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.

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.

A CASE STUDY OF THE BRITISH COLUMBIA ABALONE FISHERY

by

Patricia Koss

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ARTS

in the Department

of

Economics

SIMON FRASER UNIVERSITY

August 31, 1987

ISBN 0-315-48776-3

APPROVAL

Name: Patricia Anne Koss

Degree: Master of Arts

Title of Thesis: A Case Study of the British Columbia Abalone Fishery

Examining Committee:

Chairman: John F. Chant

Parzival Copes
Professor
Senior Supervisor

Michael A. Bowe
Instructor

R.C. Brown
Dean
Faculty of Arts
Simon Fraser University
External Examiner

Date Approved: August 31, 1987

ABSTRACT

The price of British Columbia abalone increased dramatically in 1976 as result of a surge in Japanese demand. Since then, the British Columbia abalone fishery has undergone a number of regulatory changes in an attempt to improve the efficiency of harvesting the resource. Although current rationalization techniques have met with some success, a potential for improvement remains. This analysis estimates the optimal level of exploitation by first deriving the yield-effort curve for the fishery, and then evaluating the long-run revenues associated with that curve. The results indicate that the application of effort exceeds that which is required to obtain the optimal level of sustainable rent from the fishery. A critique of past and current management regimes is provided.

A review of the property rights and contracting literature suggests that a system of private property rights is liable to effect a more efficient allocation of resources than one in which individual private property is non-existent or ill-defined. A number of property-right structures are considered. After reviewing the potential costs and benefits associated with each contractual arrangement, the analysis concludes that a leasing arrangement in which rights are transferable represents a potentially superior alternative to the present system of individual quota management.

ACKNOWLEDGEMENTS

I take this opportunity to thank my supervisory committee for their patience and support during the preparation of this thesis. I am particularly appreciative of the aid of my senior supervisor, Dr. P. Copes.

The employees of the Economics Division at the Department of Fisheries and Oceans in Vancouver and Prince Rupert have also provided assistance. The efforts of Richard Jacobson and Kevin Bates have proved invaluable.

My thanks, too, to my fellow graduate students for their friendly support. Richard Porges and Chris Wright have been especially helpful with their insightful comments. Gratitude is also extended to Dennis Jelinski for his continual encouragement.

Finally, for both their moral and financial support throughout my education, I thank my parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PART A

INTRODUCTION

This thesis represents a case study of economic fisheries management in the British Columbia abalone fishery. The conclusions reached are applicable to many fisheries composed of long-lived sedentary shellfish.

Part B of the study reviews abalone biology. A historical summary of commercial exploitation in the British Columbia abalone fishery is provided in Part C. Part D includes a derivation of the long-run yield-effort relationship for the fishery as well as the associated long-run revenue and cost curves. Based on these derivations, an estimation of maximum sustainable yield and maximum net economic yield is provided. Part E of the thesis attempts to explain the failure of the open-access and limited entry regimes that have been applied to this fishery. A critique of the present system of management by the allocation of individual quotas is also offered. As an alternative, the allocation of private ownership rights to abalone beds is recommended as a superior solution. Given the probability of political unacceptability of such a policy, the leasing of abalone beds is offered as a compromise solution.

The central point of this thesis is that a contractual arrangement that allows for the allocation of private property rights is preferable to an arrangement that permits common property structures to persist. The fugitive nature of many species of fish often renders private ownership undesirable or infeasible. However, the sedentary nature of abalone and many other shellfish is amenable to private property arrangements. The potential exists for substantial improvements in the industrial performance of fisheries of this type by implementation of a private property right structure.

PART B

THE BIOLOGY OF ABALONE

Abalone is a genus of sedentary shellfish that lives in fairly shallow water, grows slowly and is relatively immobile (Mottet, 1978: 10). Figure 1 illustrates the gross anatomy of the abalone. The foot and right shell muscle are the parts that are used in making abalone steaks and constitute approximately one–quarter to one–half of total weight. The foot is used for creeping along the ocean's bottom and is also the means by which abalone attach themselves to substrate (Mottet, 1978: 2). Since all commercial species of abalone belong to the same genus and have similar biology, the characteristics of a particular species are likely to be found in other species as well (Mottet, 1978: 1).

Habitat

The British Columbia abalone fishery is conducted exclusively on the species *Haliotis kamtschatkana*, more commonly known as the "pinto", or "northern" abalone. This species ranges from Sitka, Alaska to as far south as San Diego, California (Mottet, 1978: 10). The greatest concentrations of large–sized abalone in British Columbia are found from zero tide to a depth of five meters (Federenko and Sprout, 1982: 4).

Adequate abalone habitat requires a firm, stable substrate and some protection from direct oceanic surge. Some water movement also appears to be essential (Breen, 1980: 26). The presence of red sea urchins may be an important positive factor in abalone settlement. Newly hatched larvae spend seven to ten days drifting in plankton, after which time they will be attracted to suitable substrate by a chemical produced by encrusting red algae. Such algae grows where heavy grazing, particularly by sea urchins, prevents other algae from growing (Breen, 1980: 26). As abalone mature, a shift in diet from diatoms to kelp fragments necessitates an upward movement from the sea urchin zone to the kelp zone (Breen, 1980: 27).

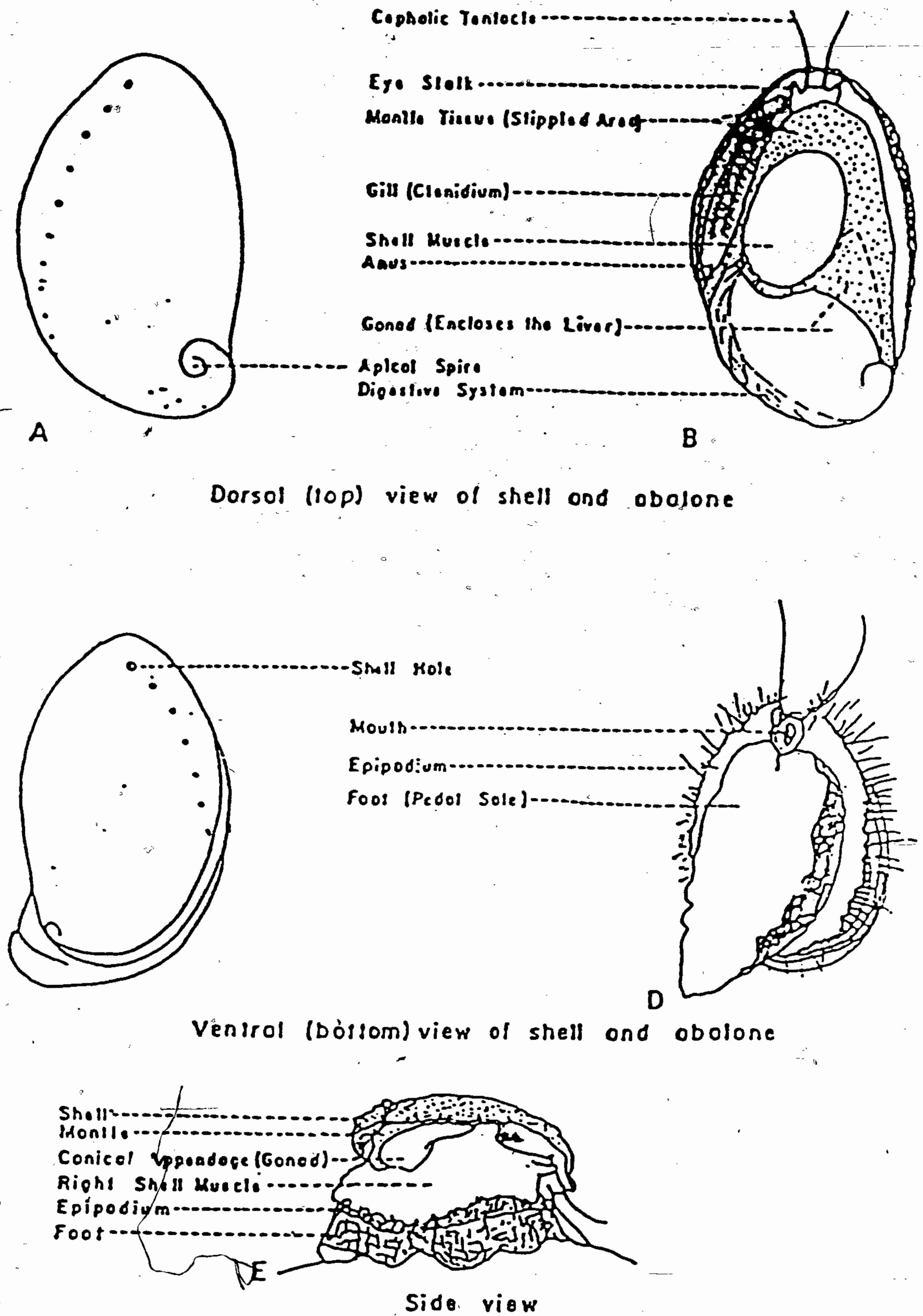


Figure 1. Gross anatomy. A, B, and C are drawn from a specimen of _Haliotis kamtschatkana_; D and E are _H. tuberculata_ from Crofts, 1929.

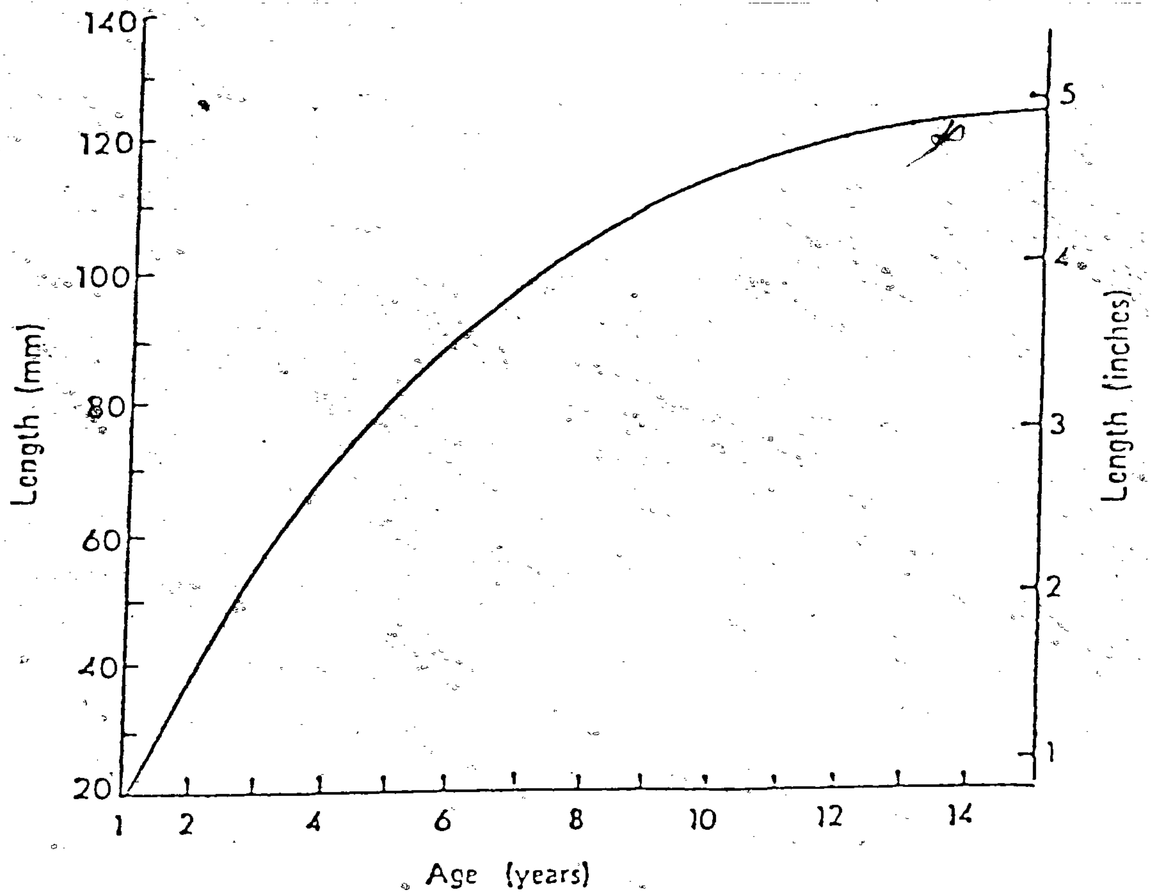
Growth and Size

Abalone take a minimum of four years to reach a length of ten centimeters. The pinto abalone requires eight years to grow to a length of 10.5 centimeters (Mottet, 1978: 17). Studies have revealed that the growth rate and the final size of adults are strongly related to habitat characteristics, particularly the type of kelp present (Breen, 1980: 28). Nourishment is generally obtained by elevating the shell and the anterior part of the foot, and extending the tentacles in order to catch drifting kelp or algae. The captured seaweed is subsequently pulled under the shell by the foot where it may be consumed immediately or stored for future consumption. If this method provides insufficient food intake, abalone will graze or forage on other vegetation during the night.

Breen (1980) found that growth rates of abalone in northern British Columbia varied greatly and appeared to be directly related to food supply. Mottet (1978: 19), however, indicates that the growth rate of most abalone species correlates most strongly with water temperature. Quayle (1971) supports this hypothesis and attributes the near identical growth rates in northern and southern British Columbia to similar water temperatures. Figure 2 depicts a suggested growth curve for the species *H. kamtschatkana*.

The amount of meat in abalone with given shell dimensions will vary depending on seasonal and environmental circumstances. A measurement of this variability is referred to as "condition". Populations normally undergo marked seasonal changes in condition caused by changes in the food supply, temperature or spawning cycle (Mottet, 1978: 21-22). In comparison with other West Coast species, it has a markedly lower recovery weight in proportion to shell measurements; thus, *H. kamtschatkana* is only moderately valued (Mottet, 1978: 10).

Figure 2: Growth Curve for Abalone[1]



Spawning

Abalone are "broadcast spawners": sex products are directly released into the seawater where fertilization takes place. Abalone have been observed climbing on top of one another during spawning. This aggregation may function as a mechanism for ensuring maximum contact between eggs and sperm, and hence a high fertilization rate (Breen and Adkins, 1980: 178).

Mottet (1978: 35) reported handling and exposure to warm air as natural spawning stimuli. The presence of sex products in the water is also reported as a natural trigger for

[1] Quayle, 1971.

spawning, as are changes in tidal temperature rhythms (Carlisle, 1945; Breen and Adkins, 1980: 178). The presence of a strong adaptive role among abalone, in regard to spawning, suggests that severe reductions in local density might have a strong, adverse effect on the recruitment rate, beyond that expected from a simple reduction in the number of spawning adults.

The fecundity of abalone increases with age; egg production ranges from 1,000 at biological minimum size to 3 million per female in later years (Mottet, 1978: 30; Federenko and Sprout, 1982: 4). In British Columbia, significant spawning does not occur until about age three, or at a length of approximately five centimeters (Federenko and Sprout, 1982: 4; Breen, 1980: 27).

The spawning season of each species must coincide with that interval of time during which environmental conditions permit adequate survival of the young. The spawning season is of direct interest in regulating the fishery, particularly if the value of the abalone is affected or it is more vulnerable to damage during that time. Spawning may, in fact, involve a reduction in body weight of five to ten percent owing to the loss of large quantities of gonadal material (Mottet, 1978: 27). It has also been observed that, during spawning, abalone are more weakly attached to the substrate than at other times of the year (Breen and Adkins, 1980: 177). For *H. kamtschatkana*, the spawning season typically occurs from April to June in the northern areas, and from June to August in southern locations (Mottet, 1978: 30–32).

Density and Abundance

Abalone density is directly related to abundance of drift algae and vegetation (Mottet, 1978: 22). Individuals tend to be clumped rather than randomly distributed (Federenko and Sprout, 1982: 4). Abalone abundance, however, is not determined by food supply. Rather, it is likely a function of the availability of planktonic larvae and suitable settling substrate, as well as the degree to which predators of settlers are present (Breen, 1980: 28). It seems clear that some habitats, especially those consisting of giant kelp (*Macrocystis integrifolia*) beds could support many more abalone than they do at present (Breen, 1980: 28).

Mortality

Abalone are somewhat vulnerable to predation when in an extended position to catch seaweed and during spawning, as they can be jarred quite easily from the substrate. They are, however, even more vulnerable to predation when foraging (Mottet, 1978: 47). Considerable movement may also take place during and after storms and when young abalone migrate from one habitat to another as they grow. Newly settled juveniles are subject to heavy predation since their nutritional requirements are such that they must place themselves on the open rock surface. However, as they grow larger, the juveniles are able to catch small pieces of drifting kelp from underneath rocks or in crevices. As the abalone continues to mature, it must again venture out on the open rock as its food requirements are greater. It has by this time, however, outgrown many predators (Breen, 1980: 27). The major predators of adult abalone include octopi and sunflower starfish. Additionally, sea urchins often invade abalone habitat (Federenko and Sprout, 1982: 7-8). The boring sponge is thought to contribute to predation by weakening the shells of old abalone, although it is unlikely that this significantly affects mortality. Shepherd et al. (1982) conducted a study on two species of South Australian abalone, *H. laevigata* and *H. ruber*, and concluded that there was no significant age dependence in mortality. Breen (1980) estimated that the annual finite natural mortality rate in British Columbia is approximately twenty-one percent, while the total annual mortality rate of fished populations is forty percent.

PART C

COMMERCIAL EXPLOITATION OF ABALONE IN BRITISH COLUMBIA

Abalone that exist in the intertidal zone can be collected by hand at low tide. Shore picking is practiced on a limited scale by native Indians (Federenko and Sprout, 1982: 9). At water depths up to about five meters it is possible, using a long pole with a chisel or gaff tied to the end, to catch abalone from a small boat. Presently, however, almost all of the world catch is taken by divers who remove the abalone from the substrate with a curved bar or chisel (Mottet, 1978: 51).

Human predation contributes significantly to abalone mortality. Often, the commercial worth of the abalone, in terms of size, cannot be determined until it is removed from the substrate. Mortality caused by inflicting wounds on undersized abalone during this process is a serious problem (Mottet, 1978: 50).

Table 1 provides data on abalone landings in British Columbia from 1952 to 1985. Prior to 1976, landings were comparatively low and highly variable from year to year. In the mid-1970s, Japanese demand for abalone soared and the British Columbia fishery responded with rapid expansion in both scale and efficiency (Federenko and Sprout, 1982: 1). Figures 3a through 4a illustrate the variation in abalone landings for British Columbia as a whole and for northern and southern British Columbia separately. In Figure 4b, the variation in abalone landings has been depicted for the Queen Charlotte Islands (Statistical Areas 1, 2W and 2E), which are a major producing region within northern British Columbia. Figures 5a through 6b illustrate the variation in catch for each statistical area on the north coast from which significant contributions to landings have been made. Figures 7a and 7b illustrate the contributions to catch by the major southern statistical areas. The locations of the statistical areas are shown in Figures 8a and 8b.

The graphs indicate a peak in landings for the northern areas occurring in 1977 or 1978. Record landings for the south coast vary between statistical areas but generally occur prior to 1977.

Table 1: **Annual Abalone Landings (kg) in British Columbia, by region, 1952 - 1985**

	Queen Charlotte Islands		North Coast		South Coast		British Columbia
Year	(1) Catch	(2) % of total	(3) Catch	(4) % of total	(5) Catch	(6) % of total	(7) Total catch
1952	nr	nr	nr	nr	5,398	100.0	5,893
1953	nr	nr	nr	nr	10,342	100.0	10,342
1954	nr	nr	nr	nr	6,849	100.0	6,849
1955	nr	nr	nr	nr	3,538	100.0	3,538
1956	nr	nr	nr	nr	499	100.0	499
1957	nr	nr	91	9.5	862	90.5	953
1958	nr	nr	nr	nr	5,307	100.0	5,307
1959	nr	nr	181	100.0	nr	nr	181
1960	nr	nr	1,497	97.1	45	2.9	1,542
1961	227	2.4	6,079	64.7	3,311	35.3	9,390
1962	9,208	52.0	17,418	98.5	272	1.5	17,690
1963	1,406	24.6	3,719	65.1	1,996	34.9	5,715
1964	19,867	34.8	29,030	50.9	28,032	49.1	57,062
1965	1,588	51.5	1,588	51.5	1,497	48.5	3,085
1966	nr	nr	nr	nr	726	100.0	726
1967	nr	nr	45	5.2	816	94.8	861
1968	nr	nr	nr	nr	91	100.0	91
1969	nr	nr	nr	nr	635	100.0	635
1970	nr	nr	5,352	33.0	10,886	67.0	16,238
1971	nr	nr	nr	nr	6,668	100.0	6,668
1972	nr	nr	nr	nr	59,601	100.0	59,601
1973	7,257	10.8	28,576	42.4	38,782	57.6	67,358
1974	nr	nr	12,247	45.8	14,515	54.2	26,672

Table 1 (cont.)

	Queen Charlotte Islands		North Coast		South Coast		British Columbia
Year	(1) Catch	(2) % of total	(3) Catch	(4) % of total	(5) Catch	(6) % of total	(7) Total catch
1975	2,268	4.0	44,679	78.2	12,474	21.8	57,153
1976	116,573	42.6	249,927	91.3	23,814	8.7	273,741
1977	318,502	66.2	461,111	95.8	20,263	4.2	481,374
1978	128,706	31.8	395,008	97.7	9,204	2.3	404,212
1979	37,695	40.0	181,215	87.0	26,954	13.0	208,169
1980	19,457	18.1	90,471	84.1	17,146	15.9	107,617
1981	29,291	31.3	77,423	82.7	16,228	17.3	93,651
1982	26,723	32.5	61,054	74.3	21,121	25.7	82,175
1983	32,756	55.8	48,518	82.7	10,137	17.3	58,654
1984	27,800	48.9	46,106	81.1	10,738	18.9	56,844
1985	14,027	30.7	35,574	77.8	10,155	22.2	45,730

nr = no landings recorded

Source: Federenko and Sprout, 1982; Farlinger and Bates, 1985.

The surge in Japanese demand provided an incentive to invest in larger boats equipped with freezing and compressing systems which were capable of making prolonged trips and to employ additional divers (Federenko and Sprout, 1982: 1). This explains the substantial shift in abalone landings from southern British Columbia to the more remote areas of the north. Larger operators now found it profitable to exploit the abalone beds of the Queen Charlotte Islands and ship their catch out of Prince Rupert to Japan (Federenko and Sprout, 1982: 1).

