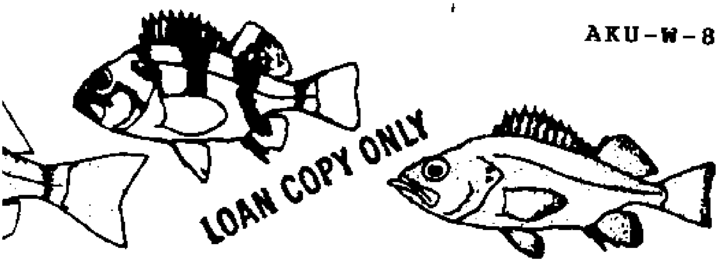
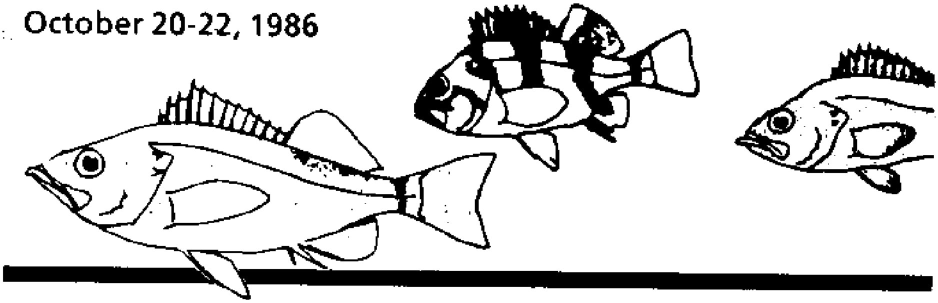


Lowell Wakefield
Fisheries Symposium

Proceedings of the International Rockfish Symposium

Anchorage, Alaska USA
October 20-22, 1986



Alaska Sea Grant Report
No. 87-2

University of Alaska
May 1987

Lowell Wakefield Fisheries Symposium

Proceedings of the

INTERNATIONAL ROCKFISH SYMPOSIUM

Anchorage, Alaska USA
October 20-22, 1986

Symposium Coordinator
Brenda R. Melteff

University of Alaska
Alaska Sea Grant Report No. 87-2
May 1987

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The International Rockfish Symposium, the fifth in the Lowell Wakefield Fisheries Symposium Series, was planned to bring together scientists and managers involved with biology and management of Sebastes species to provide information for use in developing management strategies for the rockfish complex.

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Proc. Int. Rockfish Symp.
Oct. 1986, Anchorage, Alaska

Introduction

Lewis Haldorson
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This symposium is one in an annual series, the Lowell Wakefield Fisheries Symposia. It is the first in several years to focus on a finfish resource, and it is noteworthy that the subject of the present symposium is the rockfish species complex, which is comprised of numerous species of scorpaenid fishes in the genera Sebastes and Sebastolobes. Rockfishes are an important part of North Pacific, and North Atlantic, marine resources. In the Pacific, total landings for the United States and Canada combined are estimated at 60,500, 54,000 and 51,500 metric tons in the years 1983, 1984 and 1985, respectively. These catches rank at the top of domestic bottomfish landings; yet, here in Alaska and elsewhere on the Pacific Coast we know that significant rockfish resources have been depleted and are now at population levels far below their productive optima.

In Alaskan waters the most abundant rockfish resource, the Pacific Ocean perch (Sebastes alutus), was depleted before any management was contemplated or feasible, as the pulse-fishing distant water fleets of Russia and Japan worked the continental shelf break in the 1960's. Figure 1 summarizes estimates of those catches from the Gulf of Alaska (GOA) statistical region (from Balsiger et al. 1985). In the decade beginning in 1963 the population numbers for that GOA stock of Pacific Ocean perch decreased from over 5,400,000 fish to less than 700,000, based on cohort analyses (Ito 1982). Clearly, this 85 percent reduction in the GOA Pacific Ocean perch population was an early example of what can happen to a rockfish resource exposed to high fishing mortality rates. Recent estimates of Maximum Sustainable Yield (MSY) for the GOA Pacific Ocean perch resource range from 16,000 to 47,500 metric tons (Balsiger et al. 1985), which provides a reasonable measure of the degree of overfishing to which that stock was subjected.

