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National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 82-15

A Cohort Analysis of Pacific Ocean Perch Stocks from the Gulf of Alaska and Bering Sea Regions

December 1982

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by

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December 1982

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* A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science, School of Fisheries, University of Washington, Seattle, Washington. December 1982.

Abstract

A COHORT ANALYSIS OF PACIFIC OCEAN PERCH STOCKS FROM THE GULF OF ALASKA AND BERING SEA REGIONS

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Previous assessments of Pacific ocean perch, Sebastes alutus, stocks have been based primarily on changes in catch per unit of effort (CPUE) in the trawl fishery. Most errors associated with these assessments have been related to the estimation of effective fishing effort. Standardizing and partitioning total groundfish effort into effort directed towards Pacific ocean perch has been difficult, due to the multi-species and multi-gear nature of the trawl fishery. Moreover, rapid developments in fishing technology and fishing skill have been very hard to detect and quantify. These factors have made interpretation of CPUE data difficult.

In this study cohort analysis was applied to catch at age data from the Gulf of Alaska and Bering Sea Pacific ocean perch stocks. This technique, which circumvents the need for reliable effort statistics, describes stock changes in terms of absolute values rather than as an index. Numbers at age and age specific rates of fishing mortality are estimated by this method.

The absolute abundance estimates derived from the cohort analysis differed significantly from past CPUE assessments, suggesting far more serious depletion than had previously been imagined. Using the most reasonable estimates of natural mortality and fishing mortality available, cohort analysis indicated that mean stock biomass in the Gulf of Alaska and eastern Bering Sea declined 94.5 and 84.6 percent (respectively) during 1963-76. Similarly, mean stock biomass in the Aleutian region fell 91.2 percent during 1964-76.

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

Figure No.		Page No.

Figure No.		Page No.

LIST OF TABLES

Table No.		Page No.

ACKNOWLEDGEMENTS

I wish to acknowledge with sincere gratitude Dr. Donald R. Gunderson who provided the initial impetus for this study. His continued encouragement and supervision were invaluable in making the completion of this thesis possible. Special thanks are due to Drs. James W. Balsiger and Lewis J. Bledsoe for their helpful comments during the preparation of the manuscript.

I wish to thank the Resource Ecology and Fisheries Management Division, Northwest and Alaska Fisheries Center (NWAFC), for providing financial, logistic, and computer support. Thanks are also due to the staff of the Fisheries Data Management Systems Division, NWAFC, for their assistance in compiling much of the foreign fisheries data used in this study.

Finally, the monetary award received from the Egtvedt Research Scholarship Fund is gratefully acknowledged.

INTRODUCTION

Statement of Problem

Pacific ocean perch (*Sebastes alutus*) is the most abundant rockfish species in the North Pacific and has been an important resource to foreign and domestic trawl fisheries. Prior assessments have shown that stocks in the Bering Sea and Gulf of Alaska are at low levels of abundance and are generally in a weakened state (Low 1974; Hughes and Ronholt 1976; Ronholt and Low 1978; Bakkala et al. 1980; Low et al. 1980). These low abundance levels are largely the result of excessive removals by Japanese and Soviet distant water trawlers during the mid 1960's. The current condition of these stocks calls for rebuilding in accordance with provisions of the Magnuson Fishery Conservation and Management Act (P.L. 94-265). In order for the North Pacific Fishery Management Council to devise, implement, and monitor effective rebuilding measures, reliable stock assessments are essential.

To prevent fallacious assessments, it is prudent to examine stock changes by more than one method. Different stock assessment methods may contain different sources of error. Depending on the characteristics of the fishery and the way the fishery statistics have been measured, one method may be subject to more error than another (Hayman et al. 1980). Hence, it is possible for two different methods to yield conflicting results.

Stock assessments of Pacific ocean perch have been based primarily on changes in catch per unit of effort (CPUE) in the trawl fisheries. Most errors associated with these assessments have been related to the estimation of effective fishing effort. Standardizing and partitioning total groundfish effort into effort directed towards Pacific ocean perch has been difficult, due to the multi-species and multi-gear nature of the trawl fishery. Moreover, rapid developments in technology and fishing skill have been very hard to detect and quantify. This has led to difficulty in the interpretation of catch per unit effort data. CPUE assessments have been and will continue to be useful in monitoring stock changes, but there remains a critical need to examine stock changes by alternative methods. One such method is cohort analysis.

Cohort analysis techniques have been developed to circumvent the need for reliable effort statistics and to describe stock changes in terms of absolute values rather than as an index (Pope 1972; Garrod 1975). These techniques estimate past population numbers at age and age-specific rates of instantaneous fishing mortality. Historical catch-at-age data, an estimate of natural mortality, and an estimate of fishing mortality for at least one age in each year class are required for the analysis.

Cohort analysis techniques are routinely employed as a stock assessment tool by Atlantic coast fishery scientists. It is only recently that these procedures have gained popularity with west coast fishery scientists as an alternative to traditional CPUE assessments of demersal fisheries (Hoag and McNaughton 1978; Gunderson 1978; Hayman et al. 1980). Cohort analysis has been used to assess Pacific ocean perch stocks from Queen Charlotte Sound, B.C. to Oregon (Gunderson 1978) but has yet to be attempted for the more northern stocks.

Chikuni (1975) provided the first rigorous treatment of Pacific ocean perch population dynamics in the Gulf of Alaska and Bering Sea. He relied mainly on effort and CPUE throughout the analysis. He also provided catch-at-age data for each stock. Chikuni's study has been relied on heavily by U.S. scientists in the management of the Pacific ocean perch fishery. Because of the critical need to prevent errors in stock assessments, Chikuni's catch-at-age data, updated with the most recent fisheries data available, should be re-evaluated using cohort analysis techniques.

The current study deals with the Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea (Figure 1). The study area and delineation the major stocks are described later in this paper.

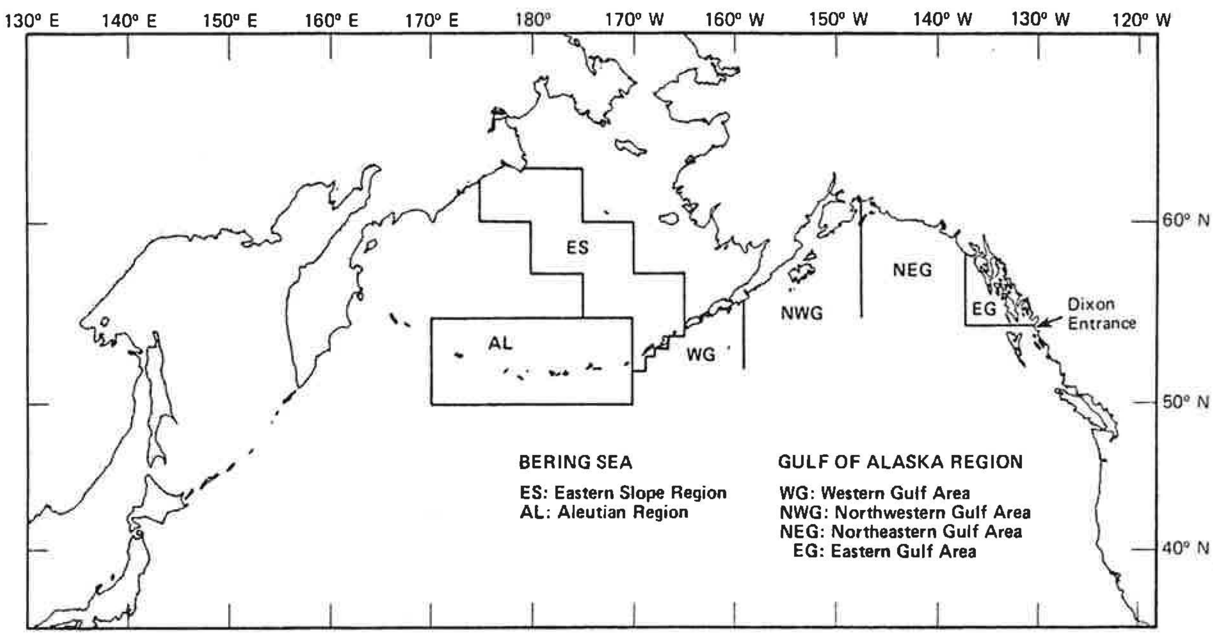

Figure 1. Study area (Bering Sea and Gulf of Alaska).

Study Objectives

The major objectives of the present study are:

1. To review and summarize the pertinent background information regarding the biology and fishery of Pacific ocean perch within the study region.

2. To perform a cohort analysis on the available catch-at-age data so as to permit the following analyses:

(a) Comparision of absolute abundance trends to Chikuni's (1975) CPUE trends. Since Chikuni's analysis contains no catch-at-age data or CPUE data beyond 1972, it will be updated with the most recent fisheries data available.

(b) Examination of year class strength and its relation to future recruitment, i.e., examination of trends in pre- and post-recruits.

(c) Examination of fishing mortality on the partially and fully recruited age groups.

3. To examine sources of bias and error associated with alternative methods of stock assessments.

BACKGROUND INFORMATION

Biological Descriptors

Description

Pacific ocean perch, *Sebastes alutus*, belong to the family Scorpaenidae and is one of over 65 species in the genus *Sebastes* occurring in the North Pacific Ocean. Phillips (1957), and Barsukov (1964a, b) provide detailed descriptions of the morphometric, meristic, and other physical characteristics of *S. alutus*, and a summary of these attributes is given by Alverson and Westrheim (1961), Major and Shippen (1970), and Hart (1973). Adult *S. alutus* can be differentiated from closely related species by its prominent, forward-directed symphyseal knob and by its red colored mouth cavity (Westrheim 1958).

Two subspecies of Pacific ocean perch were proposed by Barsukov (1964a, b): *S. alutus alutus*, inhabiting the waters from California to the Gulf of Alaska and along the Aleutian Archipelago, and *S. alutus paucispinosus*, distributed from Honshu Island into the Bering Sea. Barsukov's conclusions were based on interregional differences in the morphometric and meristic characteristics of Pacific ocean perch. Several workers believe that these differences are not significant enough to warrant subspecies classification (Hart 1973; Chikuni 1975). The current study treats Pacific ocean perch without subspecies distinction.

Distribution and Migration

Pacific ocean perch are semi-demersal and inhabit the temperate waters of the outer continental shelf and upper slope regions of the North Pacific and Bering Sea (Figure 2). Distribution along the North American coast ranges from La Jolla California to the western boundary of the Aleutian Archipelago and along the continental slope of the eastern Bering Sea. Along the Asiatic coast, small catches have been recorded from Cape Navarin to as far south as the Kuril Islands.

This species is usually associated with the gravel, rocky or boulder type substrate found in and along gullies, canyons, and submarine depressions of the upper continental slope (Alverson and Westrheim 1961). Substrate and bottom topography, however, are not the only factors determining Pacific ocean perch distribution; food, water temperature, state of maturity, oxygen content of the water, and other hydrographic factors also influence its occurrence (Lyubimova 1963, 1965; Gunderson 1971). The bathymetric range of S. alutus was reported by Clemens and Wilby (1961) as 70 to 640 m, with commercial quantities generally occurring between 110 and 457 m (Quast 1972).

Migrations of Pacific ocean perch have been studied in the Bering Sea (Moiseev and Paraketsov 1961; Lestev 1961; Paraketsov 1963; Pautov 1972), in the Gulf of Alaska

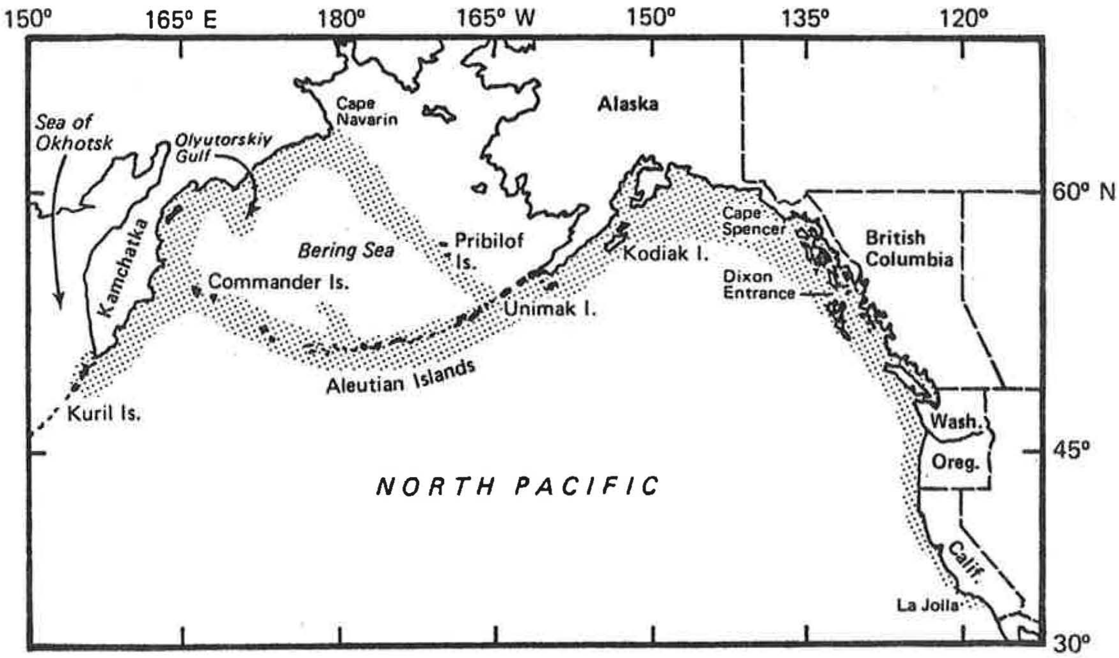

Figure 2. Distribution of Pacific ocean perch.

(Lyubimova 1963, 1964, 1965), and along the British Columbia, Washington, and Oregon coasts (Alverson 1960; Alverson and Westrheim 1961; Gunderson 1971). It is accepted that a definite, seasonal bathymetric migration of S. alutus occurs throughout its range. This movement is primarily associated with spawning behavior, with the time of spawning varying slightly between regions. Typically, this migration is characterized by a movement into deep water spawning areas to release their young during the late winter or early spring, then a return to shallower water to feed during the summer.

Diurnal vertical migrations of S. alutus have been documented by a number of investigators. Moiseev and Paraketsov (1961) indicated that Pacific ocean perch in the Bering Sea dwell near the bottom during the day and migrate as much as 40 m off the sea floor during the night. Lestev (1961) observed that schools during May and June were usually 10 to 15 m off bottom, but occasionally ascended to 50 to 90 m over depths of 140 to 359 m. This same sort of behavior has also been described for Pacific ocean perch in the Gulf of Alaska (Lyubimova 1964). These daily vertical shifts are apparently a function of light and feeding (Lestev 1961; Skalkin 1964; Pautov 1972).

Coastwide migrations of *S. alutus* have not been as well documented, primarily because tagging studies are difficult to conduct on this species. When Pacific ocean perch are brought up from commercial fishing depths, the rapid decompression often causes the swimbladder and stomach to precariously expand or "explode." Consequently, most of these fish are moribund or dead by the time they reach the surface. Until techniques are developed to tag and release viable perch, the degree of coastwide migration, if in fact it does exist, cannot be accurately elucidated.

Although coastwide movements of Pacific ocean perch have been suggested for stocks inhabiting the Gulf of Alaska (Lyubimova 1963, 1965) and Bering Sea (Moiseev and Paraketsov 1961), it seems to be the general consensus that *S. alutus* do not migrate extensively along the continental slope (Lestev 1961; Fadeev 1968; Chikuni 1975; Robinson 1972; Gunderson 1977; Westrheim 1973). In the present study, it has been assumed that migration of juvenile and adults from one major region to another is negligible.

Maturity, Fecundity, Reproduction, and Early Life History

Maturation varies with sex, age, and size of the fish. There also appear to be regional differences in the time of first maturity. Pautov (1972) reported that Pacific ocean perch from the Bering Sea reach sexual maturity at sizes from 26-31 cm in length and that males mature earlier than females, the former maturing at ages 6-7, the latter at 8-9 years. Perch from the Gulf of Alaska are believed to mature at ages 6-8 years, corresponding with lengths of 26-28 cm (Lyubimova 1965). Gunderson (1977) indicated that Pacific ocean perch inhabiting the area from Queen Charlotte Sound, British Columbia to Washington reach sexual maturity at 9-11 years for females and 6-7 years for males. Maturation of both sexes appears to depend more on the size of the fish than on its age. Chikuni (1975) concluded that Pacific ocean perch in the Bering Sea and Gulf of Alaska begin to mature at age 5, and all individuals finish their sexual maturation by age 9.

Fecundity of S. alutus has been examined by a number of authors (Westrheim 1958; Paraketsov 1963; Lisovenko 1965; Syntko 1971; Alverson and Westrheim 1961; Chikuni 1975; Gunderson 1977). Estimates have ranged from 10,000 to over 300,000 eggs per gravid female, with the quantity dependent on the length, weight, or age of the individual. Significant differences in length-fecundity and age-fecundity apparently occur between regions (Figure 3). The stocks inhabiting the eastern Pacific region (south of Dixon Entrance) are considered to be more fecund than those from the Bering Sea, and Pacific ocean perch inhabiting the Bering Sea are reportedly more fecund than fish from the Gulf of Alaska.

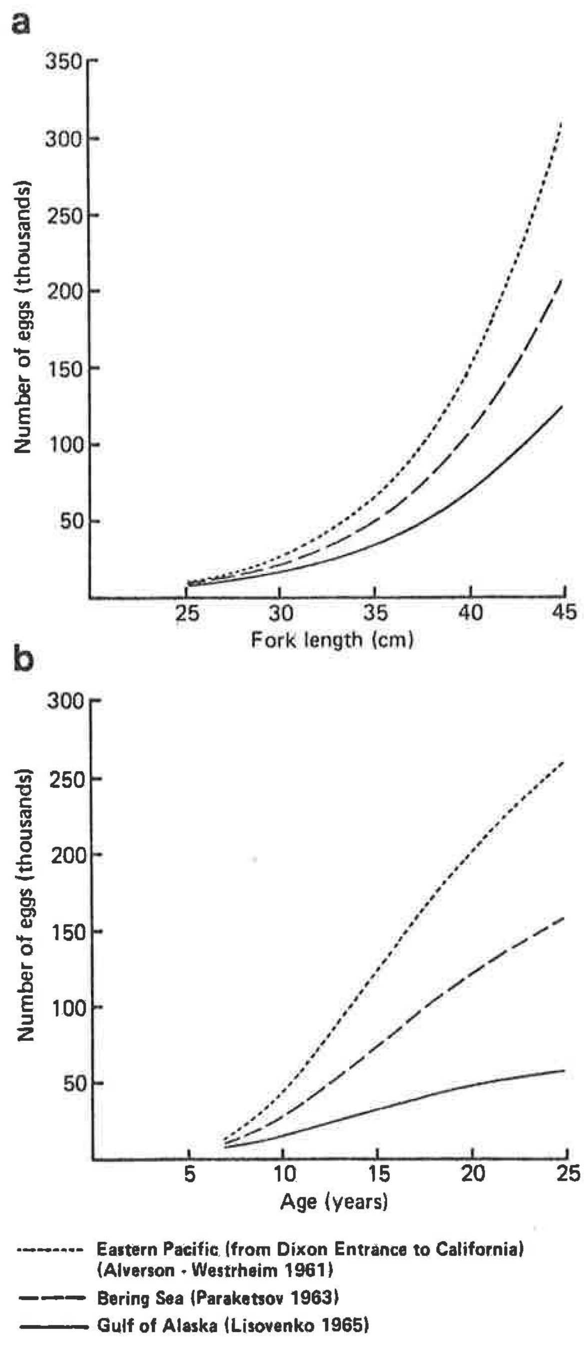

Figure 3. Comparison of (a) length-fecundity, and (b) age-fecundity relationships among regions in the North Pacific (adapted from Chikuni 1975).

Pacific ocean perch are ovoviviparous as are all members of the genus *Sebastes* (Hart 1973). During the late fall or early winter, the eggs are fertilized internally and are retained in the ovary during incubation. Just prior to parturition, the eggs are hatched within the female and the larvae then extruded. The larvae ascend to the upper layers of the water column and drift with the currents. In the Gulf of Alaska and Bering Sea, parturition occurs during the late winter or early spring at depths ranging from 250-450 m. Further details concerning the reproduction of this species are described by Westrheim (1975) and Lisovenko (1970).

The spawning sites are believed to be associated with circular or slow moving currents, so that the pelagic larvae are not carried far from the spawning grounds. Lisovenko (1964) and Lyubimova (1965) indicate that the bulk of the Pacific ocean perch larvae in the Gulf of Alaska are associated with anticyclonic gyrals. These gyrals appear at the boundary between the high velocity Alaskan Stream and the relatively stagnant coastal water -- resulting in areas of high productivity. These areas provide ideal conditions for feeding perch larvae, and the circular currents presumably prevent the larvae from being swept to unfavorable environments (Figure 4). Moiseev and Paraketsov (1961) and Hebard (1959) suggest a similar type of scenario

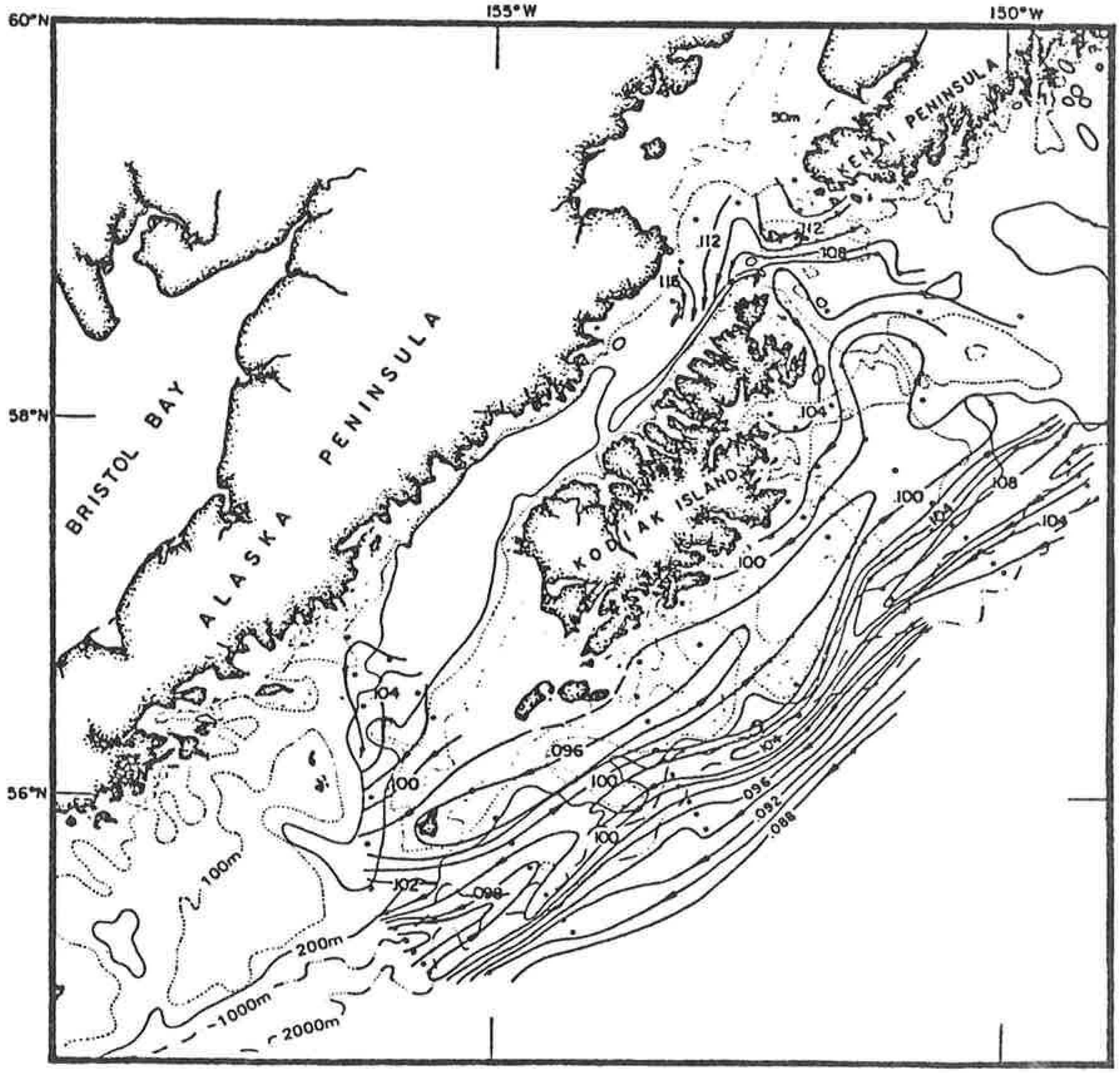

Figure 4. Geostrophic currents (0/50 db) over the continental shelf off Kodiak Island indicating the presence of gyres and counter currents that could serve to retain demersal eggs and larvae in the area prior to settling on the bottom (Favorite and Ingraham, Jr. 1977; Favorite et al. 1977).

for larvae spawned by demersal species inhabiting the area north of Unimak Island. Pruter (1973), too, recognizes the major role that gyres play in creating stable conditions which favor development of fish populations in the Bering Sea.

The hydrography of the North Pacific is variable and extremely complex. Due to the prevailing ocean currents, there is probably drift of Pacific ocean perch larvae from one region to another. However, it is currently impossible to quantify the magnitude of this drift because of inadequate sampling and the problems associated with identifying rockfish larvae to species. This study will assume that the interchange of Pacific ocean perch larvae among the major regions is minor and that the the transformation to the benthic stage occurs inshore near the spawning areas.

The length of time the larvae remain planktonic has been a point of contention in the literature. Several authors have speculated that young S. alutus remain pelagic until their second or third year of life (Alverson and Westrheim 1961; Lyubimova 1964, 1965; Paraketsov 1963; Syntko 1971). One author even contends that Pacific ocean perch do not shift their habitat to the bottom of the sea until they reach 3 to 5 years of age (Chikuni 1975). These authors based their conclusion primarily on back-calculated growth rates and not on confirmed observations of S. alutus larvae and juveniles. Moreover, no one has yet confirmed the existence of juvenile Pacific ocean perch in offshore open water by collecting free-swimming specimens there (Carlson and Haight 1976).

Carlson and Haight (1976) reject the hypothesis of an early pelagic existence of greater than 2-3 years. They show that some juveniles become demersal during their first year of life. Their conclusion was based on a comprehensive study of the environment, growth, food habits, and schooling behavior of juveniles from coastal waters of southeastern Alaska. With this information they constructed the following scenario of the early life history of Pacific ocean perch:

> "The larvae are released in spring and ascend to upper layers of the water where they become part of the plankton. Drifting with the currents, they feed first on the smallest zooplankters. In a matter of several weeks -- by early summer -- they assume the adult form and by fall take up a demersal existence in subtidal shallows inshore, locating over the roughest, most broken, often vertical substrate where shelter and intricate cover are most extensive. The young fish spend their first fall and winter months here and move deeper in spring. In their second summer (age I+) we know that at least some have taken up residence in a fiord and believe that others are along the coast in a similar environment, where they remain through their third summer (age II+). By the following spring, when the perch are age III, we believe that ours leave, presumbaly to take up residence with juvenile ages III-V in another location where they remain for another 2 to 3 years. At around age VI they obtain maturity and most join adult stocks offshore."

More recent work by Calson and Straty (1981) strongly supports these findings. The above scenario is assumed to reflect the early life history of Pacific ocean perch within the study area.

Age and Growth

Age and growth of Pacific ocean perch has been examined for stocks in the northeast Pacific (Lyubimova 1964; Alverson and Westrheim 1961; Chikuni 1970a, 1971, 1975; Westrheim 1958, 1970, 1973; Gunderson 1974; Beamish 1979; Golden et al. 1980) and Bering Sea (Moiseev and Paraketsov 1961; Gritsenko 1963; Paraketsov 1963; Chikuni 1968a, b, 1975; Chikuni and Wakabayashi 1970; Pautov 1972). A prevalent conclusion reached by these studies is that Pacific ocean perch are long lived and slow growing.

The age of S. alutus is determined by identifying annular growth rings on scales or otoliths. Chikuni and Wakabayashi (1970) and Chikuni (1975) considered scales to be the most appropriate structure for age determination. Westrheim (1958) examined otoliths, opercular bones, and maxillary bones and concluded that scales were the best material for aging. He noted, however, the difficulty in detecting scale annuli beyond the 12th ring. Gritsenko (1963) also noted the same sort of difficulty when reading Pacific ocean perch scales collected from the Bering Sea. Westrheim (1973) selected otoliths as the preferred age indicator. He indicated that surface readings of otoliths were readable to an older age than were scales, and were easier to collect and process. Beamish (1979) showed that specially prepared, thin sections from some otoliths bear many more annuli than those detected from surface readings of the whole otolith.

Age determination from scales and surfaces of otoliths indicate that the longevity of Pacific ocean perch is 25-30 years (Alverson and Westrheim 1961; Chikuni 1975; Westrheim 1973). However, Beamish (1979) contends that this species may live to be older than 70 years. He demonstrated that ages determined from surfaces of otoliths were similar up to a section age of 22-24 years, but beyond that point the section method yielded much higher ages than the surface method. At this time there is no direct evidence to conclusively validate the ages determined from scales or otoliths. No method currently exists to verify that all zones identified as annuli form once a year. Because of problems in age determination of older fish, all fish 25 and older were pooled in a single age category.

Growth analyses of Pacific ocean perch are complicated by age determination difficulties, and by bathymetric and geographic variations in the age-length relationships (Westrheim 1973). Rapid changes in the population structure and abundance, due to heavy exploitation, have undoubtedly confounded the analyses of growth. Nevertheless, some general conclusions can be reached concerning the growth of this species.