Figure 3a
Total Abalone Catch in British Columbia, 1952 – 1985

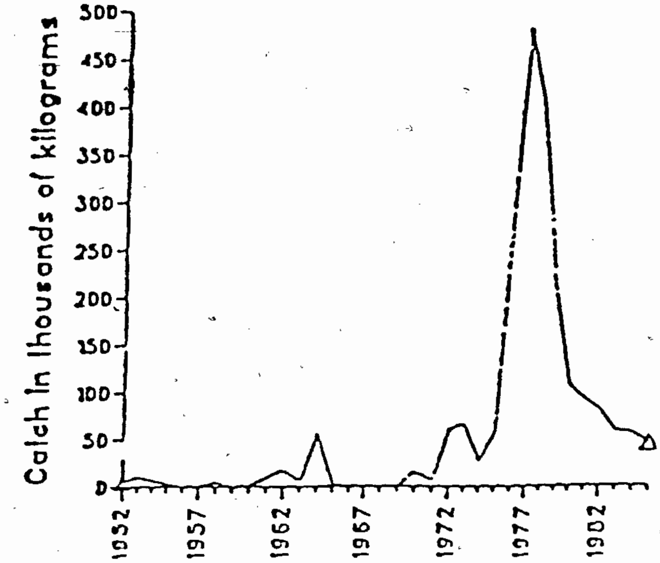


Figure 3b
Total Abalone Catch in Northern British Columbia, 1952 – 1985

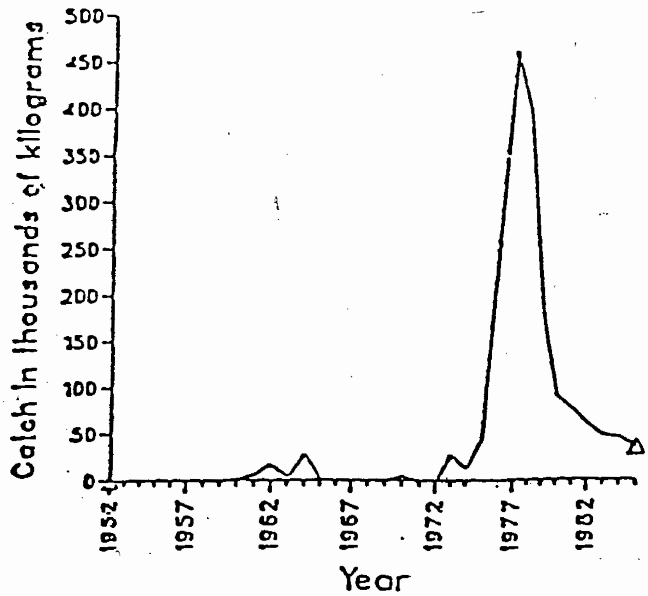


Figure 4a
Total Abalone Catch in Southern British Columbia, 1952 – 1985

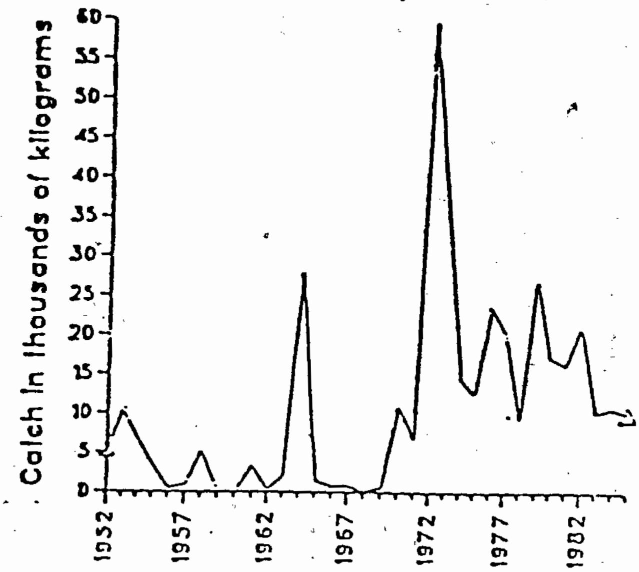


Figure 4b
Total Abalone Catch in Queen Charlotte Islands, 1952 – 1985

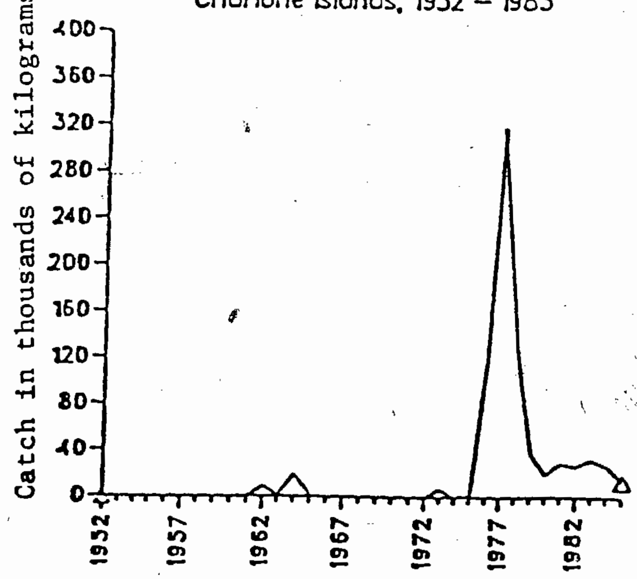


Figure 5a
Abalone Catch in Statistical Areas
2E and 6, 1961 — 1985

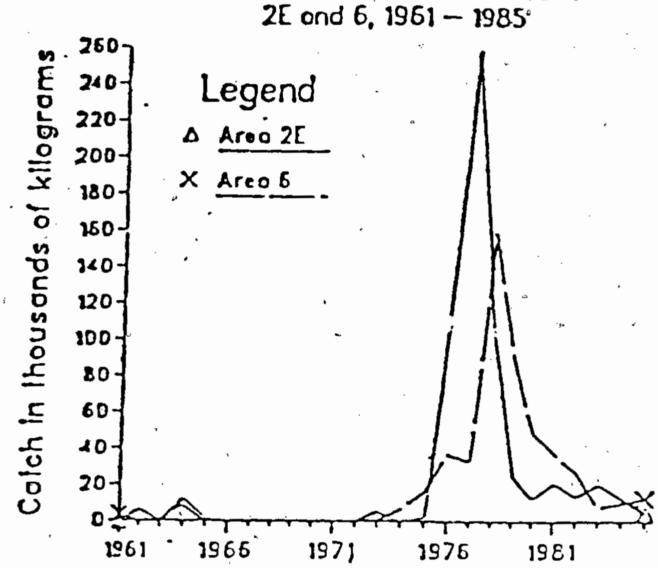


Figure 5b
Abalone Catch in Statistical Areas
1 and 5, 1959 — 1985

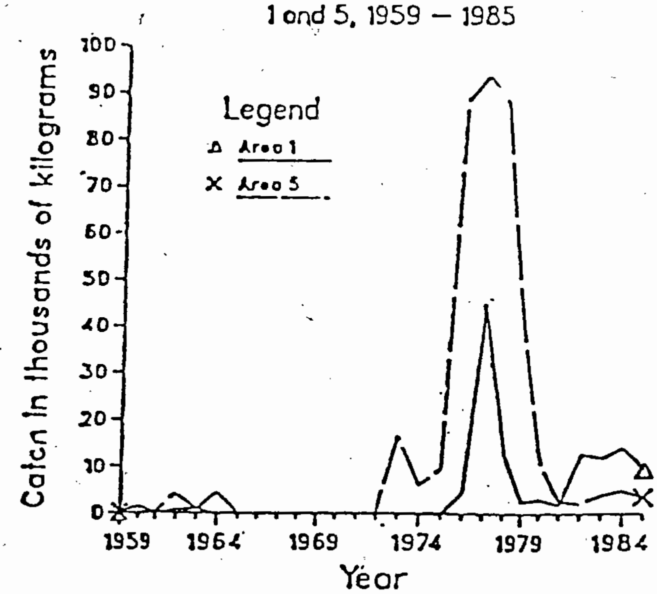


Figure 6a
Abalone Catch in Statistical Areas
2W and 3, 1962–1985

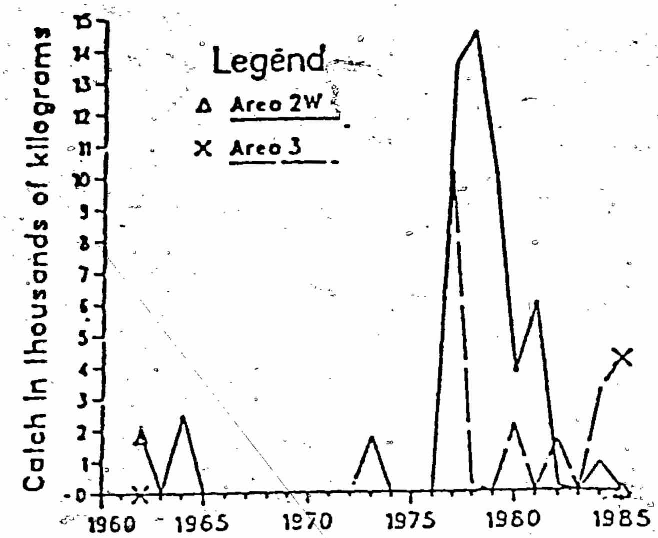


Figure 6b
Abalone Catch in Statistical Areas
4 and 7, 1961–1985

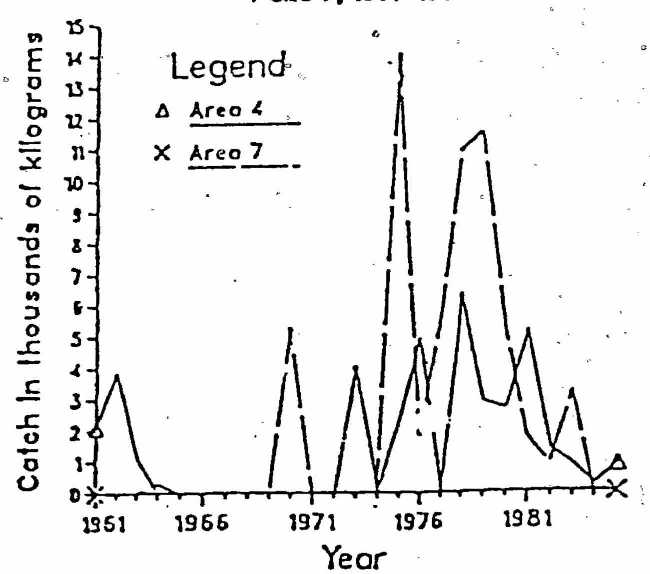


Figure 7a
Abalone Catch in Statistical Areas
12 and 23, 1952 – 1985

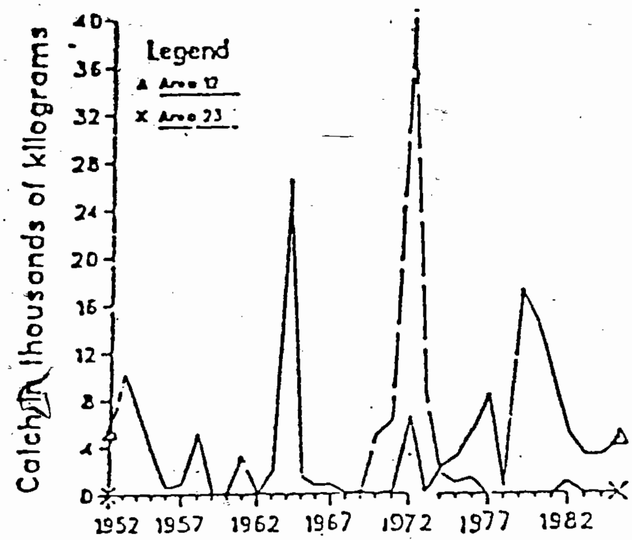


Figure 7b
Abalone Catch in Statistical Areas
19 and 20, 1970 – 1985

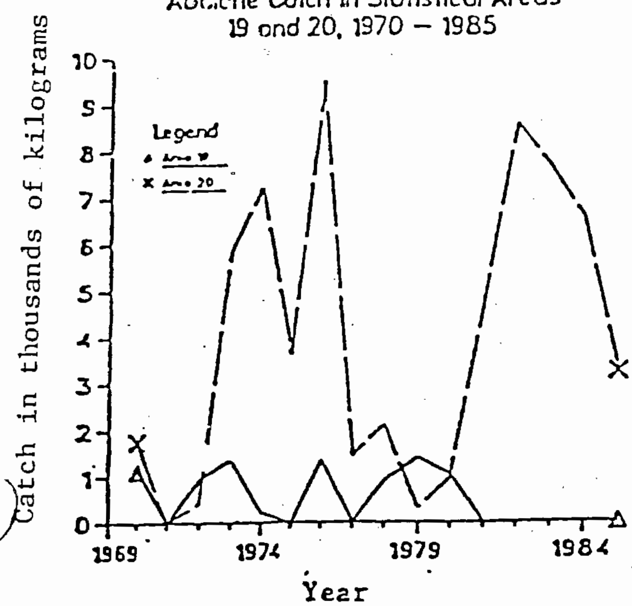


Figure 8a : Location of Statistical Areas in Northern British Columbia

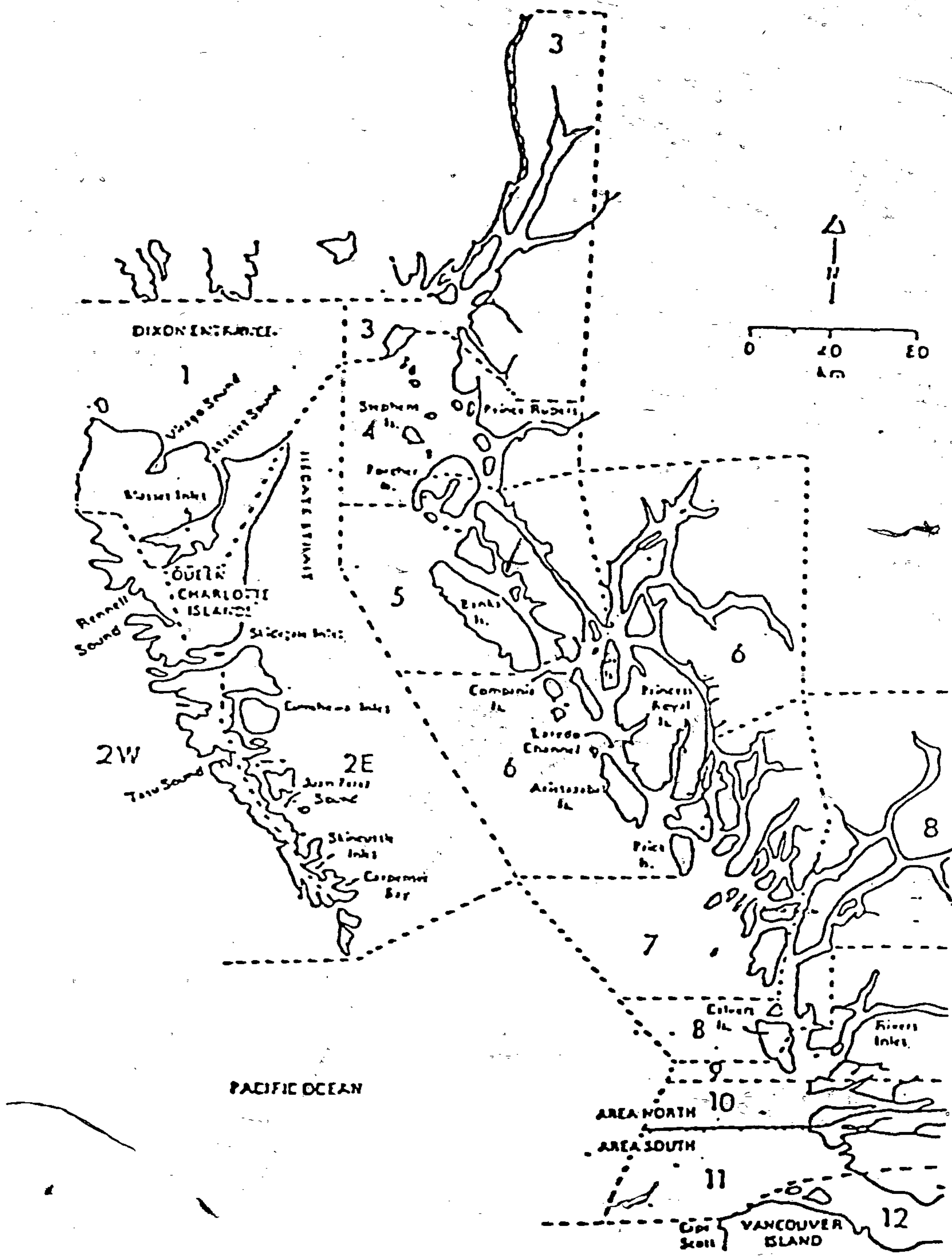
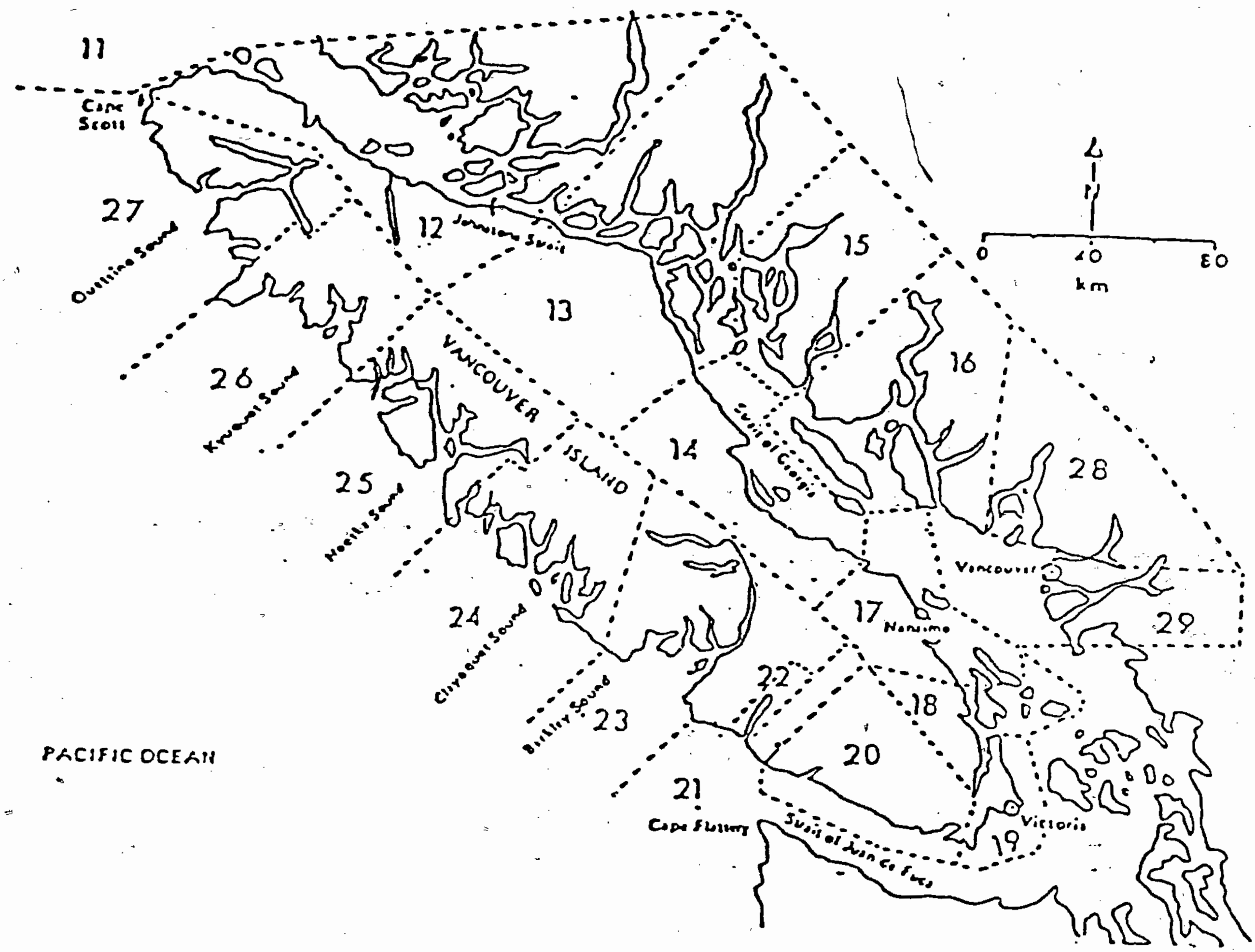


Figure 8b : Location of Statistical Areas in Southern British Columbia



PART D

A REVIEW OF FISHERY REGULATION

Federenko and Sprout (1982: 19-24) provide a detailed summary of the regulations imposed in the British Columbia abalone fishery up to 1981. Few fishing regulations existed prior to 1976 owing to the undeveloped nature of the abalone fishery at that time. The season was open year round except for a closure every third year during 1911 - 1947. Additionally, in order to protect juvenile stocks, a legal size limit of 64 mm in shell length was in place. A few area closures had also been implemented in the early 1970s. The main rationale behind these early closures was the preservation of traditional native food fishing areas and important recreational sites. The tremendous increase of pressure placed on the abalone stocks in the mid-1970s caused concern among commercial and sport fishermen, and Indian bands. This, along with the threat of severe overfishing, prompted the Department of Fisheries and Oceans in British Columbia to close the fishery in November of 1976 and to implement major regulations for the 1977 season.

The most significant alteration in the management of the abalone fishery in 1977 was the imposition of a regime of limited entry. Licenses were issued only to persons who operated vessels which landed in excess of $2,000 worth of abalone in 1976 or earlier, and made more than fifty percent of their fishing income from abalone. This resulted in the licensing of twenty-nine individuals, each of whom payed a $200 license fee. Licenses were nontransferable and the permit-holders were required to place their licenses upon vessels in which they had to own majority interest. Holders were also limited to a maximum of three divers per license. License renewal required a 2.3 metric tonne minimum landing. It was hoped that, by limiting the number of individuals participating in the abalone fishery, harvesting pressure on the stocks would be reduced, thereby eliminating the threat of severe stock depletion.

In addition to limiting entry, the government also shortened the fishing season to eight months, April 1 to November 27. The legal size limit was increased to 100 mm. This increased the age of harvestable abalone from about six years to between seven and twelve years. Supplementary closures were also introduced along the north coast, again to protect recreational and Indian food fisheries.

Despite the controls introduced in 1977, abalone landings continued to increase, as is evident from Table 1. The extent of the annual harvest was believed to be excessive in relation to that which would allow the fishery to remain productive on a perpetual basis. Owing to the threat of severe stock depletion, the season was reduced to three months (March 1 – May 31) in 1978. Additional area closures were also implemented. However, owing to an increase in the efficiency of the fleet, these measures failed to limit effort to acceptable levels.

In 1979, a total allowable catch (TAC) of 227 tonnes (i.e., metric tons) was imposed. This figure was based on the belief that the fishery could sustain an annual harvest of an estimated 113 tonnes, and on the assumption that some unfished stocks with large–sized individuals still remained. The fishery was divided into two seasons: a short open fishery (April 15 – May 3), and a longer quota fishery (May 8 – November 30) during which the remaining allowable catch was divided equally among the twenty–six license holders. In this way, the larger vessels were able to utilize their relatively greater capacity during the open fishery, and the smaller vessels were guaranteed a minimum level of catch during the quota fishery. This avoided, to some extent, a waste of capacity for larger vessels and reduced the incentive for smaller vessels to engage in a competitive "race for fish". In addition, the minimum landing requirement was revoked in 1979.

Owing to the persistence of excessive landings, the short open season was eliminated for the 1980 fishery. Subsequent to more precise biological findings, the allowable catch was reduced to 113 tonnes. This allowed each license holder a maximum of 4.5 tonnes which could be taken during the period of April 15 to November 30. Thus, the uniform quotas introduced in 1980 did not allow the owners of large vessels the option of fully utilizing their capacity.

Continued biological research once again indicated lower growth and mortality rates than previously suspected. In 1981, the allowable catch was decreased to 90.7 tonnes, thereby assigning each license holder a quota of 3.6 tonnes. The fishing season was extended by one month. A wider distribution of fishing effort was attempted by the reopening of areas previously closed to the harvesting of abalone stocks (Sprout, 1983: 1).

The total fishery quota was again reduced in 1983 to 70.8 tonnes so that individual quotas amounted to 2.7 tonnes. The season, however, was extended to cover eleven months of the year, January 15 to December 15 (Bates, 1985: 1). The 1984 season also saw a reduction in the quota to sixty tonnes or 2.3 tonnes per licensee (Farlinger and Bates, 1985: 14).

The repeated reductions in the size of the individual quotas were a response to the belief that catch levels remained excessive for adequate stock-conservation. It is important to note that although inaccurate estimates of growth and mortality rates may have been partially responsible for necessitating reductions in the size of the quota, an additional factor may have contributed to this necessity. The incentive to take catches in excess of the level allowed by the quota is by no means eliminated through the mere imposition of an individual quota system. Actions of fishermen must be monitored, and the quotas must be enforced if the desired catch level is to be realized. It is possible, and indeed probable, that some of the participants engaged in "quota busting" (Copes, 1986). The data presented in Table 1 are *reported* catches and, owing to the possibility of quota busting, may not be representative of actual catch levels after 1979. This problem, and others associated with an individual quota system, will be discussed in a later section of the thesis.

The deterioration of British Columbia's abalone stocks is apparent from the continuous decline in the total allowable harvest from 1979 onward. The goal of fisheries management is to attain a level of catch and effort that permits maximum economic returns to the fishery. In most circumstances, a requisite to obtaining maximum benefits is that of adequate stock conservation. The remainder of this thesis concerns itself with the identification of the optimal level of catch and effort and an evaluation of previous and potential methods that allow its achievement.

PART E

ECONOMICS OF THE ABALONE FISHERY

The Sustained Yield Curve for Abalone

The way in which fish stocks react to exploitation provides the basis from which fisheries management decisions are made. It is important to determine, in any given instance, whether fishing operations are or are not being undertaken in a manner ultimately wasteful to the stock. This is a difficult task owing to the complexity and variability of the conditions which must be taken into account. Russell (1931: 5–7) simplified the problem by considering a completely self-contained stock of fish of one particular kind living in a large area which is systematically fished. He also assumed the employment of perfectly selective gear such that no fish below a particular length or size entered the catchable population. Russell maintained that the weight of the catchable stock at the end of the year (P_2) could be deduced from the weight at the beginning of the year (P_1) as follows:

$$P_2 = P_1 + (A+G) - (C+M)$$

or,

$$P_2 - P_1 = (A+G) - (C+M)$$

where,

A = the amount by which the stock of fish of catchable size is increased in weight by recruitment[2] of new individuals during the year;

G = the increase in weight of the stock by growth during the year;

C = fishing mortality;[3]

M = the loss in weight of the stock by natural deaths during the year.

It can be observed that there will be a net increase in stock size during the year whenever additions to the stock through growth and recruitment exceed reductions in the stock through

[2] The term "recruitment" refers to the biomass weight of fish entering the catchable population during a given time period (Anderson, 1977: 23).

[3] Fishing mortality largely consists of the weight of the annual catch. However, it will also include such factors as mortality of undersized abalone that are discarded and loss of abalone occurring through the destruction of habitat during the collection process.

fishing and natural mortality. Specifically,

$$P_2 > P_1 \text{ when } (A+G) > (C+M)$$

$$P_2 < P_1 \text{ when } (A+G) < (C+M)$$

$$P_2 = P_1 \text{ when } (A+G) = (C+M)$$

Schaefer (1954) assumed that the growth of the fish stock is a function of its size in weight. The Schaefer model considers the fish population as a whole and concentrates on explaining variations in biomass, without regard to stock structure. The simplicity of the model and its underlying concepts is, however, appealing. Schaefer modified Russell's model by identifying the natural rate of increase of the stock, f(P), as the sum of additions to the stock by recruitment and growth, less subtractions by natural mortality. That is,

$$f(P) = A + G - M,$$

where P = the size of the stock of fish of catchable size.

The Schaefer analysis also assumes that the net increase in biomass of a fishery as a function of population, f(P), taking recruitment, growth, and natural mortality into consideration, can be represented by the following relationship:

$$f(P) = aP - bP^2,$$

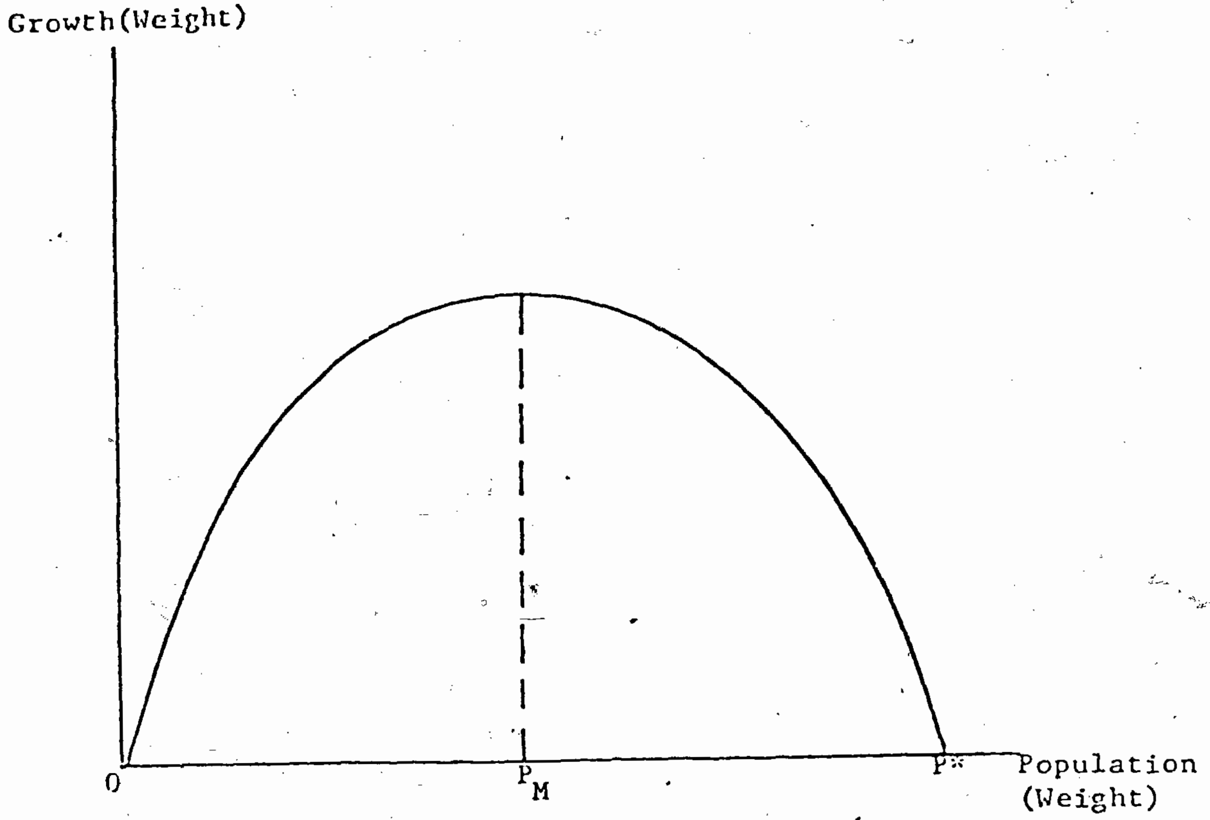
where a and b are constant parameters. This relationship can be depicted as a parabolic curve, as shown in Figure 9.

Suppose, initially, that a small fish population is introduced to an area of the sea where there was previously no fish. It appears reasonable to assume that, to begin with, population growth will initially be proportional to the population; that is,

$$f(P) = aP,$$

where a is the intrinsic growth rate, and represents the fastest growth rate ever attained by the fish stock (Cunningham et al., 1985: 28).

Figure 9: Biological Productivity Curve



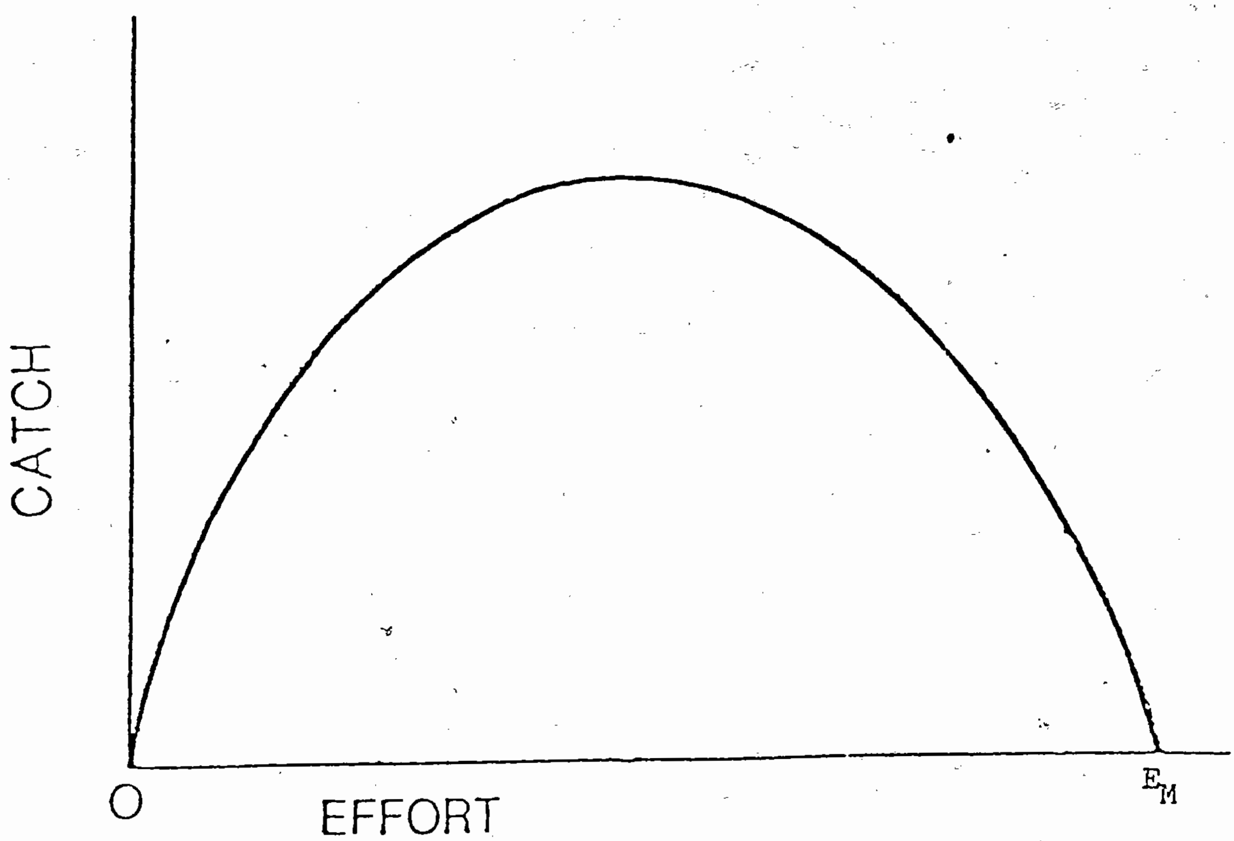
Since a given area of the sea is limited in size, there must be some maximum size of the fish population, P*, that can be supported. As the fish population size approaches this maximum, crowding will increasingly become a problem, and the growth rate of the population may be expected to decline, according to the degree of crowding. At population levels between 0 and P_M, individual growth and recruitment together are high relative to natural mortality; thus the growth rate is increasing. At population levels beyond P_M, natural mortality has increased to the extent that the growth rate of the population begins to decline. This is because a larger number of individuals are now competing for the same amount of limited space and food. The point, P*, represents natural equilibrium, where recruitment and individual growth are just balanced by natural mortality, and the growth rate of the stock is zero. In the absence of fishing, the stock will always tend toward this natural equilibrium population level.

Now consider the effects of an introduction of fishing on a stock which is at its natural equilibrium size. With the removal of part of the stock by fishing, it is reduced to a lower abundance. However, at the lower population level, the rate of stock replacement is larger, so that the removals from fishing are at least partially offset by the ability of fish at lower levels of abundance to reproduce, survive and grow better (Schaefer, 1954: 54). With a steady-state level of fishing effort, a new population equilibrium will be achieved at that population level where the net increase in weight from natural factors just equals the net decrease due to fishing mortality. A different equilibrium population will result at each long-run level of effort. The catch which can, on average, be obtained at a given level of population, without resulting in any net change in population size, may be termed the equilibrium catch, because it is the catch which is in equilibrium with the productivity of the population at any given level (Schaefer, 1954: 54). The catch corresponding to this equilibrium is sustainable because the yield each period is replaced by natural increase (Anderson, 1977: 25).

As the fishery becomes increasingly intense and continues to remove each year a catch in excess of the equilibrium catch, the population falls continuously. The natural rate of increase and the corresponding sustainable yield, however, rise for a time as the population falls. There is eventually reached a population level at which sustainable yield is a maximum. Further increase in fishing intensity drives the population down to levels where the natural rate of increase, and thus sustainable yield, begin to decline; that is, equilibrium catch is less than maximal.

The above relationship between fishing effort and sustainable yield, as hypothesized by Schaefer, is depicted in Figure 10. The sustainable yield curve is the locus of points representing sustainable yield catches for each level of effort (Anderson, 1977: 26). It is

Figure 10: Sustainable Yield Curve



important to recognize the relationship between Figure 9 and Figure 10. At natural equilibrium (P* in Figure 9), there is no effort being applied to the stock (0 in Figure 10). At the zero population level (0 in Figure 9), effort has been applied to the extent that the resource has been fully depleted (E_M in Figure 10). Thus, under simplifying assumptions, Figure 10 is a mirror image of Figure 9.[3]

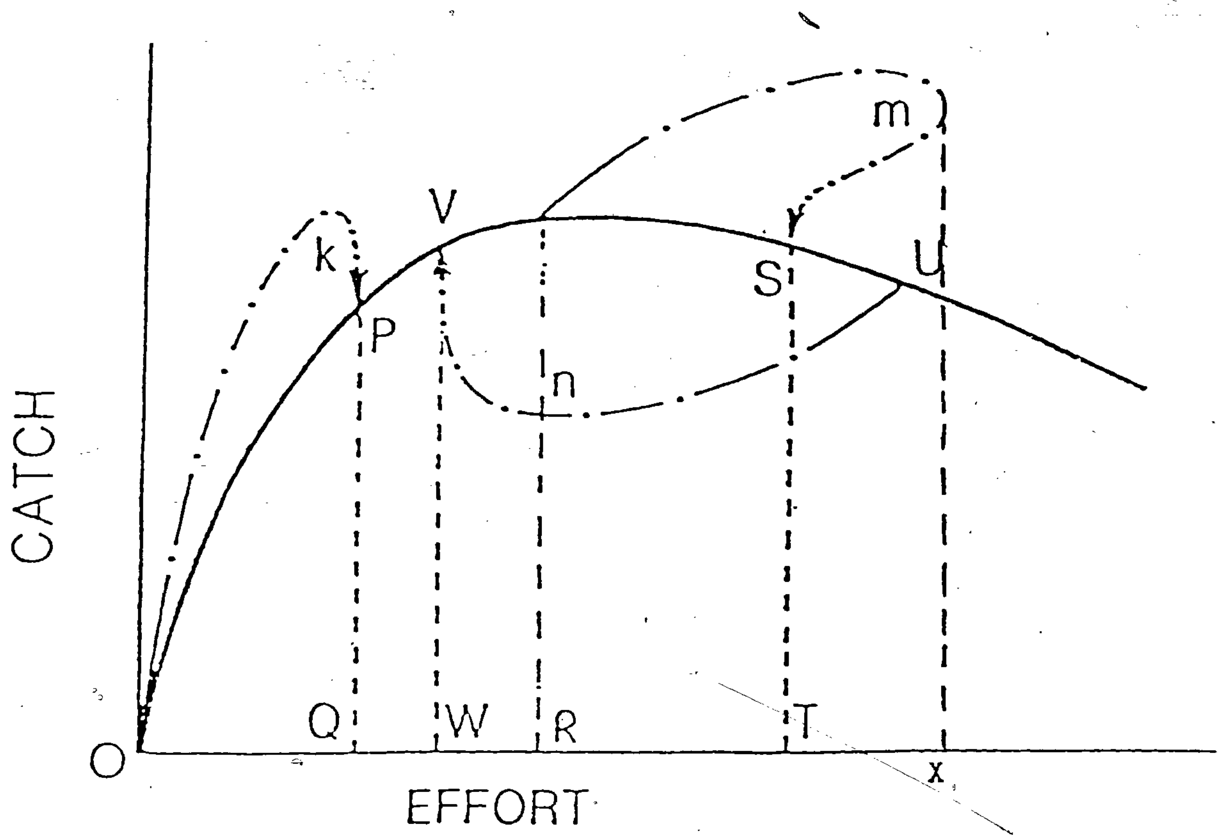
It is important to note that the relationship depicted in Figure 10 is a long run relationship. That is, a point on the yield curve is representative of the catch that can be obtained on a consistent basis after the stock has adjusted to the corresponding level of

[3] Specifically, it must be assumed that catch per unit of effort is a linear function of effort. See Cunningham et al. (1985: 29-36).

fishing effort applied on a sustained basis (Copes, 1978: 25). Thus, the level of catch associated with a particular amount of effort in a given period is not necessarily a point on the sustainable yield curve. Copes (1978: 26–27) offers a simple technique for "fitting" a sustainable yield curve to actual catch and effort data. This is accomplished by visual inspection and by taking into account the relationship between short run harvest rates and the long run yield curve. During periods in which effort is increasing, short run catches will likely exceed long run yields since the stock will not have had time to adjust to the higher effort levels. That is, that proportion of the catch in excess of the sustainable yield represents depletion of the biomass, and will not be replaced by growth. Figure 11 depicts this short-run-long-run relationship. When effort is expanded from 0 to Q, the fishery is expected to follow a course such as that depicted by loop *k*. The sustainable catch for 0Q units of effort is the amount given by PQ. Loop *m* represents an increase in effort from 0R to 0X, followed by a reduction of effort from 0X to 0T. The shapes of the short-run loops depend, of course, on the relationship between effort and short-run catch. It is reasonable to expect that an increase in effort will initially result in a proportional increase in catch. Thus, the path of loop *k*, for example, is initially represented by a straight line from the origin. Note, however, that as the fish population adjusts to the higher level of fishing effort, the short-run path approaches a point of sustainability on the long-run yield curve.

During periods of effort reduction, short run catches will tend to fall below the long run yield curve. When effort is reduced from the level associated with point U on the yield curve to the level 0W, short-run catches will follow the path depicted by loop *n* in Figure 11. The reduced effort is being applied to a relatively small stock occurring at the previously high level of effort. Stocks will take time to recover from the previously high levels of fishing pressure. However, the declining effort will permit stocks to recover and eventually allow higher catches to be obtained. Thus, the reduction in effort will initially cause yields to decline proportionately, after which the short-run path approaches the long-run equilibrium

Figure 11: Relationship Between Short Run and Long Run Yields



associated with the new lower level of effort.

It is expected that the growth curve for abalone is very shallow relative to that for many other fish stocks. This reflects the fact that it is a slow-growing, long-lived species. If a small number of abalone are introduced to a given area, the initial rate of natural increase will be very slow. This is because recruitment will be low, as it is in any small fish population, owing to the small number of mature individuals, but mainly because individual abalone grow very slowly. Thus, the maximum growth rate will be approached very gradually. Since abalone are a long-lived species, the rate of natural mortality is relatively low; thus the growth rate will begin to decline very gradually after the maximum growth rate has been attained. Correspondingly, the long-run sustainable yield curve for abalone should also be shallow. That is, only a small number of abalone, relative to total population size, can be taken per period if the amount taken is to be replaced by natural growth.

Table 2 summarizes the abalone catch and effort statistics for British Columbia and its major producing regions. The unit of effort chosen is that of an "abalone-day", where every day a vessel participates in the fishery is counted as one unit of effort. It is recognized that this unit of effort is inaccurate for a number of reasons. It applies equal weight to all days when, in fact, the proportion of the day actually spent diving for abalone varies. Additionally, it does not discriminate between boats utilizing different numbers of divers. Thus, an abalone-day can refer to both the effort produced by a boat fishing for two hours with one diver and a boat fishing for eight hours with three divers.