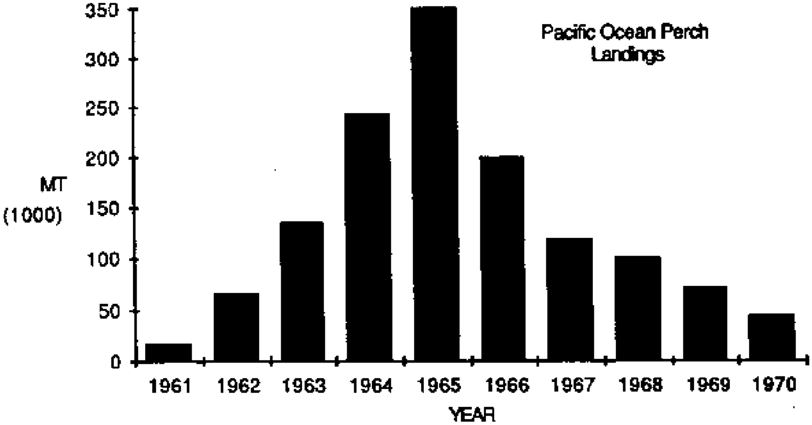

Figure 1. Pacific Ocean perch landings, in metric tons (MT), in the Gulf of Alaska statistical region for the years 1961 through 1970.

Unfortunately, the Pacific Ocean perch scenario in the Gulf of Alaska has been re-enacted in other areas, and with other species of rockfish. Certainly the recent experience with the widow rockfish (S. entomelas) fishery is familiar to most of you. Catches of this species increased dramatically in the late 1970's, followed by reduction in stock size and catches (Figure 2). Other stocks may be experiencing similar boom and bust cycles. In Alaska there is concern for a smaller fishery on inshore rockfish species off southeast Alaska. This fishery, centered at Sitka, has expanded greatly, moving from less than 200,000 lbs. in 1980 to over 1,200,000 lbs in 1984.

The history of rockfish fisheries suggests that managing such resources is not easy, and that detailed information on stock sizes and biological characteristics of the species are required. Although the Pacific Ocean perch attracted early attention, the basic biological information on the various species and assessments of stock sizes and condition have historically been sketchy; at least until the last decade. With passage of the U. S. Fisheries and Conservation Management Act in 1976, the picture began to change. The importance of the resource, and its management needs, instigated the Coastwide Rockfish Survey of 1977, the results of which were reported in a 1978 symposium in Seattle, and published in a issue of Marine Fisheries Review in 1980 (vol. 42, No. 3-4). Those studies provided much previously unavailable biological information and stock assessments.

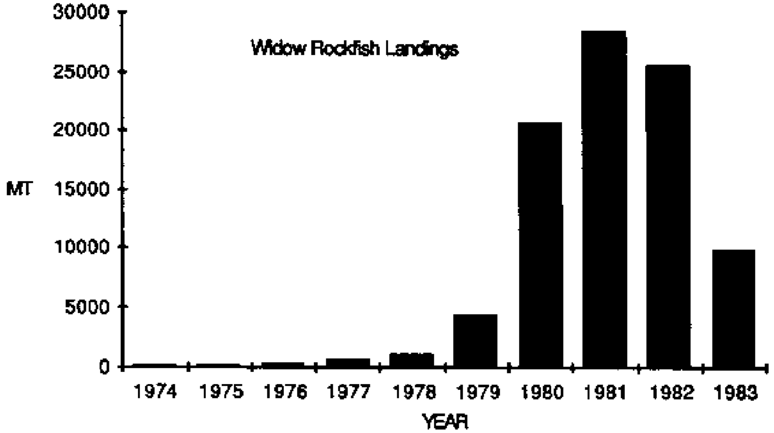

Figure 2. Landings, in metric tons (MT,) of widow rockfish in the period 1974 to 1983.