Westrheim (1973) suggests that differential growth occurs between sexes in the Gulf of Alaska, and Pautov (1972) reported a similar situation in the Bering Sea. Females supposedly grow to a slightly larger size than males. On the other hand, Gritsenko (1963), Lyubimova (1965), and Chikuni (1975) found no differences in growth patterns between males and females within the Gulf of Alaska and Bering Sea. The current study assumes that differences in growth between sexes are negligible.

Geographic differences in the growth of Pacific ocean perch have been described by several workers. Westrheim (1973) noted that mean length per age generally declined northward and westward in the northeast Pacific. Similarly, Westrheim and Syntko (1974) concluded that weight per given length increased eastward and southward from the Aleutian Islands area to the Washington-Oregon area. He also mentioned that Bering Sea S. alutus generally weigh more per given length than those in adjacent Aleutian and Unimak areas. Chikuni (1975), too, illustrated regional differences in the age-length, age-weight, and weight-length relationships for Pacific ocean perch from the North Pacific (Figure 5).

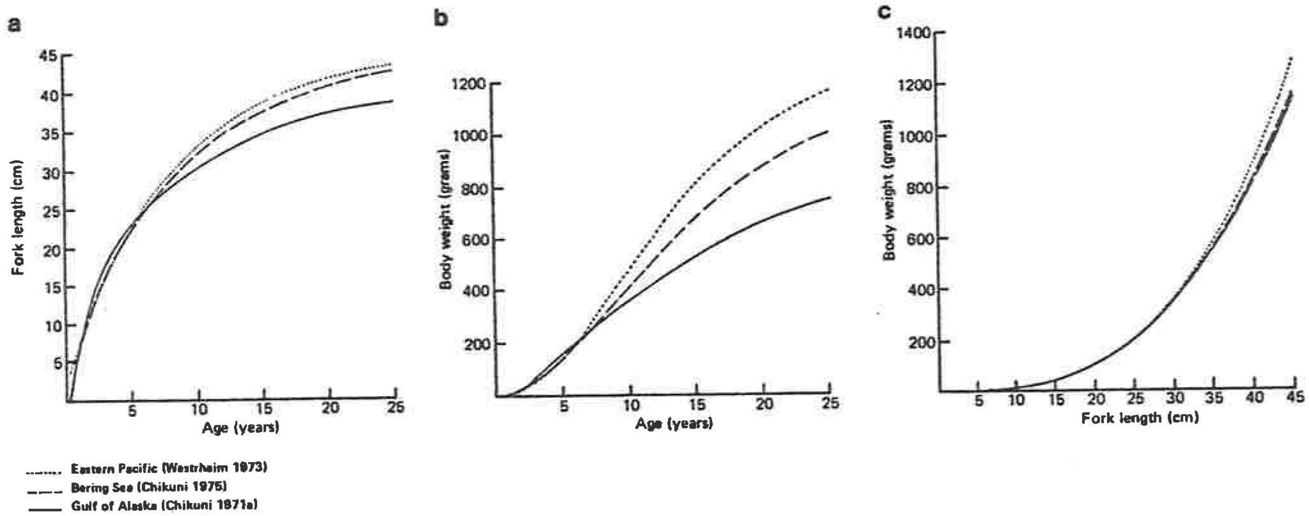

Figure 5. Comparison of (a) age-length, (b) age-weight, and (c) weight-length relationships among regions in the North Pacific (adapted from Chikuni 1975).

Description of the Fishery

Vessels and Gear

Japan and the Soviet Union have been the principal nations exploiting the Bering Sea and Gulf of Alaska Pacific ocean perch stocks. Both nations employ distant-water trawlers of varying sizes and designs as their primary method of harvest. Many of the smaller vessels function as catcher boats for the large motherships (factoryships); whereas, the larger trawlers generally operate independently by processing and freezing their own catch. Use of support vessels, which permit the fishing fleets to operate at sea for extended periods of time, is common.

Most of the Pacific ocean perch catch is headed, eviscerated, and quick frozen. It is used primarily for direct human consumption.

a) Japan

The Japanese fishery for Pacific ocean perch can be organized into three major categories; the landbased ("hokutensen") fleet, the mothership fleet, and the North Pacific trawl fleet. These fleets are controlled by the Japanese government in such a way as to minimize internal discord among her fishermen. Through a system of licensing, limitations on entry, and resource allocation, Japan has created an extremely diversified fishing industry (Kasahara 1972).

The landbased trawl fishery is conducted by independent trawlers of 100-350 gross registered tons (GRT). By Japanese regulation, these vessels are not permitted to transship their catch in offshore waters (Forrester et al. 1978); they must return to Japan when their fish holds are full. Vessels of this fleet are further restricted to waters north of latitude 48 degrees N and west of longitude 170 degrees W. Much of the fleet operates along the continental slope from north of the Kuril Islands to Cape Navarin. Fishing also occurs along the Pribilof and Aleutian Islands. Although the number of vessels licensed to operate in this fishery since 1969 has been 182, only 62 vessels operated in the U.S. fishery conservation zone in 1977 (Bakkala et al. 1979). During the earlier years, the principal gear type was the Danish seine; stern trawlers are now the mainstay of this fleet.

A portion of the Japanese Pacific ocean perch catch from the Bering Sea is taken by the mothership type fishery. This fishery employs large factoryships to receive and process catches supplied by a fleet of catcher vessels. Catcher vessels in this fleet have operated a number of gear types, including longlines, gillnets, stern trawls, pair trawls, side trawls, and Danish seines. Pacific ocean perch catches by longlines and gillnets are usually incidental and insignificant.

The mothership fleets operate mainly along the continental slope of the eastern Bering Sea and along both sides of the Aleutian Islands. Most of the trawl effort during the early 1960's was directed towards yellowfin sole (Limanda aspera) and Pacific ocean perch. With the development of techniques for processing minced fish (surimi) on board motherships in 1964, considerable effort shifted to pollock (Theragra chalcogramma), a species most suited to this type of processing (Forrester et al. 1978).

The Japanese North Pacific trawl fishery generally consists of large factory stern trawlers that operate independently of motherships. These vessels range in size from 349-5,700 GRT and customarily fish and process their own catch. Much of the effort is directed toward Pacific ocean perch and other rockfishes in the Gulf of Alaska and Aleutian Islands and toward pollock in the eastern Bering Sea. Since 1967 the Japanese government has licensed this fleet for fishing in both the Bering Sea and Gulf of Alaska (Kasahara 1972). Vessels in the landbased and mothership fleets, on the other hand, are restricted to Bering Sea waters only.

b) Soviet Union

The Soviet Union utilizes the flotilla concept in its fishing operations. This involves the deployment of several kinds of vessels in support of its catcher fleet. Support vessels typically include factoryships for receiving and processing catches, refrigerator transports to replenish stores aboard catcher vessels and to receive, freeze, and transport catches to the homeland, oil tankers, personnel transports, tugs, patrol vessels, and hospital ships (Pruter 1976). These vessels, particularly the large refrigerator transports, have enabled the Soviet fleet to locate and fish productive Pacific ocean perch grounds year round and process tremendous quantities of catch.

The Soviets have employed two basic types of vessels in their fishing operations -- side trawlers and stern trawlers (Table 1). Side trawlers of the SRT class were the prevalent fishing vessel during the early years of this nation's Pacific ocean perch fishery. These relatively small vessels lacked processing and refrigerating capabilities making them highly dependent on factoryships. The newer, larger side trawlers of the SRTR and SRTM class were equipped with freezing capacity; thus allowing them to process and freeze their own catches.

Three classes of stern trawlers have engaged in the Soviet Pacific ocean perch fishery. The smallest of the three, the SRTKs, are basically SRTMs but redesigned with a ramp at the stern for efficient deployment and retrieval of the trawl. The remaining two classes are the large factory stern trawlers of the BMRT and RTM class. These vessels

Table 1. Basic types of fishing vessels employed by the Soviet Union in the groundfish fisheries off Alaska (from Bakkala et al. 1979).

Vessel type	Gross tons	Length (m)	No. in crew	Descriptive remarks
SRT	265-335	36	22-26	Small side trawler of older type
SRTR	505-630	52	26-28	Medium side trawler -- usually transships catch to factoryship but may operate independently and process and freeze own catch
SRTM	700	54	30	Large side trawler -- frequently operates independent of factoryships and processes and freezes own catch
SRTK	775	--	--	New class of trawler equipped with stern ramp for more efficient trawling
BMRT	3,170	85	90	Factory trawler which normally processes and freezes own catch
RTM	2,657	82	--	Newer type of factory trawler having increased deck area aft for more efficient handling of gear and catch

have tremendous processing capabilities and freezing capacity which enables them to operate for long periods as independent units.

The Soviet Union has phased out the use of side trawlers in favor of the more efficient factory stern trawlers. Because of their larger size and more efficient layout for handling the trawl over the stern, the factory stern trawler is more versatile and better able to fish under worse weather conditions than a side trawler (Pruter 1976).

c) Other Nations

Minor catches of Pacific ocean perch from the Bering Sea and Gulf of Alaska have been taken by Poland, Republic of Korea, Taiwan, Canada, and the United States. These catches were taken primarily by stern trawlers. Stern trawlers in the Polish fleet are similar in size and configuration to their Soviet counterparts, ranging in length from 70 to 90 m and weighing 2,300-2,500 GRT (Wall et al. 1981). In 1977 and 1978, trawlers of the Korean fleet were comparable in size and design to the large Japanese freezer trawlers; Taiwanese trawlers ranged in size from 900 to 1,900 GRT (Nelson et al. 1981). Canadian and United Stated trawlers are considerably smaller than trawlers employed by the Asian and European nations.

Fishing Grounds, Seasons, and Depth of Fishing

The Japanese and Soviets have generally conducted trawling operations for Pacific ocean perch in the same areas (Figure 6). Productive areas in the Gulf of Alaska include the Shumagin Island grounds, the Albatross bank off of Kodiak, the Portlock bank south of the Kenai Peninsula, and the trawlable areas off of Yakutat and Southeastern. In the Bering Sea catches are taken along the entire length of the eastern slope region, with the largest catches usually being taken from both sides of the Aleutian Islands.

Pacific ocean perch are caught year round in the Gulf of Alaska and during most of the year in the eastern slope region (Figure 7). Pacific ocean perch catches from both regions are taken by a directed fishery as well as appearing incidentally in other directed fisheries, such as those for pollock, flounders, and Pacific cod. In the Aleutian region most of the 1964 to 1979 Japanese Pacific ocean perch catch was caught during a six month period from April to October (Figure 7).

Depth of fishing varies by season (Figures 8 and 9). This is apparently in response to the annual bathymetric migration of *S. alutus*. Lyubimova (1964) indicated that the most suitable depths for Pacific ocean perch fishing in the Gulf of Alaska were between 180 and 350 m in summer and 250-420 m in winter. Alverson and Westrheim (1961) reported

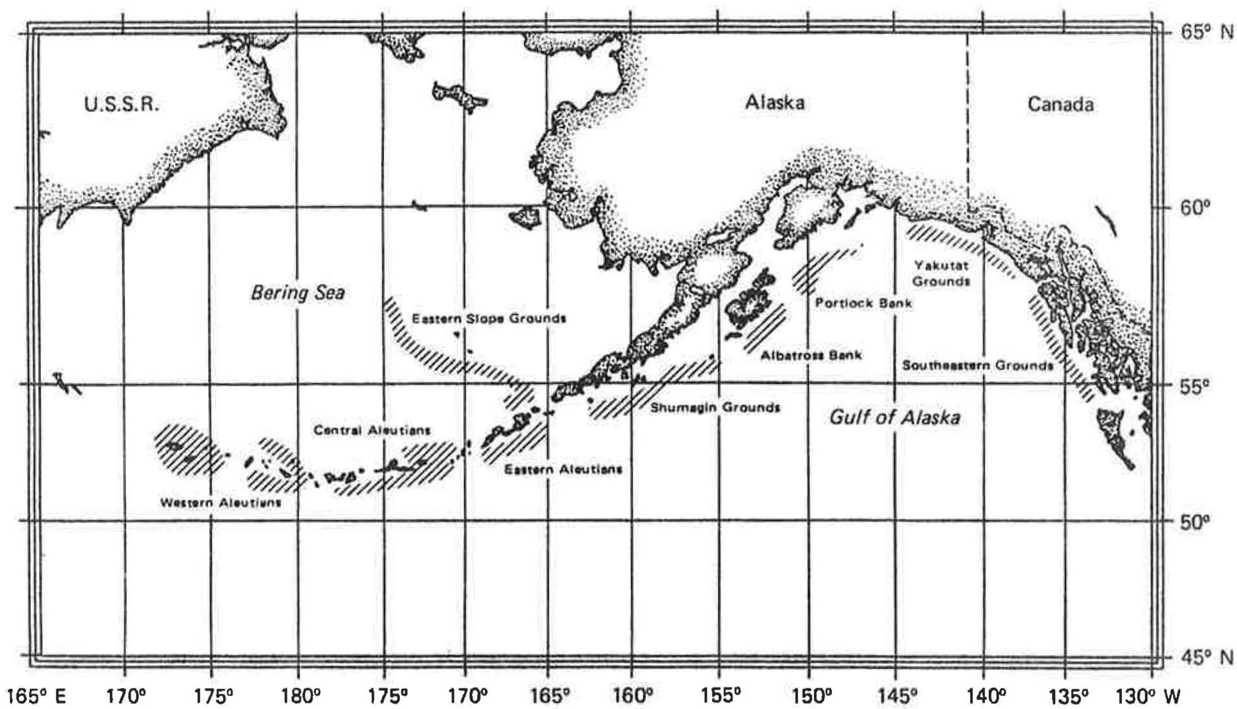

Figure 6. Major fishing areas for Pacific ocean perch within the study area (adapted from Chitwood 1969).

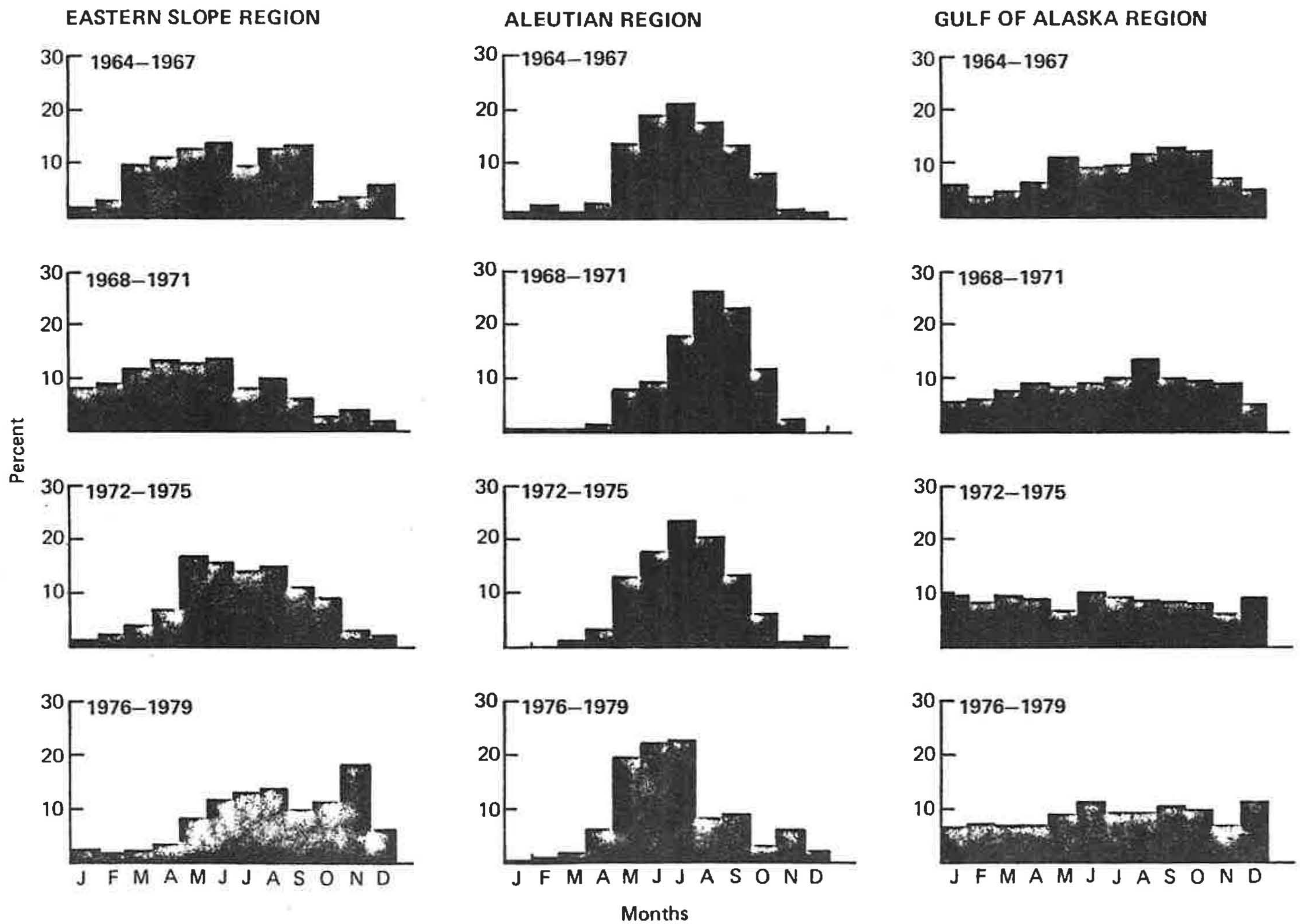

Figure 7. Percent composition of Pacific ocean perch in the total Japanese groundfish catch by study region, by month, and by four year intervals.

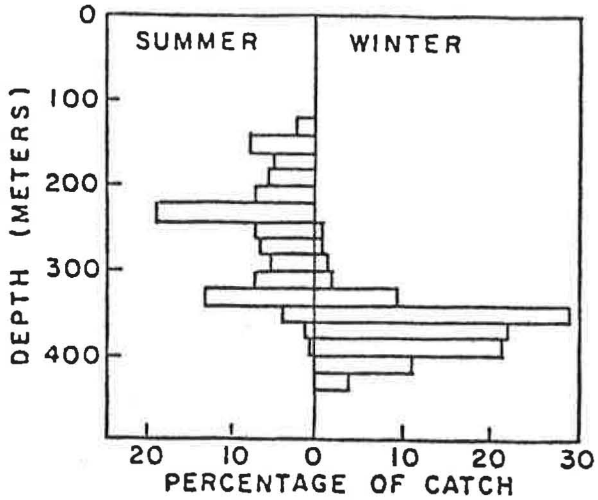

Figure 8. Vertical distribution of Pacific ocean perch taken during summer and winter in the Bering Sea (from Paraketsov, 1963).

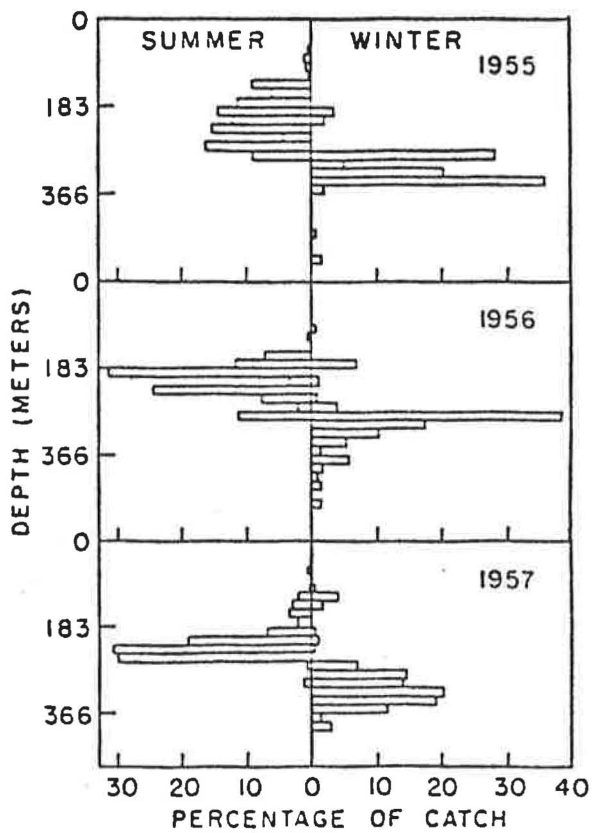

Figure 9. Vertical distribution of Pacific ocean perch taken in summer and winter by the Washington trawl fleet, 1955-57 (from Alverson and Westrheim, 1961).

a similar distribution in the waters off of Washington and Oregon. Paraketsov (1963) noted that S. alutus in the Bering Sea were common at depths of 140 to 360 m during the winter and spring. Chikuni (1975) showed that the bulk of the Japanese Pacific ocean perch catch from the Gulf of Alaska in 1965 was taken at depths between 200-300 m (Figure 10).

Lyubimova (1964) indicated differences in the size of S. alutus caught by depth. The larger adult fish were usually found at deeper depths than were the smaller juveniles. Examination of the size composition data from the Japanese groundfish fishery (Figure 11) tended to corroborate the findings of Lyubimova (op. cit.).

Catch Trends

The foreign fishery for Pacific ocean perch did not begin in earnest until 1960. During the first year the foreign fleets removed 6,100 m.t. of Pacific ocean perch from the eastern slope region (Table 2). By 1962 the fishery had expanded into the Gulf of Alaska and Aleutian Island regions. Growth of this new fishery was rapid. Within just six years of its inception, total removals (all regions combined) peaked with a harvest of 474,100 m.t. Soon after, total removals declined almost as rapidly as they had increased. In 1979 total catches amounted to only 3.3 percent of the 1965 peak catch.

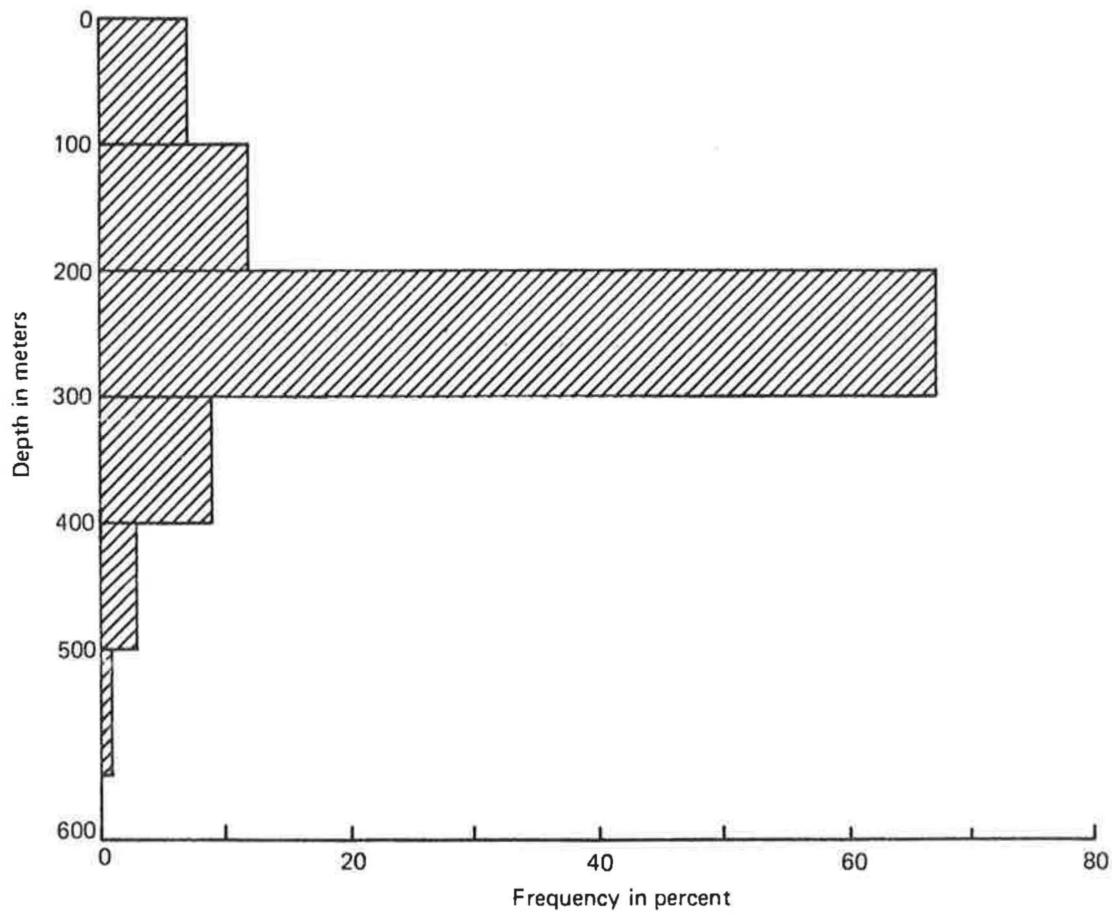

Figure 10. Vertical distribution of the catch of Pacific ocean perch from the Japanese fishery in the Gulf of Alaska in 1965 (from Chikuni 1975).

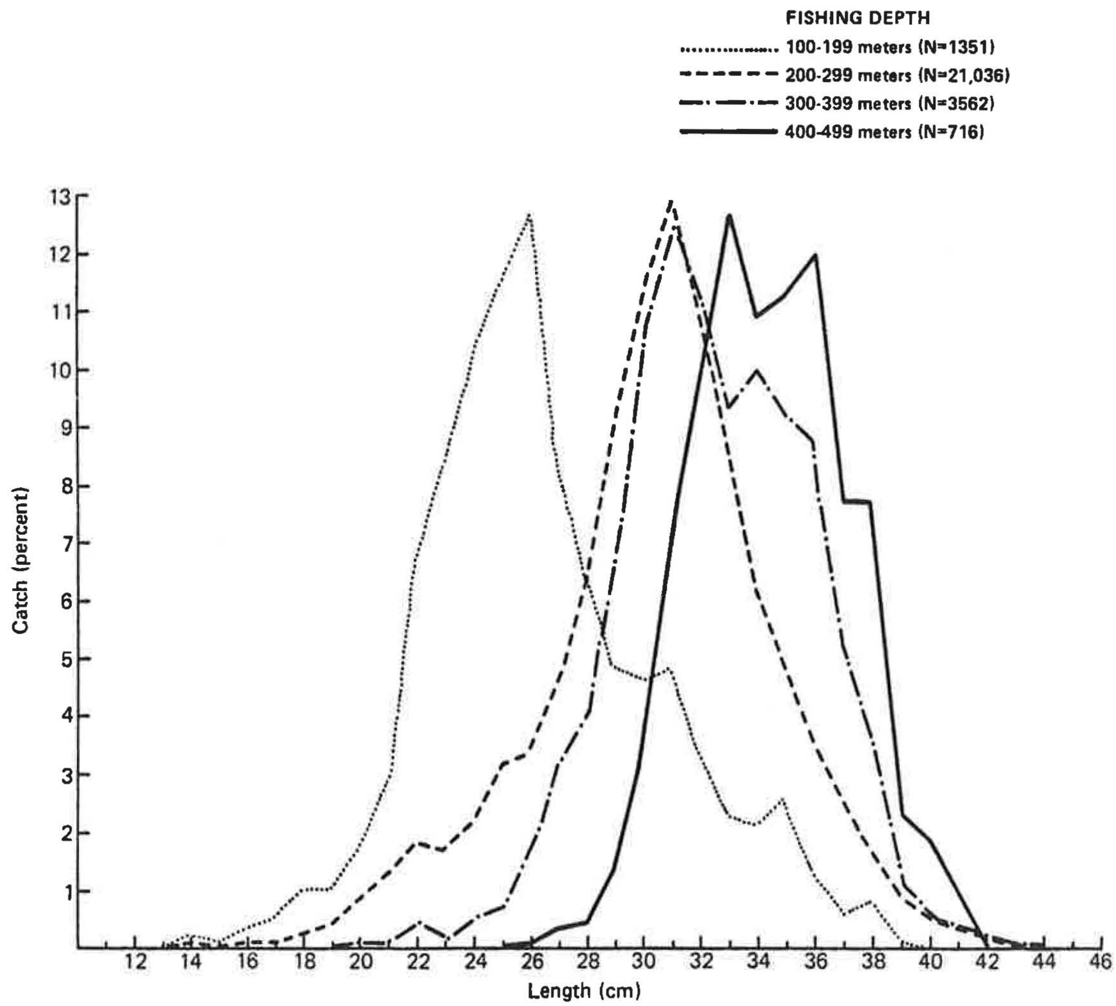

Figure 11. Size composition of Pacific ocean perch by depth from the Japanese Gulf of Alaska groundfish fishery in 1965.

Table 2. Estimated catch (x 1,000 mt) of Pacific ocean perch by nation and by region, 1960-79.