A preferable measure of fishing effort is that of a "diver-hour", where each hour dived counts as one unit of effort. Unfortunately, diver-hours have only been recorded since 1979, thus providing only seven observations of effort and corresponding short-run catch. In general, such a limited number of observations does not provide enough information from which to construct a sustainable yield curve. Another potential measure of effort is that of a "diver-day". This information is available from 1977 onward, and therefore provides only nine observations of catch and effort. Thus, with the exception of the Queen Charlotte Islands, Table 2 records effort in terms of abalone-days. This information was not available for most years in which catch was taken from the Queen Charlotte Islands; the diver-hour was chosen as the alternative unit of effort for this region. Abalone-days were not recorded in 1971 or 1979 and are not yet available for 1985. The data for 1979 and 1985 have been estimated from data available on diver-days for those years.[5] Specifically, the percentage change in the number of diver-days from 1978 to 1979 and from 1984 to 1985, was used to estimate the number of abalone days in 1979 and 1985. Despite the aforementioned inaccuracies involved

[5] Department of Fisheries and Oceans, Prince Rupert, B.C., unpublished data; and Farlinger and Bates, 1985.

Table 2: **Catch (kg.) and Effort (abalone-days) for the British Columbia Abalone Fishery, by region, 1969 - 1985**

	Area 2E		Area 6		Queen Charlotte Islands		North Coast		Area 12		Area 20		South Coast		British Columbia Total	
Year	(1) C	(2) E	(3) C	(4) E	(5) C	(6) E*	(7) C	(8) E	(9) C	(10) E	(11) C	(12) E	(13) C	(14) E	(15) C	(16) E
1969	nr	nr	nr	nr	nr	nr	nr	nr	227	nr	nr	nr	635	69	635	69
1970	nr	nr	nr	nr	nr	nr	5,352	55	nr	nr	1,769	16	10,886	75	16,238	130
1971	nr	nr	nr	nr	nr	nr	nr	nr	227	nr	nr	nr	6,668	nr	6,668	nr
1972	nr	nr	nr	nr	nr	nr	nr	nr	6,577	65	408	4	59,601	444	59,601	444
1973	5,443	14	454	3	7,257	nr	28,576	112	nr	nr	5,897	33	38,782	335	67,358	447
1974	nr	nr	6,350	42	nr	nr	12,247	74	2,268	16	7,257	49	14,515	149	26,672	223
1975	2,268	8	16,239	91	2,268	nr	44,679	294	3,175	33	3,629	69	12,474	167	57,153	461
1976	112,037	290	37,194	308	116,573	nr	249,927	954	5,443	55	9,525	94	23,814	200	273,741	1,154
1977	259,463	458	33,027	165	318,502	nr	461,111	1,034	8,545	57	1,430	15	20,263	131	481,374	1,165
1978	101,257	283	160,380	406	128,706	nr	395,008	1,099	459	42	2,115	29	9,204	nr	404,212	1,171
1979	24,874	113	88,582	nr	37,695	943	181,215	880	17,312	88	281	25	26,954	nr	208,169	1,017
1980	12,537	78	49,160	446	19,457	411	90,471	768	14,504	118	957	26	17,146	147	107,617	915
1981	21,321	138	37,755	221	29,291	811	77,423	654	9,595	121	4,805	53	16,228	218	93,651	872
1982	13,538	61	27,058	236	26,723	698	61,054	407	5,093	15	8,603	55	21,121	147	82,175	554
1983	20,643	183	7,538	61	32,756	751	48,518	452	2,452	49	7,684	71	10,137	120	58,654	572
1984	12,670	75	9,899	76	27,800	902	46,106	392	3,238	38	6,593	106	10,738	189	56,844	581
1985	4,409	26	12,804	117	14,027	262	35,575	336	4,646	75	3,258	77	10,155	230	45,730	545

C = Catch; E = Effort; nr = No landings recorded.

*Effort recorded in diver-hours

Source: British Columbia Catch Statistics, 1969–1985; Federenko and Sprout, 1982; Farlinger and Bates, 1985.

with the use of the abalone-day as a measure of fishing effort, it can be considered an unbiased estimator of actual effort. That is, there is no reason to believe that it consistently underestimates or overestimates true fishing effort.

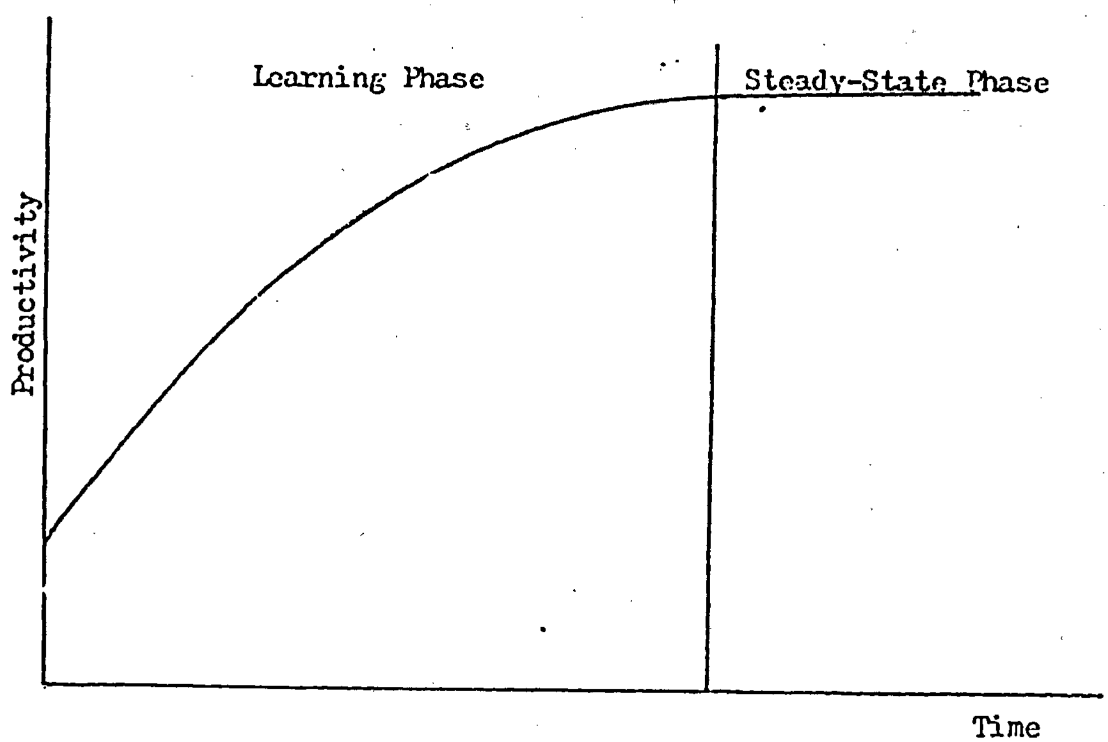
A problem that all of the aforementioned units of effort fail to overcome is that of accounting for differences in skill among abalone fishermen. Additionally, the effort data recorded in Table 2 fail to account for the fact that fishermen become more productive as skills are acquired over time. The following section attempts to compensate for this shortcoming.

Effective Effort

It is desirable to adjust the levels of effort so as to account for variations in the average skill of divers over time. It is probable that the large expansion of effort on the north coast after 1975 was largely generated by unskilled abalone fishermen. Additionally, previously unexplored areas in northern British Columbia became major producing areas after 1975. The likely consequence of a reduction in the average skill of divers and an unfamiliarity with new abalone beds is that of a significant reduction in the average productivity of effort. It has become standard practice in cost-accounting procedures to allow for the effects of learning in estimations of production costs (Horngren, 1977:206). As experience is gained, productivity increases. In general, as production skills are acquired for any process, and other variables are held constant, average productivity is expected to increase at a diminishing rate and eventually reach a steady-state maximum. As experience is gained, productivity initially increases, but there is, of course, a level of experience at which the productivity reaches a maximum. Figure 12 illustrates a "learning curve"[6] which depicts the

[6] Horngren, 1977. Arrow (1962) postulates that the learning curve first rises at an increasing rate, and reaches a point of inflection, after which the second derivative becomes negative. It is indeed probable that newcomers will acquire skills very quickly initially, say in the first few days of diving for abalone. However, since the learning process is being looked at from a seasonal perspective in this case, the learning curve is more likely to be approximated by

Figure 12: Learning Curve



relationship between the average productivity of a group of individuals and the acquisition of skill by those individuals over time.

Unfortunately, the precise effects of changes in skill and the exploitation of new areas upon the productivity of effort in the abalone fishery cannot be readily determined. An accurate account of such effects would require knowledge of the productivity of fishermen and divers with varying skills as well as their success in areas which are both familiar and unfamiliar to them. This information is not available at the present time. It is possible, however, to construct a hypothetical scenario that provides a better understanding of the effects of learning in the British Columbia abalone fishery.

---

[4](cont'd) that illustrated in Figure 12.

The learning procedure can be divided into two components: the procurement of diving skills as experience is gained; and the process of familiarization with previously unexplored areas. The difficulty lies in identifying the separate effects of these two components.

Consider initially the acquisition of diving skills alone. Assume for now that abalone occur only in a single, geographically well-defined area that has been lightly exploited for many years. If there is a sudden influx of new entrants into the fishery, one may reasonably expect the average product of fishermen's labour in this fishery to decline. Relative to experienced fishermen, the new participants will have less knowledge regarding the specific habitat in which abalone are abundant and will thus require more search time; additionally, the newcomers will be less adept in the actual collection of abalone. As was noted in Part B of the thesis, some dexterity is needed in order to remove individual abalone from the substrate unharmed. In time, however, new entrants will acquire these skills. It is desirable to derive a reasonable estimate of the effect of the acquisition of labour skills on the productivity of effort. Column 16 of Table 2 indicates that, for the fishery as a whole, no significant increase in effort took place between 1972 and 1975. Prior to 1972, a steady increase in the level of nominal effort took place. It appears as if little entry took place after 1972 until 1976. Assume that it takes three years for the average newcomer to acquire all of the skills necessary for harvesting abalone. Relative to the catch and effort levels of 1972, those of prior years are low. Thus, it is probable that a good deal of learning took place from 1972 to 1975. Suppose, for example, that, relative to the average fisherman in 1975, the average participant was forty percent as efficient in 1972, seventy percent as efficient in 1973, and ninety percent as efficient in 1974. It may be assumed that, in 1975, the majority of abalone fishermen had procured the necessary skills. In 1976, however, the level of nominal effort increased dramatically; thus, it may be conjectured that the majority of participants were inexperienced in 1976. Suppose that the decrease in the average level of skill caused the effectiveness of labour to decrease by sixty percent from 1975 to 1976. Although slight, the level of effort again increased in 1977. It is known, however, that this was not due to further entry; in order to qualify for a license in 1977, fishermen had to meet a minimum landing requirement for 1976. Therefore, the average level of skill in the fishery must have increased from 1976 to 1977, thereby resulting in upward pressure on the average contribution of labour. It might be hypothesized that the efficiency of labour in 1977 was seventy percent of that in 1975. Similarly, one might expect that, on average, each unit of labour in 1978 was ninety percent as effective as the average unit of labour expended in 1975. By 1979, the average fisherman may be considered just as competent in harvesting abalone as the average fisherman in 1975.

The above scenario concurs with the learning process illustrated in Figure 12. In terms of the obtainment of skills, the years 1972 to 1975, and 1976 to 1979 constitute the "learning phase" which is followed by the maintenance of the "steady-state phase".

The hypothetical situation described above can be summarized by using what shall be termed a "skill index", which is presented in Table 3. The skill index describes changes in the efficiency of an average unit of fishermen's labour resulting from the acquisition of diving skills alone. That is, the level and productivity of inputs other than labour are assumed constant. One might think of the introduction of a unit of labour as adding to the effectiveness of a unit of effort. Here, one unit of effort is an abalone-day. The abalone-day encompasses inputs of labour and capital employed during a day of fishing as well as the area covered during the day. In 1975, the average fisherman is assumed to have acquired all necessary skills for harvesting abalone. When exerting a unit of effort, i.e., an abalone-day, the capital he employed, the area he covered, and his own skill each would have contributed to that effort. The skill index indicates that, in 1976, an average fisherman who employed equally productive capital and harvested an area identical to that harvested by the average fisherman in 1975, would have contributed sixty percent less to the effectiveness of a unit of effort than the average fisherman in 1975.

Table 3: **Skill Index for the British Columbia Abalone Fishery, 1972 - 1979**

Year	Skill Index
1972	0.4
1973	0.7
1974	0.9
1975	1.0
1976	0.4
1977	0.7
1978	0.9
1979	1.0

Now consider the impact of labour on a unit of effort when the exploitation of previously unexplored areas is also taken into account. Table 2 indicates that Statistical Areas 2E and 6 were very lightly exploited prior to 1976. Thus, the contribution of labour to a unit of effort in these areas will have been adversely affected by both a general uncertainty regarding the location of potential abalone habitat and the decrease in the average level of fishing skill. The same is true for the north coast region as a whole, since the majority of areas in northern British Columbia had been only lightly exploited prior to 1976. Note, however, that the reduction in labour effectiveness resulting from the harvesting of new areas is likely to be less severe for the north coast as a whole than for Areas 2E and 6 individually. This is because, although many areas of northern British Columbia were unexplored, some harvesting of abalone did occur in this region prior to 1972. The south coast region, which includes Areas 12 and 20, however, was not a generally unexplored region. Furthermore, it is probable that the reduction in the average skill of divers is less pronounced in areas of the south coast than in areas of the north. This is because the new entrants were likely discouraged from harvesting abalone from beds in the south which were traditionally exploited by established fishermen. Thus, the downward pressure on the productivity of effort applied to abalone stocks in southern British Columbia is likely to have been less intense than that in northern British Columbia. It is doubtful that the effect of entry on labour's contribution to an abalone-day varied significantly among areas in the south.

Columns 1 through 4 of Table 4 depict potential "labour impact indices" for each of the relevant regions. To derive each index, the skill index presented earlier was used as a type of gauge and revised according to the trend of effort levels occurring in each area. For example, in Areas 2E and 6 there was no catch recorded prior to 1973; thus, it may be assumed that abalone fishermen were unfamiliar with these areas. It has been hypothesized that, owing to a reduction of average skill alone, the average fisherman was only seventy percent as productive in 1973 as he would be after acquiring all necessary skills. The fact that all participants were unfamiliar with Areas 2E and 6 suggests that it is likely that the average unit of labour in 1973 was even less efficient than that indicated by the skill index. Indeed, the labour productivity indices for all areas in northern British Columbia should fall entirely below the skill index until, say, 1980, when both diving skills and area-familiarity should have been sufficiently acquired. That is, it is expected that, in addition to being unskilled in fishing for abalone, the average abalone fisherman in northern British Columbia was also unfamiliar with the area he was harvesting prior to 1980. Thus, his contribution to effort was less than what it would have been if he was harvesting abalone in an area with which he was familiar.

The labour impact indices for areas in southern British Columbia are slightly different than those for areas in northern British Columbia. Dating back to at least 1952, areas along the south coast have provided abalone catches every year, with the exception of 1959 (Federenko and Sprout, 1980: 32). Thus, the extent to which fishermen are familiar with the southern areas is likely to have had little bearing on the average impact of labour on an abalone-day. Consequently, columns 3 and 4 of Table 4 are simply reproductions of the skill index shown in Table 3.

Table 4: **Contribution Indices for the British Columbia Abalone Fishery, by region, 1972 - 1985**

	Indices of Labour Impact					Index of Capital Impact
Year	(1) Areas 2E and 6	(2) North Coast	(3) Areas 12 and 20	(4) South Coast	(5) British Columbia	(6) British Columbia
1972	na	na	.40	.40	.40	1.00
1973	.30	.35	.70	.70	.61	1.00
1974	.30	.35	.90	.90	.72	1.00
1975	.30	.35	1.00	1.00	.59	1.00
1976	.20	.30	.40	.40	.32	1.30
1977	.50	.60	.70	.70	.61	1.50
1978	.80	.80	.90	.90	.80	1.60
1979	.95	.95	1.00	1.00	.96	1.60
1980	1.00	1.00	1.00	1.00	1.00	1.60
1981	1.00	1.00	1.00	1.00	1.00	1.60
1982	1.00	1.00	1.00	1.00	1.00	1.60
1983	1.00	1.00	1.00	1.00	1.00	1.60
1984	1.00	1.00	1.00	1.00	1.00	1.60
1985	1.00	1.00	1.00	1.00	1.00	1.60

na = not applicable

The labour impact index for the British Columbia abalone fishery as a whole is simply a weighted average of that for the south coast and the north coast. With the exception of the years 1978 and 1979, for which effort levels measured in abalone-days are unavailable for southern British Columbia, the index in column 5 of Table 4 was derived as follows:

$$LI_{BC} = (AD_t^S / AD_t^{BC}) LI_S + (AD_t^N / AD_t^{BC}) LI_N$$

where,

LI_{BC} = index of labour impact on effort for British Columbia abalone fishery in period t;

LI_S = index of labour impact on effort for south coast abalone fishery in period t;

LI_N = index of labour impact on effort for north coast abalone fishery in period t;

AD_t^S = number of abalone-days fished in southern British Columbia in period t;

AD_t^N = number of abalone-days fished in northern British Columbia in period t;

AD_t^{BC} = total number of abalone-days fished in British Columbia in period t;

t = 1972-1977; 1980-1985.

The proportionate number of diver days[7] for 1978 and 1979 were employed as the weights for those years. That is,

$$LI_{BC} = (DD_t^S/DD_t^{BC})LI_S + (DD_t^N/DD_t^{BC})LI_N$$

where,

DD_t^S = number of diver-days exerted on south coast in period t;

DD_t^N = number of diver days exerted on north coast in period t;

DD_t^{BC} = total number of diver-days exerted in British Columbia in period t;

t = 1978, 1979.

The learning curves for the north coast, south coast and the whole of British Columbia are illustrated in Figures 13a, 13b, and 13c, respectively. Note that the vertical axis measures the standardized average productivity of effort. The standard unit of effort is that which is exerted after skills and familiarity with the fishing ground have been fully acquired; such an effort unit has been assigned a productivity value of 1. The productivity of all other units of effort have been ascertained in relation to the standard unit. It is important to note that these learning curves depict a trend in productivity of effort where only fishing skills and the areas harvested are allowed to vary. Other variables affecting productivity are held constant. An additional factor which is likely to have had a significant effect on the

[7] Farlinger and Bates, 1985.

Figure 13a

Learning Curve for Northern British Columbia, 1973–1985

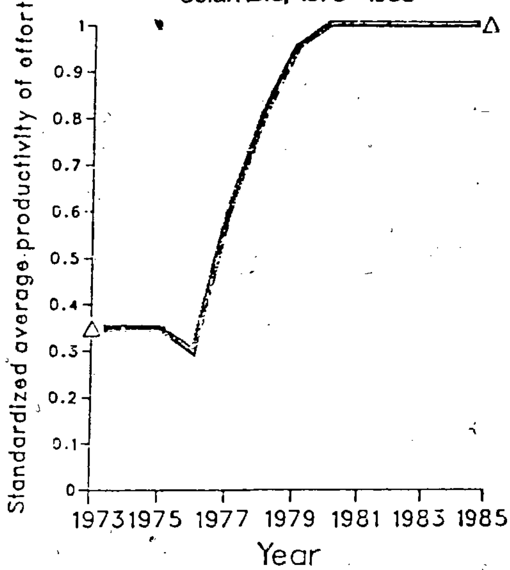


Figure 13b

Learning Curve for Southern British Columbia, 1972–1985

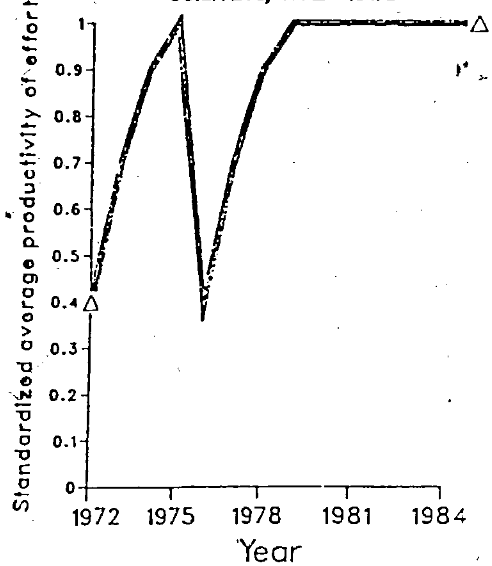
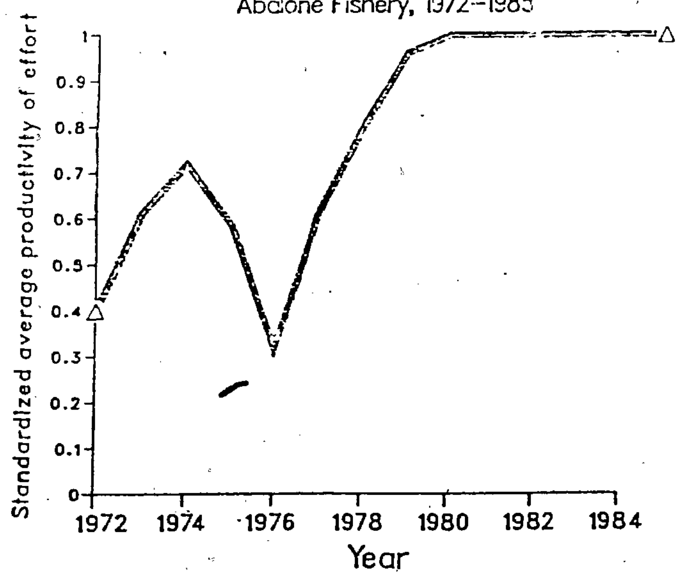


Figure 13c

Learning Curve for British Columbia Abalone Fishery, 1972–1985



productivity of an abalone-day is the employment of more efficient vessels. As mentioned earlier, there was an influx of vessels equipped with air compressors and freezing systems in 1976. Again, owing to insufficient data, it is not possible to determine the precise effect of the use of more efficient capital upon the productivity of effort, but a hypothetical scenario is helpful. In 1976, the average vessel's contribution to a unit of effort may have been thirty percent greater than that in 1975. The imposition of limited entry in 1977 likely resulted in the exit of the least efficient vessels, thus causing the average impact of capital on a unit of effort to rise further, perhaps by another twenty percent. The efficiency of the fleet continued to increase through 1978,[8] after which the impact of capital likely reached a plateau at, say, sixty percent greater than the average contribution of capital in 1975. The "index of capital impact" corresponding to this scenario is shown in column 6 of Table 4.

Table 5 summarizes the effects of learning and the additions of capital to the abalone fleet through the use of an index of effective effort[9] which has been derived by aggregating the indices of labour contribution and capital contribution. For example, in 1976 an abalone-day generated only sixty-two percent of the effectiveness of a "standard" abalone-day. A "standard" unit of effort is that which reflects the productivity of a skilled abalone fisherman, harvesting an area with which he is completely familiar, and employing the type of vessel which is representative of that which was used prior to 1976. Since, in 1976, the average fisherman contributed sixty-eight percent less to a unit of effort than the standard fisherman, and a unit of capital contributed thirty percent more than the standard unit, it may be deduced that a 1976 abalone-day was thirty-eight percent less effective than a standard abalone-day. The remainder of the index was derived in this same manner. Note that in deriving the index of effective effort, it has been implicitly assumed that this index is strictly additive with respect to the impact of labour and capital. This, is turn, stems from

[8] Federenko and Sprout, 1980.

[9] The notion of "effective effort" and its implications was obtained from P. Copes in personal conversation.

Table 5: **Indices of Effective Effort, by region, 1972 - 1985**

Year	(1) Areas 2E and 6	(2) North Coast	(3) Areas 12 and 20	(4) South Coast	(5) British Columbia
1972	na	na	.40	.40	.40
1973	.30	.35	.70	.70	.61
1974	.30	.35	.90	.90	.72
1975	.30	.35	1.00	1.00	.59
1976	.50	.60	.70	.70	.62
1977	1.00	1.10	1.20	1.20	1.11
1978	1.40	1.40	1.50	1.50	1.40
1979	1.55	1.55	1.60	1.60	1.56
1980	1.60	1.60	1.60	1.60	1.60
1981	1.60	1.60	1.60	1.60	1.60
1982	1.60	1.60	1.60	1.60	1.60
1983	1.60	1.60	1.60	1.60	1.60
1984	1.60	1.60	1.60	1.60	1.60
1985	1.60	1.60	1.60	1.60	1.60

na = not applicable

the assumption that the average units of labour in each year under consideration are equally adept at using the capital introduced to the fishery after 1975. This is a valid assumption if there is no reason to expect that the average fisherman in any given year is more skilled at using air compressors and freezing systems than the average fisherman in another year.

The effort levels for the areas under consideration have been adjusted according to the relevant indices of effective effort; these results are indicated in Table 6. The extent to which the index of effective effort deviates from the "true" index depends, of course, on the extent to which the actual changes in the relative impacts of labour and capital on a unit of effort are reflected in the hypothetical indices described above.

Assuming that entry into the fishery resulted in affecting effort in the manner described above, the effective effort employed from 1973 and 1985 will generally differ from that indicated in Table 2. Following Copes (1978), the "loop method" has been utilized in

Table 6: **Adjusted Effort in the British Columbia Abalone Fishery,by region, 1972 - 1985**

Year	(1) Area 2E	(2) Area 6	(3) North Coast	(4) Area 12	(5) Area 20	(6) British Columbia
1972	na	na	na	26	2	178
1973	4	1	39	na	23	273
1974	na	13	26	14	44	161
1975	2	27	103	33	69	272
1976	145	154	572	39	66	715
1977	458	165	1,137	68	18	1,293
1978	396	568	1,539	63	44	1,639
1979	175	na	1,364	141	40	1,587
1980	125	714	1,229	189	42	1,464
1981	221	354	1,046	194	85	1,395
1982	98	378	651	24	88	886
1983	293	98	723	78	114	915
1984	120	122	627	61	170	930
1985	42	187	538	120	123	872

na = not applicable

the estimation of the sustainable yield curves. By using the adjusted levels of effort shown in Table 6 in the construction of the yield-effort curves, it is possible to obtain a relationship between the short- and long-run similar to that depicted in Figure 6. Figures 14a to 17d include derivations of the sustainable yield curves for Areas 2E and 6, the north coast and for the British Columbia abalone fishery as a whole. The yield curves for southern British Columbia have been omitted as there is no discernible pattern between short-run and long-run catches for this region. The practice of deriving yield curves for particular areas raises questions regarding stock definition. The following sustainable yield curves illustrate a number of possible alternative definitions of stock in terms of the area definition of stock. Ideally, one should be dealing with a discrete stock. In the case of abalone, there is a good deal of stock localization but there are, presumably, stock overlaps through the dispersal of spat in the spawning process. For purposes of comparison, two curves have been constructed for each area: one using the unadjusted level of effort shown in Table 2 and another using