A perusal of the agenda for the present symposium suggests that interest in rockfishes, and the level of information about them, continue to be on the rise. Clearly, since the 1978 symposium there have been major advances in rockfish studies. If any one research area has riveted the attention of rockfish researchers it has been the aging studies which have stemmed from advances accomplished at the Pacific Biological Station at Nanaimo. The concept of individual fish living to ages over 100 years amazes fisheries biologists; in fact, many remain unrepentant skeptics. In the period when the new aging techniques were emerging I was engaged in resource assessments and life history studies on the nearshore group of rockfishes of southeast Alaska. One of the most important of those species is the yelloweye rockfish (S. ruberrimus). Applying the break-and-burn ageing techniques to yelloweye rockfish revealed a population with age structures and a sequence of life history events that were disconcertingly similar to the human species. Much of this new information is changing the way we view the biology and management of these species.

It is appropriate, therefore, that another symposium should be addressing rockfishes. From my perspective, it appears that rockfish studies are beginning to receive the support and recognition that they have long deserved. The fact that a symposium such as this is being held in Alaska is indicative of this trend. This is the state whose Chapter of the American Fisheries Society is called Oncorhynchus. Further south, in California, the California Sea Grant program has initiated a major emphasis on rockfish studies. It thus appears that this symposium is timely, and has the opportunity to take a major role as a vehicle for updating and summarizing current information and for pointing the direction for future studies.

Rockfish studies have not always enjoyed this level of support and recognition; although there have always been a few biologists who persevered in the study of these interesting fishes. This is a good time to recognize their efforts, as they sometimes had to stoop to - well - unconventional methodologies in the practice of their trade. I can think of no better example of this than the note by Love and Vucci, published in the 1974 California Fish and Game, entitled: Range extension of the China rockfish (Love and Vucci 1974). The opening sentence is sufficient: "On 24 September 1972 Vucci found a China rockfish, Sebastes nebulosus, 289 mm SL., in a trash can of filleted rockfish carcasses aboard the party boat China Clipper.". Certainly all of the early contributions have been valuable; and none more so than the work of our keynote speaker. Although Jergen Westrheim may not have scoured the trashcans around Nanaimo, his work has been extraordinarily valuable to all of us. This symposium is appropriately timed, if for no other reason than that it marks the official retirement of Jergen Westrheim from the Pacific Biological Station. Those who know him will have no doubt that it does not mark his retirement from the study of rockfishes.

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Proc. Int. Rockfish Symp.
Oct. 1986, Anchorage, Alaska

Keynote Address: Quality starts with fundamentals

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Introduction

The title of this address is apt, but not original. I borrowed it from an advertisement in the September 1986 issue of the Smithsonian Magazine (p. 99). The ad featured Larry Bird, superstar for the Boston Celtics professional basketball team. The moral was that constant practice and attention to fundamentals were necessary even for superstars.

In our profession, constant practice is not a critical factor, but attention to fundamentals certainly is. One of the major criticisms which can be levelled at fishery scientists is our tendency to underestimate the importance of fundamentals in our eagerness to address the so-called important problems. That is, running before we learn to walk! Let me hasten to add that sometimes scientists are influenced by external pressures to run when they know they haven't learned to walk. However, at other times these pressures are self-induced. Fundamentals are particularly important in rockfish studies because so little is known about these diverse fishes. For the northeast Pacific Ocean, I found only one rockfish bibliography, and that was limited to species other than Sebastes alutus (Westrheim and Leaman 1976), and excluded the purely taxonomic literature. The closing date was April 1976. The bibliography contained 171 references and referred to 20 subject categories. Only 13 of the references were published prior to 1950.

Today I wish to lightly review three examples in which fundamentals have received variable attention. These subjects are: identification, age determination, and distribution. The latter is taken in the broad sense, and hence includes behavior.

Identification

Is there any more fundamental subject than identification of the species with which we are dealing? And yet, after more than 100 years of study, the taxonomy of scorpaenids is not complete in the northeast Pacific Ocean, nor, I discovered, in some other areas of the world.