YEAR	JAPAN				U.S.S.R. 1/				OTHERS 1/2/				TOTAL			
	Eastern Slope	Aleutian	Gulf of AK	Total	Eastern Slope	Aleutian	Gulf of AK	Total	Eastern Slope	Aleutian	Gulf of AK	Total	Eastern Slope	Aleutian	Gulf of AK	Total
1960	1.1	-	-	1.1	5.0	-	-	5.0	-	-	-	-	6.1	-	-	6.1
1961	13.0	-	-	13.0	34.0	-	16.0	50.0	-	-	-	-	47.0	-	16.0	63.0
1962	12.9	0.2	-	13.1	7.0	-	65.0	72.0	-	-	-	-	19.9	0.2	65.0	85.1
1963	17.5	0.8	6.3	24.6	7.0	20.0	130.0	157.0	-	-	-	-	24.5	20.8	136.3	181.6
1964	13.6	29.2	13.4	56.2	11.5	61.0	230.0	302.5	-	-	-	-	25.1	90.2	243.4	358.7
1965	8.5	37.0	42.6	88.1	9.0	71.0	306.0	386.0	-	-	-	-	17.5	108.0	348.6	474.1
1966	16.5	32.4	65.0	113.9	2.7	57.7	135.8	196.2	-	-	-	-	19.2	90.1	200.8	310.1
1967	20.8	14.1	53.5	88.4	Tr 4/	46.6	66.5	113.1	-	-	-	-	20.8	60.7	120.0	201.5
1968	24.4	23.7	55.0	103.1	3.1	26.6	45.2	74.9	-	-	-	-	27.5	50.3	100.2	178.0
1969	15.0	15.6	53.6	84.2	Tr 4/	23.2	18.8	42.0	-	-	0.2	0.2	15.0	38.8	72.6	126.4
1970	8.7	13.6	44.4	66.7	Tr 4/	53.3	Tr 4/	53.3	-	-	0.5	0.5	8.7	66.9	44.9	120.5
1971	9.0	14.6	47.8	71.4	Tr 4/	7.2	29.7	36.9	-	-	-	-	9.0	21.8	77.5	108.3
1972	4.8	8.6	50.6	64.0	0.2	24.6	24.0	48.8	-	-	3.0	3.0	5.0	33.2	77.6	115.8
1973	2.6	9.4	47.4	59.4	1.0	2.5	5.6	9.1	-	-	3.4	3.4	3.6	11.9	56.4	71.9
1974	6.0	21.7	37.0	64.7	7.4	0.8	11.0	19.2	-	-	3.0	3.0	13.4	22.5	51.0	86.9
1975	3.4	9.4	34.1	46.9	5.4	8.1	13.3 3/	26.8	Tr 4/	Tr 4/	3.0	3.0	8.8	17.5	50.4	76.7
1976	2.6	10.8	35.4	48.8	12.1	3.7	8.5 3/	24.3	0.6	Tr 4/	1.6	2.2	15.3	14.5	45.5	75.3
1977	2.9	5.7	19.2	27.8	0.1	0.8	1.8	2.7	0.5	0.1	0.6	1.2	3.5	6.6	21.6	31.7
1978	2.0	4.8	3.9	10.7	Tr 4/	0.2	0.6	0.8	0.4	0.2	3.5	4.1	2.4	5.2	8.0	15.6
1979	1.7	5.3	6.5	13.5	Tr 4/	Tr 4/	0.8	0.8	0.2	0.2	0.8	1.2	1.9	5.5	8.1	15.5

1/ May include some amounts of rockfishes, Sebastes spp., other than Pacific ocean perch
2/ "Others" contains catches from Republic of Korea, Taiwan, Poland, U.S., and Canada
3/ From INPFC Doc. 2072. Provided by All-Union Research Institute of Marine Fisheries and Oceanography (VNIRO), Moscow
4/ TR: trace less than 50 mt

Pacific ocean perch harvests from the Gulf of Alaska have generally been greater than those taken from the Aleutian and eastern slope regions (Figure 12). These catch trends indicate the relative stock size in each of the three regions. It appears that the Gulf of Alaska contains the largest stock; the Aleutian region the next largest. Pacific ocean perch in the eastern slope region apparently comprise the least abundant stock.

Maximum sustainable yield (MSY) has been estimated at 150,000 m.t. for the Gulf of Alaska stock; 75,000 m.t. for the Aleutian stock; and 32,000 m.t. for the eastern slope stock (Chikuni 1975). Clearly, sustained exploitation of the magnitude characterizing the early years of the fishery was not possible (Table 2). Low (1974) estimated MSY for the eastern slope and Aleutian stocks combined at 12,000-17,000 m.t.

Prior to 1968 the annual Soviet Pacific ocean perch catches (all regions combined) always exceeded those taken by Japan (Figure 13). The Soviet catches reached a peak in 1965 with a harvest of 386,000 m.t.; thereafter, the catches declined precipitously to their current low levels. Japan's peak harvest occurred in 1966. Unlike the Soviet catch trend, however, catches by Japan were more uniform.

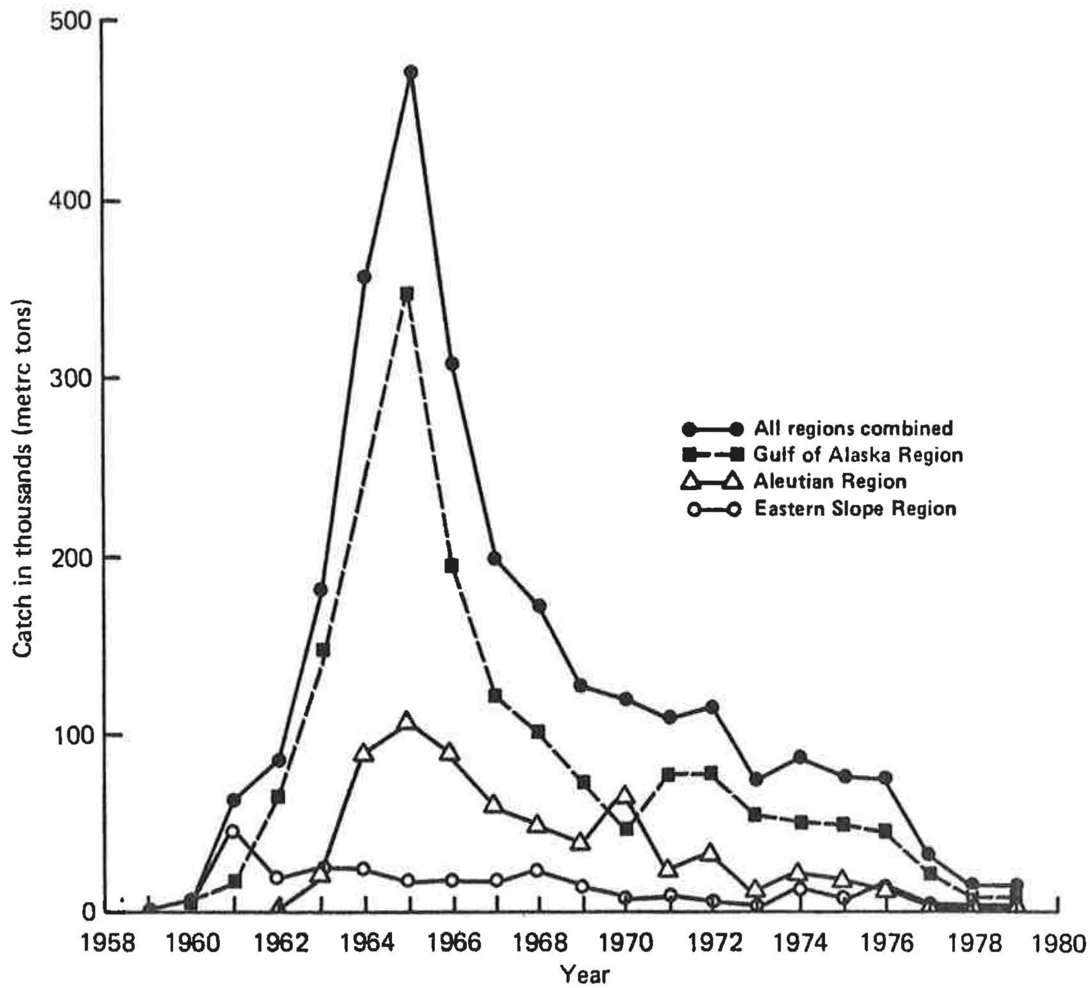

Figure 12. Catch trends of Pacific ocean perch by region, 1960-79.

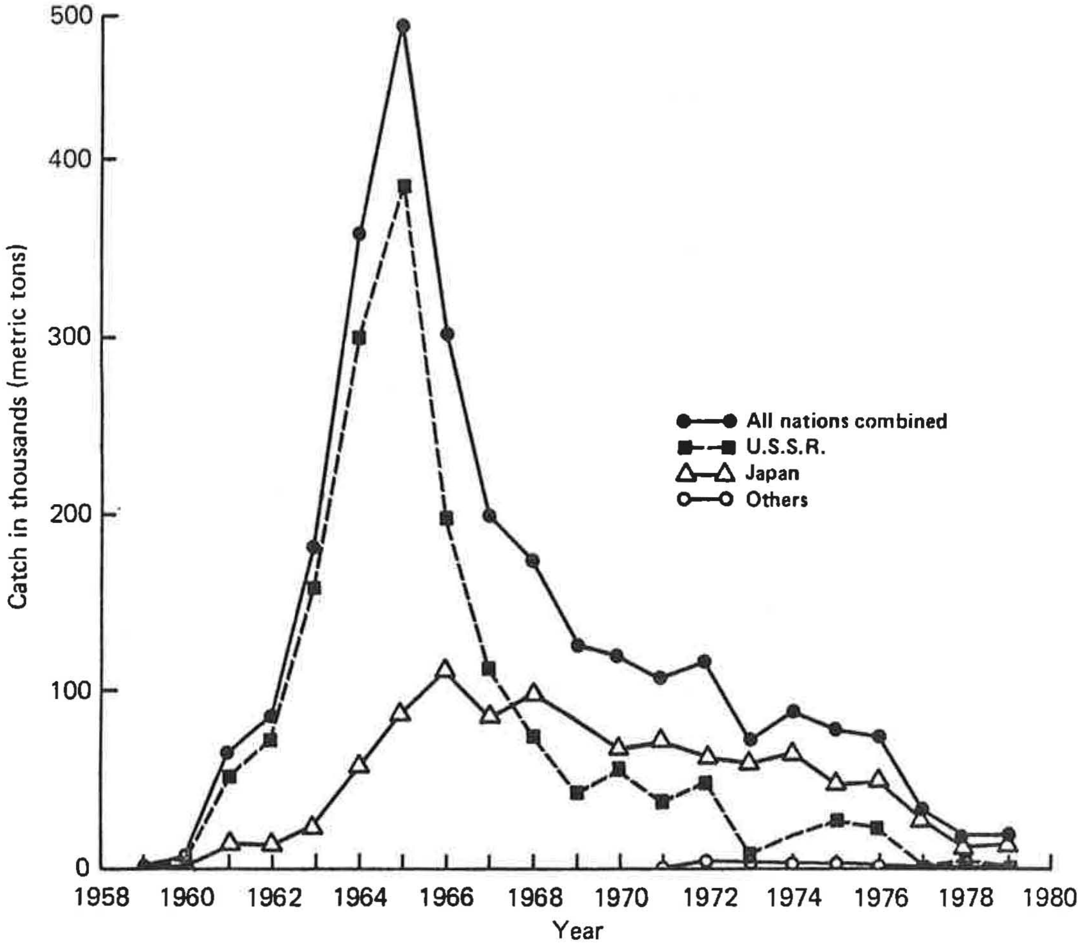

Figure 13. Catch trends of Pacific ocean perch by nation, all regions combined, 1960-79.

The Soviet Union is a classic example of a nation employing a pulse type fishing strategy. This strategy involves directing massive fishing effort on local stocks until production declines to low levels. Effort is then switched to other stocks or to different target species. In the case of the Soviet perch fishery, pulsing is evident in all three regions (Figure 14). Japan's catches, on the other hand, show a more stable catch trend.

The percent composition of Pacific ocean perch in the Japanese groundfish catch has declined throughout the years (Figure 15). In the Aleutian and Gulf of Alaska regions, this decline was probably due to a combination of decreasing stock abundance and a shift to different target species. After 1972, Pacific ocean perch never comprised more than 50 percent of the total groundfish catch from any region. Pacific ocean perch in the eastern slope region is obviously not a major target species in the Japanese groundfish fishery; percent composition of Pacific ocean perch from this region has never exceeded 9 percent.

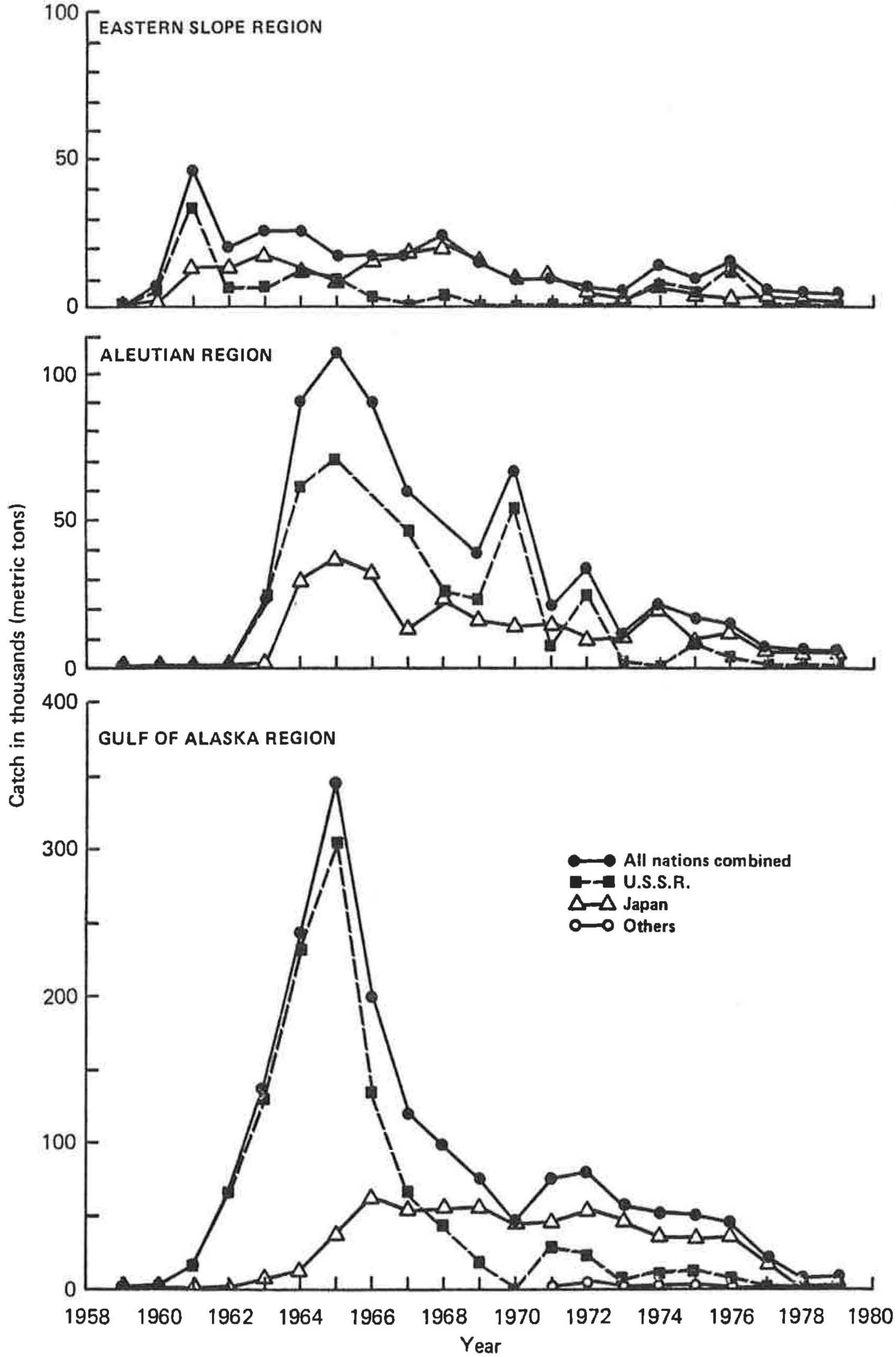

Figure 14. Catch trends of Pacific ocean perch by region and by nation, 1960-79.

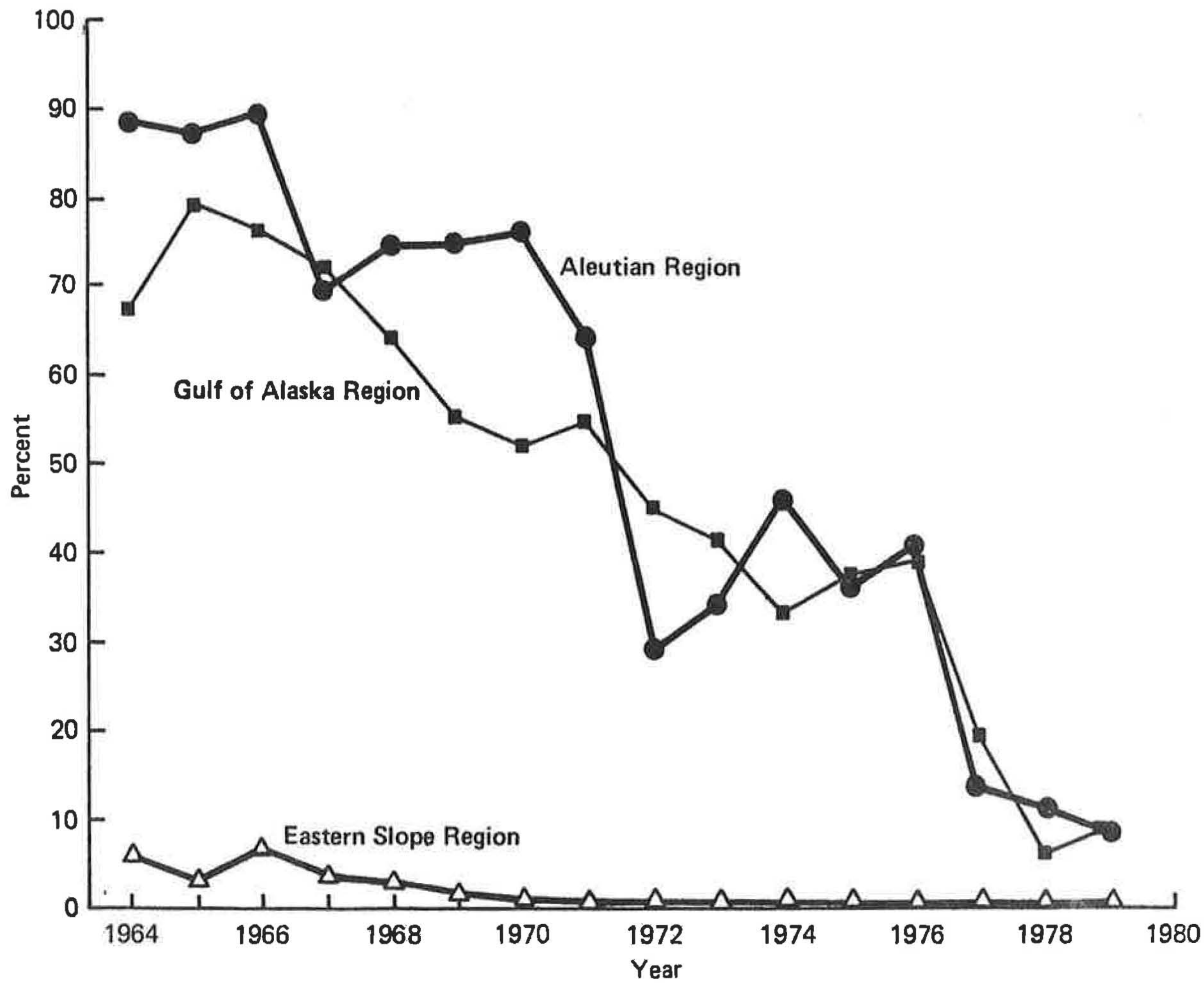

Figure 15. Percent composition of Pacific ocean perch in the total Japanese groundfish catch, by region, 1960-79.

STUDY AREA AND STOCKS INVOLVED

Description of the Study Area

This study deals with the Pacific ocean perch stocks from the Bering Sea and Gulf of Alaska (Figure 1). The Bering Sea, as referred to in this study, is composed of two major components -- the eastern slope and Aleutian Island regions. The Gulf of Alaska region encompasses the area from Dixon Entrance westward to 170 degrees W longitude. This region is further divided into four areas; the western (170 degrees W - 159 degrees W), northwestern (159 degrees W - 147 degrees W), northeastern (147 degrees W - 137 degrees W), and eastern (137 degrees W - 54 degrees 30 minutes N) Gulf. The above areal divisions are similar to those employed by Chikuni (1975).

Bering Sea

The Bering Sea encompasses a surface area of roughly 2,300,000 km squared and has an expansive continental shelf of about 1,200,000 km squared (Hood and Calder 1981). This vast area is extremely productive biologically and supports some of the world's largest fish, crab, bird, and marine mammal populations. The causal mechanisms responsible for this high productivity, however, are not yet fully understood.

Surface currents over the continental shelf are usually northerly during the summer but shift to a westerly or southwesterly direction in winter (Bakkala et al. 1979). These currents appear to be strongly influenced by large tidal cycles and by influxes of Pacific Ocean water entering along the Aleutian Archipelago. Gyral currents are common (Natarov 1963; Pruter 1973). They appear to play a major role in creating stable conditions which favor development of fish and shellfish populations within the eastern slope and Aleutian regions. In general, water circulation in the Bering Sea is cyclonic.

Seasonal ice cover within the Bering Sea plays a significant role in the distribution of fish and fishing. The annual occurrence of pack ice often closes many fishing grounds. It also causes extensive offshore movements of groundfish to deeper, warmer waters of the outer continental shelf and slope (Bakkala et al. 1979). Maximum ice coverage usually occurs in March or April (Fay 1974), when it covers most of the surface, except in areas around the southern portion of the deep sea Aleutian Basin, the western Alaska Peninsula, and the Aleutian Island region. The ice begins to retreat about April or May, and by early summer the Bering Sea is usually ice free (Bakkala et al. 1979).

The continental shelf of the eastern Bering Sea is expansive. It is remarkably smooth, with a gentle gradient resulting from sediment deposits from coastal riverine systems (Sharma 1974). By contrast, the continental slope is relatively steep and scored with valleys and large submarine canyons. Within the eastern slope region, the continental slope extends from Cape Navarin to Unimak Island in a southeasterly direction.

The Aleutian region comprises a chain of islands which form a saucer-shaped arc along the southern portion of the Aleutian Basin. These islands act as a partial barrier to the exchange of Pacific Ocean water. Bays and inlets of the fiord type are common to these islands. Between islands, the continental shelf is narrow and frequently discontinuous.

The continental slope, like that of the eastern Bering Sea, is characterized by numerous scarps, crests, and submarine valleys and canyons. Trawling in this region is often difficult because of rocky outcrops on the crests and slopes of submarine valleys and on other steep portions of the continental slope (Gershanovich 1963).

Detailed descriptions of Bering Sea oceanography can be found in Hood and Kelley (1974), and in Hood and Calder (1981).

Gulf of Alaska

The Gulf of Alaska is one of the largest and deepest bays in the world. Principal bays and inlets include Cook Inlet and Yakutat Bay. Among the larger islands within the region are Kodiak, Montague, Chichagof, Baranof, and Prince of Wales islands. Fiord coasts along the mainland and islands are common.

Compared to the eastern Bering Sea, the continental shelf of the Gulf is fairly narrow. It is widest in the northwest vicinity of Kodiak Island and narrows considerably northeastward along the coast. The bottom relief of the shelf is characterized by numerous canyons and depressions. Banks and shoals are also frequent in many parts of the shelf. Seavalleys are characteristic of the continental slope. Some of these valleys are extemely wide and bite deeply into the slope. Bottom sediments on both the shelf and slope range in size from boulder and pebble to clayey mud and silt. Further details of the bathymetry and other features of the submarine geology in the Gulf of Alaska can be found in Menard and Dietz (1951) and Gershanovich et al. (1964).

Gershanovich et al. (1964) point out that most shelf areas less than 80-100 m deep are almost completely unsuited for trawling. Such areas are characterized by numerous bedrock outcrops, residual erosion-resistant rocks, and boulder and rock fragments. Trawling in these areas frequently leads to snagged or torn nets. Gershanovich (op. cit.) further contends that, on the whole, fishing grounds of the continental slope are more suitable for trawling than on the shelf.

Surface conditions in the Gulf of Alaska are primarily associated with the Subarctic Current (Figure 16). This

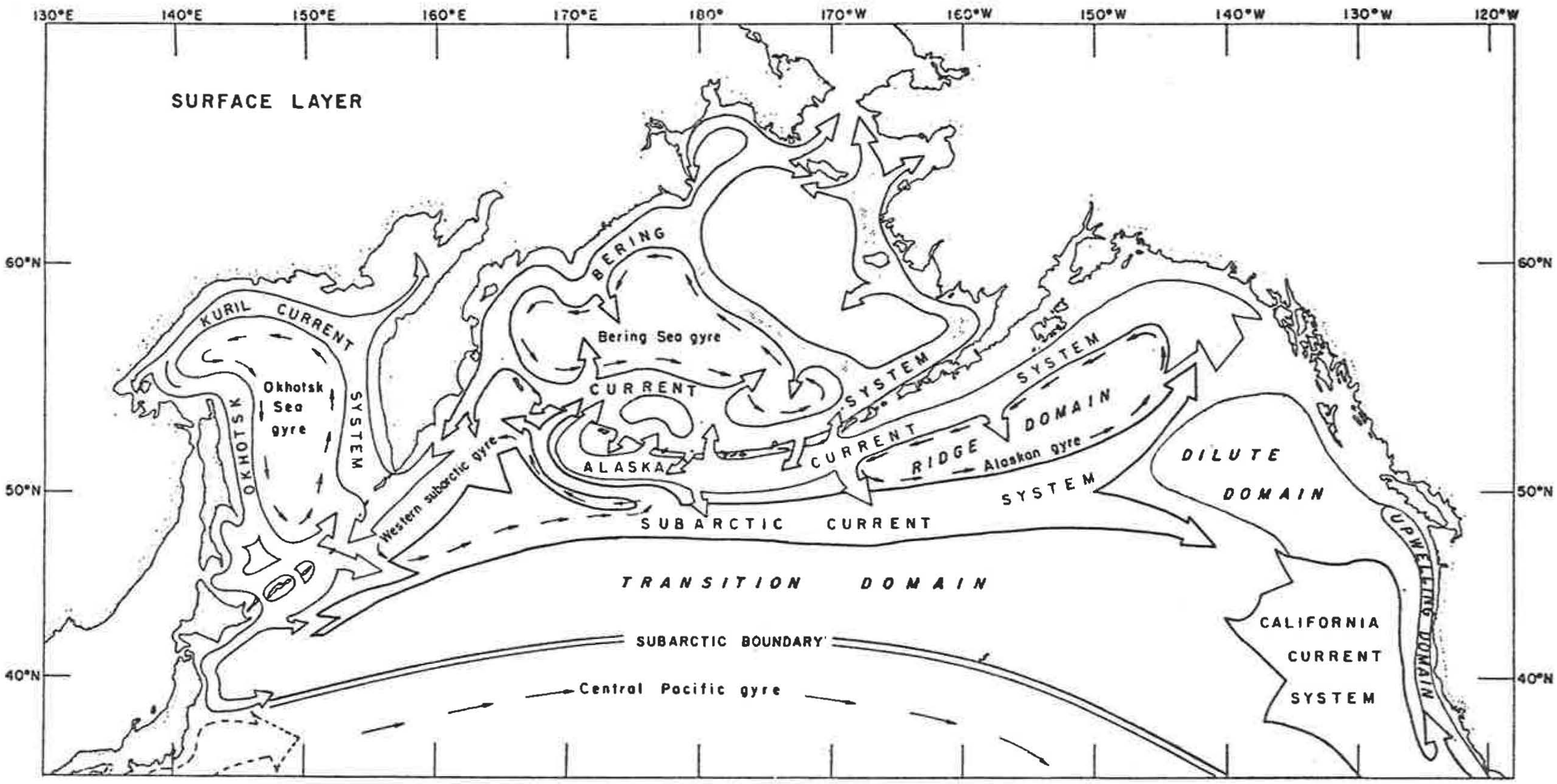

Figure 16. Major surface currents in the North Pacific Ocean (from Favorite et al. 1976).

current flows eastward from the Kuril Islands and then diverges off the coast of the North American Continent. The upper branch turns northeast into the Gulf of Alaska and merges with the Alaska Current System. Favorite et al. (1976) characterize this system as consisting of the Alaska Current (Figure 16), and its major branch, the Alaskan Stream. Associated with this system is a southerly flow into the Gulf of Alaska, the Aleutian Current; four major surface flows into the Bering Sea (Amukta, Amchitka, Buildir, and Near Currents), and a subsurface flow into the Bering Sea, the Alaskan Stream Undercurrent. Also of major importance, in terms of water circulation, is the presence of the large Alaskan Gyre which forms between the Subarctic and Alaskan Current Systems.

This study's description of the water movement in the Bering Sea and Gulf of Alaska is an oversimplification. Currents in the North Pacific are variable and extremely complex. They differ by depth, season, and region, and are effected by processes such as wind, salinity, temperature, and adverse environmental perturbations. It is beyond the scope of this paper to describe these processes in detail. A thorough description of the hydrography of the study area can be found in Dodimead et al. (1963), Favorite et al. (1976), and Favorite et al. (1977).

Stocks Involved

Westrheim (1970, 1973, 1974) concluded that Pacific ocean perch in the North Pacific form discrete stock units. He distinguished Gulf of Alaska and British Columbia stocks, with Dixon Entrance as the mutual boundary. He also presented data suggesting that Bering Sea stocks of Pacific ocean perch are separate from those in adjacent Aleutian and Gulf of Alaska regions. His conclusions were based on traditional stock differentiation data; regional differences in size distribution, weight-length and age-length relationships, and year-class strengths were observed. Similarly, Chikuni (1975) identified three main stocks within the current study area; the eastern slope, Aleutian, and Gulf of Alaska stocks. Although Chikuni believed that these stocks mix to some extent during the early life history stage, variations in growth rate, size and age composition, length-weight, age-length, and length-fecundity relationships suggest distinct stocks.