Figure 14a
Yield–Effort Relationship for
Statistical Area 2E
1973, 1975–1985

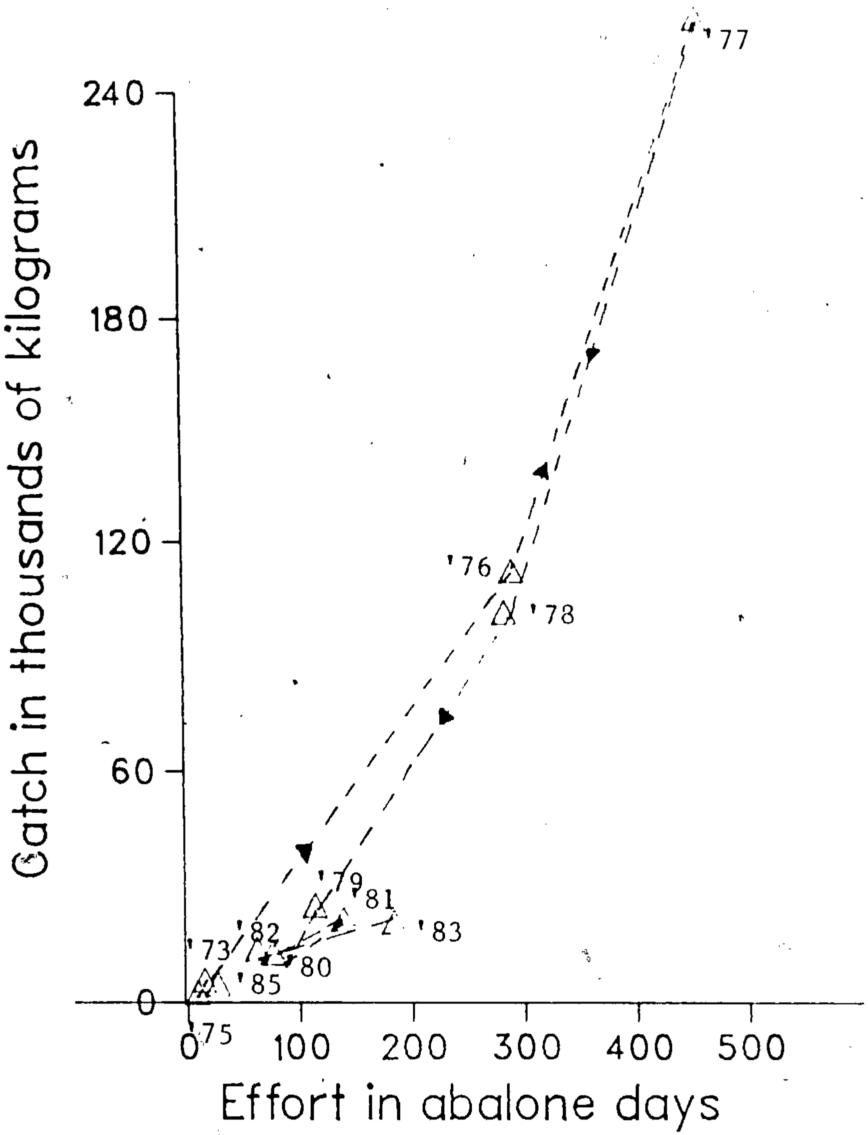


Figure 14b
Yield–Effort Relationship for
Statistical Area 2E
1973, 1975–1985

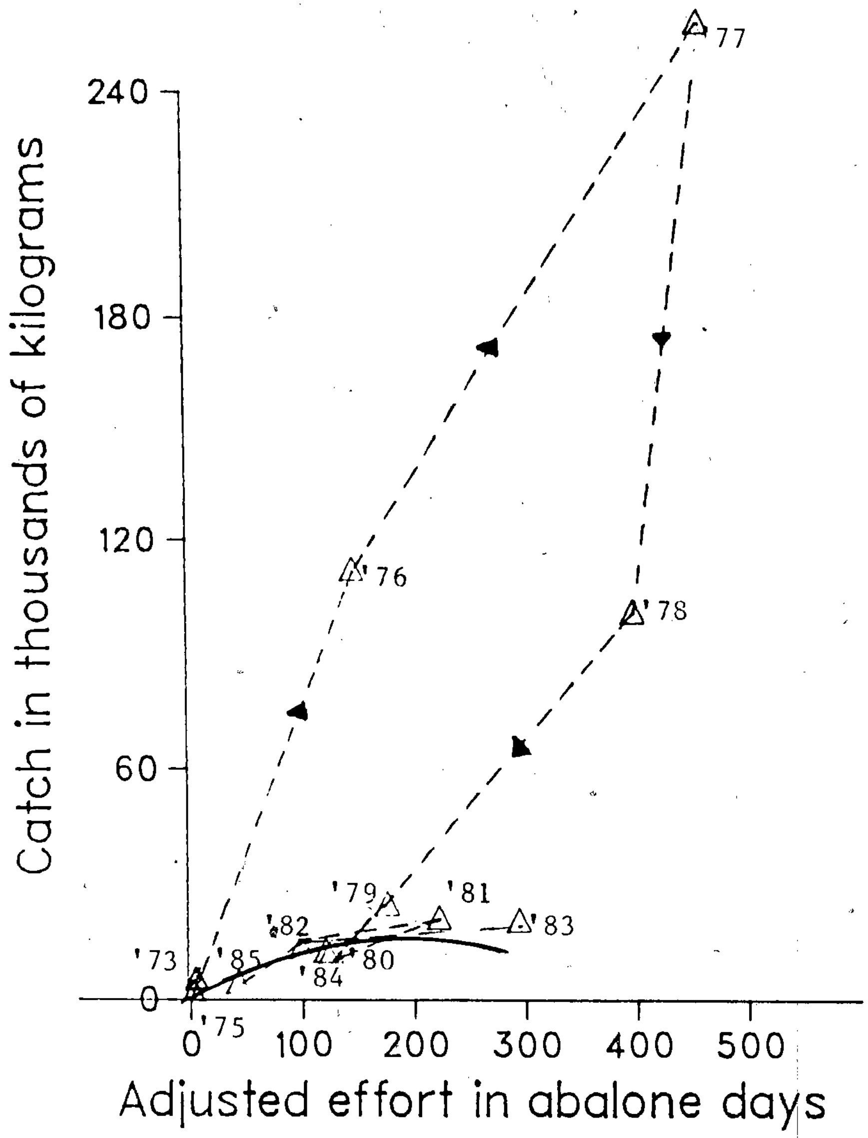


Figure 14c
Yield–Effort Relationship for Statistical Area 2E 1973, 1975–1985

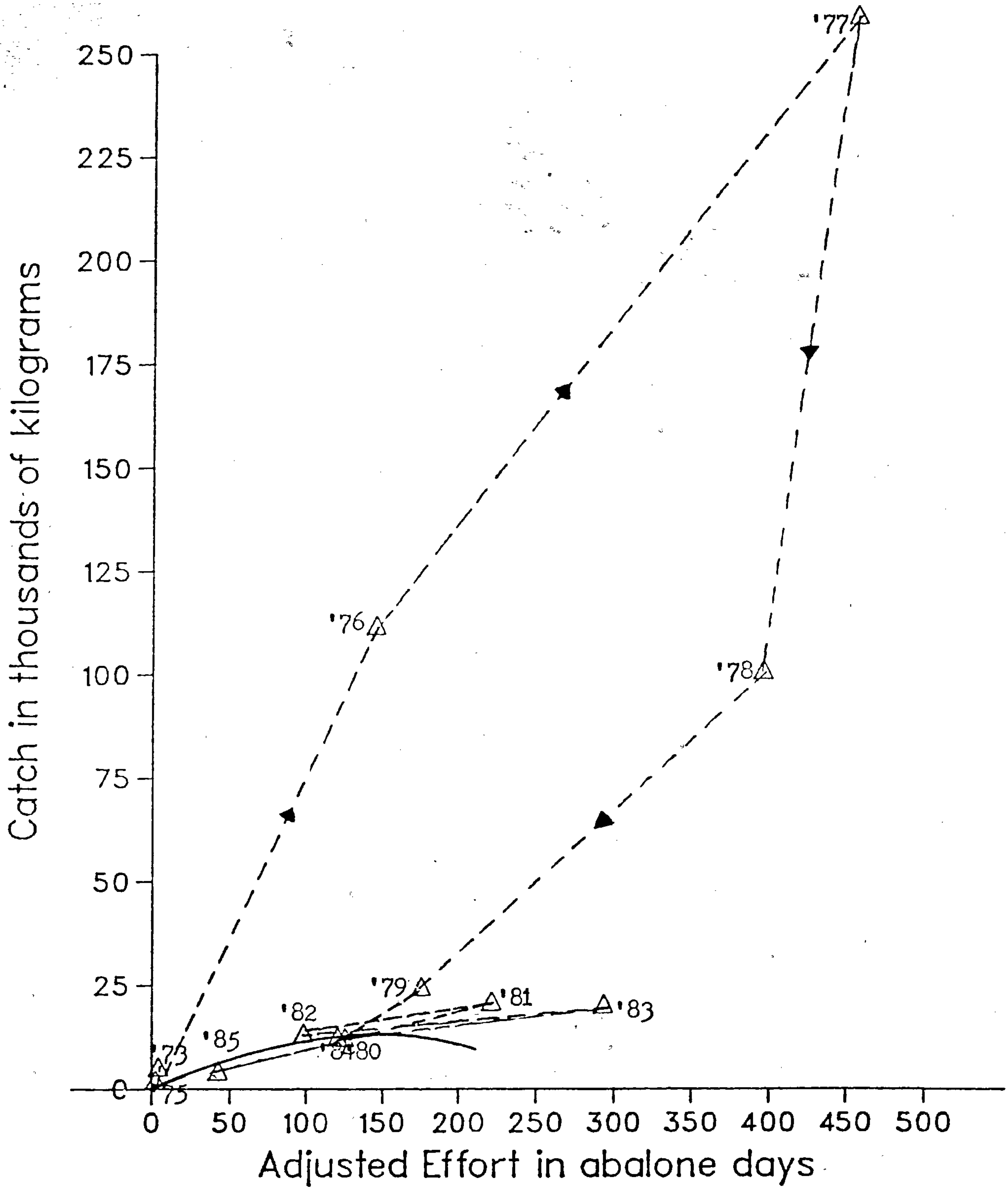


Figure 15a
Yield–Effort Relationship for
Statistical Area 6
1973–1978, 1980–1985

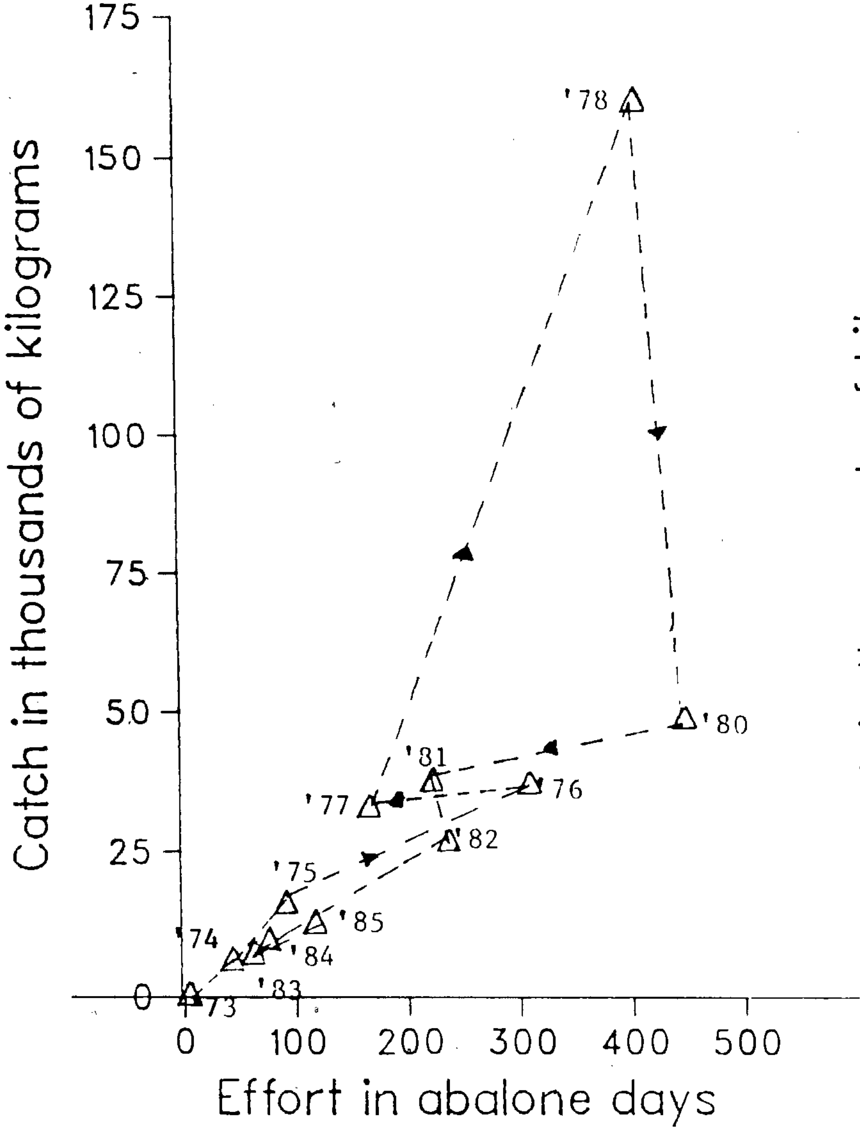


Figure 15b
Yield–Effort Relationship for
Statistical Area 6
1973–1978, 1980–1985

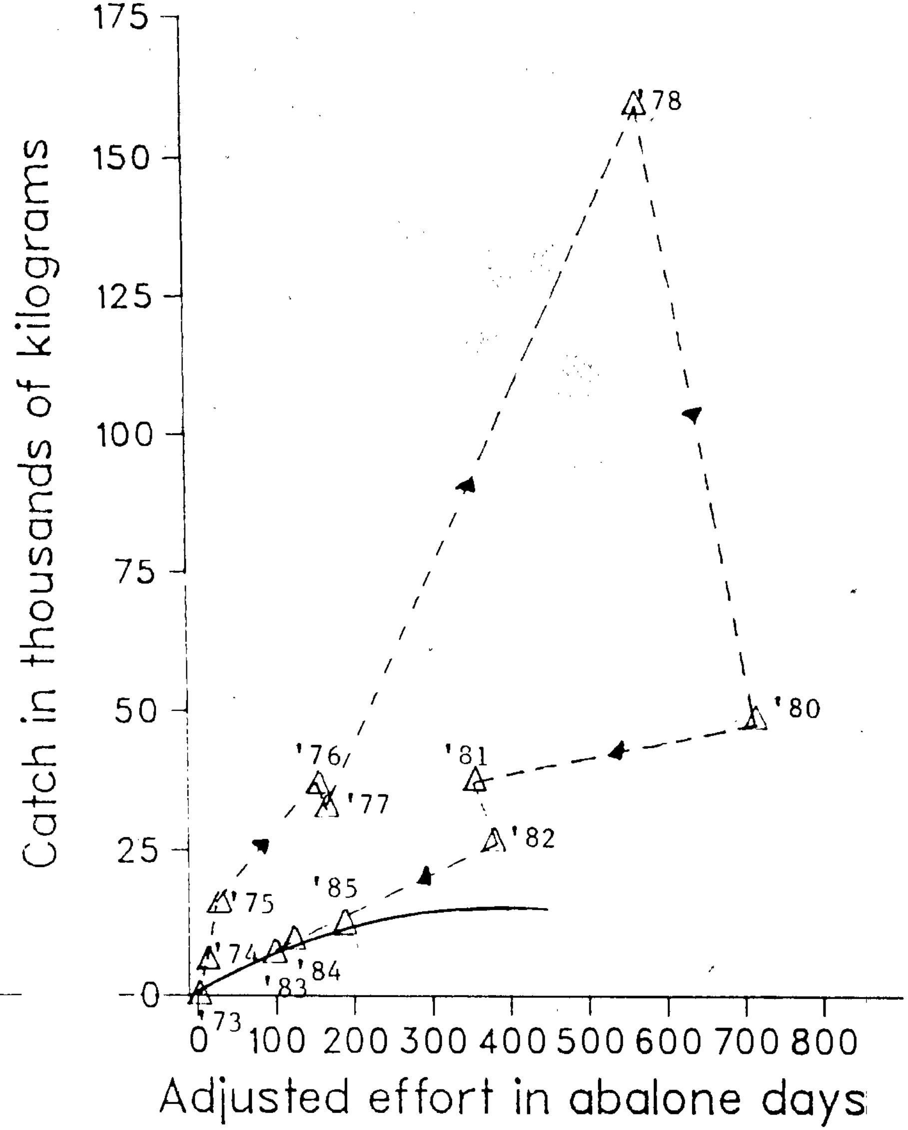


Figure 15c
Yield–Effort Relationship for Statistical Area 6 1973–1978, 1980–1985

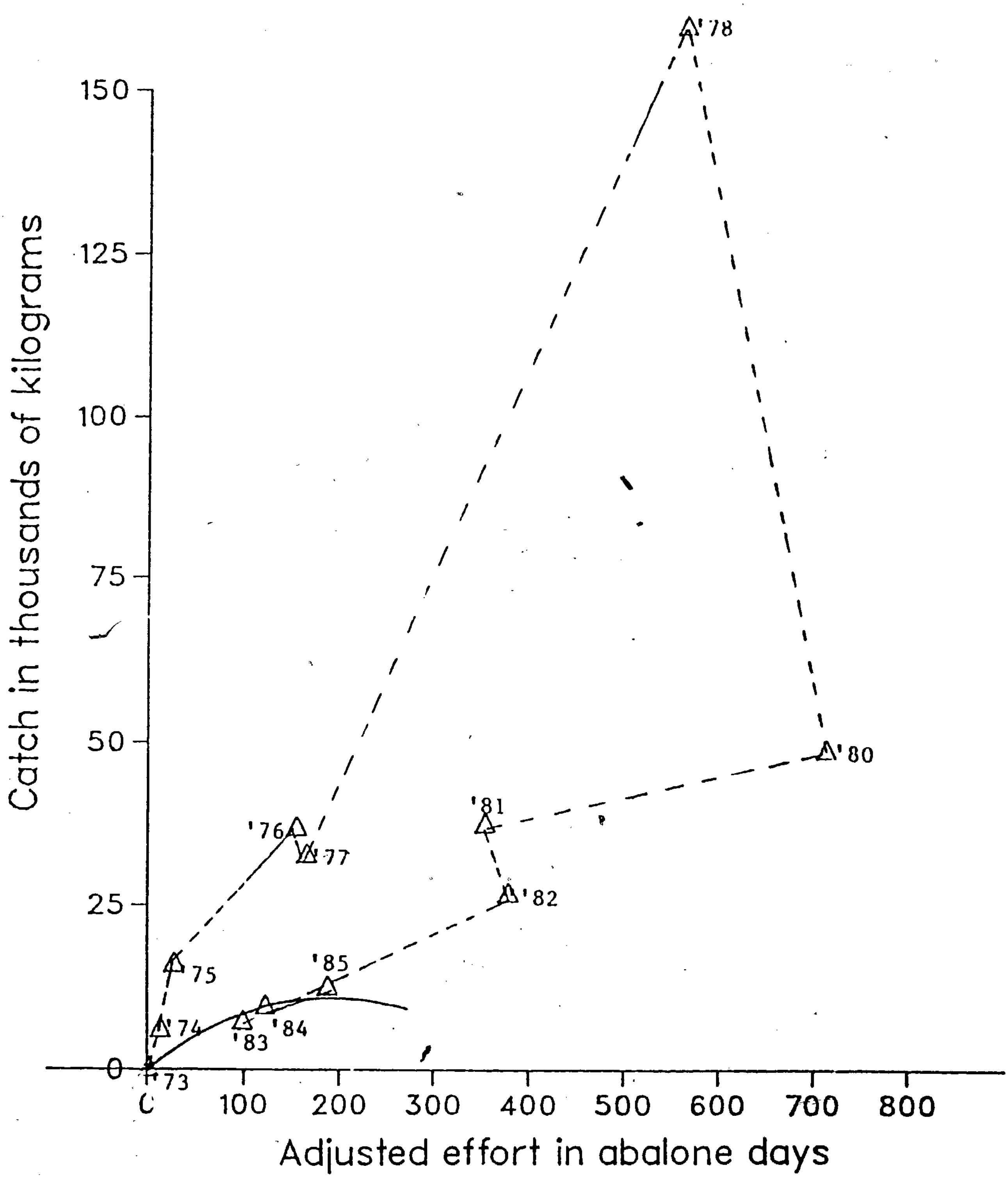


Figure 16a
Yield–Effort Relationship for
Northern British Columbia
1973–1985

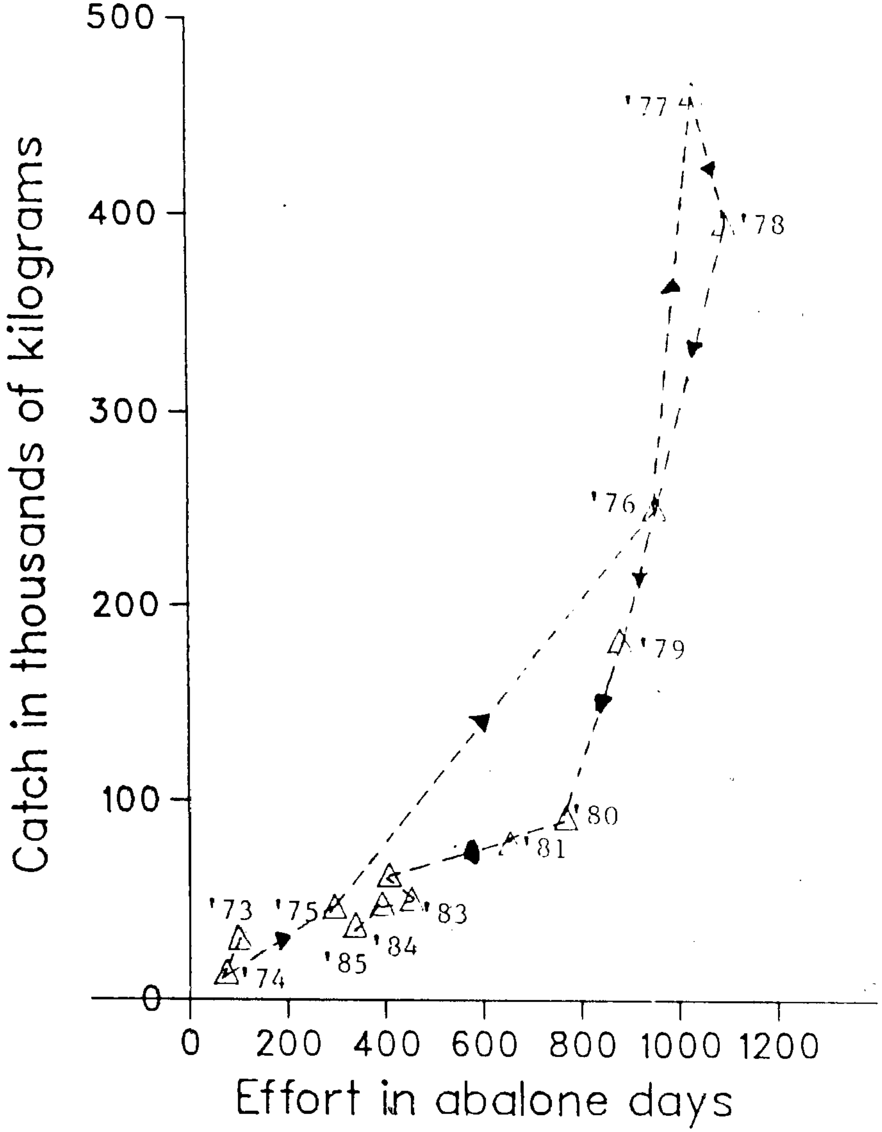


Figure 16b
Yield–Effort Relationship for
Northern British Columbia
1973–1985

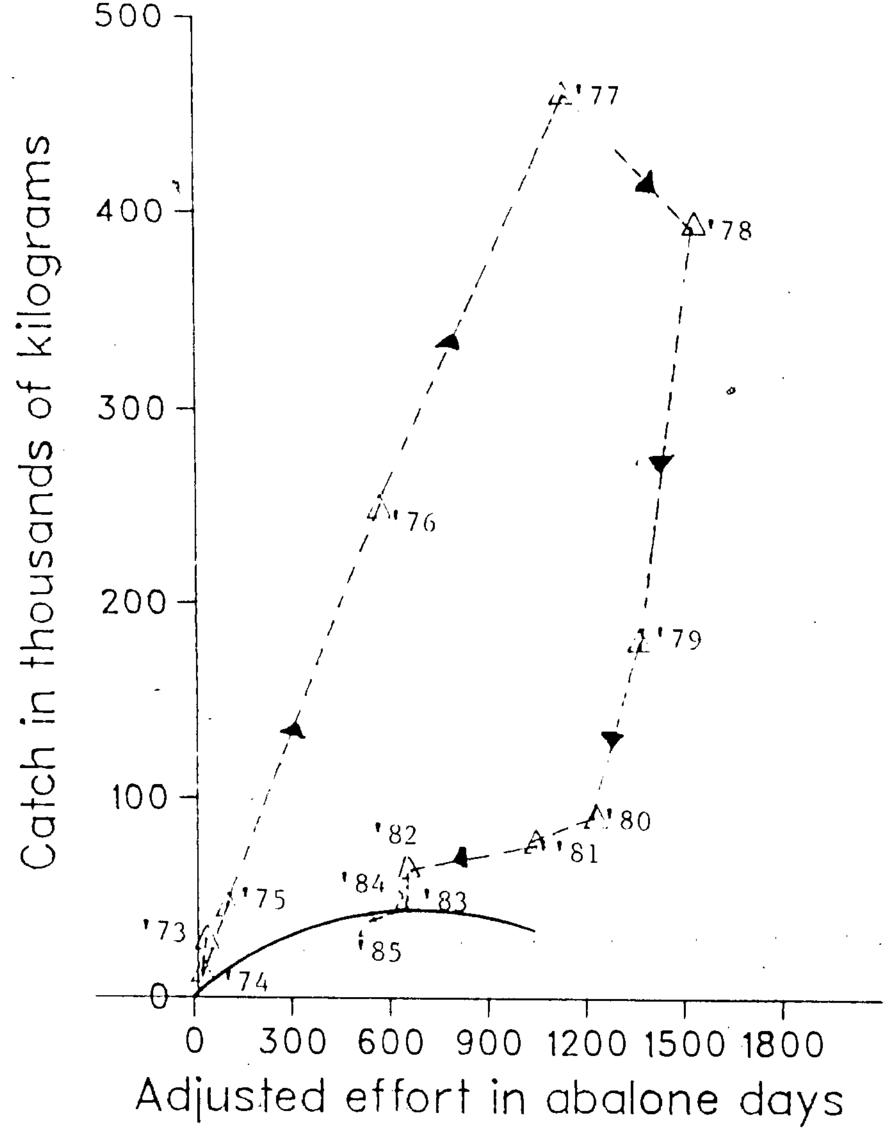


Figure 16c
Yield–Effort Relationship for Northern British Columbia 1973–1985

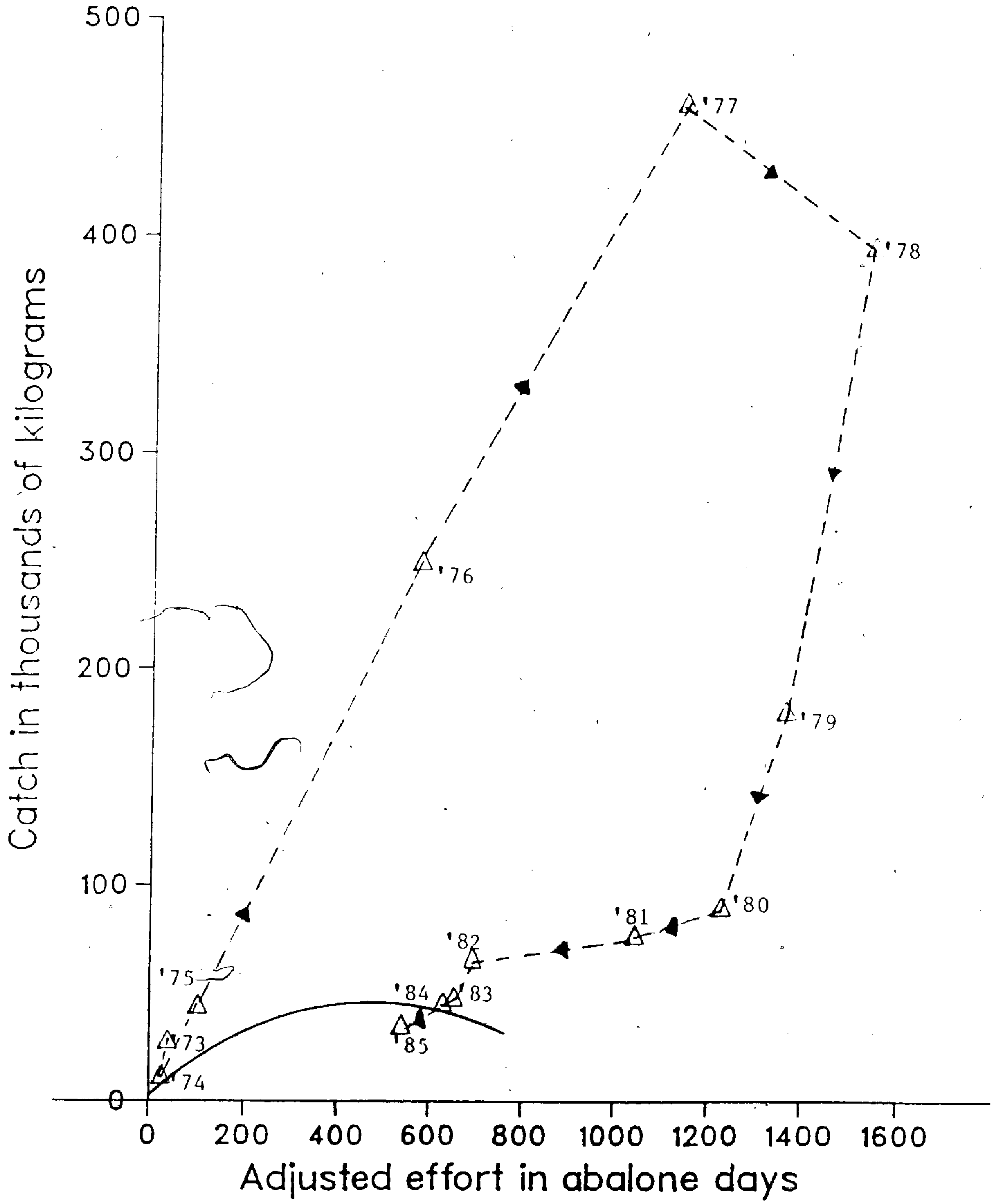


Figure 16d
Yield–Effort Relationship for Northern British Columbia 1973–1975, 1980–1985

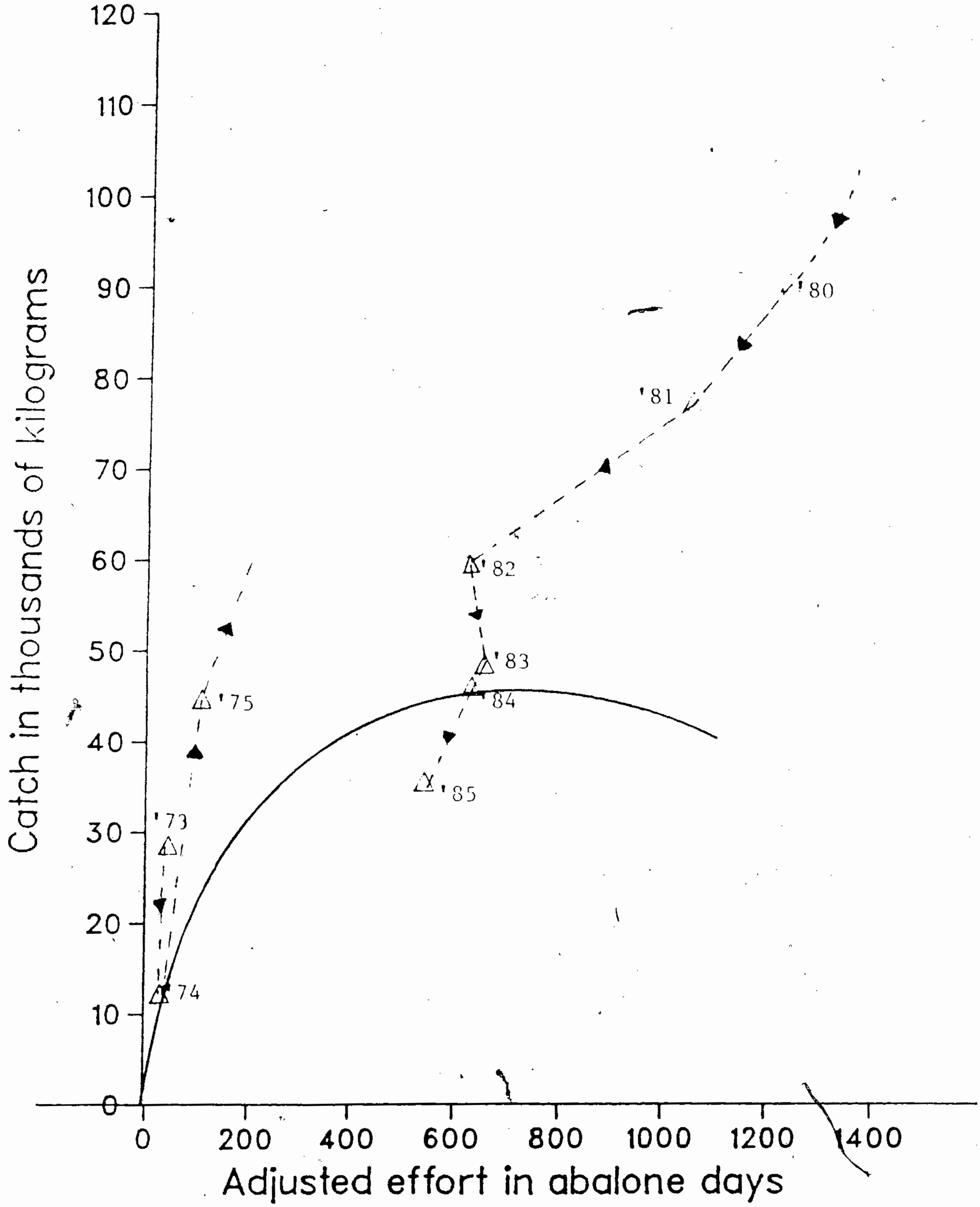


Figure 17a
Yield–Effort Relationship for
British Columbia Abalone
Fishery, 1972–1985

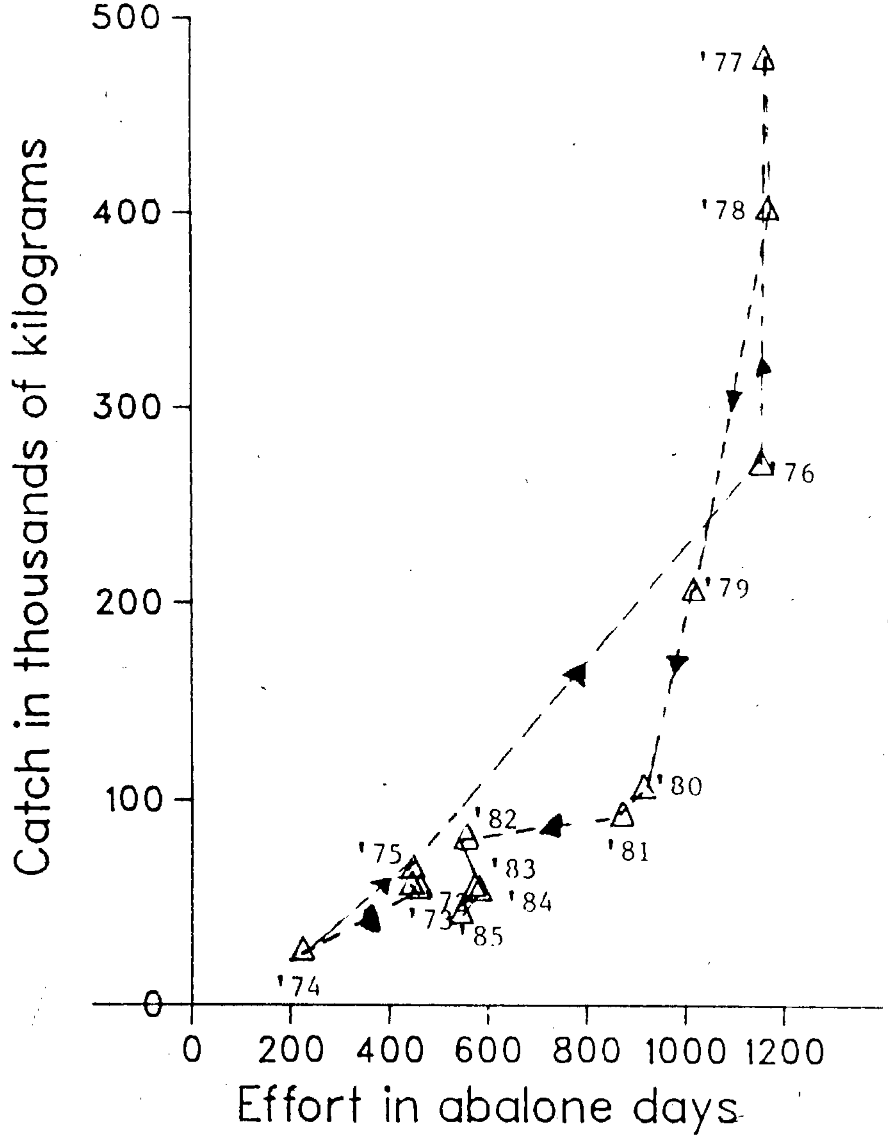


Figure 17b
Yield–Effort Relationship for
British Columbia Abalone
Fishery, 1972–1985

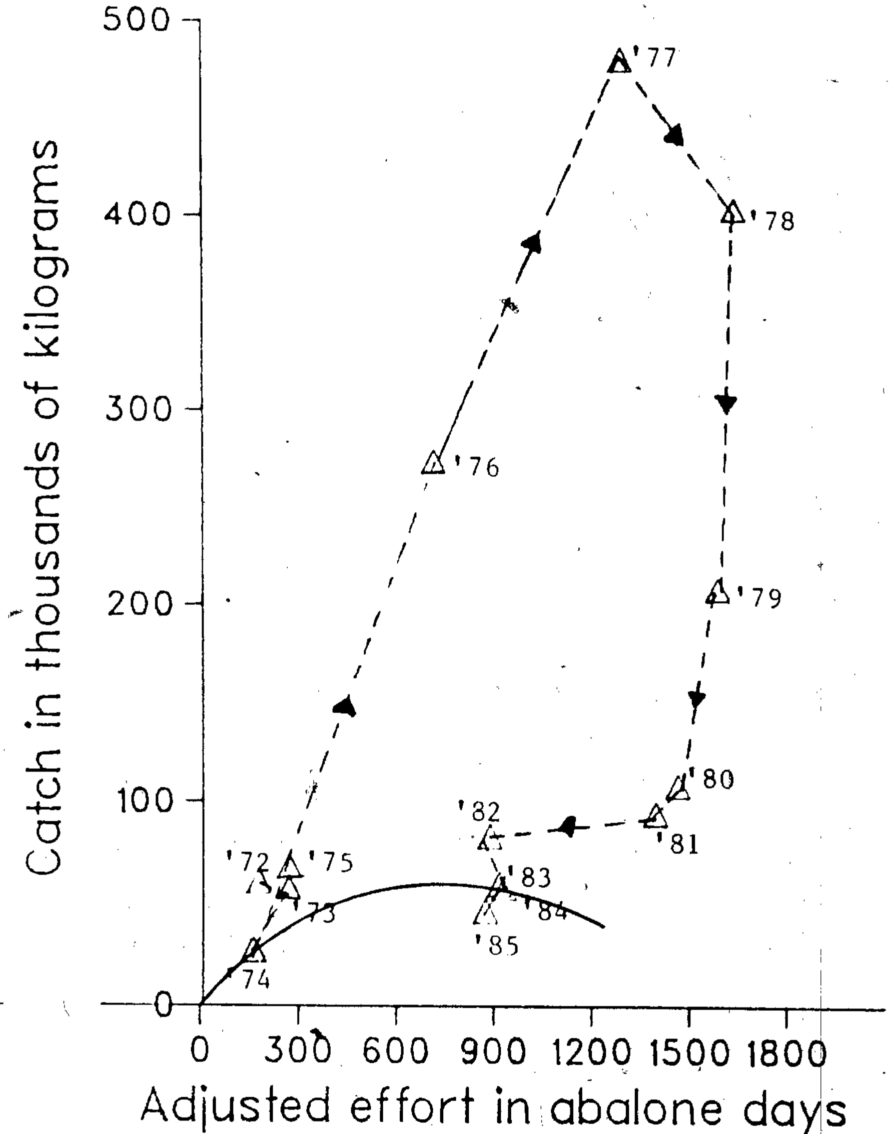


Figure 17c
Yield—Effort Relationship for British Columbia Abalone Fishery, 1972—1985

