      0.35770                   I  *
47  2.7402        2.3675      0.37269                   I  *
48  2.7044        2.3675      0.33694                   I  *
49  2.4633        2.3675      0.95834E-01               I*
50  2.4707        2.3675      0.10321                   I*
51  2.8019        2.3675      0.43440                   I   *
52  2.7614        2.3904      0.37097                   I  *
53  2.5981        2.3904      0.20766                   I *
54  2.5396        2.3904      0.14920                   I*
55  2.5169        2.3904      0.12646                   I*
56  2.6255        2.3904      0.23511                   I *
57  2.5389        2.3918      0.14716                   I*
58  2.5583        2.3918      0.16655                   I *
59  2.6791        2.3918      0.28734                   I  *
60  2.6802        2.3918      0.28843                   I  *
61  2.5306        2.3918      0.13883                   I*
62  2.1657        2.3729      -0.20719                  * I
63  2.2621        2.3729      -0.11084                   *I
64  2.5702        2.3729      0.19725                   I *
65  2.6354        2.3729      0.26249                   I *
66  2.3352        2.3729      -0.37674E-01              *
67  1.6784        2.3352      -0.65679              *     I
68  1.8752        2.3352      -0.46001                *   I
69  2.4386        2.3352      0.10341                   I*
70  2.3058        2.3352      -0.29412E-01              *
71  1.8840        2.3352      -0.45116                *   I
72  1.2613        1.6465      -0.38518                 *  I
73  1.5306        1.6465      -0.11586                   *I
74  1.9835        1.6465      0.33701                   I  *
75  1.9621        1.6465      0.31559                   I  *
```

```
  76       1.4949       1.6465 -0.15155                *I
  77      0.57998       1.0527 -0.47268             *   I
  78       1.0127       1.0527 -0.39964E-01             *
  79       1.5454       1.0527  0.49278                 I   *
  80       1.4533       1.0527  0.40060                 I   *
  81      0.67192       1.0527 -0.38073              *  I
  82      0.31481      0.65570 -0.34089              *  I
  83      0.38866      0.65570 -0.26704               * I
  84       1.2553      0.65570  0.59963                 I    *
  85       1.1869      0.65570  0.53123                 I    *
  86      0.13278      0.65570 -0.52292            *    I
  87     -0.69716 -0.11116E-01 -0.68604           *     I
  88     -0.47321 -0.11116E-01 -0.46209             *   I
  89      0.56190 -0.11116E-01  0.57301                 I    *
  90      0.69215 -0.11116E-01  0.70326                 I     *
  91     -0.13926 -0.11116E-01 -0.12815                *I
  92      -1.7958     -0.82447 -0.97129        *        I
  93     -0.93395     -0.82447 -0.10947                *I
  94     -0.23826     -0.82447  0.58622                 I    *
  95      0.14756     -0.82447  0.97203                 I        *
  96      -1.3020     -0.82447 -0.47748             *   I
  97      -1.5702      -1.0400 -0.53020            *    I
  98      -1.2208      -1.0400 -0.18076               * I
  99     -0.84397      -1.0400  0.19605                 I *
 100 -0.41864E-01      -1.0400  0.99815                 I        *
 101      -1.5233      -1.0400 -0.48324             *   I
 102      -2.0794      -1.7711 -0.30832              *  I
 103      -1.8079      -1.7711 -0.36770E-01             *
 104      -1.1332      -1.7711  0.63792                 I     *
 105     -0.91629      -1.7711  0.85483                 I       *
 106      -2.9188      -1.7711 -1.1477        *         I
 107      -2.4889      -2.2977 -0.19120               * I
 108      -3.4112      -2.2977 -1.1135        *         I
 109      -1.9449      -2.2977  0.35281                 I  *
 110      -1.4271      -2.2977  0.87060                 I       *
 111      -2.2164      -2.2977  0.81312E-01             I*
 112      -2.4889      -2.0130 -0.47590             *   I
 113      -1.5371      -2.0130  0.47590                 I   *
 114      -3.1701      -2.9006 -0.26950               * I
 115      -2.6311      -2.9006  0.26950                 I *
 116      -3.3242      -3.2716 -0.52680E-01             *
 117      -3.2189      -3.2716  0.52680E-01             *
 118      -3.3242      -3.3242  0.22737E-12             *
 119      -3.2189      -3.2189  0.22737E-12             *
 120      -3.3242      -3.3242  0.28422E-12             *
 121      -2.7181      -2.7181  0.28422E-12             *
 122      -2.9188      -2.9188  0.22737E-12             *
 123      -3.1701      -3.1701  0.28422E-12             *
 124      -2.9188      -2.0815 -0.83732         *       I
 125      -2.2164      -2.6311  0.41473                 I   *
 126      -2.9188      -2.9120 -0.67966E-02             *
 127      -3.2189      -3.1965 -0.22354E-01             *
 128      -2.9188      -3.1965  0.27775                 I  *
 129      -3.4112      -3.4112  0.17053E-12             *
```

```
DURBIN-WATSON = 1.8265    VON NEUMANN RATIO = 1.8408    RHO =  0.08676
RESIDUAL SUM =  0.30582E-10  RESIDUAL VARIANCE =  0.30926
SUM OF ABSOLUTE ERRORS=   48.427
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9467
RUNS TEST:   49 RUNS,   70 POSITIVE,   59 NEGATIVE, NORMAL STATISTIC =   -2.8549
COEFFICIENT OF SKEWNESS =  -0.0277 WITH STANDARD DEVIATION OF 0.2132
COEFFICIENT OF EXCESS KURTOSIS =   0.3307 WITH STANDARD DEVIATION OF 0.4233

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 60 GROUPS
OBSERVED  0.0  0.0  0.0  0.0  1.0  0.0  0.0  0.0  0.0  2.0  0.0  0.0  1.0  0.0  1.0  2.0  2.0  2.0  4.0  1.0
          2.0  9.0  1.0  3.0  3.0  4.0  6.0  7.0  1.0  7.0 12.0  6.0  5.0  6.0  4.0  5.0  7.0  6.0  2.0  2.0
          5.0  2.0  1.0  0.0  0.0  2.0  0.0  1.0  1.0  0.0  1.0  0.0  1.0  1.0  0.0  0.0  0.0  0.0  0.0  0.0
EXPECTED  0.2  0.1  0.1  0.2  0.2  0.3  0.3  0.4  0.5  0.6  0.8  0.9  1.1  1.3  1.5  1.8  2.1  2.4  2.7  3.0
          3.3  3.6  3.9  4.2  4.4  4.7  4.8  5.0  5.1  5.1  5.1  5.1  5.0  4.8  4.7  4.4  4.2  3.9  3.6  3.3
          3.0  2.7  2.4  2.1  1.8  1.5  1.3  1.1  0.9  0.8  0.6  0.5  0.4  0.3  0.3  0.2  0.2  0.1  0.1  0.2
CHI-SQUARE =   57.0179 WITH 27 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =    0.4132 WITH  2 DEGREES OF FREEDOM
        STOP
```

APPENDIX E-8: Shazam Regression Results on Longline Data for Eqn (225)

```
     UNIT  6 IS NOW ASSIGNED TO: OP.DAT
                SAMPLE 1 226
                READ    PL      PERCENT
        2 VARIABLES AND      226 OBSERVATIONS STARTING AT OBS       1

                GENR LPL=LOG(PL)
                GENR LPL2=LPL**2
                GENR LPER=LOG(PERCENT)
                GENR D40=(PL.EQ.40)
                GENR D41=(PL.EQ.41)
                GENR D42=(PL.EQ.42)
                GENR D43=(PL.EQ.43)
                GENR D44=(PL.EQ.44)
                GENR D45=(PL.EQ.45)
                GENR D46=(PL.EQ.46)
                GENR D47=(PL.EQ.47)
                GENR D48=(PL.EQ.48)
                GENR D49=(PL.EQ.49)
                GENR D50=(PL.EQ.50)
                GENR D51=(PL.EQ.51)
                GENR D52=(PL.EQ.52)
                GENR D53=(PL.EQ.53)
                GENR D54=(PL.EQ.54)
                GENR D55=(PL.EQ.55)
                GENR D56=(PL.EQ.56)
                GENR D57=(PL.EQ.57)
                GENR D58=(PL.EQ.58)
                GENR D59=(PL.EQ.59)
                GENR D60=(PL.EQ.60)
                GENR D61=(PL.EQ.61)
                GENR D62=(PL.EQ.62)
                GENR D63=(PL.EQ.63)
                GENR D64=(PL.EQ.64)
                GENR D65=(PL.EQ.65)
                GENR D66=(PL.EQ.66)
                GENR D67=(PL.EQ.67)
                GENR D68=(PL.EQ.68)
                GENR D69=(PL.EQ.69)
                GENR D70=(PL.EQ.70)
                GENR D71=(PL.EQ.71)
                GENR D72=(PL.EQ.72)
                GENR D73=(PL.EQ.73)
                GENR D74=(PL.EQ.74)
                GENR D75=(PL.EQ.75)
                GENR D76=(PL.EQ.76)
                GENR D77=(PL.EQ.77)
                GENR D78=(PL.EQ.78)
                GENR D79=(PL.EQ.79)
                GENR D80=(PL.EQ.80)
                GENR D81=(PL.EQ.81)
                GENR D82=(PL.EQ.82)
                GENR D83=(PL.EQ.83)
                GENR D84=(PL.EQ.84)
                GENR D85=(PL.EQ.85)
```

```
            GENR D86=(PL.EQ.86)
            GENR D87=(PL.EQ.87)
            GENR D88=(PL.EQ.88)
            GENR D89=(PL.EQ.89)
            GENR D90=(PL.EQ.90)
            GENR D91=(PL.EQ.91)
            GENR D92=(PL.EQ.92)
            GENR D93=(PL.EQ.93)
            GENR D94=(PL.EQ.94)
            GENR D95=(PL.EQ.95)
            GENR D96=(PL.EQ.96)
            GENR D97=(PL.EQ.97)
            GENR D99=(PL.EQ.99)
            GENR D101=(PL.EQ.101)
            GENR D110=(PL.EQ.110)
            GENR D120=(PL.EQ.120)

 ¦ OLS LPER LPL LPL2 (D42 D43 D44  D45  D46 D47 D48 &
 ¦                    D49  D50  D51  D53  D54  D55  D56 D57 D58 &
 ¦                    D59  D60  D61  D62  D63  D64  D65  D66 D67 D68 &
 ¦                    D69  D72  D73  D75 D76 D77  D78 &
 ¦                    D79  D80  D81  D82  D83  D84  D85  D86 D87 D88 &
 ¦                    D89  D90  D91  D92  D93  D94  D95 D96 D97 D99 &
 ¦                    D101) /LIST LM BEG=1

REQUIRED MEMORY IS PAR=  136 CURRENT PAR=  238
FOR MAXIMUM EFFICIENCY USE AT LEAST PAR=   238
OLS ESTIMATION
     226 OBSERVATIONS     DEPENDENT VARIABLE = LPER
...NOTE..SAMPLE RANGE SET TO:    1,  226

**** STEPWISE REGRESSION ****
***PARAMETERS FOR STEPWISE REGRESSION:   PE=0.050000 AND  PR=0.050000.


-----------------------------------------------------------------------
¦**** STEPPING SEQUENCE ****¦                 ¦     ¦      ¦            ¦
¦      ¦         ¦          ¦                 ¦     ¦      ¦            ¦
¦ STEP ¦VARIABLE ¦          ¦                 ¦D.F. ¦ D.F. ¦            ¦
¦NUMBER¦ LABEL   ¦ STATUS   ¦         F-VALUE ¦NUM. ¦ DEN. ¦F-PROBABILITY¦
¦----------------------------------------------------------------------¦
¦    0 ¦LPL2     ¦FORCED IN ¦         33.3293 ¦   1 ¦  224¦    0.000573¦
¦    0 ¦LPL      ¦FORCED IN ¦       1020.9834 ¦   1 ¦  223¦    0.000000¦
¦    1 ¦D91      ¦STEPPED IN¦          7.9790 ¦   1 ¦  222¦    0.005166¦
¦    2 ¦D93      ¦STEPPED IN¦          6.6945 ¦   1 ¦  221¦    0.010315¦
¦    3 ¦D94      ¦STEPPED IN¦          6.9359 ¦   1 ¦  220¦    0.009051¦
¦    4 ¦D90      ¦STEPPED IN¦          7.9551 ¦   1 ¦  219¦    0.005238¦
¦    5 ¦D88      ¦STEPPED IN¦          8.4500 ¦   1 ¦  218¦    0.004030¦
¦    6 ¦D89      ¦STEPPED IN¦          9.7477 ¦   1 ¦  217¦    0.002042¦
¦    7 ¦D85      ¦STEPPED IN¦          8.2698 ¦   1 ¦  216¦    0.004437¦
¦    8 ¦D87      ¦STEPPED IN¦          5.7654 ¦   1 ¦  215¦    0.017200¦
¦    9 ¦D84      ¦STEPPED IN¦          4.6286 ¦   1 ¦  214¦    0.032568¦
¦   10 ¦D83      ¦STEPPED IN¦          4.7881 ¦   1 ¦  213¦    0.029749¦
¦   11 ¦D82      ¦STEPPED IN¦          5.3910 ¦   1 ¦  212¦    0.021194¦
¦   12 ¦D95      ¦STEPPED IN¦          5.1204 ¦   1 ¦  211¦    0.024668¦
```

```
 |  13 |D92      |STEPPED IN|     5.7984 |  1 |   210|    0.016909|
 |  14 |D86      |STEPPED IN|     6.4933 |  1 |   209|    0.011550|
 |  15 |D99      |STEPPED IN|     6.2350 |  1 |   208|    0.013305|
 |  16 |D96      |STEPPED IN|     6.3403 |  1 |   207|    0.012564|
 |  17 |D81      |STEPPED IN|     5.8730 |  1 |   206|    0.016243|
 |  18 |D97      |STEPPED IN|     7.0159 |  1 |   205|    0.008712|
 |  19 |D101     |STEPPED IN|     7.7479 |  1 |   204|    0.005886|
 |  20 |D80      |STEPPED IN|     6.4270 |  1 |   203|    0.011997|
 |  21 |D47      |STEPPED IN|     5.1197 |  1 |   202|    0.024725|
 |  22 |D79      |STEPPED IN|     4.8370 |  1 |   201|    0.029001|
 |  23 |D48      |STEPPED IN|     4.7959 |  1 |   200|    0.029689|
 |  24 |D46      |STEPPED IN|     5.3539 |  1 |   199|    0.021701|
 |  25 |D78      |STEPPED IN|     4.8957 |  1 |   198|    0.028070|
 |  26 |D77      |STEPPED IN|     5.1463 |  1 |   197|    0.024385|
 |  27 |D45      |STEPPED IN|     5.2476 |  1 |   196|    0.023045|
 |  28 |D76      |STEPPED IN|     4.9991 |  1 |   195|    0.026498|
 |  29 |D49      |STEPPED IN|     4.6517 |  1 |   194|    0.032258|
 |  30 |D75      |STEPPED IN|     4.5283 |  1 |   193|    0.034612|
 |*SUMMARY FOR POTENTIAL VARIABLES NOT ENTERED INTO THE REG. EQUATION*|
 |     |D42      |IF ENTERED|     0.2472 |  1 |   192|    0.619646|
 |     |D43      |IF ENTERED|     0.1231 |  1 |   192|    0.726072|
 |     |D44      |IF ENTERED|     2.0526 |  1 |   192|    0.153574|
 |     |D50      |IF ENTERED|     1.2211 |  1 |   192|    0.270522|
 |     |D51      |IF ENTERED|     0.4251 |  1 |   192|    0.515172|
 |     |D53      |IF ENTERED|     0.4978 |  1 |   192|    0.481311|
 |     |D54      |IF ENTERED|     0.0099 |  1 |   192|    0.921046|
 |     |D55      |IF ENTERED|     0.1047 |  1 |   192|    0.746660|
 |     |D56      |IF ENTERED|     0.0790 |  1 |   192|    0.779015|
 |     |D57      |IF ENTERED|     0.2296 |  1 |   192|    0.632369|
 |     |D58      |IF ENTERED|     0.6357 |  1 |   192|    0.426244|
 |     |D59      |IF ENTERED|     0.9530 |  1 |   192|    0.330187|
 |     |D60      |IF ENTERED|     0.8077 |  1 |   192|    0.369919|
 |     |D61      |IF ENTERED|     1.3587 |  1 |   192|    0.245203|
 |     |D62      |IF ENTERED|     0.9984 |  1 |   192|    0.318949|
 |     |D63      |IF ENTERED|     1.1317 |  1 |   192|    0.288743|
 |     |D64      |IF ENTERED|     0.2592 |  1 |   192|    0.611236|
 |     |D65      |IF ENTERED|     0.0685 |  1 |   192|    0.793761|
 |     |D66      |IF ENTERED|     0.0078 |  1 |   192|    0.929629|
 |     |D67      |IF ENTERED|     0.0204 |  1 |   192|    0.886527|
 |     |D68      |IF ENTERED|     0.4714 |  1 |   192|    0.493189|
 |     |D69      |IF ENTERED|     1.0233 |  1 |   192|    0.313013|
 |     |D72      |IF ENTERED|     3.0370 |  1 |   192|    0.082994|
 |     |D73      |IF ENTERED|     2.8063 |  1 |   192|    0.095525|
 |**** END OF STEPPING SEQUENCE ****   |    |      |            |
 ---------------------------------------------------------------------

  R-SQUARE =   0.9344     R-SQUARE ADJUSTED =   0.9235
 VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.23329
 STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.48300
 SUM OF SQUARED ERRORS-SSE=   45.025
 MEAN OF DEPENDENT VARIABLE = -0.32390
 LOG OF THE LIKELIHOOD FUNCTION = -138.376

 MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
```

APPENDIX B-8: Shazam Regression Results on Longline Data for Eqn (225)

```
    AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.26736
      (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
    AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -1.3213
    SCHWARZ(1978) CRITERION-LOG SC = -0.82182
   MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
    CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.27318
    HANNAN AND QUINN(1979) CRITERION -HQ=  0.32637
    RICE (1984) CRITERION-RICE=  0.28141
    SHIBATA (1981) CRITERION-SHIBATA=  0.25741
    SCHWARTZ (1978) CRITERION-SC=  0.43963
    AKAIKE (1974)INFORMATION CRITERION-AIC=  0.26679

                     ANALYSIS OF VARIANCE - FROM MEAN
                      SS          DF           MS              F
 REGRESSION         641.10        32.        20.034          85.877
 ERROR              45.025       193.       0.23329
 TOTAL              686.13       225.        3.0494

                     ANALYSIS OF VARIANCE - FROM ZERO
                      SS          DF           MS              F
 REGRESSION         664.81        33.        20.146          86.355
 ERROR              45.025       193.       0.23329
 TOTAL              709.84       226.        3.1409


 VARIABLE   ESTIMATED   STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
   NAME    COEFFICIENT   ERROR     193 DF      CORR.  COEFFICIENT  AT MEANS

 LPL         150.36      4.6762     32.155    0.9180   22.383      -1942.8
 LPL2       -18.020     0.57036    -31.594   -0.9154  -22.321       978.17
 D45        0.64249     0.25235     2.5461    0.1803  0.48620E-01 -0.35108E-01
 D46        0.71307     0.25088     2.8423    0.2004  0.53961E-01 -0.38965E-01
 D47        0.77304     0.24972     3.0956    0.2175  0.58500E-01 -0.42242E-01
 D48        0.69394     0.24882     2.7889    0.1968  0.52514E-01 -0.37920E-01
 D49        0.54020     0.24813     2.1771    0.1548  0.40879E-01 -0.29519E-01
 D75       -0.53353     0.25072    -2.1280   -0.1514 -0.40374E-01  0.29154E-01
 D76       -0.61171     0.25136    -2.4336   -0.1725 -0.46291E-01  0.33426E-01
 D77       -0.68475     0.25208    -2.7164   -0.1919 -0.51818E-01  0.37418E-01
 D78       -0.72411     0.25287    -2.8636   -0.2019 -0.54797E-01  0.39569E-01
 D79       -0.79741     0.25375    -3.1426   -0.2206 -0.60344E-01  0.43574E-01
 D80       -0.96030     0.25471    -3.7702   -0.2619 -0.72670E-01  0.52475E-01
 D81        -1.1313     0.25576    -4.4231   -0.3034 -0.85607E-01  0.61816E-01
 D82        -1.4078     0.25691    -5.4799   -0.3669 -0.10654      0.76931E-01
 D83        -1.4457     0.25815    -5.6000   -0.3739 -0.10940      0.78997E-01
 D84        -1.5123     0.25950    -5.8277   -0.3868 -0.11444      0.82638E-01
 D85        -1.8711     0.26095    -7.1703   -0.4586 -0.14159      0.10224
 D86        -1.4549     0.26250    -5.5422   -0.3705 -0.11010      0.79500E-01
 D87        -1.7535     0.26417    -6.6379   -0.4311 -0.13270      0.95820E-01
 D88        -2.1557     0.26594    -8.1060   -0.5040 -0.16313      0.11780
 D89        -2.1930     0.26783    -8.1879   -0.5078 -0.16595      0.11983
 D90        -2.4365     0.30372    -8.0222   -0.5001 -0.16084      0.99856E-01
 D91        -2.5499     0.27194    -9.3765   -0.5594 -0.19296      0.13933
 D92        -2.3686     0.50014    -4.7359   -0.3227 -0.90225E-01  0.32358E-01
 D93        -2.6506     0.30968    -8.5592   -0.5245 -0.17410      0.10863
```

```
     D94       -2.6487     0.31187      -8.4928    -0.5216 -0.17397      0.10855
     D95       -1.9015     0.31418      -6.0523    -0.3994 -0.12490      0.77930E-01
     D96       -2.2792     0.50572      -4.5068    -0.3086 -0.86820E-01  0.31137E-01
     D97       -1.7377     0.37512      -4.6323    -0.3163 -0.93400E-01  0.47476E-01
     D99       -2.4462     0.51069      -4.7900    -0.3260 -0.93182E-01  0.33418E-01
     D101      -2.1341     0.51438      -4.1489    -0.2862 -0.81293E-01  0.29154E-01
     CONSTANT  -312.27      9.5781      -32.602    -0.9200  0.00000E+00   964.09

         OBS.  OBSERVED    PREDICTED   CALCULATED
          NO.    VALUE       VALUE       RESIDUAL
           1   -3.9633      -3.7474     -0.21587                  * I
           2   -2.3539      -2.8067      0.45281                    I    *
           3   -2.5383      -2.8067      0.26838                    I  *
           4   -4.2687      -2.8067      -1.4620     *              I
           5   -2.7334      -2.8067      0.73324E-01                I*
           6   -3.9633      -2.3876      -1.5757     I              I
           7   -3.6497      -2.3876      -1.2620       *            I
           8   -1.8579      -2.3876      0.52972                    I    *
           9   -2.7334      -2.3876     -0.34575                *   I
          10   -1.6660      -1.9998      0.33383                    I  *
          11   -3.6497      -1.9998      -1.6498     I              I
          12   -1.2623      -1.9998      0.73753                    I       *
          13   -1.8643      -1.9998      0.13551                    I*
          14   -1.7720      -1.6414     -0.13058                   *I
          15   -1.6928      -1.6414     -0.51444E-01               *I
          16  -0.99967      -1.6414      0.64170                    I      *
          17   -1.7838      -1.6414     -0.14242                   *I
          18  -0.92130      -1.3104      0.38912                    I   *
          19   -1.2413      -1.3104      0.69096E-01                I*
          20  -0.79186      -1.3104      0.51856                    I    *
          21  -0.98350      -1.3104      0.32693                    I  *
          22  -0.41098     -0.36283     -0.48149E-01                *
          23   0.25668E-01 -0.36283      0.38850                    I   *
          24  -0.42925     -0.36283     -0.66414E-01               *I
          25  -0.63677     -0.36283     -0.27394                 *  I
          26   0.12751     -0.11462E-01  0.13898                    I*
          27  -0.10005E-02 -0.11462E-01  0.10462E-01                *
          28  -0.98716E-01 -0.11462E-01 -0.87254E-01               *I
          29  -0.73647E-01 -0.11462E-01 -0.62184E-01               *I
          30   0.47623      0.30641      0.16983                    I *
          31   0.62433      0.30641      0.31792                    I  *
          32   0.18482      0.30641     -0.12159                   *I
          33  -0.59750E-01  0.30641     -0.36616                *   I
          34   0.64867      0.46363      0.18504                    I *
          35   0.74384      0.46363      0.28021                    I  *
          36   0.52177      0.46363      0.58133E-01                I*
          37  -0.59750E-01  0.46363     -0.52338               *    I
          38   0.63869      0.52586      0.11284                    I*
          39   0.73141      0.52586      0.20555                    I *
          40   0.59443      0.52586      0.68576E-01                I*
          41   0.13889      0.52586     -0.38696                *   I
          42   0.81226      0.18240      0.62986                    I      *
          43   0.69265      0.18240      0.51025                    I    *
          44   0.29639      0.18240      0.11399                    I*
```

```
 45  -0.32523E-01  0.18240    -0.21492               * I
 46   0.96774      0.36097     0.60677                 I     *
 47   0.29342      0.36097    -0.67556E-01              *I
 48   0.59443      0.36097     0.23346                 I *
 49   0.20376      0.36097    -0.15721               * I
 50   0.94585      0.52235     0.42350                 I   *
 51   0.53649      0.52235     0.14143E-01               *
 52   0.57098      0.52235     0.48629E-01               I*
 53   0.42068      0.52235    -0.10167                  *I
 54    1.0571      0.66745     0.38964                 I   *
 55   0.75612      0.66745     0.88670E-01               I*
 56   0.81137      0.66745     0.14392                   I*
 57   0.71246      0.66745     0.45007E-01               *
 58    1.1272      0.79713     0.33007                 I  *
 59   0.74384      0.79713    -0.53289E-01              *I
 60   0.69813      0.79713    -0.98995E-01              *I
 61   0.52532      0.79713    -0.27181              *  I
 62    1.2856      0.91218     0.37347                 I   *
 63   0.80469      0.91218    -0.10749                  *I
 64   0.95743      0.91218     0.45253E-01               *
 65   0.90745      0.91218    -0.47280E-02               *
 66    1.3805       1.0133     0.36718                 I   *
 67   0.79254       1.0133    -0.22081               * I
 68   0.97908       1.0133    -0.34271E-01               *
 69    1.1675       1.0133     0.15417                 I *
 70    1.3898       1.1013     0.28845                 I  *
 71   0.96698       1.1013    -0.13435                  *I
 72    1.2355       1.1013     0.13414                   I*
 73    1.2669       1.1013     0.16561                 I *
 74    1.4972       1.1768     0.32037                 I  *
 75    1.0892       1.1768    -0.87557E-01              *I
 76    1.3556       1.1768     0.17878                 I *
 77    1.5195       1.1768     0.34272                 I   *
 78    1.5221       1.2403     0.28180                 I  *
 79    1.2596       1.2403     0.19259E-01               *
 80    1.4262       1.2403     0.18590                 I *
 81    1.6760       1.2403     0.43564                 I    *
 82    1.5386       1.2925     0.24604                 I  *
 83    1.2140       1.2925    -0.78525E-01              *I
 84    1.4791       1.2925     0.18655                 I *
 85    1.7879       1.2925     0.49537                 I    *
 86    1.6392       1.3340     0.30523                 I  *
 87    1.3658       1.3340     0.31873E-01               *
 88    1.6004       1.3340     0.26643                 I  *
 89    1.8302       1.3340     0.49621                 I    *
 90    1.6206       1.3651     0.25548                 I  *
 91    1.4054       1.3651     0.40262E-01               *
 92    1.4951       1.3651     0.13005                   I*
 93    1.8825       1.3651     0.51741                 I    *
 94    1.4450       1.3864     0.58599E-01               I*
 95    1.5929       1.3864     0.20647                 I *
 96    1.5919       1.3864     0.20545                 I *
 97    1.9193       1.3864     0.53284                 I     *
 98    1.2644       1.3984    -0.13402                  *I
```

```
 99   1.4798       1.3984     0.81359E-01             I*
100   1.5045       1.3984     0.10610                 I*
101   1.8260       1.3984     0.42757                 I    *
102   1.3612       1.4015    -0.40266E-01             *
103   1.4619       1.4015     0.60367E-01             I*
104   1.3186       1.4015    -0.82948E-01            *I
105   1.7116       1.4015     0.31013                 I   *
106   1.2856       1.3961    -0.11041                *I
107   1.5094       1.3961     0.11334                 I*
108   1.2955       1.3961    -0.10061                *I
109   1.5771       1.3961     0.18106                 I *
110   1.1808       1.3825    -0.20168               * I
111   1.4859       1.3825     0.10343                 I*
112   1.1979       1.3825    -0.18463               * I
113   1.5306       1.3825     0.14812                 I *
114   1.0032       1.3611    -0.35795             *   I
115   1.4495       1.3611     0.88355E-01             I*
116   1.1086       1.3611    -0.25259              *  I
117   1.2372       1.3611    -0.12394                *I
118  0.87755       1.3324    -0.45483            *    I
119   1.3247       1.3324    -0.76990E-02             *
120   1.0896       1.3324    -0.24281              *  I
121   1.0882       1.3324    -0.24416              *  I
122   1.0170       1.2965    -0.27948              *  I
123   1.2140       1.2965    -0.82494E-01            *I
124   1.0156       1.2965    -0.28092              *  I
125  0.75612       1.2965    -0.54039           *     I
126  0.71540       1.2539    -0.53846           *     I
127   1.1069       1.2539    -0.14694               * I
128   1.0606       1.2539    -0.19329               * I
129  0.84286       1.2539    -0.41099             *   I
130  0.66783       1.2047    -0.53686           *     I
131   1.1820       1.2047    -0.22655E-01             *
132  0.98954       1.2047    -0.21515               * I
133  0.35977       1.2047    -0.84492        *        I
134  0.72465       1.1493    -0.42465             *   I
135  0.94701       1.1493    -0.20228               * I
136  0.98432       1.1493    -0.16497               * I
137  0.38662       1.1493    -0.76267         *       I
138  0.54407       1.0879    -0.54387           *     I
139  0.98694       1.0879    -0.10101                *I
140  0.89568       1.0879    -0.19226               * I
141  0.36880       1.0879    -0.71914          *      I
142  0.53298      0.48734     0.45633E-01             *
143  0.65233      0.48734     0.16498                 I *
144  0.57098      0.48734     0.83635E-01             I*
145  0.19310      0.48734    -0.29425              *  I
146  0.26773      0.33661    -0.68879E-01            *I
147  0.47250      0.33661     0.13589                 I*
148  0.62540      0.33661     0.28879                 I   *
149 -0.19183E-01  0.33661    -0.35580             *   I
150 -0.34591E-01  0.18578    -0.22037               * I
151  0.47250      0.18578     0.28672                 I   *
152  0.40613      0.18578     0.22035                 I *
```

APPENDIX E-8: Shazam Regression Results on Longline Data for Eqn (225)