Biochemical genetic analyses have been employed by several workers in an attempt to identify Pacific ocean perch stocks. Utilizing electrophoretic techniques, Wishard et al. (1980) identified an eastern Pacific stock (existing off Washington and Oregon), a Gulf of Alaska stock, and a stock tentatively identified off Prince William Sound. These workers, however, did not sample the entire range of

Pacific ocean perch commercial abundance. The Aleutian and Bering Sea areas were not sampled, and no samples were taken from the zone of contact between the Gulf of Alaska and Washington coasts. Without this area of contact, samples along a continuum may appear as discrete groups (Wishard and Gunderson 1981).

Wishard and Gunderson (1981) electrophoretically examined Pacific ocean perch tissue samples collected from nearly all areas of this species' commercial range. The results indicated that there were significant differences between the extremes of the range, but there appeared to be no sharp boundaries. The electrophoretic evidence suggests that Pacific ocean perch are differentiated along a continuum, and indicate that no interruption of gene flow occurs between the eastern Gulf of Alaska and the Bering Sea through the Aleutian Island chain.

At this time one can only speculate as to the causal mechanisms responsible for the genetically observed Pacific ocean perch clines. One possible hypothesis is that gene flow occurs only during the pelagic larval period, with the direction and amount of flow regulated by the prevailing ocean currents. Although the larval drift from one region to another is assumed to be minor, even small amounts of gene flow are capable of preventing differentiation between populations (Wishard and Gunderson 1981). Apparently the interchange of Pacific ocean perch populations is not large enough to prevent local aggregations from developing different age structures, length relationships, and ages at maturity (Gunderson 1972; Wishard and Gunderson op. cit.).

The author recognizes that local aggregations are probably scattered throughout the study area. For purposes of the current study, however, it is possible to group these aggregations into three broad stocks; the eastern slope, Aleutian, and Gulf of Alaska stocks, the same stocks previously delineated by Chikuni (1975). Although it is apparent that no sharp boundaries exist between the major groupings, differences in population characteristics (fecundity, growth, mortality, etc.) suggest that Pacific ocean perch in each region can be managed as a unit. It is assumed that each region (Figure 1) contains a single stock.

MATERIALS AND METHODS

Data Employed

Annual catch-at-age data are required for a cohort analysis. The data should reflect the true age composition of the catch, and the total landings should account for all fishery removals from the population. Such information is not readily available as a single data base for the Pacific ocean perch fishery. This fishery is multi-national, multi-species, and multi-gear in nature. Some nations provide incomplete catch data and collect insufficient biological data. Consequently, the data for this study had to be derived and extrapolated from a variety of sources.

Data Sources

From 1964 to 1979, Japan provided the International North Pacific Fisheries Commission (INPFC) with annual catch, effort, and size composition data from its Bering Sea and Gulf of Alaska groundfish fisheries. This information is detailed and complete, in temporal and geographic sequence, and is perhaps among the best on demersal fisheries anywhere in the world. The data are reported by year, by month, by species, by gear type, and by vessel size category (since 1968) for each 1 degree longitude by 1/2 degree latitude statistical block. After transmittal through INPFC channels, these data were made available to the author through the Northwest and Alaska Fisheries Center (NWAFC), National Marine Fisheries Service (NMFS).

Catch statistics of the Soviet Union's Pacific ocean perch harvest, prior to 1977, were extracted from published sources. Chikuni's (1975) estimates of the Soviet Union's catches were used in this study for the years 1960-1972. Soviet production statistics published in INPFC documents (Anon. 1978; Okada et al. 1980) were employed for 1973-1976.

Catches of *S. alutus* by nations other than Japan and the Soviet Union were combined under the category of "other nations." The United States, Canada, Poland, Republic of Korea, and Taiwan were included in this group. Production statistics for these nations, prior to 1977, were obtained through INPFC statistical yearbooks and documents.

The Magnuson Fishery Conservation and Management Act (MFCMA) of 1976 requires that foreign nations, which conduct fishing operations within the 200 mile U.S. fishery conservation zone (FCZ), report detailed statistics of their catch and effort. These statistics are reported in a similar fashion to those provided to INPFC by Japan. Information concerning gear type, size of vessel, amount of effort expended, and catch by species is reported by nation, by year, and by month for each 1 degree longitude by 1/2 degree latitude statistical block. Complete statistics in this format are available for the Soviet Union and other nations for the years 1977-79. These data are computerized and are available through NWAFC, NMFS.

Another provision of the MFCMA requires that foreign vessels accept and provide accommodations for U.S. fisheries observers. The purpose of these observers is to collect data which is applied by the United States to estimate the foreign commercial catch, determine incidental catches of prohibited species, provide information needed to assess the biological status of fish stocks, and report on compliance by foreign vessels with U.S. fishing regulations (Nelson et al. 1981). Data collected by observers were made available to the author through NWAFC, NMFS.

Chikuni (1975) estimated the annual age composition of the Japanese Pacific ocean perch catch for each stock from 1963 to 1972. This author also provided corresponding estimates of the size composition and data needed to estimate the average weight per fish in the catch. Estimates of the 1960-72 all nation removals of Pacific ocean perch were provided as well. This information was codified and transferred to computer disk.

An examination was also made of the data collected from NMFS trawl surveys. It was concluded that this data base would not contribute significantly to the cohort analysis. Most of the surveys were not directed towards S. alutus, and much of the trawling was conducted only in the shallower portions of the bathymetric range occupied by Pacific ocean perch. Length and age data were also available from the NMFS surveys, but added little to the data base already available.

Data pertaining to the current study were codified and stored on computer disk and magnetic tape. The information was partitioned into convenient subfiles for easy access, versatility, and economical usage. Storage and analysis of the data was accomplished with the Burroughs 7811 computer housed at the NWAFC.

Modification of Catch Data

The international landings used in this study were derived from the aforementioned data sources. In the case of the Japanese Pacific ocean perch catches, Chikuni's (1975) estimates were employed for the years 1960-1963. Data submitted to INPFC by Japan were used for the years 1964-1979. Only catches taken within the boundaries of each region (Figure 1) were extracted from the data base.

Prior to 1969, Pacific ocean perch catches from the landbased fleet were incorporated into a "rockfish" category. This category not only included Pacific ocean perch, but other rockfish species as well. Because of the need to account for all Pacific ocean perch removals, an attempt was made to estimate the fraction of this species in the pre-1969 landbased rockfish catch.

Landbased catches taken in 1969 and 1970 were used to estimate this fraction. They were the first two years in which the rockfish catches were partitioned into two categories -- Pacific ocean perch and "other rockfish." These catches were summed for both years by region and by category. The proportion of Pacific ocean perch within the 1969-1970 rockfish catch was then determined, and showed that Pacific ocean perch accounted for 65 percent of the total rockfish catch in the eastern slope region, and 85 percent of the catch in the Aleutian region.

Assuming that the resulting proportions are representative of Pacific ocean perch in the pre-1969 landbased rockfish catch, estimates of the Pacific ocean perch catch were obtained.

Catches by the Soviet Union and other nations were derived as previously stated. Every attempt was made to compile the best catch data available. Landings by nation and region are given in Table 2.

Modification of Weight and Age Data

Chikuni (1975) estimated the relative age composition of Pacific ocean perch in the Japanese catch. He also provided the information required to estimate average weight of perch in the catch. This information was available for each stock from 1963 to 1972. Unfortunately, comparable weight and age data were lacking for a four year period from

1973 to 1976. Biological data from the U.S. observer program provided the necessary information for the years 1977 to 1979.

An attempt was made to estimate the average weight of Pacific ocean perch in the Japanese catch for the years of insufficient data (1973 to 1976). First, average lengths and weights were calculated for each stock from the data provided by Chikuni (1975). The average weights were then regressed on the average lengths, assuming a power curve relationship of the form:

$$\overline{W} = \alpha \overline{L}^{\beta}$$

where, $\overline{W}$ = mean weight (kg)
$\overline{L}$ = mean length (cm)
α, β = constants

This relationship was log-linearized to permit the use of linear least squares regression techniques.

The resulting regression equations are given in Table 3. By inserting an estimate of the average length into the appropriate regression equation, an estimate of the average weight could be made. Average lengths for 1973 to 1976 were calculated from the Japanese reported (INPFC) size composition data. These data were then used to estimate the corresponding average weights. Estimates of the average length and weight of ocean perch in each stock are given in Table 4.

Table 3. Length-weight coefficients and calculated average weights (kg) at selected average lengths (cm) for Pacific ocean perch, by region. Based on data from Chikuni (1975).

	Coefficients[a]		Calculated average weight at		
Region	a	b	25 m	35 cm	45 cm
Eastern slope	4.785×10^{-5}	2.626	.2243	.5428	1.0501
Aleutian	4.283×10^{-5}	2.668	.2299	.5641	1.1029
Gulf of Alaska	1.538×10^{-5}	2.960	.2113	.5720	1.2036

a/ For the formula $\overline{W} = a\overline{L}^{b}$, where $\overline{W}$ = average weight (kg)

$\overline{L}$ = average fork length (cm)

Table 4. Estimates of the average length (cm) and weight (kg) of Pacific ocean perch, by region, from the Japanese groundfish fishery 1963-79.[a/]

	Eastern Slope		Aleutian		Gulf of Alaska	
Year	$\bar{L}$	$\bar{W}$	$\bar{L}$	$\bar{W}$	$\bar{L}$	$\bar{W}$
1963	37.645	.70208	--	--	31.667	.42585
1964	35.149	.58427	34.729	.54593	32.101	.44108
1965	33.894	.52200	33.035	.48176	30.978	.40072
1966	34.923	.56932	33.066	.48649	30.504	.37960
1967	34.247	.32846	33.748	.51953	32.868	.47123
1968	34.400	.54811	30.036	.37688	33.554	.50393
1969	29.345	.34500	29.921	.36873	32.782	.46753
1970	33.000	.53607	31.290	.41733	33.523	.50721
1971	29.783	.35991	32.606	.46605	32.532	.46307
1972	29.591	.34985	32.429	.45768	32.572	.46570
1973	35.023	.54392	32.960	.48010	32.017	.43951
1974	30.351	.37346	30.705	.39740	35.294	.58645
1975	29.520	.34720	32.023	.44455	34.616	.55373
1976	27.023	.27528	30.508	.39063	32.820	.47294
1977	36.133	.57061	30.804	.38842	32.728	.36464
1978	34.924	.57366	31.898	.36128	32.981	.34008
1979	35.772	.52746	31.510	.36846	34.910	.41690

a/ Data sources: Length data; 1963-72 Chikuni (1975)
1973-76 INPFC foreign reported
1977-79 U.S. observer program

Weight data; 1963-72 Chikuni (1975)
1977-79 U.S. observer program

Age composition data from the Japanese Pacific ocean perch catches were unavailable by stock for the years 1973 to 1976. Attempts were made to estimate the relative age composition for the years of insufficient data.

The age distributions used prior to 1973 were estimated by Chikuni (1975); an iterative age-length method was employed to obtain these estimates. Although the resulting age compositions were assumed to be correct, the technique used by Chikuni was not clearly defined. The procedures and assumptions were not understood well enough by the current author to warrant attempting this method on the 1973-76 Pacific ocean perch length data.

In the past when age composition data were unavailable for a period of years, the common practice was to apply an age-length key from some other period. However, Kimura (1977) and Westrheim and Ricker (1978) point out that such a practice invariably leads to biased estimates when there is substantial overlap in size between successive ages. This overlap is considerable in Pacific ocean perch populations. It is not uncommon to have nine or more age classes represented by a one cm size interval. Hence, age-length keys derived prior to 1973 were not used to estimate the 1973-76 age composition.

MacDonald and Pitcher (1979) described a method of separating age groups from size frequency data. Basically, this technique involves statistically separating normally distributed components from a distribution of grouped interval measurements. This method was attempted after the original FORTRAN program (MacDonald 1980) was modified and tested on the NWAFC Burroughs 7811 computer. The local program (footnote 1) was executed using data from the 1965 Bering Sea age-length key and corresponding length frequency data provided by Chikuni (1975).

The results were discouraging. The program continually aborted after numerous attempts with varying input parameters. It was concluded that there were far too many age components (20) within the narrow range of the length frequency distribution (21-46 cm); that is, the procedure was not able to statistically and reliably identify each age class. Further consideration of this procedure was abandoned.

After considering the alternatives, an estimate of the age composition during 1973-76 was was made by averaging the Japanese age composition data (proportion at each age) for 1972 and 1977. The 1977 data were obtained from samples of

[1] Modified by Mike McPhail and Gary Walters, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, WA. "Program NORM/SEP Users Manual," 18 p.

the Japanese stern trawl fleet obtained by U.S. observers. A 1973-76 average was calculated for each stock. The averaging procedure was similar to that employed by Hoag and McNaughton (1978) to estimate Pacific halibut (Hippoglossus stenolepis) age structure for five years of insufficient data. By using this procedure it is obvious that any marked differences in year class strength would be masked. And although this method is rather crude, at this time, it seems to be the most appropriate for estimating the unknown age composition.

Age and size composition of Pacific ocean perch within the commercial catch of the Soviet Union and other nations was essentially unknown, but was assumed to be similar to that of the Japanese catch. In order to estimate the number of Pacific ocean perch caught annually, the total international landings were divided by the estimated average weight of Pacific ocean perch in the catch (Table 4). The number of fish caught at each age (Table 5) was then estimated by multiplying the total number of fish by the proportion of fish at each age.

Cohort Analysis Procedures

The term "cohort analysis", as used in this study, refers to procedures which estimate stock size and instantaneous rates of fishing mortality at age. More specifically, these procedures involve sequentially

Table 5. Estimated number (in thousands) of Pacific ocean perch landed by age group, during 1963-79.

Age	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
					Eastern Slope Region					
5	1	460	23	465	76	140	270	6	2,151	4
6	56	344	215	1,160	1,203	607	2,952	209	1,135	1,521
7	147	589	892	1,568	3,439	2,499	13,369	983	1,990	3,307
8	307	1,224	2,472	1,872	4,097	3,858	13,043	1,719	5,079	2,767
9	1,417	3,372	4,761	2,678	5,516	4,199	4,887	2,175	7,682	2,888
10	2,080	5,340	5,371	3,086	6,453	5,188	1,952	2,433	3,381	1,609
11	1,420	5,177	4,573	2,502	6,605	5,624	1,339	2,282	1,108	755
12	1,295	4,369	3,567	2,030	6,529	5,238	1,304	1,944	510	419
13	1,916	3,944	2,652	2,077	6,472	4,636	1,213	1,456	375	274
14	3,043	3,725	2,001	2,378	6,155	4,034	922	982	368	213
15	4,027	3,385	1,559	2,600	5,275	3,417	622	636	373	176
16	4,289	2,848	1,240	2,573	4,009	2,805	417	414	325	137
17	3,901	2,238	992	2,300	2,748	2,223	296	276	238	94
18	3,203	1,693	791	1,892	1,786	1,701	226	190	145	59
19	2,450	1,250	627	1,450	1,121	1,259	178	136	78	33
20	1,790	915	493	1,056	703	913	139	102	38	17
21	1,274	679	389	749	443	647	113	80	18	9
22	890	503	305	516	285	457	87	65	10	6
23	628	378	241	354	190	321	65	54	3	3
24	443	292	194	243	133	231	52	45	3	1
25	321	228	161	172	95	166	39	41	3	1
Total	34,897	42,953	33,519	33,721	66,333	50,163	43,485	16,228	25,013	14,293
					Aleutian Region					
5		264	359	1,704	1,846	1,094	221	1,555	187	7
6		479	6,994	5,649	5,748	21,261	8,607	6,043	875	682
7		1,206	14,146	11,649	5,526	34,554	34,283	16,431	2,053	4,251
8		2,957	17,463	17,835	7,256	19,966	23,918	40,798	5,917	11,048
9		8,393	24,547	22,299	8,436	9,636	6,577	33,215	10,192	15,146
10		13,879	27,529	21,632	8,891	5,525	2,389	12,552	7,133	10,453
11		22,437	31,295	21,761	10,726	5,806	2,988	5,851	4,084	6,420
12		35,226	33,089	22,224	14,511	7,848	5,903	5,915	3,274	5,397
13		37,192	27,484	19,335	16,462	8,729	7,755	8,400	3,293	5,404
14		24,883	18,562	14,427	14,125	7,447	6,187	10,163	3,195	5,049
15		11,665	10,873	9,742	9,744	5,218	3,515	8,817	2,619	3,895
16		4,428	5,851	6,260	5,924	3,163	1,652	5,627	1,787	2,445
17		1,504	2,982	3,889	3,377	1,695	716	2,853	1,048	1,284
18		496	1,480	2,408	1,881	827	295	1,250	561	602
19		165	740	1,500	1,040	374	126	497	281	254
20		50	359	963	584	160	53	192	136	109
21		17	202	648	339	80	21	64	70	44
22		0	112	463	199	40	11	32	37	22
23		0	67	333	117	13	11	16	19	15
24		0	45	259	70	13	0	16	9	7
25		0	22	222	47	0	0	0	5	7
Total		165,241	224,201	185,202	116,849	133,449	105,228	160,288	46,775	72,541
					Gulf of Alaska Region					
5	1,440	883	11,657	7,776	1,120	497	575	1,372	385	1,416
6	3,617	2,152	20,182	14,653	2,699	1,253	885	1,540	1,674	6,115
7	11,938	11,312	43,845	33,537	6,876	2,963	3,028	1,903	7,247	7,998
8	31,334	42,987	92,474	68,556	15,330	6,542	8,401	4,169	16,485	10,764
9	53,963	81,615	144,670	98,125	25,160	11,592	13,681	6,993	21,539	16,213
10	53,163	85,037	153,195	96,856	29,794	16,245	17,469	8,047	19,380	18,863
11	37,960	67,709	121,617	73,369	28,114	19,029	18,898	7,321	13,590	16,063
12	26,726	54,079	84,732	48,349	23,861	19,923	17,780	6,152	9,205	11,764
13	20,420	44,864	57,590	30,046	19,812	19,585	15,358	5,294	7,849	9,148
14	16,355	37,248	39,408	18,673	16,552	18,452	12,749	4,886	8,519	8,398
15	13,411	30,406	27,490	12,008	14,031	16,742	10,420	4,798	9,791	8,565
16	10,978	24,115	19,574	7,988	12,020	14,555	8,432	4,807	10,460	8,681
17	8,834	18,597	14,006	5,448	10,339	12,109	6,693	4,727	9,991	8,265
18	7,105	14,072	10,265	3,809	8,964	9,783	5,264	4,515	8,569	7,365
19	5,633	10,540	7,742	2,751	7,843	7,735	4,115	4,187	6,778	6,265
20	4,449	7,781	5,916	2,010	6,876	6,025	3,168	3,798	5,054	5,149
21	3,553	5,849	4,611	1,534	6,086	4,693	2,469	3,417	3,682	4,232
22	2,913	4,415	3,567	1,164	5,475	3,718	1,957	3,072	2,661	3,516
23	2,400	3,366	2,958	899	4,966	2,963	1,568	2,762	1,941	2,983
24	2,048	2,649	2,436	741	4,533	2,426	1,289	2,487	1,439	2,583
25	1,792	2,152	2,088	635	4,202	2,008	1,071	2,266	1,105	2,300
Total	329,032	551,828	870,023	528,927	254,653	198,838	155,270	88,513	167,344	166,646

Table 5. Continued.

Age	1973	1974	1975	1976	1977	1978	1979
				Eastern Slope Region			
5	1	7	5	11	0	10	0
6	355	1,927	1,361	2,985	6	74	0
7	807	4,374	3,090	6,775	75	233	58
8	799	4,334	3,062	6,714	294	223	155
9	815	4,420	3,123	6,847	271	514	251
10	684	3,706	2,618	5,741	576	347	425
11	443	2,404	1,698	3,724	498	420	467
12	358	1,941	1,371	3,007	483	215	490
13	276	1,496	1,057	2,318	394	162	248
14	412	2,235	1,579	3,463	673	274	346
15	516	2,799	1,977	4,335	881	342	319
16	433	2,350	1,660	3,640	745	214	323
17	308	1,672	1,181	2,590	531	274	83
18	217	1,180	834	1,829	378	368	228
19	52	280	198	433	81	257	86
20	136	739	522	1,145	245	257	123
21	2	11	8	17	0	0	0
22	1	7	5	11	0	0	0
23	1	4	3	6	0	0	0
24	0	2	1	3	0	0	0
25	0	2	1	3	0	0	0
Total	6,616	35,886	25,352	55,597	6,131	4,184	3,602
				Aleutian Region			
5	141	323	224	212	190	230	502
6	1,329	3,035	2,110	1,990	1,660	1,448	972
7	3,262	7,451	5,181	4,885	3,475	1,389	2,009
8	2,570	5,871	4,082	3,849	936	2,345	3,150
9	3,520	8,040	5,590	5,271	1,278	1,090	1,717
10	3,458	7,898	5,492	5,178	2,291	1,202	1,373
11	2,669	6,098	4,240	3,998	2,155	1,176	1,364
12	1,338	3,057	2,126	2,004	569	800	870
13	1,777	4,060	2,823	2,662	1,171	581	679
14	1,175	2,684	1,866	1,759	426	291	231
15	1,083	2,474	1,720	1,622	573	620	452
16	523	1,263	878	828	185	875	585
17	833	1,902	1,323	1,247	841	682	275
18	473	1,081	752	709	506	518	154
19	211	481	335	316	228	642	145
20	139	317	220	208	165	391	109
21	7	17	12	11	0	0	0
22	5	11	8	7	0	0	0
23	2	6	4	4	0	0	0
24	1	3	2	2	0	0	0
25	1	3	2	2	0	0	0
Total	24,517	56,075	38,990	36,764	16,647	14,280	14,587
				Gulf of Alaska Region			
5	1,437	974	1,019	1,078	817	167	153
6	5,544	3,757	3,932	4,156	2,944	630	229
7	9,958	6,748	7,063	7,466	6,350	1,517	1,409
8	12,858	8,714	9,120	9,640	8,044	4,474	2,635
9	14,899	10,097	10,567	11,170	7,985	3,616	3,600
10	13,051	8,844	9,257	9,784	5,337	2,317	2,547
11	12,614	8,549	8,947	9,457	5,936	2,693	1,704
12	9,419	6,383	6,681	7,062	4,514	2,329	1,199
13	7,032	4,766	4,988	5,272	3,234	1,710	1,210
14	7,417	5,027	5,261	5,561	3,856	986	888
15	5,826	3,948	4,132	4,368	2,328	757	1,094
16	5,941	4,026	4,214	4,454	2,393	842	960
17	4,928	3,339	3,495	3,694	1,611	638	624
18	4,864	3,296	3,450	3,646	1,872	412	377
19	3,426	2,322	2,430	2,569	936	273	272
20	2,849	1,931	2,021	2,136	794	127	299
21	1,630	1,104	1,156	1,222	0	0	0
22	1,360	922	965	1,020	0	0	0
23	1,155	783	819	866	0	0	0
24	1,001	678	710	750	0	0	0
25	885	600	628	664	0	0	0
Total	128,094	86,806	90,855	90,035	58,951	23,488	19,200

calculating the number of individuals and fishing mortalities of a cohort (year class) at successive ages from catch at age data. Also required is an estimate of M and a known or assumed value of F for one age in each cohort to start the computations. The age chosen is usually the oldest, or one of the oldest, because estimates of F computed for younger ages converge asymptotically to their true values for the given M. Otherwise, estimates for the older ages diverge progressively (unless the intial trial value of F happens to be correct) (Ricker 1975).

A number of procedures have been developed independently under different initial assumptions (Fry 1949; Jones 1964; Murphy 1965; Gulland 1965; Pope 1972). The three more commonly used cohort analysis procedures are outlined below.

Murphy's Method

As with all cohort analysis or virtual population analysis techniques, the Murphy (1965) method begins with Baranov's catch equation,

$$C_{i,j} = N_{i,j} \frac{F_{i,j}}{F_{i,j} + M} [1 - \exp - (F_{i,j} + M)] \qquad (1)$$

where, C(i,j) = number of year class i fish caught at age j

N(i,j) = number of year class i fish present at age j

F(i,j) = coefficient of instantaneous fishing mortality for year class i at age j

M = coefficient of instantaneous natural mortality

The catch of year class C(i,j) fish one year later is expressed as:

$$C_{i,j+1} = N_{i,j} \{\exp-(F_{i,j}+M)\} \frac{F_{i,j+1}}{F_{i,j+1} + M} \{1-\exp-(F_{i,j+1}+M)\} \quad (2)$$

The ratio of catches in successive years is then:

$$\frac{C_{i,j+1}}{C_{i,j}} = \{\exp-(F_{i,j}+M)\} \frac{\{F_{i,j+1}\} \{F_{i,j}+M\} \{1-\exp-(F_{i,j+1}+M)\}}{\{F_{i,j}\} \{F_{i,j+1}+M\} \{1-\exp-(F_{i,j}+M)\}} \quad (3)$$

Since C(i,j) and C(i,j+1) are known, and given an estimate of M and either F(i,j) or F(i,j+1), the remaining F value can be calculated by an iterative procedure. Once estimates of F(i,j) have been obtained, population size at each age can be calculated for each year class by employing equation (1). These calculations are carried out sequentially for all ages of a cohort for which corresponding catch at age data are available.

Gulland's Method

Gulland's (1965) method, also known as "virtual population analysis", is based on Baranov's catch equation (equation 1) and the following equation:

$$N_{i,j+1} = N_{i,j} \exp - (F_{i,j} + M) \quad (4)$$

It follows that,

$$\frac{N_{i,j+1}}{C_{i,j}} = \frac{[F_{i,j} + M] [\exp - (F_{i,j} + M)]}{[F_{i,j}] [1 - \exp - (F_{i,j} + M)]} \quad (5)$$

Like Murphy's (1965) method, there is no analytical solution for F(i,j) (formula 5). However, if N(i,j+1), C(i,j), and M are known, then one can solve for F(i,j) by an iterative procedure. Formula (4) can then be used to estimate N(i,j). Equation (5) is used to obtain F(i,j-1) and so on.

To initiate Gulland's procedure, an estimate of the population size of the oldest age at which the year class was fished N(i,t) is needed. This can be accomplished by using the best estimate or guess of fishing mortality for the oldest age in the year class (F(i,t)) and solving for N(i,t) using equation (1), i.e.,

$$N_{i,t} = \frac{C_{i,t}\,[F_{i,t} + M]}{F_{i,t}\,[1 - \exp - (F_{i,t} + M)]} \tag{6}$$

These calculations are sequentially carried backward until estimates of N(i,j) and F(i,j) are completed for the appropriate ages of the cohort in question.

<u>Pope's Method</u>

Pope (1972) was the first to coin the term "cohort analysis." His method, an approximation of Gulland's (1965) virtual population analysis, provides an analytical solution to estimates of stock size and fishing mortality and makes it possible to calculate variances of N(i,j) and F(i,j). This approximation appears to be very good (less than 4%

error) when M<0.3 and the starting (input) value of F<1.2 (Pope 1972). The basic equation of Pope's analysis is:

$$N_{i,j} = C_{i,j} \exp\left[\frac{M}{2}\right] + N_{i,j+1} \exp(M) \qquad (7)$$

In this method, the stock size at each age of a given cohort is estimated sequentially by knowing or assuming a value of M and a starting value of N(i,j+1). Like Gulland's (1965) method, the number of fish alive at the oldest age in the cohort is used to start the computations; equation (6) can be used to estimate N(i,t). The subsequent N(i,j)'s are then estimated by working back through the cohort employing equation (7) where N(i,t) from equation (6) becomes N(i,i+1) in equation (7). Finally, the F(i,j)'s are estimated from the calculated N(i,j)'s using the equation:

$$F_{i,j} = \ln\left[\frac{N_{i,j}}{N_{i,j+1}}\right] - M \qquad (8)$$

It should be noted that there are two possible forms of expressing the trial value N(i,t), which is needed to start the Gulland (1965) or Pope (1972) procedures. If fishing is not complete for the oldest age group, i.e., the year class is still being fished, equation (6) is used. However, if fishing is complete for the oldest age group, then the following formula is applied:

$$N_{i,t} = \frac{C_{i,t} \{F_{i,t} + M\}}{F_{i,t}} \qquad (9)$$

Program Availability

A variety of cohort analysis programs are available. Although catch-at-age data are a common input to these programs, each program usually contains special features which make it unique. Depending on the assumptions and circumstances, one program may be more desirable than another. Three programs were examined for this study; the major features of each are discussed below.

The Murphy (1965) approach was codified in FORTRAN IV for the CDC 7600 computer at the Lawrence Berkley Laboratory, California. This program, entitled ICPF (footnote 2), was later modified for implementation on the NWAFC Burroughs 7811 machine. The ICPF program enables the user to obtain the results for multiple year classes when natural mortality and one value of age-specific fishing mortality are input. This is done by stipulating that two adjacent age classes are exploited at the same rate during a given year. The program links the year classes at the given

[2] Developed by William Fox and William Lenarz, National Marine Fisheries Sevice, Southwest Fisheries Center, LaJolla, CA. Program and documentation obtained through Donald R. Gunderson, Fisheries Research Institute, University of Washington, Seattle, WA.

ages by using the appropriate F value from a completed cohort as input to initiate the calculations for the adjacent cohort.

The Gulland (1965) and Pope (1972) procedures are available as interactive APL programs and are entitled VPA and COHORT, respectively. Both programs are a subset of a total package of programs entitled FISH (Rivard 1980). FISH, which is designed to provide assistance in stock assessments, is available on the NWAFC Burroughs 7811 computer. All programs in this package were tested using sample runs present in the original program description manual. With the exception of certain plotting routines, output results were identical.

VPA and COHORT are similar in that both programs reconstruct the age composition of the stock and estimate the corresponding rates of fishing mortality for a specified number of years. They differ, however, in the derivation of the estimates obtained and the type of output generated.