Within the region extending from the Gulf of California to the Gulf of Alaska, there are 68 "certified" scorpaenid species, currently classified into four genera--Scorpaena (1); Scorpaenodes (1); Sebastolobus (2); and Sebastes (64) (Chen 1975; Robins 1980; and Eschmeyer et al 1983). Only Sebastes continues to present taxonomic problems, and will be our exclusive subject for the remainder of this presentation. The Bering Sea, where the ranges of Asiatic and North American scorpaenids probably overlap, has been excluded, because I could find no definitive taxonomic work comparable to that for the northeast Pacific Ocean.

Taxonomic problems of Sebastes at the species level stemmed originally from inadequate technology. Initial criteria were morphological characteristics, such as Cramer's (1895) cranial criteria, whose variation did not necessarily reflect genetic separation. The first step toward to genetic basis for classification of rockfishes was taken by Tsuyuki, Roberts, and Vanstone (1965), who employed relatively simple protein electrophoresis on nine species of rockfishes as well as other marine species.

Subsequent electrophoretic analyses revealed the presence of sibling species, or variants, of S. eos (Barrett et al 1966); S. crameri and S. reedi (Westrheim and Tsuyuki 1967); and S. aleutianus and S. diploproa (Tsuyuki et al 1968). More complex and comprehensive electrophoretic analyses by Seeb (1985) revealed the presence of the variants B of S. aleutianus and S. reedi in the Gulf of Alaska, and suggested that S. ciliatus comprised two "sister" species. Tsuyuki, Roberts and Vanstone (1965, p. 209) noted in a footnote that S. ciliatus was actually a "complex of three or four forms."

Seeb (1985) also demonstrated the natural hybridization of S. auriculatus and caurinus in Puget Sound, Washington. This may explain the variability in numbers of coronal spines of S. auriculatus, reported by Hitz and DeLacy (1961).

The variant species of S. aleutianus and S. reedi are not a serious problem in British Columbia waters, because variant A predominated there in both species (Tsuyuki et al 1968). Variant B of S. aleutianus predominated in samples collected off southeastern Alaska. S. reedi electropherograms were not collected north or south of British Columbia.

Perhaps the most graphic example of underestimating the importance of rockfish species identification occurred in the northwest Atlantic Ocean. During 1947-54, extensive and comprehensive trawl surveys were conducted to assess the redfish (Sebastes) resource (Templeman 1959). Unfortunately, during the survey only one species, S. marinus, was assumed to occupy the region. As late as 1966 only one species was acknowledged (Leim and Scott 1966). Barsukov (1968) reported that there were three species--S. marinus (Linnaeus 1758; S. fasciatus (Storer 1856); and S. mentella (Travin 1951).

While these species are now accepted, identification problems persist, as indicated by the recent report of Power and Ni (1985).

In the western Pacific Ocean, Sebastes species diversity is similar to that in the eastern Pacific Ocean (Matsubara 1943). Here too problems abound. Chen (1985) reported that S. inermis, a ubiquitous and commercially important species, comprises three meristic types which seem to represent three separate species. However, "no known features can clearly differentiate some of the specimens which are meristically intermediate" (op. cit. p 23). Does this sound familiar?

Age Determination

If identification of species is of primary importance, certainly validated age determination must be the next most important subject, and certainly the one most frequently treated in a superficial manner enroute to so-called more important problems. While the resolution of some of the rockfish identification problems required new technologies developed in the 1960s, such is not the case with age determination problems. Van Oosten (1929) described the basic procedures for age determination and Walford and Mosher (1943a and b) enlarged on these. Unfortunately, few studies have followed their precepts.

Beamish and McFarlane (1983) surveyed 500 studies published during 1907-80 which included estimates of fish age. Of these, only 65 percent mentioned age validation or attempted to validate the ageing technique, and less than 3 percent of the studies included validation of all age classes. They also reviewed 75 additional reports published in primary journals during 1965-80 which dealt with stock dynamics. Only 40 percent of these mentioned or attempted age validation, and none successfully validated all age classes used in the analysis. Beamish and McFarlane (op. cit.) cite two examples where use of inaccurate ages caused serious problems in management and or understanding of fish populations. One of these examples was S. alutus.