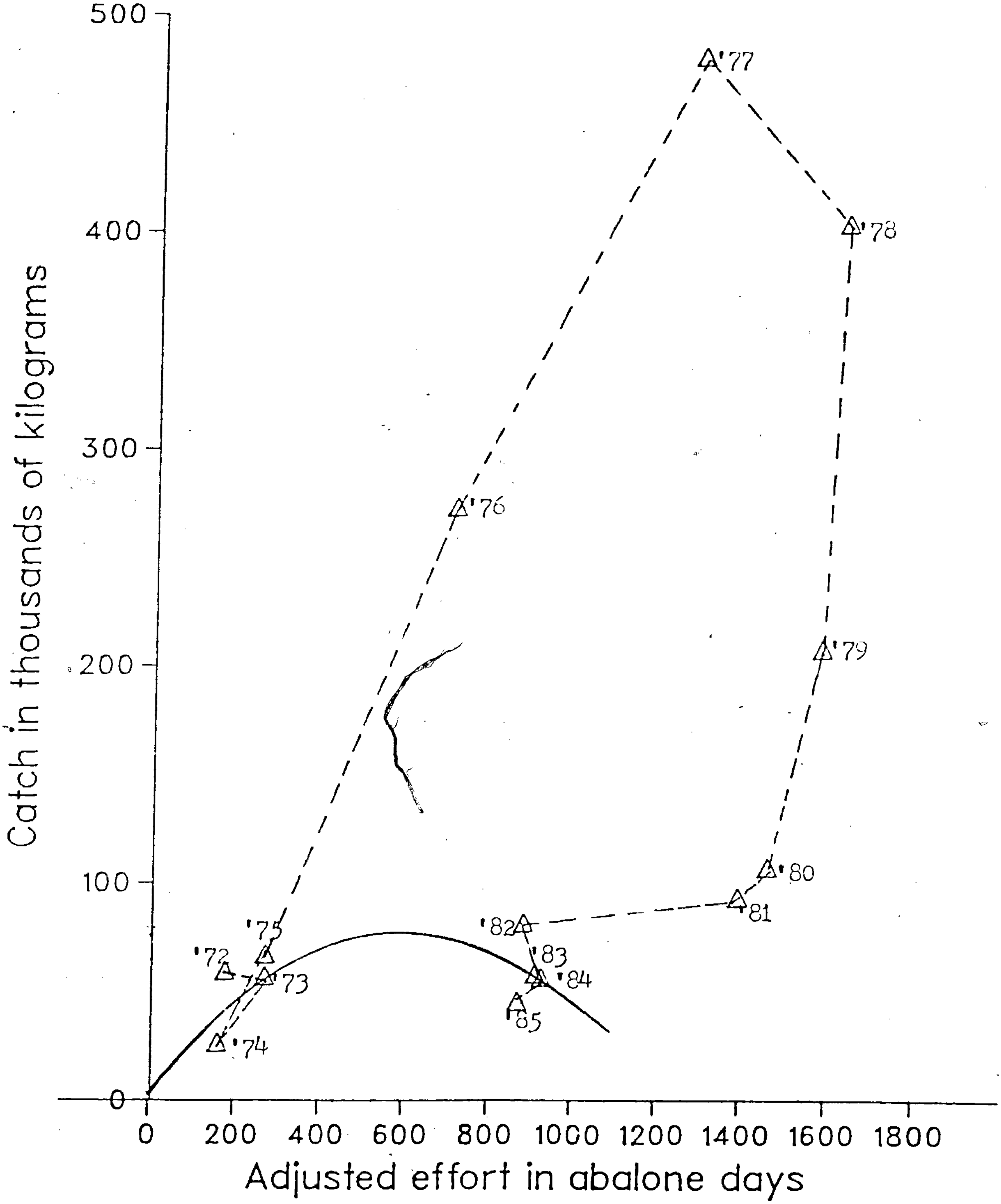
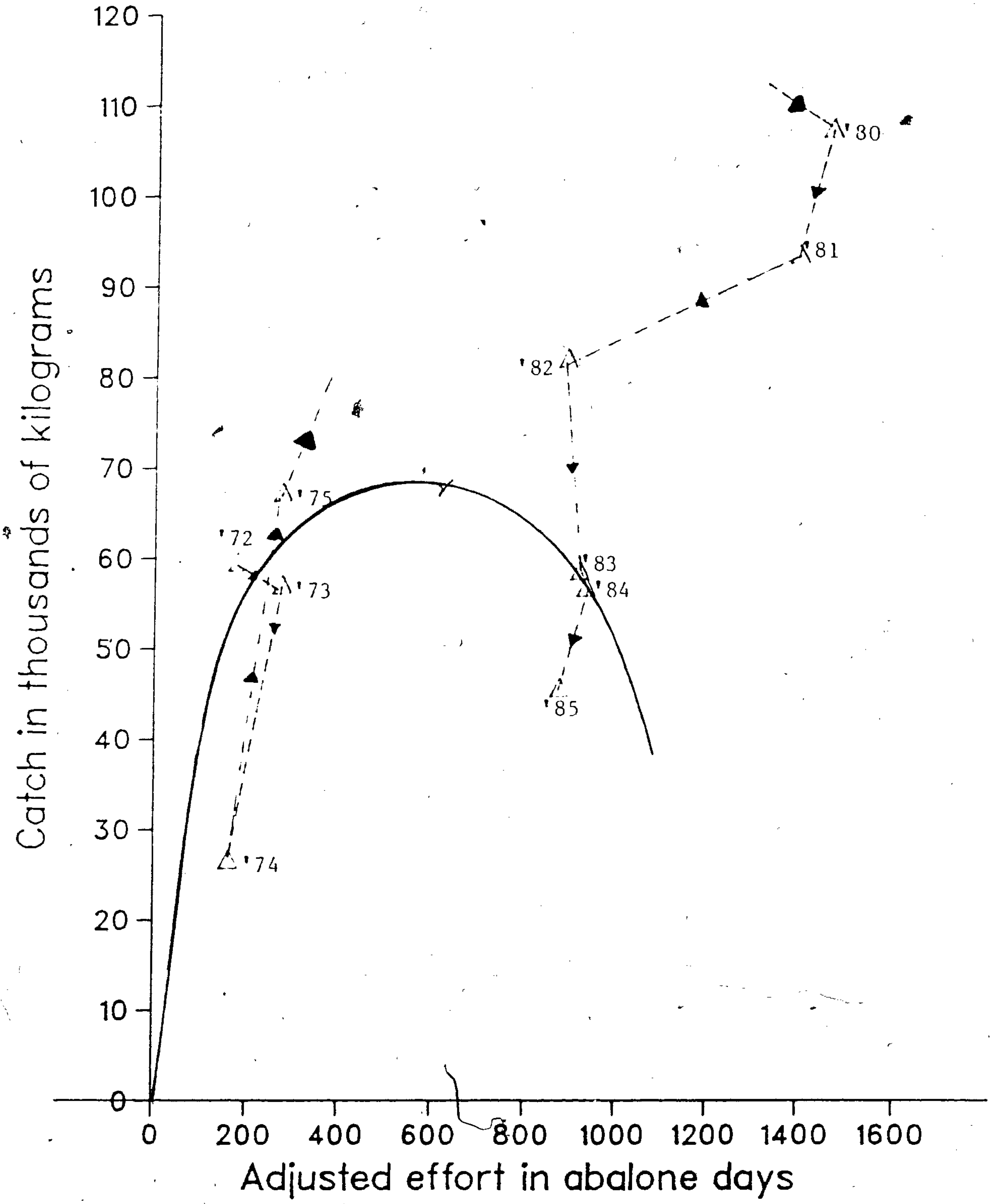


Figure 17d
Yield–Effort Relationship for British Columbia Abalone Fishery, 1972–1975, 1980–1985



the adjusted effort levels shown in Table 6. A magnified version of each of the latter has also been provided. Of particular interest is the size of the short-run loops. Their considerable length can be explained by the population characteristics of abalone and by contemplating the course which the British Columbia abalone fishery has followed since the mid-1970s. Few areas of northern British Columbia were exploited to any significant extent prior to 1976. The biomass was allowed to maintain its natural equilibrium level with few interruptions from fishermen. The large expansion in catch from 1975 to 1977, observed in Area 2E, thus consists of partial depletion of the biomass plus the growth in the stock that occurred during that period. Note that it is only the annual productivity of the stock that constitutes a sustainable yield. Therefore, that proportion of the catch that can be attributed to a fishing up of old-aged abalone is not sustainable.

Breen (1980: 27) reports that the existence of abalone aged fifty years or more is not improbable. The longevity of the species implies that unharvested stocks can reach very high population levels. It is likely, then, that a substantial proportion of the observed catch from Statistical Area 2E represents a fishing down of the biomass. The slow-growing nature of abalone will cause many years to pass before a large reduction in the biomass is replaced by stock recruitment. The long-run yield associated with the effort levels observed in the mid- to late-1970s is, as may be observed, far below the corresponding short-run catch. The same phenomenon discussed above can be observed in Area 6, with biomass depletion occurring later than in Area 2E. Area 6 may, in fact, have posed as an alternative to Area 2E when catches from the latter began to decline in 1977.

The derivation of yield curves using the adjusted measures of effort allows for a more accurate estimate of maximum sustainable yield for the areas under consideration, than if effort remained unadjusted. Figures 14c and 15c indicate that the maximum sustainable yield for Areas 2E and 6 are 13,000-13,500 kilograms and 11,000-11,500 kilograms, respectively.

The importance of allowing for variations in the average level of effective effort through time becomes particularly evident when comparing Figures 16a and 16b. As can be observed, the use of adjusted effort levels results in an estimated yield curve that is significantly different than the one derived using the unadjusted measure of effort. Figures 16c and 16d imply a maximum sustainable yield of approximately 45,000–46,000 kilograms for northern British Columbia. Figure 16d represents a magnified version of the sustainable yield curve for the north coast, where the years 1976–1979 have been omitted. Figure 17c indicates that the maximum sustainable yield for the British Columbia abalone fishery as a whole is approximately 70,000–72,000 kilograms. The years 1976–1979 have been omitted in Figure 17d to allow for easier viewing of the curve. The maximum sustainable yield estimates for northern British Columbia and the British Columbia total imply that the maximum sustainable yield for the south coast is about 25,000–26,000 kilograms. Note that each of the yield curves have been left "open–ended". This is contrary to Schaefer's logistic growth model, where yield curves take on the shape of a parabola. It is highly unlikely, however, that the sustainable yield curves for most fish populations precisely conform to such a functional relationship between catch and effort. In particular, it is improbable that a fish stock will ever be harvested to complete extinction (Copes, 1978: 29–30). This may be the situation, for example, when a significant proportion of the sexually mature individuals are below recruitment size, so that a large part of the spawning stock remains unaffected by fishing activity (Copes, 1978: 30). In deriving the yield curve for the abalone fishery, the use of the loop method does not rely on a pre–determined functional form. The available short–run data provide no justification for drawing a zero–ended yield curve.

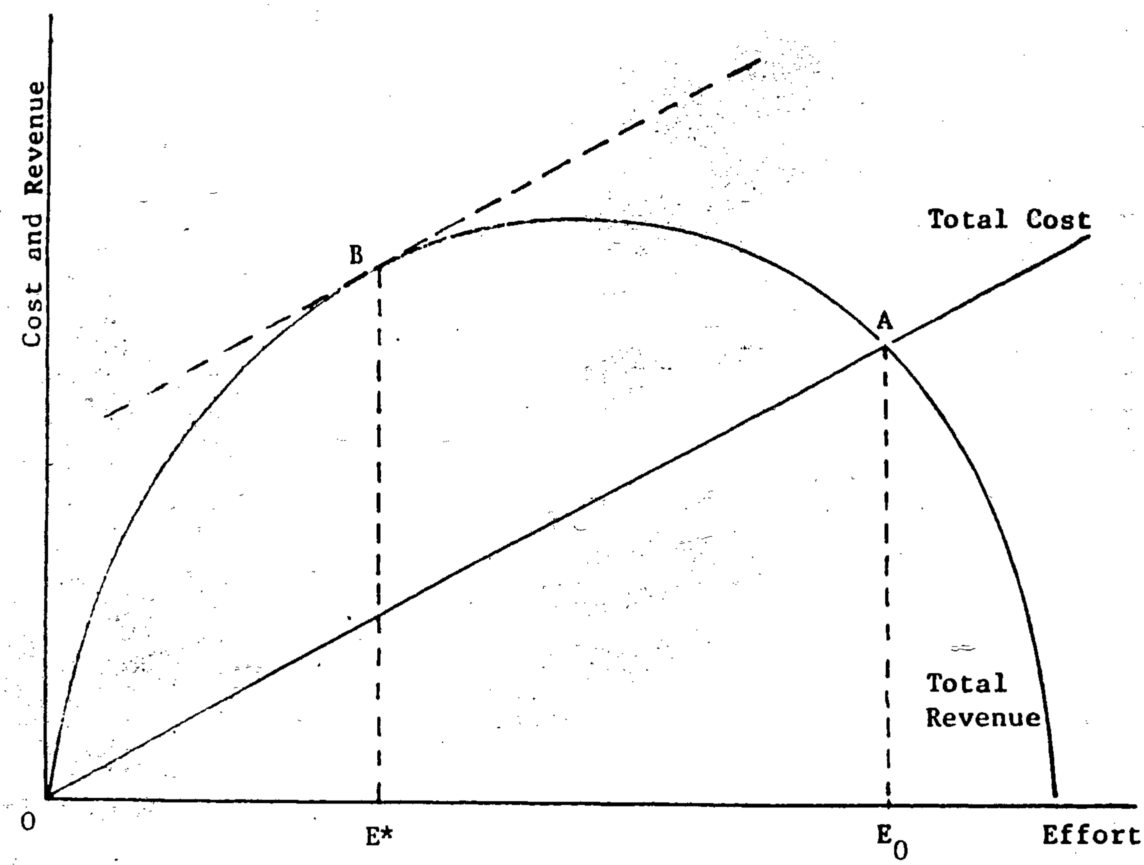
The preceding analysis has concerned itself with ascertaining the sustainable yield curve for the British Columbia abalone fishery, and the identification of maximum sustainable yield. It is important to realize that the maximum sustainable yield refers to that maximum amount of the abalone population that can be removed on a sustained basis. That is, the maximum sustainable yield is the largest catch per period that allows the maintenance of a stable population size in the long run. Such a measure is not necessarily indicative of what ***should*** be harvested on a sustained basis. Fishing effort should be applied in such a way that net returns from the fishery are maximized. The sustainable catch corresponding to this level of effort does not necessarily coincide with the maximum sustainable yield. Specifically, the net benefits obtainable from fishing may be greatest at a level of effort which is lower or higher than that associated with maximum sustainable catch. The sustainable level of catch associated with the highest net returns from fishing is referred to as ***maximum net economic yield*** (MEY).

The Determination of Maximum Net Economic Yield

In order to estimate the levels of catch and effort that correspond to a situation in which the net returns from fishing are maximimized, it is necessary to ascertain the relationships between revenue and effort, and cost and effort. Presumably, the exertion of different levels of effort results in various levels of costs and revenues. The objective here is to identify that level of effort at which the excess of revenue over cost is greatest. This is achieved by deriving the long run revenue and cost curves.

The sustainable yield curve generated by the Schaefer model can be easily transformed into a sustainable revenue curve. By assuming a constant price for fish, and multiplying the sustainable yield curve by this price, a total revenue curve for the fishery as a whole is obtained. A constant price for fish is generally justified by assuming that the fishery being considered provides only a fraction of the world supply of the species in question. Consequently, variations in local supply are not expected to affect price (Cunningham et al., 1985: 42). Figure 18 depicts a long run revenue curve derived in this manner. Also depicted is a total cost curve. The derivation of the latter is based on the assumption that the cost of effort is a linear function of the amount of effort. Such an assumption rests on the hypothesis that long run effort is varied by the expansion or contraction of the number of

Figure 18: Theoretical Derivation of Cost and Revenue Curves



optimally-sized vessels, rather than by an increase in effort on the part of existing vessels (Cunningham et al., 1985: 44).

Point A in Figure 18 represents what has been termed "open-access equilibrium". In the absence of regulation, fishermen will tend to apply fishing effort until the total revenue for the fishery as a whole is equivalent to total costs (Anderson, 1977: 31). In an unregulated fishery, new fishermen will be attracted into the fishery as long as there exists profits; conversely, if losses are being generated, some operations will exit the fishery (Cunningham et al., 1985: 44).

Point B in Figure 18 corresponds to "maximum net economic yield", where the revenue obtained from exerting an additional unit of effort is equal to the cost of doing so. It is clear that some form of regulation is required if fishermen are to be induced to apply effort in a manner that maximizes profits.

An explanation is required regarding the failure of an open-access fishery to yield resource rents. A generally accepted axiom of economic theory upholds that individuals seek to maximize their individual wealth. If the individual wealth-maximization hypothesis holds, why, then, do fishermen, acting on their own, fail to gravitate toward the optimum level of effort? The preceding analysis implies that fishermen can be made better off at a lower level of fishing effort than that associated with open-access equilibrium. This is easily seen by inspecting Figure 18. At the open access equilibrium level of effort, $0E_0$, no resource rents are being generated. At lower levels of effort, the existence of positive resource rents allows for the distribution of additional income among fishermen. Up to a point, lower levels of effort result in higher sustainable yields of abalone since the stock is subject to a lower rate of fishing mortaility. Thus, effort levels below the open access level are associated with lower total costs; consequently positive resource rents are generated.

What initially appears as irrational behaviour on the part of fishermen can be fully understood and justified upon consideration of the nature of the resource which is being exploited. An individual fishing unit will act just as any other profit-maximizing firm; that is, each boat will continue to produce effort as long as the return from doing so exceeds the cost of the last unit of effort expended. In a fishery in which all vessels are identical, the application of effort levels that fall short of $0E_0$ in Figure 18 result in all fishing enterprises earning revenues in excess of their total costs, where costs include normal returns to capital and labour. In an open access fishery, additional fishing units will be attracted to obtain a a share of the excess profits. Entry will continue until the effort level $0E_0$ has been attained, where all potential rent will have been dissipated and only normal returns to capital and labour are available. This phenomenon does not exist in other industries where the firms or individuals involved usually own or control the resources employed in production. In the fishing industry, no one firm (fisherman) is able to influence the catch per unit of effort in the fishery. Rather, this will be determined by the combined independent decisions of all of the individual boat operators (Anderson, 1977: 58). Although each fisherman acts independently as a profit maximizer, the combined actions of all fishermen result in a sub-optimal configuration of effort and catch.

Derivation of the Long Run Revenue Curve for the British Columbia Abalone Fishery

The annual revenue from fishing is the product of the price per unit of catch and the total catch taken in a particular year. Table 2 records the annual abalone catch in kilograms. Table 7 records the landed price per kilogram of abalone from 1970 to 1985 in current and constant (1981) dollar terms as well as the associated constant dollar landed value.[10] Note that columns 1 and 2 of Table 7 record the average prices per kilogram and have been obtained by dividing the total annual revenue received in the fishery by the total quantity of reported catch. The landed value figures represent *short run* revenue in constant (1981) dollars.

It is important to note that it is the *sustainable* or *long run* revenue which is of interest. That is, it is desirable to determine the maximum return from the fishery that can be attained on a perpetual basis. Therefore, the relevant variable to be considered is the long run or sustainable catch rather than the short run catches recorded in Table 2. The latter are catches that are not generally sustainable at the corresponding effort levels;

[10] Federenko and Sprout (1980) record nominal prices from 1952 to 1980; nominal prices for 1981 to 1985 were obtained from Fisheries Production Statistics of British Columbia, 1981-1985, Marine Resources Branch, Ministry of Environment, Province of British Columbia; real prices in 1981 constant dollars for 1970 to 1985 were obtained by indexing nominal prices according to the Canadian consumer price index, Catalogue No. 62-010, Statistics Canada. The CPI was chosen over the GNP deflator series because, in general, less than 50% of the total landed value is reinvested into vessel maintenance. Thus, the CPI gives a more accurate indication of the purchasing power of fishery revenues.

Table 7: **Landed Price (per kg.) in Nominal Terms and in Constant (1981) Dollars, and Constant (1981) Dollar Landed Value of Abalone in British Columbia, 1970 - 1985**

Year	(1) Nominal Price ($)	(2) Price in constant (1981) dollars	(3) Landed Value in constant (1981) dollars
1970	.93	2.27	36,860
1971	.79	1.87	12,469
1972	.99	2.24	133,506
1973	1.39	2.92	196,685
1974	1.63	3.09	82,416
1975	2.34	4.00	228,612
1976	3.15	5.01	1,371,442
1977	4.06	5.98	2,878,617
1978	4.30	5.82	2,352,514
1979	5.71	7.08	1,473,837
1980	6.20	6.97	750,090
1981	9.42	9.42	882,192
1982	8.49	7.66	629,461
1983	8.25	7.04	412,924
1984	9.14	7.47	424,625
1985	9.66	7.59	347,091

Source: Federenko and Sprout (1980); Fisheries Production Statistics of British Columbia, 1981-1985.

consequently, the revenues that are generated by these short-run yields are not sustainable at those levels of effort. Part D of the thesis included the estimation of the sustainable yield curve for the abalone fishery. Recall that this curve illustrated the relationship between the level of effort expended per period and the long-run catch associated with each level of effort. It is possible, therefore, to ascertain the long-run catch for particular levels of effort by inspecting Figure 17c. This information is recorded in Table 8. The effort levels recorded in Table 8 are adjusted effort levels which are capable of generating the corresponding sustained catches recorded in column 1 of Table 8.

Long run revenue is obtained by multiplying the long run catches by the price. However, it is immediately obvious from column 2 of Table 7 that there has been a great

Table 8: **Long Run Catch and the Relationship Between Price and Long Run Revenue, by Level of Adjusted Effort**

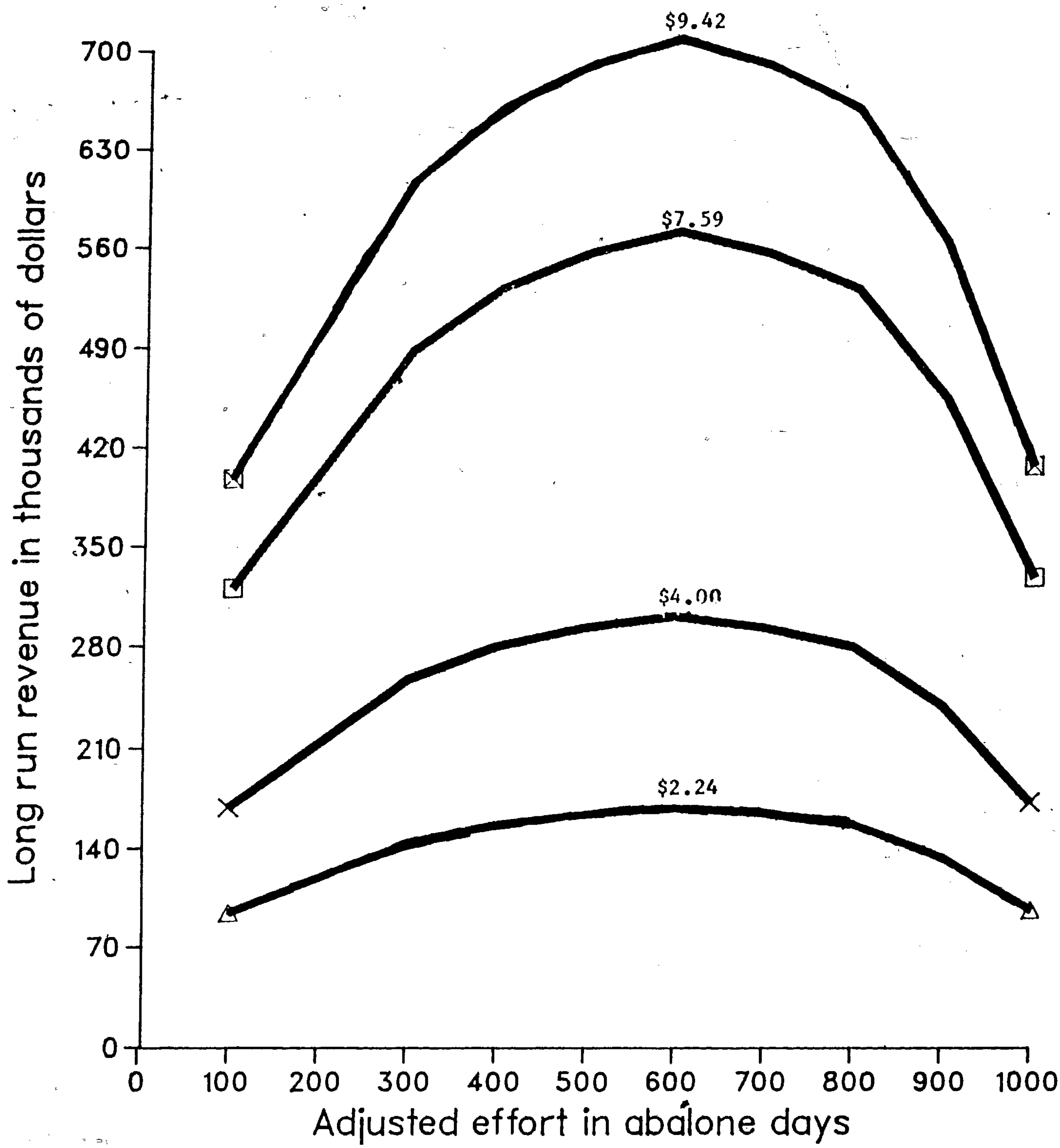
Effort	(1) Long Run Catch(kg.)	(2) Long Run Revenue($) (P=$2.24)	(3) Long Run Revenue($) (P=$4.00)	(4) Long Run Revenue($) (P=$7.59)	(5) Long Run Revenue($) (P=$9.42)
100	42,300	94,752	169,200	321,057	398,466
200	53,300	119,392	213,200	404,547	502,086
300	64,300	144,032	257,200	488,037	605,706
400	70,000	156,800	280,000	531,300	659,400
500	73,300	164,192	293,200	556,347	690,486
600	75,300	168,672	301,200	571,527	709,326
700	73,300	164,192	293,200	556,347	690,486
800	70,000	156,800	280,000	531,300	659,400
900	60,000	134,400	240,000	455,400	565,200
1,000	43,300	96,992	173,200	328,647	407,886

P = constant (1981) price per kilogram

deal of variation in price. Owing to the fact that abalone is sold in a large world market, the price for abalone in British Columbia is determined by external market forces. The British Columbia supply of abalone constitutes only a small proportion of the world's supply. Therefore, the quantity of abalone produced in British Columbia will have no influence on price. Thus, it may be assumed that if a particular price prevails, the yield curve can be converted to a revenue curve using that particular price. For given levels of effort and long run catch, different prices will generate different revenue curves. The last four columns of Table 8 record the long run revenues for different given prices of abalone in constant (1981) dollars. Specifically, these are the prices prevailing in the years 1972, 1975, 1985, and 1981. Each of these revenue series are plotted against the corresponding adjusted effort levels in Figure 19.

By inspecting column 2 of Table 7 it is evident that the real price of abalone remained relatively stable from 1982 to 1985. A possible reason for this price stability is the

Figure 19
Sustainable Revenue Curves



integration of British Columbia abalone sales into the Japanese market. It may be conjectured that a point of stability in the landed price of abalone has been attained. The average constant (1981) dollar price prevailing from 1982 to 1985 is $7.44/kg. It seems reasonable to employ the long run revenue curve associated with this particular price in the economic analysis of the British Columbia abalone fishery. Table 9 records the resulting long run revenues and corresponding adjusted levels of effort for which long run catches were possible to estimate. The long run revenue curve that is representative of the data presented in Table 9 is illustrated in Figure 20. This long run revenue curve implies a maximum sustainable revenue of approximately $560,000.

Derivation of the Long Run Cost Curve for the British Columbia Abalone Fishery

A brief digression regarding the way in which the cost data for this fishery have been estimated and compiled is necessary. In 1983, the Department of Fisheries and Oceans, Vancouver, B.C., conducted a cost and earnings study for the 1982 fishing season. Of the twenty-two vessels that participated in the abalone fishery that year, ten were included in the survey and were categorized according to vessel length. The raw data, of particular interest to this paper have been reproduced in Table 10. The miscellaneous costs referred to in Table 10 include items such as moorage, gear storage and accounting fees. Additional information has been employed in conjunction with the results of this survey, and has been summarized in Table 11.[11]

In order to generate cost estimates from the available information, the following assumptions have been made:

1. The composition of the fishing fleet, with respect to vessel-length, remains constant at the 1982 distribution for the period in question.
2. The proportion of abalone earnings relative to other fishing earnings for each vessel category also remains constant at the 1982 level.

[11] Unpublished data, Department of Fisheries and Oceans, Vancouver, B.C.

Table 9: **Effort (Abalone–Days) and Long Run Revenue (in 1981 Constant Dollars) in the British Columbia Abalone Fishery**

Effort	Long Run Revenue (P=$7.44)
100	314,712
200	396,552
300	478,392
400	520,800
500	545,352
600	560,232
700	545,352
800	520,800
900	446,400
1,000	322,152

3. The cost data obtained, for each vessel category, from the 1982 survey are representative of the average vessel in that category.
4. There are no absentee owners. Each vessel–owner conducts his operation personally with the aid of (a) diver(s) and a tender.[12]

Table 12 provides a summary of the fixed costs incurred in the abalone fishery from 1975 to 1985. Each of these costs is associated with a fishing vessel. Since many of the vessels are also engaged in other fisheries, it is inappropriate to allocate one–hundred percent of the fixed costs to the abalone fishery. Instead, the proportion of average fishing earnings per vessel attributable to abalone has been used as a proxy for allocating the fixed costs. There is of course, no need to apply this procedure to data on the cost of the abalone license. Each series of data in Table 12, with the exception of license fees, has been indexed according to a price series for capital expenditure in the Canadian ship–building and

[12] The tender is a separate individual from the abalone fisherman whose input involves the cleaning and storing of abalone catch.

Figure 20
Long Run Revenue Curve for British Columbia Abalone Fishery, P = $7.44/kg.

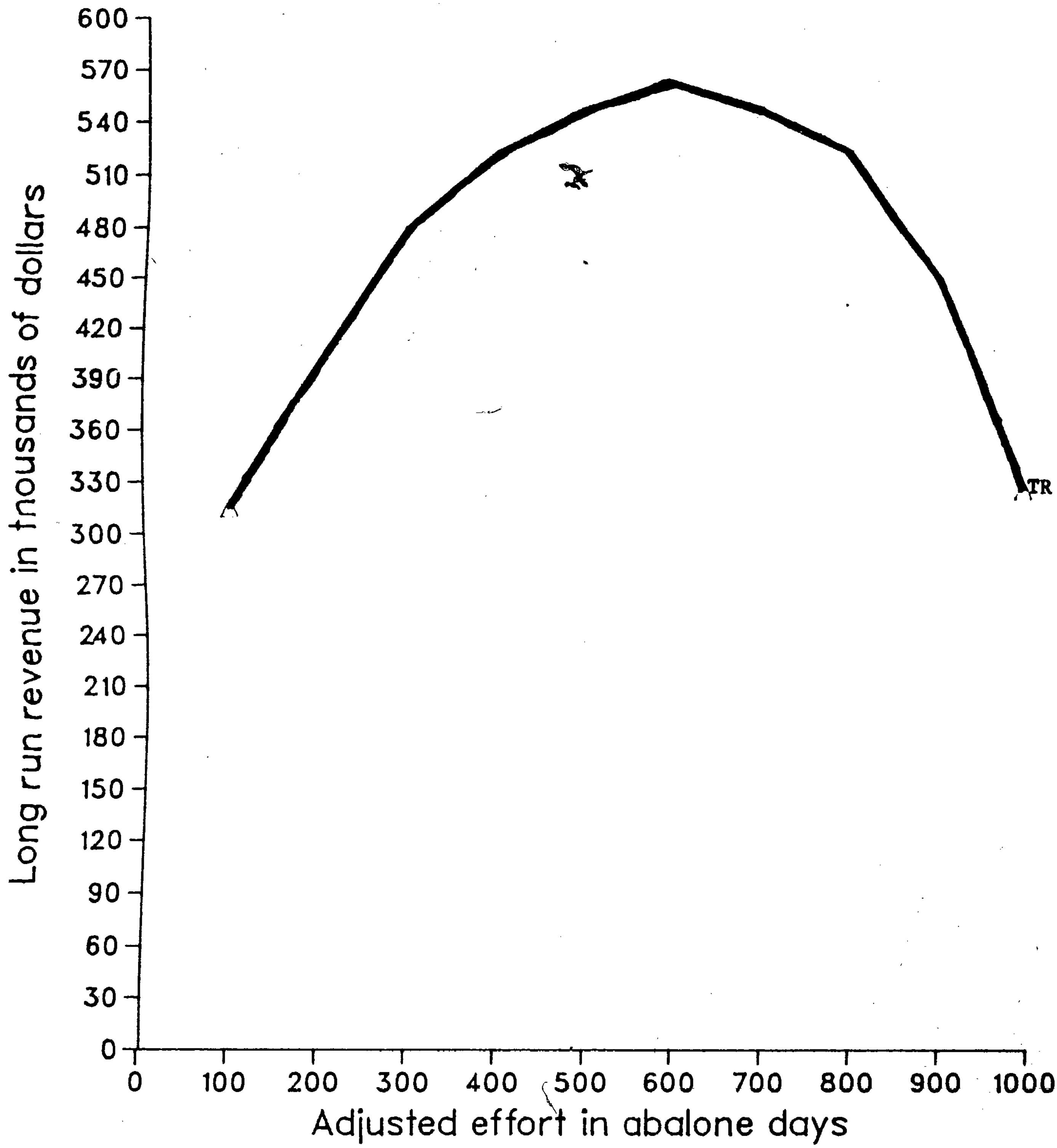


Table 10: **Summary of Vessel–Associated Costs ($) Reported in Cost and Earnings Survey, by Vessel–Length Category, in the B.C. Abalone Fishery, 1982**

Category	0m. - 8.8m.	8.9m. - 13.4m.	13.5m. >
Average market value of vessel at end of 1982 season	30,000	106,000	175,000
Average outstanding debt per vessel at end of 1982 season	9,000	85,000	48,000
Average fuel, oil and grease cost per vessel	500	4,726	14,325
Average cost of provisions per vessel	898	3,387	5,147
Average repair and maintenance costs per vessel	951	2,944	1,850
Insurance, license fees and miscellaneous fixed costs per vessel	636	7,317	6,586

Source: Cost and Earnings Survey, 1982, Department of Fisheries and Oceans, Vancouver, B.C.

boat-building industry and is recorded in constant (1981) dollars.[13]

The average opportunity cost of capital per vessel, seen in column 1 of Table 12, is based on a five percent real rate of return to vessel value per year and has been calculated as follows:

$$OCK = a_1b_1rV_1 + a_2b_2rV_2 + a_3b_3rV_3$$

where,

OCK = average opportunity cost of capital per vessel;

[13] Catalogue Number 42–218, Statistics Canada.