```
153     -0.10093       0.18578      -0.28670            * I
154  0.76035E-01   0.63581E-01   0.12454E-01              *
155      0.29342   0.63581E-01       0.22984              I *
156      0.26467   0.63581E-01       0.20109              I *
157     -0.37980   0.63581E-01      -0.44338          *   I
158     -0.25360  -0.97385E-01      -0.15622            * I
159      0.42265  -0.97385E-01       0.52003              I   *
160      0.26467  -0.97385E-01       0.36205              I  *
161     -0.82326  -0.97385E-01      -0.72587        *     I
162     -0.56563      -0.35257      -0.21307            * I
163     -0.14156      -0.35257       0.21100              I *
164     -0.11429      -0.35257       0.23828              I *
165     -0.58879      -0.35257      -0.23622            * I
166     -0.50088      -0.62028       0.11940              I*
167     -0.37980      -0.62028       0.24048              I *
168     -0.42925      -0.62028       0.19103              I *
169      -1.1712      -0.62028      -0.55091         *    I
170     -0.87467      -0.99789       0.12322              I*
171     -0.99967      -0.99789  -0.17804E-02              *
172     -0.40797      -0.99789       0.58992              I    *
173      -1.7093      -0.99789      -0.71137        *     I
174      -1.5702       -1.1408      -0.42938          *   I
175      -1.2413       -1.1408      -0.10049             *I
176     -0.34531       -1.1408       0.79553              I     *
177      -1.4065       -1.1408      -0.26566           *  I
178      -1.2588       -1.3165   0.57754E-01              I*
179      -1.1520       -1.3165       0.16452              I *
180     -0.70118       -1.3165       0.61536              I    *
181      -2.1542       -1.3165      -0.83763      *       I
182      -1.7720       -1.7882   0.16224E-01              *
183      -2.0250       -1.7882      -0.23677            * I
184     -0.79186       -1.7882       0.99632              I       *
185      -2.5639       -1.7882      -0.77577       *      I
186      -1.8905       -1.4885      -0.40202           *  I
187      -1.0729       -1.4885       0.41551              I  *
188      -1.0385       -1.4885       0.44999              I   *
189      -1.9519       -1.4885      -0.46348          *   I
190      -2.0174       -1.9071      -0.11030             *I
191      -2.0250       -1.9071      -0.11785             *I
192      -1.3130       -1.9071       0.59406              I    *
193      -2.2730       -1.9071      -0.36592           *  I
194      -2.3539       -2.4327   0.78786E-01              I*
195      -2.9375       -2.4327      -0.50480          *   I
196      -1.4828       -2.4327       0.94986              I       *
197      -2.9565       -2.4327      -0.52385          *   I
198      -2.0174       -2.5965       0.57908              I    *
199      -2.2538       -2.5965       0.34270              I  *
200      -1.7720       -2.5965       0.82453              I      *
201      -4.3428       -2.5965       -1.7463  I           I
202      -2.2538       -2.9697       0.71595              I     *
203      -2.3126       -2.9697       0.65711              I     *
204      -4.3428       -2.9697       -1.3731   *          I
205      -3.2702       -3.2158  -0.54401E-01             *I
206      -2.9375       -3.2158       0.27831              I *
```

```
    207   -2.3126      -3.2158       0.90313                   I        *
    208   -4.3428      -3.2158      -1.1270        *           I
    209   -3.1701      -3.1701      0.11369E-12                *
    210   -3.9633      -3.5904     -0.37291                *   I
    211   -2.4651      -3.5904       1.1253                    I           *
    212   -4.3428      -3.5904     -0.75240            *       I
    213   -3.9633      -3.7295     -0.23381                  * I
    214   -3.6497      -3.7295      0.79850E-01                I*
    215   -3.5756      -3.7295      0.15396                    I *
    216   -3.2702      -3.1259     -0.14426                   *I
    217   -2.9375      -3.1259      0.18844                    I *
    218   -3.1701      -3.1259     -0.44180E-01                *
    219   -3.6497      -3.6497      0.17053E-12                *
    220   -2.9375      -3.2565      0.31904                    I  *
    221   -3.5756      -3.2565     -0.31904                 *  I
    222   -4.2687      -4.2687      0.17053E-12                *
    223   -4.2687      -4.2687      0.11369E-12                *
    224   -4.2687      -3.6287     -0.64004             *      I
    225   -3.5756      -4.3318      0.75622                    I       *
    226   -4.2687      -5.4219       1.1532                    I           *

DURBIN-WATSON = 2.2378    VON NEUMANN RATIO = 2.2478    RHO = -0.13828
RESIDUAL SUM =  0.30411E-10  RESIDUAL VARIANCE =  0.23329
SUM OF ABSOLUTE ERRORS=   72.706
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9344
RUNS TEST:  118 RUNS,  123 POSITIVE,  103 NEGATIVE, NORMAL STATISTIC =    0.6565
COEFFICIENT OF SKEWNESS =  -0.8506 WITH STANDARD DEVIATION OF 0.1619
COEFFICIENT OF EXCESS KURTOSIS =   2.5572 WITH STANDARD DEVIATION OF 0.3224

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 60 GROUPS
OBSERVED  4.0  1.0  0.0  1.0  0.0  0.0  1.0  0.0  0.0  0.0  0.0  0.0  2.0  1.0  3.0  2.0  1.0  0.0  5.0  3.0
          3.0  5.0  6.0  2.0  9.0 12.0  6.0 16.0 12.0  8.0 14.0 14.0 13.0 14.0 10.0 10.0  8.0  5.0  6.0  3.0
          7.0  1.0  5.0  3.0  1.0  2.0  1.0  1.0  1.0  1.0  1.0  0.0  0.0  2.0  0.0  0.0  0.0  0.0  0.0  0.0
EXPECTED  0.4  0.2  0.2  0.3  0.3  0.5  0.6  0.7  0.9  1.1  1.3  1.6  2.0  2.3  2.7  3.2  3.6  4.1  4.7  5.2
          5.7  6.3  6.8  7.3  7.7  8.2  8.5  8.7  8.9  9.0  9.0  8.9  8.7  8.5  8.2  7.7  7.3  6.8  6.3  5.7
          5.2  4.7  4.1  3.6  3.2  2.7  2.3  2.0  1.6  1.3  1.1  0.9  0.7  0.6  0.5  0.3  0.3  0.2  0.2  0.4
CHI-SQUARE =   95.2616 WITH 25 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =   84.5501 WITH  2 DEGREES OF FREEDOM
    STOP
```

APPENDIX E-9: Shazam Regression Results on Trap Data for Eqn (225)

```
UNIT  6 IS NOW ASSIGNED TO: OP.DAT
       SAMPLE 1 265
       READ    PL       PERCENT
  2 VARIABLES AND      265 OBSERVATIONS STARTING AT OBS       1

       GENR LPL=LOG(PL)
       GENR LPL2=LPL**2
       GENR LPER=LOG(PERCENT)
       GENR D41=(PL.EQ.41)
       GENR D42=(PL.EQ.42)
       GENR D43=(PL.EQ.43)
       GENR D44=(PL.EQ.44)
       GENR D45=(PL.EQ.45)
       GENR D46=(PL.EQ.46)
       GENR D47=(PL.EQ.47)
       GENR D48=(PL.EQ.48)
       GENR D49=(PL.EQ.49)
       GENR D50=(PL.EQ.50)
       GENR D51=(PL.EQ.51)
       GENR D52=(PL.EQ.52)
       GENR D53=(PL.EQ.53)
       GENR D54=(PL.EQ.54)
       GENR D55=(PL.EQ.55)
       GENR D56=(PL.EQ.56)
       GENR D57=(PL.EQ.57)
       GENR D58=(PL.EQ.58)
       GENR D59=(PL.EQ.59)
       GENR D60=(PL.EQ.60)
       GENR D61=(PL.EQ.61)
       GENR D62=(PL.EQ.62)
       GENR D63=(PL.EQ.63)
       GENR D64=(PL.EQ.64)
       GENR D65=(PL.EQ.65)
       GENR D66=(PL.EQ.66)
       GENR D67=(PL.EQ.67)
       GENR D68=(PL.EQ.68)
       GENR D69=(PL.EQ.69)
       GENR D70=(PL.EQ.70)
       GENR D71=(PL.EQ.71)
       GENR D72=(PL.EQ.72)
       GENR D73=(PL.EQ.73)
       GENR D74=(PL.EQ.74)
       GENR D75=(PL.EQ.75)
       GENR D76=(PL.EQ.76)
       GENR D77=(PL.EQ.77)
       GENR D78=(PL.EQ.78)
       GENR D79=(PL.EQ.79)
       GENR D80=(PL.EQ.80)
       GENR D81=(PL.EQ.81)
       GENR D82=(PL.EQ.82)
       GENR D83=(PL.EQ.83)
       GENR D84=(PL.EQ.84)
       GENR D85=(PL.EQ.85)
       GENR D86=(PL.EQ.86)
```

APPENDIX E-9: Shazam Regression Results on Trap Data for Eqn (225)

```
          GENR D87=(FL.EQ.87)
          GENR D88=(FL.EQ.88)
          GENR D89=(FL.EQ.89)
          GENR D90=(FL.EQ.90)
          GENR D91=(FL.EQ.91)
          GENR D92=(FL.EQ.92)
          GENR D93=(FL.EQ.93)
          GENR D94=(FL.EQ.94)
          GENR D95=(FL.EQ.95)
          GENR D96=(FL.EQ.96)
          GENR D97=(FL.EQ.97)
          GENR D99=(FL.EQ.99)
          GENR D100=(FL.EQ.100)

 ¦ OLS LPER LFL LFL2 &
 ¦                (D41 D42 D43 D44 D45 D46 D47 D48 D49 D50 &
 ¦                 D51 D52 D53 D54 D55 D56  D57  D58  D59 &
 ¦                 D61 D62 D67 &
 ¦                 D73 D77 D79 &
 ¦                 D82 D83 D85 D87 D88 D89 D90 D91 D92 D93 D94 &
 ¦                 D95 D96 D97 D99 D100 &
 ¦                 /LIST LM

 REQUIRED MEMORY IS PAR=  144 CURRENT PAR=  240
 FOR MAXIMUM EFFICIENCY USE AT LEAST PAR=   237
 OLS ESTIMATION
     265 OBSERVATIONS     DEPENDENT VARIABLE = LPER
 ...NOTE..SAMPLE RANGE SET TO:    1,  265

 **** STEPWISE REGRESSION ****
 ***PARAMETERS FOR STEPWISE REGRESSION:   PE=0.050000 AND  PX=0.050000.

 ----------------------------------------------------------------------
 ¦**** STEPPING SEQUENCE ****¦                ¦    ¦     ¦            ¦
 ¦      ¦        ¦           ¦                ¦    ¦     ¦            ¦
 ¦      ¦        ¦           ¦                ¦    ¦     ¦            ¦
 ¦ STEP ¦VARIABLE ¦          ¦                ¦D.F. ¦ D.F. ¦          ¦
 ¦NUMBER¦ LABEL   ¦ STATUS   ¦        F-VALUE ¦NUM. ¦ DEN. ¦F-PROBABILITY¦
 ¦--------------------------------------------------------------------¦
 ¦                                                                    ¦
 ¦    0 ¦LFL2     ¦FORCED IN ¦       18.0215 ¦   1 ¦   263¦    0.000030¦
 ¦    0 ¦LFL      ¦FORCED IN ¦     2688.4885 ¦   1 ¦   262¦    0.000000¦
 ¦    1 ¦D89      ¦STEPPED IN¦       20.5603 ¦   1 ¦   261¦    0.000009¦
 ¦    2 ¦D87      ¦STEPPED IN¦       12.1791 ¦   1 ¦   260¦    0.000568¦
 ¦    3 ¦D91      ¦STEPPED IN¦       10.8264 ¦   1 ¦   259¦    0.001141¦
 ¦    4 ¦D43      ¦STEPPED IN¦       10.6629 ¦   1 ¦   258¦    0.001242¦
 ¦    5 ¦D100     ¦STEPPED IN¦        9.4161 ¦   1 ¦   257¦    0.002383¦
 ¦    6 ¦D99      ¦STEPPED IN¦        6.9288 ¦   1 ¦   256¦    0.008999¦
 ¦    7 ¦D50      ¦STEPPED IN¦        5.2792 ¦   1 ¦   255¦    0.022394¦
 ¦    8 ¦D85      ¦STEPPED IN¦        4.4631 ¦   1 ¦   254¦    0.035613¦
 ¦    9 ¦D52      ¦STEPPED IN¦        4.1793 ¦   1 ¦   253¦    0.041958¦
 ¦   10 ¦D93      ¦STEPPED IN¦        4.2598 ¦   1 ¦   252¦    0.040050¦
 ¦   11 ¦D53      ¦STEPPED IN¦        3.9141 ¦   1 ¦   251¦    0.048979¦
 ¦*SUMMARY FOR POTENTIAL VARIABLES NOT ENTERED INTO THE REG. EQUATION*¦
 ¦      ¦D41      ¦IF ENTERED¦        0.1820 ¦   1 ¦   250¦    0.670039¦
 ¦      ¦D42      ¦IF ENTERED¦        0.6100 ¦   1 ¦   250¦    0.435527¦
```

```
 |        |D44       |IF ENTERED|     1.3843 |  1 |  250|     0.240495|
 |        |D45       |IF ENTERED|     0.9165 |  1 |  250|     0.339333|
 |        |D46       |IF ENTERED|     1.9955 |  1 |  250|     0.159016|
 |        |D47       |IF ENTERED|     0.3922 |  1 |  250|     0.531733|
 |        |D48       |IF ENTERED|     2.7960 |  1 |  250|     0.095751|
 |        |D49       |IF ENTERED|     0.0656 |  1 |  250|     0.798106|
 |        |D51       |IF ENTERED|     3.0060 |  1 |  250|     0.084194|
 |        |D54       |IF ENTERED|     2.1963 |  1 |  250|     0.139606|
 |        |D55       |IF ENTERED|     1.1198 |  1 |  250|     0.290979|
 |        |D56       |IF ENTERED|     0.0925 |  1 |  250|     0.761278|
 |        |D57       |IF ENTERED|     0.0928 |  1 |  250|     0.760880|
 |        |D58       |IF ENTERED|     0.2181 |  1 |  250|     0.640888|
 |        |D59       |IF ENTERED|     0.7853 |  1 |  250|     0.376368|
 |        |D61       |IF ENTERED|     1.5777 |  1 |  250|     0.210269|
 |        |D62       |IF ENTERED|     0.3024 |  1 |  250|     0.582843|
 |        |D67       |IF ENTERED|     0.1316 |  1 |  250|     0.717090|
 |        |D73       |IF ENTERED|     0.2382 |  1 |  250|     0.625923|
 |        |D77       |IF ENTERED|     0.6384 |  1 |  250|     0.425036|
 |        |D79       |IF ENTERED|     0.9554 |  1 |  250|     0.329306|
 |        |D82       |IF ENTERED|     0.6251 |  1 |  250|     0.429893|
 |        |D83       |IF ENTERED|     0.3004 |  1 |  250|     0.584102|
 |        |D88       |IF ENTERED|     1.0726 |  1 |  250|     0.301354|
 |        |D90       |IF ENTERED|     2.2347 |  1 |  250|     0.136207|
 |        |D92       |IF ENTERED|     0.5112 |  1 |  250|     0.475266|
 |        |D94       |IF ENTERED|     0.1307 |  1 |  250|     0.718026|
 |        |D95       |IF ENTERED|     0.4806 |  1 |  250|     0.488787|
 |        |D96       |IF ENTERED|     0.0390 |  1 |  250|     0.843618|
 |        |D97       |IF ENTERED|     1.4637 |  1 |  250|     0.227482|
 |**** END OF STEPPING SEQUENCE ****       |    |     |             |
 ------------------------------------------------------------------------


  R-SQUARE =    0.9416      R-SQUARE ADJUSTED =    0.9385
 VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.15108
 STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.38869
 SUM OF SQUARED ERRORS-SSE=   37.920
 MEAN OF DEPENDENT VARIABLE = -0.12842
 LOG OF THE LIKELIHOOD FUNCTION = -118.407

 MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
  AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.15906
    (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
  AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -1.8386
  SCHWARZ(1978) CRITERION-LOG SC =  -1.6495
 MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
  CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.15950
  HANNAN AND QUINN(1979) CRITERION -HQ=  0.17160
  RICE (1984) CRITERION-RICE=  0.16088
  SHIBATA (1981) CRITERION-SHIBATA=  0.15822
  SCHWARTZ (1978) CRITERION-SC=  0.19215
  AKAIKE (1974)INFORMATION CRITERION-AIC=  0.15904

                       ANALYSIS OF VARIANCE - FROM MEAN
                       SS           DF          MS                  F
 REGRESSION          611.07         13.       47.006              311.136
```

```
ERROR              37.920        251.       0.15108
TOTAL              648.99        264.        2.4583

                     ANALYSIS OF VARIANCE - FROM ZERO
                       SS         DF             MS                  F
REGRESSION         615.44         14.        43.960             290.978
ERROR              37.920        251.       0.15108
TOTAL              653.36        265.        2.4655


VARIABLE    ESTIMATED   STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
  NAME     COEFFICIENT    ERROR     251 DF      CORR. COEFFICIENT  AT MEANS

LPL         217.71      4.3114       50.497     0.9541  33.078         -7100.4
LPL2       -26.329     0.52011      -50.622    -0.9544 -33.277          3608.0
D43       -0.57063     0.18930      -3.0145    -0.1869 -0.49612E-01  0.83840E-01
D50        0.46073     0.17864       2.5791     0.1607  0.40056E-01 -0.67692E-01
D52        0.39156     0.17800       2.1998     0.1375  0.34043E-01 -0.57529E-01
D53        0.35186     0.17785       1.9784     0.1239  0.30591E-01 -0.51697E-01
D85       -0.42208     0.17970      -2.3488    -0.1466 -0.36696E-01  0.62014E-01
D87       -0.75382     0.18121      -4.1599    -0.2540 -0.65538E-01  0.11075
D89        -1.0398     0.18312      -5.6783    -0.3374 -0.90403E-01  0.15277
D91       -0.75432     0.20481      -3.6830    -0.2264 -0.58771E-01  0.88662E-01
D93       -0.44037     0.20733      -2.1240    -0.1329 -0.34311E-01  0.51761E-01
D99        0.94152     0.40075       2.3494     0.1467  0.36888E-01 -0.27667E-01
D100        1.1880     0.40188       2.9561     0.1834  0.46545E-01 -0.34909E-01
CONSTANT   -448.58      8.9157      -50.314    -0.9538  0.00000E+00   3493.1

    OBS.  OBSERVED     PREDICTED   CALCULATED
     NO.    VALUE        VALUE      RESIDUAL
       1   -2.6736      -3.1876      0.51396                    I      *
       2   -3.5756      -3.1876     -0.38794               *    I
       3   -3.5756      -3.1876     -0.38794               *    I
       4   -2.0636      -2.6688      0.60528                    I       *
       5   -2.6736      -2.6688     -0.48008E-02                *
       6   -2.4889      -2.6688      0.17993                    I *
       7   -2.9004      -2.6688     -0.23157                 *  I
       8   -1.5559      -2.7624      1.2065                     I             I
       9   -3.3814      -2.7624     -0.61896            *       I
      10   -2.1982      -2.7624      0.56421                    I      *
      11   -3.5756      -2.7624     -0.81312          *         I
      12   -3.1011      -2.7624     -0.33866                *   I
      13  -0.86038      -1.7539      0.89349                    I           *
      14   -2.6736      -1.7539     -0.91978        *           I
      15   -1.2801      -1.7539      0.47374                    I     *
      16   -1.7958      -1.7539     -0.41894E-01               *I
      17   -3.1011      -1.7539      -1.3472     I              I
      18  -0.86038      -1.3527      0.49231                    I     *
      19   -1.7603      -1.3527     -0.40757               *    I
      20  -0.94161      -1.3527      0.41108                    I    *
      21  -0.87948      -1.3527      0.47321                    I     *
      22   -3.1011      -1.3527      -1.7484     I              I
      23   -1.5559     -0.98605     -0.56985             *      I
      24   -1.5750     -0.98605     -0.58899            *       I
```

```
25  -0.53785     -0.98605      0.44819                    I     *
26  -0.69716     -0.98605      0.28889                    I   *
27   -1.7260     -0.98605     -0.73992          *         I
28  -0.96758     -0.65191     -0.31567                *   I
29  -0.65971     -0.65191     -0.77975E-02                *
30   0.15615     -0.65191      0.80806                    I         *
31   0.49742E-01 -0.65191      0.70166                    I        *
32   -1.3168     -0.65191     -0.66485           *        I
33  -0.59966     -0.34841     -0.25125                 *  I
34  -0.71496E-01 -0.34841      0.27691                    I   *
35   0.78800     -0.34841       1.1364                    I             I
36   0.34359     -0.34841      0.69200                    I        *
37  -0.80744     -0.34841     -0.45903              *     I
38  -0.32989     -0.73783E-01 -0.25611                 *  I
39  -0.72774     -0.73783E-01 -0.65396            *       I
40   0.86120     -0.73783E-01  0.93498                    I           *
41   0.52295     -0.73783E-01  0.59673                    I       *
42  -0.91130     -0.73783E-01 -0.83752         *          I
43   0.13191      0.63431     -0.50240              *     I
44   0.80737      0.63431      0.17306                    I *
45    1.3953      0.63431      0.76095                    I         *
46    1.0564      0.63431      0.42209                    I    *
47  -0.21940      0.63431     -0.85371         *          I
48   0.20376      0.39519     -0.19143                  * I
49   0.85271      0.39519      0.45753                    I     *
50    1.1719      0.39519      0.77668                    I         *
51   0.98694      0.39519      0.59175                    I       *
52   0.22234      0.39519     -0.17284                  * I
53   0.82505      0.98399     -0.15894                  * I
54   0.95050      0.98399     -0.33493E-01                *
55    1.4873      0.98399      0.50328                    I     *
56    1.2404      0.98399      0.25641                    I  *
57   0.41673      0.98399     -0.56726             *      I
58   0.86162       1.1185     -0.25687                 *  I
59    1.4289       1.1185      0.31038                    I   *
60    1.3089       1.1185      0.19038                    I *
61    1.3888       1.1185      0.27030                    I  *
62   0.60432       1.1185     -0.51418             *      I
63   0.91389      0.91901     -0.51217E-02                *
64    1.4693      0.91901      0.55025                    I      *
65    1.5484      0.91901      0.62940                    I       *
66    1.3392      0.91901      0.42019                    I    *
67   0.57942      0.91901     -0.33959                *   I
68    1.0989       1.0507      0.48256E-01                I*
69    1.3780       1.0507      0.32732                    I   *
70    1.3013       1.0507      0.25059                    I  *
71    1.4226       1.0507      0.37194                    I    *
72   0.95089       1.0507     -0.99805E-01               *I
73   0.99510       1.1627     -0.16764                  * I
74    1.2579       1.1627      0.95148E-01                I*
75    1.2387       1.1627      0.75920E-01                I*
76    1.1656       1.1627      0.29033E-02                *
77   0.89772       1.1627     -0.26503                 *  I
78    1.1930       1.2562     -0.63157E-01               *I
```

```
  79   1.3151    1.2562    0.58896E-01         I*
  80   1.3384    1.2562    0.82246E-01         I*
  81   1.2244    1.2562   -0.31807E-01         *
  82  0.95089    1.2562   -0.30528         *   I
  83   1.5456    1.3319    0.21374             I  *
  84   1.2078    1.3319   -0.12414             * I
  85   1.3013    1.3319   -0.30622E-01         *
  86   1.1125    1.3319   -0.21939          *  I
  87   1.0953    1.3319   -0.23663          *  I
  88   1.4514    1.3908    0.60560E-01         I*
  89   1.2482    1.3908   -0.14264           * I
  90   1.2782    1.3908   -0.11267            *I
  91   1.0849    1.3908   -0.30597         *   I
  92   1.1391    1.3908   -0.25170          *  I
  93   1.4612    1.4337    0.27427E-01         *
  94   1.3691    1.4337   -0.64595E-01        *I
  95   1.3813    1.4337   -0.52461E-01        *I
  96   1.3818    1.4337   -0.51959E-01        *I
  97   1.5911    1.4337    0.15733             I *
  98   1.3795    1.4614   -0.81928E-01        *I
  99   1.0640    1.4614   -0.39743        *    I
 100   1.2387    1.4614   -0.22279          *  I
 101  0.99695    1.4614   -0.46450       *     I
 102   1.5634    1.4614    0.10194             I*
 103   1.4902    1.4747    0.15536E-01         *
 104   1.3865    1.4747   -0.88123E-01        *I
 105   1.2782    1.4747   -0.19652          *  I
 106   1.2161    1.4747   -0.25857          *  I
 107   1.5349    1.4747    0.60262E-01         I*
 108   1.5276    1.4741    0.53494E-01         I*
 109   1.4533    1.4741   -0.20832E-01         *
 110   1.3013    1.4741   -0.17280           * I
 111   1.3538    1.4741   -0.12031           * I
 112   1.7502    1.4741    0.27616             I   *
 113   1.7038    1.4603    0.24349             I  *
 114   1.3151    1.4603   -0.14528           * I
 115   1.4619    1.4603    0.15216E-02         *
 116   1.2404    1.4603   -0.21994          *  I
 117   1.6440    1.4603    0.18369             I *
 118   1.2906    1.4341   -0.14345           * I
 119   1.3865    1.4341   -0.47516E-01        *I
 120   1.4224    1.4341   -0.11675E-01         *
 121   1.4619    1.4341    0.27806E-01         *
 122   1.5539    1.4341    0.11987             I *
 123   1.2182    1.3958   -0.17764           * I
 124   1.5234    1.3958    0.12764             I *
 125   1.3953    1.3958   -0.55374E-03         *
 126   1.4161    1.3958    0.26288E-01         *
 127   1.4754    1.3958    0.79641E-01         I*
 128   1.1404    1.3461   -0.20574          *  I
 129   1.3865    1.3461    0.40412E-01         I*
 130   1.1099    1.3461   -0.23625          *  I
 131   1.2404    1.3461   -0.10573            *I
 132   1.5444    1.3461    0.19823             I  *
```

```
 133   1.2430        1.2855      -0.42546E-01           *I
 134   1.3780        1.2855       0.92463E-01           I*
 135   1.2627        1.2855      -0.22834E-01           *
 136   1.1656        1.2855      -0.11990              * I
 137   1.3679        1.2855       0.82328E-01           I*
 138   1.3135        1.2145       0.98913E-01           I*
 139   1.1439        1.2145      -0.70637E-01           *I
 140   0.98283       1.2145      -0.23171             *  I
 141   1.1912        1.2145      -0.23350E-01           *
 142   1.4231        1.2145       0.20857               I  *
 143   1.3135        1.1336       0.17988               I *
 144   1.2282        1.1336       0.94602E-01           I*
 145   1.0723        1.1336      -0.61307E-01           *I
 146   1.2947        1.1336       0.16115               I *
 147   1.5252        1.1336       0.39161               I    *
 148   1.0702        1.0431       0.27126E-01           *
 149   1.1217        1.0431       0.78591E-01           I*
 150   0.78800       1.0431      -0.25508             *  I
 151   0.88954       1.0431      -0.15355              * I
 152   1.2972        1.0431       0.25410               I  *
 153   1.3900        0.94349      0.44655               I     *
 154   1.0876        0.94349      0.14406               I *
 155   0.47872       0.94349     -0.46477          *     I
 156   1.0170        0.94349      0.73551E-01           I*
 157   1.0801        0.94349      0.13662               I *
 158   1.0849        0.83518      0.24967               I  *
 159   0.98991       0.83518      0.15473               I *
 160   0.63816       0.83518     -0.19702             *  I
 161   0.83073       0.83518     -0.44455E-02           *
 162   1.0494        0.83518      0.21424               I  *
 163   1.0105        0.71853      0.29198               I   *
 164   0.77611       0.71853      0.57583E-01           I*
 165   0.69515       0.71853     -0.23380E-01           *
 166   0.45489       0.71853     -0.26364             *  I
 167   0.76174       0.71853      0.43215E-01           I*
 168   0.86162       0.59389      0.26774               I  *
 169   0.71050       0.59389      0.11661               I *
 170   0.20294       0.59389     -0.39095           *    I
 171   0.67447       0.59389      0.80588E-01           I*
 172   0.71930       0.59389      0.12542               I *
 173   0.74811       0.46160      0.28651               I   *
 174   0.41739       0.46160     -0.44204E-01           *I
 175   0.56380E-01   0.46160     -0.40522           *    I
 176   0.58667       0.46160      0.12508               I *
 177   0.55389       0.46160      0.92288E-01           I*
 178   0.42003       0.32198      0.98045E-01           I*
 179   0.41739       0.32198      0.95414E-01           I*
 180   0.17982       0.32198     -0.14216              * I
 181   0.47250       0.32198      0.15052               I *
 182   0.80245       0.32198      0.48047               I     *
 183   0.36256       0.17534      0.18722               I *
 184  -0.10870       0.17534     -0.28404            *   I
 185  -0.26344E-01   0.17534     -0.20168             *  I
 186   0.30380       0.17534      0.12846               I *
```

APPENDIX E-9: Shazam Regression Results on Trap Data for Eqn (225)