One problem not considered by Van Oosten (1929) or Walford and Mosher (1943a and b) was a change over time in interpreting annuli criteria. Kimura (1973) documented this devastating phenomenon with respect to the Pacific sardine (Sardinops sagax). In a classic study, Walford and Mosher (1943a and b) developed and validated criteria for ageing this species. However, during the next 20 years, scale-reading staff gradually changed, and so did the interpretation of criteria for the first annulus. The result was that growth appeared to increase as the abundance of sardines declined. Density-dependent growth was duly reported (Marr 1960).

In summary, validation of age-determination methods must be considered to be an on-going occupation.

As for rockfishes in the northeast Pacific Ocean, I could not find any species for which ages have been validated for all age classes, as suggested by Beamish and McFarlane (1985). However, the earlier methods employing scales or surface readings of otoliths have been largely discredited, at least for the older age classes, as the result of new techniques described by Beamish (1979), Bennett et al (1982), and Chilton and Beamish (1982). Despite the lack of complete validation, there is little doubt now that we are dealing with species whose life span is substantially longer than heretofore considered. More importantly, the slower growth and extended longevity imply a substantially lower optimum exploitation rate.

Distribution

Distribution may well be the third most important subject, and certainly the least studied. Accessibility and cost are important inhibitory factors, particularly for the offshore species.

Distribution of S. alutus is at least partially delineated, and is indeed complex. These fish form schools which vary in shape from stratus-like to cumulus-like "clouds" which do not always maintain contact with the bottom (Westrheim 1970). Based on on-bottom trawl catches, catch rate, size composition, age composition, and sex ratio vary bathymetrically, both intra- and inter-seasonally (Westrheim 1970, 1973, 1975). Furthermore, age-length relationship varies bathymetrically (op. cit. 1973, 1975), and proportions of S. alutus in research vessel catches of rockfish vary with type of bottom (Westrheim 1970, 1974). Bottom type is often ignored as a parameter in studying distribution, or conducting biomass surveys using the swept-area method.

The above-mentioned studies marked a good beginning, but can hardly be considered complete. Unfortunately, similar studies on other important offshore species are minor or non-existent, and may well prove to be more difficult than those for S. alutus.

The distribution/behavior of S. alutus has an obvious effect on estimating mortality rates and abundance. Since age composition varies bathymetrically, data collected from commercial landings should be corroborated with research vessel samples which span the more important depth intervals. Abundance estimates, either by CPUEs or biomass estimates, are affected by the schooling behavior. Catchability likely varies inversely with absolute abundance, and if so, CPUE is too low when abundance is high, and too high when absolute abundance is low. The vertical schooling would affect estimates of CPUE and biomass, based on the conventional swept-area method with on-bottom trawls. Such biomass estimates are also affected, in some areas, by the propensity of the fish to prefer certain bottom types, unless this factor has been incorporated into the survey plan.

Summary

My theme of this keynote address is the importance of fundamentals in the practice of fisheries science. The choice of rockfish for examples was only dictated by the subject of this symposium. And now, how well are we doing with respect to rockfish? Currently, I think we are doing as well as possible, considering the inevitable limitations.

We have correctly identified all or nearly all the important commercial species in the northeast Pacific, and most of the others as well. Personally, I hope that electrophoresis will be utilized more extensively here and elsewhere in the world. Electrophoresis is not a difficult procedure, and some species might benefit by electrophoretic corroboration of their status.

Age determination has turned the corner. Long life-span and lower optimum exploitation rates are generally accepted. Firm proof of absolute age determination will be very difficult. For example, tagging juvenile rockfish of known age, or adult fish of any age, is technically impossible at this time, for most species including *S. alutus*.

Distribution/behavior is probably our weakest point. There appears to be little interest, or support, except for the inshore species, which admittedly are more accessible and less costly to study. Perhaps the research climate will improve before all of you must face retirement.

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Session I -- History of the Fisheries

Proc. Int. Rockfish Symp.
Oct. 1986, Anchorage, Alaska

The redfish resources off Canada's east coast

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Introduction

The existence of redfish of the Genus Sebastes in the Northwest Atlantic has been known since at least 1856 when Storer briefly described and named Sebastes fasciatus from the Gulf of Maine. Since then, a great deal of work has been carried out by Canadian, American and other scientists on the distribution and biology of the redfish species in the western Atlantic and important commercial fisheries have been developed, first by the United States, but followed by increasing participation by Canada and other nations.