In VPA, estimates of population size and fishing mortality are calculated according to the procedures outlined in the "Gulland's Method" section. An initial estimate of F(i,j) is determined by employing equations (7) and (8). An iterative procedure is then used to calculate sequential values of F(i,j) of equation (5). The iterative process is exited when:

$$\left| \frac{F_{i,j} [1 - \exp - (F_{i,j} + M)]}{F_{i,j} + M} - \frac{C_{i,j}}{N_{i,j+1}} \right| < 10^{-5}$$

COHORT uses the basic procedures described in the "Pope's Method" section to calculate population size and fishing mortalities. Given information on weight-at-age at mid-year, COHORT will estimate the average biomass and the population biomass at the beginning of each year.

The reader is referred to appendices I and II for detailed descriptions of the input and algorithms used in COHORT and VPA, respectively. The notation and descriptions used in these appendices are those of Rivard (1980).

Program Input

Catch at Age

Because of the absence of ages greater than 20 years in the 1977-79 catches (Table 5), only 5-20 year olds were employed in the preliminary analyses. It was felt that by doing so, much of the error associated with using incorrectly aged older fish would be reduced. Fishing was considered incomplete at age 20 and complete at age 25.

In addition to the required catch-at-age data, an estimate of natural mortality and one value of fishing mortality is required for each year class. Published estimates of natural and fishing mortality vary considerably. An attempt was made to delineate reasonable bounds around the input mortalities. Mortality estimates used in this study were based on those taken from the literature.

Natural Mortality (M)

Quast (1972) employed a catch curve analysis on age data collected in 1964 from the Gulf of Alaska. The results indicated an annual mortality rate of 0.16. Quast reasoned that a value of 0.20 should be used as an approximate rate of natural mortality for the virgin population.

Chikuni (1975) estimated natural mortality rates for each stock within the study area. These estimates were obtained by regressing Jackson estimates of total mortality (Z) against effective fishing effort (f). The intercept on the Z-axis is an estimate of M and the slope of the regression line is an estimate of the catchability coefficient (q). Chikuni's best estimate of the regressions are given in Table 6.

The estimate of M from the Aleutian regression seems rather high. The plot of the original regression data suggested an inverse correlation of Z versus f. To counter this, Chikuni (1975) arbitrarily selected three positively correlated data points from the original eight to calculate the Aleutian regression. Because of the wide scatter of the original data points and the fact that only three points were employed, the Aleutian estimates of M and q should be viewed with caution.

Table 6. Resulting regressions of total mortality (Z) versus effective fishing effort (f), by stock (from Chikuni 1975).

Stock	$Z = M + qf$[a/]
Eastern slope	$Z = 0.271 + 0.1095\ f$
Aleutian	$Z = 0.424 + 0.0436\ f$
Gulf of Alaska	$Z = 0.193 + 0.0115\ f$
Eastern Pacific[b/]	$Z = 0.227 + 0.0362\ f$

a/ Units of f: 1,000 trawl hours

b/ Eastern Pacific stock inhabits the area from off British Columbia to off California.

Gunderson (1978) concluded that an estimate of M between 0.10 and 0.15 for various "eastern Pacific" stocks resulted in cohort analysis estimates of biomass that agreed best with those obtained using alternative techniques (e.g. trawl surveys, CPUE analyses, etc.)

It appears that mortality estimates based on regression methods are generally higher than those obtained by indirect methods. The reason for this discrepancy is not fully understood. However, difficulties in aging, inaccurate measurements of effective fishing effort, variable recruitment, and inter-annual variations in the exploitation rate undoubtedly contribute to the biases associated with the regression methods.

Previous studies which required estimates of Pacific ocean perch natural mortality usually employed values of about 0.2. Robinson (1972) concluded that a value of less than 0.2 best described the Bering Sea stocks and a value of slightly more than 0.2 characterized the Gulf of Alaska stock. Similarly, Quast (1972) employed a natural mortality value of 0.2 for his analysis of S. alutus stocks off Alaska. Low (1974), too, used a value of 0.2 to describe natural mortality of Pacific ocean perch in the Bering Sea.

Recent work by Archibald et al. (1981) indicate that the value of natural mortality is between 0.04 and 0.05 for the "eastern Pacific" stocks. These estimates were derived from analyses of age data obtained through the application of new aging techniques (Beamish 1979). The data employed were collected in 1978 and 1979 from the British Columbia coast. Age groups in this data ranged from 4 to 77 years. The current author questions the validity of ocean perch ages greater than 25 years. It is felt that the mortality estimates derived by Archibald et al. (op cit.) may be too low and should be viewed with caution.

Natural mortality undoubtedly varies with age, year class, and stock size. Unfortunately, no estimates of age specific natural mortalities have been published, since the data available do not allow realistic estimation of age specific and yearly fluctuations of natural mortality in Pacific ocean perch populations. It was initially assumed, however, that natural mortality was 0.15 for all ages and year classes within each stock. Natural mortality was later varied to test the effect of errors on the estimates of fishing mortality and stock abundance.

<u>Terminal Fishing Mortality (F(t))</u>

To start the cohort analysis computations, an estimate of fishing mortality (F(t)) at the oldest age (or at one of the older ages) of each year class is required. As with natural mortality, published estimates of fishing mortality vary considerably.

Chikuni (1970b) estimated total mortality (Z) by catch curve analysis. The data were collected during 1963-1969 from the Albatross Bank area in the Gulf of Alaska. Assuming a constant natural mortality of 0.15 for all years, estimates of fishing mortality ranged from 0.4636 to 0.8813. Robinson (1972) later transformed Chikuni's (1970b) data into numbers-caught-per-hour and employed a Jackson (1939) type procedure to estimate survival rates (S). These rates were then used to compute instantaneous total mortality rates, i.e., $-\ln S = Z$. Again, assuming a constant natural mortality of 0.15, estimates of fishing mortality ranged from 0.1643 to 1.2954.

As previously mentioned, Chikuni (1975) computed a catchability coefficient (q) for each stock (Table 6). By multiplying q by effective fishing effort (f), an estimate of instantaneous fishing mortality is obtained. Annual fishing effort from Chikuni (op cit.) was subsequently employed to estimate instantaneous fishing mortalities for each stock. During the period 1964-72 estimates of F ranged from 0.0876 to .6522 for the Gulf of Alaska stock, 0.1853 to 0.6414 for the Aleutian stock, and 0.1369 to 0.7172 for the eastern slope stock.

The wide variability in the estimates of instantaneous fishing mortality (e.g., Gulf of Alaska, Table 7) suggests that F is not precisely known. Therefore, a prudent measure

Figure 7. Estimated instantaneous fishing mortalities $(\hat{F})$, as determined by different authors.

Region/Source	$\hat{F}$ 1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Gulf of Alaska										
Chikuni 1970b 1/	0.4636	0.4784	0.7683	0.8813	0.5520	0.5800	--	--	--	--
Robinson 1972 1/	0.6604	1.2954	0.9065	0.1643	0.7511	1.0000	--	--	--	--
Chikuni 1975 2/	0.2054	0.4232	0.6522	0.3342	0.2645	0.2563	0.1807	0.0876	0.1519	0.1769
Eastern Slope										
Chikuni 1975 2/	--	0.6658	0.3679	0.3165	0.4150	0.7172	0.5333	0.3000	0.2957	0.1369
Aleutian										
Chikuni 1975 2/	--	0.4146	0.5005	0.6414	0.2712	0.2389	0.1888	0.5031	0.1853	0.3104

1/ $\hat{F}$ estimated as: $\hat{F} = Z - M$. Assuming a constant natural mortality (M = 0.15).

2/ Yearly effort estimated by dividing density index into total international catch. F was then estimated by multiplying the effort figure by the appropriate catchability coefficient (q) given in table 6.

is to assume a reasonable terminal mortality to begin the cohort analysis computations, then bound this estimate with a range of suitable values. In the present study a terminal fishing mortality of 0.35 was presupposed for all fully recruited year classes in each stock. This value was within the bounds of published F estimates and seemed to be a reasonable mortality to begin the computations. The cohort analysis was later run with a range of terminal fishing mortalities around the 0.35 value.

Based on the catch at age data (Table 5) and past catch curve analyses (Robinson 1972; Quast 1972; Chikuni 1970b), it is apparent that complete recruitment to the fishery is variable. Assuming that full recruitment occurs at or near the modal age of the catch, complete recruitment could occur anywhere from age 7 to 16. This high variability is due to year to year variation in availability, year class strength, and fishing pressure. Rather than attempt to incorporate complex schedules of recruitment, recruitment in this study was assumed to be constant between years. Full recruitment was assumed to occur at age 11 for the Gulf of Alaska stock and at age 10 for the Bering Sea and Aleutian stocks. This assumption was based on an examination of the pooled age data from 1963 to 1979 and on the recruitment values employed by Chikuni (1975).

Age groups which are not yet fully recruited usually exhibit a lesser fishing mortality than those that are. This is an important consideration when assigning terminal fishing mortalities to the cohorts in the last year of historical catch, i.e., the same terminal fishing mortality should not be assigned to both fully and incompletely recruited cohorts. The F(t) values for the incompletely recruited year classes should be adjusted relative to the first fully recruited age group.

Selectivity factors at age were subsequently derived to estimate the terminal fishing mortalities of the incompletely recruited year classes. The derivation of these factors was similar to the procedure described by Schweigert and Hourston (1980).

First, program COHORT was executed for each stock by employing a constant natural mortality of 0.15 and a terminal fishing mortality of 5.0. This value of F(t) is obviously quite high but was applied to assure accurate estimates of fishing mortalities at the younger ages of each cohort. COHORT proceeds by working backward through successively younger ages in a year class. As cumulative fishing mortality increases, the resulting mortality estimates theoretically converge to their true values. Pope (1972) concluded that as long as the cumulative fishing mortality rates (exclusive of F(t)) exceed 2.0, errors in the estimates of age specific F should not be greater than about 10%. Table 8 demonstrates the effects of increased F(t) values on age specific F's for the 1958 year class from the Gulf of Alaska.

Each COHORT run produced a table of fishing mortality rates by year and age group. Mean fishing mortality at age was calculated from the first 12 years (1963-74) of estimated F's. Twelve years was chosen because this allowed the age specific F's to be based on at least three sequential back calculations. These calculations were carried out for all age groups from age five up to and including the age at full recruitment.

To estimate the selectivity factors (Table 9), the mean F's at age for the incompletely recruited cohorts (ages 5-9 years for both Bering Sea stocks and ages 5-10 years for the Gulf of Alaska stock) were scaled relative to the mean F of the the first fully recruited age group. The product of the selectivity factors at age and the fishing mortality of the first fully recruited age group provides approximate estimates of the terminal fishing mortalities for the year classes not yet fully recruited.

Selectivity factors appear to vary between years, probably due to differential availability between age groups and inter-annual differences in the bathymetric range of the trawl fishery. Age composition data (Table 5) indicated

Table 8. Age specific fishing mortalities of the 1958 year class from the Gulf of Alaska, as determined by cohort analysis, with M = 0.15 and varying F(t) values.

	F_t					
Age	0.10	0.25	0.50	1.00	3.00	5.00
5	0.003	0.003	0.003	0.003	0.003	0.003
6	0.005	0.005	0.005	0.005	0.005	0.005
7	0.131	0.133	0.133	0.134	0.134	0.134
8	0.292	0.298	0.300	0.301	0.302	0.302
9	0.156	0.160	0.162	0.162	0.163	0.163
10	0.136	0.140	0.141	0.142	0.142	0.142
11	0.219	0.226	0.229	0.230	0.231	0.231
12	0.097	0.101	0.102	0.103	0.104	0.104
13	0.164	0.171	0.174	0.176	0.176	0.176
14	0.250	0.265	0.270	0.273	0.274	0.274
15	0.260	0.280	0.287	0.291	0.293	0.293
16	0.272	0.300	0.311	0.317	0.320	0.320
17	0.379	0.436	0.459	0.471	0.478	0.479
18	0.817	1.085	1.223	1.306	1.358	1.364
19	0.473	0.879	1.257	1.622	1.979	2.028
20	0.100	0.250	0.500	1.000	3.000	5.000

Table 9. Selectivity factors to estimate the terminal fishing mortalities for the incompletely recruited cohorts, relative to the first fully recruited age group.

	Selectivity Factors		
Age	Eastern Slope	Aleutian	Gulf of Alaska
5	0.0440	0.0344	0.0526
6	0.1527	0.2876	0.1034
7	0.5138	0.7231	0.2196
8	0.7256	0.9688	0.4669
9	0.9099	1.0977	0.7936
10	1.0000	1.0000	0.9833
11	--	--	1.0000

that selectivity varied between stocks, with age at recruitment showing only minor variations between years in the Gulf of Alaska, while varying to the largest extent in the Aleutian region. Where between year variability was common, the assumption of constant selectivity factors for all years adds an additional source of error to the analysis. Such errors will only effect the most recent cohorts, however.

Weight at Age

Abundance estimates from cohort analysis are expressed as the number of individuals at each age. A more recognized expression of stock abundance is biomass. In order to convert numbers at age to biomass, mean weight at age information is required.

Chikuni (1975) provided age-length and weight-length information for each stock. The age-length data were represented by the von Bertalanffy growth model,

$$l(t) = L_\infty \, [1 - \exp(-k[t - t_o])] \qquad (10)$$

where, $l(t)$ = length (cm) at age t
L_∞ = theoretical maximum length
k = constant expressing the rate of approach to L_∞
$t(0)$ = theoretical age at which length equals 0.

The weight-length data were expressed well by a power curve relationship of the form,

$$w(t) = \alpha\, l(t)^{\beta} \qquad (11)$$

where, $w(t)$ = mean weight (gm) at age t
$l(t)$ = length (cm) at age t
α, β = constants.

Stock specific growth parameters estimated by Chikuni (1975) (Table 10) were employed to calculate mean weight at age for the years 1963-76. Mean weight at age was calculated as:

$$w(t) = \alpha \{L_{\infty} (1 - \exp\{-k(t - t_0)\})\}^{\beta}$$

Age, length, and weight data collected by U.S. observers were used to estimate stock specific growth parameters for the years 1977-79. Age-length keys were constructed for each stock and were then applied to the length frequency data to estimate mean length at age. The resulting estimates were subsequently fitted to the von Bertalanffy growth model (equation 10). The program VONB (Rivard 1980), which utilizes the Marquardt method (Ricker 1975; Bard 1974) to estimate the parameters, was employed to do this.

Parameters of the weight-length relationship were estimated by log-linearizing equation 11 and then applying linear least squares regression to the appropriate mean weight at length data.

Table 10. Parameters of the von Bertalanffy equation and length-weight relationship used to convert numbers at age to biomass at age.[a]

Region/year[b]	L_∞	K	t_o	α	β
Eastern slope					
1963-76	45.84	.1055	-1.3085	.02602	2.813
1977	46.32	.1104	-0.5961	.00784	3.108
1978	43.94	.1128	-2.0002	.00578	3.212
1979	43.28	.1319	-1.0803	.00126	3.604
Aleutian					
1964-76	45.84	.1055	-1.3085	.02285	2.828
1977	49.39	.0691	-4.4201	.01871	2.884
1978	43.94	.1093	-1.6759	.00629	3.145
1979	42.42	.1321	-1.3073	.01302	2.968
Gulf of Alaska					
1963-76	41.13	.1043	-3.0046	.01544	2.948
1977	40.28	.1408	-1.8440	.00668	3.151
1978	39.36	.1765	-0.5272	.00634	3.120
1979	39.50	.1738	-1.8709	.00092	3.672

a/ Formula used to calculate weight-at-age (gm):

$$W_t = \alpha \, [\, L_\infty \, (1 - e^{-k(t-t_o)} \,) \,]^{\beta}$$

b/ Data sources: 1963-76 Chikuni (1975)
1977-79 U.S. observer program

Parameter values used to calculate mean weight at age are summarized in Table 10. The weights are assumed to be taken as mid-year estimates (Appendix I).

Application

Programs ICPF, COHORT, and VPA were executed with identical catch at age data and with the same F(t) and M parameter values. This was done to compare differences in the estimates of N(i,j) and F(i,j) from the three cohort analysis procedures examined in this study. The estimates of age specific fishing mortality and abundance (number of fish) from the 1958 Gulf of Alaska year class were used to evaluate these differences (Table 11).

Murphy's (1965) method (program ICPF) involves solving the ratio of catch equations (C(i,j+1)/C(i,j)) for successive years of a cohort. Gulland's (1965) method (program VPA), on the other hand, sequentially solves the ratios of N(i,j+1)/C(i,j) for a given year class. In both methods, F(i,j) values are solved for by iteration. Although the Murphy and Gulland methods were developed independently of each other, both are fundamentally the same. The abundance and fishing mortality estimates from each program were virtually identical when the analyses were started with the oldest age in the cohort (Table 11).

Table 11. Numbers of Pacific ocean perch at age (in thousands) in the 1958 Gulf of Alaska year class and instantaneous fishing mortality (F) by age as calculated by three different cohort analysis programs. All three programs employed identical catch at age data and input parameter values (F_t=0.35 M=0.15).

	Cohort Analysis Program					
	ICPF		COHORT		VPA	
Age	N	F	N	F	N	F
5	513,912	0.003	516,241	0.003	513,913	0.003
6	440,993	0.005	442,997	0.005	440,994	0.005
7	377,572	0.133	379,294	0.133	377,573	0.133
8	284,408	0.299	285,785	0.299	284,409	0.299
9	181,486	0.161	182,375	0.161	181,486	0.161
10	132,933	0.141	133,629	0.140	132,933	0.141
11	99,386	0.228	99,945	0.228	99,386	0.228
12	68,076	0.102	68,491	0.102	68,076	0.102
13	52,899	0.174	53,243	0.173	52,899	0.174
14	38,271	0.269	38,545	0.268	38,271	0.269
15	25,182	0.285	25,385	0.284	25,182	0.285
16	16,294	0.308	16,444	0.306	16,294	0.308
17	10,307	0.451	10,418	0.449	10,307	0.451
18	5,650	1.156	5,725	1.160	5,650	1.156
19	1,531	1.050	1,545	1.059	1,531	1.050
20	461	0.350	461	0.350	460	0.350

Pope's (1972) method (program COHORT) is an approximate form of Gulland's sequential population analysis. As would be expected, abundance and fishing mortality estimates from COHORT differ from those calculated by VPA and ICPF (Table 11). These differences, though, are relatively minor.

After examining the output and flexibility of each program, COHORT was selected as the preferred cohort analysis procedure. This program was subsequently employed for all cohort analysis runs.

Analysis was executed for each stock using a constant natural mortality of 0.15 and a terminal fishing mortality (age 20) of 0.35 for all cohorts. These parameter values were considered to be the most appropriate for beginning the computations. The resulting executions were designated as the base runs. Because of the uncertainty about the actual values of M and F(t), various combinations of these parameter values were tried. Natural mortality was varied between 0.05 and 0.30 and trial terminal fishing mortality ranged from 0.175 to 1.05.

RESULTS AND DISCUSSION

Pope (1972) demonstrated that the convergence properties of cohort analysis are such that it is not critical to have a precise estimate of F(t). As cohort analysis proceeds backward over successively younger ages, the errors in the estimates of fishing mortality and abundance diminish at a rate that is proportional to cummulative fishing mortality. Estimates at the younger ages of each cohort generally converge to their true value for a given terminal fishing mortality. Abundance and fishing mortality estimates at the older ages are less precise, unless, of course, the value of F(t) happens to be correct.

Precise estimates of F(t) for each cohort in each stock were not satisfactorily known. Therefore, estimates of abundance and fishing mortality for the older ages in each year and for the most recent years should be excluded when examining historical trends. Unless stated otherwise, only abundance and fishing mortality estimates that were based on at least three sequential back calculations were examined.

Results from the base runs are given in Tables 12-20. Abundance is described in terms of numbers of fish and biomass at age. Instantaneous fishing mortality is given by age group within each year.

Table 12. Numbers at age (in thousands) of Pacific ocean perch in the eastern slope stock as estimated by the cohort analysis base run.

POPULATION NUMBERS

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	86138	82078	81442	87430	74574	50545	39687	39031	36930	32949	23754	16343	6031	1522	604	35	72
6	71878	74138	70218	70076	74821	64116	43375	33908	33589	29790	28355	20445	14060	5186	1300	519	21
7	85526	61814	63492	60238	59239	63283	54622	34594	28991	27857	24230	24076	15809	10839	1694	1113	378
8	60043	73477	52658	53821	50393	47797	52149	34610	28864	23107	20909	20106	16665	10740	3043	1389	742
9	58460	51394	62107	43029	44587	39572	37560	32785	28195	20131	17321	17255	13285	11503	3015	2347	988
10	42137	49002	41107	49039	34551	33259	30165	27794	26200	17140	14648	14152	10751	8537	3548	2344	1543
11	33529	34338	37222	30398	39345	23752	23813	24152	21666	19414	13260	11973	8743	6825	2021	2520	1696
12	28064	27541	24752	27795	23843	27737	15226	19254	18671	17620	16009	11002	8075	5950	2419	1278	1779
13	24157	22954	19651	17995	22040	14465	19014	11895	14769	15597	14777	13447	7669	5678	2331	1634	900
14	20833	19014	16097	14454	13561	12966	8149	15240	8887	12364	13170	12462	10186	5620	2737	1641	1256
15	21768	15108	12910	11999	10234	5962	7417	6158	12206	7308	10444	10953	8653	7303	1624	1731	1158
16	15679	15000	9863	9665	7915	3915	1962	5807	4710	10160	6127	8510	6831	5614	2264	581	1173
17	13250	9516	10268	7339	5932	3093	767	1301	4614	3753	8618	4872	5145	4339	1455	1257	301
18	7434	7785	6114	7918	4183	2556	600	386	864	3751	3143	7131	2642	3332	1332	759	828
19	6501	3427	5130	4528	5060	1943	622	307	156	609	3173	2504	5043	1500	1171	796	312
20	6499	3322	1790	3834	2552	3315	505	370	138	62	494	2683	1895	4157	890	933	447
5+	581895	549909	514823	499559	472830	398276	335632	287594	269450	241611	218432	197916	141482	98644	31450	20877	13595
6+	495757	467831	433381	412129	398257	347731	295945	248563	232520	208663	194678	181573	135451	97122	30845	20842	13522
7+	423879	393693	363163	342052	323436	283615	252570	214655	198931	178872	166322	161129	121392	91936	29546	20322	13502
8+	338353	331879	299670	281814	264197	220333	197949	180060	169939	151015	142093	137052	105583	81098	27852	19210	13123

Table 13. Mean biomass at age (mt) of Pacific ocean perch in the eastern slope stock as determined by the cohort analysis base run.

MEAN POPULATION BIOMASS

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	12880	12237	12177	13037	11145	7547	5913	5836	5351	4927	3552	2443	901	227	59	4	8
6	14261	14679	13915	13788	14725	12662	8297	6708	6548	5753	5591	3853	2646	667	183	91	3
7	21399	15402	15783	14878	14378	15516	11828	8533	6995	6531	5961	5432	3536	1655	312	235	70
8	18206	22144	15611	16063	14656	13906	13660	10246	7935	6573	6229	5389	4559	1991	690	366	167
9	20669	17764	21334	14901	14905	13366	12509	11327	8566	6651	6049	5302	4141	2608	837	699	260
10	16899	19000	15737	19520	12779	12539	11995	10911	10040	6704	5883	4981	3832	2006	1116	837	468
11	15220	14643	16141	13495	16603	9588	10727	10648	9787	8829	6048	4949	3629	2124	694	1000	587
12	14103	12967	11757	13761	10409	12815	7484	9382	9479	8963	8150	5123	3776	2142	969	561	689
13	13043	11731	10272	9516	10384	6682	10356	6264	8214	8712	8249	7128	4002	2447	1058	816	384
14	11704	10356	9162	8029	6074	6526	4669	8978	5302	7473	7901	6859	5692	2115	1295	849	580
15	12792	8657	7890	6909	4629	2533	4631	3802	7849	4716	6647	6145	4944	3028	649	939	574
16	9231	9338	6387	5720	3839	1445	1203	3880	3151	7006	4095	5001	4107	2303	1173	296	617
17	8109	6068	7135	4430	3164	1200	438	843	3288	2713	6195	2875	3293	2009	780	751	167
18	4281	5267	4369	5280	2417	1132	362	210	603	2857	2326	4986	1669	1710	801	385	480
19	4085	2175	3840	2973	3560	921	419	182	88	474	2520	1885	3957	1008	845	481	188
20	4580	2341	1261	2702	1799	2336	356	261	97	43	348	1891	1335	2929	589	605	278
5+	201461	184769	172771	165001	145466	120714	104846	98011	93295	88926	85743	74245	56018	30970	12049	8915	5521
6+	188581	172532	160594	151963	134320	113167	98932	92175	87944	83999	82191	71802	55116	30744	11990	8911	5513
7+	174320	157853	146679	138176	119596	100504	90635	85467	81396	78246	76600	67948	52470	30077	11807	8820	5510
8+	152921	142451	130897	123298	105218	84988	78808	76934	74401	71715	70640	62516	48934	28421	11495	8584	5440

Table 14. Instantaneous fishing mortality (F) by age for Pacific ocean perch in the eastern slope stock as estimated by the cohort analysis base run.

FISHING MORTALITY

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	0.000	0.006	0.000	0.006	0.001	0.003	0.007	0.000	0.065	0.000	0.000	0.000	0.001	0.008	0.002	0.368	0.015
6	0.001	0.005	0.003	0.018	0.017	0.010	0.076	0.007	0.037	0.057	0.014	0.107	0.110	0.969	0.005	0.167	0.053
7	0.002	0.010	0.015	0.028	0.065	0.043	0.306	0.031	0.077	0.137	0.037	0.218	0.237	1.120	0.049	0.256	0.180
8	0.006	0.018	0.052	0.038	0.092	0.091	0.314	0.055	0.210	0.138	0.042	0.264	0.221	1.120	0.110	0.190	0.254
9	0.026	0.073	0.086	0.069	0.143	0.121	0.151	0.074	0.348	0.168	0.052	0.323	0.292	1.026	0.102	0.269	0.318
10	0.055	0.125	0.152	0.070	0.225	0.184	0.072	0.099	0.150	0.107	0.052	0.332	0.304	1.291	0.192	0.174	0.350
11	0.047	0.177	0.142	0.093	0.200	0.295	0.063	0.107	0.057	0.043	0.037	0.244	0.235	0.887	0.309	0.198	0.350
12	0.051	0.188	0.169	0.082	0.350	0.228	0.097	0.115	0.030	0.026	0.024	0.211	0.202	0.787	0.242	0.200	0.350
13	0.089	0.205	0.157	0.133	0.381	0.424	0.071	0.141	0.028	0.019	0.020	0.128	0.161	0.580	0.201	0.113	0.350
14	0.171	0.237	0.144	0.195	0.672	0.409	0.130	0.072	0.046	0.019	0.034	0.215	0.183	1.091	0.308	0.198	0.350
15	0.222	0.276	0.139	0.266	0.811	0.962	0.095	0.118	0.033	0.026	0.055	0.322	0.283	1.021	0.879	0.239	0.350
16	0.349	0.229	0.146	0.338	0.790	1.480	0.260	0.080	0.077	0.015	0.079	0.353	0.304	1.200	0.438	0.506	0.350
17	0.382	0.292	0.110	0.412	0.692	1.490	0.538	0.260	0.057	0.027	0.039	0.462	0.284	1.031	0.500	0.268	0.350
18	0.624	0.267	0.150	0.298	0.617	1.263	0.521	0.757	0.200	0.017	0.077	0.196	0.416	0.895	0.365	0.739	0.350
19	0.521	0.499	0.141	0.423	0.273	1.198	0.369	0.649	0.776	0.060	0.018	0.128	0.043	0.373	0.077	0.428	0.350
20	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350

Table 15. Numbers at age (in thousands) of Pacific ocean perch in the Aleutian stock as estimated by the cohort analysis base run.

POPULATION NUMBERS

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	150706	162447	241936	238962	131573	84574	59291	54883	47138	35431	24374	22269	22753	15042	12891	45313
6	155978	129469	139486	206655	203964	112231	72589	49589	47065	40566	30365	20680	18959	19387	12770	10882
7	163422	133807	104947	114816	172537	155829	88613	56871	41870	39877	33682	23320	15842	14472	15147	9648
8	175539	139539	102045	79521	93696	116447	102317	61026	47045	32094	31296	22078	15265	9103	9233	11748
9	172900	148345	103902	71285	61713	62122	78037	50215	47036	30242	25239	21490	15216	9568	6967	5771
10	163298	141030	104908	68741	53529	44177	47367	36352	33765	26433	22764	14265	13310	8206	7049	4985
11	143798	127676	95846	70226	50917	40947	35807	29124	24671	19364	19543	12266	7183	6652	4937	4952
12	123191	102952	80858	62307	50493	38439	32471	25391	21279	15278	14191	11163	6624	2473	3727	3159
13	94254	73351	57914	48977	40165	36179	27608	22461	18817	13308	11909	9378	7636	3842	1601	2465
14	58881	46620	37635	31909	26882	26472	23945	15969	16277	11182	9805	6483	5453	4103	2220	839
15	29881	27594	22906	19009	14360	16229	17045	11181	10781	9326	8535	5949	3849	3061	3136	1641
16	14827	14897	13663	10677	7321	7519	10707	6491	7194	5666	7022	5051	3525	1808	2103	2124
17	8982	8654	7393	5952	3694	3367	4939	3996	3929	3923	4391	4872	3533	2266	1385	998
18	6181	6336	4682	2756	1990	1607	2233	1604	2467	2190	2604	2015	2966	1884	1170	559
19	1692	4860	4080	1796	627	946	1109	763	860	1565	1446	1238	1037	1895	1152	526
20	182	1303	3496	2120	581	192	697	494	396	505	1151	799	755	599	1420	396
5+	1463714	1268881	1125698	1035709	914043	747276	604776	426411	370589	286949	248318	183316	143905	104361	86907	106007
6+	1313007	1106435	883762	796748	782470	662702	545485	371527	323451	251518	223943	161046	121151	89319	74016	60694
7+	1157029	976965	744276	590092	578507	550471	472897	321938	276386	210953	193578	140367	102192	69932	61246	49812
8+	993607	843158	639329	475276	405969	394642	384284	265067	234516	171076	159896	117047	86350	55460	46099	40164

Table 16. Mean biomass at age (mt) of Pacific ocean perch in the Aleutian stock as estimated by the cohort analysis base run.