```
187   0.41673      0.17534       0.24139                      I  *
188  -0.21940      0.21967E-01  -0.24137                   *  I
189  -0.23193      0.21967E-01  -0.25390                   *  I
190  -0.40347      0.21967E-01  -0.42543                 *    I
191   0.15014      0.21967E-01   0.12818                      I *
192  -0.18164E-01  0.21967E-01  -0.40131E-01                 *I
193  -0.11878     -0.13786       0.19078E-01                  *
194  -0.37106     -0.13786      -0.23320                   *  I
195  -0.74866     -0.13786      -0.61080              *       I
196   0.49742E-01 -0.13786       0.18760                      I *
197   0.25774     -0.13786       0.39560                      I    *
198  -0.28399E-01 -0.30388       0.27548                      I   *
199  -0.10870     -0.30388       0.19518                      I  *
200   -1.0966     -0.30388      -0.79273            *         I
201  -0.36962     -0.30388      -0.65733E-01                 *I
202  -0.16487     -0.30388       0.13901                      I *
203  -0.39156     -0.47584       0.84280E-01                  I*
204  -0.88189     -0.47584      -0.40605                 *    I
205  -0.94161     -0.47584      -0.46577                *     I
206  -0.49758     -0.47584      -0.21738E-01                  *
207  -0.33687     -0.47584       0.13897                      I *
208  -0.96758     -0.65350      -0.31408                  *   I
209  -0.80296     -0.65350      -0.14946                    * I
210   -1.0161     -0.65350      -0.36261                 *    I
211  -0.87948     -0.65350      -0.22597                   *  I
212  -0.65072E-01 -0.65350       0.58843                      I       *
213  -0.67924     -0.83663       0.15739                      I *
214  -0.80296     -0.83663       0.33672E-01                  *
215   -1.2801     -0.83663      -0.44350                *     I
216  -0.64436     -0.83663       0.19228                      I *
217   -1.1648     -0.83663      -0.32812                  *   I
218   -1.3704      -1.4471       0.76674E-01                  I*
219   -1.2874      -1.4471       0.15974                      I *
220   -1.7898      -1.4471      -0.34267                  *   I
221   -1.9805      -1.4471      -0.53341               *      I
222  -0.80744      -1.4471       0.63966                      I       *
223   -1.5559      -1.2184      -0.33745                  *   I
224   -1.2874      -1.2184      -0.68912E-01                 *I
225   -1.1026      -1.2184       0.11582                      I*
226   -1.0300      -1.2184       0.18842                      I *
227   -1.7779      -2.1705       0.39267                      I    *
228   -1.5750      -2.1705       0.59549                      I       *
229   -2.8824      -2.1705      -0.71188             *        I
230   -2.1982      -2.1705      -0.27697E-01                  *
231   -2.4191      -2.1705      -0.24859                   *  I
232   -2.0636      -1.6196      -0.44394                *     I
233   -1.5750      -1.6196       0.44595E-01                  I*
234   -2.1982      -1.6196      -0.57859               *      I
235   -1.3903      -1.6196       0.22933                      I  *
236   -1.7260      -1.6196      -0.10634                     *I
237   -3.1701      -2.8668      -0.30325                  *   I
238   -2.6736      -2.8668       0.19318                      I *
239   -2.4889      -2.8668       0.37792                      I    *
240   -2.9004      -2.8668      -0.33589E-01                  *
```

```
      241  -3.1011     -2.8668     -0.23426              *  I
      242  -2.0636     -2.0387     -0.24864E-01             *
      243  -1.9805     -2.0387      0.58203E-01             I*
      244  -1.5096     -2.0387      0.52911                 I      *
      245  -1.5006     -2.0387      0.53812                 I      *
      246  -2.4651     -3.0088      0.54373                 I      *
      247  -3.5756     -3.0088     -0.56672            *      I
      248  -3.5756     -3.0088     -0.56672            *      I
      249  -2.4191     -3.0088      0.58971                 I       *
      250  -2.4651     -2.4743      0.91851E-02             *
      251  -2.4889     -2.4743     -0.14626E-01             *
      252  -2.0099     -2.4743      0.46437                 I     *
      253  -3.1701     -3.1382     -0.31837E-01             *
      254  -3.3814     -3.1382     -0.24315              *  I
      255  -2.9004     -3.1382      0.23783                 I  *
      256  -3.1011     -3.1382      0.37156E-01             *
      257  -3.1701     -2.9251     -0.24496              *  I
      258  -2.4889     -2.9251      0.43621                 I     *
      259  -3.5756     -3.1559     -0.41965              *    I
      260  -3.1011     -3.1559      0.54812E-01             I*
      261  -3.5756     -3.3901     -0.18548               * I
      262  -3.1011     -3.3901      0.28897                 I   *
      263  -3.1701     -3.6275      0.45740                 I     *
      264  -3.1701     -3.1701      0.56843E-12             *
      265  -3.1701     -3.1701      0.56843E-12             *

 DURBIN-WATSON = 2.0409    VON NEUMANN RATIO = 2.0486    RHO = -0.02392
 RESIDUAL SUM =  0.16439E-09  RESIDUAL VARIANCE =  0.15108
 SUM OF ABSOLUTE ERRORS=   74.167
 R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9416
 RUNS TEST:  133 RUNS,  135 POSITIVE,  130 NEGATIVE, NORMAL STATISTIC =   -0.0558
 COEFFICIENT OF SKEWNESS =  -0.3085 WITH STANDARD DEVIATION OF 0.1496
 COEFFICIENT OF EXCESS KURTOSIS =   2.0863 WITH STANDARD DEVIATION OF 0.2982

     GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 20 GROUPS
 OBSERVED  2.0  0.0  3.0  4.0  5.0  9.0 15.0 28.0 26.0 38.0 42.0 33.0 18.0 14.0 11.0  9.0  4.0  1.0  1.0  2.0

 EXPECTED  0.9  1.2  2.6  4.8  8.2 12.8 18.3 23.9 28.6 31.2 31.2 28.6 23.9 18.3 12.8  8.2  4.8  2.6  1.2  0.9

 CHI-SQUARE =   17.5943 WITH  4 DEGREES OF FREEDOM

 JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
 CHI-SQUARE =   49.4157 WITH  2 DEGREES OF FREEDOM
          STOP
```

APPENDIX E-10: Shazam Regression Results on Longline (Male) Data,
Using Eqn (225)

```
    UNIT  6 IS NOW ASSIGNED TO: OP.DAT
                SAMPLE 1 163
                READ    PL      PERCENT
       2 VARIABLES AND      163 OBSERVATIONS STARTING AT OBS       1

                GENR LPL=LOG(PL)
                GENR LPL2=LPL**2
                GENR LPER=LOG(PERCENT)
                GENR D40=(PL.EQ.40)
                GENR D41=(PL.EQ.41)
                GENR D42=(PL.EQ.42)
                GENR D43=(PL.EQ.43)
                GENR D44=(PL.EQ.44)
                GENR D45=(PL.EQ.45)
                GENR D46=(PL.EQ.46)
                GENR D47=(PL.EQ.47)
                GENR D48=(PL.EQ.48)
                GENR D49=(PL.EQ.49)
                GENR D50=(PL.EQ.50)
                GENR D51=(PL.EQ.51)
                GENR D52=(PL.EQ.52)
                GENR D53=(PL.EQ.53)
                GENR D54=(PL.EQ.54)
                GENR D55=(PL.EQ.55)
                GENR D56=(PL.EQ.56)
                GENR D57=(PL.EQ.57)
                GENR D58=(PL.EQ.58)
                GENR D59=(PL.EQ.59)
                GENR D60=(PL.EQ.60)
                GENR D61=(PL.EQ.61)
                GENR D62=(PL.EQ.62)
                GENR D63=(PL.EQ.63)
                GENR D64=(PL.EQ.64)
                GENR D65=(PL.EQ.65)
                GENR D66=(PL.EQ.66)
                GENR D67=(PL.EQ.67)
                GENR D68=(PL.EQ.68)
                GENR D69=(PL.EQ.69)
                GENR D70=(PL.EQ.70)
                GENR D71=(PL.EQ.71)
                GENR D72=(PL.EQ.72)
                GENR D73=(PL.EQ.73)
                GENR D74=(PL.EQ.74)
                GENR D75=(PL.EQ.75)
                GENR D76=(PL.EQ.76)
                GENR D77=(PL.EQ.77)
                GENR D78=(PL.EQ.78)
                GENR D79=(PL.EQ.79)
                GENR D80=(PL.EQ.80)
                GENR D81=(PL.EQ.81)
                GENR D83=(PL.EQ.83)
                GENR D84=(PL.EQ.84)
                GENR D85=(PL.EQ.85)
```

APPENDIX E-10: Shazam Regression Results on Longline (Male) Data,
Using Eqn (225)

```
               GENR D87=(FL.EQ.87)

      OLS LPER LPL LPL2 &
   |              (D40  D41  D42  D43  D44  D45  D46  D47  D48  D49 &
   |               D50  D51  D52  D53  D54  D55  D56  D57  D58  D59 &
   |               D60  D61  D62  D63  D64  D65  D66  D67  D68  D69 &
   |                 D70  D71  D72  D73  D74  D75  D76  D77  D78  D79 &
   |               D80  D81  D83  D84  D85  D87 &
   |                 ) /LIST LM BEG=1

  REQUIRED MEMORY IS PAR=   78 CURRENT PAR=  238
  FOR MAXIMUM EFFICIENCY USE AT LEAST PAR=   142
  OLS ESTIMATION
      163 OBSERVATIONS     DEPENDENT VARIABLE = LPER
  ...NOTE..SAMPLE RANGE SET TO:     1,   163

  **** STEPWISE REGRESSION ****
  ***PARAMETERS FOR STEPWISE REGRESSION:   PE=0.050000 AND  PX=0.050000.


  -----------------------------------------------------------------------
  |**** STEPPING SEQUENCE ****|                 |      |      |           |
  |      |        |           |                 |      |      |           |
  |      |        |           |                 |      |      |           |
  | STEP |VARIABLE |          |                 |D.F.  | D.F. |           |
  |NUMBER| LABEL   | STATUS   |         F-VALUE |NUM.  | DEN. |F-PROBABILITY|
  |-----------------------------------------------------------------------|
  |                                                                       |
  |    0 |LPL2     |FORCED IN |          4.3609 |    1 |  161|    0.038355|
  |    0 |LPL      |FORCED IN |       1191.8888 |    1 |  160|    0.000000|
  |    1 |D87      |STEPPED IN|         10.5974 |    1 |  159|    0.001387|
  |    2 |D85      |STEPPED IN|         12.0432 |    1 |  158|    0.000672|
  |    3 |D84      |STEPPED IN|          9.5046 |    1 |  157|    0.002425|
  |    4 |D40      |STEPPED IN|          5.7325 |    1 |  156|    0.017848|
  |    5 |D54      |STEPPED IN|          6.0306 |    1 |  155|    0.015172|
  |    6 |D51      |STEPPED IN|          6.1543 |    1 |  154|    0.014192|
  |    7 |D52      |STEPPED IN|          6.7299 |    1 |  153|    0.010409|
  |    8 |D50      |STEPPED IN|          7.8094 |    1 |  152|    0.005873|
  |    9 |D53      |STEPPED IN|          6.8788 |    1 |  151|    0.009623|
  |   10 |D55      |STEPPED IN|          6.2610 |    1 |  150|    0.013423|
  |   11 |D56      |STEPPED IN|          6.7513 |    1 |  149|    0.010316|
  |   12 |D83      |STEPPED IN|          6.9730 |    1 |  148|    0.009169|
  |   13 |D49      |STEPPED IN|          7.6306 |    1 |  147|    0.006478|
  |   14 |D57      |STEPPED IN|          6.7611 |    1 |  146|    0.010282|
  |   15 |D81      |STEPPED IN|          6.1993 |    1 |  145|    0.013917|
  |   16 |D48      |STEPPED IN|          6.5334 |    1 |  144|    0.011631|
  |   17 |D58      |STEPPED IN|          6.6574 |    1 |  143|    0.010890|
  |   18 |D59      |STEPPED IN|          4.1170 |    1 |  142|    0.044331|
  |*SUMMARY FOR POTENTIAL VARIABLES NOT ENTERED INTO THE REG. EQUATION*|
  |      |D41      |IF ENTERED|          2.4132 |    1 |  141|    0.122564|
  |      |D42      |IF ENTERED|          3.3421 |    1 |  141|    0.069651|
  |      |D43      |IF ENTERED|          0.2046 |    1 |  141|    0.651714|
  |      |D44      |IF ENTERED|          0.0405 |    1 |  141|    0.840812|
  |      |D45      |IF ENTERED|          0.9406 |    1 |  141|    0.333778|
  |      |D46      |IF ENTERED|          1.1457 |    1 |  141|    0.286292|
  |      |D47      |IF ENTERED|          2.2923 |    1 |  141|    0.132258|
```

APPENDIX E-10: Shazam Regression Results on Longline (Male) Data,
Using Eqn (225)

```
¦       ¦D60     ¦IF ENTERED¦     2.7733 ¦  1 ¦   141¦     0.098076¦
¦       ¦D61     ¦IF ENTERED¦     0.3803 ¦  1 ¦   141¦     0.538428¦
¦       ¦D62     ¦IF ENTERED¦     0.0017 ¦  1 ¦   141¦     0.967061¦
¦       ¦D63     ¦IF ENTERED¦     0.1462 ¦  1 ¦   141¦     0.702727¦
¦       ¦D64     ¦IF ENTERED¦     0.5700 ¦  1 ¦   141¦     0.451539¦
¦       ¦D65     ¦IF ENTERED¦     0.7827 ¦  1 ¦   141¦     0.377833¦
¦       ¦D66     ¦IF ENTERED¦     1.3556 ¦  1 ¦   141¦     0.246270¦
¦       ¦D67     ¦IF ENTERED¦     2.4476 ¦  1 ¦   141¦     0.119950¦
¦       ¦D68     ¦IF ENTERED¦     1.8479 ¦  1 ¦   141¦     0.176202¦
¦       ¦D69     ¦IF ENTERED¦     1.0193 ¦  1 ¦   141¦     0.314425¦
¦       ¦D70     ¦IF ENTERED¦     0.1294 ¦  1 ¦   141¦     0.719643¦
¦       ¦D71     ¦IF ENTERED¦     0.8868 ¦  1 ¦   141¦     0.347972¦
¦       ¦D72     ¦IF ENTERED¦     0.3842 ¦  1 ¦   141¦     0.536382¦
¦       ¦D73     ¦IF ENTERED¦     1.8480 ¦  1 ¦   141¦     0.176191¦
¦       ¦D74     ¦IF ENTERED¦     0.2746 ¦  1 ¦   141¦     0.601076¦
¦       ¦D75     ¦IF ENTERED¦     0.2273 ¦  1 ¦   141¦     0.634282¦
¦       ¦D76     ¦IF ENTERED¦     1.0891 ¦  1 ¦   141¦     0.298470¦
¦       ¦D77     ¦IF ENTERED¦     0.5803 ¦  1 ¦   141¦     0.447470¦
¦       ¦D78     ¦IF ENTERED¦     0.9512 ¦  1 ¦   141¦     0.331096¦
¦       ¦D79     ¦IF ENTERED¦     1.6942 ¦  1 ¦   141¦     0.195171¦
¦       ¦D80     ¦IF ENTERED¦     0.0087 ¦  1 ¦   141¦     0.925642¦
¦**** END OF STEPPING SEQUENCE ****     ¦    ¦      ¦             ¦
---------------------------------------------------------------------


 R-SQUARE =   0.9500     R-SQUARE ADJUSTED =   0.9430
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.17456
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.41780
SUM OF SQUARED ERRORS-SSE=   24.787
MEAN OF DEPENDENT VARIABLE = -0.55311E-01
LOG OF THE LIKELIHOOD FUNCTION = -77.7888

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.19705
   (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -1.6257
 SCHWARZ(1978) CRITERION-LOG SC =  -1.2272
MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.20037
 HANNAN AND QUINN(1979) CRITERION -HQ=  0.23133
 RICE (1984) CRITERION-RICE=  0.20485
 SHIBATA (1981) CRITERION-SHIBATA=  0.19125
 SCHWARTZ (1978) CRITERION-SC=  0.29312
 AKAIKE (1974)INFORMATION CRITERION-AIC=  0.19677

                    ANALYSIS OF VARIANCE - FROM MEAN
                    SS          DF           MS                 F
REGRESSION        471.17        20.        23.558             134.959
ERROR             24.787        142.      0.17456
TOTAL             495.95        162.       3.0614

                    ANALYSIS OF VARIANCE - FROM ZERO
                    SS          DF           MS                 F
REGRESSION        471.67        21.        22.460             128.668
```

APPENDIX 6-16: Shazam Regression Results on Longline (Male) Data,
Using Eqn (225)

```
 ERROR          24.787        142.       0.17456
 TOTAL          496.45        163.        3.0457


VARIABLE    ESTIMATED   STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
  NAME     COEFFICIENT    ERROR     142 DF     CORR.  COEFFICIENT  AT MEANS

LPL         422.24      10.166      41.534    0.9612   49.396       -31168.
LPL2       -52.259      1.2579     -41.543   -0.9612  -49.697        15789.
D40        0.95356     0.27394      3.4809    0.2804  0.73477E-01 -0.31730
D48       -0.65373     0.22087     -2.9706   -0.2419 -0.57984E-01  0.29004
D49       -0.85282     0.22045     -3.8686   -0.3088 -0.75643E-01  0.37837
D50        -1.1359     0.22098     -5.1401   -0.3961 -0.10075      0.50394
D51        -1.1788     0.22155     -5.3205   -0.4077 -0.10456      0.52299
D52        -1.1742     0.22210     -5.2869   -0.4055 -0.10415      0.52095
D53        -1.0820     0.22255     -4.8620   -0.3778 -0.95973E-01  0.48006
D54        -1.2464     0.22286     -5.5929   -0.4249 -0.11056      0.55301
D55        -1.0034     0.22302     -4.4991   -0.3532 -0.89000E-01  0.44518
D56       -0.96443     0.22301     -4.3246   -0.3411 -0.85543E-01  0.42789
D57       -0.78875     0.22283     -3.5397   -0.2848 -0.69960E-01  0.34994
D58       -0.62877     0.22248     -2.8262   -0.2308 -0.55771E-01  0.27897
D59       -0.45039     0.22197     -2.0290   -0.1679 -0.39949E-01  0.19982
D81         1.2588     0.43329      2.9053    0.2369  0.56353E-01 -0.13963
D83         1.2980     0.32511      3.9925    0.3177  0.81919E-01 -0.28794
D84         2.6757     0.44280      6.0428    0.4523  0.11978     -0.29679
D85         3.1666     0.44666      7.0895    0.5113  0.14176     -0.35123
D87         3.4808     0.45545      7.6426    0.5399  0.15582     -0.38608
CONSTANT   -850.51      20.483     -41.522   -0.9612  0.00000E+00   15377.

  OBS.  OBSERVED      PREDICTED   CALCULATED
   NO.    VALUE         VALUE      RESIDUAL
   1  -2.6882       -3.0920     0.40378                   I    *
   2  -2.9759       -3.0920     0.11610                   I*
   3  -3.6119       -3.0920     -0.51989            *     I
   4  -3.3814       -3.1716     -0.20988               *  I
   5  -2.2256       -3.1716     0.96597                   I          *
   6  -2.9188       -3.1716     0.25282                   I  *
   7  -1.7720       -2.3801     0.60814                   I      *
   8  -2.9759       -2.3801     -0.59583           *      I
   9  -1.2107       -2.3801     1.1694                     I             *
  10  -2.2256       -2.3801     0.15447                   I *
  11  -1.7720       -1.6658     -0.10616                 *I
  12  -1.5995       -1.6658     0.663108E-01              I*
  13  -1.6106       -1.6658     0.25521                   I  *
  14  -2.2256       -1.6658     -0.55983           *      I
  15  -0.98350      -1.0238     0.403108E-01              *
  16  -1.0385       -1.0238     -0.146495E-01             *
  17  -1.2107       -1.0238     -0.18685                * I
  18  -1.0189       -1.0238     0.493238E-02              *
  19  -0.60881      -0.44964    -0.15916                * I
  20  -0.954108E-01 -0.44964    0.35623                   I   *
  21  -0.83471      -0.44964    -0.38507             *    I
  22  -1.0189       -0.44964    -0.56924           *      I
```

APPENDIX B-10: Shazam Regression Results on Longline (Male) Data,
Using Eqn (225)

```
23 -0.20334      0.60849E-01 -0.26419                  *  I
24  0.19227      0.60849E-01  0.13142                     I *
25 -0.31197      0.60849E-01 -0.37282                 *   I
26 -0.27575      0.60849E-01 -0.33660                 *   I
27  0.25619      0.51149     -0.25530                  *  I
28  0.82110      0.51149      0.30961                     I   *
29  0.12927      0.51149     -0.38221                *    I
30 -0.34956      0.51149     -0.86104           *         I
31  0.44725      0.25208      0.19516                     I *
32  0.82110      0.25208      0.56902                     I      *
33  0.19885      0.25208     -0.53232E-01                *I
34 -0.45887      0.25208     -0.71095            *        I
35  0.30748      0.39428     -0.86798E-01                *I
36  0.92624      0.39428      0.53196                     I     *
37  0.48612      0.39428      0.91840E-01                 I*
38 -0.14272      0.39428     -0.53700               *     I
39  0.77749      0.40255      0.37494                     I    *
40  0.77565      0.40255      0.37310                     I   *
41  0.22074      0.40255     -0.18180                   * I
42 -0.16370      0.40255     -0.56624              *      I
43   1.0494      0.60373      0.44569                     I    *
44  0.38186      0.60373     -0.22188                  *  I
45  0.74858      0.60373      0.14485                     I *
46  0.23507      0.60373     -0.36866                 *   I
47   1.0131      0.80792      0.20514                     I *
48  0.79841      0.80792     -0.95095E-02                 *
49  0.86920      0.80792      0.61282E-01                 I*
50  0.55101      0.80792     -0.25691                  *  I
51   1.3100      1.0576       0.25237                     I  *
52  0.94624      1.0576      -0.11135                    *I
53   1.1278      1.0576       0.70263E-01                 I*
54  0.84630      1.0576      -0.21129                  *  I
55   1.4628      1.0108       0.45196                     I    *
56  0.94624      1.0108      -0.64598E-01                *I
57  0.95628      1.0108      -0.54556E-01                *I
58  0.67803      1.0108      -0.33280                 *   I
59   1.6022      1.3339       0.26833                     I  *
60   1.2337      1.3339      -0.10015                    *I
61   1.3890      1.3339       0.55161E-01                 I*
62   1.1105      1.3339      -0.22334                  *  I
63   1.7661      1.4172       0.34893                     I   *
64   1.1253      1.4172      -0.29192                 *   I
65   1.3615      1.4172      -0.55685E-01                *I
66   1.4159      1.4172      -0.13209E-02                 *
67   1.7603      1.6033       0.15692                     I *
68   1.4450      1.6033      -0.15831                   * I
69   1.7000      1.6033       0.96664E-01                 I*
70   1.5081      1.6033      -0.95276E-01                *I
71   1.9465      1.7417       0.20474                     I *
72   1.4209      1.7417      -0.32081                 *   I
73   1.8080      1.7417       0.66218E-01                 I*
74   1.7916      1.7417       0.49850E-01                 I*
75   1.8967      1.8681       0.28618E-01                 *
```

```
  76   1.7238       1.8681      -0.14426                * I
  77   1.9251       1.8681       0.57022E-01              I*
  78   1.9267       1.8681       0.58625E-01              I*
  79   1.9318       2.2376      -0.30576              *   I
  80   1.6965       2.2376      -0.54103            *     I
  81   1.9716       2.2376      -0.26599               *  I
  82   2.0549       2.2376      -0.18267                * I
  83   2.0391       2.1292      -0.90044E-01             *I
  84   1.8184       2.1292      -0.31078              *   I
  85   2.0753       2.1292      -0.53876E-01             *I
  86   2.0980       2.1292      -0.31166E-01              *
  87   1.9799       1.9947      -0.14803E-01              *
  88   1.8972       1.9947      -0.97530E-01             *I
  89   1.9448       1.9947      -0.49934E-01             *I
  90   2.1242       1.9947       0.12948                  I *
  91   1.6226       1.8354      -0.21284               *  I
  92   1.9771       1.8354       0.14174                  I *
  93   1.9092       1.8354       0.73854E-01              I*
  94   2.1371       1.8354       0.30173                  I   *
  95   1.5090       1.6525      -0.14351                * I
  96   1.8895       1.6525       0.23703                  I  *
  97   1.8168       1.6525       0.16431                  I *
  98   1.9978       1.6525       0.34536                  I   *
  99   1.5014       1.4471       0.54356E-01              I*
 100   1.6683       1.4471       0.22122                  I  *
 101   1.5098       1.4471       0.62787E-01              I*
 102   1.8184       1.4471       0.37135                  I   *
 103   1.2036       1.2202      -0.16649E-01              *
 104   1.6588       1.2202       0.43858                  I    *
 105   1.3334       1.2202       0.11320                  I*
 106   1.6214       1.2202       0.40114                  I    *
 107   1.0494       0.97299      0.76434E-01              I*
 108   1.5030       0.97299      0.52998                  I     *
 109   1.2039       0.97299      0.23089                  I  *
 110   1.3938       0.97299      0.42078                  I    *
 111   0.60759      0.70639     -0.98714E-01             *I
 112   1.3838       0.70630      0.67749                  I       *
 113   0.90260      0.70630      0.19629                  I *
 114   1.0300       0.70630      0.32367                  I   *
 115   0.33218      0.42107     -0.88894E-01             *I
 116   0.88542      0.42107      0.46435                  I     *
 117   0.73573      0.42107      0.31466                  I   *
 118   0.55101      0.42107      0.12994                  I *
 119  -0.29334      0.11815     -0.32149              *   I
 120   0.54058      0.11815      0.42243                  I    *
 121   0.28367      0.11815      0.16553                  I *
 122   0.14497      0.11815      0.26819E-01              *
 123  -0.98350     -0.20166     -0.78184           *        I
 124  -0.95410E-01 -0.20166      0.10625                  I*
 125  -0.24080     -0.20166     -0.39137E-01              *
 126  -0.25231     -0.20166     -0.50654E-01             *I
 127  -0.98350     -0.53759     -0.44591             *    I
 128   0.59212E-01 -0.53759      0.59680                  I      *
```

```
130 -0.57982     -0.53759     -0.42232E-01                     *I
131  -1.4355     -0.88890     -0.54658                   *      I
132 -0.78746     -0.88890      0.10145                          I*
133 -0.89894     -0.88890     -0.10039E-01                      *
134  -1.5279     -0.88890     -0.63895                  *       I
135  -1.9951      -1.2549     -0.74018                 *        I
136 -0.78746      -1.2549      0.46746                          I     *
137  -1.0441      -1.2549      0.21080                          I  *
138  -1.6145      -1.2549     -0.35953                      *   I
139  -2.2828      -1.6350     -0.64780                  *       I
140  -1.1940      -1.6350      0.44096                          I    *
141  -1.9951      -1.6350     -0.36011                      *   I
142  -1.4482      -1.6350      0.18682                          I *
143  -2.6882      -2.0285     -0.65977                  *       I
144  -2.9759      -2.0285     -0.94745               *          I
145  -1.0441      -2.0285      0.98435                          I           *
146  -2.2256      -2.0285     -0.19715                        * I
147  -3.3814      -2.4348     -0.94659               *          I
148  -1.8140      -2.4348      0.62080                          I      *
149  -2.6311      -2.4348     -0.19629                        * I
150  -2.9759      -2.8534     -0.12253                         *I
151  -2.2256      -2.8534      0.62777                          I       *
152  -4.0174      -2.8534      -1.1640            *             I
153  -2.9759      -3.2837      0.30780                          I   *
154  -1.9951      -3.2837       1.2886                          I             I
155  -4.0174      -3.2837     -0.73365                 *        I
156  -3.3814      -3.7253      0.34391                          I   *
157  -4.0174      -3.7253     -0.29208                      *   I
158  -2.9188      -2.9188     -0.34106E-12                      *
159  -3.6119      -3.8147      0.20273                          I *
160  -4.0174      -3.8147     -0.20273                        * I
161  -2.9188      -2.9188     -0.56843E-12                      *
162  -2.9188      -2.9188     -0.45475E-12                      *
163  -3.6119      -3.6119     -0.45475E-12                      *

DURBIN-WATSON = 2.3300    VON NEUMANN RATIO = 2.3444    RHO = -0.16831
RESIDUAL SUM = -0.59345E-10  RESIDUAL VARIANCE =  0.17456
SUM OF ABSOLUTE ERRORS=  47.776
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9500
RUNS TEST:   92 RUNS,   80 POSITIVE,   83 NEGATIVE, NORMAL STATISTIC =    1.4977
COEFFICIENT OF SKEWNESS =   0.0264 WITH STANDARD DEVIATION OF 0.1901
COEFFICIENT OF EXCESS KURTOSIS =   0.9900 WITH STANDARD DEVIATION OF 0.3780