Table 11: Average Proportions of Total Fishing Earnings and Fishing Effort Attributable to the Abalone Fishery, By Vessel Length Category, 1982

Category	0m. - 8.8m.	8.9m. - 13.4m.	13.5m. >
Proportion of Vessels in each Vessel Length Category	31.82%	45.45%	22.73%
Proportion of Total Fishing Earnings Attributable to the Abalone Fishery	80.0%	79.3%	59.9%
Proportion of Total Fishing Days Attributable to the Abalone Fishery	79.0%	78.0%	62.3%

Source: Unpublished data, Department of Fisheries and Oceans, Vancouver, B.C.

V_1 = average market value of vessel in 0m. - 8.8m. category;

V_2 = average market value of vessel in 8.9m. - 13.4m. category;

V_3 = average market value of vessel in 13.5m. > category;

r = real rate of return (5%);[14]

a_1, a_2, a_3 = proportion of total vessels in each category;

b_1, b_2, b_3 = respective proportions of fishing earnings attributable to abalone in each vessel category.

The average opportunity cost of capital per vessel represents the amount that would be necessary to compensate the vessel owner for foregone opportunities. That is, the capital embodied in a fishing vessel could be invested elsewhere. Since the current real market rate of interest is approximately five percent, the foregone earnings from alternative investment have been estimated to be five percent of the market value of the vessel. As is indicated in Table 10, the average fisherman resorted to at least partial external financing for the

[14] Based on personal conversation with Richard Jacobson, Head of Shellfish Division, Department of Fisheries and Oceans, Vancouver, B.C.

purchase of vessel and gear. Thus, the opportunity cost of capital must also include the cost of debt or interest payments. In performing the above calculation, it has been implicity assumed that the average fisherman has complete ownership of his vessel. If, however, it can be assumed that capital markets are frictionless, then the real rate of return on foregone investment alternatives is identical to the real cost of borrowing. Under these circumstances, the above method used to estimate the opportunity cost of capital generates the same result as would the summing of interest payments and earnings which could have been realized if the capital tied up in that proportion of the vessel which was owned had been invested elsewhere.

Depreciation costs per vessel (DC) have been calculated based on an average vessel life of thirty years:[15]

$$DC = a_1b_1dV_1 + a_2b_2dV_2 + a_3b_3dV_3$$

where,

d = rate of depreciation (3.33%).

Similarly, repair and maintenance costs (RMC) have been calculated as follows:

$$RMC = a_1b_1RMC_1 + a_2b_2RMC_2 + a_3b_3RMC_3$$

The series recorded in the column labeled "Insurance and Miscellaneous Fixed Costs" (IMC) was obtained simply by subtracting the $200.00 license fee from the data recorded in the last category of Table 10 and performing the following calculation:

$$IMC = a_1b_1IMC_1 + a_2b_2IMC_2 + a_3b_3IMC_3$$

The license fee series has been deflated according to the Canadian consumer price index.[16] It may be noted from Table 12 that, from 1977 onward, the number of licenses

---

[15] Based on personal conversation with Richard Jacobson, Head of Shellfish Division, Department of Fisheries and Oceans, Vancouver, B.C.

[16] Catalogue Number 62-010, Statistics Canada.

Table 12: Fixed Costs ($) in the British Columbia Abalone Fishery, 1975 - 1985
(in constant 1981 dollars)

Year	(1) Average opportunity cost of capital per vessel	(2) Average depreciation costs per vessel	(3) Repair and maintenance costs costs per vessel	(4) Insurance and miscellaneous fixed costs per vessel	(5) Average fixed costs per vessel	(6) Number of vessels	(7) License fees	(8) Number of licenses
1975	1,749	1,154	781	1,780	5,464	21	0	0
1976	1,903	1,256	849	1,937	5,945	43	0	0
1977	2,044	1,349	913	2,081	6,387	22	295	29
1978	2,190	1,446	978	2,230	6,844	25	271	27
1979	2,436	1,608	1,088	2,480	7,612	25	248	26
1980	2,650	1,749	1,183	2,698	8,280	25	225	26
1981	2,953	1,949	1,318	3,006	9,226	24	200	26
1982	3,208	2,117	1,432	3,264	10,021	22	181	26
1983	3,304	2,181	1,475	3,363	10,323	22	171	26
1984	3,583	2,364	1,599	3,646	11,192	16	164	26
1985	3,764	2,484	1,680	3,831	11,759	16	157	26

Source: Unpublished data, Department of Fisheries and Oceans, Vancouver, B.C.

exceeds the number of vessels. When limited entry was introduced in 1977, abalone licenses were issued to individuals with the restriction that the licensee must place the license upon a vessel in which he was the major owner. No explicit restricitons were placed on the number of licenses per vessel. Although licenses were deemed nontransferable, it became possible for an individual operator to accumulate more than one license by "leasing" licenses from those operators leaving the abalone fishery.

Table 13 summarizes the operating costs incurred in the abalone fishery for the period 1975 to 1985. Fuel, oil and grease costs (FOG) have been calculated in the same manner as the other vessel-associated costs in Table 12, but have been indexed according to the Vancouver price index for motor gasoline.[17]

$$FOG = a_1b_1FOG_1 + a_2b_2FOG_2 + a_3b_3FOG_3$$

Divers and tenders are paid on a share basis with the former generally receiving between twenty and thirty percent of the total landed value of abalone and the latter between five and ten percent. It is assumed that each vessel employs one tender, regardless of the number of divers participating in the vessel's fishing operation. The vessel's crew, therefore receives between twenty-five and forty percent of the landed value.[18] By taking the midpoint of this range, average labour costs per vessel (LC) in (1981) constant dollars have been estimated at 32.5% of average landed value per vessel per year:

$$LC = (.325LV)/N$$

where,

LV = total landed value per year in 1981 constant dollars;

N = number of vessels participating each year.

Note that the series for the landed value of abalone has been taken from column 3 of

---

[17] Catalogue Number 62-010, Statistics Canada.

[18] Based on personal conversation with Kevin Bates, Department of Fisheries and Oceans, Prince Rupert, B.C.

Table 7. This series has been deflated according to the Canadian consumer price index. It is unecessary, therefore, to deflate the labour cost series. It is also important to note that this series does not include a return to the vessel owner.

As a proxy for allocating provisions per vessel (P) to the abalone fishery, the proportion of fishing days spent in the pursuit of abalone has been employed:

$$P = a_1f_1P_1 + a_2f_2P_2 + a_3f_3P_3$$

where,

f_1, f_2, f_3 = average proportion of fishing days attributable to abalone for each vessel category.

The series for provisions has been deflated according to the Canadian consumer price index for food.[19]

Column 3 of Table 15 provides an estimate of the labour opportunity costs of abalone fishing (OPP) to the vessel owner/operator. In addition to the direct monetary outlays required for operating expenses, the cost of fishing also includes some measure of foregone alternatives. This has already been accounted for in the estimate of fixed costs in column 1 of Table 12, which records the average opportunity cost of the vessel and gear. Fishermen also incur an opportunity cost in terms of foregone earnings from alternative employment. In order for abalone fishing to be worthwhile, the returns from fishing must cover that which could be earned by an individual in his best alternative form of employment in addition to the other costs of fishing. At this point it is convenient to distinguish between divers and vessel owner/operators. Specifically, the vessel owner/operator hires divers to collect abalone and compensates them with a percentage of the landed value of abalone collected by individual divers. Although the vessel owner/operator may also participate in the abalone diving, it is assumed that he is not compensated in this manner. Rather, his compensation takes the form of proceeds over and above the total costs of fishing. Opportunity costs have already been implicity accounted for in the case of divers. That is, divers must be earning

[19] Catalogue Number 62-010, Statistics Canada.

Table 13: **Average Operating Costs Per Vessel in the British Columbia Abalone Fishery, 1975 - 1985**
(in constant 1981 dollars)

Year	(1) Fuel, oil and grease (FOG)	(2) Labour (LC)	(3) Provisions (P)
1975	824	3,538	1,045
1976	911	10,366	1,073
1977	1,015	42,525	1,163
1978	1,079	30,583	1,343
1979	1,176	19,160	1,519
1980	1,424	9,751	1,683
1981	1,966	11,946	1,874
1982	2,295	9,299	2,010
1983	2,544	6,100	2,085
1984	2,725	8,625	2,199
1985	2,928	7,050	2,264

Source: Cost and Earnings Survey, 1982, Department of Fisheries and Oceans, Vancouver, B.C.

at least as much in the abalone fishery as they would in any other form of employment available to them. The labour costs recorded in column 2 of Table 13 thus include compensation for divers' foregone alternatives. However, these costs must be explicitly derived for the vessel owner/operator; failure to do so would overestimate the benefits he derives from fishing.[20]

The British Columbia abalone fishery is a part-time fishery. That is, most participants also engage in fishing other species. It is reasonable to presume, therefore, that the vessel owner's opportunity cost of fishing abalone is the income he could have earned by fishing some other species. It is necessary to derive an estimate of the value of this foregone income. Table 14 provides the information required to derive a proxy for the opportunity

[20] As noted by Copes (1986b: 11), other components of operating costs also have an opportunity cost. Fuel and other supplies, for example, have been removed from their potential use elsewhere in the economy where they could have contributed to increased production. An accurate account of total social costs incurred should include all foregone alternatives.

cost.

In 1981, the average employment income for full-time, full-year workers in fishing, trapping, and related occupations in British Columbia was $17,300.[21] In order to estimate the average employment income for the remaining years in the 1975-1985 period, the use of a proxy is required. Table 14 records the total landed value of fish per fisherman in British Columbia from 1975 to 1985.[22] Assuming a constant proportion of part-time and full-time fishermen, and a constant proportion of the landed value allocated to the cost of fishing over this period, it may be expected that the average fishing income in British Columbia fluctuated in roughly the same manner as did the landed value of fish per fisherman. That is, the proportionate change in average employment income between 1981 and another year in the series should be approximately equal to the proportionate change in the landed value of fish per fisherman between 1981 and that same year. Thus, the series recorded in column 1 of Table 15 has been derived by applying to the 1981 average fishing income of $17,300 the proportionate changes in landed value per fisherman relative to the landed value in 1981.

The estimated labour opportunity cost to the vessel-owner of fishing abalone is given in column 3 of Table 15. Its derivation assumes a work-year of 240 days (i.e., 11 months per year and 5 days per week). Consideration must also be given to the fact that the abalone fisherman allocates a certain amount of time to activities, in addition to actual fishing, that are necessary to the operation of his fishing enterprise. For example, the repair and maintenance of the vessel is vital to an individual's operation. To exclude the time spent on such activities would underestimate the proportion of the year attributable to abalone fishing and, therefore, underestimate the opportunity cost to the vessel owner. A crude approximation of the time allocated to these supplementary activities is equal to that of

---

[21] 1981 Census of Canada, Catalogue No. 92-930 (Vol.1), Statistics Canada.

[22] Volumes 9 - 18, Canadian Fisheries Annual Statistical Review.

Table 14: **Total Landed Value, Number of Registered Fishermen, and Landed Value per Fisherman in the British Columbia Fisheries, 1975 - 1985**
(recorded in thousands of constant (1981) dollars)

Year	(1) Total landed value in constant (1981) dollars	(2) Number of registered fishermen	(3) Landed value per fishermen in constant (1981) dollars
1975	142,960	12,578	11.37
1976	247,640	14,018	17.67
1977	270,680	13,753	19.68
1978	351,250	16.785	20.93
1979	421,790	19,384	21.76
1980	203,890	18,871	10.80
1981	236,200	17,454	13.53
1982	218,600	17,298	12.64
1983	181,870	17,061	10.66
1984	193,060	16,770	11.51
1985	298,510	18,168	16.43

Source: Canadian Fisheries Annual Statistical Review, Volumes 9 - 18.

actual fishing.[23] The estimate of opportunity cost has been derived by performing the following calculation:

$$OPP = (2AD/240N)(AEI)$$

where,

OPP = labour opportunity cost to vessel owner of fishing abalone;

AD = number of abalone-days;

N = number of owner/operators which is identical to the number of vessels;

AEI = average employment income for fishermen in British Columbia.

[23] Based on personal conversation with Richard Jacobson, Head of Shellfish Division, Department of Fisheries and Oceans, Vancouver, B.C.

Table 15: **Estimated Average Fishing Income, Percentage of Year Engaged in Abalone Fishery, and Estimated Opportunity Cost to Vessel-Owner of Fishing Abalone in British Columbia, 1975 - 1985**
(recorded in 1981 constant dollars)

Year	(1) Average employment income	(2) Proportion of year allocated to the abalone fishery (2AD/240N)	(3) Labour opportunity cost of vessel owner/operator
1975	14,538	18.29%	2,659
1976	22,594	22.36%	5,052
1977	25,164	44.13%	11,105
1978	26,762	39.03%	10,445
1979	27,823	33.90%	9,432
1980	13,809	30.50%	4,212
1981	17,300	30.28%	5,238
1982	16,162	20.98%	3,391
1983	13,630	21.67%	2,954
1984	14,717	30.26%	4,453
1985	21,008	28.39%	5,964

Source: 1981 Census of Canada, Catalogue No. 92-930 (Vol. 1), Statistics Canada.

Further discussion regarding the estimate of labour opportunity cost to the abalone vessel owner/operator is required. Included in the series for average employment income of fishermen in column 1 of Table 15 is the averaged income of highliners, average fishermen. and marginal fishermen. Highliners earn a large amount of producers' surplus whereas marginal fishermen earn a negligible income above opportunity cost. In order for the average employment income of all fishermen to reasonably correspond to the foregone alternatives of the average abalone fisherman, it must be assumed that the distribution of skills in the abalone fishery is the same as that for all British Columbia fisheries. Under these circumstances, the average abalone fisherman has the equivalent skills to an average British Columbia fisherman. Additionally, it must be assumed that in transferring to another fishery, the average abalone fisherman will acquire the same level of skill relative to other members of the new fishery as he had acquired in the abalone fishery.

The use of average employment income of all British Columbia fishermen as a proxy for the opportunity cost of the vessel owner/operator in the abalone fishery implies that fishermen are perfectly mobile between fisheries. In reality, however, there are institutional impediments to the mobility of fishermen, in the form of various limited entry arrangements in British Columbia fisheries. Nonetheless, it is assumed that by leasing his abalone license, an abalone fisherman is able to use the leasing proceeds to buy his way into another fishery.

Table 16 provides a summary of total costs in the British Columbia abalone fishery, where each series has been aggregated as follows:

$$TFC = N(AFC) + L(LF)$$

$$TOC = N(FOG + LC + P + OPP)$$

$$TC = TFC + TOC$$

where,

TFC = total fixed costs;

TOC = total operating cost;

TC = total costs incurred in the fishery;

AFC = average total fixed costs excluding license fees;

L = number of licenses;

LF = license fee per vessel.

Having estimated a cost series for the abalone fishery, it is now possible to obtain a cost curve. Embodied in the total costs of fishing abalone are fixed costs and variable costs. It is only the latter that will vary with effort. The revenue curve illustrated in Figure 21 is a reproduction of that shown in Figure 20. Recall that the derivation of the long run revenue curve involved the assumption of a constant price of abalone which was taken to be the average price for the years 1982-1985. A similar assumption is necessary in order to obtain a long run cost curve for the abalone fishery. Specifically, it shall be assumed that

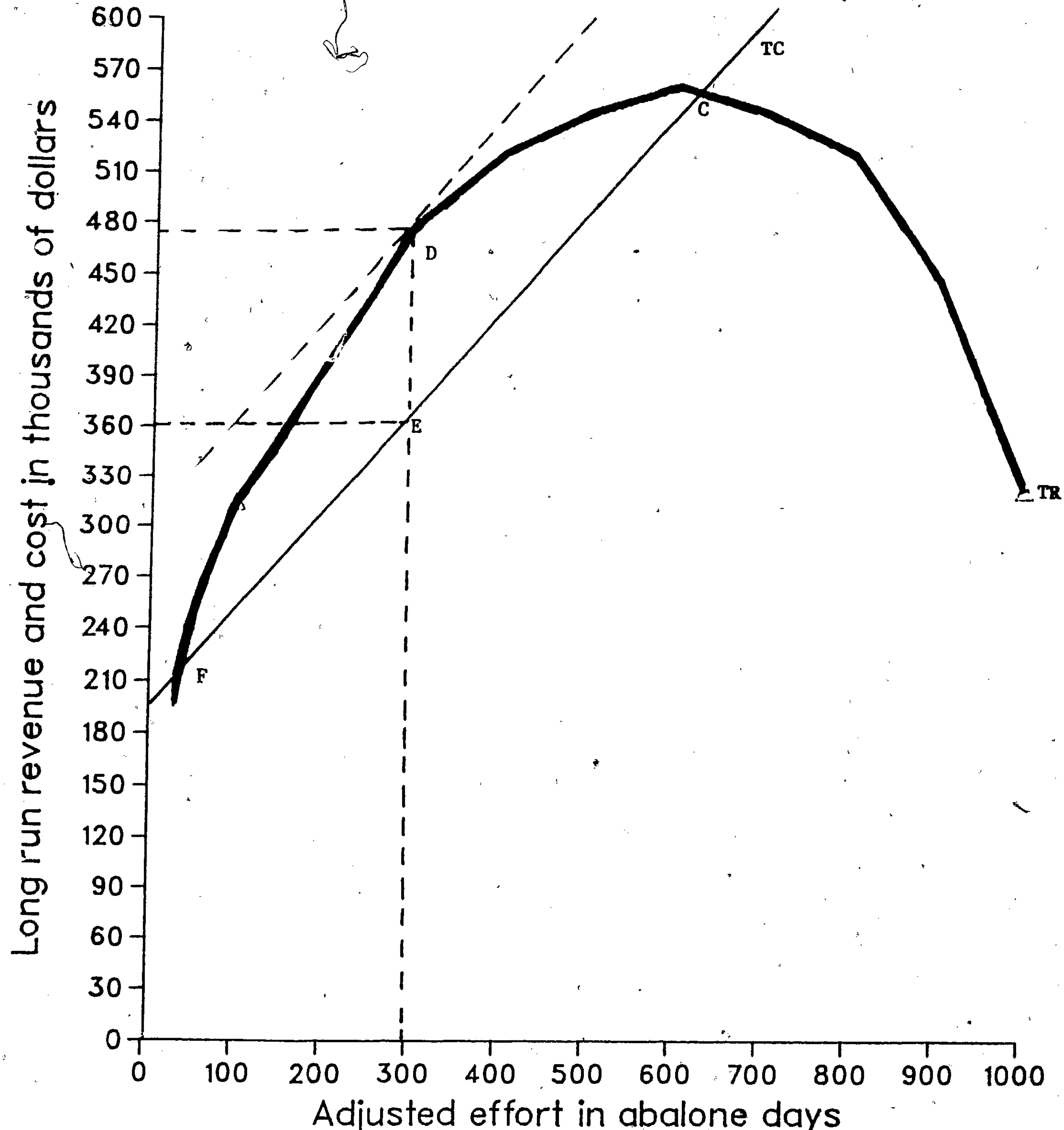
Table 16: **Fixed Costs, Operating Costs, Total Costs and Total Cost per Unit of Effort in the British Columbia Abalone Fishery, 1975 - 1985**
(recorded in 1981 constant dollars)

Year	(1) Total fixed costs	(2) Total operating costs	(3) Total costs	(4) Total cost per unit of effort
1975	114,744	169,386	284,130	367.43
1976	255,635	748,286	1,003,921	648.43
1977	149,069	1,227,776	1,376,845	1,053.89
1978	178,417	1,086,250	1,264,667	927.63
1979	196,748	782,175	978,923	769.10
1980	212,850	426,750	639,600	466.39
1981	226,624	504,576	731,200	578.64
1982	225,168	373,890	599,058	674.89
1983	231,552	301,026	532,578	526.27
1984	183,336	288,032	471,368	495.75
1985	192,226	291,296	483,522	534.49

the variable cost of abalone fishing per unit of effort is constant. The supposition that all units of effort are obtained at equal cost generates a proportional relationship between effort and variable cost. Thus, an increase in effort by one abalone-day will increase variable costs by a given amount, regardless of the level of effort being exerted at the time.

Fixed costs include vessel-associated costs, accounting fees and license fees. All but the license fees vary in direct proportion to the number of vessels in the abalone fishery. It is assumed that the number of vessels participating in the fishery will remain stable at sixteen and the number of licenses stable at twenty-six. Note from Table 12 that the average fixed costs per vessel have been steadily increasing. Therefore, an average over the last four years is not indicative of the current state of fixed costs in the fishery. It is preferable to take the last available observation, that of $11,759 per vessel in 1985. The historical upward movement in average fixed costs implies that even this figure may be downwardly biased for future use. This may be offset, however, by a historical improvement in the terms of trade

Figure 21
Maximization of Resource Rent
and Partial Producer Surplus



for fish relative to other products. Thus, in terms of the extent to which this economic analysis reflects the current state of the fishery, both the long run revenue curve and the vertical intercept of the total cost curve (which reflects total fixed costs) are likely to be downwardly biased. The $200.00 license fee has not been revised since it was first introduced in 1977. In real terms, therefore, license fees have steadily decreased. If the nominal fee is to remain at $200.00 then the use of the 1985 license fee, recorded in constant (1981) dollars, overestimates real license fees for future years. However, this latter bias can be considered insignificant because license fees constitute a very small proportion of total costs. Thus, the total fixed costs currently incurred in the British Columbia abalone fishery have been estimated by performing the following calculation:

$$(AFC)(N) + (LF)(L) = TFC$$

$$(\$11,759)(16) + (\$157)(26) = \$192,226$$

This figure represents the vertical intercept of the total cost curve.

The slope of the total cost curve depends upon the way in which total operating costs vary with effort. Column 4 of Table 16 records the operating costs per abalone-day from 1975, to 1985. There appears to be no specific historical trend in these figures. Recall that in deriving the total revenue curve, the average price prevailing from 1982 to 1985 was employed. It is reasonable, therefore, to take the average variable cost per unit of effort over the last four years. That is, cost as a function of effort is assumed constant at $557.85 per abalone-day. It is now possible to plot the cost curve as a function of effort as is illustrated in Figure 21.

It is worthwhile reviewing the situation which is represented in Figure 21. Note that the horizontal axis measures adjusted effort in abalone-days. Thus, movements along the revenue curve to the right represent changes in sustainable revenue resulting from increases in the number of abalone-days fished by skilled fishermen who employ both vessels with air compressors and freezing systems and skilled divers, and who exploit areas with which they are completely familiar. Similarly, movements along the cost curve to the right represent changes in costs as effective effort is increased. It can be noted from column 5 of Table 5 that the adjustments to actual effort in deriving effective effort remained unchanged from 1980 to 1985. Therefore, the practice of taking the average of costs over the last four years results in a cost per unit of effort that is compatible with adjusted effort levels.

Maximum Economic Yield

It is important to note that, with the exception of license fees, the foregoing analysis has neglected to account for the costs incurred in managing or regulating the fishery. It remains expedient to continue to ignore these costs for now and to assume that the estimated cost curve in Figure 21 reflects the "true" cost function for the British Columbia abalone fishery. Management costs will, however, be considered in the following section of the paper. It shall also be initially assumed that all fishing units are identical and earn no profits in excess of normal returns to capital and labour.

Proper use of a fish stock requires that resources utilized to exploit the stock are allocated in such a way that the net benefits available to society are maximized (Anderson, 1977: 32). Economic theory dictates that this maximum is attained when the marginal revenue of effort is equal to the marginal cost of effort. Given the cost and revenue conditions depicted in Figure 21, it appears that rents are maximized when the effort associated with approximately 300 abalone fishing-days is expended. Maximum economic rent then amounts to the distance labeled DE, or approximately $120,000. Consider, however, what is embodied in the area labelled CDFEC in Figure 21. Profits generated in excess of total costs include both a return to the resource itself and above normal returns to the fishing operation. Recall that, in calculating the total cost of fishing, the opportunity cost of capital and of the owner-operators' labour was included. Thus, area CDFEC embodies ***resource rent***,[24] and

---

[24] Resource rents refer to the excess of revenues over costs calculated at marginal opportunity costs (Copes, 1986b: 9).

producers' surplus (Copes, 1972: 152-155). The latter potentially arises when an assumption made earlier in the analysis is dropped. Specifically, it was assumed that all fishing units are identical and that no intramarginal rents are earned. The likelihood that skills vary among owner-operators is now addressed. The earnings of fishermen will depend to a large extent upon the degree of skill they have attained. A highly skilled fisherman is likely to earn income in excess of his opportunity costs, but even the most poorly skilled fisherman is likely to recover in net earnings an amount that is at least equal to his opportunity cost. If the latter did not hold, such a fisherman is apt to exit the fishery. The excess of a skilled fishermen's net earnings over his opportunity cost can be considered a rent in the form of producers' surplus. It is not possible, however, to distingush what portion of area CDFEC may be attributed to the producers' surplus of owner-operators, and what portion to resource rent.

Implicit in the cost curve of Figure 21 is a very important component of returns to the fishery that has not yet been addressed. Specifically, no mention has been made of the producers' surplus of divers. Recall that divers in the abalone fishery are paid on a share basis. That is, each diver receives between twenty and thirty percent of the landed value of the abalone he personally collects. The earnings of individual divers also depend to a large extent upon the degree of skill they have attained. The excess of a skilled diver's earnings over opportunity cost constitutes a portion of the total producers' surplus generated in the abalone fishery. Above normal returns to divers have, however, been included in the total cost curve. If the area between the total revenue curve and the total cost curve is to reflect *total* rents earned in the fishery, these above normal returns to divers must be subtracted from the total cost curve. In order to determine the magnitude of these above normal returns, the opportunity cost of diving must be ascertained.

It is probable that most of the divers employed in the abalone fishery are non-union divers without any specialized skill such as underwater construction. Such an individual generally receives between twenty and thirty dollars an hour for diving services.[25] From 1982 to 1985 there was an average of twenty-eight divers employed per year in the British Columbia abalone fishery.[26] The average total annual payment to divers from 1982 to 1985 was approximately twenty-five percent of the landed value of abalone, or $113,381 (in (1981) constant dollars). The divers' foregone hourly wage in (1981) constant dollars[27] is between $15.90 and $23.85, the average of which is $19.88. Recall the earlier estimate that supplementary activities such as vessel maintenance and repair required the same input of time as did actual fishing. It is assumed that it is only the vessel owner/operator that undertakes these supplementary activities and that divers are concerned only with the actual collection of abalone. A "diver-hour" includes time spent travelling from site to site as well as actual diving activity. There was an annual average of 1900 diver-hours employed in the abalone fishery from 1982 to 1985.[28] This information allows the approximation of the total opportunity cost for divers by taking the product of the average hourly alternative wage and the the number of diver-hours employed. This results in an estimated annual total opportunity cost of diving in the abalone fishery of $37,772. This estimate in turn allows the calculation of divers' producers' surplus in the abalone fishery. Subtracting the above opportunity cost from the 1982-1985 average of total diver-earnings results in a rent in the form of divers' producers' surplus of $75,609 (in constant 1981 dollars). This rent will, of course, fluctuate with changes in the landed value of abalone and changes in the opportunity cost of diving. Assuming that the proportion of landed value to the opportunity cost of diving remains relatively constant, and also assuming that the number of divers employed annually does not change significantly, it is possible to derive a reasonable estimate of the average divers' producers' surplus obtained per unit of effort. Table 2 indicates that the

[25] Based on telephone conversation with representative of All Sea Enterprises Ltd., Vancouver, B.C.

[26] Unpublished data, Department of Fisheries and Oceans, Vancouver, B.C.

[27] Deflated by Canadian consumer price index, Catalogue No. 62-010, Statistic Canada.

[28] Unpublished data, Department of Fisheries of Oceans, Vancouver, B.C.

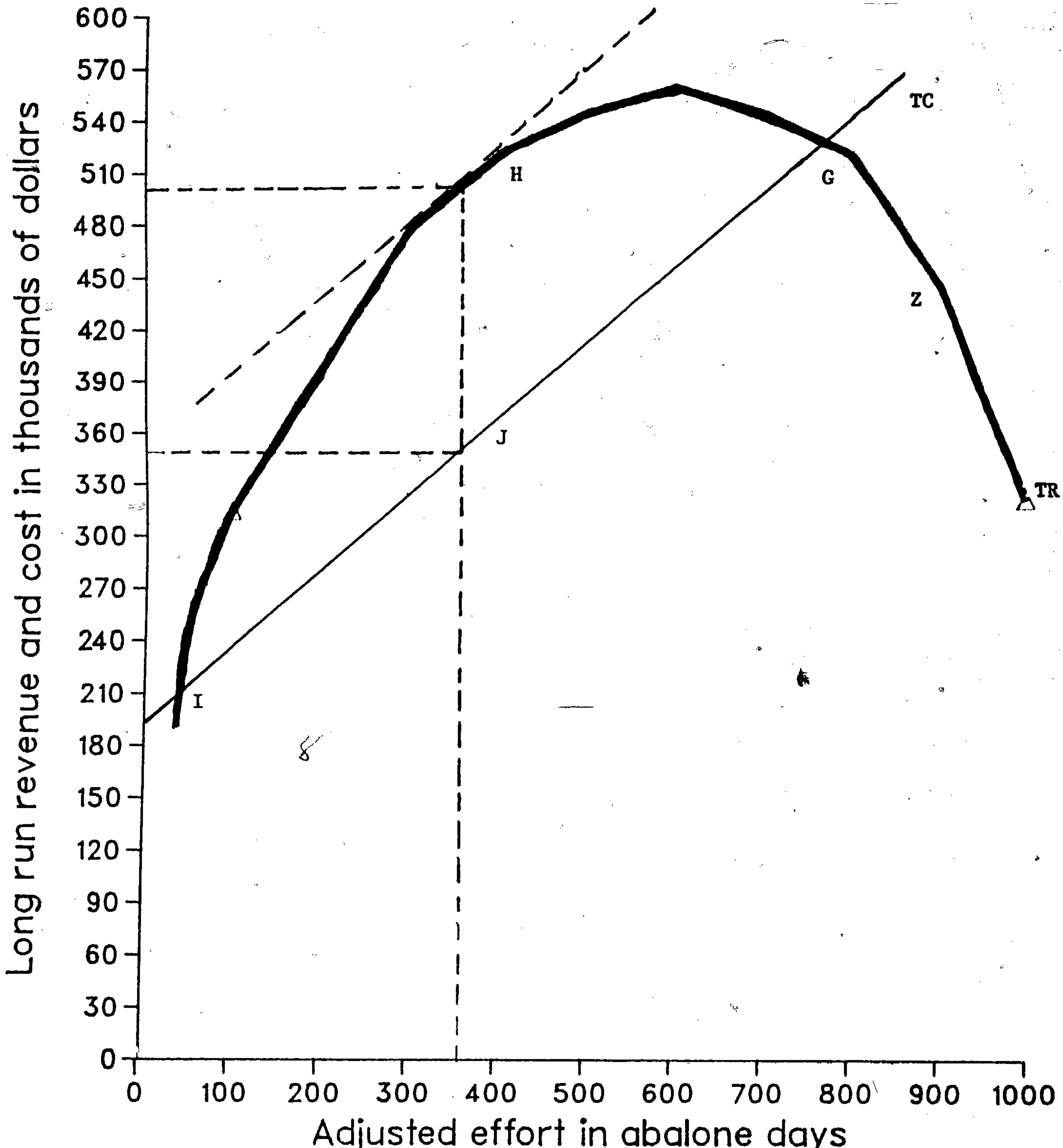
average number of abalone-days fished per year from 1982 to 1985 was 563. Dividing this figure into the estimated producers' surplus results in a rent per abalone-day of $134.30. This rent is one of the considerations that reflects the profitability of the abalone fishery, and should therefore be included in the analysis as a net benefit. Specifically, the divers' producers' surplus should be either added to net benefits or subtracted from variable costs. The latter is the more correct approach, since producers' surplus is not a cost but rather a component of economic rent. Prior to accounting for divers' producers' surplus, a constant cost per unit of effort of $557.85 was estimated. Consideration of diver-rents reduces this figure to $423.55 per abalone-day. Figure 22 illustrates the revenue and cost curves after this revision has been effected, and implies a maximum sustainable rent of approximately $150,000 at 370 units of effort.[29]

The essential difference between the cost curves illustrated in Figures 21 and 22 is that the former is derived with the implicit assumption that all divers are identical and marginal. That is, all divers were assumed to earn a return in the abalone fishery that exactly offset their opportunity costs. The derivation of the cost curve in Figure 22 does not rely on this assumption. The estimated average producer's surplus going to divers has been subtracted from the total variable cost of fishing. Thus, the distance HJ in Figure 22 refers to maximized resource rent and producers' surplus of *both* owner-operators and divers, whereas the distance DE in Figure 21 is representative of the maximum sustainable resource rent and the producers' surplus of owner-operators alone.