MEAN POPULATION BIOMASS

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	20714	22323	33161	32741	18022	11619	8044	7537	6484	4864	3330	3047	3115	2377	1381	6773
6	28479	22998	24962	37238	35216	19686	12685	8985	8542	7290	5256	3575	3272	3604	1734	2040
7	37610	29162	22802	25850	35494	31648	18402	12889	9147	8811	6835	4729	3026	2919	2643	2093
8	48849	36539	25927	21238	23231	29016	22133	16245	11498	8626	7887	5574	3687	2338	1777	2928
9	55764	44695	30342	22097	18700	19397	19452	14776	12745	9385	6856	6087	4047	2771	1690	1634
10	59384	47992	35448	24361	19263	16346	15387	12362	10625	9359	6965	4234	3938	2446	1958	1622
11	56578	47437	36044	27686	20544	16915	14025	11569	9072	7703	6926	4238	2044	2144	1485	1789
12	49384	40218	32669	25907	22060	16812	13953	11272	8725	6948	5969	4772	2624	941	1267	1247
13	38063	30107	24541	20719	18476	16674	11959	10802	8252	6451	5019	4072	3199	1518	537	1050
14	25135	20319	16604	13383	12853	13039	10205	8041	7599	5967	4699	3076	2522	2003	946	381
15	14050	12935	10457	7995	6901	8666	7135	5901	5189	5299	4334	3023	1763	1530	1377	788
16	7954	7431	6438	4564	3532	4259	4724	3540	3742	3470	4081	2946	1977	1018	836	1070
17	5551	4734	3440	2648	1836	2022	2171	2321	2178	2357	2233	2812	1920	1131	542	524
18	4218	3936	2313	1104	1078	1031	1051	917	1522	1377	1411	1130	1836	1073	504	304
19	1193	3316	2398	862	295	653	609	448	534	1079	874	782	639	1250	462	295
20	119	853	2288	1387	380	126	456	323	259	330	753	523	494	375	757	228
5+	453046	374995	309834	269780	237879	207908	162392	127927	106114	89315	73428	54622	40104	29437	19897	24767
6+	432332	352672	276674	237039	219857	196289	154348	120390	99629	84451	70099	51574	36989	27060	18516	17994
7+	403853	329674	251711	199801	184641	176603	141663	111405	91088	77161	64843	47999	33717	23456	16782	15954
8+	366242	300512	228909	173951	149147	144955	123261	98517	81940	68350	58007	43270	30691	20537	14139	13860

Table 17. Instantaneous fishing mortality (F) by age for Pacific ocean perch in the Aleutian stock as estimated by the cohort analysis base run.

FISHING MORTALITY

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	0.002	0.002	0.008	0.008	0.009	0.003	0.029	0.004	0.000	0.004	0.014	0.011	0.010	0.014	0.019	0.012
6	0.003	0.060	0.045	0.030	0.119	0.086	0.094	0.019	0.016	0.036	0.114	0.117	0.120	0.097	0.130	0.101
7	0.008	0.121	0.127	0.053	0.243	0.271	0.223	0.040	0.116	0.092	0.272	0.274	0.404	0.300	0.104	0.253
8	0.018	0.145	0.209	0.104	0.261	0.250	0.562	0.110	0.292	0.090	0.226	0.222	0.317	0.117	0.320	0.339
9	0.054	0.196	0.263	0.136	0.184	0.121	0.614	0.247	0.426	0.134	0.421	0.329	0.467	0.155	0.185	0.384
10	0.096	0.236	0.251	0.150	0.118	0.060	0.336	0.238	0.406	0.152	0.468	0.536	0.544	0.358	0.203	0.350
11	0.184	0.307	0.281	0.180	0.131	0.082	0.194	0.164	0.329	0.161	0.410	0.466	0.916	0.430	0.297	0.350
12	0.368	0.425	0.351	0.289	0.183	0.181	0.219	0.150	0.319	0.099	0.264	0.230	0.395	0.285	0.263	0.350
13	0.554	0.517	0.446	0.450	0.267	0.263	0.397	0.172	0.370	0.155	0.458	0.392	0.471	0.398	0.496	0.350
14	0.608	0.561	0.533	0.648	0.355	0.290	0.612	0.243	0.407	0.120	0.350	0.371	0.427	0.119	0.152	0.350
15	0.546	0.553	0.613	0.804	0.497	0.266	0.815	0.291	0.493	0.134	0.375	0.373	0.606	0.225	0.240	0.350
16	0.388	0.551	0.681	0.911	0.627	0.270	0.836	0.352	0.456	0.105	0.216	0.207	0.292	0.117	0.595	0.350
17	0.199	0.464	0.837	0.946	0.682	0.260	0.975	0.332	0.434	0.260	0.629	0.346	0.479	0.511	0.757	0.350
18	0.090	0.290	0.808	1.331	0.594	0.220	0.924	0.473	0.305	0.265	0.593	0.515	0.298	0.342	0.649	0.350
19	0.111	0.179	0.505	0.979	1.031	0.155	0.659	0.506	0.383	0.157	0.444	0.345	0.398	0.139	0.918	0.350
20	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350

Table 18. Numbers at age (in thousands) of Pacific ocean perch in the Gulf of Alaska stock as estimated by the cohort analysis base run.

POPULATION NUMBERS

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	516241	368602	282193	247073	223333	193853	159679	124231	117869	87401	69013	57400	52110	36583	29280	8279	9234
6	662913	442997	316439	232071	205444	191185	166390	136903	105653	101094	73913	58067	48501	43906	30487	24443	6971
7	781167	567219	379294	253638	186151	174323	163392	142392	116405	89384	81339	58474	46493	38098	33934	23509	20454
8	775758	661281	477715	285785	187194	153842	147292	137824	120792	93467	69513	60771	44069	33465	25864	23316	18827
9	666225	638631	529289	325381	182375	146897	126344	118982	114758	88673	70462	47902	44221	29469	19860	14799	15918
10	526873	523361	473957	321347	189023	133629	115681	96053	95921	78791	61280	46825	31862	28258	15001	9685	9383
11	412790	404162	371569	265813	186728	135052	99945	83361	75208	64580	50316	40636	32097	18836	15245	7960	6187
12	301643	320075	285049	206983	160720	134636	98587	68491	64958	52124	40682	31605	27045	19326	7438	7615	4353
13	215103	234832	225320	166734	133296	116196	97399	68359	53243	47370	33950	26277	21281	17079	10082	2214	4393
14	156943	166196	160500	140506	115634	96349	81841	69584	53926	38545	32284	22697	18195	13689	9809	5678	320
15	133186	119909	108490	101583	103611	84171	65809	58613	55357	38511	25385	20906	14872	10780	6622	4866	3972
16	100197	102192	74998	67874	76293	76161	56915	46976	45998	38563	25200	16444	14332	8967	5226	3540	3485
17	49854	76056	65585	46391	51009	54514	52049	41164	35973	29886	25138	16179	10418	8426	3585	2278	2266
18	49852	34714	48208	43456	34875	34312	35687	38590	31045	21693	18056	17064	10827	5725	3825	1591	1369
19	38894	36316	16824	31970	33869	21701	20457	25832	29026	18771	11838	11028	11630	6118	1545	1556	988
20	16153	28251	21479	7298	24965	21875	11502	13789	18350	18695	10344	7011	7338	7755	2883	461	1086
5+	5403792	4724793	3836908	2743901	2094519	1768698	1498968	1271143	1134481	907546	698713	539285	435290	326479	220688	141791	109205
6+	4887551	4356192	3554715	2496828	1871186	1574845	1339289	1146913	1016612	820145	629700	481885	383180	289896	191408	133512	99971
7+	4224638	3913195	3238276	2264758	1665743	1383660	1172900	1010009	910958	719052	555787	423818	334679	245990	160921	109068	93000
8+	3443471	3345976	2858981	2011120	1479592	1209337	1009507	867618	794553	629668	474448	365344	288186	207892	126986	85559	72546

Table 19. Mean biomass at age (mt) of Pacific ocean perch in the Gulf of Alaska stock as estimated by the cohort analysis base run.

MEAN POPULATION BIOMASS

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1513
6	126006	84231	58275	42753	38892	36319	31629	25943	19972	18651	13526	10688	8846	7946	5753	4106	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	202581	170358	113991	66157	47769	40128	38114	36190	29859	23398	16678	14960	10426	7492	6098	5313	5226
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3010
11	148171	138690	114358	84917	64747	47104	33836	29993	25597	21024	16358	13571	10234	4987	4763	2313	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	90738	93473	85947	66824	54474	46909	39585	29125	21775	18830	13375	10524	8235	6274	3855	435	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	63523	51957	47015	47957	48417	37817	30329	28258	25221	17040	11179	9453	6336	4164	2753	2015	1712
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1037
18	26672	15418	24679	24010	17335	16723	19036	20963	15229	10157	8898	8848	5150	1992	1575	673	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	8502	14870	11306	3841	13141	11514	6054	7258	9659	9840	5445	3690	3862	4082	1489	200	527
5+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32597
6+	1493342	1332623	1043496	776479	628631	526823	446055	394451	335205	262178	198414	153979	117771	80417	52970	34135	31084
7+	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8+	1190188	1120081	903895	679875	548014	451008	377436	336185	289502	224070	167518	130752	99171	64695	39820	25210	24575

Table 20. Instantaneous fishing mortality (F) by age for Pacific ocean perch in the Gulf of Alaska stock as estimated by the cohort analysis base run.

FISHING MORTALITY

	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
5	0.003	0.003	0.046	0.035	0.005	0.003	0.004	0.012	0.004	0.018	0.023	0.018	0.021	0.032	0.031	0.022	0.018
6	0.006	0.005	0.071	0.070	0.014	0.007	0.006	0.012	0.017	0.067	0.084	0.072	0.091	0.108	0.110	0.028	0.036
7	0.017	0.022	0.133	0.154	0.041	0.018	0.020	0.015	0.069	0.101	0.142	0.133	0.179	0.237	0.225	0.072	0.077
8	0.045	0.073	0.234	0.299	0.092	0.047	0.063	0.033	0.159	0.133	0.222	0.168	0.252	0.372	0.408	0.232	0.163
9	0.091	0.148	0.349	0.393	0.161	0.089	0.124	0.065	0.226	0.220	0.259	0.258	0.298	0.525	0.568	0.306	0.278
10	0.115	0.193	0.428	0.393	0.186	0.140	0.178	0.095	0.246	0.298	0.261	0.228	0.376	0.467	0.484	0.298	0.344
11	0.104	0.199	0.435	0.353	0.177	0.165	0.228	0.099	0.217	0.312	0.315	0.257	0.357	0.779	0.544	0.454	0.350
12	0.100	0.201	0.386	0.290	0.174	0.174	0.216	0.102	0.166	0.279	0.287	0.246	0.310	0.501	1.062	0.400	0.350
13	0.108	0.231	0.322	0.216	0.175	0.201	0.186	0.087	0.173	0.233	0.253	0.218	0.291	0.405	0.424	1.786	0.350
14	0.119	0.277	0.307	0.155	0.168	0.231	0.184	0.079	0.187	0.268	0.285	0.273	0.373	0.576	0.551	0.207	0.350
15	0.115	0.319	0.319	0.136	0.158	0.241	0.187	0.092	0.212	0.274	0.284	0.228	0.356	0.574	0.476	0.184	0.350
16	0.126	0.294	0.330	0.136	0.186	0.231	0.174	0.117	0.281	0.278	0.293	0.306	0.381	0.767	0.680	0.296	0.350
17	0.212	0.306	0.262	0.135	0.247	0.274	0.149	0.132	0.356	0.354	0.237	0.252	0.449	0.640	0.662	0.359	0.350
18	0.167	0.574	0.261	0.099	0.324	0.367	0.173	0.135	0.353	0.456	0.343	0.233	0.421	1.160	0.750	0.327	0.350
19	0.170	0.375	0.685	0.097	0.287	0.485	0.244	0.192	0.290	0.446	0.374	0.257	0.255	0.603	1.059	0.210	0.350
20	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350

Abundance

Stock size was initially examined by grouping the estimated number of fish at age into pre- and post-recruits. For purposes of this analysis, recruitment was assumed to be "knife-edge" at age 11 for the Gulf of Alaska stock and at age 10 for the Bering Sea stocks. Pre-recruits in each stock consisted of all individuals less than the age of full recruitment; post-recruits comprised those individuals greater than that age.

The abundance estimates of pre- and post-recruits show an almost continuous decline in all three stocks (Table 21). Pre-recruits in the eastern slope region show a decline of 89 percent from 1963 to 1976. Nearly the same percentage decline was observed in the Aleutian region during the period from 1964 to 1976. The greatest reduction in pre-recruits was noted in the Gulf of Alaska region; pre-recruits in this region decreased 95 percent from 1963 to 1976.

Post-recruits, those that were assumed fully vulnerable to the gear, also showed drastic reductions in abundance. In the Aleutian region, post-recruits declined 91 percent from 1964 to 1976. From 1963 to 1976, the Gulf of Alaska post-recruits declined 92 percent while those in the eastern slope region decreased 73 percent.

Table 21. Abundance of pre- and post-recruits (thousands of fish)[1/] by stock, 1963-76. Estimated from the cohort analysis base runs.

	Eastern Slope		Aleutian		Gulf of Alaska	
Year	Pre-recruits	Post-recruits	Pre-recruits	Post-recruits	Pre-recruits	Post-recruits
1963	362,045	219,850	--	--	3,929,177	1,474,615
1964	342,901	207,008	818,545	645,169	3,202,091	1,522,702
1965	329,917	184,906	713,607	555,274	2,458,887	1,378,021
1966	314,594	184,965	692,316	433,382	1,665,295	1,078,606
1967	303,614	169,216	711,239	324,470	1,173,520	920,999
1968	265,313	132,963	663,483	250,560	993,729	774,969
1969	227,393	108,239	531,203	216,073	878,778	620,190
1970	174,928	112,666	400,847	203,929	756,385	514,758
1971	156,569	112,881	272,584	153,826	671,398	463,083
1972	133,834	107,771	230,154	140,435	538,810	368,736
1973	114,569	103,863	178,210	108,739	425,520	273,193
1974	98,225	99,691	144,956	103,362	329,439	209,846
1975	65,850	75,632	109,837	73,479	267,256	168,034
1976	39,790	58,854	88,035	55,875	209,779	116,700

1/ Pre-recruits: Eastern slope 5-9 yr olds
Aleutian 5-9 yr olds
Gulf of Alaska 5-10 yr olds

Post-recruits: Eastern slope 10-20 yr olds
Aleutian 10-20 yr olds
Gulf of Alaska 11-20 yr olds

The number of 5 year olds, as determined by cohort analysis, was employed as an index of year class strength. Estimates for the 1958 to 1971 year classes are shown in Figure 17. The Gulf of Alaska stock shows a continuous, long-term decline in year class size. The 1958 year class from this stock was estimated at over 516.2 million individuals. Thirteen years later, the abundance of 5 year olds in 1976 (1971 year class) was estimated at 36.6 million fish, a reduction of 93 percent.

Two consecutive strong year classes were evident in the Aleutian stock. They were the 1961 and 1962 year classes, and both were about equal to or slightly greater than the same year classes from the Gulf of Alaska stock. They were later followed by three year classes (1963-1965) of much smaller size. Year class strength in this stock appears to have stabilized somewhat after the 1965 year class entered the fishery.

Marked fluctuations in year class size were not evident in the eastern slope stock. The strong 1961 and 1962 year classes purported by Chikuni (1975) were not obvious. There was, however, a slight increase in abundance of about 7 percent in the 1961 year class. The overall trend in year class strength was downward in this region.

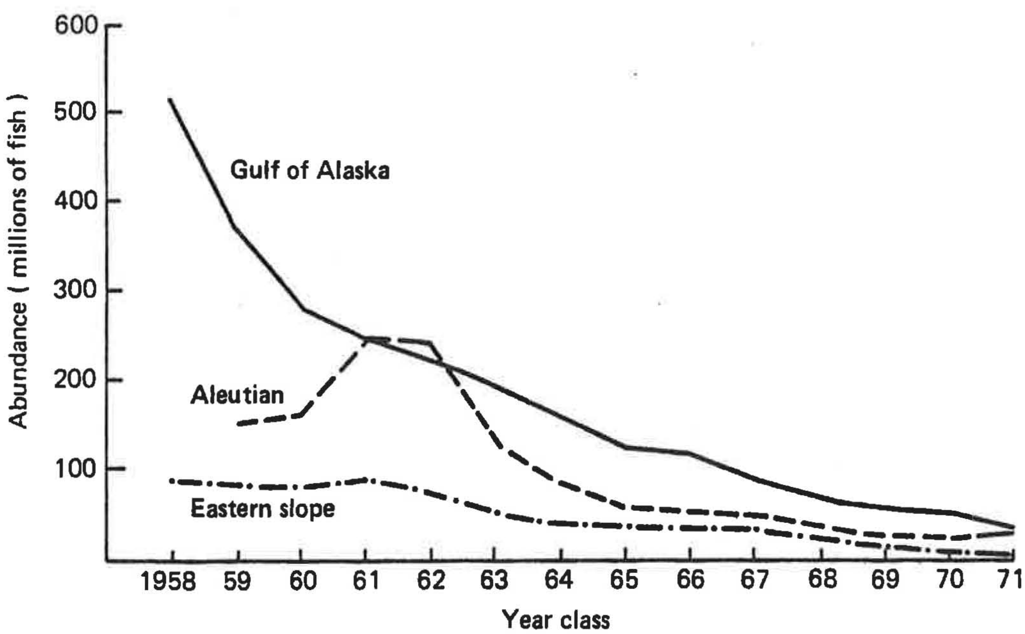

Figure 17. The abundance of 5 year olds in each stock as determined by the cohort analysis base runs, 1958-1971 year classes.

The exact cause of the overall weakening of year class strength is not known. However, the excessive removals taken during the 1960's and early 1970's undoubtedly diminished the reproductive potential of each stock. Adverse environmental factors may also have contributed to the decline in year class strength. The compensatory and depensatory mechanisms affecting recruitment are not fully understood. Until these mechanisms are known with greater certainty, the cause of reduced year class strength will remain in doubt.

Annual changes in absolute abundance, as determined by the cohort analysis base runs, are depicted in Figure 18. In all three regions, absolute stock size has decreased in a continuous fashion. Mean stock biomass (5 to 20 year olds) from 1963-1976 showed reductions of 94.5 and 84.6 percent for the Gulf of Alaska and eastern slope stocks, respectively. From 1964 to 1976, mean population biomass fell 91.2 percent in the Aleutian region.

The continuous downward trend in stock abundance suggests that the three Pacific ocean perch populations have been overexploited on an annual basis. So much so, that the harvest in any given year always exceeded surplus production. This created a negative net production which prevented any increase in population size.

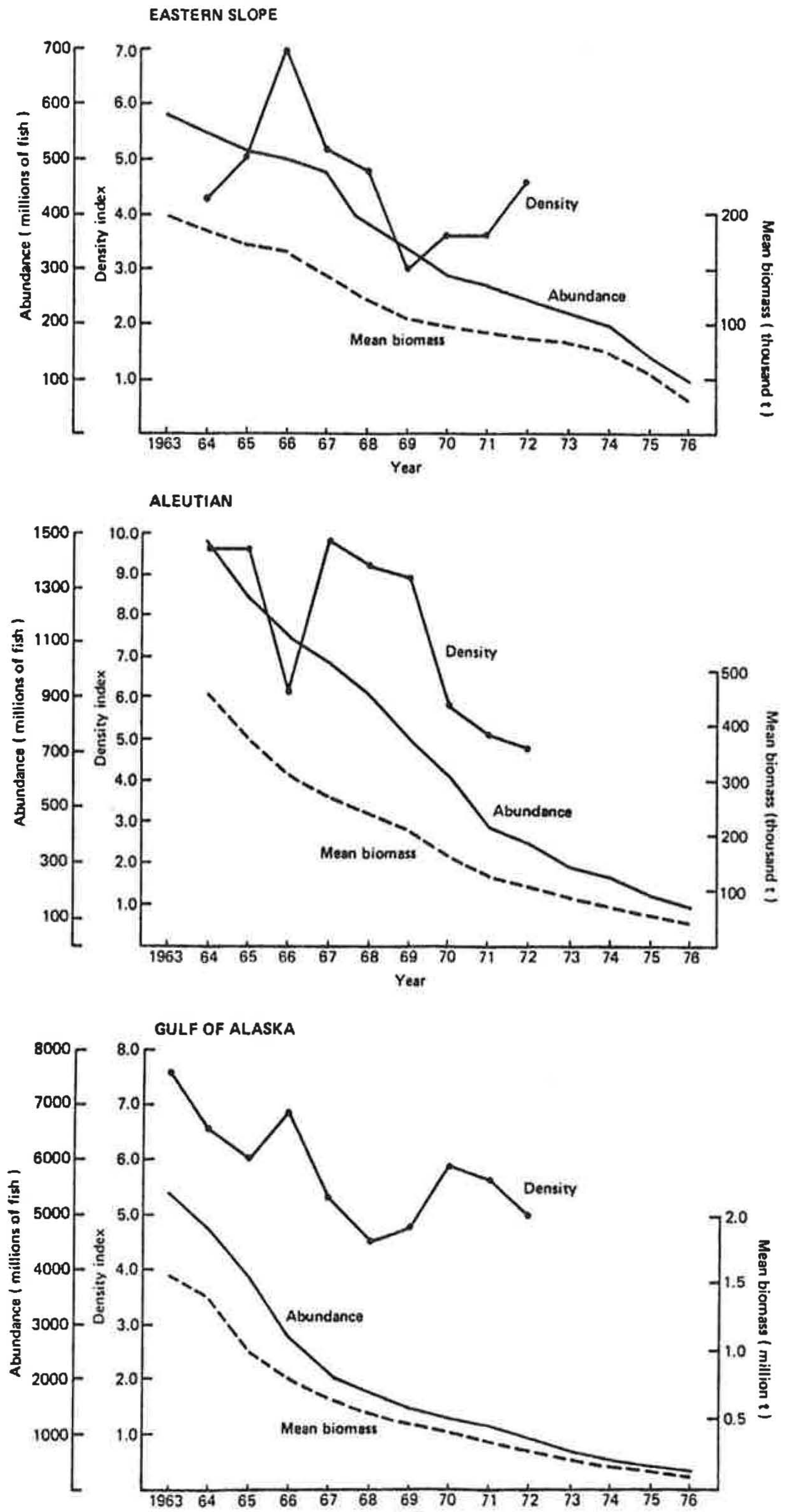

Figure 18. Estimates of population numbers and mean biomass (age 5 to 20) in each stock as determined by the cohort analysis base runs, 1963-1976. Density index derived by Chikuni (1975).

The large removals taken during the early and mid 1960's apparently started this "snowball" effect of decreasing stock abundance. With the excessive removals of older fish during those years, the reproductive potential of each stock was lessened. As noted by Quast (1972) and Gunderson (1977), Pacific ocean perch populations lack the resilience of highly fecund fish such as the gadoids. Once the older fish were reduced to low levels, the fishery apparently moved into shallower water and began harvesting the smaller fish. By harvesting those fish that had not yet reached their full reproductive potential, a further decline in stock abundance was inevitable.

An examination of the foreign reported catch and effort statistics was undertaken to determine if trends in CPUE parallel abundance trends from cohort analysis. Only data provided by Japan were utilized, since Japan was the only nation to provide detailed fishery statistics since 1964. The data employed were taken from the mothership and North Pacific trawl fisheries. CPUE was calculated as the catch of Pacific ocean perch in metric tons per stern trawl hour. This abundance index was determined for the period from 1964 to 1979 and was based on catch and effort data from all stern trawlers combined.

The overall trend of this index (Figure 19) appears to correlate well with the downward slide in absolute stock abundance. In the Gulf of Alaska stock, CPUE declined about 82 percent from 1965 to 1976; during this same period mean biomass fell approximately 92 percent. CPUE in the Aleutian stock fell from 7.32 to 0.65 during the period from 1964 to 1976, a reduction of 91 percent. Similarly, the mean biomass in the Aleutian stock declined by 91 percent during the same period. A comparison between CPUE and absolute stock abundance was not attempted for the eastern slope stock. Most of the trawl effort in this region was not directed towards Pacific ocean perch, and CPUE is probably not a reliable index of stock abundance.

Stern trawlers operating in the Japanese Pacific ocean perch fishery vary widely in size. As such, the fishing efficiency of each vessel is not constant. The above CPUE trends were based on catch and effort data from all vessel size classes combined. Perhaps a more realistic index of stock abundance would be CPUE based on individual vessel size categories.

After 1968, Japan began reporting catch and effort statistics by 9 vessel tonnage categories to INPFC. This classification allowed catch rates to be computed on a more detailed vessel class basis. The smallest category included boats ranging in weight from 71 to 100 gross tons. The

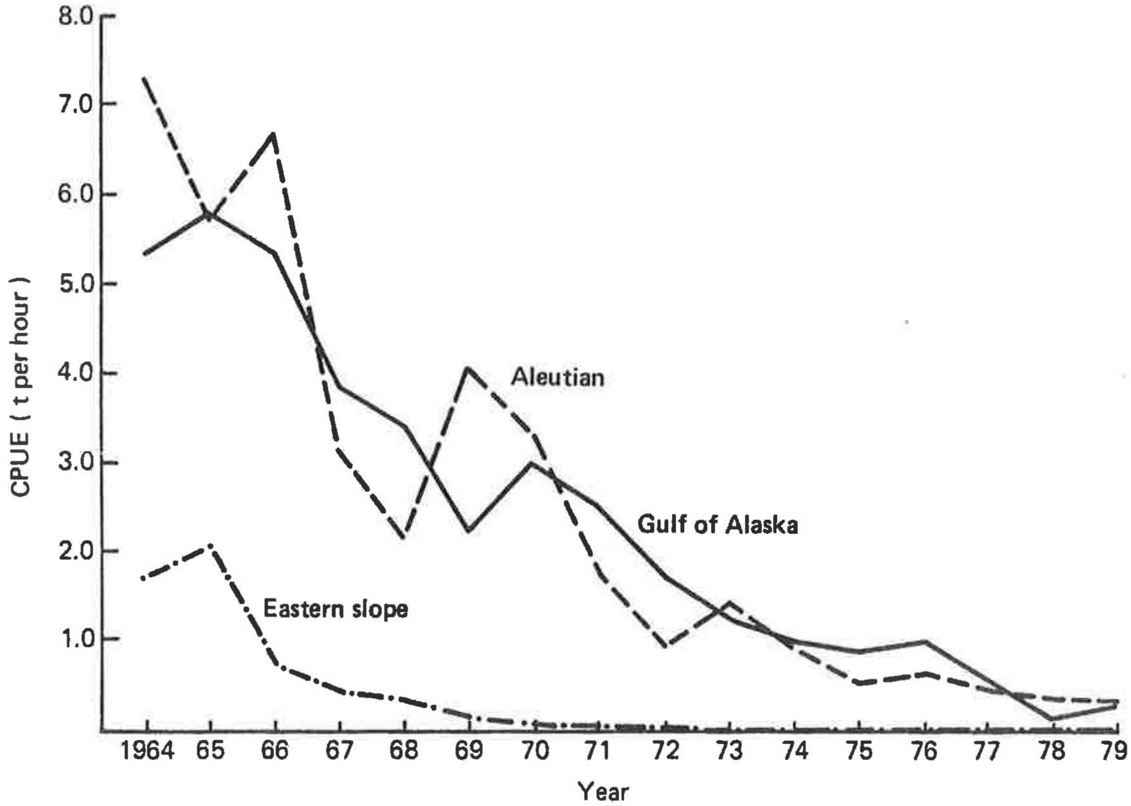

Figure 19. Catch of Pacific ocean perch per stern trawl hour, 1964-1979. Based on nominal trawl effort from the Japanese mothership, and North Pacific trawl fisheries, all stern trawlers combined.

largest vessel class was comprised of vessels weighing greater than 3,500 tons. Catch, effort, and CPUE for each vessel class in each region is given in Tables 22-24.

In the eastern slope region, CPUE of each vessel class has declined since 1968 to such low levels that recent values may not be meaningful (Table 22). Since most of the effort in this region is not directed specifically at Pacific ocean perch, CPUE may not be the best index of stock abundance. Nevertheless, continuing low Pacific ocean perch harvests despite high effort suggests low levels of abundance, since there is still a strong consumer demand for Pacific ocean perch in Japan.

Vessel classes 4 and 7 account for the majority of the Pacific ocean perch catch in the Aleutian region (Table 23). CPUE of both vessel classes have shown drastic declines since 1968-1969. Vessel class 4 shows a reduction in CPUE of 83.1 percent from 1968 to 1979; for vessel class 7 this reduction was 91.2 percent. Similarly, CPUE for all vessel classes combined declined about 84 percent during the eleven year period from 1968 to 1979.