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 30 GROUPS
OBSERVED  0.0  1.0  0.0  2.0  1.0  1.0  3.0  4.0  7.0  1.0  7.0 11.0 11.0 14.0 20.0 16.0 15.0 10.0  9.0 10.0
          8.0  3.0  4.0  1.0  0.0  0.0  2.0  0.0  0.0  2.0
EXPECTED  0.4  0.3  0.6  0.9  1.5  2.1  3.1  4.2  5.6  7.1  8.7 10.2 11.5 12.4 12.9 12.9 12.4 11.5 10.2  8.7
          7.1  5.6  4.2  3.1  2.1  1.5  0.9  0.6  0.3  0.4
CHI-SQUARE =   30.4644 WITH  7 DEGREES OF FREEDOM
JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =    5.8087 WITH  2 DEGREES OF FREEDOM
          STOP
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data, Using Eqn (225)

```
UNIT  6 IS NOW ASSIGNED TO: OP.DAT
           SAMPLE 1 223
           READ    PL      PERCENT
  2 VARIABLES AND      223 OBSERVATIONS STARTING AT OBS       1

           GENR LPL=LOG(PL)
           GENR LPL2=LPL**2
           GENR LPER=LOG(PERCENT)
           GENR D38=(PL.EQ.38)
           GENR D40=(PL.EQ.40)
           GENR D41=(PL.EQ.41)
           GENR D42=(PL.EQ.42)
           GENR D43=(PL.EQ.43)
           GENR D44=(PL.EQ.44)
           GENR D45=(PL.EQ.45)
           GENR D46=(PL.EQ.46)
           GENR D47=(PL.EQ.47)
           GENR D48=(PL.EQ.48)
           GENR D49=(PL.EQ.49)
           GENR D50=(PL.EQ.50)
           GENR D51=(PL.EQ.51)
           GENR D52=(PL.EQ.52)
           GENR D53=(PL.EQ.53)
           GENR D54=(PL.EQ.54)
           GENR D55=(PL.EQ.55)
           GENR D56=(PL.EQ.56)
           GENR D57=(PL.EQ.57)
           GENR D58=(PL.EQ.58)
           GENR D59=(PL.EQ.59)
           GENR D60=(PL.EQ.60)
           GENR D61=(PL.EQ.61)
           GENR D62=(PL.EQ.62)
           GENR D63=(PL.EQ.63)
           GENR D64=(PL.EQ.64)
           GENR D65=(PL.EQ.65)
           GENR D66=(PL.EQ.66)
           GENR D67=(PL.EQ.67)
           GENR D68=(PL.EQ.68)
           GENR D69=(PL.EQ.69)
           GENR D70=(PL.EQ.70)
           GENR D71=(PL.EQ.71)
           GENR D72=(PL.EQ.72)
           GENR D73=(PL.EQ.73)
           GENR D74=(PL.EQ.74)
           GENR D75=(PL.EQ.75)
           GENR D76=(PL.EQ.76)
           GENR D77=(PL.EQ.77)
           GENR D78=(PL.EQ.78)
           GENR D79=(PL.EQ.79)
           GENR D80=(PL.EQ.80)
           GENR D81=(PL.EQ.81)
           GENR D82=(PL.EQ.82)
           GENR D83=(PL.EQ.83)
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data, Using Eqn (225)

```
          GENR D84=(FL.EQ.84)
          GENR D85=(FL.EQ.85)
          GENR D86=(FL.EQ.86)
          GENR D87=(FL.EQ.87)
          GENR D88=(FL.EQ.88)
          GENR D89=(FL.EQ.89)
          GENR D90=(FL.EQ.90)
          GENR D91=(FL.EQ.91)
          GENR D92=(FL.EQ.92)
          GENR D93=(FL.EQ.93)
          GENR D94=(FL.EQ.94)
          GENR D95=(FL.EQ.95)
          GENR D96=(FL.EQ.96)
          GENR D97=(FL.EQ.97)
          GENR D99=(FL.EQ.99)
          GENR D101=(FL.EQ.101)
          GENR D110=(FL.EQ.110)
          GENR D114=(FL.EQ.114)
          GENR D120=(FL.EQ.120)

   OLS LPER LPL LPL2 &
 |                                     (D45 D46 D47 D48 &
 |                  D49 D50 D51 D52 D53 D54 D55 D56 D57 D58 &
 |                  D59 D60 D61 D62 D63 D64 D65 D66 D67 D68 &
 |                  D69 D70 D71 D72 D73 D74 D75 D76 D77 D78 &
 |                  D79 D80 D81 D82 D83 D84 D85 D86 D87 D88 &
 |                  D89 D90 D91 D92 D93 D94 D95 D96 D97 D99 &
 |                   ) /LIST LM

REQUIRED MEMORY IS PAR=  138 CURRENT PAR=  238
FOR MAXIMUM EFFICIENCY USE AT LEAST PAR=   239
OLS ESTIMATION
    223 OBSERVATIONS     DEPENDENT VARIABLE = LPER
...NOTE..SAMPLE RANGE SET TO:    1,  223

**** STEPWISE REGRESSION ****
***PARAMETERS FOR STEPWISE REGRESSION:   PE=0.050000 AND  PX=0.050000.


-----------------------------------------------------------------
|**** STEPPING SEQUENCE ****|          |     |      |            |
|      |        |            |          |     |      |            |
| STEP |VARIABLE|            |          |D.F. | D.F. |            |
|NUMBER| LABEL  | STATUS     |   F-VALUE|NUM. | DEN. |F-PROBABILITY|
|---------------------------------------------------------------|
|    0 |LPL2    |FORCED IN  |  15.8086 |   1 |  221|    0.000095|
|    0 |LPL     |FORCED IN  | 580.7617 |   1 |  220|    0.000000|
|    1 |D94     |STEPPED IN|    9.5057 |   1 |  219|    0.002313|
|    2 |D91     |STEPPED IN|   10.6905 |   1 |  218|    0.001253|
|    3 |D93     |STEPPED IN|   10.2082 |   1 |  217|    0.001608|
|    4 |D90     |STEPPED IN|    8.4067 |   1 |  216|    0.004127|
|    5 |D89     |STEPPED IN|    8.2880 |   1 |  215|    0.004396|
|    6 |D88     |STEPPED IN|    8.8963 |   1 |  214|    0.003191|
|    7 |D57     |STEPPED IN|    6.9604 |   1 |  213|    0.008952|
```

```
¦   8 ¦D60     ¦STEPPED IN¦    7.2431 ¦  1 ¦  212¦    0.007688¦
¦   9 ¦D58     ¦STEPPED IN¦    7.5765 ¦  1 ¦  211¦    0.006432¦
¦  10 ¦D59     ¦STEPPED IN¦    7.3409 ¦  1 ¦  210¦    0.007300¦
¦  11 ¦D56     ¦STEPPED IN¦    8.1891 ¦  1 ¦  209¦    0.004646¦
¦  12 ¦D55     ¦STEPPED IN¦    8.7127 ¦  1 ¦  208¦    0.003525¦
¦  13 ¦D61     ¦STEPPED IN¦    9.2509 ¦  1 ¦  207¦    0.002660¦
¦  14 ¦D62     ¦STEPPED IN¦    8.5702 ¦  1 ¦  206¦    0.003804¦
¦  15 ¦D54     ¦STEPPED IN¦    7.5100 ¦  1 ¦  205¦    0.006681¦
¦  16 ¦D85     ¦STEPPED IN¦    7.5593 ¦  1 ¦  204¦    0.006509¦
¦  17 ¦D95     ¦STEPPED IN¦    7.7278 ¦  1 ¦  203¦    0.005952¦
¦  18 ¦D99     ¦STEPPED IN¦    7.9585 ¦  1 ¦  202¦    0.005267¦
¦  19 ¦D87     ¦STEPPED IN¦    8.2944 ¦  1 ¦  201¦    0.004411¦
¦  20 ¦D92     ¦STEPPED IN¦    9.3346 ¦  1 ¦  200¦    0.002558¦
¦  21 ¦D96     ¦STEPPED IN¦    9.4864 ¦  1 ¦  199¦    0.002365¦
¦  22 ¦D97     ¦STEPPED IN¦    9.9105 ¦  1 ¦  198¦    0.001900¦
¦  23 ¦D84     ¦STEPPED IN¦    7.8218 ¦  1 ¦  197¦    0.005677¦
¦  24 ¦D86     ¦STEPPED IN¦    7.9696 ¦  1 ¦  196¦    0.005251¦
¦  25 ¦D83     ¦STEPPED IN¦    9.0787 ¦  1 ¦  195¦    0.002932¦
¦  26 ¦D82     ¦STEPPED IN¦    8.9470 ¦  1 ¦  194¦    0.003143¦
¦  27 ¦D48     ¦STEPPED IN¦    7.5174 ¦  1 ¦  193¦    0.006689¦
¦  28 ¦D47     ¦STEPPED IN¦    6.6423 ¦  1 ¦  192¦    0.010713¦
¦  29 ¦D45     ¦STEPPED IN¦    7.0612 ¦  1 ¦  191¦    0.008548¦
¦  30 ¦D46     ¦STEPPED IN¦    7.6263 ¦  1 ¦  190¦    0.006320¦
¦  31 ¦D49     ¦STEPPED IN¦    7.0799 ¦  1 ¦  189¦    0.008470¦
¦  32 ¦D64     ¦STEPPED IN¦    5.5293 ¦  1 ¦  188¦    0.019741¦
¦  33 ¦D81     ¦STEPPED IN¦    5.1371 ¦  1 ¦  187¦    0.024570¦
¦  34 ¦D63     ¦STEPPED IN¦    4.1371 ¦  1 ¦  186¦    0.043379¦
¦*SUMMARY FOR POTENTIAL VARIABLES NOT ENTERED INTO THE REG. EQUATION*¦
¦     ¦D50     ¦IF ENTERED¦    0.9215 ¦  1 ¦  185¦    0.338348¦
¦     ¦D51     ¦IF ENTERED¦    0.3003 ¦  1 ¦  185¦    0.584369¦
¦     ¦D52     ¦IF ENTERED¦    3.8334 ¦  1 ¦  185¦    0.051749¦
¦     ¦D53     ¦IF ENTERED¦    3.5199 ¦  1 ¦  185¦    0.062217¦
¦     ¦D65     ¦IF ENTERED¦    1.9601 ¦  1 ¦  185¦    0.163180¦
¦     ¦D66     ¦IF ENTERED¦    0.2955 ¦  1 ¦  185¦    0.587347¦
¦     ¦D67     ¦IF ENTERED¦    0.0000 ¦  1 ¦  185¦    0.995811¦
¦     ¦D68     ¦IF ENTERED¦    0.0046 ¦  1 ¦  185¦    0.945728¦
¦     ¦D69     ¦IF ENTERED¦    0.4049 ¦  1 ¦  185¦    0.525381¦
¦     ¦D70     ¦IF ENTERED¦    0.9595 ¦  1 ¦  185¦    0.328585¦
¦     ¦D71     ¦IF ENTERED¦    2.3734 ¦  1 ¦  185¦    0.125129¦
¦     ¦D72     ¦IF ENTERED¦    0.8309 ¦  1 ¦  185¦    0.363213¦
¦     ¦D73     ¦IF ENTERED¦    2.3804 ¦  1 ¦  185¦    0.124578¦
¦     ¦D74     ¦IF ENTERED¦    2.3492 ¦  1 ¦  185¦    0.127059¦
¦     ¦D75     ¦IF ENTERED¦    0.5173 ¦  1 ¦  185¦    0.472914¦
¦     ¦D76     ¦IF ENTERED¦    0.1186 ¦  1 ¦  185¦    0.730897¦
¦     ¦D77     ¦IF ENTERED¦    0.0003 ¦  1 ¦  185¦    0.986589¦
¦     ¦D78     ¦IF ENTERED¦    0.0362 ¦  1 ¦  185¦    0.849317¦
¦     ¦D79     ¦IF ENTERED¦    0.4632 ¦  1 ¦  185¦    0.497000¦
¦     ¦D80     ¦IF ENTERED¦    2.4573 ¦  1 ¦  185¦    0.118694¦
¦**** END OF STEPPING SEQUENCE ****       ¦    ¦     ¦            ¦
--------------------------------------------------------------------


 R-SQUARE =   0.9311     R-SQUARE ADJUSTED =   0.9178
VARIANCE OF THE ESTIMATE-SIGMA**2 =  0.15435
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data, Using Eqn (225)

```
STANDARD ERROR OF THE ESTIMATE-SIGMA =  0.39287
SUM OF SQUARED ERRORS-SSE=   28.708
MEAN OF DEPENDENT VARIABLE = -0.26940E-01
LOG OF THE LIKELIHOOD FUNCTION = -87.8507

MODEL SELECTION TESTS - SEE JUDGE ET.AL.(1985, P.242)
 AKAIKE (1969) FINAL PREDICTION ERROR- FPE =   0.17996
   (FPE ALSO KNOWN AS AMEMIYA PREDICTION CRITERION -PC)
 AKAIKE (1973) INFORMATION CRITERION- LOG AIC =  -1.7181
 SCHWARZ(1978) CRITERION-LOG SC =  -1.1528
MODEL SELECTION TESTS - SEE RAMANATHAN(1989,P.166)
 CRAVEN-WAHBA(1979) GENERALIZED CROSS VALIDATION(1979) -GCV=  0.18505
 HANNAN AND QUINN(1979) CRITERION -HQ=  0.22539
 RICE (1984) CRITERION-RICE=  0.19267
 SHIBATA (1981) CRITERION-SHIBATA=  0.17146
 SCHWARTZ (1978) CRITERION-SC=  0.31574
 AKAIKE (1974)INFORMATION CRITERION-AIC=  0.17940

                     ANALYSIS OF VARIANCE - FROM MEAN
                     SS           DF            MS                   F
REGRESSION         388.08         36.         10.780               69.843
ERROR              28.708        186.        0.15435
TOTAL              416.79        222.         1.8774

                     ANALYSIS OF VARIANCE - FROM ZERO
                     SS           DF            MS                   F
REGRESSION         388.24         37.         10.493               67.984
ERROR              28.708        186.        0.15435
TOTAL              416.95        223.         1.8697


VARIABLE   ESTIMATED  STANDARD   T-RATIO    PARTIAL STANDARDIZED ELASTICITY
  NAME    COEFFICIENT   ERROR     186 DF     CORR.  COEFFICIENT  AT MEANS

LPL          131.17     4.1107     31.908    0.9195  24.487       -20408.
LPL2        -15.691    0.49944    -31.418   -0.9173 -24.414        10271.
D45         0.66685    0.20761     3.2121    0.2293  0.64740E-01 -0.44401
D46         0.61707    0.20642     2.9894    0.2141  0.59907E-01 -0.41086
D47         0.67788    0.20550     3.2986    0.2351  0.65811E-01 -0.45135
D48         0.74422    0.20481     3.6336    0.2575  0.72250E-01 -0.49552
D49         0.52405    0.20430     2.5651    0.1848  0.50876E-01 -0.34893
D54        -0.58650    0.20327    -2.8853   -0.2070 -0.56939E-01  0.39051
D55        -0.80821    0.20321    -3.9772   -0.2800 -0.78463E-01  0.53813
D56        -0.85061    0.20316    -4.1868   -0.2935 -0.82579E-01  0.56636
D57        -0.97693    0.20312    -4.8095   -0.3326 -0.94843E-01  0.65047
D58        -0.94702    0.20308    -4.6632   -0.3235 -0.91939E-01  0.63055
D59        -0.90981    0.20304    -4.4810   -0.3121 -0.88327E-01  0.60578
D60         -1.0107    0.20299    -4.9791   -0.3429 -0.98121E-01  0.67295
D61        -0.89626    0.20292    -4.4168   -0.3081 -0.87012E-01  0.59676
D62        -0.83202    0.20285    -4.1017   -0.2880 -0.80775E-01  0.55398
D63        -0.41242    0.20277    -2.0340   -0.1475 -0.40039E-01  0.27460
D64        -0.52401    0.20268    -2.5855   -0.1863 -0.50873E-01  0.34890
D81        -0.47841    0.20396    -2.3456   -0.1695 -0.46445E-01  0.31854
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data, Using Eqn (225)

```
D82       -0.76022    0.20448     -3.7179    -0.2630 -0.73804E-01  0.50618
D83       -0.83175    0.20508     -4.0558    -0.2850 -0.80749E-01  0.55380
D84       -0.91218    0.20576     -4.4332    -0.3091 -0.88556E-01  0.60735
D85        -1.2891    0.20653     -6.2414    -0.4161 -0.12514      0.85829
D86       -0.87443    0.20739     -4.2163    -0.2954 -0.84892E-01  0.58222
D87        -1.2068    0.20835     -5.7923    -0.3909 -0.11716      0.80354
D88        -1.6170    0.20940     -7.7217    -0.4927 -0.15698       1.0766
D89        -1.6720    0.21056     -7.9409    -0.5032 -0.16232       1.1133
D90        -1.9097    0.24026     -7.9482    -0.5035 -0.16092      0.95362
D91        -2.0708    0.21317     -9.7145    -0.5802 -0.20104       1.3788
D92        -2.0385    0.40228     -5.0675    -0.3483 -0.99628E-01  0.33933
D93        -2.1593    0.24414     -8.8447    -0.5441 -0.18196       1.0783
D94        -2.3403    0.24562     -9.5278    -0.5727 -0.19721       1.1687
D95        -1.6225    0.24721     -6.5633    -0.4336 -0.13672      0.81023
D96        -2.0344    0.40601     -5.0106    -0.3449 -0.99425E-01  0.33864
D97        -1.5259    0.29759     -5.1275    -0.3519 -0.10523      0.50799
D99        -2.2541    0.40949     -5.5046    -0.3743 -0.11016      0.37521
CONSTANT   -272.66     8.4388     -32.310    -0.9213  0.00000E+00  10121.

 OBS.  OBSERVED     PREDICTED    CALCULATED
  NO.  VALUE        VALUE        RESIDUAL
   1  -3.1466      -3.1533      0.66988E-02                 *
   2  -2.0557      -2.3220      0.26631                     I  *
   3  -2.2073      -2.3220      0.11476                     I*
   4  -1.4872      -2.3220      0.83482                     I         *
   5  -2.9004      -1.9513      -0.94909         *          I
   6  -1.5702      -1.9513      0.38111                     I    *
   7  -2.4079      -1.9513      -0.45661               *    I
   8  -1.5418      -1.6080      0.66227E-01                 I*
   9  -1.3205      -1.6080      0.28750                     I   *
  10  -1.3056      -1.6080      0.30237                     I   *
  11  -1.7661      -1.2903      -0.47575               *    I
  12  -1.8018      -1.2903      -0.51146             *      I
  13  -0.68518     -1.2903      0.60517                     I      *
  14  -1.1520      -1.2903      0.13833                     I *
  15  -0.85097     -0.99677     0.14580                     I *
  16  -1.5141      -0.99677     -0.51736             *      I
  17  -0.47321     -0.99677     0.52356                     I     *
  18  -0.89894     -0.99677     0.97829E-01                 I*
  19  -0.20825     -0.58973E-01 -0.14928                  * I
  20  0.14237      -0.58973E-01 0.20134                     I  *
  21  -0.11766     -0.58973E-01 -0.58685E-01               *I
  22  -0.52346E-01 -0.58973E-01 0.66266E-02                 *
  23  0.43048      0.14091      0.28957                     I  *
  24  -0.26397     0.14091      -0.40487               *    I
  25  0.92579E-01  0.14091      -0.48330E-01               *I
  26  0.30454      0.14091      0.16363                     I *
  27  0.69764      0.43133      0.26630                     I  *
  28  0.35557      0.43133      -0.75760E-01               *I
  29  0.24295      0.43133      -0.18839                  * I
  30  0.42918      0.43133      -0.21532E-02                *
  31  0.85442      0.70839      0.14602                     I *
  32  0.65285      0.70839      -0.55546E-01               *I
```

```
33   0.78573     0.70839    0.77335E-01              I*
34   0.54058     0.70839   -0.16781                * I
35   0.94157     0.68112    0.26045                  I  *
36   0.46499     0.68112   -0.21613               *  I
37   0.70112     0.68112    0.19995E-01              *
38   0.61681     0.68112   -0.64314E-01             *I
39   0.85442     0.33313    0.52129                  I      *
40   0.59388     0.33313    0.26075                  I  *
41   0.37363     0.33313    0.40504E-01              I*
42   0.23507     0.33313   -0.98054E-01             *I
43   0.85442     0.49327    0.36115                  I    *
44   0.18814     0.49327   -0.30513              *   I
45   0.39339     0.49327   -0.99873E-01             *I
46   0.12222     0.49327   -0.37105             *    I
47   0.85442     0.63835    0.21607                  I  *
48   0.14237     0.63835   -0.49598            *     I
49   0.92579E-01 0.63835   -0.54577           *      I
50  -0.60181E-02 0.63835   -0.64436          *       I
51   0.60868     0.76916   -0.16049                * I
52   0.49896     0.76916   -0.27021               *  I
53   0.28818     0.76916   -0.48098            *     I
54   0.27003     0.76916   -0.49914            *     I
55   0.43048     0.29997    0.13051                  I *
56   0.46499     0.29997    0.16502                  I *
57   0.31042     0.29997    0.10452E-01              *
58  -0.60181E-02 0.29997   -0.30599              *   I
59   0.65389     0.18274    0.47114                  I     *
60  -0.69350E-01 0.18274   -0.25209               *  I
61   0.64851E-01 0.18274   -0.11789                * I
62   0.81580E-01 0.18274   -0.10116                 *I
63   0.48489     0.23267    0.25222                  I  *
64   0.23270     0.23267    0.27767E-04              *
65   0.26544     0.23267    0.32766E-01              *
66  -0.52346E-01 0.23267   -0.28502              *   I
67   0.56076     0.18711    0.37365                  I    *
68  -0.13011     0.18711   -0.31722              *   I
69   0.19557     0.18711    0.84584E-02              *
70   0.12222     0.18711   -0.64891E-01             *I
71   0.24842     0.28681   -0.38391E-01              *
72   0.53122     0.28681    0.24440                  I  *
73   0.37363     0.28681    0.86818E-01              I*
74  -0.60181E-02 0.28681   -0.29283              *   I
75   0.67600     0.38336    0.29264                  I   *
76   0.23270     0.38336   -0.15066                * I
77   0.19557     0.38336   -0.18780                * I
78   0.42918     0.38336    0.45820E-01              I*
79   0.60868     0.33188    0.27679                  I   *
80   0.93490E-01 0.33188   -0.23839               *  I
81   0.28818     0.33188   -0.43702E-01             *I
82   0.33719     0.33188    0.53021E-02              *
83   0.67600     0.48625    0.18975                  I *
84   0.39339     0.48625   -0.92661E-01             *I
85   0.50682     0.48625    0.20565E-01              *
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data,
Using Eqn (225)

```
  86  0.36880     0.48625     -0.11745                  *I
  87  0.83638     0.58142      0.25496                   I  *
  88  0.23270     0.58142     -0.34873               *   I
  89  0.52473     0.58142     -0.56695E-01              *I
  90  0.73189     0.58142      0.15046                   I *
  91   1.1647      1.0234      0.14136                   I *
  92  0.88170      1.0234     -0.14166                 * I
  93   1.0664      1.0234      0.43077E-01               I*
  94  0.98058      1.0234     -0.42777E-01              *I
  95  0.83638     0.92590     -0.89515E-01              *I
  96  0.68107     0.92590     -0.24482                *  I
  97  0.99251     0.92590      0.66614E-01               I*
  98   1.1936     0.92590      0.26772                   I  *
  99   1.1512      1.4562     -0.30502               *   I
 100   1.1750      1.4562     -0.28127               *   I
 101   1.0564      1.4562     -0.39982              *    I
 102   1.3805      1.4562     -0.75694E-01              *I
 103   1.3798      1.4551     -0.75293E-01              *I
 104   1.3169      1.4551     -0.13812                 * I
 105   1.2522      1.4551     -0.20287                *  I
 106   1.4570      1.4551      0.19199E-02               *
 107   1.3247      1.4468     -0.12209                 * I
 108   1.4670      1.4468      0.20176E-01               *
 109   1.1912      1.4468     -0.25558                *  I
 110   1.8083      1.4468      0.36151                   I    *
 111   1.3470      1.4317     -0.84636E-01              *I
 112   1.5162      1.4317      0.84556E-01               I*
 113   1.2939      1.4317     -0.13776                 * I
 114   1.6216      1.4317      0.18989                   I *
 115   1.3016      1.4100     -0.10849                  *I
 116   1.6513      1.4100      0.24130                   I  *
 117   1.3719      1.4100     -0.38104E-01               *
 118   1.8009      1.4100      0.39084                   I    *
 119   1.6513      1.3822      0.26916                   I  *
 120   1.6407      1.3822      0.25855                   I  *
 121   1.4651      1.3822      0.82918E-01               I*
 122   1.5182      1.3822      0.13601                   I *
 123   1.4219      1.3484      0.73537E-01               I*
 124   1.6722      1.3484      0.32386                   I   *
 125   1.6463      1.3484      0.29798                   I   *
 126   1.8231      1.3484      0.47473                   I     *
 127   1.3691      1.3088      0.60314E-01               I*
 128   1.7322      1.3088      0.42335                   I    *
 129   1.5442      1.3088      0.23532                   I  *
 130   1.2851      1.3088     -0.23742E-01               *
 131   1.4722      1.2638      0.20841                   I  *
 132   1.5862      1.2638      0.32233                   I   *
 133   1.6407      1.2638      0.37691                   I    *
 134   1.5280      1.2638      0.26418                   I  *
 135   1.3132      1.2136      0.99587E-01               I*
 136   1.6300      1.2136      0.41643                   I    *
 137   1.5569      1.2136      0.34328                   I   *
 138   1.5182      1.2136      0.30460                   I   *
```

APPENDIX E-11: Shazam Regression Results on Longline (Female) Data,
Using Eqn (225)

```
139   1.3132       1.1583       0.15484                 I *
140   1.3021       1.1583       0.14375                 I *
141   1.2692       1.1583       0.11085                 I*
142   1.2975       1.1583       0.13912                 I *
143   1.0519       1.0983      -0.46409E-01            *I
144   1.1918       1.0983       0.93520E-01             I*
145   1.2607       1.0983       0.16245                 I *
146   1.1515       1.0983       0.53241E-01             I*
147   0.75940      1.0336      -0.27420               *  I
148   1.2084       1.0336       0.17476                 I *
149   1.0869       1.0336       0.53276E-01             I*
150   1.0926       1.0336       0.58993E-01             I*
151   0.89036      0.96450     -0.74141E-01            *I
152   1.0094       0.96450      0.44918E-01             I*
153   0.95897      0.96450     -0.55314E-02             *
154   0.85442      0.96450     -0.11008                *I
155   0.56076      0.89115     -0.33039              *   I
156   1.1404       0.89115      0.24924                 I  *
157   0.94740      0.89115      0.56252E-01             I*
158   0.39945      0.89115     -0.49170            *     I
159   0.21430      0.81373     -0.59942          *       I
160   0.59388      0.81373     -0.21985               *  I
161   0.62487      0.81373     -0.18886                * I
162   0.64080      0.81373     -0.17293                * I
163   0.31335      0.25399      0.59365E-01             I*
164   0.35557      0.25399      0.10159                 I*
165   0.26544      0.25399      0.11451E-01             *
166   0.81580E-01  0.25399     -0.17241                * I
167  -0.61875E-01 -0.11292      0.51041E-01             I*
168  -0.26397     -0.11292     -0.15105                * I
169   0.33146     -0.11292      0.44438                 I    *
170  -0.45728     -0.11292     -0.34437              *   I
171  -0.75502     -0.27315     -0.48187            *     I
172  -0.50418     -0.27315     -0.23103               *  I
173   0.37363     -0.27315      0.64678                 I      *
174  -0.20702     -0.27315      0.66125E-01             I*
175  -0.44473     -0.44574      0.10105E-02             *
176  -0.41703     -0.44574      0.28705E-01             *
177  -0.22246E-01 -0.44574      0.42349                 I   *
178  -0.89894     -0.44574     -0.45321            *     I
179  -0.95451     -0.91811     -0.36404E-01             *
180  -1.2946      -0.91811     -0.37652             *    I
181  -0.11766     -0.91811      0.80045                 I        *
182  -1.3056      -0.91811     -0.38753             *    I
183  -1.0729      -0.60218     -0.47076            *     I
184  -0.33687     -0.60218      0.26531                 I *
185  -0.29975     -0.60218      0.30243                 I  *
186  -0.69917     -0.60218     -0.96981E-01            *I
187  -1.2073      -1.0364      -0.17096                * I
188  -1.2946      -1.0364      -0.25827               *  I
189  -0.62736     -1.0364       0.40899                 I   *
190  -1.0161      -1.0364       0.20241E-01             *
191  -1.5418      -1.5512       0.94358E-02             *
```

```
192  -2.2073     -1.5512     -0.65606               *      I
193 -0.74655     -1.5512      0.80467                      I          *
194  -1.7093     -1.5512     -0.15804                    * I
195  -1.2073     -1.7138      0.50653                      I      *
196  -1.5141     -1.7138      0.19971                      I   *
197  -1.0328     -1.7138      0.68101                      I         *
198  -3.1011     -1.7138     -1.3873         X              I
199  -1.5141     -2.0618      0.54768                      I       *
200  -1.5702     -2.0618      0.49160                      I      *
201  -3.1011     -2.0618     -1.0393            *           I
202  -2.4651     -2.3359     -0.12948                    * I
203  -2.2073     -2.3359      0.12865                      I *
204  -1.5702     -2.3359      0.76571                      I         *
205  -3.1011     -2.3359     -0.76517              *         I
206  -2.4191     -2.4191      0.22737E-12                  *
207  -3.1466     -2.6579     -0.48868                  *     I
208  -1.7260     -2.6579      0.93190                      I           *
209  -3.1011     -2.6579     -0.44322                  *     I
210  -3.1466     -2.9591     -0.18749                    * I
211  -2.9004     -2.9591      0.58643E-01                  I*
212  -2.8302     -2.9591      0.12885                      I *
213  -2.4651     -2.3638     -0.10127                     *I
214  -2.2073     -2.3638      0.15656                      I *
215  -2.4191     -2.3638     -0.55286E-01                 *I
216  -2.9004     -2.9004      0.22737E-12                  *
217  -2.2073     -2.5187      0.31147                      I   *
218  -2.8302     -2.5187     -0.31147                    *   I
219  -3.5066     -3.5066      0.22737E-12                  *
220  -3.5066     -1.5195     -1.9870         X               I
221  -3.5066     -2.8005     -0.70604               *        I
222  -2.8302     -3.4044      0.57417                      I      *
223  -3.5066     -4.3416      0.83507                      I          *

DURBIN-WATSON = 2.1817     VON NEUMANN RATIO = 2.1916     RHO = -0.10557
RESIDUAL SUM =  0.50306E-10  RESIDUAL VARIANCE =  0.15435
SUM OF ABSOLUTE ERRORS=   57.304
R-SQUARE BETWEEN OBSERVED AND PREDICTED = 0.9311
RUNS TEST:  117 RUNS,  123 POSITIVE,  100 NEGATIVE, NORMAL STATISTIC =     0.7715
COEFFICIENT OF SKEWNESS =  -0.9573 WITH STANDARD DEVIATION OF 0.1629
COEFFICIENT OF EXCESS KURTOSIS =   4.6768 WITH STANDARD DEVIATION OF 0.3245

    GOODNESS OF FIT TEST FOR NORMALITY OF RESIDUALS - 60 GROUPS
OBSERVED  2.0  0.0  0.0  1.0  0.0  1.0  0.0  0.0  0.0  0.0  1.0  1.0  0.0  2.0  1.0  0.0  3.0  8.0  3.0  2.0
          3.0  4.0  7.0  7.0  4.0 10.0  9.0 11.0 14.0  6.0 19.0 17.0  9.0 13.0  6.0  4.0 15.0  9.0  3.0  6.0
          4.0  1.0  4.0  3.0  1.0  1.0  1.0  1.0  0.0  1.0  2.0  2.0  0.0  1.0  0.0  0.0  0.0  0.0  0.0  0.0
EXPECTED  0.4  0.2  0.2  0.3  0.3  0.4  0.6  0.7  0.9  1.1  1.3  1.6  1.9  2.3  2.7  3.1  3.6  4.1  4.6  5.1
          5.7  6.2  6.7  7.2  7.6  8.1  8.4  8.6  8.8  8.9  8.9  8.8  8.6  8.4  8.1  7.6  7.2  6.7  6.2  5.7
          5.1  4.6  4.1  3.6  3.1  2.7  2.3  1.9  1.6  1.3  1.1  0.9  0.7  0.6  0.4  0.3  0.3  0.2  0.2  0.4
CHI-SQUARE =   82.6351 WITH 21 DEGREES OF FREEDOM

JARQUE-BERA ASYMPTOTIC LM NORMALITY TEST
CHI-SQUARE =  225.6160 WITH  2 DEGREES OF FREEDOM
          STOP
```

APPENDIX F: Shazam (White, 1987) Command Programs for Appendix E

The following Shazam command programs generated the analysis in Appendix F.