Today there are 8 different stocks or management units of redfish recognized off the east coast of North America (excluding West Greenland) and the nominal catch is the second largest of all groundfish species in this area. Of these units, 7 are located off the east coast of Canada. These stocks were originally managed by the International Commission for the Northwest Atlantic Fisheries (ICNAF) but with extended jurisdiction, are now managed either by Canada alone or internationally through the Northwest Atlantic Fisheries Organization (NAFO). The total allowable catch from these 7 units for 1985, under quota regulation, was about 199,000 mt of which Canada's allocation was 140,870 mt. A total of 72,200 mt were taken with a landed value of 15.2 million dollars to the Canadian industry.

This paper presents information on the distribution and biology of the different species of redfish (Sebastes spp.), the history of the fishery, present management practices and ongoing research for the area off the east coast of Canada. The paper is, by no means, meant to be an exhaustive review of this topic.

Distribution and Biology

Geographic distribution

Redfish are distributed fairly extensively in the Northwest Atlantic (Fig. 1). Their southernmost range limit is in the deep waters off New Jersey, and they can be found inhabiting water from 75-750 m north from this area: off the Nova Scotia and Newfoundland Banks, in the Gulf of St. Lawrence, along the continental slope from the southwestern Grand Bank to Hamilton Inlet Bank and in the area of Flemish Cap. The fish are also present, but in fewer numbers, northward to off the coast of Baffin Island, and off West Greenland. This distribution has been determined over a number of years from larvae distribution (eg. Murray and Hjort 1912; Dannevig 1919; Frost 1936), exploratory fishing (eg. Templeman and Handrigan MS 1949; Templeman 1957; Templeman 1961) and commercial fishing (eq. Savvatimski and Sidorenko 1966).

Within this area of distribution, redfish are found over a wide range of depths. In the Gulf of Maine, although most commonly found in depths greater than about 75 m, they have been, on occasion, found in shallow enough water to be taken on hook and line (Anon. 1956). Off the east coast of Canada, the main concentrations are found between about 200-750 m on the west slope of Flemish Cap, the south and northeast slopes of Grand Bank, the northeast slopes of Funk Island Bank and Hamilton Bank, the north slope of Belle Island Bank, off southwest Newfoundland and in the Gulf of St. Lawrence (Ni and McKone 1983). According to these authors, the general patterns of distribution and concentration noted between 1978 and 1980 were similar to those determined during 1947-1954 by Templeman (1959).

There is no evidence for any large scale migrations of redfish in the Northwest Atlantic, although it is known that redfish in the Gulf of St. Lawrence move to the mouth of the Gulf during the winter months (Atkinson 1984).

Depth distribution

Numerous studies have shown that the proportion of larger redfish increases with depth. Templeman and Knapp-Fisher (MS 1951) noted that, when fishing along the edges of the Grand Bank at greater depths than previously, larger fish were obtained than had been caught in shallower waters. Perlmutter (1953), Schroeder (1955), Templeman (1955, 1957, 1959) and Hennemuth and Brown (MS 1964) all reported the same phenomenon from analyses of data from the Gulf of Maine to NAFO Division 2J off Labrador. Other authors have also shown that the distribution of fish up and down the slopes can change with season (Sidorenko MS 1966; Chekova 1972; Nikolskaya MS 1973; Atkinson 1984). All of these studies indicated that redfish generally move into deeper waters during the winter months as hypothesized 1961 by Templeman and Pitt.