In the Gulf of Alaska region, vessel classes 7, 8, and 9 accounted for most of the Pacific ocean perch harvested by Japanese stern trawlers (Table 24). As in the other two regions, the overall trend in CPUE is downward. The decline in CPUE ranged from 80.1 to 93.3 percent for the 3 major

Table 22. Pacific ocean perch catch and effort data of stern trawlers in the Japanese mothership and North Pacific trawl fishery by vessel class in the eastern Bering Sea slope region, 1968-1979.

	Vessel Class a/						
Year	3	4	5	6	7	8	9
(A) Catch in Metric Tons.							
1968	895	3,847	695	1,938	378	10,012	1,776
1969	361	3,709	102	258	94	4,037	2,103
1970	77	215	78	55	301	3,168	1,495
1971	96	1,558	35	203	992	1,855	459
1972	8	997	317	15	404	316	1,310
1973	—	377	—	199	487	146	398
1974	—	640	90	520	700	609	735
1975	—	578	204	343	784	171	293
1976	—	310	188	152	772	70	545
1977	—	380	357	155	114	193	534
1978	—	531	154	178	54	130	545
1979	—	731	201	42	104	44	85
(B) Fishing Effort in Number of Hours Trawled.							
1968	10,360	29,815	2,627	1,770	148	6,697	4,564
1969	9,505	26,462	1,617	1,463	1,228	9,542	12,536
1970	10,346	29,370	1,778	239	3,420	12,241	13,945
1971	12,548	41,096	2,082	1,914	3,522	14,614	26,638
1972	16,630	30,207	2,896	1,831	5,823	16,081	24,502
1973	—	25,674	1,307	1,612	3,494	11,810	39,696
1974	—	28,953	2,720	3,941	3,668	17,096	39,112
1975	—	41,734	5,506	4,063	3,792	15,797	36,325
1976	—	48,293	4,064	455	1,899	14,720	25,958
1977	—	44,420	3,018	1,533	465	9,869	31,791
1978	—	59,446	5,589	3,802	468	9,853	35,256
1979	—	52,733	5,093	3,095	1,523	9,330	29,140
(C) Catch in Metric Tons per Hour Trawled.							
1968	.086	.129	.265	1.095	2.554	1.495	.389
1969	.038	.140	.063	.176	.076	.423	.168
1970	.007	.007	.044	.230	.088	.259	.107
1971	.008	.038	.017	.106	.282	.127	.017
1972	.001	.033	.110	.008	.069	.020	.054
1973	—	.015	—	.123	.139	.012	.010
1974	—	.022	.033	.132	.191	.036	.019
1975	—	.014	.037	.084	.207	.011	.008
1976	—	.006	.046	.334	.406	.005	.015
1977	—	.009	.118	.010	.245	.020	.017
1978	—	.009	.028	.047	.115	.013	.016
1979	—	.014	.040	.014	.068	.005	.003

a/ No data for classes 1 and 2. 1973-1979 data converted to pre-1973 gross tonnage classification of:

1 = 71-100	4 = 301-500	7 = 1501-2500
2 = 101-200	5 = 501-1000	8 = 2501-3500
3 = 201-300	6 = 1001-1500	9 = 3501 and above

Table 23. Pacific ocean perch catch and effort data of stern trawlers in the Japanese mothership and North Pacific trawl fishery by vessel class in the Aleutian region, 1968-1979.

Year	Vessel Class a/ 4	5	6	7	8	9
(A) Catch in Metric Tons.						
1968	12,157	280	32	2,711	6,787	532
1969	7,290	440	—	4,839	1,125	144
1970	2,384	1,227	—	7,741	249	82
1971	3,322	889	1,038	4,984	2,249	449
1972	3,527	1,318	645	2,035	188	135
1973	4,596	—	995	1,881	—	—
1974	10,679	1,564	1,326	2,507	25	16
1975	3,916	972	764	1,815	666	—
1976	4,862	823	786	1,600	83	—
1977	2,802	771	219	580	37	—
1978	2,342	480	140	855	183	—
1979	2,265	691	50	696	141	16
(B) Fishing Effort in Number of Hours Trawled.						
1968	8,575	115	8	216	759	772
1969	1,952	335	—	910	179	38
1970	1,755	600	—	976	161	25
1971	4,543	634	383	720	785	176
1972	6,534	546	493	423	114	56
1973	3,999	—	658	533	36	—
1974	13,912	1,822	967	529	70	22
1975	12,337	1,233	543	521	509	—
1976	10,179	897	698	575	251	—
1977	7,599	1,096	248	411	89	—
1978	8,889	961	206	595	315	—
1979	9,517	1,110	68	631	213	29
(C) Catch in Metric Tons per Hour Trawled.						
1968	1.42	2.43	4.00	12.55	8.94	0.69
1969	3.73	1.31	—	5.32	6.28	3.79
1970	1.36	2.04	—	7.93	1.55	3.28
1971	0.73	1.40	2.71	6.92	2.86	2.55
1972	0.54	2.41	1.31	4.81	1.65	2.41
1973	1.15	—	1.51	3.53	—	—
1974	0.77	0.86	1.37	4.74	0.36	0.73
1975	0.32	0.79	1.41	3.48	1.31	—
1976	0.48	0.92	1.13	2.78	0.33	—
1977	0.37	0.70	0.88	1.41	0.42	—
1978	0.26	0.50	0.68	1.44	0.58	—
1979	0.24	0.62	0.74	1.10	0.66	0.55

a/ No data for classes 1, 2, and 3 which are mainly side and pair trawls.
1973-1979 data converted to pre-1973 gross tonnage classification of:

1 = 71-100	4 = 301-501	7 = 1501-2500
2 = 101-200	5 = 501-1000	8 = 2501-3500
3 = 201-300	6 = 1001-1500	9 = 3501 and above

Table 24. Pacific ocean perch catch and effort data of stern trawlers in the Japanese mothership and North Pacific trawl fishery by vessel class in the Gulf of Alaska region, 1968-1979.

	Vessel Class a/					
Year	4	5	6	7	8	9
(A) Catch in Metric Tons.						
1968	1,149	3,401	235	12,465	21,727	15,827
1969	4,227	2,143	360	10,096	28,008	8,700
1970	5,482	1,511	—	9,472	21,614	6,110
1971	2,887	2,772	—	13,088	14,522	14,371
1972	4,332	2,618	2,830	12,388	13,560	13,827
1973	12,315	2,691	2,350	10,342	7,317	12,333
1974	7,492	3,009	2,858	2,947	10,692	9,897
1975	2,338	4,568	4,644	4,928	10,941	6,706
1976	1,613	6,434	4,556	3,463	10,135	9,151
1977	2,522	2,357	1,682	2,281	6,511	3,891
1978	508	233	326	621	1,230	984
1979	1,046	234	696	952	1,935	1,631
(B) Fishing Effort in Number of Hours Trawled.						
1968	1,246	3,496	51	2,255	4,185	4,846
1969	5,510	2,459	241	2,351	7,394	5,886
1970	4,559	1,159	—	1,687	4,108	3,166
1971	5,860	2,265	6	2,506	3,239	4,990
1972	11,437	1,957	1,256	2,979	4,401	5,930
1973	18,048	2,782	2,345	4,955	3,858	5,411
1974	14,380	3,318	3,250	1,702	6,476	7,314
1975	13,736	5,406	6,319	1,310	7,107	5,106
1976	11,674	7,315	4,828	1,015	4,758	5,205
1977	12,497	6,010	2,556	2,117	6,770	3,789
1978	11,387	2,824	2,639	1,933	6,786	2,328
1979	8,711	1,844	2,509	1,788	5,591	2,503
(C) Catch in Metric Tons per Hour Trawled.						
1968	0.92	0.97	4.61	5.53	5.19	3.27
1969	0.77	0.87	1.49	4.29	3.79	1.48
1970	1.20	1.30	—	5.61	5.26	1.93
1971	0.49	1.22	—	5.22	4.48	2.88
1972	0.38	1.34	2.25	4.16	3.08	2.33
1973	0.68	0.97	1.00	2.09	1.90	2.28
1974	0.52	0.91	0.88	1.73	1.65	1.35
1975	0.17	0.84	0.73	3.76	1.54	1.31
1976	0.14	0.88	0.94	3.41	2.13	1.76
1977	0.20	0.39	0.66	1.08	0.96	1.03
1978	0.04	0.08	0.12	0.32	0.18	0.42
1979	0.12	0.13	0.28	0.53	0.35	0.65

a/ Excluding minor catches from classes 1, 2, and 3. 1973-1979 data converted to pre-1973 gross tonnage classification of:

1 = 71-100	4 = 301-501	7 = 1501-2500
2 = 101-200	5 = 501-1000	8 = 2501-3500
3 = 201-300	6 = 1001-1500	9 = 3501 and above

vessel classes during the period from 1968 to 1979. For the same period, CPUE of all vessel classes combined dropped 91.7 percent.

The analysis of CPUE presented thus far was rather simplistic. No attempts were made to adjust for differences in effective fishing effort. Effort was treated as if all stern trawl hours were directed toward catching Pacific ocean perch; such was not the case. Any vessel operating in the Pacific ocean perch fishery does not depend solely on this species to fill its fish holds. Some hauls are directed towards S. alutus on one day or at one time, and other hauls on other days or at other times are directed towards other species. Furthermore, with recent quota restrictions on the harvest of Pacific ocean perch, much of the Japanese trawl effort has shifted to other target species. Recent changes in CPUE may not be indicative of actual changes in stock abundance.

Other factors affecting CPUE as an indicator of stock abundance have been described by Ricker (1975), Beverton and Holt (1957), and Gulland (1969). Factors pertaining to the groundfish fisheries of the North Pacific in general and to the Pacific ocean perch fishery in particular have been discussed by Low (1974) and Chikuni (1975).

Chikuni (1975) derived a relative abundance index based on changes in CPUE in the Japanese trawl fisheries. Stern trawlers of vessel class 8 were employed as the standard vessel for all regions. Since S. alutus is caught in a multi-species fishery, Chikuni attempted to account for effort directed only toward this species. To accomplish this he regressed CPUE of vessel class 8 against the percent composition of Pacific ocean perch in the annual groundfish catch. The density index was then determined by inserting an arbritrarly set percentage figure (95 percent for the Bering Sea stocks and 85 percent for the Gulf of Alaska stock) into the regression equation. This adjusted CPUE supposedly represents what the true CPUE would be if all the effort were directed solely to harvesting Pacific ocean perch.

The trend of Chikuni's (1975) density index did not correlate well with changes in absolute stock abundance (Figure 18). This index indicated that after 1968 the eastern slope stock began a steady recovery. The results from cohort analysis, on the other hand, indicated a continuous long-term decline in stock abundance from 1963 to 1976. Similar discrepancies between the Chikuni density index and the results from cohort analysis were noted in the other two stocks as well. When confronted with this kind of conflicting information, one might wonder which set of estimates is more reliable.

The Chikuni index assumes that the percentage of Pacific ocean perch in the total groundfish catch represents the fraction of the total effort directed toward catching S. alutus. However, if all the effort was directed to catching Pacific ocean perch and this species represented only 20 percent of the total groundfish catch, no adjustment to the CPUE figure should be required. Chikuni's density index, however, would still make the correction to CPUE as if only 20 percent of the total effort was directed toward Pacific ocean perch. The density index in this case would biased toward the high side. Furthermore, this method involves such hazards as arbitrarily fixing the standard catch proportion at 95 percent for the Bering Sea stocks and 85 percent for the Gulf of Alaska stock.

When employing CPUE as an index of stock abundance, the major source of bias stems from the measurement of effective fishing effort. Effective effort is very difficult to measure, particularly in multi-species fisheries. Chikuni (1975) attempted to estimate effective fishing effort, but as noted above, there were drawbacks with his method. Furthermore, none of the CPUE indicies considered in this analysis have made adjustments for learning and skill factors. Rapid developments in technology and fishing skill undoubtedly occurred throughout the history of the Pacific ocean perch fishery, and CPUE may be seriously biased an an index of stock abundance unless these factors are considered.

The abundance results from cohort analysis do not depend on having accurate measures of effective fishing effort. Cohort analysis provides stock assessments independent of effort. Stock size is measured as an absolute value, rather than as an index. Although cohort analysis is free of errors associated with the estimation of effective fishing effort, this type of analysis is subject to its own set of errors. These potential errors are discussed later in the thesis.

Because of the uncertainty regarding the actual values of the input parameters, the cohort analysis was executed with an array of M and F(t) combinations. M was varied using values of 0.05, 0.10, 0.15, 0.20, and 0.30. The values of F(t) employed were 0.175, 0.350. 0.525, 0.700, and 1.050. These values encompass a range of conceivable values for the model parameters. For each stock, twenty five runs were necessary to accommodate all possible combinations of these trial values.

Tables 25-27 show the effects on the estimates of stock abundance when M and F(t) are varied. These abundance estimates are for the 5 to 20 year olds present in each stock during 1964. Abundance is expressed as numbers (N) or

Table 25. Abundance of 5-20 year olds in the eastern slope stock in 1964, as estimated by cohort analysis with varying M and F(t) parameter values.[1]

		M				
F_t		0.05	0.10	0.15	0.20	0.30
	N	355,940	461,860	626,035	891,027	2,099,396
0.175	B_o	146,134	179,908	229,320	304,816	623,616
	$\bar{B}$	139,639	170,988	216,768	286,428	576,708
	N	325,051	414,665	549,909	762,459	1,693,580
0.350	B_o	129,621	157,431	197,006	255,736	492,735
	$\bar{B}$	122,690	148,340	184,769	238,664	453,640
	N	314,856	399,083	524,769	719,989	1,559,456
0.525	B_o	124,171	150,010	186,334	239,524	449,479
	$\bar{B}$	117,072	140,838	174,179	222,837	412,944
	N	309,833	391,403	512,372	699,038	1,493,233
0.700	B_o	121,486	146,352	181,072	231,526	428,121
	$\bar{B}$	114,292	137,129	168,944	215,026	392,839
	N	304,955	383,937	500,309	678,631	1,428,618
1.050	B_o	118,878	142,796	175,952	223,736	407,282
	$\bar{B}$	111,573	133,504	163,832	207,402	373,205

1/ N = number of fish (thousands)

B_o = initial biomass (mt)

$\bar{B}$ = mean biomass (mt)

Table 26. Abundance of 5-20 year olds in the Aleutian stock in 1964, as estimated by cohort analysis with varying M and F(t) parameter values.[1/]

		M				
F_t		0.05	0.10	0.15	0.20	0.30
	N	1,032,082	1,231,797	1,506,761	1,899,881	3,393,432
0.175	B_o	380,580	440,874	520,253	628,274	1,005,052
	$\overline{B}$	347,403	400,069	469,331	563,455	890,299
	N	1,014,933	1,205,389	1,463,714	1,826,074	3,149,700
0.350	B_o	372,118	429,335	503,705	603,240	938,242
	$\overline{B}$	338,759	388,506	453,046	539,241	827,856
	N	1,009,273	1,196,670	1,449,498	1,801,693	3,069,145
0.525	B_o	369,326	425,525	498,240	594,971	916,161
	$\overline{B}$	335,904	384,686	447,666	531,240	807,215
	N	1,006,485	1,192,373	1,442,488	1,789,666	3,029,372
0.700	B_o	367,950	423,647	495,545	590,891	905,259
	$\overline{B}$	334,497	382,802	445,012	527,292	797,023
	N	1,003,776	1,188,196	1,435,666	1,777,951	2,990,565
1.050	B_o	366,613	421,821	492,923	586,917	894,621
	$\overline{B}$	333,128	380,969	442,428	523,445	787,076

1/ N = number of fish (thousands)

B_o = initial biomass (mt)

$\overline{B}$ = mean biomass (mt)

Table 27. Abundance of 5-20 year olds in the Gulf of Alaska stock in 1964, as estimated by cohort analysis with varying M and F(t) parameter values.1/

		M				
F_t		0.05	0.10	0.15	0.20	0.30
	N	3,471,711	4,171,316	5,151,257	6,571,373	11,999,481
0.175	B_o	1,193,807	1,414,166	1,716,172	2,143,023	3,701,505
	$\overline{B}$	1,111,882	1,306,211	1,571,651	1,944,890	3,290,456
	N	3,258,725	3,875,475	4,724,793	5,933,619	10,417,903
0.350	B_o	1,089,212	1,276,162	1,528,009	1,877,632	3,117,606
	$\overline{B}$	1,005,657	1,169,308	1,389,183	1,693,135	2,759,404
	N	3,188,429	3,777,804	4,583,953	5,722,951	9,895,185
0.525	B_o	1,054,690	1,230,601	1,465,870	1,789,966	2,924,626
	$\overline{B}$	970,433	1,123,942	1,328,755	1,609,801	2,583,717
	N	3,153,796	3,729,663	4,514,511	5,619,022	9,637,098
0.700	B_o	1,037,682	1,208,144	1,435,228	1,746,718	2,829,343
	$\overline{B}$	953,002	1,101,504	1,298,878	1,568,611	2,496,894
	N	3,120,161	3,682,862	4,446,934	5,517,798	9,385,275
1.050	B_o	1,021,165	1,186,313	1,405,412	1,704,594	2,736,374
	$\overline{B}$	935,962	1,079,580	1,269,696	1,528,383	2,412,070

1/ N = number of fish (thousands)

B_o = initial biomass (mt)

$\overline{B}$ = mean biomass (mt)

biomass (B_o) at the beginning of the year, and mean annual population biomass ($\overline{B}$). It is apparent that changes in terminal fishing mortality for a given M have relatively minor effects on the estimates of stock abundance. On the other hand, changes in M for a given terminal fishing mortality have a much greater influence on the estimates of stock size.

The abundance estimates from the Gulf of Alaska during 1964 (Table 27) were used to demonstrate the consequences of varying F(t) and M. Increasing the base terminal fishing mortality by a factor of 2, and without changing the base M, stock abundance (N) decreased only 4.4 percent. However, increasing the base natural mortality by the same factor, and not changing the base F(t) value, stock size expanded over 120.0 percent. The smallest estimates of abundance occurred when the smallest value of M and the largest value of F(t) were employed concurrently. Conversely, the largest estimates of stock abundance were obtained when the largest value of M and the smallest value of F(t) were used in the same run. These same sort of dynamics were evident in the other two stocks as well (Tables 25 and 26).

The paired values of M=0.05, F(t)=1.050, and M=0.30, F(t)=0.175 yielded the lowest and highest estimates respectively of stock abundance in any given year. Abundance estimates based on these two sets of parameter values established a "range" about the base population estimates. For each stock, the estimates of mean population biomass from the base runs and from the "range" parameter sets were plotted against time (Figure 20).

In each region the trend in mean biomass, irregardless of the parameter set employed, was downward (Figure 20). When M=0.30 and F(t)=0.175 were employed, the decline in biomass was much steeper than when the other two parameter sets were utilized. The estimates of abundance were highly sensitive to increases in natural mortality.

The above estimates of abundance were based on catch at age data for 5 to 20 year olds. The data comprised the seventeen year period from 1963 to 1979. Age composition data utilized in this study were obtained from two different sources -- Chikuni (1975) and the U.S. observer program. As previously mentioned, adequate age information was unavailable for the period from 1973 to 1976. Therefore, an "average" age composition had to be calculated for each stock. Although the above age data may not be entirely precise, it was believed to represent the best available information.

To examine the effects of employing an "average" age composition within the data series, a comparison was made between the abundance estimates calculated from the base runs (1963-1979 data) and those obtained by using only

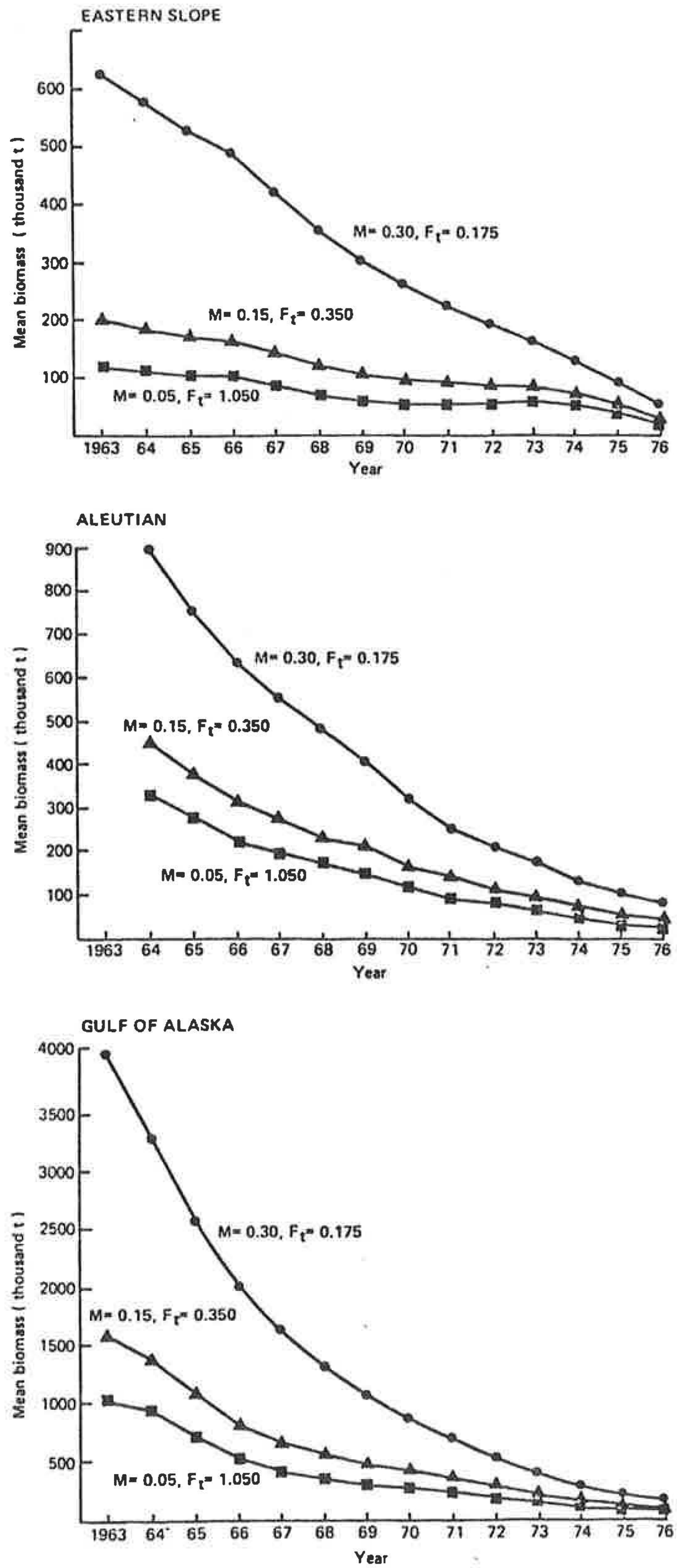

Figure 20. Mean biomass (mt) in each stock as determined by the cohort analysis base (M=0.15, F(t)=0.35), and "range" parameter (M=0.30, F(t)=0.175 and M=0.05, F(t)=1.05) runs, 1963-1976.

Chikuni's (1975) age information (1963-1972 data). Employing only the catch at age data from 1963 to 1972, cohort analysis was executed separately for 5-20 and 5-25 year olds. Both runs were executed with parameter values of M=0.15 and F(t)=0.35. This data was also subjected to a cohort analysis with M and F values derived by Chikuni (op. cit.)

Chikuni (1975) calculated natural mortality and a catchability coefficient (q) for each stock (Table 6). Multiplying q by Chikuni's estimates of yearly effective fishing effort yielded corresponding estimates of fishing mortality (Table 7); these estimates were used as the terminal fishing mortalities for the oldest age group in the catch. Terminal mortalities for the incompletely recruited cohorts in the final year of catch (1972) were adjusted in accordance with the selectivity factors presented in Table 9.

The results of these additional runs are given in Tables 28-30. Only abundance estimates through 1969 were examined. Abundance estimates after that year are probably less accurate, since the cohort analysis has not proceeded backward far enough over the successively younger ages.

In all three stocks, abundance has continuously declined irregardless of the data series employed. In no instance was there any indication of an upward trend in

Table 28. Population abundance of the eastern slope stock, as determined by cohort analysis, employing four different data series. Abundance is expressed in terms of thousands of fish (N), biomass (mt) presented at the beginning of each year (B_o) and mean annual biomass ($\bar{B}$).

Year		Data Series: Base[1/] (5-20 yr olds)	1963-1972[2/] (5-20 yr olds)	1963-1972[2/] (5-25 yr olds)	Chikuni[3/] (5-25 yr olds)
	N	581,895	445,500	443,173	792,349
1963	B_o	215,237	185,306	185,369	304,655
	$\bar{B}$	201,461	170,671	168,822	270,674
	N	549,909	384,033	382,566	649,562
1964	B_o	197,006	158,596	158,730	249,958
	$\bar{B}$	184,769	144,924	143,958	221,698
	N	514,823	326,048	324,798	534,952
1965	B_o	181,177	134,051	133,912	204,089
	$\bar{B}$	172,771	124,166	123,383	182,539
	N	499,559	296,070	294,832	476,067
1966	B_o	174,175	119,115	118,663	173,986
	$\bar{B}$	165,001	108,605	107,076	153,341
	N	472,830	273,767	273,263	446,769
1967	B_o	163,231	102,979	102,764	148,853
	$\bar{B}$	145,466	83,917	83,089	122,267
	N	398,276	210,980	213,546	404,927
1968	B_o	134,440	70,913	71,393	115,434
	$\bar{B}$	120,714	56,042	55,367	94,955
	N	335,632	158,954	171,667	344,901
1969	B_o	111,950	46,202	48,266	89,217
	$\bar{B}$	104,846	38,764	40,759	78,328

1/ Based on 1963 to 1979 catch at age data; M = 0.15, F(t) = 0.35

2/ Based on 1963 to 1972 catch at age data; M = 0.15, F(t) = 0.35

3/ Based on 1963 to 1972 catch at age data; M = .271 and F(t) parameters derived from Chikuni (1975)

Table 29. Population abundance of the Aleutian stock, as estimated by cohort analysis, employing four different data series. Abundance is expressed in terms of thousands of fish (N), biomass (mt) presented at the beginning of each year (B_o) and mean annual biomass ($\bar{B}$).

Year		Data Series: Base 1/ (5-20 yr olds)	1964-1972 2/ (5-20 yr olds)	1964-1972 2/ (5-25 yr olds)	Chikuni 3/ (5-25 yr olds)
	N	1,463,714	1,491,655	1,488,673	6,067,177
1964	B_o	503,705	509,856	508,217	1,687,174
	$\bar{B}$	453,046	459,347	457,725	1,443,540
	N	1,268,881	1,288,120	1,285,643	4,667,316
1965	B_o	429,280	435,104	433,650	1,323,888
	$\bar{B}$	374,995	380,948	379,308	1,126,199
	N	1,125,698	1,138,907	1,137,142	3,760,249
1966	B_o	353,181	358,695	357,631	1,045,080
	$\bar{B}$	309,834	315,361	313,253	886,747
	N	1,035,709	1,055,942	1,054,686	3,097,018
1967	B_o	297,523	304,062	303,184	833,092
	$\bar{B}$	269,780	276,325	274,960	713,343
	N	914,043	938,510	937,982	2,398,903
1968	B_o	259,571	266,955	266,586	655,546
	$\bar{B}$	237,879	245,298	244,854	560,448
	N	747,276	759,176	758,937	1,658,839
1969	B_o	225,080	231,277	231,117	490,197
	$\bar{B}$	207,908	214,027	213,854	416,507

1/ Based on 1964 to 1979 catch at age data; M = 0.15, F(t) = 0.35

2/ Based on 1964 to 1972 catch at age data; M = 0.15, F(t) = 0.35

3/ Based on 1964 to 1972 catch at age data; M = 0.424 and F(t) parameters derived from Chikuni (1975)

Table 30. Population abundance of the Gulf of Alaska stock, as estimated by cohort analysis, employing four different data series. Abundance is expressed in terms of thousands of fish (N), biomass (mt) presented at the beginning of each year (B_o) and mean annual biomass ($\bar{B}$).

Year		Base1/ (5-20 yr olds)	1963-19722/ (5-20 yr olds)	1963-19722/ (5-25 yr olds)	Chikuni3/ (5-25 yr olds)
	N	5,403,792	5,352,224	5,602,708	8,065,786
1963	B_o	1,667,103	1,662,463	1,805,079	2,570,371
	$\bar{B}$	1,572,541	1,567,411	1,698,642	2,397,441
	N	4,724,793	4,633,409	4,846,449	6,903,174
1964	B_o	1,528,009	1,515,397	1,641,272	2,307,294
	$\bar{B}$	1,389,183	1,375,859	1,489,612	2,100,008
	N	3,836,908	3,731,355	3,914,068	5,656,801
1965	B_o	1,279,456	1,261,538	1,373,297	1,956,312
	$\bar{B}$	1,085,903	1,067,287	1,168,317	1,704,640
	N	2,743,901	2,637,654	2,792,757	4,325,422
1966	B_o	931,355	909,976	1,007,764	1,526,461
	$\bar{B}$	813,808	791,703	882,661	1,362,434
	N	2,094,519	1,983,380	2,116,489	3,493,181
1967	B_o	729,737	704,658	791,354	1,259,148
	$\bar{B}$	662,853	637,381	710,723	1,144,553
	N	1,768,698	1,642,091	1,747,063	2,977,738
1968	B_o	614,191	584,121	653,407	1,075,406
	$\bar{B}$	556,567	526,246	586,401	978,716
	N	1,498,968	1,364,029	1,452,345	2,553,922
1969	B_o	514,449	480,373	539,767	921,677
	$\bar{B}$	470,541	436,284	489,562	845,144

1/ Based on 1963 to 1979 catch at age data; M = 0.15, F(t) = 0.35

2/ Based on 1963 to 1972 catch at age data; M = 0.15, F(t) = 0.35

3/ Based on 1963 to 1972 catch at age data; M = 0.193 and F(t) parameters derived from Chikuni (1975) abundance, as suggested by Chikuni's (1975) density indices for the same time period (Figure 18). The largest estimates of abundance in each stock were obtained with the Chikuni data series.