APPENDIX F-1: Shazam Program for Regressing Eqn (85) on Figure 6-1

```
  FILE 6 OP.DAT
  Sample 1 30
  Read  YEAR  HARVEST  EFFORT
           1     316.48    98.90
           2    2842.71   890.11
           3    5276.09  1681.31
           4    7226.96  2373.62
           5    8982.28  3065.92
           6   10244.51  3659.33
           7   11332.41  4252.73
           8   11997.38  4747.24
           9   12546.37  5241.74
          10   12758.81  5637.34
          11   12914.09  6032.95
          12   13011.69  6428.55
          13   12862.55  6725.25
          14   12704.25  7021.95
          15   12532.45  7318.66
          16   12344.18  7615.36
          17   11985.76  7813.16
          18   11648.42  8010.96
          19   11326.13  8208.76
          20   11014.34  8406.56
          21   10709.61  8604.37
          22   10409.34  8802.17
          23   10111.57  8999.97
          24    9814.85  9197.77
          25    9518.12  9395.57
          26    9125.60  9494.47
          27    8759.98  9593.37
          28    8417.18  9692.27
          29    8093.87  9791.18
          30    7787.38  9890.08
 NL 1 /NCOEF=2 LIST RSTAT AUTO BEG=3
 EQ HARVEST = a*EFFORT*(1-b*EFFORT)
 COEF a 4.4  b .00007
 END
```

APPENDIX F-2: Shazam Program for Regressing Eqn (85) on Figure 6-1

Replace the last four lines in Appendix G-1 with:

```
GENR LCPUE=(LAG(HARVEST)/LAG(EFFORT))
GENR LEFFORT=LAG(EFFORT)
NL 1 /NCOEF=3 LIST RSTAT BEG=2 AUTO
EQ HARVEST = EFFORT*LCPUE*(1 + a*(1-b*LCPUE) - c*LEFFORT)
COEF a .2101  b .2501  c .000031
END
```

APPENDIX F-3: Shazam Program for Regressing Eqn (154) on Figure 7-6

```
  FILE 6 OP.DAT
  Sample 1 42
  Read   EFFORT       HARVEST
               .00         .00
               .07      440.94
              7.21    44762.84
             27.34   164672.92
             60.59   353940.05
            107.20   606592.83
            167.47   917066.49
            241.72  1279533.52
            330.18  1687557.36
            433.22  2135075.43
            551.33  2616558.24
            684.80  3124985.73
            834.07  3653895.76
            999.73  4197147.28
           1182.26  4747643.65
           1382.14  5298044.70
           1600.02  5841158.04
           1836.56  6369461.60
           2092.20  6874150.03
           2363.97  7335588.92
           2634.14  7693121.54
           2900.29  7941015.65
           3162.78  8082407.41
           3421.99  8120183.38
           3678.30  8056976.53
           3932.10  7895161.06
           4183.80  7636845.94
           4433.80  7283867.08
           4682.54  6837778.06
           4930.47  6299839.18
           5178.04  5671004.88
           5425.74  4951909.23
           5674.09  4142849.36
           5923.59  3243766.75
           6174.82  2254226.11
           6428.35  1173391.55
           6492.17   888780.01
           6556.18   598361.81
           6620.39   302111.06
           6659.01   121549.51
           6671.91    60892.43
           6683.52     6099.84
NL 1 /NCOEF=2 LIST RSTAT
EQ HARVEST = a*EFFORT*(1-b*EFFORT)
COEF a 6000 b .0002
END
```

APPENDIX F-4: Shazam Program for Regressing Eqn (221) on Figure 8-3

```
FILE 6 OP.DAT
Sample 1 55
READ       NUM   FL     EGGS
             1   57.9    58200
             2   58.0   191800
             3   58.0   114700
             4   58.9   283900
             5   60.0   136900
             6   60.7   113700
             7   61.0    64500
             8   61.4   162400
             9   62.0   127900
            10   75.6   250200
            11   63.3   205700
            12   64.0   161800
            13   64.2   130800
            14   65.0   101300
            15   65.0   195200
            16   66.1   112000
            17   66.5    85700
            18   67.1   119500
            19   67.3   245200
            20   67.5   127300
            21   67.8   239600
            22   69.2   260700
            23   69.5   188900
            24   70.0   240400
            25   71.1   186000
            26   72.0   223100
            27   73.0   238000
            28   74.0   263000
            29   74.9   165000
            30   75.4   228500
            31   76.2   203600
            32   76.8   168700
            33   62.8   257800
            34   78.0   268500
            35   78.0   154300
            36   80.2   202400
            37   80.4   308900
            38   80.5   191400
            39   81.0   342400
            40   81.1   203900
            41   81.3   228400
            42   81.5   278000
            43   81.5   336200
            44   82.5   218700
            45   82.9   485000
            46   84.4   341600
            47   84.5   313800
```

```
                    48    85.5    416700
                    49    85.6    429000
                    50    85.7    462200
                    51    87.4    486200
                    52    88.5    240600
                    53    89.2    524400
                    54    94.5    563600
                    55   110.2    977000

GENR LEGGS=LOG(EGGS)
GENR LFL=LOG(FL)
STAT FL EGGS LFL LEGGS
OLS LEGGS  FL / LIST BEG=5
STOP
```

APPENDIX F-5: Shazam Program for Regressing Eqn (222)

```
     FILE 6 OP.DAT
     Sample 1 54
       READ       NUM       FL      EGGS      AGE
                   1       57.9     58.200    22
                   2       58.0    191.800     5
                   3       58.0    114.700     6
                   4       58.9    283.900    15
                   6       60.7    113.700     5
                   7       61.0     64.500    28
                   8       61.4    162.400     7
                   9       62.0    127.900     7
                  10       75.6    250.200    15
                  11       63.3    205.700     6
                  12       64.0    161.800    11
                  13       64.2    130.800     6
                  14       65.0    101.300    26
                  15       65.0    195.200     8
                  16       66.1    112.000    15
                  17       66.5     85.700    11
                  18       67.1    119.500    12
                  19       67.3    245.200    18
                  20       67.5    127.300     7
                  21       67.8    239.600    17
                  22       69.2    260.700    12
                  23       69.5    188.900     5
                  24       70.0    240.400    14
                  25       71.1    186.000    20
                  26       72.0    223.100     8
                  27       73.0    238.000    20
                  28       74.0    263.000    13
                  29       74.9    165.000    15
                  30       75.4    228.500    11
                  31       76.2    203.600    21
                  32       76.8    168.700    12
                  33       62.8    257.800     6
                  34       78.0    268.500    17
                  35       78.0    154.300    16
                  36       80.2    202.400    15
                  37       80.4    308.900    22
                  38       80.5    191.400    23
                  39       81.0    342.400     8
                  40       81.1    203.900    11
                  41       81.3    228.400    21
                  42       81.5    278.000    13
                  43       81.5    336.200    13
                  44       82.5    218.700    43
                  45       82.9    485.000    14
                  46       84.4    341.600    11
                  47       84.5    313.800    18
                  48       85.5    416.700    32
                  49       85.6    429.000    15
```

```
            50     85.7   462.200   11
            51     87.4   486.200    9
            52     88.5   240.600   15
            53     89.2   524.400   21
            54     94.5   563.600   20
            55    110.2   977.000   34
GENR LAGE=LOG(AGE)
GENR LEGGS=LOG(EGGS)
GENR LFL=LOG(FL)
GENR FLAGE=(FL/AGE)
GENR LFLAGE=LOG(FLAGE)
OLS LEGGS  FL LAGE    /BEG=5 MAX
STOP
```

APPENDIX F-6: Shazam Program for Regressing Eqn (225) on Trawl Data

```
FILE 6 OP.DAT
Sample 1 129

READ    NUMBER     FL     PERCENT
             1     19       .036
             2     22       .033
             3     26       .042
             4     27       .066
             5     28       .229
             6     29       .125
             7     30       .208
             8     33       .042
             9     33       .066
            10     33       .054
            11     34       .042
            12     35       .125
            13     35       .229
            14     36       .540
            15     36       .164
            16     36       .036
            17     37      1.370
            18     37       .787
            19     37       .322
            20     37       .240
            21     37       .218
            22     38      2.409
            23     38      1.311
            24     38       .322
            25     38       .440
            26     38       .381
            27     39      3.322
            28     39      2.852
            29     39      1.575
            30     39      1.079
            31     39      1.631
            32     40      4.693
            33     40      5.769
            34     40      2.685
            35     40      2.478
            36     40      6.145
            37     41      8.140
            38     41      8.260
            39     41      4.368
            40     41      4.956
            41     41      7.830
            42     42     12.957
            43     42     12.357
            44     42      7.841
            45     42      8.473
            46     42     14.573
            47     43     15.490
            48     43     14.946
```

49	43	11.744
50	43	11.831
51	43	16.476
52	44	15.822
53	44	13.438
54	44	12.675
55	44	12.390
56	44	13.812
57	45	12.666
58	45	12.914
59	45	14.572
60	45	14.588
61	45	12.561
62	46	8.721
63	46	9.603
64	46	13.068
65	46	13.949
66	46	10.332
67	47	5.357
68	47	6.522
69	47	11.457
70	47	10.032
71	47	6.580
72	48	3.530
73	48	4.621
74	48	7.268
75	48	7.114
76	48	4.459
77	49	1.786
78	49	2.753
79	49	4.690
80	49	4.277
81	49	1.958
82	50	1.370
83	50	1.475
84	50	3.509
85	50	3.277
86	50	1.142
87	51	.498
88	51	.623
89	51	1.754
90	51	1.998
91	51	.870
92	52	.166
93	52	.393
94	52	.788
95	52	1.159
96	52	.272
97	53	.208
98	53	.295
99	53	.430
100	53	.959
101	53	.218
102	54	.125

```
          103        54      .164
          104        54      .322
          105        54      .400
          106        54      .054
          107        55      .083
          108        55      .033
          109        55      .143
          110        55      .240
          111        55      .109
          112        56      .083
          113        56      .215
          114        57      .042
          115        57      .072
          116        58      .036
          117        58      .040
          118        59      .036
          119        63      .040
          120        64      .036
          121        67      .066
          122        68      .054
          123        70      .042
          124        71      .054
          125        73      .109
          126        74      .054
          127        75      .040
          128        75      .054
          129        83      .033

GENR LFL=LOG(FL)
GENR LFL2=LFL**2
GENR LPER=LOG(PERCENT)

GENR D19=(FL.EQ.19)
GENR D22=(FL.EQ.22)
GENR D26=(FL.EQ.26)
GENR D27=(FL.EQ.27)
GENR D28=(FL.EQ.28)
GENR D29=(FL.EQ.29)
GENR D30=(FL.EQ.30)
GENR D33=(FL.EQ.33)
GENR D34=(FL.EQ.34)
GENR D35=(FL.EQ.35)
GENR D36=(FL.EQ.36)
GENR D37=(FL.EQ.37)
GENR D38=(FL.EQ.38)
GENR D39=(FL.EQ.39)
GENR D40=(FL.EQ.40)
GENR D41=(FL.EQ.41)
GENR D42=(FL.EQ.42)
GENR D43=(FL.EQ.43)
GENR D44=(FL.EQ.44)
GENR D45=(FL.EQ.45)
GENR D46=(FL.EQ.46)
GENR D47=(FL.EQ.47)
```

```
          GENR D48=(FL.EQ.48)
          GENR D49=(FL.EQ.49)
          GENR D50=(FL.EQ.50)
          GENR D51=(FL.EQ.51)
          GENR D52=(FL.EQ.52)
          GENR D53=(FL.EQ.53)
          GENR D54=(FL.EQ.54)
          GENR D55=(FL.EQ.55)
          GENR D56=(FL.EQ.56)
          GENR D57=(FL.EQ.57)
          GENR D58=(FL.EQ.58)
          GENR D59=(FL.EQ.59)
          GENR D63=(FL.EQ.63)
          GENR D64=(FL.EQ.64)
          GENR D67=(FL.EQ.67)
          GENR D68=(FL.EQ.68)
          GENR D70=(FL.EQ.70)
          GENR D71=(FL.EQ.71)
          GENR D73=(FL.EQ.73)
          GENR D74=(FL.EQ.74)
          GENR D75=(FL.EQ.75)
          GENR D83=(FL.EQ.83)

OLS LPER LFL LFL2 &
                  (D19  D22  D26  D27  D28 D29 D30 D33 D34 D35 &
                   D36  D37  D38  D39  D40 D41 D42 D43 D44 D45 &
                   D46  D47  D48  D49  D50 D51 D52 D53 D54 D55 &
                   D56  D57  D58  D59  D63 D64 D67 D68 D70 D71 &
                   D73  D74  D75  D83) /LIST LM

          STOP
```

APPENDIX F-7: Shazam Program for Regressing Eqn (225) on Longline Data

```
FILE 6 OP.DAT
Sample 1 226

READ     FL       PERCENT
         38         .019
         40         .095
         40         .079
         40         .014
         40         .065
         41         .019
         41         .026
         41         .156
         41         .065
         42         .189
         42         .026
         42         .283
         42         .155
         43         .170
         43         .184
         43         .368
         43         .168
         44         .398
         44         .289
         44         .453
         44         .374
         45         .663
         45        1.026
         45         .651
         45         .529
         46        1.136
         46         .999
         46         .906
         46         .929
         47        1.610
         47        1.867
         47        1.203
         47         .942
         48        1.913
         48        2.104
         48        1.685
         48         .942
         49        1.894
         49        2.078
         49        1.812
         49        1.149
         50        2.253
         50        1.999
         50        1.345
         50         .968
         51        2.632
         51        1.341
         51        1.812
```

51	1.226
52	2.575
52	1.710
52	1.770
52	1.523
53	2.878
53	2.130
53	2.251
53	2.039
54	3.087
54	2.104
54	2.010
54	1.691
55	3.617
55	2.236
55	2.605
55	2.478
56	3.977
56	2.209
56	2.662
56	3.214
57	4.014
57	2.630
57	3.440
57	3.550
58	4.469
58	2.972
58	3.879
58	4.570
59	4.582
59	3.524
59	4.163
59	5.344
60	4.658
60	3.367
60	4.389
60	5.977
61	5.151
61	3.919
61	4.955
61	6.235
62	5.056
62	4.077
62	4.460
62	6.570
63	4.242
63	4.918
63	4.913
63	6.816
64	3.541
64	4.392
64	4.502
64	6.209
65	3.901

65	4.314
65	3.738
65	5.538
66	3.617
66	4.524
66	3.653
66	4.841
67	3.257
67	4.419
67	3.313
67	4.621
68	2.727
68	4.261
68	3.030
68	3.446
69	2.405
69	3.761
69	2.973
69	2.969
70	2.765
70	3.367
70	2.761
70	2.130
71	2.045
71	3.025
71	2.888
71	2.323
72	1.950
72	3.261
72	2.690
72	1.433
73	2.064
73	2.578
73	2.676
73	1.472
74	1.723
74	2.683
74	2.449
74	1.446
75	1.704
75	1.920
75	1.770
75	1.213
76	1.307
76	1.604
76	1.869
76	.981
77	.966
77	1.604
77	1.501
77	.904
78	1.079
78	1.341
78	1.303

78	.684
79	.776
79	1.526
79	1.303
79	.439
80	.568
80	.868
80	.892
80	.555
81	.606
81	.684
81	.651
81	.310
82	.417
82	.368
82	.665
82	.181
83	.208
83	.289
83	.708
83	.245
84	.284
84	.316
84	.496
84	.116
85	.170
85	.132
85	.453
85	.077
86	.151
86	.342
86	.354
86	.142
87	.133
87	.132
87	.269
87	.103
88	.095
88	.053
88	.227
88	.052
89	.133
89	.105
89	.170
89	.013
90	.105
90	.099
90	.013
91	.038
91	.053
91	.099
91	.013
92	.042
93	.019

```
          93          .085
          93          .013
          94          .019
          94          .026
          94          .028
          95          .038
          95          .053
          95          .042
          96          .026
          97          .053
          97          .028
          99          .014
         101          .014
         110          .014
         114          .028
         120          .014

GENR LFL=LOG(FL)
GENR LFL2=LFL**2
GENR LPER=LOG(PERCENT)

GENR D40=(FL.EQ.40)
GENR D41=(FL.EQ.41)
GENR D42=(FL.EQ.42)
GENR D43=(FL.EQ.43)
GENR D44=(FL.EQ.44)
GENR D45=(FL.EQ.45)
GENR D46=(FL.EQ.46)
GENR D47=(FL.EQ.47)
GENR D48=(FL.EQ.48)
GENR D49=(FL.EQ.49)
GENR D50=(FL.EQ.50)
GENR D51=(FL.EQ.51)
GENR D52=(FL.EQ.52)
GENR D53=(FL.EQ.53)
GENR D54=(FL.EQ.54)
GENR D55=(FL.EQ.55)
GENR D56=(FL.EQ.56)
GENR D57=(FL.EQ.57)
GENR D58=(FL.EQ.58)
GENR D59=(FL.EQ.59)
GENR D60=(FL.EQ.60)
GENR D61=(FL.EQ.61)
GENR D62=(FL.EQ.62)
GENR D63=(FL.EQ.63)
GENR D64=(FL.EQ.64)
GENR D65=(FL.EQ.65)
GENR D66=(FL.EQ.66)
GENR D67=(FL.EQ.67)
GENR D68=(FL.EQ.68)
GENR D69=(FL.EQ.69)
GENR D70=(FL.EQ.70)
GENR D71=(FL.EQ.71)
GENR D72=(FL.EQ.72)
```

```
                    GENR D73=(FL.EQ.73)
                    GENR D74=(FL.EQ.74)
                    GENR D75=(FL.EQ.75)
                    GENR D76=(FL.EQ.76)
                    GENR D77=(FL.EQ.77)
                    GENR D78=(FL.EQ.78)
                    GENR D79=(FL.EQ.79)
                    GENR D80=(FL.EQ.80)
                    GENR D81=(FL.EQ.81)
                    GENR D82=(FL.EQ.82)
                    GENR D83=(FL.EQ.83)
                    GENR D84=(FL.EQ.84)
                    GENR D85=(FL.EQ.85)
                    GENR D86=(FL.EQ.86)
                    GENR D87=(FL.EQ.87)
                    GENR D88=(FL.EQ.88)
                    GENR D89=(FL.EQ.89)
                    GENR D90=(FL.EQ.90)
                    GENR D91=(FL.EQ.91)
                    GENR D92=(FL.EQ.92)
                    GENR D93=(FL.EQ.93)
                    GENR D94=(FL.EQ.94)
                    GENR D95=(FL.EQ.95)
                    GENR D96=(FL.EQ.96)
                    GENR D97=(FL.EQ.97)
                    GENR D99=(FL.EQ.99)
                    GENR D101=(FL.EQ.101)
                    GENR D110=(FL.EQ.110)
                    GENR D120=(FL.EQ.120)

OLS LPER LFL LFL2 (D42 D43 D44  D45  D46 D47 D48 &
                   D49  D50  D51  D53  D54  D55  D56 D57 D58 &
                   D59  D60  D61  D62  D63  D64  D65  D66 D67 D68 &
                   D69  D72  D73  D75 D76 D77  D78 &
                   D79  D80  D81  D82  D83  D84  D85  D86 D87 D88 &
                   D89  D90  D91  D92  D93  D94  D95 D96 D97 D99 &
                   D101) /LIST LM BEG=1

     STOP
```

APPENDIX F-8: Shazam Program for Regressing Eqn (225) on Trap Data

```
FILE 6 OP.DAT
Sample 1 265

READ     FL        PERCENT
         41         .069
         41         .028
         41         .028
         42         .127
         42         .069
         42         .083
         42         .055
         43         .211
         43         .034
         43         .111
         43         .028
         43         .045
         44         .423
         44         .069
         44         .278
         44         .166
         44         .045
         45         .423
         45         .172
         45         .390
         45         .415
         45         .045
         46         .211
         46         .207
         46         .584
         46         .498
         46         .178
         47         .380
         47         .517
         47        1.169
         47        1.051
         47         .268
         48         .549
         48         .931
         48        2.199
         48        1.410
         48         .446
         49         .719
         49         .483
         49        2.366
         49        1.687
         49         .402
         50        1.141
         50        2.242
         50        4.036
         50        2.876
         50         .803
         51        1.226
```

51	2.346
51	3.228
51	2.683
51	1.249
52	2.282
52	2.587
52	4.425
52	3.457
52	1.517
53	2.367
53	4.174
53	3.702
53	4.010
53	1.830
54	2.494
54	4.346
54	4.704
54	3.816
54	1.785
55	3.001
55	3.967
55	3.674
55	4.148
55	2.588
56	2.705
56	3.518
56	3.451
56	3.208
56	2.454
57	3.297
57	3.725
57	3.813
57	3.402
57	2.588
58	4.691
58	3.346
58	3.674
58	3.042
58	2.990
59	4.269
59	3.484
59	3.590
59	2.959
59	3.124
60	4.311
60	3.932
60	3.980
60	3.982
60	4.909
61	3.973
61	2.898
61	3.451
61	2.710
61	4.775

62	4.438
62	4.001
62	3.590
62	3.374
62	4.641
63	4.607
63	4.277
63	3.674
63	3.872
63	5.756
64	5.495
64	3.725
64	4.314
64	3.457
64	5.176
65	3.635
65	4.001
65	4.147
65	4.314
65	4.730
66	3.381
66	4.588
66	4.036
66	4.121
66	4.373
67	3.128
67	4.001
67	3.034
67	3.457
67	4.685
68	3.466
68	3.967
68	3.535
68	3.208
68	3.927
69	3.719
69	3.139
69	2.672
69	3.291
69	4.150
70	3.719
70	3.415
70	2.922
70	3.650
70	4.596
71	2.916
71	3.070
71	2.199
71	2.434
71	3.659
72	4.015
72	2.967
72	1.614
72	2.765

72	2.945
73	2.959
73	2.691
73	1.893
73	2.295
73	2.856
74	2.747
74	2.173
74	2.004
74	1.576
74	2.142
75	2.367
75	2.035
75	1.225
75	1.963
75	2.053
76	2.113
76	1.518
76	1.058
76	1.798
76	1.740
77	1.522
77	1.518
77	1.197
77	1.604
77	2.231
78	1.437
78	.897
78	.974
78	1.355
78	1.517
79	.803
79	.793
79	.668
79	1.162
79	.982
80	.888
80	.690
80	.473
80	1.051
80	1.294
81	.972
81	.897
81	.334
81	.691
81	.848
82	.676
82	.414
82	.390
82	.608
82	.714
83	.380
83	.448
83	.362

83	.415
83	.937
84	.507
84	.448
84	.278
84	.525
84	.312
85	.254
85	.276
85	.167
85	.138
85	.446
86	.211
86	.276
86	.332
86	.357
87	.169
87	.207
87	.056
87	.111
87	.089
88	.127
88	.207
88	.111
88	.249
88	.178
89	.042
89	.069
89	.083
89	.055
89	.045
90	.127
90	.138
90	.221
90	.223
91	.085
91	.028
91	.028
91	.089
92	.085
92	.083
92	.134
93	.042
93	.034
93	.055
93	.045
94	.042
94	.083
95	.028
95	.045
96	.028
96	.045
97	.042
99	.042

```
        100          .042

 GENR LFL=LOG(FL)
 GENR LFL2=LFL**2
 GENR LPER=LOG(PERCENT)

 GENR D41=(FL.EQ.41)
 GENR D42=(FL.EQ.42)
 GENR D43=(FL.EQ.43)
 GENR D44=(FL.EQ.44)
 GENR D45=(FL.EQ.45)
 GENR D46=(FL.EQ.46)
 GENR D47=(FL.EQ.47)
 GENR D48=(FL.EQ.48)
 GENR D49=(FL.EQ.49)
 GENR D50=(FL.EQ.50)
 GENR D51=(FL.EQ.51)
 GENR D52=(FL.EQ.52)
 GENR D53=(FL.EQ.53)
 GENR D54=(FL.EQ.54)
 GENR D55=(FL.EQ.55)
 GENR D56=(FL.EQ.56)
 GENR D57=(FL.EQ.57)
 GENR D58=(FL.EQ.58)
 GENR D59=(FL.EQ.59)
 GENR D60=(FL.EQ.60)
 GENR D61=(FL.EQ.61)
 GENR D62=(FL.EQ.62)
 GENR D63=(FL.EQ.63)
 GENR D64=(FL.EQ.64)
 GENR D65=(FL.EQ.65)
 GENR D66=(FL.EQ.66)
 GENR D67=(FL.EQ.67)
 GENR D68=(FL.EQ.68)
 GENR D69=(FL.EQ.69)
 GENR D70=(FL.EQ.70)
 GENR D71=(FL.EQ.71)
 GENR D72=(FL.EQ.72)
 GENR D73=(FL.EQ.73)
 GENR D74=(FL.EQ.74)
 GENR D75=(FL.EQ.75)
 GENR D76=(FL.EQ.76)
 GENR D77=(FL.EQ.77)
 GENR D78=(FL.EQ.78)
 GENR D79=(FL.EQ.79)
 GENR D80=(FL.EQ.80)
 GENR D81=(FL.EQ.81)
 GENR D82=(FL.EQ.82)
 GENR D83=(FL.EQ.83)
 GENR D84=(FL.EQ.84)
 GENR D85=(FL.EQ.85)
 GENR D86=(FL.EQ.86)
 GENR D87=(FL.EQ.87)
 GENR D88=(FL.EQ.88)
```

```
          GENR D89=(FL.EQ.89)
          GENR D90=(FL.EQ.90)
          GENR D91=(FL.EQ.91)
          GENR D92=(FL.EQ.92)
          GENR D93=(FL.EQ.93)
          GENR D94=(FL.EQ.94)
          GENR D95=(FL.EQ.95)
          GENR D96=(FL.EQ.96)
          GENR D97=(FL.EQ.97)
          GENR D99=(FL.EQ.99)
          GENR D100=(FL.EQ.100)

OLS LPER LFL LFL2 &
                (D41 D42 D43 D44 D45 D46 D47 D48 D49 D50 &
                 D51 D52 D53 D54 D55 D56 D57 D58 D59 D61 &
                 D62 D67 D73 D77 D79 D82 D83 D85 D87 D88 &
                 D89 D90 D91 D92 D93 D94 D95 D96 D97 D99 &
                 D100 /LIST LM
           STOP
```

APPENDIX F-9: Shazam Program for Regressing Eqn (225) on Longline (Male) Data

```
FILE 6 OP.DAT
Sample 1 163

READ      FL        PERCENT
          40          .068
          40          .051
          40          .027
          41          .034
          41          .108
          41          .054
          42          .170
          42          .051
          42          .298
          42          .108
          43          .170
          43          .202
          43          .244
          43          .108
          44          .374
          44          .354
          44          .298
          44          .361
          45          .544
          45          .909
          45          .434
          45          .361
          46          .816
          46         1.212
          46          .732
          46          .759
          47         1.292
          47         2.273
          47         1.138
          47          .705
          48         1.564
          48         2.273
          48         1.220
          48          .632
          49         1.360
          49         2.525
          49         1.626
          49          .867
          50         2.176
          50         2.172
          50         1.247
          50          .849
          51         2.856
          51         1.465
          51         2.114
          51         1.265
          52         2.754
```