Temperature distribution

Templeman (1959) indicated that in North American waters, redfish concentrations were usually associated with water temperatures of 3-6°C. He did, however, note that substantial catches were sometimes

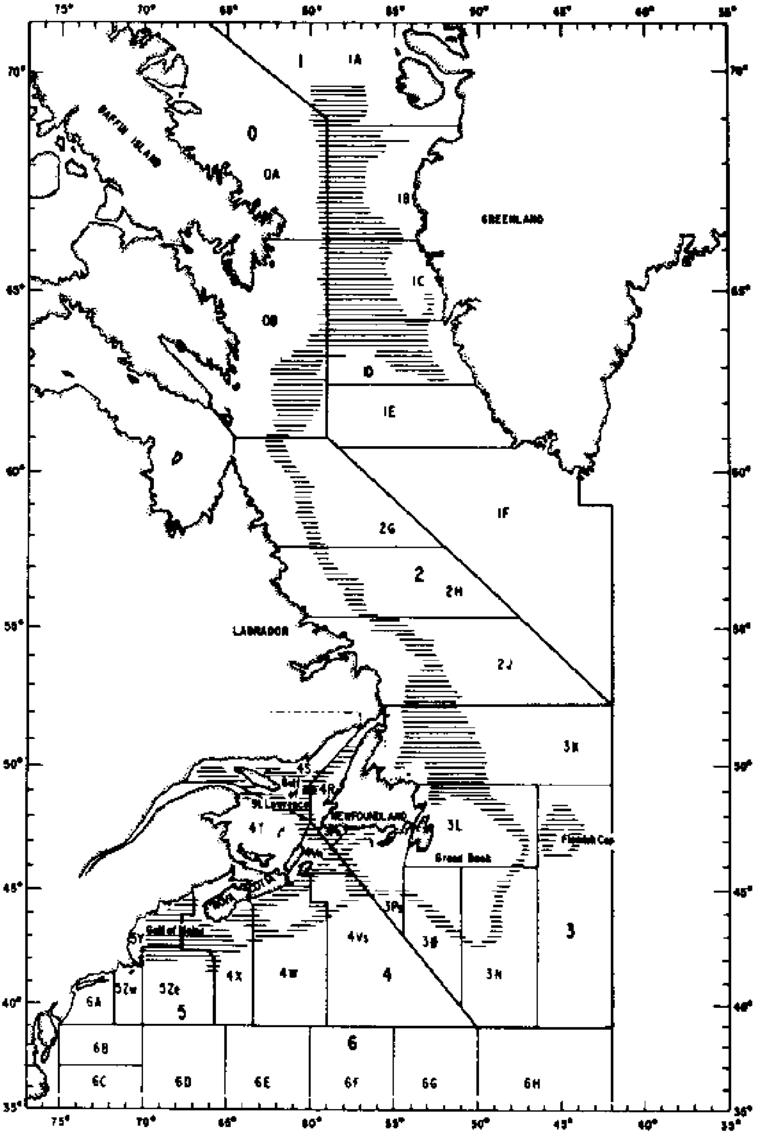

Figure 1: Map of the Northwest Atlantic showing the distribution of redfish, NAFO Divisions and locations noted in the text.

sometimes taken in areas with temperatures of 1-2°C. Atkinson (1984) found that during the winter, the largest concentrations of redfish in the Gulf of St. Lawrence were located in temperatures close to 7°C. It would appear that, given a fairly wide range of temperatures, redfish distribution is more influenced by depth then by temperature.

Diel movements

The movement of Northwest Atlantic redfish up in the water column at night and down again during daylight (diel movement) is well documented. Steele (1957) noted that catches were greatly reduced when fishing was done at night. Konstantinov and Shcherbino (1958) reviewed changes in commercial catches of redfish on Flemish Cap and slopes of the Grand Bank and noted that at night the redfish were following upward migrations of their prey. Sandeman (1969a) also noted that there were significant differences in research catches at different time periods on the eastern slopes of the Grand Bank. Parsons and Parsons (1976) attempted to quantify the differences in day-night catches in NAFO Division 3P. They also found that there was differential diel variation with size, in that it appeared that there were greater proportions of intermediate sized fish (22-30 cm) moving off the bottom at night. They pointed out the importance of these phenomena when considering the design of, and interpretation of results from, trawling surveys aimed at redfish.

Reproduction

The redfish of the North Atlantic are ovoviviparous but the females are quite fecund, producing up to about 58,000 eggs (Jones 1969). Ni and Sandeman (1984) showed that a geographic cline in size at maturity exists with a decreasing trend from north to south. They also found that the size at maturity is much greater for females than males. For beaked redfish, the length at 50% maturity of males ranged from about 29 cm in the north (NAFO Subareas 0 and 1) to about 15 cm in the south (NAFO Division 4X) while it ranged from about 45 cm to 25 cm for females over the same area.