In both the Aleutian and Gulf of Alaska stocks, abundance estimates from the two 1963-1972 data series did not differ greatly from the base results (Tables 29 and 30). The differences in mean biomass between the three data sets never exceeded 9 percent. This situation, however, did not occur with the eastern slope stock (Table 28). In 1969 mean biomass in this region differed by 63 percent between the base and the 1963-1972 data series results for 5-20 year olds.

When employing only the 1963-1972 catch at age data, differences in abundance between the 5-20 and 5-25 year olds were relatively minor. The greatest differences in mean biomass between the two age groupings occurred in the Gulf of Alaska stock (Table 30). These differences, however, never exceeded 12.5 percent. Mean biomass of the 5-20 and 5-25 year olds in the other two stocks never differed by more than 5.1 percent for any given year.

Fishing Mortality

Instantaneous rates of fishing mortality as determined from the base runs are presented in Tables 14, 17, and 20. Only mortality estimates that were based on at least three sequential back calculations were examined. Under this criterion, the estimates of fishing mortality for the 5-17 year olds in each year (up to and including 1976) should be sufficiently accurate for purposes of this study.

The highest estimates of age specific fishing mortality were noted in the eastern slope stock (Table 14). In 1976 the age specific mortality rates were extremely high relative to earlier years. This is probably best explained by the drastic reduction in the age specific catch from 1976 to 1977 (Table 5). Total catch in terms of number of individuals declined 89 percent within that one year period. Consequently, cohort analysis had to generate high fishing mortalities in order to explain the existence of such large numbers in the 1976 catch.

The fishing mortality estimates from cohort analysis permitted an examination of the historical recruitment patterns to the fishery. Assuming that Pacific ocean perch were fully recruited at age 10 in the Bering Sea stocks and at age 11 in the Gulf of Alaska stock, fishing intensity relative to the first fully recruited age group was determined. This was done by pooling the mortality estimates by age for each 2 or 3 year period. An average was subsequently calculated for each age and then adjusted relative to the first fully recruited age group. This procedure was completed for the base mortality estimates, as well as for the "range" results (i.e. cohort analysis runs employing M=0.05, F(t)=1.05 and M=0.30, F(t)=0.175).

The results indicated that the pattern of recruitment to the fishery has changed throughout the years (Table 31). For any given region, however, the overall pattern seemed to vary little with the choice of input parameters.

During the mid 1960's and early 1970's, the younger fish became increasingly vulnerable to the gear (Table 31). These changes were particularly noticeable in the eastern slope and Aleutian regions. In both regions, fishing intensity increased substantially on the pre-recruited age groups. Within the eastern slope and Aleutian regions, the highest relative fishing intensities for 7-9 year olds were recorded during 1969-1971. This pattern tended to reverse itself during the period from 1972 to 1976. With the exception of a moderate increase in fishing intensity on the younger ages during 1966-1968, the overall recruitment pattern in the Gulf of Alaska has remained relatively constant.

Gunderson (1978) examined the recruitment patterns of Pacific ocean perch within several stocks along the British Columbia, Washington and Oregon coast. He, too, noted a trend towards increased fishing intensity on younger fish. He reasoned that this trend could partially be explained by increased fishing in shallow waters, where younger fish are

Table 31. Fishing intensity by age group and stock, relative to the assumed age at full recruitment.

EASTERN SLOPE

Age	M = 0.05, F(t) = 1.05					M = 0.15, F(t) = 0.35					M = 0.30, F(t) = 0.175				
	63-65	66-68	69-71	72-74	75-76	63-65	66-68	69-71	72-74	75-76	63-65	66-68	69-71	72-74	75-76
5	.03	.02	.22	.00	.01	.02	.02	.22	.00	.01	.00	.02	.23	.00	.00
6	.04	.10	.37	.36	.14	.03	.09	.37	.36	.68	.00	.10	.35	.36	.58
7	.10	.29	1.17	.79	.90	.24	.28	1.29	.80	.85	.05	.29	1.44	.81	.80
8	.26	.48	1.72	.88	.92	.22	.46	1.80	.90	.84	.18	.47	1.81	.97	.77
9	.64	.71	1.66	1.12	.86	.56	.70	1.78	1.11	.83	.42	.71	2.07	1.09	.79
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

ALEUTIAN

Age	M = 0.05, F(t) = 1.05					M = 0.15, F(t) = 0.35					M = 0.30, F(t) = 0.175				
	64-65	66-68	69-71	72-74	75-76	64-65	66-68	69-71	72-74	75-76	64-65	66-68	69-71	72-74	75-76
5	.02	.05	.06	.02	.03	.01	.05	.06	.02	.02	.01	.04	.05	.02	.02
6	.24	.36	.34	.19	.27	.19	.38	.31	.16	.22	.12	.39	.27	.14	.17
7	.46	.80	.83	.48	.81	.39	.82	.84	.47	.63	.23	.83	.84	.46	.47
8	.54	1.16	1.38	.59	.61	.49	1.10	1.45	.59	.50	.39	.95	1.56	.61	.40
9	.79	1.18	1.48	.92	.79	.75	1.12	1.55	.96	.74	.67	1.00	1.65	1.03	.66
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

GULF OF ALASKA

Age	M = 0.05, F(t) = 1.05					M = 0.15, F(t) = 0.35					M = 0.30, F(t) = 0.175				
	63-65	66-68	69-71	72-74	75-76	63-65	66-68	69-71	72-74	75-76	63-65	66-68	69-71	72-74	75-76
5	.09	.08	.04	.08	.09	.07	.06	.04	.07	.05	.04	.05	.03	.06	.02
6	.13	.15	.07	.28	.25	.11	.13	.07	.25	.18	.08	.11	.05	.23	.11
7	.24	.34	.20	.43	.45	.23	.31	.19	.42	.37	.22	.28	.16	.43	.27
8	.47	.63	.48	.58	.42	.48	.63	.47	.59	.55	.44	.66	.42	.63	.43
9	.78	.91	.76	.82	.82	.80	.92	.76	.83	.72	.76	.97	.74	.89	.58
10	.97	1.03	.95	.90	.79	1.00	1.03	.96	.89	.74	1.00	1.03	.93	.87	.68
11	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

usually more abundant. He also suggested that the younger fish may have recruited to the fishery earlier, once the abundance of the older age groups had become reduced.

The two suppositions forwarded by Gunderson (1978) likely pertain to the stocks of the current study. Determining which factor had the greatest influence on lowering the age of recruitment was difficult to assess. Data concerning the catch at age by depth was unavailable from the commercial fishery during the years of heavy exploitation. However, Chikuni (1975) indicated that the Japanese fishery, in trying to compensate for low yields, expanded their fishing operation to shallower and shallower waters, thus intensifying its effort on the schools of smaller fish. Whatever the cause, it had the effect of substantially lowering the age at recruitment in the eastern slope and Aleutian regions, from 10 years in 1963-1965 to about age 7-8 in 1969-1971.

Mortality generally increased with age (Figure 21). This relationship, based on average fishing mortalities from 1963 to 1976, also varied by region. In the Aleutian stock, mortality increased rapidly from age 5 to age 9, leveled off to about age 12, and thereafter increased sharply to age 17. A similar trend was noted in the eastern slope region, but age specific mortality rates in this region were significantly lower. Fishing mortality in the Gulf of

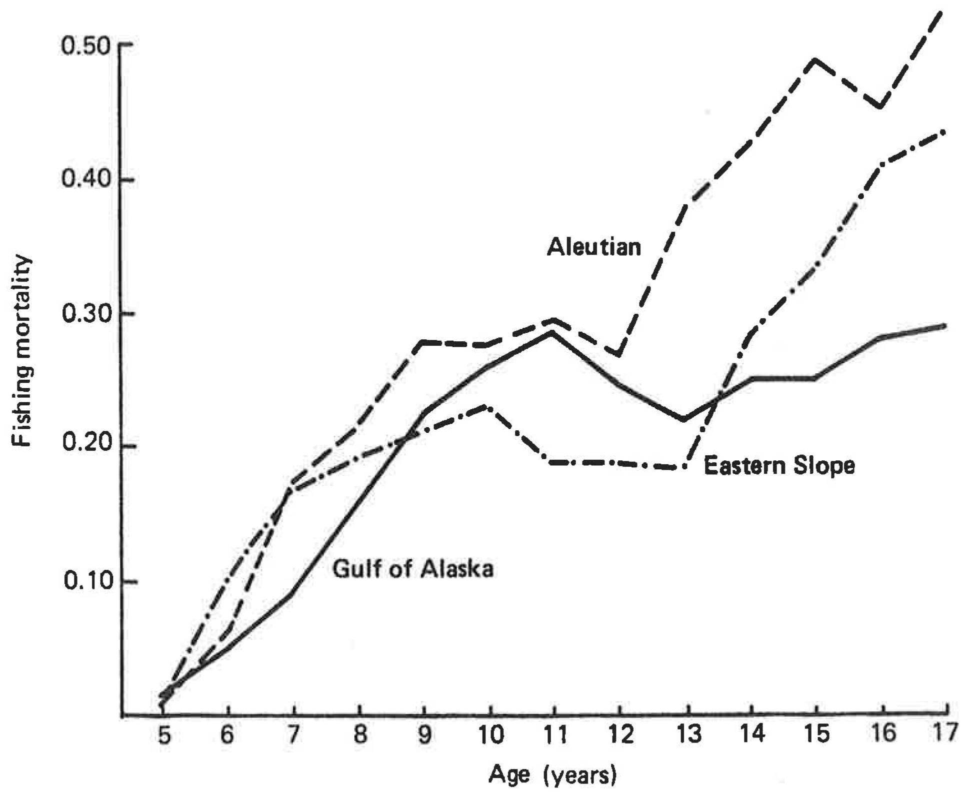

Figure 21. Average age-specific fishing mortality by stock. Based on the fishing mortality estimates from the cohort analysis base runs, 1963-1976.

Alaska increased continuously to age 11 but did not exhibit the marked increase in mortality during the later ages.

The increase in fishing mortality by age is probably due to the selectivity of the gear. As the fish become older and recruit to the fishing grounds, they become increasingly vulnerable to the trawls. Once fully recruited, however, the fishing mortality of these fish should remain relatively constant. The Gulf of Alaska stock appears to be an example of such a case (Figure 21). In this region mortality increased to age 11 (the assumed age at full recruitment) and, thereafter, mortality remained fairly stable.

Age specific fishing mortality from the other two stocks did not follow the same trend as that observed in the Gulf of Alaska region (Figure 21). Mortality rates within the Bering Sea and Aleutian stocks increased to about ages 9-10 and then appeared to level off somewhat for a span of approximately 3 to 4 ages. Rather than remain at a stable level after the age of assumed full recruitment, fishing mortality increased sharply after ages 12 and 13 in the Aleutian and eastern slope stocks, respectively. The reason for this dramatic increase in fishing mortality at the later ages is not clear. However, it does suggest that full recruitment in the Aleutian and eastern slope stocks may occur at a much higher age than previously thought.

Yearly trends in fishing mortality were examined after calculating the following weighted average:

$$\bar{F}_i = \frac{\Sigma\ (F_{i,j} * N_{i,j})}{\Sigma\ N_{i,j}}$$

where, $\bar{F}(i)$ = mean fishing mortality in year i
$F(i,j)$ = fishing mortality at age j in year i
$N(i,j)$ = number of fish at age j in year i

Only those age groups which were assumed to be fully recruited were employed in the summation. This average was calculated for the results from the base runs, as well as for the fishing mortality estimates obtained from the "range" parameter runs. The average, annual fishing mortality rates for each stock are shown in Figure 22.

Fishing mortality has fluctuated throughout the years, with the greatest annual changes occurring in both of the Bering Sea stocks (Figure 22). In all three stocks, mortality has increased during the later years of the series. It is apparent that the overall trends in fishing mortality do not change appreciably with changes in the input parameters.

Average fishing mortality in the eastern slope stock increased to high levels during 1967 and 1968. Mortality declined precipitously after 1968 and remained at relatively low levels for a period of about five years. These mortality rates, however, are deceptively low. The bulk of

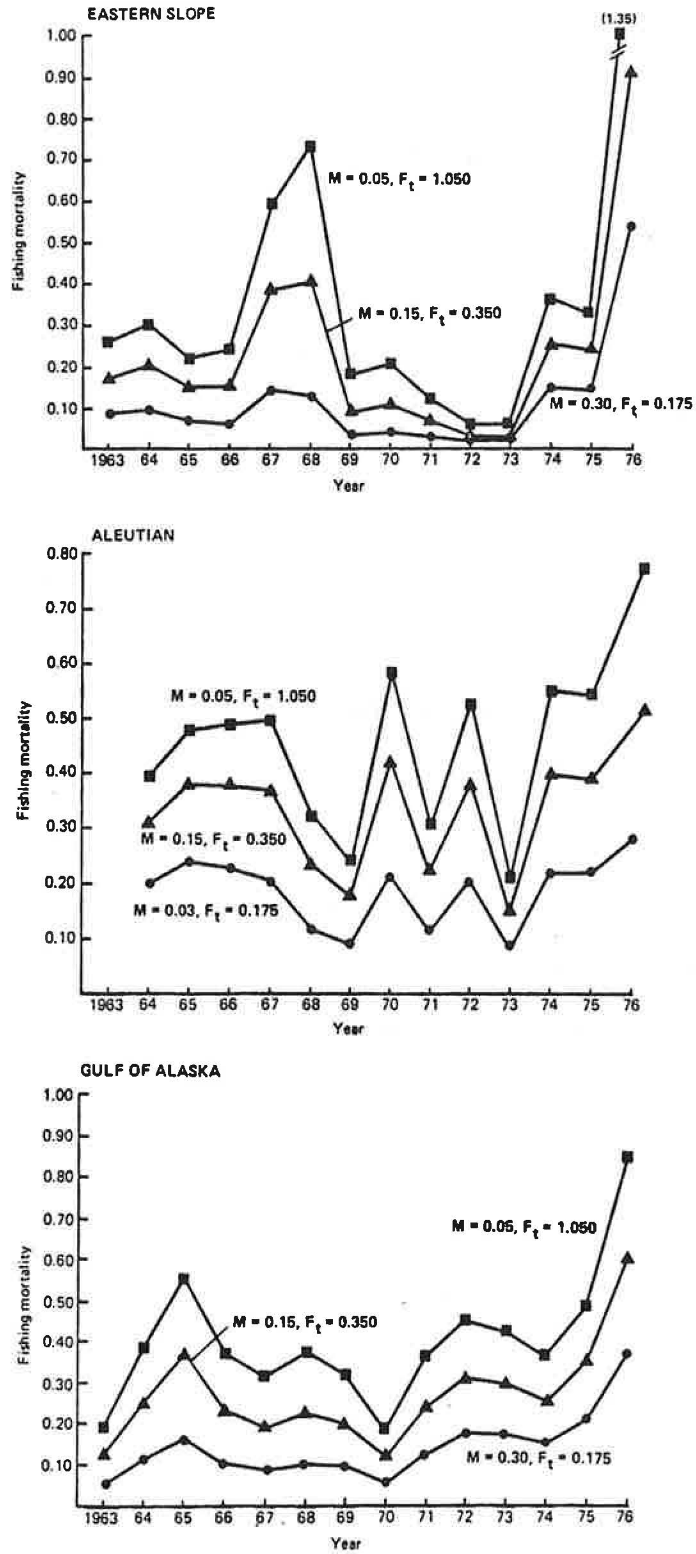

Figure 22. Average fishing mortality in the Bering Sea stocks (10-20 year olds), and Gulf of Alaska stock (11-20 year olds), 1963-1976. Based on the fishing mortality estimates from the base and "range" parameter runs.

the catches in 1969, 1971, and 1972 were comprised of ages less than 10 years and therefore were not included in the estimates of average fishing mortality. Mortality increased sharply during the period from 1973 to 1976. Low stock abundance coupled with continued large catches were the primary reasons for this upward trend. Although average mortality rates were not estimated after 1976, recent catches (Table 5) suggest that fishing mortality was probably relatively low from 1977 to 1979.

The trend in average fishing mortality in the Aleutian stock remained fairly constant during the four year period from 1964 to 1967. This was followed by a sharp decline in 1968 and 1969. Thereafter, fishing mortality fluctuated widely throughout the 1970's. These large annual changes in mortality were mainly due to the fluctuating catches taken during that period. Although the catches in the 1970's were significantly less than those taken during the 1960's, many of the mortality rates estimated for the 1970's exceeded those of the previous decade. This was due to the fact that population abundance had been reduced to very low levels. As with the eastern slope stock, the 1977-1979 Aleutian catches indicate that the average annual fishing mortality in these years were probably much less than the mortality recorded in 1976.

Average annual fishing mortality in the Gulf of Alaska stock did not exhibit the large fluctuations that were evident in the Bering Sea stocks. The greatest change in mortality within the Gulf stock occurred from 1975 to 1976. Using the estimates from the base runs, average fishing mortality increased about 74 percent during this one year period. Although this was considered a large increase, yearly changes of much greater magnitude were not uncommon in the Bering Sea stocks.

Despite the declining trend in catches, average fishing mortality in all three stocks remained relatively high during 1974 to 1976. This was not surprising considering that the stocks had been reduced to extremely low levels. Pacific ocean perch stocks in all three regions appear to be depleted, and it is questionable whether these stocks can sustain even 1977-1979 levels of harvest.

Drastic actions are probably required to return these stocks to former levels of abundance. Perhaps a first step should be to impose a ban on Pacific ocean perch fishing. However, even with such a moratorium, there is no assurance that the stocks will attain their former levels. As pointed out by Quast (1972), the niche formerly held by the large standing stocks of S. alutus during the early 1960's, may now be filled by another, faster growing, species. In addition, incidental catches made while seeking other species may be sufficiently great to keep Pacific ocean perch stocks in a depleted state, even in the absence of targeted fishery on *S. alutus*.

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APPENDICES

Appendix I. Input information and basic algorithms used in COHORT (from Rivard 1980).

Input Information.

The input information required by COHORT consists of:

t_o : first year of prediction;

t_f : final year of prediction;

b : age of youngest age-group;

m : age of oldest age-group;

$C_{\iota,\tau}$: catch between time t and t+1 and for age i to i+1. Note that τ refers to the period t, t+1, while ι refers to age-interval i, i+1.

$F_{\iota,f}$: (i = b, ..., m): the instantaneous rate of fishing mortality for each age-category in the final year (t_f).

$F_{\mu,\tau}$: (t = t_o, ..., t_f): the instantaneous rate of fishing mortality for the oldest age-group in each year.

M_ι : (i = b, ..., m): the instantaneous rate of natural mortality for age i (those are assumed to be constant for all years considered).

$W_{i+.5,t+.5}$: (i = b, ..., m; t = t_o, ..., t_f) weight-at-age, expressed in kilograms. Those are required only when population biomass is to be calculated (and production). The weights are taken as mid-year estimates.

Algorithm.

The calculations are performed in the following manner:

Population numbers: $N_{i,t}$

The program calculates population numbers by using three different equations.

Note that μ refers to the age-interval m,m+1, while τ_f refers to the time-interval t_f,t_f+1.

A) for the first (m-b-1) age-groups in the final year (i.e. for i = b, ..., m-1 and t = t_f), the $N_{i,t}$ are calculated as

$$N_{i,t_f} = C_{l,\tau_f} Z_{l,\tau_f} / F_{l,\tau_f} (1 - e^{-Z_{l,f}}) \qquad [1.1]$$

where $$Z_{l,\tau_f} = F_{l,\tau_f} + M_l \quad .$$

B) for the oldest age-group in each year (i.e. for i = m and t = t_o, ..., t_f), the population numbers are calculated as [1.1] if fishing is not complete for the oldest age-group and as

$$N_{m,t} = C_{\mu,\tau} Z_{\mu,\tau} / F_{\mu,\tau} \quad , \qquad [1.2]$$

if the fishing is complete for the oldest age-group.

Fishing is considered to be incomplete if the last row of the catch table (i.e. corresponding to the oldest age-group) includes only the catches from the oldest age-group but not the catches of older fish from the same cohort. If the catches of older fish have been added to the last row of the catch table or if there are no older fish, then fishing should be considered to be complete.

C) for the remainder of the table (i.e. for i = b, ..., m-1 and t = t_o, ..., t_f-1), population numbers are calculated by using the approximation

$$N_{i,t} = C_{l,\tau} e^{M_l/2} + N_{i+1,t+1} e^{M_l} \quad . \qquad [1.3]$$

Finally, the total population numbers are calculated for each year as

$$N_{\cdot,t} = \sum_{i=b}^{m} N_{i,t} \; (t = t_o, \ldots, t_f) \quad . \qquad [1.4]$$

Population biomass: $B_{i,t}$.

An 'average biomass' estimate and an estimate for 'population biomass at the beginning of the year' are calculated from the estimated population numbers and from the weight-at-age data. The 'average biomass' is calculated as

$$\bar{B}_{\iota,\tau} = W_{i+.5,t+.5}\, N_{i,t}\, (1 - e^{-Z_{\iota,\tau}}) / Z_{\iota,\tau} \quad .$$

Population biomass at the beginning of the year is calculated as

$$B_{i,t} = W_{i,t}\, N_{i,t} \quad ,$$

where $W_{i,t}$ represents weight-at-age corrected to the beginning of the year. The $W_{i,t}$ are approximated by

$$W_{i,t} = e^{(\ln W_{i-.5,t-.5} + \ln W_{i+.5,t+.5})/2} \quad .$$

For $t = t_o$ and $i = b$, the $W_{i,t}$ are approximated by the relationship

$$W_{i,t} = e^{(2 \ln W_{i+.5,t+.5} - \ln W_{i+1,t+1})} \quad .$$

For $t = t_f+1$ and $i = m+1$, the weights are approximated by the equation

$$W_{i+1,t+1} = e^{(2 \ln W_{i+.5,t+.5} - \ln W_{i,t})} \quad .$$

<u>Catch biomass:</u> $Y_{\iota,\tau}$

$$Y_{\iota,\tau} = W_{i+.5,t+.5}\, C_{\iota,\tau} \quad .$$

<u>Mean weight of individuals in catch:</u> $\bar{W}_\tau$

$$\bar{W}_\tau = \sum_\iota Y_{\iota,\tau} / \sum_\iota C_{\iota,\tau} \quad .$$

<u>Mean age of individuals in catch:</u> $\bar{i}_\tau$

$$\bar{f}_\tau = \sum_\iota i\, C_{\iota,\tau} / \sum_\iota C_{\iota,\tau} \quad .$$

Production over τ.

For each age-group, total production between t and t+1 (or say over a period τ) is evaluated from the summation of:

1) the observed change in biomass between t and t+1:

$$\Delta B_{l,\tau} = N_{i,t} \left(W_{i+1,t+1}\, e^{-Z_{l,\tau}} - W_{i,t}\right) \quad ;$$

2) the loss of biomass through natural mortality:

$$D_{l,\tau} = \frac{M}{Z_{l,\tau}} \; W_{i+.5,t+.5}\, N_{i,t} \left(1-e^{-Z_{l,\tau}}\right) \quad ;$$

3) the loss of biomass through fishing mortality: $Y_{l,\tau}$.

Since a number of cohorts exist simultaneously in the exploited population, total production over τ can be evaluated from

$$P_{\bullet,\tau} = B_{b,t} + G_{\bullet,\tau}$$

$$= B_{b,t} + \sum_{l} \Delta B_{l,\tau} + \sum_{l} D_{l,\tau} + \sum_{l} Y_{l,\tau}$$

where $B_{b,t}$ is the recruitment (expressed in biomass units) entering the exploited population at the beginning of the period τ (exogenous component) and $G_{\bullet,\tau}$ is the increase of biomass due to growth only (endogenous component)*. The net production can now be calculated as

$$P^{*}_{\bullet,\tau} = P^{**}_{\bullet,\tau} - \sum_{l} Y_{l,\tau} \quad ,$$

where $P^{**}_{\bullet,\tau}$, or 'surplus production', is defined as

$$P^{**}_{\bullet,\tau} = P_{\bullet,\tau} - \sum_{l} D_{l,\tau} \quad .$$

Surplus production is thus defined as the excess of recruitment and growth over the loss of biomass through natural deaths.

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* Note that the program also calculates the distribution of the growth component over the different age-groups from the evaluation of $(G_{l,\tau} / G_{\bullet,\tau}) \times 100$, where $G_{l,\tau} = \Delta B_{l,\tau} + D_{l,\tau} + Y_{l,\tau}$.

Fishing mortalities.

Age-specific rates of fishing mortality are calculated for each year (i.e. for $i = b, \ldots, m-1$ and $t = t_o, \ldots, t_f-1$) as

$$F_{i,t} = \ln\left(\frac{N_{i,t}}{N_{i+1,t+1}}\right) - M_i \quad . \qquad [1.5]$$

Note that the instantaneous rates of fishing mortality are provided as input data for each age-group in the final year and for the oldest age-group in each year.

An indication of the overall fishing mortality is obtained by calculating the following weighted F:

$$\overline{F}_t = \sum (N_{i,t} F_{i,t}) / \sum N_{i,t} \quad .$$

The summation is taken over the fully recruited ages only. The weighted F is calculated for each year t of the cohort analysis and appears on the bottom line of the table for age-specific fishing mortalities.

Appendix II. Input information and basic algorithms used in VPA (from Rivard 1980).

Input Information.

The input information required by VPA consists of:

t_o	: first year of the catch matrix;
t_f	: final year in the catch matrix;
b	: age of youngest age-group in the catch matrix;
m	: age of the oldest age-group in the catch matrix;
$C_{\iota,\tau}$	($t = t_o, \ldots, t_f$; $i = b, \ldots, m$): catch-at-age, given in numbers;
F_{ι,τ_f}	($i = b, \ldots, m$): the instantaneous rate of fishing mortality for each age-group in the final year (t_f);
$F_{\mu,\tau}$	($t = t_o, \ldots, t_f$): the instantaneous rate of fishing mortality for the oldest age-group in each year;
M_ι	($i = b, \ldots, m$): the instantaneous rate of natural mortality for each age-group (those are assumed to be constant for all years considered);
$W_{i+.5,t+.5}$	($i = b, \ldots, m$; $t = t_o, \ldots, t_f$): weight-at-age, expressed in kilograms. Those are required only when population biomass is to be calculated. The weights are taken as mid-year estimates.

Algorithm.

The function VPA calculates the population numbers at age and the instantaneous rate of fishing mortality at age; when information on weight-at-age is available, the function also calculates the catch biomass (yield) and the population biomass. The calculations are performed in the following manner:

Population numbers: $N_{i,t}$

The function calculates the population numbers by using three different equations:

A) for the first (m-b-1) age-groups in the final year (i.e. for i = b, ..., m-1 and t = t_f), the $N_{i,t}$ are calculated from equation [1.1].

B) for the oldest age-group in each year (i.e. for i = m and t = t_o, ..., t_f), the $N_{i,t}$ are calculated as equation [1.1] in COHORT if fishing is not complete for the oldest age-group and as equation [1.2] in COHORT if fishing is complete for the oldest age-groups.

C) for the remainder of the table (i.e. for i = b, ..., m-1 and t = t_o, ..., t_f-1), the population numbers are calculated as

$$N_{i,t} = N_{i+1,t+1}\, e^{(F_{l,\tau} + M_l)} \quad . \qquad [2.1]$$

In order to use the preceding equation, an estimate of $F_{l,\tau}$ is necessary. That estimate can be obtained by using the catch equation

$$C_{l,\tau} = N_{i+1,t+1}\, F_{l,\tau} \frac{(e^{F_{l,\tau}+M_l} - 1)}{F_{l,\tau}+M_l} \quad . \qquad [2.2]$$

Equation [2.2] involves only one unknown, namely $F_{l,\tau}$, which the functicn calculates by using the Newton-Raphson method of successive approximations (see Seber, 1973: section 1.3.8). An initial estimate of $F_{l,\tau}$ is calculated by using equations [1.3] and [1.5]. Successive values of $F_{l,\tau}$ are then calculated by the Newton-Raphson method. We exit the iterative process when

$$\left| \frac{F_{l,\tau}\,(e^{F_{l,\tau}+M_l} - 1)}{F_{l,\tau} + M_l} - \frac{C_{l,\tau}}{N_{i+1,t+1}} \right| < 10^{-5} \; .$$

Once the final value of $F_{l,\tau}$ has been found, the $N_{i,t}$ are calculated by using equation [2.1] which is given above.

<u>Catch Biomass:</u> $Y_{l,\tau}$

$$Y_{l,\tau} = W_{i+.5,t+.5}\, C_{l,\tau} \quad .$$

<u>Mean weight of individuals in catch:</u> $\overline{W}_\tau$

$$\overline{W}_\tau = \sum_{l} Y_{l,\tau} \Big/ \sum_{l} C_{l,\tau} \quad .$$

<u>Mean population biomass:</u> $\overline{B}_{l,\tau}$

$$\overline{B}_{l,\tau} = W_{i+.5,t+.5}\, N_{i,t}\, (1-e^{-Z_{l,\tau}}) \,/\, Z_{l,\tau}$$

<u>Fishing mortalities:</u> $F_{l,\tau}$

Age-specific rates of fishing mortality are determined from equation [2.2]. Thereafter, an indication of the overall fishing mortality rate is obtained by calculating the following weighted F:

$$\overline{F}_\tau = \sum_{l} (N_{i,t}\, F_{l,\tau}) \Big/ \sum_{l} N_{i,t} \quad .$$

where the summation is taken over all ages. The weighted F is calculated for each year of the cohort analysis and is printed on the bottom line of the table for age-specific rates of fishing mortality.