52	2.222
52	2.385
52	1.735
53	3.706
53	2.576
53	3.089
53	2.331
54	4.318
54	2.576
54	2.602
54	1.970
55	4.964
55	3.434
55	4.011
55	3.036
56	5.848
56	3.081
56	3.902
56	4.120
57	5.814
57	4.242
57	5.474
57	4.518
58	7.004
58	4.141
58	6.098
58	5.999
59	6.664
59	5.606
59	6.856
59	6.867
60	6.902
60	5.455
60	7.182
60	7.806
61	7.684
61	6.162
61	7.967
61	8.150
62	7.242
62	6.667
62	6.992
62	8.366
63	5.066
63	7.222
63	6.748
63	8.475
64	4.522
64	6.616
64	6.152
64	7.373
65	4.488
65	5.303
65	4.526

65	6.162
66	3.332
66	5.253
66	3.794
66	5.060
67	2.856
67	4.495
67	3.333
67	4.030
68	1.836
68	3.990
68	2.466
68	2.801
69	1.394
69	2.424
69	2.087
69	1.735
70	.816
70	1.717
70	1.328
70	1.156
71	.374
71	.909
71	.786
71	.777
72	.374
72	1.061
72	.867
72	.560
73	.238
73	.455
73	.407
73	.217
74	.136
74	.455
74	.352
74	.199
75	.102
75	.303
75	.136
75	.235
76	.068
76	.051
76	.352
76	.108
77	.034
77	.163
77	.072
78	.051
78	.108
78	.018
79	.051
79	.136
79	.018

```
          80          .034
          80          .018
          81          .054
          83          .027
          83          .018
          84          .054
          85          .054
          87          .027

GENR LFL=LOG(FL)
GENR LFL2=LFL**2
GENR LPER=LOG(PERCENT)

GENR D40=(FL.EQ.40)
GENR D41=(FL.EQ.41)
GENR D42=(FL.EQ.42)
GENR D43=(FL.EQ.43)
GENR D44=(FL.EQ.44)
GENR D45=(FL.EQ.45)
GENR D46=(FL.EQ.46)
GENR D47=(FL.EQ.47)
GENR D48=(FL.EQ.48)
GENR D49=(FL.EQ.49)
GENR D50=(FL.EQ.50)
GENR D51=(FL.EQ.51)
GENR D52=(FL.EQ.52)
GENR D53=(FL.EQ.53)
GENR D54=(FL.EQ.54)
GENR D55=(FL.EQ.55)
GENR D56=(FL.EQ.56)
GENR D57=(FL.EQ.57)
GENR D58=(FL.EQ.58)
GENR D59=(FL.EQ.59)
GENR D60=(FL.EQ.60)
GENR D61=(FL.EQ.61)
GENR D62=(FL.EQ.62)
GENR D63=(FL.EQ.63)
GENR D64=(FL.EQ.64)
GENR D65=(FL.EQ.65)
GENR D66=(FL.EQ.66)
GENR D67=(FL.EQ.67)
GENR D68=(FL.EQ.68)
GENR D69=(FL.EQ.69)
GENR D70=(FL.EQ.70)
GENR D71=(FL.EQ.71)
GENR D72=(FL.EQ.72)
GENR D73=(FL.EQ.73)
GENR D74=(FL.EQ.74)
GENR D75=(FL.EQ.75)
GENR D76=(FL.EQ.76)
GENR D77=(FL.EQ.77)
GENR D78=(FL.EQ.78)
GENR D79=(FL.EQ.79)
GENR D80=(FL.EQ.80)
```

```
          GENR D81=(FL.EQ.81)
          GENR D83=(FL.EQ.83)
          GENR D84=(FL.EQ.84)
          GENR D85=(FL.EQ.85)
          GENR D87=(FL.EQ.87)

OLS LPER LFL LFL2 &
                 (D40 D41 D42 D43 D44 D45 D46 D47 D48 D49 &
                  D50 D51 D52 D53 D54 D55 D56 D57 D58 D59 &
                  D60 D61 D62 D63 D64 D65 D66 D67 D68 D69 &
                  D70 D71 D72 D73 D74 D75 D76 D77 D78 D79 &
                  D80 D81 D83 D84 D85 D87 &
                  ) /LIST LM
     STOP
```

APPENDIX F-10: Shazam Program for Regressing Eqn (225) on Longline (Female) Data

```
FILE 6 OP.DAT
Sample 1 223

READ     FL        PERCENT

         38          .043
         40          .128
         40          .110
         40          .226
         41          .055
         41          .208
         41          .090
         42          .214
         42          .267
         42          .271
         43          .171
         43          .165
         43          .504
         43          .316
         44          .427
         44          .220
         44          .623
         44          .407
         45          .812
         45         1.153
         45          .889
         45          .949
         46         1.538
         46          .768
         46         1.097
         46         1.356
         47         2.009
         47         1.427
         47         1.275
         47         1.536
         48         2.350
         48         1.921
         48         2.194
         48         1.717
         49         2.564
         49         1.592
         49         2.016
         49         1.853
         50         2.350
         50         1.811
         50         1.453
         50         1.265
         51         2.350
         51         1.207
         51         1.482
         51         1.130
```

52	2.350
52	1.153
52	1.097
52	.994
53	1.838
53	1.647
53	1.334
53	1.310
54	1.538
54	1.592
54	1.364
54	.994
55	1.923
55	.933
55	1.067
55	1.085
56	1.624
56	1.262
56	1.304
56	.949
57	1.752
57	.878
57	1.216
57	1.130
58	1.282
58	1.701
58	1.453
58	.994
59	1.966
59	1.262
59	1.216
59	1.536
60	1.838
60	1.098
60	1.334
60	1.401
61	1.966
61	1.482
61	1.660
61	1.446
62	2.308
62	1.262
62	1.690
62	2.079
63	3.205
63	2.415
63	2.905
63	2.666
64	2.308
64	1.976
64	2.698
64	3.299
65	3.162
65	3.238

65	2.876
65	3.977
66	3.974
66	3.732
66	3.498
66	4.293
67	3.761
67	4.336
67	3.291
67	6.100
68	3.846
68	4.555
68	3.647
68	5.061
69	3.675
69	5.214
69	3.943
69	6.055
70	5.214
70	5.159
70	4.328
70	4.564
71	4.145
71	5.324
71	5.188
71	6.191
72	3.932
72	5.653
72	4.684
72	3.615
73	4.359
73	4.885
73	5.159
73	4.609
74	3.718
74	5.104
74	4.744
74	4.564
75	3.718
75	3.677
75	3.558
75	3.660
76	2.863
76	3.293
76	3.528
76	3.163
77	2.137
77	3.348
77	2.965
77	2.982
78	2.436
78	2.744
78	2.609
78	2.350

79	1.752
79	3.128
79	2.579
79	1.491
80	1.239
80	1.811
80	1.868
80	1.898
81	1.368
81	1.427
81	1.304
81	1.085
82	.940
82	.768
82	1.393
82	.633
83	.470
83	.604
83	1.453
83	.813
84	.641
84	.659
84	.978
84	.407
85	.385
85	.274
85	.889
85	.271
86	.342
86	.714
86	.741
86	.497
87	.299
87	.274
87	.534
87	.362
88	.214
88	.110
88	.474
88	.181
89	.299
89	.220
89	.356
89	.045
90	.220
90	.208
90	.045
91	.085
91	.110
91	.208
91	.045
92	.089
93	.043
93	.178

```
            93          .045
            94          .043
            94          .055
            94          .059
            95          .085
            95          .110
            95          .089
            96          .055
            97          .110
            97          .059
            99          .030
           101          .030
           110          .030
           114          .059
           120          .030

GENR LFL=LOG(FL)
GENR LFL2=LFL**2
GENR LPER=LOG(PERCENT)

GENR D38=(FL.EQ.38)
GENR D40=(FL.EQ.40)
GENR D41=(FL.EQ.41)
GENR D42=(FL.EQ.42)
GENR D43=(FL.EQ.43)
GENR D44=(FL.EQ.44)
GENR D45=(FL.EQ.45)
GENR D46=(FL.EQ.46)
GENR D47=(FL.EQ.47)
GENR D48=(FL.EQ.48)
GENR D49=(FL.EQ.49)
GENR D50=(FL.EQ.50)
GENR D51=(FL.EQ.51)
GENR D52=(FL.EQ.52)
GENR D53=(FL.EQ.53)
GENR D54=(FL.EQ.54)
GENR D55=(FL.EQ.55)
GENR D56=(FL.EQ.56)
GENR D57=(FL.EQ.57)
GENR D58=(FL.EQ.58)
GENR D59=(FL.EQ.59)
GENR D60=(FL.EQ.60)
GENR D61=(FL.EQ.61)
GENR D62=(FL.EQ.62)
GENR D63=(FL.EQ.63)
GENR D64=(FL.EQ.64)
GENR D65=(FL.EQ.65)
GENR D66=(FL.EQ.66)
GENR D67=(FL.EQ.67)
GENR D68=(FL.EQ.68)
GENR D69=(FL.EQ.69)
GENR D70=(FL.EQ.70)
GENR D71=(FL.EQ.71)
GENR D72=(FL.EQ.72)
```

```
                    GENR D73=(FL.EQ.73)
                    GENR D74=(FL.EQ.74)
                    GENR D75=(FL.EQ.75)
                    GENR D76=(FL.EQ.76)
                    GENR D77=(FL.EQ.77)
                    GENR D78=(FL.EQ.78)
                    GENR D79=(FL.EQ.79)
                    GENR D80=(FL.EQ.80)
                    GENR D81=(FL.EQ.81)
                    GENR D82=(FL.EQ.82)
                    GENR D83=(FL.EQ.83)
                    GENR D84=(FL.EQ.84)
                    GENR D85=(FL.EQ.85)
                    GENR D86=(FL.EQ.86)
                    GENR D87=(FL.EQ.87)
                    GENR D88=(FL.EQ.88)
                    GENR D89=(FL.EQ.89)
                    GENR D90=(FL.EQ.90)
                    GENR D91=(FL.EQ.91)
                    GENR D92=(FL.EQ.92)
                    GENR D93=(FL.EQ.93)
                    GENR D94=(FL.EQ.94)
                    GENR D95=(FL.EQ.95)
                    GENR D96=(FL.EQ.96)
                    GENR D97=(FL.EQ.97)
                    GENR D99=(FL.EQ.99)
                    GENR D101=(FL.EQ.101)
                    GENR D110=(FL.EQ.110)
                    GENR D114=(FL.EQ.114)
                    GENR D120=(FL.EQ.120)

OLS LPER LFL LFL2 &
                                        (D45 D46 D47 D48 &
                D49 D50 D51 D52 D53 D54 D55 D56 D57 D58 &
                D59 D60 D61 D62 D63 D64 D65 D66 D67 D68 &
                D69 D70 D71 D72 D73 D74 D75 D76 D77 D78 &
                D79 D80 D81 D82 D83 D84 D85 D86 D87 D88 &
                D89 D90 D91 D92 D93 D94 D95 D96 D97 D99 &
                 ) /LIST LM

    STOP
```

APPENDIX G: Example Types of Functional Responses

The form, shape and behaviour of 12 response functions are discussed in the following appendices. Response functions I to III (see Figure G-1) are adapted from the response types discussed by Holling (1959). The mirror images of the functions (Figure G-2) are labeled, respectively, Ia to IIIa. The inverses of functions I to III (Figure G-3) are labeled, respectively, Ib to IIIb. The inverses of the mirror images of functions I to III (Figure G-4) are labeled, respectively, Ic to IIIc.

Symmetry causes the Type Ic function to equal the Type I and the Type Ib function to equal the Type Ia.

In a fish stock with planktonic larval stage, the numbers of potential recruits will tend to vary with the stock numbers or biomass. Based on the functional response types shown in this appendix response Types I, III and IIb are good choices. Peterman (1982) provides strong arguments against a linear recruitment to adult relation—eliminating the Type I function. Equation Type III implies a strong compensatory effect (when the stock biomass is low) and it is a relatively complex function. Functional response Type IIb appears to be the best choice and is consistent with Peterman's findings.

$$\text{Recruits}_p = a(1 - e^{-bX}) \qquad (164)$$

Recruits_p = potential recruits (in tonnes/metre)

X = stock total biomass (it is the integral of X_i over the length of the fishery

X_i = point i biomass density

The rate of piece growth, in any location, is likely to vary inversely with the stock local density and that rate might be described by equation Type Ia, IIIa or IIc (Appendix C). A logistic type growth curve (simple and linear) is the result when eqn Ia is used:

$$r_i = (1-gX_i)r \qquad (165)$$

r_i = growth rate at location i
X_i = biomass density at location i
r = maximum growth rate
g = a parameter

and eqn IIc produces the following nonlinear growth curve:

$$r_i = [1-g(e^{hX_i} - 1)]r \qquad (166)$$

h = a parameter

The first derivatives of eqns (165) and (166), with respect to Xi (the local biomass) are negative and, therefore, consistent with an inverse relationship between local growth and local biomass. The second derivative of eqn (165) is zero, which means that the marginal reduction in growth does not vary with the stock density. The second derivative of eqn (166) is negative, which means that the decline in the growth rate accelerates as stock density increases. While the realism of eqn (166) is desirable, the simplicity of the relation in eqn (165) generates an elegant illustration of the basic concept of location selectivity.

$$\text{Growth}_i = rX_i(1 - gX_i) \qquad (167)$$

APPENDIX G-1: Function Types I to III (Holling, 1959); Along with the Mirror Images, Inverses and Inverted Mirror Images

TYPE I - FUNCTION FORM	• $Y = a + bX$
• Slope Characteristics	• Upward Sloping; $dY/dX = b > -0-$ • Constant; $d^2Y/dX^2 = -0-$
• Parameter Inferences	• Y-intercept = a • slope = $b = (Y_1-a)/X_1 = (Y_2-Y_1)/(X_2-X_1)$
TYPE II - FUNCTION FORM	• $Y = a(\exp^{bX}) - c$
• Slope Characteristics	• Upward Sloping; $dY/dX = ab(\exp^{bX}) > -0-$ • Increasing; $d^2Y/dX^2 = ab^2(\exp^{bX})$
• Parameter Inferences	• Y-intercept = a - c • a = c when Y-intercept = -0- • $b = [ln(Y_1+c)-ln(a)]/X_1$ • as a increases to 1.0E8, a type I function is approached; at a = 1.0E20 a three step *step-function* is generated.
TYPE III - FUNCTION FORM	• $Y = a/(b + \exp^{-cX}) - g$
• Slope Characteristics	• Upward Slope; $dY/dX = ca\exp^{-cX}/(b+\exp^{-cX})^2$ • Increasing to mid point then decreasing $d^2Y/dX^2 = c^2a\exp^{-cX}(b-\exp^{-cX})/(b-\exp^{-cX})^3$
• Parameter Inferences	• Y-intercept=$a/(1+b)-g$, X-intercept=20,000 • $a = Y_{max}b(1+B)$ • $b = \exp^{-cX_o}$; X_o is the inflection point X; it is developed from the second derivative • X_o increases with c; for large values of c the equation degenerates toward a Type IIc • $g = a/(b+1)$; Y-intercept shift.
TYPE Ia - INVERSE OF I	• $Y = a - bX$
• Slope Characteristics	• Downward Sloping ($dY/dX = -b < -0-$) • Constant ($d^2Y/dX^2 = -0-$)
• Parameter Inferences	• Y-intercept = a • slope = $b = (Y_1-a)/X_1 = (Y_2-Y_1)/(X_2-X_1)$
TYPE IIa - INVERSE OF II	• $Y = a(\exp^{-bX}) - c$
• Slope Characteristics	• Upward Sloping ($dY/dX = ab(\exp^{bX}) > -0-$) • Increasing ($d^2Y/dX^3 = ab^2(\exp^{bX})$)
• Parameter Inferences	• Y-intercept = a - c • c is a up/down shift parameter • $b = [ln(Y_1+c)-ln(a)]/X_1$
TYPE IIIa - INVERSE OF III	• $Y = a/(b + \exp^{cX}) - g$
• Slope Characteristics	• downward Slope; $dY/dX = ca\exp^{cX}/(b+\exp^{cX})^2$ • decreasing to mid point then increasing
• Parameter Inferences	• Y-intercept = $a/(1+b)-g = 0$ = X-intercept • $a = Y_{max}b(1+B)$ • $b = \exp^{-cX_o}$; X_o is the inflection point X; it is developed from the second derivative • X_o decreases with c; for large values of c the equation degenerates toward a Type IIa • $g = a/(b+\exp^{c200000})$; Y-intercept shift.

APPENDIX C-1: Function Types I to III (Holling, 1959); Along with the Mirror Images, Inverses and Inverted Mirror Images (Continued)

TYPE Ib - INVERTED I	• $Y = a + bX$
• Comments	• Same as Type I
• Parameter Inferences	• Y-intercept = a
	• slope = $b = (Y_1-a)/X_1 = (Y_2-Y_1)/(X_2-X_1)$
TYPE IIb - INVERTED II	• $Y = c - a(\exp^{-bX})$
• Slope Characteristics	• Upward Sloping ($dY/dX = ab(\exp^{bX}) >$ -0-)
	• Decreasing ($d^2Y/dX^2 = -ab^2(\exp^{bX})$)
• Parameter Inferences	• Y-intercept = c - a
	• c is a up/down shift parameter
	• $b = -ln((c-Y_1)/a)/X_1$
TYPE IIIb - INVERTED III	• $Y = ln[a/(X+g) - b]/c$
• Slope Characteristics	• Upward Sloping
	• Decreasing to the mid point of Y=10,000) and then the slope is increasing
• Parameter Inferences	• Y-intercept = ∞, X-intercept = 200,000
	• $a=(\exp^{c10000}-1)/[1/(100000+g)-1/(200000+g)]$
	• $b = a/(200000+g) -1$
	• c = controls the slope of the function
	• g = X-intercept shift. $g > 0$, iff $X \leq 0$.
	• This function is very sensitive to chnages in the parameter values.

TYPE Ic - INVERTED Ib	• $Y = a - bX$
• Comments	• Same as Type Ia
• Parameter Inferences	• Y-intercept = a
	• slope = $b = (Y_1-a)/X_1 = (Y_2-Y_1)/(X_2-X_1)$
TYPE IIc - INVERTED IIb	• $Y = c - a(\exp^{bX})$
• Slope Characteristics	• Downward Sloping ($dY/dX = -ab(\exp^{bX}) >$ -0-)
	• Decreasing ($d^2Y/dX^2 = -ab^2(\exp^{bX})$)
• Parameter Inferences	• Y-intercept = c - a
	• c is a up/down shift parameter
	• a = c when Y-intercept = -0-
	• $b = ln((c-Y_1)/a)/X_1$
TYPE IIIc - INVERTED IIIb	• $Y = ln[a/(X+g) - b]/c$
• Slope Characteristics	• Downward Sloping
	• Increasing to mid point of Y = 10,000 and then the slope is decreasing
• Parameter Inferences	• Y-intercept = -0-, X-intercept = -0-
	• $a =(\exp^{-c10000}-\exp^{-c20000})$ $/[1/(100000+g)-1/(200000+g)]$
	• $b = a/(200000+g) - \exp^{-c10000}$
	• c = controls the slope of the function
	• g = X-intercept shift. $g > 0$, iff $X \leq 0$.
	• This function is very sensitive to chnages in the parameter values.

APPENDIX G-2: Numerical Examples of Functions

STOCK BIOMASS (tonnes)	TYPE I	TYPE II	TYPE III	TYPE Ia	TYPE IIa	TYPE IIIa
	FUNCTION VALUES			MIRROR IMAGE VALUES		
-0-	-0-	-0-	-0-	20,000	20,000	20,000
10,000	1,000	164	87	19,000	17,035	19,913
20,000	2,000	356	229	18,000	14,488	19,771
30,000	3,000	579	459	17,000	12,301	19,542
40,000	4,000	838	826	16,000	10,423	19,175
50,000	5,000	1,141	1,402	15,000	8,810	18,598
60,000	6,000	1,493	2,281	14,000	7,425	17,720
70,000	7,000	1,903	3,562	13,000	6,235	16,438
80,000	8,000	2,380	5,316	12,000	5,213	14,684
90,000	9,000	2,935	7,518	11,000	4,336	12,483
100,000	10,000	3,583	10,000	10,000	3,583	10,000
110,000	11,000	4,336	12,483	9,000	2,935	7,518
120,000	12,000	5,213	14,684	8,000	2,380	5,316
130,000	13,000	6,235	16,438	7,000	1,903	3,562
140,000	14,000	7,425	17,720	6,000	1,493	2,281
150,000	15,000	8,810	18,598	5,000	1,141	1,402
160,000	16,000	10,423	19,175	4,000	838	826
170,000	17,000	12,301	19,542	3,000	579	459
180,000	18,000	14,488	19,771	2,000	356	229
190,000	19,000	17,035	19,913	1,000	164	87
200,000	20,000	20,000	20,000	-0-	-0-	-0-
	PARAMETER VALUES:			PARAMETER VALUES:		
a =	.00	1,000	136.59	20,000	21,000	3,008,583
b =	.10	1.52226E-5	6.7379E-3	.10	1.52226E-5	148.413
c =	na	1,000	.000050	na	1,000	.000050
d =	na	na	20,136	na	na	20,136
g =	na	na	135.675	na	na	135.675

FUNCTION FORMS -**TYPE I** $Y = a + bX$
TYPE II $Y = a(\exp^{bX}) - c$
TYPE III $Y = a/(b + \exp^{-cX}) - g$

--**TYPE Ia** $Y = a - bX$
TYPE IIa $Y = a(\exp^{-bX}) - c$
TYPE IIIa $Y = a/(b + \exp^{cX}) - g$

APPENDIX C-2: Numerical Examples of Functions (Continued)

STOCK BIOMASS (tonnes)	TYPE Ib	TYPE IIb	TYPE IIIb	TYPE Ic	TYPE IIc	TYPE IIIc
	INVERTED VALUES			INVERTED MIRROR IMAGE VALUES		
-0-	-0-	-0-	-0-	20,000	20,000	20,000
10,000	1,000	2,965	7,588	19,000	19,836	12,412
20,000	2,000	5,512	8,200	18,000	19,644	11,800
30,000	3,000	7,699	8,579	17,000	19,421	11,421
40,000	4,000	9,577	8,864	16,000	19,162	11,136
50,000	5,000	11,190	9,100	15,000	18,859	10,900
60,000	6,000	12,575	9,306	14,000	18,507	10,694
70,000	7,000	13,765	9,493	13,000	18,097	10,507
80,000	8,000	14,787	9,668	12,000	17,620	10,332
90,000	9,000	15,664	9,836	11,000	17,065	10,164
100,000	10,000	16,417	10,000	10,000	16,417	10,000
110,000	11,000	17,065	10,164	9,000	15,664	9,836
120,000	12,000	17,620	10,332	8,000	14,787	9,668
130,000	13,000	18,097	10,507	7,000	13,765	9,493
140,000	14,000	18,507	10,694	6,000	12,575	9,306
150,000	15,000	18,859	10,900	5,000	11,190	9,100
160,000	16,000	19,162	11,136	4,000	9,577	8,864
170,000	17,000	19,421	11,421	3,000	7,699	8,579
180,000	18,000	19,644	11,800	2,000	5,512	8,200
190,000	19,000	19,836	12,412	1,000	2,965	7,588
200,000	20,000	20,000	20,000	-0-	-0-	-0-
	PARAMETER VALUES:			PARAMETER VALUES:		
a =	.00	21,000	1.00008265	20,000	1,000	3.9997E+10
b =	.10	1.522E-5	5.000363E-6	.10	1.522E-5	1.99985E+5
c =	na	21,000	1.22060E-3	na	21,000	1.22060E-3
d =	na	na	na	na	na	na
g =	na	na	1.00000	na	na	1.00000

FUNCTION FORMS -- TYPE Ib $Y = a + bX$
TYPE IIb $Y = c - a(\exp^{-bX})$
TYPE IIIb $Y = -\ln[a/(X+g) - b]/c$

-- TYPE Ic $Y = a - bX$
TYPE IIc $Y = c - a(\exp^{bX})$
TYPE IIIc $Y = \ln[a/(X+g) - b]/c$

FIGURE G-1: Shape of Functional Response Types I Through III

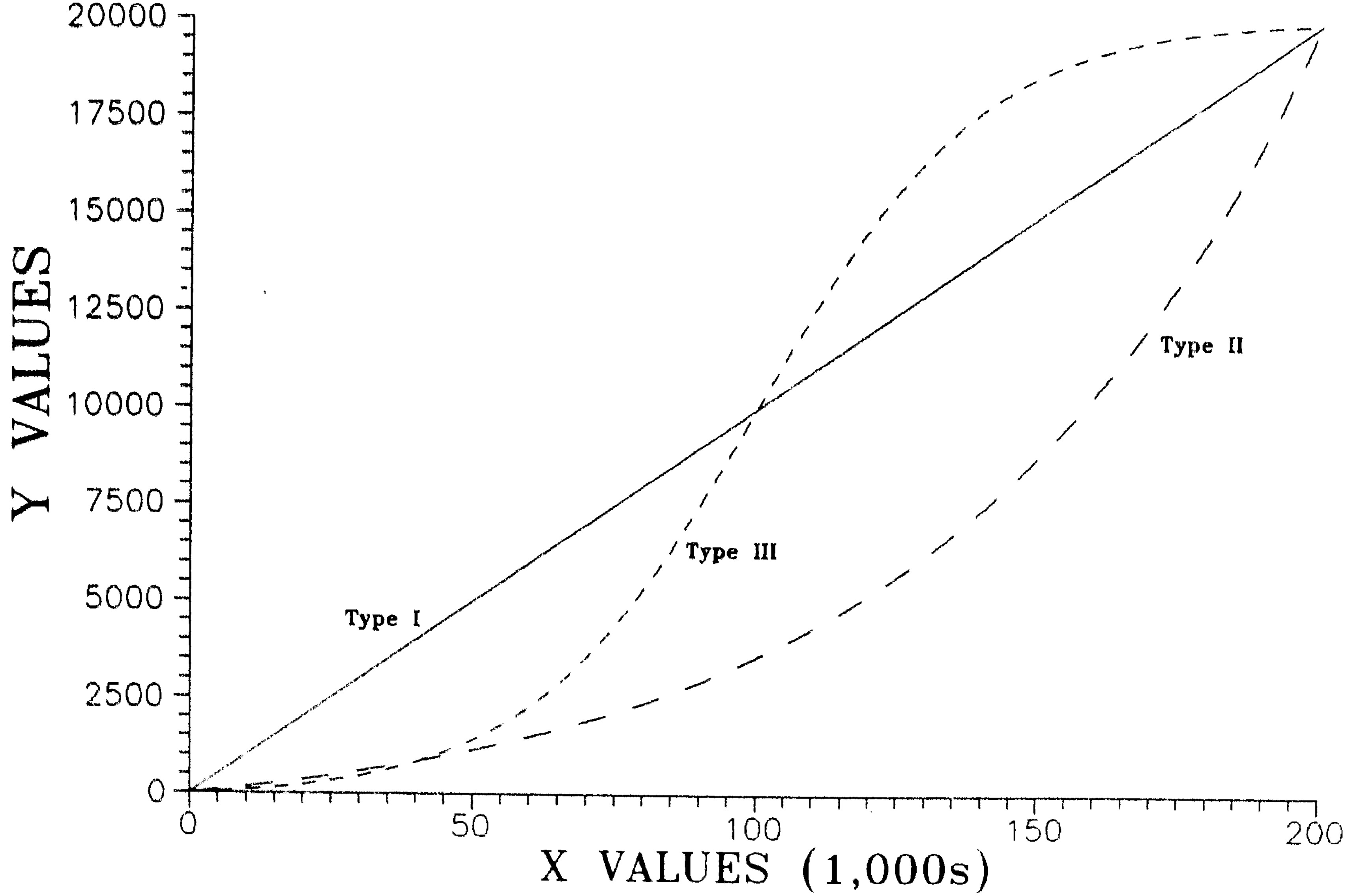


FIGURE G-2: Shape of Functional Response Types Ia Through IIIa
(Mirror Images of Equation Types I Through III)

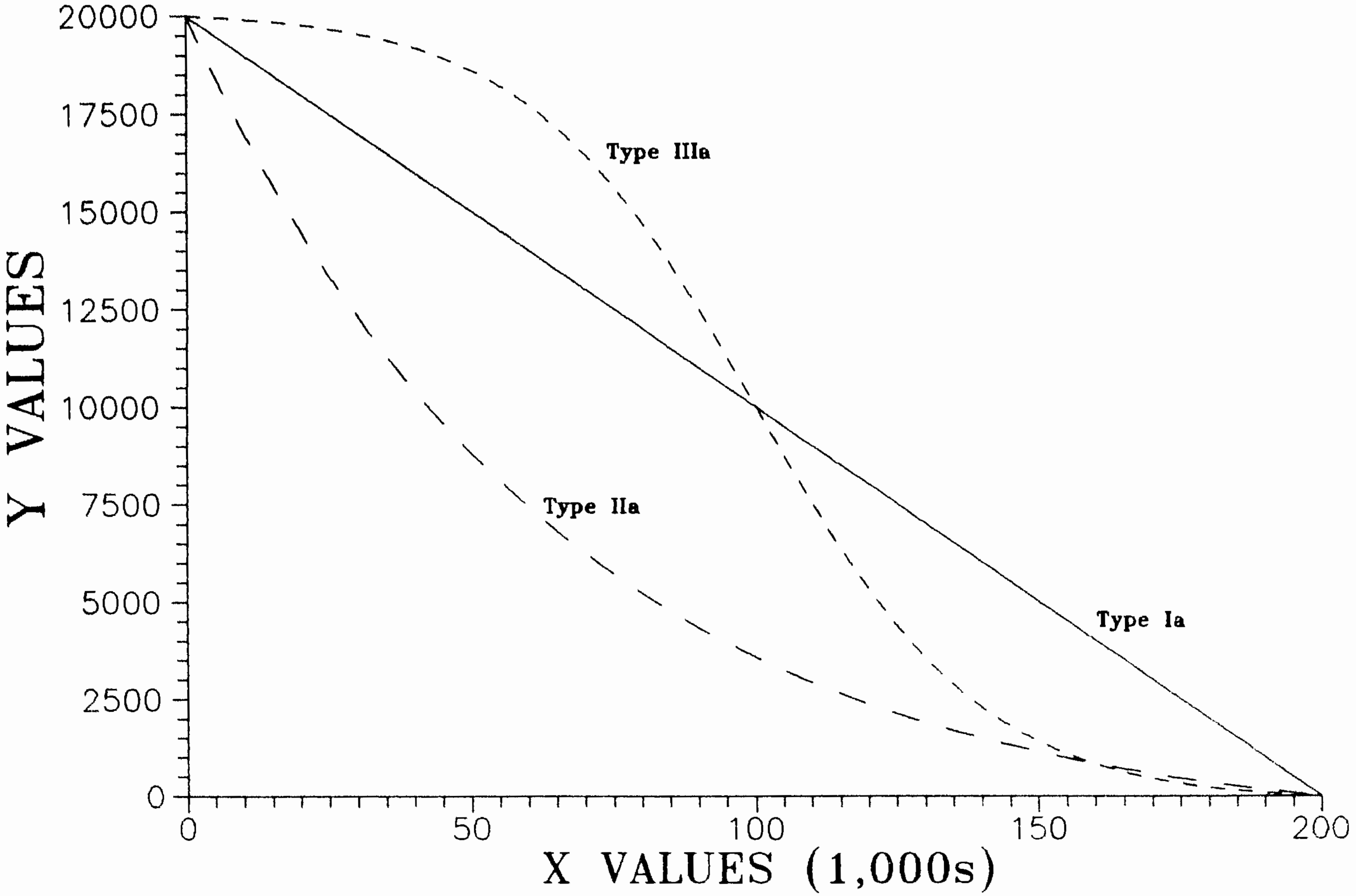


FIGURE G–3: Shape of Functional Response Types Ib Through IIIb (Inverses of Equations Types I Through III)