---

[29] Clark and Munro (1975) advocate the use of a dynamic model in order to determine the maximized present value of returns over time, which in turn implies selecting an optimal stock level as a function of time. Such an analysis, through the application of a social discount rate, properly takes into account the likelihood that fish consumption today is more valuable than fish consumption tomorrow. At the same time, however, proponents of the dynamic model often assume a constant price of fish for the sake of simplicity. Historically, there has been and continues to be an improvement in the terms of trade for fish relative to other commodities. Thus, the reduced future value of fish resulting from the application of a positive social discount rate may be offset by the real appreciation in the value of fish. Relative to the dynamic model, the analysis presented here is inferior in its neglect of the social rate of time preferences but superior in that it is likely to come closer to reflecting the discounted value of revenue over time.

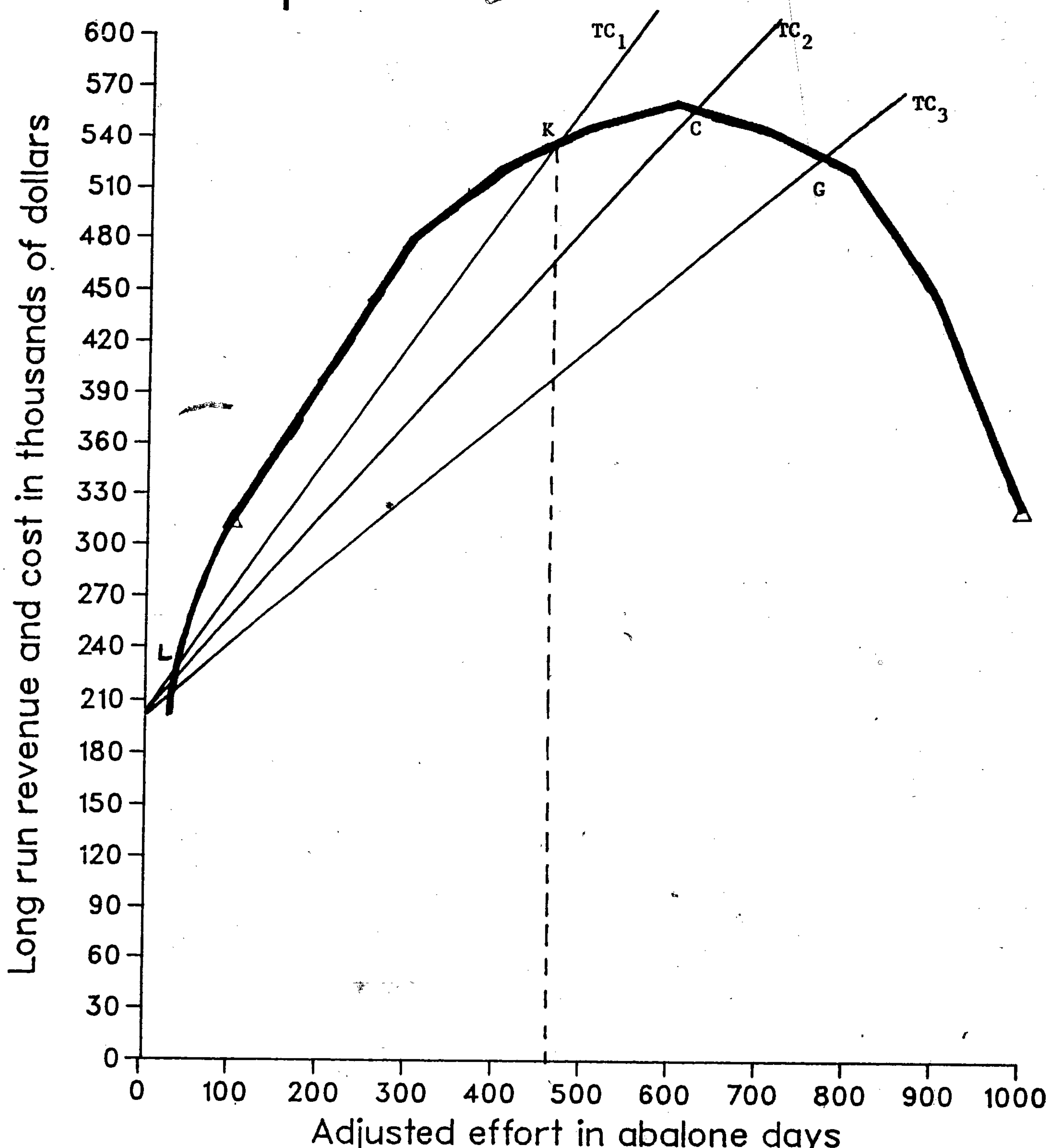
Figure 22
Maximization of Resource Rent and Total Producer Surplus



The Schaefer model defines the intersection of the total cost and total revenue curves as open-acces equilibrium. Consider points C and G in Figures 21 and 22, respectively. It is important to recognize that neither of these points are representative of an open-access equilibrium. Recall that the total cost curves in both diagrams have been derived for a fishery in which restricted entry has been imposed. Thus, movements along the total cost curve result from variations in the level of effort on the part of existing vessels. In the Schaefer model of an open-access fishery, movements along the total cost curve occur when long-run effort is varied by an expansion or contraction in the number of optimally-sized vessels. Additionally, the Schaefer model assumes that all fishing units are identical and marginal; thus, no intramarginal rents are generated. The intersection of the total cost and total revenue curves in the Schaefer model is, therefore, associated with the level of effort at which all *resource rents* are dissipated. Point G in Figure 22 corresponds to a case in which resource rent *plus* producers' surplus is completedly dissipated. This is a situation which is never likely to obtain. When fishermen in total exert 780 abalone-days worth of effort, the resulting sustainable revenue is precisely offset by total costs, which include opportunity costs. That is, both resource rent and producers' surplus are zero. Recall that it is the *average* producers' surplus which has been deducted from the original cost curve. Given no change in the relative skill levels of fishermen, if this average is to sum to zero, it must be the case that the producers' surplus realized by intramarginal fishermen is exactly offset by deficits incurred by submarginal units. As mentioned earlier, any fishing enterprise that does not recoup, on average, at least its opportunity cost, can be expected to eventually exit the fishery. Therefore, the situation at point G is not sustainable and, consequently, cannot be an equilibrium.

Now consider the total cost curve labelled TC_1 in Figure 23. Define this to the total cost curve that obtains when above normal returns to owner-operators and divers are included in the cost calculation. TC_2 and TC_3 are simply reproductions of the cost curves illustrated in Figures 21 and 22, respectively. TC_1 cannot be derived explicitly with the available data,

Figure 23
Comparison of Cost Curves



since it is not possible to empirically distinguish between owner-operators' producers' surplus and resource rent. Suppose, however, that this had been possible and that TC_1 is generated by subtracting the above normal returns to owner-operators from the cost curve labelled TC_2. Then area KLK represents resource rents alone, and point K corresponds to a situation in which all resource rents have been dissipated.

If only vessel numbers are limited and there are no further restrictions on catch or effort, there exists a tendency for the fishery to converge to point K. If all vessels acting together exert a level of effort which is less than approximately 465 days, resource rents will be generated. The existence of such rents will encourage existing vessels to expand their effort in order to appropriate a portion of these rents.

Although the absence of further effort restrictions is unlikely to result in the complete dissipation of resource rent *and* producers' surplus, it is equally unlikely that such a regime could lead to the optimal solution. Although the analysis now allows for the coexistence of marginal and intramarginal fishermen so that the existence of producers' surplus is recognized, resource rents may continue to be dissipated in this type of fishery. Individual fishermen are powerless to exert control over fish stocks; therefore, no one fisherman is personally motivated to conserve or enhance the resource since the expense incurred by doing so will yield him a negligible return. Most of the resulting additions to catch or improvements in returns would accrue to other fishermen (Copes, 1981: 113).

There remains yet another societal benefit typically generated by any economic activity. *Consumer surplus* is the value of fish to consumers over and above purchase price (Copes, 1986: 9). Ordinarily, the pursuit of optimum social benefits involves the maximization of combined resource rent, producer surplus *and* consumer surplus. However, since the majority of abalone harvested in British Columbia is exported to Japan, the potential social benefits domestically available in the form of consumer surplus can be considered negligible. Certainly, the rationalization of the British Columbia abalone fishery does not include as an objective the maximization of consumer surplus to the Japanese.

It is evident from Table 9 and Figure 22 that current levels of effective effort of approximately 872 abalone-days applied to the abalone stock are far too high. Long-run deficits are being incurred and, as is evident from Tables 7 and 16, there are also short run deficits in evidence. However, since the average vessel is recovering an amount in excess of variable costs, one does not observe a definite trend of exit from the fishery.

It is important to emphasize once again that the cost curve illustrated in Figure 22 does not include the costs of managing the fishery. Such costs must be subtracted from the resource rent component of the excess of revenues over costs. in order to calculate net social benefits. The extent of management costs depends, of course, upon the type of regulatory regime being followed. The discussion of alternative management schemes in the next section undertakes to qualify the effect on the position of the cost curve under different regulatory arrangements.

The absence of property rights over fish stocks negates the possibility of an individual fisherman correcting the revenue/cost squeeze that is related to excessive exploitation of the resource (Copes, 1978: 48). It is only through collective action at the industry level that attainment of maximum economic yield is possible. Although such action has been undertaken in the British Columbia abalone fishery, the preceding analysis indicates that economic rents are far from being maximized. Indeed, the cost and revenue estimations of this analysis indicate that the British Columbia abalone fishery is presently incurring a long run deficit at point Z in Figure 22 which corresponds to an effective effort level of 872 abalone-days. It is evident that the quota for the fishery is not excessive since the present catch level approximates that compatible with maximum economic yield. What is required, however, is a significant reduction in the application of fishing power.

The remainder of this paper concerns itself with the consideration of alternative regulatory regimes and their potential success in improving the economic rents generated in the abalone fishery.

PART F

ALTERNATIVE FISHERIES MANAGEMENT REGIMES

An Evaluation of Alternative Management Schemes

The conclusions drawn in the foregoing analysis indicate the desirability for the regulation of commercial fisheries. It is assumed that the ultimate goal of rationalization in the British Columbia abalone fishery entails the maximization of the *socially* determined net benefits derived from the resource. Owing to the absence of fully defined property rights to the resource, social costs and benefits do not always converge with private costs and benefits. Fishermen do not generally take into account the effects of their actions beyond their own individual operations. Consequently, the private costs of fishing incurred by an individual vessel may be less than the cost which the fishery as a whole incurs from the operations of that vessel. This phenomenon will be elaborated upon as the discussion continues. For now, it is important to recognize that the relevant variables to be considered in fisheries management are the *social* costs and benefits of fishing.

Unfortunately, it is often the case that a social cost-benefit analysis generates ambiguous results. This is primarily due to a complication that typifies much of welfare economics – that of incomparability of values among different individuals. For example, it is very difficult to determine the value that one individual or community derives from a particular fishery relative to another individual or community. Moreover, it is even more difficult to measure such values. In addition to the pecuniary benefits originating from fishing activity, there are also non-pecuniary benefits that are important. A "true" social cost-benefit analysis would take into account such non-pecuniary benefits. The implementation of policy based on an analysis that has neglected to do so can often cause irreparable social damage. Consider, for example, the possibility of an Indian food fishery generating greater monetary net benefits if it was converted to a commercial fishery. Failure to also account for the significant social costs involved with the loss of a fishery to an Indian community would not satisfy the requirements for social optimization. Owing to disagreement among economic analysts regarding the proper method of measuring non-pecuniary social costs and benefits, such factors are often treated as constraints rather than components of the objective function. This paper takes a similar approach. That is, the long-run net monetary social benefits from fishing represent the maximization objective. Subsequent consideration is then given to incommensurable costs and benefits if such factors are of relevance. The generation of an optimal monetary return to society involves the consideration of the following subsidiary goals (Pearse, 1982: 4–6).

First, fisheries policy must ensure that the resource is properly protected. Overexploitation may lead to severe resource depletion, thereby greatly reducing the long-term commercial revenues potentially available from the resource. An additional adverse effect of stock depletion involves the loss of incommensurable benefits that accrue to society through recreational activities or the mere existence of the resource itself. The avoidance of stock depletion will generally be achieved inadvertently along with the maximization of net monetary social benefits. Thus, it need not be given explicit attention.

A second consideration is that of economic efficiency in commercial exploitation. Long-run rent maximization in the fishery entails the employment of input configurations that minimize the costs of fishing for the fishery as a whole. Any other form of resource allocation involves a waste of resources and a subsequent loss to society. Crutchfield (1979: 743) has identified the following elements as necessary conditions to achieving this rationalization objective:

1. Production should be organized so as to attain that level of catch at which the marginal social value of the harvest is equated to the incremental social cost (including management costs) to take the catch. This equality also entails that the catch be of optimal size or age composition.
2. Economic efficiency necessitates a particular configuration of vessel-gear-fishermen units to minimize the aggregate real cost of taking any given catch.
3. Optimal fleet deployment is attained when no increase in yield or decrease in cost can be achieved by altering the area or time fished.

Any policy of fisheries management that causes a substitution away from the optimal configuration of inputs of production is inconsistent with rent maximization.

Owing to rapid changes in resource abundance, in markets, and in fishing technology and effort, any proposed fisheries policy should involve flexibility. The inability of a particular regulatory regime to adapt to changing circumstances is likely to generate social losses.

A fourth consideration is that of administrative simplicity. A management regime that is complex to administer is also likely to be costly. Specifically, a regulation that is in consonance with the private incentives of fishermen will be less costly to enforce than one which is in conflict with fishermen's incentives.

The extent of economic returns to the fishermen themselves must be carefully examined. The fact that the ocean's resources are common property, suggests that society as a whole should share in any benefits obtained from the sea. It may then be undesirable for fishermen to earn "excessive" profits. The term "excessive" requires clarification. Economic theory generally maintains that efficiency is served when competitive firms earn zero economic profits. There is no justification, however, for the government, acting on society's behalf, to appropriate producer surplus. Producer surplus is a "quasi-rent" accruing to fishermen who are able to harvest the resource at a lower cost than marginal fishermen. It is a return that derives from the efficiency of intra-marginal fishermen, rather than from the value of the common property resource. Only resource rents are *potentially* available for redistribution to society in general, although the resource rent and the producer surplus combined represent the maximization objective. Extraction of all of the resource rents by taxation or license fees implies that marginal fishermen would earn a return that just covers their opportunity costs of fishing. In many instances, however, the opportunity costs of fishermen are very low, and earning that are restricted to that level are often socially unacceptable.

In Canada, the level of fishermen's incomes are of particular concern on the east coast, where earnings from fishing activity remain low for a majority of full-time fishermen (Kirby, 1982: 309). A primary policy objective for Atlantic fisheries is that "employment in the Atlantic fishing industry should be maximized subject to the constraint that those employed receive a reasonable income as a result of fishery related activities . . ." (Kirby, 1982: 309). The level of fishing earnings among west-coast fishermen is also an important priority in fisheries management. An immediate objective of the *Davis Plan* of 1968 was to increase the earning power of British Columbia salmon fishermen (Pearse, 1982: 79). It is clearly in the Canadian interest that fisheries managers find a balance between "excessive" and "inadequate" fishermen incomes.

It is difficult to determine whether or not the estimates of opportunity cost derived in Part D of the thesis can be considered reflective of "adequate" incomes. Recall that the abalone fishery is a part-time fishery for the majority of participants. Given the available information, it is not possible to define "adequacy" because it is not known what proportion of the year marginal fishermen allocate to fishing abalone, nor is the value of their total employment income known. Given that the improvement of fishermen incomes is an objective, however, and given the availability of the required information, adequacy of earnings can be achieved through the redistribution of maximized resource rent to those fishermen in need. Thus, the improvement of fishing incomes need not conflict with the broad goal of maximizing returns to the fishery. It is simply a matter of redistributing rents to fishermen, after long-run benefits have been maximized.

It is important to note that there may often be trade-offs in the fulfillment of the above subsidiary goals, as under many circumstances the goals have conflicting objectives. It may be very difficult, for example, to maintain administrative simplicity and concurrently impose flexible regulations. It is necessary, however, to determine that mix of flexibility and simplicity that maximizes the returns from the fishery.

As mentioned earlier, strict adherence to the attainment of the above goals is not necessarily socially desirable. There may be a number of constraints to the objective of maximizing the net monetary benefits of a fishery. In Canada, one very important constraint associated with fisheries management is that a policy be consistent with the social and cultural values of those groups most affected by such a policy. It is politically desirable that the special needs of coastal communities and the unique dependence of Indians on fish for nutritional needs and cultural activities be seriously addressed.

A small percentage of abalone found in British Columbia is harvested by native Indians, and there are no communities significantly dependent upon the abalone fishery. Any potential conflict between the commercial abalone fishery and the Indian food fishery should be carefully examined before advocating the use of a particular management tool. This thesis does not explicity consider such potential conflicts, as it is primarily concerned with the working of the commercial fishery. It is assumed that the effects of such conflicts will have a negligible impact on the maximization of sustainable monetary net social benefits.

The British Columbia abalone fishery is amenable to a number of policy options. Conceptually, an accurate and exhaustive account of the costs and benefits associated with each of the alternatives should allow for the unequivocal selection of an optimal management regime. In practice, however, such an account of all of the relevant variables is not possible. This is primarily due to the limited availability of data. However, even if the required information were readily available, the problem of assessing incommensurable variables would remain. Although such complications introduce an element of uncertainty into the evaluation process, it remains possible to speculate on a preference for one regulatory regime over another under differing circumstances. Different regulatory regimes can be thought of as alternative forms of contractual arrangement in the fishery. Before discussing the relative merits of various contracts, a discussion of contractual objectives and the associated complications when dealing with a non-exclusive fish resource is desirable.

It has been determined that the failure to achieve optimal resource allocation in the fishing industry is primarily the result of the absence of private property rights (Cheung, 1970; Copes, 1972; Randall, 1975; Abgrall, 1978). A good or an asset is "private property" if three distinct sets of rights are associated with its ownership (Cheung, 1974: 57; Mercuro and Ryan, 1979: 1011). These rights include:

1. The exclusive right to use, or decide how to use the good.
2. The exclusive right to receive income from the good.
3. The right to transfer, or freely alienate, its ownership. This entails both the right to enter into contracts with other individuals and to choose the form of such contracts.

An open access fishery, of course, violates all three of the above conditions. Unrestricted access grants all fishermen an uncontested right to use the resource but allows no individual fisherman the power to exclude other potential users; consequently, no one fisherman is able to receive exclusive income from the resource. These circumstances obviously preclude the possibility of meeting the third requirement of transferability of ownership. The complete abstraction from all characteristics which define private property is the precise reason that a contractual structure allowing for open access results in an undesirable allocation of resources.

Agnello and Donnelly (1976: 519) state that the principal effect of common property is to create "technological external diseconomies", resulting in a greater allocation of resources to the fishing industry than would result from a private property right structure. A technological externality in production occurs when the actions of one firm or individual actually modify the physical production relationships of other firms or individuals (Goetz and Buchanan, 1971: 885). Such a modification has adverse effects when the recipient of the externality experiences higher costs of production than would otherwise be the case. The allocation of resources to the fishing industry is greater than is socially optimal under these circumstances. When making his production decisions, an individual fisherman will fail to take into account the external costs he imposes on other fishermen. Economic efficiency in the use of inputs is attained when the value of the incremental output obtained from employing an additional unit of input is equal to the marginal cost of employing that additional unit. Thus, output will be varied until this equality is achieved. It is important to note that the term ***economic*** efficiency embodies both ***private*** and ***social*** efficiency. When a fisherman's private marginal cost of production falls short of the social marginal cost, the end result is an excess of inputs allocated to the fishery, from society's point of view. Thus, a contractual arrangement which fails to "internalize" external costs of production will cause economic inefficiencies in commercial exploitation in that private and social costs will not converge.

An externality which is common to all fisheries where well-defined property rights are absent is that of a ***stock externality***, which occurs when the application of fishing pressure reduces the size of the fish population and hence increases the cost of another firm's catch (Agnello and Donnelly, 1976: 520). That is, a reduction in stock abundance resulting from one vessel's fishing activity necessitates a higher level of effort on the part of an equally efficient vessel that subsequently enters the fishery, if the two vessels are to obtain catches of equal size. Given that an increase in fishing effort in a particular fishery increases the fishing mortality, the stock of fish, the average age, weight, and size of the fish will decrease, making fishing more difficult, i.e., decreasing the catch per unit of fishing effort (Huang and Lee, 1976: 847).

Another type of externality which is particularly relevant to the abalone fishery is a ***grounds-quality externality*** (Agnello and Donnely, 1976: 521; Agnello and Donnelly, 1975: 524). A sufficient amount of kelp is vital to the productivity of an abalone bed. In order to facilitate collection of abalone, a diver will often slash away any kelp impeding his progress. This significantly reduces the future productivity of that abalone bed, and thus increases the future harvesting costs of fishermen.

An open-access regime most certainly does not ensure that the resource is properly protected. No individual will take the trouble to husband and maintain a resource unless he has some property right in the yield (Scott, 1955: 116).

Finally, the dissipation of resource rent that occurs under an open access fishery negates the possibility of redistributing rents to marginal fishermen with low opportunity costs. Although those fishermen with above-average skills may earn some economic rents in the form of producer surplus, many fishermen are able only to recover the economic costs of fishing. Since the low earnings of marginal fishermen are often considered socially unacceptable, it may be desirable to supplement their incomes. It is preferable to undertake such subsidization through a redistribution of resource rents generated in the fishery rather than by social transfers in the form of welfare payments and unemployment compensation. The former method of redistribution is considered by fishermen to be a less demeaning way in which to receive income.

A fully-defined private property regime would involve none of the above problems associated with open access. Exclusive rights generate an incentive to nurture and husband the resource in order to maximize individual wealth. Private property rights result in a production decision rule which internalizes the external diseconomies associated with common property harvest (Agnello and Donnelly, 1976: 520). The right to exclude others ensures an individual's control over his own production activities. Note, however, that a private property regime would do nothing to increase the level of fishermen's opportunity costs. Yet, because the fact that even incomplete property rights generally allow for the creation of resource rents, there exists the possibility of redistributing such rents to fishermen with low incomes.

It has been theoretically observed that exclusive rights develop in response to increasing scarcity and value of resources and the costs associated with their inefficient use (Demsetz, 1967; Krier and Montgomery, 1973). Common property persists where the social, political or economic costs of acquiring and enforcing property rights are greater than the benefits that can be obtained (Christy, 1975: 698). As the value of the resource increases, the potential gains from more efficient use are increased. That is, the costs associated with altering the structure of the contract become more worthwhile to undertake as the resource becomes more valuable. Such a situation is representative of the British Columbia abalone fishery. The rise in the world price of abalone in 1976 instigated the imposition of limited entry licensing in 1977. As the value of abalone continued to increase, individual quotas were resorted to in 1979. Thus, there has been a progressive move toward structuring the contract so as to more fully specify the property rights of the individuals involved.

With non-exclusive fishing rights and in the absence of collusion among fishermen, rent becomes a residual, with every decision-making unit maximizing the portion left behind by others. Therefore, the behaviour of individuals participating in an open-access fishery is consistent with individual wealth maximization. What separates the open-access fishery from other competitive industries is the absence of a contractual constraint on other people's use of the fishing ground (Cheung, 1970: 59). Consider the exploitation of a particular abalone bed. If an individual fishing operation had complete control over the bed, it is expected that the returns generated from this abalone bed would be maximized. By pursuing individual profit maximization, the vessel(s) would apply the optimal level and composition of effort in the harvesting of abalone. This is not possible under an open access management regime. No one operation has control over the application of total effort; thus there exists no entity to insure efficiency of production. Owing to the technological externalities that tend to typify much of common property resource exploitation, individual wealth maximization is not generally consistent with aggregate wealth maximization for the fishery.

The analysis in Part D of the thesis provides a strong indication that too many resources, in the form of excessive fishing effort, continue to be employed in the abalone fishery in spite of attempts at rationalization. Recall that the optimal level of effort to be exerted annually was estimated at 365 abalone-days. Since 1976, this level of effort has been significantly surpassed. It is desirable, therefore, to account for the "market failure" that has occurred with the previous and present attempts to rationalize the fishery and to consider potentially viable alternatives.

The alternative management strategies considered here include the following:

1. Corrective taxes.
2. Limited licensing.
3. Individual quotas.
4. The sale or the leasing of abalone beds.

The above options represent the viable alternatives open to the management of the abalone fishery. Although corrective taxes are not generally employed in the rationalization of a fishery, they are sometimes advocated in the theoretical literature. Limited entry licensing and the individual quota system of management are the two policy options that have had the greatest support both in administrative terms and theoretical argumentation. The sale or leasing option has been seriously considered only to a very limited extent in fisheries management. This stems from the fact that most fisheries are not compatible with such a structure of management. In particular, the fugitive nature of most species renders it impossible to define biologically discrete productive areas which are potentially saleable or leasable. However, the sedentary nature of abalone stocks renders the consideration of this proposal worthwhile. In discussing the advantages and disadvantages of each type of management regime, the following approach is taken. The theoretical rationale is analysed and the relative merits of the regime are evaluated with specific reference to the British Columbia abalone fishery.

Corrective Taxes

One method of controlling effort that is often advocated but rarely adopted is that of corrective taxes on landings or effort. The impostion of royalties can be used in conjunction with other forms of regulation or serve as the only measure taken to control effort in an open access fishery. It is important to note that the open access equilibrium is sub-optimal only in the sense that too many resources are attracted to the fishery. In other ways, competition brings about results that are usually considered desirable, such as the adoption of the best available technology (Cunningham et al., 1985: 161). Owing to an excess of participants attracted to the fishery, a consequence of open access is the dissipation of resource rents.

A tax could be imposed on either effort or catch in such a way that fishermen find it profitable to operate at effort levels that maximize the aggregate returns from fishing. The appropriate tax represents the economic rent gained by society that can be captured on a sustained basis. Thus, this approach does not depend on property rights at all, but rather on removing all financial incentives to expand fishing capacity (Pearse, 1981: 140).

In practice it is likely to be simpler to tax catch rather than effort, since it is often very difficult to obtain a precise definition of effort. Moreover, even given perfect knowledge of the factors of production comprising effort, a separate tax would have to be levied on each factor if a distortion of factor inputs is to be avoided (Cunningham et al., 1985: 163; Clive and Southey, 1970: 50). That is, a levy on one or a few facets of effort is likely to cause substitutions away from the taxed inputs of production and toward the now relatively lower-cost factors. Although the level of inputs employed in an open access fishery is excessive, the configuration of those inputs is likely to be optimal. Thus factor-substitutions resulting from the imposition of taxes on various components of effort will probably cause inefficiency in production. That is, the minimum cost of individual exploitation under a system of corrective taxes exceeds the minimum cost of exploitation in the absence of corrective taxes. Although license fees represent a tax on effort, and are relatively simple to administer, license fees alone do not provide significant control over the exertion of fishing effort.

Essentially, the levying of taxes can potentially convert the externalities obtaining in an open access fishery into contractual costs to the individual decision-maker (Crutchfield, 1979:

744). Corrective taxes are, however, more theoretically appealing than they are practical. Immediately obvious difficulties are those of compliance and enforcement. The larger the number of vessels and the more numerous the ports of landing, the greater will be the costs incurred for the monitoring and enforcement of tax collection (Pearse, 1981: 140; Scott and Southey, 1970: 50). An additional impracticality is that of the necessity of administrative flexibility (Cunningham et al., 1985: 165; Pearse, 1981: 140; Cassidy, 1973: 527; Anderson, 1977: 164). In order to maintain the fishery in a condition of maximum efficiency, charges must be continually revised in the face of changing prices, costs and technology. Failing this, any rents not completely appropriated by the levy, would eventually be dissipated by higher costs. The administrative costs of data collection and revenue collection would be substantial.

An additional drawback of the tax as a management device rests on the likelihood that the impact on effort of the tax is realized only after a considerable time-lag. Fishing vessels and other capital equipment represent a "sunk cost" to fishermen. Participation in the fishery is apt to continue in order to make such investment worthwhile. It may be years before the impact of a tax is sufficiently damaging to cause some fishermen to retire.

The imposition of taxes leads to a deterioration in the financial situation of all fishermen (Cunningham et al., 1985: 164). In open access equilibrium, marginal fishermen just cover their total economic costs of fishing. After the introduction of taxation, some fishermen incur deficits and exit the fishery. Equilibrium is restored when marginal fishermen again earn normal profits. However, the post-taxation marginal fishermen were previously earning intra-marginal rents. Taxation makes all fishermen worse off to the extent that intra-marginal rents are eroded.

Largely owing to the administrative impractability and political unacceptability of a rationalization scheme based on the collection of royalties, most fisheries have relied on alternative forms of management. The administrative complexities involved with such a scheme will be severe for all kinds of fisheries, including that of abalone, since prices, costs and technology are continually changing. A further complication involved with imposing a tax on catches in the abalone fishery, relates to the numerous ports of landing employed by fishermen. The monitoring and enforcement procedure would be costly. A tax collection scheme is highly impractical and can thus be safely dismissed as a viable management option.

Limited Entry Licensing

Limited entry is a form of contractual arrangement in which access to the resource is restricted. That is, access is limited to those individuals holding explicit rights. The owners of these rights can collectively claim the right to the specified resources and thereby exclude others. However, the rights are co-equal and do not define or limit the amount of the resource that they entitle to individual holders (Pearse, 1981: 138).

The purpose of limited entry licensing is to reduce the level of effort applied to a particular stock of fish. Historical evidence indicates, however, that the level of effort as a whole may only be negligibly affected by simply limiting one dimension of effort. Complications arise when production techniques are highly flexible. When contemplating the imposition of effort restrictions, consideration must be given to the reactions of the regulatees to such regulations. This is particularly important when effort is multidimensional and flexible (Wilen, 1979: 856). Restrictions on inputs do nothing to alleviate fishermen's incentives to expand fishing power and effort in a profitable fishery (Pearse, 1981: 140). A natural response of fishermen to restrictions on the use of one input is to increase the relative use of other inputs. Not only will such a response reduce the extent of total effort reduction, but it is also likely to be very costly.

Consider the consequences of the introduction of limited entry licensing in 1977 in the British Columbia abalone fishery. Column 6 of Table 12 indicates that the number of participating vessels decreased from forty-three in 1976 to twenty-two vessels in 1977. As illustrated in Figure 16c, however, catch during this period rose significantly as did the level of effort in terms of days spent fishing.

The following scenario provides a likely explanation for the above phenomenon. The limitation on the number of participants resulted in an increase in the potentially available rent per individual fisherman. In order to increase the likelihood of capturing a larger portion of this higher rent, it is likely that each fisherman attempted in some way to augment his application of effort. This augmentation could be achieved in a number of ways including more time spent fishing per season, more divers per vessel, and increased sophistication of vessels. In a flexible fishery, any regulatory scheme that attempts to improve efficiency by restricting one or a few facets of effort is bound to fail (Wilen, 1979: 857; Pearse, 1981: 140). Although the level of effort may be somewhat alleviated, inefficient substitution to other components of effort is probable. It is conceptually conceivable that all dimensions of effort could be controlled by regulations. However, the administrative and enforcement costs involved in such a task would be extreme (Copes, 1981: 123). Indeed, even if such comprehensive restrictions were costless, a tight rein on input substitutions remains undesirable. To operate effectively, fishermen need the power to manage their individual production activities independently. Although complete input restrictions would prevent fishermen from engaging in inefficient capacity-increasing activity, it would also prevent them from pursuing production improvements that are cost-reducing. It is desirable to impede capacity improvements that result in the dissipation of resource rents but undesirable to restrict vessel improvements stemming from technical innovations that may have cost-reducing effects. To the contrary, such improvements should be encouraged since they motivate individual fishermen to operate efficiently (Copes, 1981: 123).