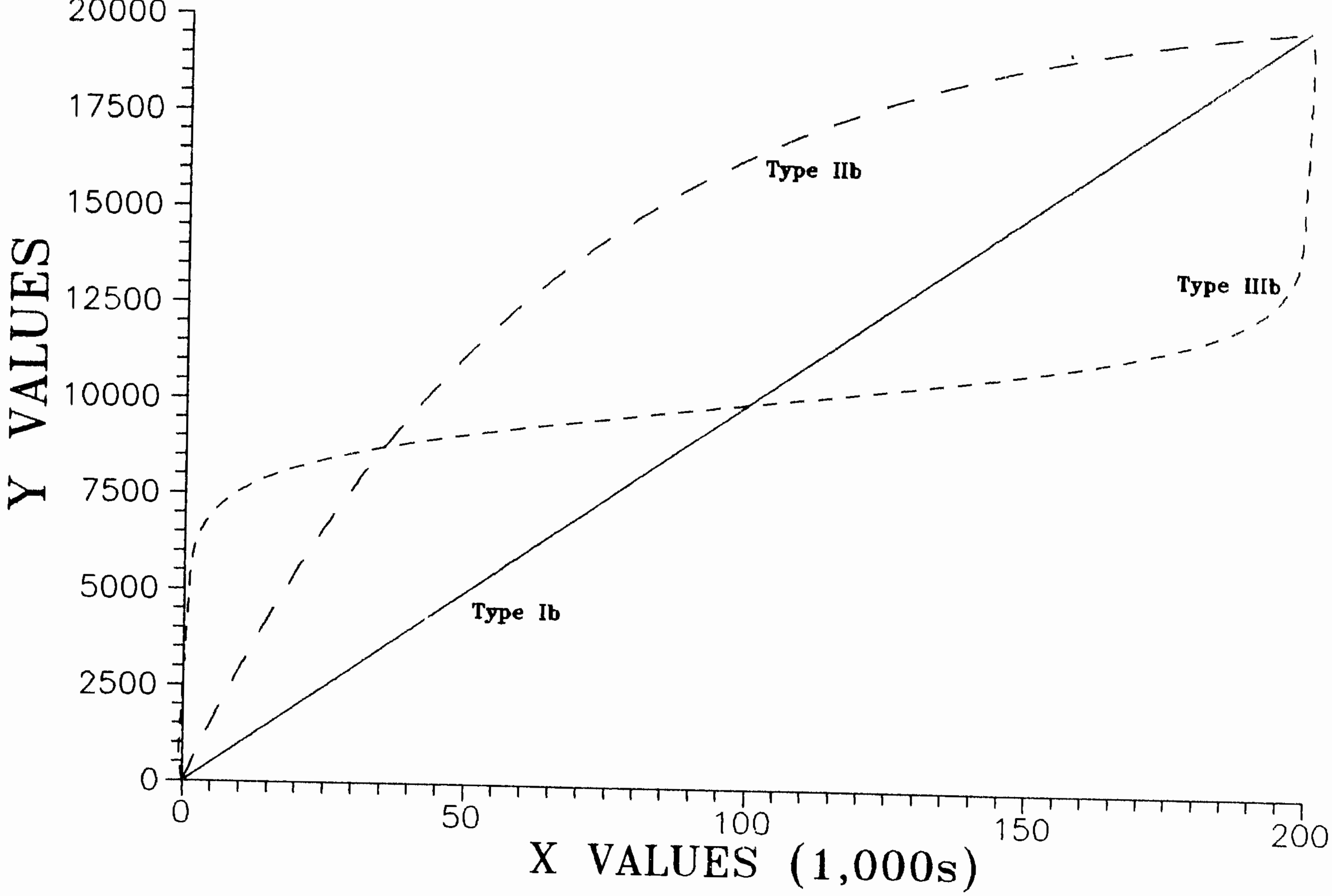
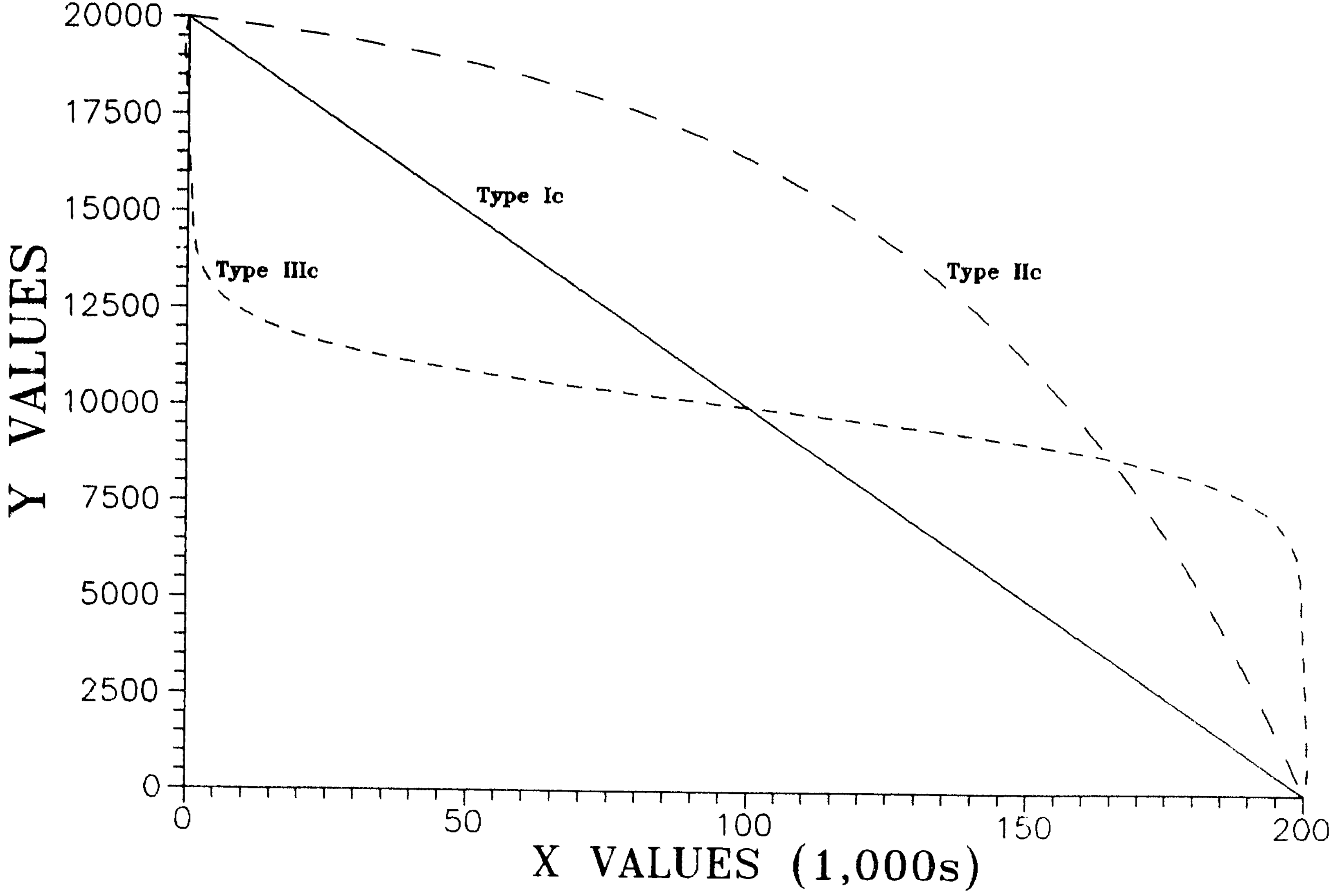


FIGURE G-4: Shape of Functional Response Types Ic Through IIIc (Inverses of Equations Ia Through IIIa)



BIBLIOGRAPHY

Abbott E. 1952. Flatland. (7th edition). Dover Publications, Inc. New York, N.Y.

Abdel-khalik, A.R. 1989. Non-market Accounting Decisions and Research: Connecting the Old and the New. Draft of a report to be presented at: The Golden Jubilee of Illinois Ph.D. in Accountancy program on June 1-3, 1989. Draft Date: May 4, 1989.

Ackerman, B. 1990. FAX on the history of: The Sablefish Fishery 1981-1989. (Canadian) Department of Fisheries and Oceans, Offshore Division, Vancouver, B.C. (phone: 604-666-3991).

Abler, R., J.S. Adams and P. Gould. 1971. Spacial Organization (The Geographer's View of the World). Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Abrramowitz, M. and A. Stegan. 1972. Handbook of Mathematical Functions. Dover Publications, Inc. New York, N.Y.

Akerlof, C. 1970. "The Market for Lemons: Quality Uncertainty and the Market Mechanism." Quarterly Journal of Economics. August. pp.487-500.

Alchian A. and H. Demsetz. 1972. "Production, Information Costs, and Economic Organization." The American Economic Review. Vol.12. pp.777-795.

Allen, P.M. and J. McGlade. 1986. "Dynamics of Discovery and Exploitation: The Case of the Scotian Shelf Groundfish Fisheries." Can. J. Fish. Aquat. Sci., Vol. 43. pp.1187-1200.

Allen, T. and T. Star. 1982. Hierarchy: Perspectives for Ecological Complexity. The University of Chicago Press. Chicago, IL.

Andersen, P. 1983, "On Rent of Fishing Grounds: A Translation of Jens Warming's 1911 Article, with an Introduction." History of Political Economy. Vol. 15 No. 3. pp.391-396.

Anderson, L.G. 1977. The Economics of Fisheries Management. Johns Hopkins University Press. London.

Argue, A., R. Hilborn, R. Peterman, M. Staley and C. Walters. 1983. Strait of Georgia Chinook and Coho Fishery. Can. Bull. Fish. Aquat. Sci. Vol. 211

Arnason, R. 1989. "Minimum Information Management with the Help of Catch Quotas." in: Rights Based Fishing, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.215-241.

Ashby, W.R. 1952a. "Can a Mechanical chess-player Outplay its Designer?" British Journal of Philos. Science. Vol. 3. No. 44.

_____. 1952b. Design for a Brain. Chapman & Hall. London.

_____. 1958. "General Systems Theory as a New Discipline." General Systems. Vol. 3. pp.1-6.

Baden, J. 1977. "A Primer for the Management of Common Pool Resources." Managing the Commons. Edited by G. Harden and J. Baden. W.H. Freeman and Co. San Francisco. pp.137-146.

Baiman, S. 1975. "The Evaluation and Choice of Internal Information Systems Within a Multiperson World." Journal of Accounting Research. Vol. 13. pp.1-15.

_____. 1982. " Agency Research in Management Accounting: A Survey." Journal of Accounting Literature. Vol. 1. pp.154-210.

Bartlet, J. 1951. Familiar Quotations. Little Brown & Co. Boston, Massachusetts.

Beamish, R. and D. Chiton. 1982. "Preliminary Evaluation of a Method to Determine the Age of Sablefish." Can. J. Fish. Aquat. Sci. Vol. 39. pp.277-287.

Beamish, R., C. Houle and R. Scarsbrook. 1980. A Summary of Sablefish Tagging and Biological Studies Conducted During 1979 by the Pacific Biological Station. Can. MS Rep. Fish. Aquat. Sci. No. 1588. (November).

Beamish, R. and G. McFarlane. 1983. "Summary of Results of the Canadian Sablefish Tagging Program." in: Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program, Report 83-3, Fairbanks, Alaska. (August). pp.147-183.

Becker, G. 1983. "A Theory of Competition Among Pressure Groups for Political Influence." Quarterly Journal of Economics. August. Vol. XCVIII. No. 3. pp.371-397.

Begon, M. and M. Mortimer. 1986. Population Ecology: A Unified Study of Animals and Plants. (2nd edition). Sinauer Associates Inc. Publishers. Sunderland, Mass.

Bell, F. and A. Pruter. 1958. "Climatic Temperature Changes and Commercial Yields of Some Marine Fishes." J. Fish. Res. Bd. Canada. Vol. 15. No. 4. pp.625-683.

Bell, G., D. Slind and J. Bagshaw. 1986. Pictorial Atlas of Histology of the Sablefish. Canadian Special Publication of Fisheries and Aquatic Sciences. No. 94.

Bertalanffy, L. von. 1951. "General System Theory: A New Approach to Unity of Science." Human Biology. Vol.23. pp.302-361.

_____. 1968. General System Theory: Foundations, Development, Applications. George Braziller, Inc. New York, N.Y.

_____. 1975. Perspectives on General System Theory. Editor: E. Taschdjian. George Braziller, Inc. New York, N.Y.

_____. 1981. A Systems View of Man. Editor: P. LaViolette. Westview Press. Boulder, Colorado.

Beverton, R. and S. Holt. 1957 On the Dynamics of Exploited Fish Populations. Ministry of Agriculture, Fisheries and Food. Fisheries Investigations Series 2(19).

Blomqvist, Å, P. Wonnacott and R. Wonnacott. 1983. Economics. (1st Canadian Edition). McGraw-Hill Ryerson Ltd. Toronto, Ont.

Boulding, K. 1985a. The World as a Total System. Sage Publications. London.

_____. 1985b. Human Betterment. Sage Publications. London.

Burchfield, R. 1987. The Compact Edition of the Oxford English Dictionary, Vol. III: A Supplement to the Oxford English Dictionary. Oxford at the Clarendon Press.

Campbell, H. 1981. "The Bay of Fundy Herring Fishery." Technical Report 20, Case Study No. 5 of: The Public Regulation of Commercial Fisheries in Canada. Economic Council of Canada.

Canada. 1927a. Report and Evidence of Special Committee Appointed to Enquire into the Claims of the Allied Indian Tribes of British Columbia. Ottawa.

_____. 1927b. The Revised Statues of Canada, Chapter 98: The Indian Act. Section 141. Ottawa: F.A. Acland.

Canadian Press (Williams Lake, B.C.). 1989. "Ottawa Rebuked Over Charges Against Indian." The Globe and Mail. (Toronto newspaper) May 18, 1989. p. A18.

Capra, F. 1983. The Turning Point: Science, Society and the Rising Culture. Bantam Books. Toronto, Ont.

Cauvin, D. 1979. "Regulating Access in Canada's Inland Fisheries." J. Fish. Res. Vol. 36, No. 7, pp.827-836.

Chamut, P.S. 1989. Individual Quotas in the Sablefish Fishery. (Discussion Paper attached to a letter sent to the sablefish licence holders). Fisheries and Oceans, Pacific Region, Vancouver, Canada.

Chiang, A.C. 1974. Fundamental Methods of Mathematical Economics. (2nd edition). McGraw-Hill Book Co. New York, N.Y.

Clark, C.W. 1976. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. John Wiley & Sons. Toronto, Ont.

_____. 1985. Bioeconomic Modeling and Fisheries Management. John Wiley & Sons. Toronto, Ont.

Clark, C. and G. Munro. 1975. "The Economics of Fishing and Modern Capital Theory: A Simplified Approach." Journal of Environmental Economics and Management. Vol. 2. pp.92-106.

Clark, I., P. Major and N. Mollett. 1989. "The development and Implementation of New Zealand's ITQ Management System." in: Rights Based Fishing, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.117-145.

Coase, R. 1969. "The Problem of Social Cost." The Journal of Law and Economics. Vol.III. October. pp.1-44.

Cohen, M. 1977. The Food Crisis in Prehistory: Overpopulation and the Origins of Agriculture. Yale University, London.

Cook, B. 1983. Optimal Harvest Levels for Canada's Pacific Halibut Fishery. Ph.D. Dissertation, Department of Economics, Simon Fraser University. Burnaby, British Columbia, Canada.

Cook, R. 1987. "The Triumph and Trials of Materialism: 1900-1945." in: The Illustrated History of Canada. Editor: C. Brown. Lester & Orpen Ltd. Toronto, Ontario. pp.375-466

Copes, P. 1970. "The Backward-Bending Supply Curve of the Fishing Industry." Scottish Journal of Political Economy. Vol. XVII. pp.69-77.

_____. 1972. "Factor Rents, Sole Ownership and the Optimal Level of Fisheries Exploitation." The Manchester School. June. pp.145-163.

_____. 1978a. Resource Management for the Rock Lobster Fisheries of South Australia. A Report Commissioned by the Steering Committee for the Review of Fisheries of the S. Australian Government. March.

_____. 1978b. "Canada's Atlantic Coast Fisheries: Policy Development and the Impact of Extended Jurisdiction." Canadian Public Policy. Vol. IV: No. 2. (Spring). pp.155-171.

_____. 1980. "The Evolution of Marine Fisheries Policy in Canada." Journal of Business Administration. Vol. 11 1/2. Fall 1979/Spring 1980. pp. 125-148.

_____. 1981. "Rational Resource Management and Institutional Constraints: the case of the Fishery." Economics and Resource Policy. Editor: J.A. Butlin. Longman. London. pp.113-128.

_____. 1986a. Prawn Fisheries Management in South Australia, with Specific Reference to Problems in Gulf of St. Vincent and Investigator Strait. Report to the Minister of Fisheries of S. Australia. July.

_____. 1986b. "A Critical Review of the Individual Quota as a Device in Fisheries Management." Land Economics. Vol.62. No.3. August. pp.278-291.

_____. 1986c. "The Fishery as Employer of Last Resort: A Failure of Regional Policy in Atlantic Canada." Discussion Paper. Institute of Fisheries Analysis. Simon Fraser University, B.C.

_____. 1988a. "Why are Fishing Incomes Often Low? A Critical Review of the Conventional Wisdom." Discussion Paper. Institute of Fisheries Analysis. Simon Fraser University, B.C.

_____. 1988b. "An Indian Commercial Fishery on the Skeena River: Issues and Trade-offs." Discussion Paper. Institute of Fisheries Analysis. Simon Fraser University, B.C.

Courthion, P. 1977. Impressionism. J. Shepley (translator). Harry N. Abrams Inc., Publishers, New York, N.Y.

Crutchfield, J. 1979. "Economic and Social Implications of the Main Policy Alternatives for Controlling Fishing Effort." Journal of the Fisheries Research Board of Canada. Vol. 36, No. 7. pp.742-752.

Cunningham, S. M. Dunn and D. Whitmarsh. 1985. Fisheries Economics: An Introduction. Mansell Publishing Limited. London. pp.309-355.

De Bané, P. and J. Austin. 1984. Joint Statement on the New Policy for the Pacific Fisheries. Minister of Fisheries and Oceans and Minister of State for Social Development. Fisheries and Oceans, Canada.

della Mirandola, Pico. 1948. Oration on the Dignity of Man. Translated by: Elizabeth Livermore Forbes. University of Chicago Press, Chicago, IL.

Dixit, A. and P. Weller. 1979. "The Three Consumer Surpluses." Economica. Vol. 46. pp.125-135.

Downs, A. 1967. Inside Bureaucracy. Little, Brown and Co. Boston, Massachusetts.

Dyck, N. 1988. "Native People: Polical Organization and Activism." in: The Canadian Encyclopedia. (2nd edition). Vol. III. Hurtig Publishers. Edmonton, Alberta. pp.1457-1458.

Ellis, R. 1982. The Book Of Whales. Alfred A. Knopf. New York, N.Y.

Encyclopeadia Britannica. 1967. William Benton Publisher. Vol. 4. Toronto, Ontario.

Eschmeyer, W., E. Herald and H. Hammann. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin Company, Boston. Massachusetts.

Fama E. and M. Jensen. 1982. "Agency Problems and the Survival of Organizations." Discussion Paper. University of Chicago, Chicago, IL.

Finch, F.E., H.R. Jones and J. Litterer. 1976. Managing for Organizational Effectiveness: An Experimental Approach. McGraw-Hill Book Co., New York, N.Y.

Fisheries & Marine Service. 1976. Policy for Canada's Commercial Fisheries. Fisheries and Marine Service, Environment Canada. May.

Fisheries and Oceans. 1978. Resource Prospects for Canada's Atlantic Fisheries 1979-1985, Fisheries Research Branch of Fisheries and Oceans, Ottawa, Ontario, Canada.

_____. 1983. Enterprise allocations for the Atlantic Offshore Groundfish Fisheries. Fisheries and Oceans, Ottawa, Canada.

_____. 1985. Commercial Fisheries Licensing Policy for Eastern Canada. Atlantic Fisheries Service, Fisheries and Oceans, Canada.

Flew, A. 1971. An Introduction to Western Philosophy. The Bobbs-Merrill Co. Inc. New York. N.Y.

Flood, R., M. Jackson and P. Keys. 1989. Proceedings of the United Kingdom Systems Society Conference on: Systems Prospects: The Next Ten Years of Systems Research. Plenum Press. New York, N.Y.

Fo'c'sle. 1988. "The Science of Cod." Fo'c'sle. A Special Science Edition. Vol. 8, No. 2, February. Fisheries and Oceans, Newfoundland Region.

Fox, W. 1970. "An Exponential Surplus-Yield Model for Optimizing Exploited Fish Populations." Trans. Amer. Fish. Soc. No. 1. pp.80-90.

_____. 1975. "Fitting the Generalized Stock Production Model by Least-Squares and Equilibrium Approximation." Fishery Bulletin, Vol. 73, No. 1, pp.23-37.

Framework III. 1988. An Integrated Software Package—Spreadsheet, Graphics, Word Processor and Data Base. Ashton-Tate. Torrance, California.

Friedman, M. 1981. Price Theory. Aldine Publishing Co., New York, N.Y.

Fraser, C. and J. Jones. 1989. "Enterprise Allocations: The Atlantic Experience." in: Rights Based Fishing, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.267-288.

Fraser, G. 1977. *License Limitation in the British Columbia Salmon Fishery*. Environment Canada, Fish And Marine Service, Pacific Region, Technical Report PAC/T-77-13.

Fung Yu-Lan. 1966. *A Short History of Chinese Philosophy*. Editor: D. Bodde. Collier MacMillan Publishers. London.

Galbraith, J. 1987. *Economics in Perspective: A Critical History*. Houghton Mifflin Company. Boston, Massachusetts.

Gause, G. 1936. "The Principles of Biocoenology." *Quarterly Review of Biology*. Vol. 11. pp.320-336.

Gause, G. and A. Witt. 1935. "Behaviour of Mixed Populations and the Problem of Natural Selection." *American Naturalist*. Vol. 69. pp.596-609.

Gislason, G., J. MacMillan and J. Craven. 1982. *The Manitoba Commercial Freshwater Fishery: An Economic Analysis*. The University of Manitoba Press, Canada.

Glasbeek, H.J. 1968. "Limited Liability for Neglegent Misstatement." in: *Studies in Canadian Tort Law*. Editor: A.M. Linden. Butterworths, Toronto. pp.115-138.

Glavin, T. 1989a. "Indian Fishing Rights Vindicated: Judge Blasts Fisheries Officials." *The Vancouver Sun*. (newspaper). May 18, 1989. p.A9.

_____. 1989c. "Indians' Acquital Surprises Feds." *The Vancouver Sun*. (newspaper). April 12, 1989. p.A14.

_____. 1989b. "Ottawa Broke Law in Halting Fishing by Indians, Judge Says." *The Vancouver Sun*. (newspaper). June 16, 1989. p.A9.

_____. 1990a. *A Death Feast in Dimla-Hamid*. New Star Books, Vancouver.

_____. 1990b. "Judge Condems FEderal Fishing Rules." *The Vancouver Sun*. (newspaper). June 28, 1990. p.B4.

Gomperz, H. 1908. *Weltanschauugslehre; ein Versuch die Hauptprobleme der allgemeinen theoretischen Philosophie geschichtlich zu entwickeln und sachlich zu bearbeiten*. vol.II/I. E. Diederichs, Jena, Germany.

Gordon, H.S. 1954. "The Economic Theory of a Common Property Resource: The Fishery." *The Journal of Political Economy*. Vol. LXII. No. 2. pp.124-142.

Gough, J. 1988. "Fisheries History." *The Canadian Encyclopedia*. (2nd edition). Vol. II. Hurtig Publishers. Edmonton, Alberta. pp.641-644.

Gould, S. 1989. *Wonderful Life: The Burges Shale and the Nature of History*. W.W. Norton & Company. London.

Graham, J. 1972. *Systems Analysis in Business*. George Allen and Unwin Ltd. London.

Graham, M. 1935. "Modern Theory of Exploiting a Fishery, and Application to North Sea Trawling." Journ. Cons. Int. Expl. de la Mer. Vol. X. No. 3. pp.264-274.

Green, H.A. 1976. Consumer Theory. (revised edition). J.W. Arrowsmith Ltd. Bristol, G.B.

Greenwald, D. and Associates. 1983. The McGraw-Hill Dictionary of Modern Economics. McGraw-Hill Book Co. Toronto, Ont.

Gulland, J.A. 1961. Fishing and the Stocks of Fish at Iceland. U.K. Min. Afric. Fish. Food. Fish. Invest. (Ser. 2) 23(4).

_____. 1983. Fish Stock Assessment: A Manual of Basic Methods. FAO/Wiley series on food and agriculture. John Wiley and Sons. Toronto, Ont.

Gulland, J.A. and L.K. Borema. 1973. "Scientific Advice on Catch Levels." Fishery Bulletin. Vol. 71. No. 2. pp.325-335.

Hayek, F.A. von. 1943. Ethics. vol. LIV.

_____. 1952. The Counter Revolution of Science. Free Press. Glencoe, IL.

Harden, G. 1960. "The Competitive Exclusion Principle." Science. Vol. 131. pp.1292-1297.

_____. 1968. "The Tragedy of the Commons." Science. Vol.162. pp.1243-1248.

_____. 1977. "What Marx Missed." Managing the Commons. Edited by G. Harden and J. Baden. W.H. Freeman and Co. San Francisco. pp.3-7.

_____. 1986 Filters Against Folly: How to Survive Despite Economists, Ecologists and the Merely Eloquent. Penguin Books. Markham, Ontario.

Harris, L. 1990. Independent Review of the State of the Northern Cod Stock. Communications Directorate, Department of Fisheries and Oceans, Ottawa, Ontario, Canada.

Hart, J.L. 1973. Pacific Fishes of Canada. Fisheries Research Board of Canada. Ottawa.

Heaps T. and B. Pratt. 1989. The Social Discount Rate for Silvicultural Investments. Prepared for the B.C. Ministry of Forests: Industry Development and Marketing Branch. February.

Heaps, T. and J. Helliwell. 1985. "The Taxation of Natural Resources." in: The Handbook of Public Economics. Vol. I. Editors: A. Auerbach and M. Feldstein. Elsevier Science Publishers B.V., Amsterdam, Netherlands. pp.421-471.

Heisenberg, W. 1971. Physics and Beyond: Encounters and Conversations. Harper & Row, New York, N.Y.

Helgason, T. 1989. "Should Quotas be Based on Shadow Value Rather than Weight?" in: Rights Based Fishing, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.215-241.

Henderson, J. and R. Quandt. 1980. Microeconomic Theory: A Mathematical Approach. (3rd edition). McGraw-Hill Book Company. New York, N.Y.

Heyamoto, H. and M.S. Alton. 1965. "Distribution, Abundance and Size of Sablefish Found in Deep Water Off the Columbia River." Comm. Fish. Review. U.S. Dept Interior. Vol. 27, No. 11. pp.1-8.

Holling, C. 1984. Adaptive Environmental Assessment and Management. Wiley IIASA International Series on Applied Systems Analysis; 3. John Wiley & Sons. Toronto, Ont.

Howard, E., (editor). 1975. Gimli Saga. Gimli Woman's Institute. D.W. Friesen and Sons Ltd., Altona, Manitoba.

Hume, S. 1991. "How to Save Fishery: Hand it Back to the Indians." The Vancouver Sun. (newspaper). July 17, 1991. p.A11.

Huntsman, A.G. 1944, "Fishery Depletion." Science. Vol. XCIX.

Jackson, P.M. 1983. The Political Economy of Bureaucracy. Barnes and Noble Books, Totowa, New Jersey.

Jensen, M. and W.Meckling. 1976. "Theory of the Firm: Managerial Behaviour, Agency Costs and Ownership Structure." Journal of Financial Economics. March. pp.305-360.

Johnson, R. Newell and C. Vergin. 1974. Production and Operations Management: A Systems Concept. Houghton & Mifflin Co. Boston, Massachusetts.

Jordon, C.W. 1952. Life Contingencies. The Society of Actuaries. Chicago, Illinois.

Kementa, J. 1971. Elements of Econometrics. MacMillan Publishing Co., Inc.

Kendall, A. and J.B. Clark. 1982. "Ichthyoplankton of Washington, Oregon, and Northern California, April-May 1980." NWAFC Proc. Rep. 82-11.

Kennedy, P. 1985. A Guide to Econometrics. (2nd edition). The MIT Press, Cambridge, Massachusetts.

Kennedy, W. and F. Pletcher. 1968. The 1964-65 Sablefish Study. Fisheries Research Board of Canada, Biological Station, Nanaimo, B.C. (June).

Ketchen, K. and C. Forrester. 1954. "The Sablefish Fishery of British Columbia." Bull. Pac. Mar. Fish. Comm. Vol. 3. pp.58-72.

Kew, J.E.M. 1990. "History of Coastal British Columbia Since 1846." in: Handbook of North American Indians: (Vol. 7) Northwest Coast. Editor: W.C. Sturtevant. Smithsonian Institution. pp.159-168.

Kibizaki, Osamu. 1965. (translated title) Demersal Fish Resources in the Northern Pacific. Japanese Fish. Res. Conserv. Assoc. Fish. Res. Ser. No. 11 [Original in Japanese - translation by Mr. Yutaka Kitano].

Kingsland, S. 1988. Modeling Nature: Episodes in the History of Population Ecology. University of Chicago Press. Chicago, IL.

Koestler, A. 1960. The Lotus and the Robot. Hutchinson. London.

_____. 1967. The Ghost in the Machine. MacMillan, New York, N.Y.

_____. "the Tree and the Candle." in: Unity and Diversity of Systems: Festschrift for L. von Bertalanffy. Editor: R.G. Jones.

_____. The Roots of Coincidence. Random House. New York, N.Y.

Kulikov, M. Yn. 1965. "Vertical Distribution of Sablefish on the Bering Sea Continental Slope." English Trans. in: Soviet Fish Invest. in Northwest Pacific. Part IV. pp.157-161.

Lamb, A. and Edgell. 1986. Coastal Fishes of the Pacific Northwest. Harbour Publishing Co. Ltd., Madeira Park, British Columbia, Canada.

Lane, D.E. 1988. "Investement Decision Making by Fishermen." Can. J. Fish. Aquat. Sci. Vol. 45. pp.182-796.

Larkin, P. and W. Ricker. 1964. "Canada's Pacific Marine Fisheries. Past Performance and Future Prospects. in: Inventory of the Natural Resources of British Columbia. pp.194-268.

Laszlo, E. 1973. The World System: Models, Norms, Applications. George Braziller, Inc. New York, N.Y.

Layard, P.R. and A.A. Walters. 1978. Microeconomic Theory. McGraw-Hill, New York, N.Y.

Leaman, B.D. Davenport, J Selsby and D, Yao. 1980. Biological Observer Coverage of Foreign Fisheries of Canada's Pacific Coast, 1978. Can. Tech Rep. Fish. Aquat. Sci. No. 956. (July).

_____. 1981. Biological Observer Coverage of Foreign Fisheries of Canada's Pacific Coast, 1979. Can. Tech Rep. Fish. Aquat. Sci. No. 1006. (March).

Levy, H. and M. Sarnat. 1972. Investment and Portfolio Analysis. John Wiley & Sons, Inc., New York, N.Y.

Liebenstein, H. 1975. "Allocative Efficiency vs *X-Efficiency*." Microeconomics, Selected Readings. (2^{nd} edition). Editor: E. Mansfield. W.W. Norton and Co. Inc. New York, N.Y. pp.218-237.

Lofti, A. 1965. "Fuzzy Sets." Information and Control. Vol. 8. pp.338-353.

Longva, L. 1990. The ITQ System in the Sablefish Fishery of British Columbia: A Critical Discussion. Institute of Fisheries Analysis, Simon Fraser University, British Columbia, Canada.

Loose, V. 1977. Guidelines for Benefit-Cost Analysis. Environment and Land Use Committee Secretariat. Queen's Printer. Victoria, B.C., Canada

Lloyd, W.F. 1833. "On the Checks to Population" Reprinted in: Managing the Commons. Editors: G. Hardin and J. Baden, . W.H. Freeman and Co., San Francisco. pp.8-15.

Ludwig, D. and C.J. Walters. 1981. "Measurement Errors and Uncertainty in Parameter Estimates for Stock and Recruitment." Can. J. Fish. and Aquat. Sci. Vol. 38. pp.711-720.

_____. 1982. "Optimal Harvesting with Imprecise Parameter Estimates." Ecol. Modelling. Vol. 14. pp.273-292.

Ludwig, D. and J. Varah. 1979. "Optimal Harvesting of a Randomly Fluctuating Resource. 2. Numerical Methods and Results." SIAM (Soc. Ind. Appl. Math.) J. Appl. Math. pp.185-205.

Lyall, C. 1986. Murphy's Law (A *Shareware* PC Program). RR 2, Kingman, Alt., Canada, TOB-2MO.

MacArthur, R.H. and E.O. Wilson. 1967. The Theory of Island Biography. Princeton University Press, New Jersey.

MacDonald, J. 1981. The Pacific Salmon Fishery. Economic Council of Canada. Technical Report No. 9. The Public Regulation of Commercial Fisheries in Canada: Case Study NO. 4.

McFarlane, G. and R. Beamish. 1983a. "Biology of Adult Sablefish in Waters off Western Canada." in: Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program, Report 83-3, Fairbanks, Alaska. (August). pp.59-80.

_____. 1983b. "Preliminary Observations on the Juvenile Biology of Sablefish in Waters off the West Coast of Canada." in: Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program, Report 83-3, Fairbanks, Alaska. (August). pp.119-135.

_____. 1983c. "Overview of the Fishery and Management Strategies for Sablefish off the West Coast of Canada." in: Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program, Report 83-3, Fairbanks, Alaska. (August). pp.137-140.

_____. 1986. "Production of Strong Year-Classes of Sablefish Off the West Coast of Canada." INPFC Bull. 47. Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station Nanaimo, British Columbia.

McFarlane, G., W. Shaw and A. Tyler. 1985. "Sablefish." in: Groundfish Stock Assessments for West Coast of Canada in 1984 and Recommended Yield Options for 1985. Editors: A. Tyler and G. McFarlane. Can. MS Rep. Fish. Aquat. Sci. No.1813, (April). pp.163-186.

Macgillivary, P.B. 1990. Assessment of New Zealand's Individual Transferable Quota Fisheries Management. Economic and Commercial Analysis Report No. 75. Department of Fisheries and Oceans, Scotia-Fundy Region, Halifax, Nova Scotia, Canada.

McKellar, N.B. 1977. Restrictive Licensing as a Fisheries Management Tool. Paper No. 6, White Fish Authority, Fisheries Economics Research Unit. Edinburgh. October.

MacKenzie W. and J. Gough. 1988. "Fisheries: Resource Harvesting." Canadian Encyclopedia. (2nd edition). Vol. II. Hurtig Publishers. Edmonton, Alberta. p.780.

Mackie, J.L. 1984. Problems from Locke. Clarendon Press, Oxford.

Maddala, G.S. 1977. Econometrics. McGraw-Hill Book Co. New York, N.K.

Mannheim, K. Man and Society in an Age of Reconstruction: with a Bibliographical Guide to the Study of Modern Society. Routledge & K. Paul. London.

Mansfield, E. 1975. Micro-economics. W.W. Norton & Co., Inc. New York, N.Y.

Margenau, Henry 1983. Open Vistas: Philosophical Perspectives of Modern Science. Ox Bow Press Woodbridge, Connecticut.

Marshall, A. 1938. Principles of Economics. (8th edition). MacMillan Co., New York, N.Y.

Martindale, C. 1981. Cognition and Consciousness. Dorsey Press. Homewood, IL.

Masaki Saki. 1986. An Analysis of the B.C. Sablefish Fishery. Institute of Fisheries Analysis, Simon Fraser University, British Columbia, Canada.

Mason, F., R. Beamish and G. McFarlane. 1983. "Sexual Maturity, Fecundity, Spawning, and Early Life History of Sablefish in Waters off the Pacific Coast of Canada." In: Proceedings of the International Sablefish Symposium. University of Alaska Sea Grant College Program, Report 83-3, Fairbanks, Alaska, USA. (August). pp.137-140.

Meany, T. 1982. "The Nature and Adequacy of Property Rights in Australian Fisheries." in: Policy and Practice in Fisheries Management. Editors: N. Sturgess and T. Meany. Canberra: Australian Government Publishing Service.

Meredith, D. 1990. *CC4: The Calculus Calculator*. IBM microcomputer software and manual. Department of Mathematics. San Francisco State University. San Francisco, CA.

_____. 1991. *Calculus Calculator*. IBM microcomputer software and manual (update to CC4), Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Mesarovic, M.D. and Y. Takahara. 1975. *General Systems Theory: Mathematical Foundations*. Academic Press. London.

Mises, L. von. 1944. *Bureaucracy*. Yale University Press.

Mishan, E. 1968, "What is Producer Surplus." *American Economic Review*. Vol. 58. December. pp.1269-1283.

Morehouse, T.A. and J. Hession. 1972. "Politics and Management: The Problem of Limited Entry." in: *Alaska Fisheries Policy: Economics, Resources and Management*. Editors: A. Tussing, T. Morehouse and J. Babb. Institute of Social, Economic & Government Research, University of Alaska.

Muhsam, H. 1977. "An Algebraic Theory of the Commons." in: *Managing the Commons*. Editors: G. Harden and J. Baden. W.H. Freeman and Company. San Francisco. pp.34-37.

Munro, G. 1987. Comments to: Trond S. Paulsen's Paper The Norwegian Licensing System. in: *The Regulation of Fisheries: Legal, Economic and Social Aspects*. Editors: G. Ulfstein, P. Andersen and R. Churchill. Council of Europe, Division for Higher Education and Research, Strasbourg. pp.121-122.

Munro, G.R. and Susan McCorquodale. 1981. "The Northern Cod Fishery of Newfoundland." Technical Report 18, Case Study No.3 of *The Public Regulation of Commercial Fisheries in Canada*. Economic Council of Canada.

Muse, B. and K. Schelle. 1989. *Individual Fisherman's Quotas: A Preliminary Review of Some Recent Programs*. Alaska Commercial Fisheries Entry Commission, Juneau, Alaska, Report CFEC 89-1, February.

NAFMAC. 1984. *Report to Minister of [New Zealand] Fisheries on Future Policy for the Inshore Fishery*. [New Zealand] National Fisheries Management Advisory Committee.

Neher P., R. Arnason and N. Mollett. 1989. "Introduction." in: *Rights Based Fishing*, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.1-4.

Ni, I-Hsun. 1978. *Comparative Fish Studies*. Ph.D. Thesis, Department of Zoology, University of British Columbia, Vancouver, B.C. Canada.

Niskanen, W.A. 1971. *Bureaucracy and Representative Government*. Aldine-Atherton Inc. New York, N.Y.

NOAA. 1979. National Marine Service Cruise Results. Cruise No.79-1, Gulf of Alaska Seamount Survey.

NRA, Northwest Resources Analysis. 1983. Limited Entry in the Pacific Halibut Fishery: The Individual Quota Option (Supplemental Report). Report to the North Pacific Fisheries Management Council, Anchorage, Alaska, July.

Osterman, W. 1978. Observer's Report Japanese Fishing Vessel *Mito Maru No. 82*: December 2-5, 1977. Sablefish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (May).

_____. 1978a. Observer's Report Japanese Fishing Vessel *Ryusho Maru No. 18*: December 15-18, 1977. Sablefish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (May).

Oxford Dictionary of Quotations. 1980. Oxford University Press. Toronto, Ont.

Parsons, R. 1974. Statistical Analysis: A Decision Making Approach. Harper & Row, Publishers, New York, N.Y.

Paulik, G. 1981. "Anchovies, Birds and Fishermen in the Peru Current." in: Resource Management and Environmental Uncertainty: Lessons from Upwelling Fisheries. Editors: M. Glantz and J. Thompson. John Wiley & Sons. Toronto, Ontario. pp.35-79.

Pearl, R. and L.J. Reed. 1920. "On the Rate of Growth of the Population of the United States Since 1790 and Its Mathematical Representation." Proceedings of the National Academy of Sciences of the U.S.A. Vol. 6. pp.275-288.

Pearse, P. 1980. Regulating Fishing Effort. FAO, Technical Paper No. 7. Rome .

_____. 1981. Conflict and Opportunity: Towards a New Policy for Canada's Pacific Fisheries. Vancouver: Commission on Pacific Fisheries Policy.

_____. 1982. Turning the Tide: A New Policy for Canada's Pacific Fisheries. Final Report of the Commission on Pacific Fisheries Policy. Vancouver, B.C.

Pearse, P. and J. Wilen. 1979. "Impact of Canada's Pacific Salmon Fleet Control Program." Journal of the Fisheries Research board of Canada. Vol. 7. pp.764-769.

Pella, J. and P.K. Tomlinson. 1969. "A Generalized Stock Production Model." Bulletin of the Inter-American Tropical Tuna Commission. Vol. 13. pp. 421-458.

Peltzman, S. 1976. "Toward a More General Theory of Regulation." Journal of Law and Economics. Vol. 5. pp.211-240.

Peterman, R. 1982. "Nonlinear Relation Between Smolts and Adults in Babine Lake Sockeye Salmon and Implications for Other Salmon Populations." Can. J. Fish. Aquat. Sci. Vol. 39. pp.904-913.

_____. 1990. Density-dependent Marine Processes in North Pacific Salmonids: Lessons for Experimental Design of Large-scale Manipulations of Fish Stocks. Presented at: The International Council for the Exploration of the Sea (ICES) Symposium: The Ecology and Management Aspects of Extensive Aquaculture. Nantes, France 20-23 June, 1989.

Phillips, J.B. 1954. "The Sablefish Fishery of California. I. History and Research." Pacific Marine Fish. Comm. Bull., No.3, pp.6-37.

Pitcher, T.J. and P.J. Hart. 1982. Fisheries Ecology. Croom Helm. London.

Poincaré, H. 1946. The Foundations of Science. Translator: G. Halsted. The Science Press. Lancaster, PA.

Popper, K. 1960. The Poverty of Historicism. Basic Books, Inc. Publishers. New York, N.Y.

_____. 1961. The Logic of Scientific Discovery. Basic Books, Inc. New York, N.Y.

Posner, R. 1974. "Theories of Economic Regulation." Bell Journal of Economic and Management Science. Autumn. Vol. 5. pp.335-358.

Press, W., B. Flannery, S. Teukolsky and W. Vetterling. 1987. Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, Cambridge, New York, N.Y.

Prigogine, I. and I. Stengers. 1984. Order Out of Chaos. Bantam Books, Inc. Toronto, Canada.

Quinton, A. 1973. The Nature of Things. Routledge & Kegan Paul. London.

Radovich, J. 1981. "The Collapse of the California Sardine Fishery." in: Resource Management and Environmental Uncertainty: Lessons from Upwelling Fisheries. Editors: M. Glantz and J. Thompson. John Wiley & Sons. Toronto, Ontario. pp.107-136.

Rettig, R.B. 1989. "Is Fishery Management at a Turning Point." in: Rights Based Fishing, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of the NATO Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.47-64.

Ricker, W.E. 1954. "Stock and Recruitment." J. Fish. Res. Board Can. Vol. 11. pp.559-623.

_____. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Board Can. Vol. 191.

_____. 1976. "Ricker: Review of Pacific Salmon Growth Rate and Mortality." J. Fish. Res. Board Can. Vol. 33. pp.1485-1524.

Richards, P. 1979. Offshore Black Cod Fishery. Department of Fisheries and Oceans (Vancouver). Internal Document #5606-82-10-1. July.

Roff, D.A. 1984. "The Evolution of Life History Parameters in Teleosts." Can. J. Fish. Aquat. Sci. Vol. 41. pp.989-1000.

Roff, D.A. and D.J. Fairbairn. 1980. "An Evaluation of Gulland's Method for Fitting the Schaefer Model." Can. J. Fish. Aquat. Sci. Vol. 37. pp. 1229-1235.

Roszak T. 1975. Unfinished Animal: The Aquarian Frontier and the Evolution of Consciousness. Harper & Row , Publishers, New York, N.Y.

Russel, E. 1931. "Some Theoretical Considerations on the *Overfishing* Problem." Journ. Cons. Int. Expl. de la Mer. Vol. VI. No.1, pp.3-20.

Russell, B. 1956. "The Cult of Common Usage." in: Portraits from Memory. George Allen and Unwin, London. pp.154-159.

Saetersdal, Gunnar. 1987. "200 Mile Zones-Have the Expectations been Fulfilled?." in: The Regulation of Fisheries: Legal, Economic and Social Aspects. Editors: G. Ulfstein, P. Andersen and R. Churchill. Council of Europe, Division for Higher Education and Research, Strasbourg. pp. 6-21.

Saunders, M. 1986. "Sablefish." in: Groundfish Stock Assessments for the West Coast of Canada in 1985 and Recommended Yield Options for 1986. Editors: A. Tyler, R.P. Foucher and J. Fargo. Can. MS Rep. Fish. Aquat. Sci. No. 1897. (September). pp.30-34.

Saunders, M., W. Shaw and G. McFarlane. 1988. "Sablefish." in: Groundfish Stock Assessments for the West Coast of Canada in 1987 and Recommended Yield Options for 1988. Editors: J. Fargo, M. Saunders and A.V. Tyler. Canadian Technical Report of Fisheries and Aquatic Sciences. No. 1617. (March). pp.107-301.

Saunders M. and G. McFarlane. 1990. "Sablefish." in: Groundfish Stock Assessments for the West Coast of Canada in 1989 and Recommended Yield Options for 1990. Editors: A. Tyler and J. Fargo. Canadian Technical Report of Fisheries and Aquatic Sciences. No. 1732, (March). pp.127-149.

Scarsbrook, J., G. McFarlane and W. Shaw. 1988. "Effectiveness of Experimental Mechanisms in Sablefish Traps." North American Journal of Fisheries Management. Vol. 8 pp.158-161.

Schaefer, M. 1954. "Some Considerations of Population Dynamics and Economics in Relation to the Management of Commercial Marine Fisheries." *Bulletin of the Inter-American Tropical Tuna Commission*. Vol. 1(2). pp.25-56.

_____. 1957a. "Biological and Economic Aspects of the Management of Commercial Fisheries. *Trans. Amer. Fish Soc*. Vol. 88 (1). pp.100-104.

_____. 1957a. "Some Considerations of Population Dynamics in Relation to the Management of Commercial Marine Fisheries." *J. Fish. Res. Bd. Canada*. 145. pp.669-681.

_____. 1970. "Men Birds, and Anchovies in the Peru Current—Dynamic Interactions." *Trans. Amer. Fish Soc*. Vol. 99. pp.461-467.

Schnute, J. 1977. "Improved Estimates for the Schaefer Production Model: Theoretical Considerations." *J. Fish Res. Board Can*. Vol.34. pp.583-603.

Scott, A. 1955. "The Fishery: The Objective of Sole Ownership." *Journal of Political Economy*. Vol. 63. April. pp.116-124.

_____. 1979. "Development of Economic Theory on Fisheries Regulation." *J. Fish. Res*. Vol. 36, No. 7, pp.725-741.

_____. 1989. "Conceptual Origins of Rights Based Fishing" in: *Rights Based Fishing*, Editors: P. Neher, R. Arnason and N. Mollett. Proceedings of NATO's Advanced Research Workshop on Scientific Foundations for Rights Based Fishing, Reykjavik, Iceland, 1988. Kluwer Academic Publishers, Norwell, MA, USA. pp.11-38.

Scott, W.G. and T.R. Mitchell. 1972. *Organization Theory: A Structural and Behavioral Analysis*. Richard D. Irwin-Dorsey Ltd. Georgetown Ontario.

The [B.C.] Select Committee on Agriculture, 1979. *The Salmon Industries in British Columbia*. Phase III Research Report. March.

Selsby, J., M. Smith and S. Maththews. 1977. *Observer's Report Polish Fishing Vessel Tulcana: October 6-15*. Report No. 11 Dogfish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (November).

Selsby, J., S. Maththews and G. Thomas. 1977. *Observer's Report Polish Fishing Vessel Tulcana: October 28 - November 10, 1977*. Report No. 12 Dogfish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (November).

Selsby, J. and S. Maththews. 1978. *Observer's Report Polish Fishing Vessel Wlocznik: November 5-9, 1977*. Report No. 12 Dogfish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (February).

Shaw, W., G. McFarlane, D. Davenport and W. Andrews. 1985. Distribution and Abundance of Larval Sablefish in the Surface Waters off the West Coast of Vancouver Island, April 16 to May 10, 1984. Can. MS Rep. Fish. Aquat. Sci. Report No. 1835.

Shubnikov, D.A. 1963. (translated title) "Data on the Biology of Blackcod of the Baring Sea." Trudy Vsesoyuznogo N.-I. Instituta Morskogo Rybnogo Khozyaistva i Okeanografii (VNIRO). Vol. 68. pp.271-280.

Skolimoswski, H. 1973. "The Twilight of Physical Description and the Ascent of Normative Models." in: The World System: Models, Norms, Applications. Editor: E. Laszlo. George Braziller, Inc. New York, N.Y.

Silverberg, E. 1978. The Structure of Economics: A Mathematical Analysis. McGraw-Hill Book Company. New York, N.Y.

Simon, A. 1984. Neptune's Revenge: The Ocean of Tomorrow. Bantam Books. Toronto, Ont.

Simon, H.A. 1965. "The Architecture of Complexity." General Systems. Vol. 10. pp.63-76.

_____. 1975. "Theories of Decision-Making in Economics and Behavioural Science." in: Micro-Economics: Selected Readings. (2nd edition). Editor: E. Mansfield. W.W. Norton & Co. Inc. New York, N.Y. pp.85-98.

_____. 1977. The New Science of Management Decision. Prentice-Hall Inc. Englewood Cliffs, New Jersey.

Sinclair, S. 1960. License Limitation—British Columbia: A Method of Economic Fisheries Management. Department of Fisheries. Ottawa, Ont.

_____. 1978. A Licensing and Fee System for the Coastal Fisheries of British Columbia. Vancouver: Department of Fisheries and Oceans.

Sinclair, Upton. 1946. The Jungle. Robert Bentley Inc. Cambridge, Massachusetts.

Sinclair, W.F. 1977. Management Alternatives and Strategic Planning for Ontario Fisheries. Ontario region, Fisheries and Marine Service, Department of Fisheries and Environment.

_____. 1979. "Management Alternatives and Strategic Planning for Canada's Fisheries." J. Fish. Res. Vol. 36, No. 7, pp.1017-1030.

Smith, A. 1812. An Inquiry into the Nature and Causes of the Wealth of Nations. Ward, Lock and Co. Ltd. London.

Spurr, S. and B. Barnes. 1980. Forest Ecology. (3rd edition). John Wiley & Sons. Toronto, Ontario.

Stanley, S. 1979. Macroevolution: Pattern and Process. W.H. Freeman and Co. San Francisco, California.

Stearns, M.L. 1990. "Haida Since 1960." in: Handbook of North American Indians: (Vol. 7) Northwest Coast. Editor: W. Sturtevant. Smithsonian Institution. pp.261-266.

Stewart, Ian. 1989. Does God Play Dice? The Mathematics of Chaos. Basil Backwell Ltd. Oxford, U.K.

Storebakken, T. and E. Austreng. 1987a. "Ration Level for Salmonids I. Growth, Survival, Body Composition, and Feed Conversion in Atlantic Salmon Fry and Fingerlings." Aquaculture. Vol. 60. pp.189-206

_____. 1987b. "Ration Level for Salmonids II. Growth, Feed Intake Protein Digestibility, Body Composition and Feed Conversion in Rainbow Trout Weighing 0.5-1.0 KG." Aquaculture. Vol. 60 pp.207-221.

Stigler, G. 1966. The Theory of Price. (3rd edition). MacMillan Publishing Co., Inc. New York, N.Y.

_____. 1971. "The Theory of Economic Regulation." The Bell Journal of Economic and Management Science. Vol. 2. No. 1. pp.2-21.

Sullivan, K. and K. Smith. 1982. "Energetics of Sablefish, Under Laboratory Conditions." Can. J. Fish. Aquat. Sci. Vol. 39. pp.1012-1020.

Syskes, J.B. 1982. The Concise Oxford Dictionary of Current English. Oxford University Press, New York, N.Y.

Terry, J.M., J.W. Balsiger and R.J. Marasco. 1983. Economic and Biological Measures of the Status of Stocks. Presented at the 71st Statutory Meeting of the International Council for the Exploration of the Sea. Sweden. October.

Thomson, R.E. 1981. Oceanography of the British Columbia Coast. Department of Fisheries and Oceans, Canadian Special Publication of Fisheries and Aquatic Sciences 56. Sidney, B.C.

Thomas, G. 1978. Observer's Report Japanese Fishing Vessel *Mito Maru No. 82*: December 16-17, 1977. Sablefish. Department of Fisheries and the Environment, Fisheries and Marine Service. Pacific Biological Station. Nanaimo, British Columbia. (May).

Tullock, Gordon. 1965. The Politics of Bureaucracy. Public Affairs Press. Washington, D.C.

_____. 1975. "The Transitional Gains Trap." Bell Journal of Economics. Vol. 6. pp.671-678.

_____. 1976. "Regulating the Regulators." Government Controls and the Free Market: The U.S. Economy in the 1970s. Editor: Svetozar Pejovich. College Station. TX: Texas A&M University Press. pp.141-159.

Turvey, R. 1964. "Optimization and Suboptimization in Fishery Regulation." American Economic Review. Vol. 54. pp.64-76.

Uhler, R.S. 1980. "Least Squares Regression Estimates of the Schaefer Production Model: Some Monte Carlo Simulation Results." Can. J. Fish. Aquat. Sci. Vol.37 pp.1284-1294.

Van Horne, J. 1974. Financial Management and Policy. Prentice-Hall: Canada Ltd. Toronto. Ont.

Verhulst, P. 1845. "Recherches mathématiques sur la loi d'accroissement de la population." Nouveaux Mémoires de l'Académie Royale des Sciences et Belles-Lettres de Bruxelles. ser. 2. 18. pp.3-38.

Wallace, B.A. 1989. Choosing Reality: A Contemplative View of Physics and the Mind. New Science Library, Shambhala Publications, Boston, Massachusetts.

Ware, D.M. 1984. "Fitness of Different Reproductive Strategies in Teleost Fishes." in: Fish Reproduction: Strategies and Tactics. Editors: G.W. Potts and R.J. Wootton. Academic Press. London.

Warming, Jens. 1911. "Om Grundrente af Fiskegrunde." [On Rent of Fishing Grounds]. Nationaløkonomisk Tidsskrift. Vol. 49. pp.499-505.

Warner, W. 1983. Distant Water: The Fate of the North Atlantic Fisherman. Little, Brown and Company, Toronto, Canada.

Watson, L. 1987. Supernature II. Hodder and Stoughton Paperbacks. London.

Weiss, P. 1962a. Experience and Experiment in Biology." Science. Vol. 136. pp.468-471.

_____. 1962b. "From Cell to Molecule." The Molecular Control of Cellular Activity. Editor: J.M. Allen. New York, N.Y.

Westrheim, S. (editor) 1980. Assessment of Groundfish Stocks off the West Coast of Canada in 1979 and Recommended Total Allowable Catches for 1980. Can. Data Rep. Fish and Aquatic Sci. Vol. 208.

White, K. 1987. Shazam: The Econometrics Computer Program. V6. Department of Economics, University of British Columbia.

White, K., S.D. Wong, D. Whistler and S.A. Haun. 1990. Shazam: Econometrics Computer Program. User's Reference Manual, V6.2. McGraw-Hill Book Co. New York, N.Y.

Wilen, J.E. 1979. "Fishermen Behavior and the Design of Efficient Fisheries Regulation." J. Fish. Res. Vol. 36, No. 7, pp.855-858.

Williamson, O.E. 1964. The Economics of Discretionary Behaviour: Managerial objectives in a Theory of the Firm. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

_____. 1967. "Hierarchical Control and Optimum Firm Size." Journal of Political Economy. April. Vol.75. pp.123-138.

_____. 1975. Markets and Hierarchies: Analysis and Antitrust Implications. Free Press., New York, N.Y.

Wimsatt, W. 1980. "Randomness and Perceived-Randomness in Evolutionary Biology." Synthese. Vol. 43. No. 2. pp.287-229.

Wittgenstein, L. 1953. Philosophical Investigations, MacMillan, New York, N.Y.

_____. 1958. The Blue and Brown Books. Harper Press, Oxford, Blackwell.

_____. 1975. Philosophical Remarks. Editor: R. Rhees. Translators: R. Hargreaves and R. White. Barnes & Noble Books. New York, N.Y.

Woodger, J.H. 1930-1931. "The *Concept of Organism* and the Relation Between Embryology and Genetics." Quart. Rev. Biol. Vol. 5/6. pp.1-3.

Whorf, B.L. 1952. Collected Papers on Metalinguistics. Washington Foreign Service Institute, Department of State.

_____. 1956. Language, Thought and Reality: Selected Wrightings of B.L. Whorf. Editor: J. Carroll. John Wiley & Sons. New York, N.Y.

Wright, C.A. 1954. Cases on the Law of Torts. Butterworth and Co. (Canada) Ltd. Toronto. Ontario.

Wright, C.A. 1968. "The Province and Function of the Law of Torts." in: Studies in Canadian Tort Law. Editor: A.M. Linden. Butterworths, Toronto. pp.1-9.

Wright, C.A. and A.M. Linden. 1980. Canadian Tort Law: Cases, Notes & Materials. Butterworths, Toronto.

Wright, S. 1932. "The Roles of Mutation, Inbreeding, Crossbreeding and Selection in Evolution. Proc. Sixth Internat. Congr. Genetics. pp.161-183.