A contractual arrangement involving limited entry licensing in essence eliminates none of the characteristics inherent in common property arrangements. The property right in the yield remains uncertain for each individual. Therefore, there is no incentive to adhere to the conditions required for an economically efficient fishery. Namely, owing to the difficulty of restricting effort to its optimal composition, restricted entry does not ensure optimal levels of catch. The composition of the catch is also unlikely to be that which is socially desirable. The absence of individual property rights results in fishermen harvesting fish which are not of an optimal size or age. This is a direct consequence of the fact that fishermen are not assured of receiving the additional benefits potentially available from harvesting when the catch is of optimal composition. To avoid this situation, size limits have often been imposed. The employment of inefficient input configurations is also likely to continue under limited entry. Such inefficiencies may, in fact, be more pronounced than under a regime of open access. This is because the increase in potentially available rents per fisherman that result from restricted access, make excess capacity investments more worthwhile. The same holds true for fleet deployment; under a limited entry regime, the area or time fished is likely to be extended beyond that which is optimal.

In the past, fisheries managers have dealt with such problems by imposing further restrictions on the application of effort. Examples include area and seasonal closures, gear restrictions, vessel-size limitations, and the imposition of a total allowable catch. Careful use of such supplementary restrictions in conjunction with limited entry licensing can result in a considerable improvement in the return to the fishery. By setting a total allowable catch for the fishery on an annual basis, overfishing can be mitigated. The use of seasonal and area closures may aid in the protection of spawning stocks and juvenile stocks, which in turn may improve both the level of recruitment in the fishery and the selectivity of the catch. Vessel-size limitations and gear restrictions reduce the tendency for excessive capital investment that is often prevalent in unregulated fisheries.

Regulators must be discriminatory regarding those facets of effort which are to be controlled. In particular, it is important to distinguish between investment in capital that merely serves to increase capacity and that which improves the efficiency of a vessel. Regulations that impede the latter type of investments represent obstacles to the cost minimization procedure.

It is unlikely that a management regime consisting of limited entry licensing and modified by various supplementary measures could result in optimal long run catch and effort levels. To achieve this would require tight controls on all components of effort as well as restrictions regarding the area and frequency of the application of that effort. Such a procedure often involves additional costs in excess of the resulting increase in fishing returns. However, limited entry licensing can result in the avoidance of some rent dissipation, particularly when used in conjuction with a few carefully chosen supplementary restrictions. In many types of fisheries, such a management regime poses the only viable alternative to open access. This is particularly the case in fisheries where the fish are of a highly migratory nature. The sendentary nature of abalone stocks, however, allows for the potential implementation of alternative rationalization schemes which appear preferable to that of limited entry licensing.

The success of a limited entry program depends upon the degree to which fishermen comply with the supplementary restrictions. The monitoring and enforcement of compliance may be costly. Where possible, it is preferable to select a contractual arrangement in which unenforced individual maximizing behaviour results in a socially desirable outcome. This can be achieved only if individuals can be assured of deriving benefits from behaving in the socially desirable manner. Such benefits are not guaranteed with limited entry. Fishermen are given a *collective* right to the resource as opposed to an *individual* right. Although fishermen may behave in an economically efficient manner, they will do so subject to artificially imposed constraints - constraints which must be enforced at a cost. The British Columbia abalone fishery is a fishery in which these costly constraints may not be necessary under an alternative form of contractual arrangement. That is, a contractual arrangement in which fishermen's profit-maximizing incentives are unconstrained *may* be less costly to enforce than one which restricts these incentives by regulatory means.

Under an individual quota system, the right of each holder is "stinted", or specified with respect to the quantity of the resource he may take (Pearse, 1981: 138). That is, a fixed share of the catch is allocated in advance to individual operators (Copes, 1986a).

The justification for management by individual quota allocation is based on the fact that such a regime bestows partial property rights on fish resource users. Many external diseconomies associated with both open access fisheries and those fisheries subject to limited entry licensing are thereby mitigated. Consider, for example, the so-called "stock externality". Given that individual quotas are enforced, fishermen should exploit the catch associated with their quotas in a way which minimizes their total costs of fishing. Since costs are an increasing function of effort, such minimizing behaviour implies exertion of the least amount of effort required to take the given catch. As indicated earlier, such an incentive does not exist under the regimes of open access and limited entry. If limited entry licensing is supplemented by the imposition of a total allowable catch, the extent of the stock externality is equivalent to that under an individual quota system, but the tendency for individual fishermen to "race for fish" is not removed. The incentive for operators to capture as large a share of the total allowable catch as possible and to do so as quickly as possible remains. Such behaviour results in a higher total cost of fishing for the fishery as a whole in comparison to a situation where individuals are assured of retrieving a given level of catch for the season. Assurance of a right to a portion of the fishery's output should result in a significant alleviation of stock externalities, since fishermen will no longer find it necessary to "race for fish". That is, competitive interception of the stock is discouraged under the individual quota system.

The major advantage deriving from the allocation of individual quotas is the possibility of approaching optimal input-output configurations in production as well as optimal fleet deployment. After fishermen have been allocated the right to a particular quantity of fish, it is reasonable to suppose that they will harvest that amount at the minimum possible cost. Assuming the individual quotas are strictly enforced, the profit-maximizing incentives of fishermen should ensure that the level and composition of effort is also socially optimal. This is unlikely to be the case under a limited entry regime, even if supplementary regulations are imposed. The setting of the total allowable catch at the optimal level does not reduce the incentives for overinvestment in fishing capacity. The impossibility of restricting all facets of effort does not allow for the elimination of overinvestment, although excess capital investment may be significantly alleviated. Note, however, that the complete or partial suppression of overinvestment is costly because it conflicts with an individual fisherman's incentives when there are potential rents to be earned. Thus, it would be necessary to monitor the level *and* composition of effort. Although vessel number are relatively easy to monitor, it would be much more difficult to monitor, say, the number of divers on each vessel. With an individual quota system, it is only individual catches that must be monitored; this procedure is likely to be less costly than the former. It is purported that because quantitative rights encourage efficiency in production, with respect to the composition of effort, this system can be *largely* self-regulating (Pearse, 1981: 141).

Profit maximizing behaviour dictates that fishermen will take fish that are most valuable in terms of size or age. In attempting to obtain a yield where catch composition is such that the quota generates the highest possible returns to a fisherman, an individual may inadvertently jeopardize stock survival. Specifically, the process of "high-grading", or discarding low-valued fish, is likely to result in a higher mortality of the stock (Copes, 1986a). Thus, the aforementioned alleviation of stock externalities resulting form the fact that an individual quota system reduces the prevalence of competitive stock interception, is likely to be at least partially offset by the process of high-grading.

Enforcement is likely to be one of the most difficult problems associated with an individual quota system (Copes, 1986a). If enforcement does not accompany the imposition of quotas, fishermen are likely to engage in "quota busting". This will, of course, result in an actual catch level in excess of the optimum. Even though fishermen are assured of a property right in the yield for the period in question, the lack of exclusive rights results in an absence of incentives to nurture the resource.

Given that the fishery quota is set at the optimal catch level, any catch in excess of the quota can be said to result in a resource loss. The extent of resource loss is the cost associated with failing to monitor and enforce the individual quotas. It is expected that monitoring and enforcement of quotas is carried out to the extent that the marginal cost of doing so is equated to the marginal benefit from doing so. The latter is the marginal reduction in resource loss.

Column 6 of Table 6 indicates that the level of effective effort in the abalone fishery has steadily declined since 1978, this being the period during which individual quotas have been in place. However, a potential inefficiency remains. The heterogeneity of fishermen renders the allocation of uniform quotas undesirable. In fulfilling their quotas, skilled fishermen have the ability to generate a larger contribution to net social benefits than unskilled fishermen. Therefore, it would be more efficient for skilled fishermen to harvest relatively more of the resource. Uniform quotas will be costly to assign and enforce because of opposition from the more productive fishermen. It is possible that this system may leave skilled fishermen worse off than under conditions of common property conditions (Johnson and Libecap, 1982: 1010). In many instances of individual quota management this problem is dealt with by allocating quotas on the basis of historical catch records. Since the size of a fisherman's catch and his level of fishing skill are approximately proportional, such an allocation is likely to allow for the maintenance of efficiencies resulting from the higher–skilled fishermen securing the larger share of the catch. However, the relative efficiency of fishermen is not permanent. Thus, a fisherman who is unskilled at the time of allocation will be granted a relatively small quota; as his skills improve, efficiency considerations suggest that his share of the catch should also be increased. Note that this problem could be overcome by the allocation of quotas of shorter duration, but only at an increase in administrative costs. There is another problem with allocation quotas on the basis of historical catch records. Even though one fisherman's catch may be very high relative to another's, the contribution of the former to the net social benefits deriving from the fishery may actually fall short of the latter's contribution. This is because the opportunity cost of the skilled fisherman with a high catch may be higher than that of the unskilled fisherman with the low catch. This indicates that society incurs a greater cost from having the skilled fisherman employed in the abalone fishery that it does from having the unskilled fisherman so occupied.

The heterogeneity of fishermen could also be recognized by allowing competitive bidding for quotas units. More efficient fishermen will be able to secure larger quotas as they will be willing to pay more for them than the less efficient fishermen.

An important issue concerning both individual quota management and limited entry licensing is the question of transferability, which is also advocated as a means of taking into account the heterogeneity of fishermen. When quotas are transferable, many marginal fishermen should be willing to sell their rights to those fishermen earning intramarginal rents. Although the individual quotas in the British Columbia abalone fishery have been deemed nontransferable, contractual loopholes have allowed fishermen to "lease" their quotas for long periods of time. Note, however, that such leasing is probably accomplished at a higher cost than if the right was legally transferable.

The transfer of licenses or quotas often leads to what has been termed the "transitional gains trap" (Copes, 1986a). The initial holders of quotas are able to capitalize the stream of future benefits and extract them from successive holders to whom they lease the quotas. Thus, the increased rents resulting from rationalization accrue only to the first generation of beneficiaries. Successive generations earn the same returns that they would earn under an open access regime. To avoid this problem by imposing nontransferability, however, is to obstruct, in part, the purpose of an individual quota management regime, this being the allocation of more well-defined property rights. Nontransferability violates the right to freely alienate ownership. Quantitative rights must be transferable so that rights, like any other input, may gravitate to their highest valued use. Transferability is essential to ensure achievement of the necessary marginal equalities (Randall, 1975: 733). Economic theory holds that any voluntary exchange will leave all existing parties better off (Mercuro and Ryan, 1979: 1011).

The extent or existence of the transitional gains trap is related to the initial allocation of rights. If quotas are granted freely or at a nominal fee, as they were in the British Columbia abalone fishery, then the intitial holders will be the primary beneficiaries of rationalization. If, however, the initial holders are also required to purchase the rights at their full value, transitional gains would not arise. In order to achieve such an allocation of rights, a competitive bidding process appears the most promising. Note that this achieves an equitable distribution of rents among generations of fishermen, but does not address the question of improving fishermen's incomes. It is true that the incomes of all fishermen could be improved by issuing non-transferable quotas at a nominal fee. Note, however, that not all fishermen in the British Columbia abalone fishery are in need of subsidization.[30] It would be politically unacceptable to discriminate among skilled and unskilled fishermen by setting nominal fees for quotas that differed across income groups. Conversely, it is also undesirable for society to undertake the subsidization of *all* fishing incomes, when not all fishermen can be considered "poor". If transferable quotas were allocated through competitive bidding, the expected capitalized stream of earnings for the period in question could be captured by the government. There then exists the potential for an ex-post redistribution of rents for those fishermen whose income for that year is considered socially unacceptable. It is possible to

[30] There are currently only a few participants that can be considered to be marginal fishermen; based on personal conversation with Richard Jacobson, Department of Fisheries and Oceans, Vancouver, B.C.

treat the objectives of economic efficiency and acceptable levels of income as two separate issues that do not have to be served simultaneously. One does not necessarily have to be served at the expense of the other. An ex-post distribution of rents is, however, often objected to by virtue of the fact that it may offend the beneficiaries of the redistribution. That is, recipients may consider income earned in this manner to be undignified or demeaning.

An additional advantage of transferability is the likely alleviation of enforcement costs. An auctioning of non-uniform quotas allows the more productive fishermen to advantageously exploit their skills and should thereby result in a lower incidence of quota busting. This is not likely to result in a significant mitigation of enforcement costs, however, since the incentive to quota-bust still exists, although perhaps to a lesser degree.

Although the individual quota system may help to alleviate some externalities, it will not result in their elimination. Recipients of quotas purchase the right to harvest a particular amount of unidentified abalone. An individual does not have the incentive to leave an adequate number of abalone behind for the purpose of increased future productivity of a particular bed, because he is not assured of benefiting from the potential increase in that bed's productivity. Thus, the stock externality is still likely to occur under individual quota management. Similarly, the individual quota system also allows for the continuance of the grounds-quality externality. When diving for abalone among kelp beds, care must be taken in order that the habitat is not destroyed. Divers may not undertake these costly precautions since the potential benefits from doing so may accrue to someone other than themselves. The rights associated with individual quotas are not completely specified. If they were, then all rewards and penalties accruing from an action would accrue to the actor (Randall, 1975: 733).

A complete specification of rights is essential in order to achieve an economically efficient allocation of resources. Since rights provide, among other things, an information system, a completely specified set of rights will reduce both ignorance and uncertainty. Also essential for reducing uncertainty as to the outcomes of decisions and actions is the enforceability and enforcement of the set of rights (Randall, 1975: 733).

Quotas are not strictly enforced in the British Columbia abalone fishery,[31] presumably because it is too costly to do so. The lack of enforcement renders the existing contract, that of an individual quota management regime, unfulfilled, as does the nontransferability of the quota. As mentioned earlier, even though fishermen do, in fact, lease their right to exploit, the restrictions involved are likely to make it costly to do so. That is, there are institutional impediments to persons attempting to trade. In essence, non-transferability imposes a restriction on the right to receive income. This in turn will yield predictable changes in behaviour in the exercise of the exclusive right to use or decide how to use the good (Cheung, 1974: 57). An alternative perception of non-transferability is that it achieves a particular allocation of income. The practice of charging a nominal fee for a non-transferable quota reflects a situation whereby all generations are treated equitably. Conversely, if the license-holder was permitted to sell the license at its capitalized value, this would signify discrimination in favour of the initial holder. However, if all participants, including the initial holder of the quota, were required to purchase the quota at a fee that reflected the capitalized value of all future rents, this would also result in the equitable treatment of all generations.

The holders of individual quotas have been assigned a *partial* property right to the yield of the British Columbia abalone fishery. Even in the absence of legal impediments to alienation, the property right would remain incomplete. The individual quota regime allows for the continuance of externalities in production because the property right remains only partially specified. That is, holders of quotas are allocated the right to take a particular quantity of an *unspecified* resource. In addition, the enforcement of rights is incomplete.

[31] Based on personal communication from Richard Jacobson, Head of Shellfish Division, Department of Fisheries and Oceans, Vancouver, B.C.

A Case for Private Ownership or Leasing of Abalone Beds

Since abalone are sedentary shellfish that move very little beyond the pelagic stage, it would be relatively easy to define boundaries between different abalone beds. Abalone beds vary in size according to how conducive the habitat is to abalone growth and survival.

Consider the consequences of auctioning off the right to exploit particular abalone beds in perpetuity. Through a competitive bidding process, the purchase price for each bed should equal the capitalized value of the expected future net rents attainable from the bed. Conceptually, then, society is able to extract all future resource rents from the abalone fishery. It may be desirable to allow a portion of these resource rents to accrue to low-income fishermen. This could be achieved by permitting marginal fishermen to purchase the right to harvest a particular bed at a fee that is less than the expected capitalized value of the future stream of resource rent from the bed in question.

Auctioning is not the only means by which rights can be allocated. Competitive bidding is, however, likely to involve lower administrative costs than if the government were to determine the value of each abalone bed and set prices accordingly.

The heterogeneity of fishermen is properly accounted for under such a system. The more productive operators will be willing to pay a higher price for a particular bed than fishermen with lesser skills. Thus, their competitive advantage can by exploited by virtue of their relatively lower costs of production.

Given transferability of ownership, owners of beds will have every incentive to harvest stocks of optimal composition at optimal levels since they are assured of a perpetual right in the yield from the bed which they own, if they so desire.

If the right to ownership is not transferable, operators can be expected to exert excessive pressure on the stock just prior to retirement. Given the right to transfer, however, the proceeds from exchange will be greater, the more valuable the existing stock.

Exclusive rights to a specified resource will also result in optimal input configurations. The owners of abalone beds can be expected to pursue cost-minimization strategies of production just as any other competitive firm.

After the initial allocation process, the transactions costs incurred by society are likely to be minimal. Monitoring and enforcement of fishermen behaviour is unnecessary under private ownership since the existence of property rights to abalone beds provide individuals with the incentive to operate in a socially desirable manner. High costs will be incurred in the enforcement of the property right itself. Owing to the geographical isolation and dispersion of abalone beds, the harvesting of abalone by poachers is very difficult to detect. Note, however, that this is a problem that derives from the nature of the resource and, excluding open access, is equally perplexing for all types of management regimes.

The production externalities that are allowed to continue under the regimes of limited entry and individual quota management will be eliminated under the private ownership of abalone beds. The exertion of harvesting pressure on any stock will have consequences only for the operator who exerted that pressure. No fisherman is able to influence, through his own production process, the success with which other fishermen harvest their stocks. Any benefits deriving from the nurturing of the habitat, or improvements in the quality of the fishing ground, will accrue only to the individual who undertakes such efforts.

A potential positive externality that is introduced is what might be termed a *pelagic externality*. When two or more beds are adjacent to one another or relatively close together, the larvae from one sub-stock of abalone may drift to an adjacent ground during the pelagic stage. Thus, the benefits resulting from a particular owner's maintenance of a bed's productivity may partially accrue to the owner of an adjacent bed. Consequently, a divergence between private and social costs occurs. The distortionary effects arising from such an externality may be considered minor.

It is probable that some scattered stocks of abalone would fall outside the boundaries of private beds. It is not necessary for all stocks to become subject to a private license. Indeed, it may be preferable to reserve some areas for recreational and Indian food fisheries. Even some clustered beds of abalone may not be considered worthwhile to currently exploit by potential bidders. Given time, however, such beds may become more attractive as a result of a continuing increase in the price of abalone or an increase in the productivity of the bed due to light harvesting pressure.

The assignment of full private property rights in fisheries is often considered to be politically unacceptable. This presumably derives from a desire to perpetuate the commons; that is, to allow society as a whole to enjoy ownership of the ocean's resources. Often overlooked is the fact that ownership involves responsibility for the costs of managing the resource. It appears likely that, in the case of the abalone fishery, society would derive greater benefits from private management of the resource. An empirical cost-benefit analysis involving all of the relevant variables is required to make a more definitive judgement.

There are two aspects related to the desire to perpetuate the commons. One involves the question of physical access to areas. When the government foregoes ownership of a resource the public no longer has the right of access to that resource. Public oppostion resulting from a government proposal to sell an area in which abalone occur is could be considerable. It is possible to sell abalone fishermen full rights to an identified stock of abalone but not to any other aspect of the foreshore areas in which the abalone occur. This would allow other individuals to harvest different species and to engage in various other recreational activities. The largest public resistance regarding access to the area concerned may thus be avoided. Such a property-right formation would, of course, involve fairly high enforcement costs since the activities of non-abalone fishermen and recreational users would require careful monitoring in order to ensure that abalone stocks were exploited only by individuals granted the right to do so. Additionally, the other fishing and recreational activities may have adverse effects on the abalone fishery. However, the retention of social benefits deriving from the right of public access would likely render the costs of these adversities worthwhile.

The second aspect involved with the desire to retain public ownership of resources is the question of utilization of the resource within an area. By relinquishing ownership of a resource, not only does the public no longer have access to the resource, but it is also more difficult to interfere in the abalone fishery when it interfaces with other resource uses. When dealing with a marine environment, one is inevitably dealing with multiple resource use. If the government releases one of these resources to a private entity, it may result in the creation of legal obstacles when dealing with multiple resource use problems.

Given the improbability of eliminating the public desire to perpetuate the commons, the following compromise is proposed. The government, on behalf of society, could lease beds of abalone to individual operators. From an economic standpoint, this solution is inferior to that of private ownership since a lease is a less fully defined form of property right. Neverthless, certain precautions can be taken to "minimize the inefficiencies". Leases should be extended for a considerable length of time (at least ten years) in order that lease-holders can be provided with some reasonable assurance of a right in the yield. Again, competitive bidding for leases and transferability is advocated for the reasons discussed earlier. Furthermore, the terms of the contract should require that the stock and its habitat be of a particular condition upon expiry of the lease.

Note the higher transactions costs associated with a leasing arrangement relative to one of private ownership. The former involves the monitoring and enforcement of fishermen behaviour regarding stock and habitat maintenance. The administrative costs involved in structuring the contract will also be higher. Costs will be incurred in attempting to determine desired stock and habitat conditions and these requirements must be stipulated in the contract in such a way so as to avoid future complications. Another potentially desirable contractual stipulation is the retention of government rights in dealing with multiple resource use problems.

It is believed that the leasing arrangement, too, will be met with consternation from public officials.[32] Such a contractual structure, however, involves the same degree of private property rights as does the current individual quota arrangement. The former merely involves the identification of the stocks associated with the right to fish. Herein lies the advantage of leasing over individual quotas. The state or condition of any bed or sub-stock of abalone can be attributed to the effort of the lease-holder. Thus, that individual or fishing unit is able to derive the benefits from, or suffer the consequences of, his harvesting procedures. This is not the case with individual quotas. Rather, the fishery as a whole sustains the consequences, be they adverse or beneficial, of each individual's actions.

In considering a leasing arrangement, there arise some contractual peculiarities which do not present themselves if full private property rights are granted. In the event that abalone beds are leased, there will exist a relationship between the contracting parties which will persist over a long period of time. The government and the lease-holders will have to deal with each other regularly over a wide range of issues, many of which will be unknown in advance. In order to exercise the contract, individuals will be forced to rely on agents for purposes of gathering information, making decisions, negotiating the contract, and adjusting the terms of the ongoing relationships.

A leasing arrangement involves a much higher degree of risk and uncertainty on the part of fishermen than a private ownership arrangement. Both arrangements will, of course, involve uncertainty of future yields. In comparison to a private property regime, a leasing arrangement may also involve greater uncertainty regarding government response to changing

[32] Based on personal communication from Richard Jacobson, Head of Shellfish Division, Department of Fisheries and Oceans, Vancouver, B.C.

conditions over the course of the contract. It is probable that in a situation where the government retains ultimate ownership of a resource, it will be less hesitant to interfere in question of resource use, relative to a case where ownership has been relinquished. Such uncertainties will affect the outcome of the competitive bidding process, owing to the effect of risk on the expected value of the capitalized stream of rents over the duration of the lease. On the one hand, a long-term lease reduces the risk undertaken by a fisherman in that he is assured of the right to participate for an extended period. However, the price which he bids for the lease is more likely to reflect actual capitalized rents if he is bidding for a short-term lease. The income stream is less predictable in the far future than it is in the near future. Additionally, the longer the duration of the contract, the more probable that the conditions of the contract will be altered prior to termination. In general, the longer the anticipated relationship and the more complexity and uncertainty entailed in that relationship, the less attention will be focused on stipulating price and quantity variables at the contract formation stage. Rather emphasis will be placed on the establishment of rules to govern the relationship (Goldberg, 1976: 432).

It is likely that all concerned parties will prefer a contract that reflects a considerable degree of flexibility. Since the stream of capitalized future rents generated by a particular abalone bed is uncertain, it will not generally coincide with the amount of an individual bid for a lease on that particular bed. It may be desirable, therefore, to stipulate at the time of contract formation, a procedure whereby the amount of deviation of realized rents from expected rents for a particular period accrue to the appropriate party. Thus, if actual resource rents exceeded expected resource rents in a given year, the excess would accrue to the government. Conversely, any shortcoming in actual rents relative to perceived rents should accrue to fishermen. This procedure would, of course, require neutral third party verification of expected rents and would also involve a considerable degree of monitoring of catches over the term of the lease. The practical considerations involved impose serious obstacles to a contract formulated in this manner. Third-party verification would involve the necessity for accurate estimates of individual producers' surplus in order to ensure that it is only resource rents that accrue to the public. This, in turn, requires third-party acquisition of knowledge regarding fishermen's present and future skill levels, a task that may considered impossible in practical terms.

Contract flexibility may be achieved to some degree by providing for insurance against unexpected changes in exogenous variables, that is, factors outside the control of any concerned parties. The adversities stemming from uncertainty may also be alleviated by selecting a contract of optimal duration. Specifically, it is desirable to minimize the cost of uncertainty resulting from unknown future variables as well as uncertainty arising from the fact that leases are temporary. In the latter case, a contract of fairly long duration provides significant assurance that a lease-holder will reap the benefits of his efforts. Conversely, a short-term contract allows for more frequent revisions of leasing bids; this is desirable when faced with significant fluctuations in variables such as demand and technology.

The singular advantage of a transferable leasing arrangement over an individual transferable quota system, involves the proprietary nature of the contract. The more well-defined property associated with the lease relative to an individual quota, provides fishermen with a fuller incentive to harvest in the socially optimal manner. Such an incentive arises because an individual is more likely to suffer the consequences or reap the benefits of his individual actions. Thus, under a leasing arrangement, the privately optimal input-output configuration will more closely approach that which is socially optimal, as compared to a system of individual quotas.

SUMMARY

The analysis undertaken in Part B of this paper, indicates that the British Columbia abalone fishery should extract approximately 68,600 kilograms of abalone from the fishery per year. In order to maximize the net benefits attainable from the fishery, it is also implied that the effort employed to take this catch be reduced by approximately sixty percent.

It is possible that the above input-output configuration can be most efficiently achieved, in economic terms, by the allocation of transferable private property rights to specific beds of abalone. Furthermore, this allocation should be accomplished by a competitive bidding procedure.

The likelihood of the above proposal being politically unacceptable is significant. In order that access and utilization priveleges to the abalone fishery remain ultimately at the disposal of the public, a leasing arrangement may be a viable alternative.

The costs associated with the formation of property and of the subsequent contracts are twofold: there are costs related to defining and policing exclusivity, and there are costs associated with negotiating and enforcing contracts and the exchange of property.

When determining the optimal contractual arrangement for any resource, including fisheries, the general issue to be considered is the extent to which the gains and costs of actions are weighed in the market (Cheung, 1970: 67). If the market does not exhaustively account for the consequences of all actions, as is the case with common property regimes in fisheries, it is economically desirable to consider alternative legal arrangements or government regulations.

It is beyond the scope of this thesis to offer a definitive judgement regarding the superiority of a single rationalization scheme. From a theoretical viewpoint, a management regime which offers the most well-defined property rights to participants appears to be

economically most efficient. However, the costs associated with administering and enforcing private property may not be worthwhile. In addition, the social costs involved with the loss of public ownership must also be considered.

A comprehensive cost-benefit analysis must be undertaken in order to determine the desirability of one management regime over another. This thesis indicates that it is worthwhile to seriously consider a leasing arrangement as a viable alternative to the individual quota system.

REFERENCES

Abgrall, Jean-Francois. 1978. Fishery industry: in support of the single manager. *Canadian Journal of Agricultural Economics* 26(2): 35-42.

Agnello, Richard J., and Lawrence P. Donnelly. 1975. Property rights and efficiency in the oyster industry. *Journal of Law and Economics* 18(2): 521-533.

Agnello, Richard J., and Lawrence P. Donnelly. 1976. Externalities and property rights in the fisheries. *Land Economics* 52(4): 518-529.

Anderson, Lee G. 1977. *The economics of fisheries management.* Baltimore and London: The Johns Hopkins University Press.

Arrow, Kenneth. J. 1962. The economics of learning. *Journal of Economic Studies* 29:????

Bates, K.T. 1985. Review of the 1983 commercial abalone fishery in British Columbia. *Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1826.* Department of Fisheries and Oceans, Prince Rupert, B.C.

Breen, Paul. 1980. The northern abalone: muscled mollusc. *Diver* 6(6):26-28.

Breen, Paul, and Bruce Adkins. 1980. Spawning in a British Columbia population of northern abalone, *Haliotis kamtschatkana. The Veliger* 23(2): 177-179.

Carlisle, John. 1945. The technique of inducing spawning in *Haliotis rufescens Swainson. Science* 102(2657): 566-597.

Cassidy, P.A. 1973. Commonality, fishery resources, potential and policy: comment. *American Journal of Agricultural Economics* 55(3): 526-529.

Cheung, Steven N.S. 1970. The Structure of a Contract and the Theory of a Non-Exclusive Resource. *Journal of Law and Economics.* 13:49-70.

Cheung, Steven N.S. 1974. A theory of price control. *Journal of Law and Economics* 17(1): 53-72.

Christy, Francis T., Jr. 1975. Property rights in the world ocean. *Natural Resources Journal* 15(4): 695-712.

Copes, Parzival. 1972. Factor rents, sole ownership and the optimum level of fisheries exploitation. *Manchester School of Economic and Social Studies* 40(2): 145-163.

Copes, Parzival. 1978. Resource management for the rock lobster fisheries of South Australia. A report commissioned by the Steering Committee for the Review of Fisheries of the South Australian Government.

Copes, Parzival. 1981. Rational resource management and institutional constraints: the case of the fishery. In J.A. Butlin (ed.). *Economics and resources policy,* 113-128. London: Longman.

Copes, Parzival. 1986a. A Critical Review of the Individual Quota as a Device in Fisheries Management. *Land Economics.* 62(3): 278–291.

Copes, Parzival. 1986b. Prawn fisheries management in South Australia, with specific reference to problems in Gulf St. Vincent and Investigator Strait. Report to the Minister of Fisheries of South Australia.

Crutchfield, J.A. 1979. Economic and social implications of the main policy alternatives for controlling fishing effort. *Journal of the Fisheries Research Board of Canada* 36(7): 742–752.

Cunningham, Stephen, Michael R. Dunn and David Whitmarsh. 1985. *Fisheries economics: an introduction.* London: Mansell Publishing Ltd.

Demsetz, Harold. 1967. Toward a theory of property rights. *American Economic Review* 57: 347–357.

Farlinger, S., and K.T. Bates. 1985. Review of shellfish fisheries in northern British Columbia to 1984. *Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1841.* Department of Fisheries and Oceans, Prince Rupert, B.C.

Federenko, A.Y., and P.E. Sprout. 1982. Abalone biology, fishery regulations, commercial catch (1952–1980), and current state of resource in British Columbia. *Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1658.* Department of Fisheries and Oceans, Prince Rupert, B.C.

Goetz, Charles, J., and James M. Buchanan. 1971. External diseconomies in competitive supply. *American Economic Review* 61(5): 883–890.

Goldberg, Victor P. 1976. Regulation and administered contracts. *Bell Journal of Economics* 7: 426–448.

Horngren, Charles T. 1977. *Cost accounting: a managerial emphasis.* Englewood Cliffs, N.J.: Prentice–Hall, Inc.

Huang, David S., and Chae W. Lee. 1976. Toward a general model of fishery production. *Southern Economic Journal* 43(1): 846–854.

Johnson, Ronald N., and Gary D. Libecap. 1982. Contracting problems and regulation: the case of the fishery. *American Economic Review* 72(5): 1005–1022.

Kirby, Michael J.L. 1982. Navigating troubled waters: a new policy for the Atlantic fisheries. *Report of the Task Force on Atlantic Fisheries.* Ottawa: Canadian Government Publishing Centre, Supply and Service Canada.

Krier, James E., and David Montgomery. 1973. Resource allocation, information cost and the form of government intervention. *Natural Resources Journal* 13: 89–105.

Mercuro, Nicholas, and Timothy Ryan. 1979. The role of nonattenuated rights in positive economics: a critical appraisal. *Journal of Economic Issues* 13(4): 1007–1018.

Mottet, Madelon Green. 1978. A review of the fishery biology of abalones. *Technical Report No. 37.* Department of Fisheries, State of Washington.

Pearse, Peter H. 1981. Fishing rights, regulations and revenues. *Marine Policy* 5(2): 135–146.

Pearse, Peter H. 1982. Turning the tide: a new policy for Canada's Pacific fisheries. Vancouver: The Commission of Pacific Fisheries Policy, Final Report.

Quayle, D.B. 1971. Growth, morphetry, and breeding in the British Columbia abalone (*Haliotis kamtschatkana* Jonas). *Technical Report No. 279.* Fisheries Research Board of Canada.

Randall, Alan. 1975. Property rights and social microeconomics. *Natural Resources Journal* 15: 729–747.

Russell, E.S. 1931. Some theoretical considerations on the "overfishing" problem. *Journal du Conseil International Pour L'exploration de la Mer* 6(1): 3–20.

Schaefer, Milner B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bulletin of the Inter-American Tropical Tuna Commission* 1(2): 27–56.

Scott, Anthony. 1955. The fishery: the objectives of sole ownership. *Journal of Political Economy.* 63:116–124.

Scott, Anthony, and Clive Southey. 1970. The problem of achieving regulation of a fishery. In A.D. Scott (ed.) *Economics of fisheries management: a symposium.* H.R. MacMillan Lectures in Fisheries.

Shepherd, S.A., G.P. Kirkwood and R.L. Sandland. 1982. Studies on southern Australian abalone (Genus *Haliotis*); mortality of two exploited species. *Australian Journal of Marine Freshwater Resources* 33: 265–272.

Sprout, P.E. 1983. Review of 1981 commercial abalone fishery in British Columbia. *Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1692.* Department of Fisheries and Oceans, Prince Rupert, B.C.

Wilen, James E. 1979. Fishermen behavior and the design of efficient fisheries regulation programs. *Journal of the Fisheries Research Board of Canada* 36(7): 855–858.