In 1955, Magnûsson stated that redfish in Northeast Atlantic waters mated during October-January but Sorokin (1961) postulated that they copulated during August-October. Steele (1957) felt that gonad development in the Gulf of St. Lawrence redfish fit the pattern described by Magnûsson and therefore assigned an October-January copulation period. Sidorenko (1966) stated that copulation occurred from August to November in the Northwest Atlantic while Nikolskaya (MS 1973) suggested an August-October period. More recently, the latter author (1977) suggested that in the region of southern Labrador, the mating season is more protracted, running from July to December. From the results of a large number of samples collected off the south coast of Newfoundland (NAFO Division 3P), Ni and Templeman (1985) concluded that copulation most likely occurs during the same period as determined by Magnûsson (1955) for Northeast Atlantic redfish (i.e October-January), but that fertilization is delayed until February-April.

The larvae are released when about 7-9 mm in length (Templeman 1959; Bainbridge and Cooper 1971). The extrusion times vary with area. Travin and Pechenik (1962) found that larval extrusion peaked in May in NAFO

Divisions 3K and 3L and in June off the Labrador coast. They also reported that peak larval extrusion took place in April-May on Flemish Cap. Bainbridge and Cooper (1971) state that extrusion takes place in June off Labrador and the northeast coast of Newfoundland and that larvae are first extruded in April on Flemish Cap. According to Templeman (1976), extrusion on Flemish Cap extends from March or April to July or August with the earliest spawning taking place in deeper water. Ni and Templeman (1985) indicated that larval release takes place from April-July (mainly May-June) off the south coast of Newfoundland, while in the Gulf of St. Lawrence, larvae are released during May-July (Steele 1957). In the Gulf of Maine, larvae are extruded from April-September (Kelly and Wolf 1959).

Ageing and growth rates

After being released at lengths of 7-9 mm, sharp-beaked redfish grow slowly and attain lengths of between 40-50 cm. The golden redfish grow much larger and can achieve lengths of 60-70 cm.

The ageing and, therefore, growth rates of Sebastes spp. have been contentious issues for a number of years. Saemundsson (1932) mentioned that this fish is slow-growing and long lived. During the 1950's a number of papers (e.g. Bratberg 1955; Sandeman 1957; Kotthaus 1958; Kelly and Wolf 1959; Rasmussen 1958) described the growth of redfish in various parts of the Atlantic Ocean based on ageing studies using scales or otoliths. Of these authors, Kotthaus alone was of the opinion that the fish were short lived and fast growing. At a Redfish Symposium held in Copenhagen, Denmark in 1959, a decision was reached in favor of slow growth 'though further work is still required to confirm this interpretation' (Lundbeck 1961).

Today it is generally aceppted that these fish are slow growing but the actual rates are still questioned. Researchers in eastern North America rely on the use of otolith interpretation for the determination of redfish ages while European and Soviet scientists use scales. This has resulted in differences in the ages obtained for fish from the same management units in that at present, Canadian readers age redfish up to age 29 then add a 30+ group, while European and eastern readers assign a maximum age of about 20-25 years to the oldest fish caught. Sandeman (1969b) has aged redfish up to 50 years using otoliths. These differences in ageing techniques and resultant differences in growth rates have not been resolved to date.

Using otoliths, Sandeman (1969b) illustrated that differences in growth rates exist between males and females, with females almost always showing greater total growth than males. On average, females were larger then males at any of the older ages. This was considered to be related to the fact that males mature at a much smaller size than do the females. Sandeman's Fig. 17 (reproduced here as Fig. 2) gives a good representation of the differences in ageing and hence, estimated growth rates, that exist to this day between North American (otolith) readers and those from Europe and the USSR (scales (Surkova 1962)).

Recent work on age validation of Northwest Atlantic redfish has been carried out by McKone and Legge (MS 1980) dealing with redfish in the Gulf of St. Lawrence and by Mayo et al. (1981) on redfish from

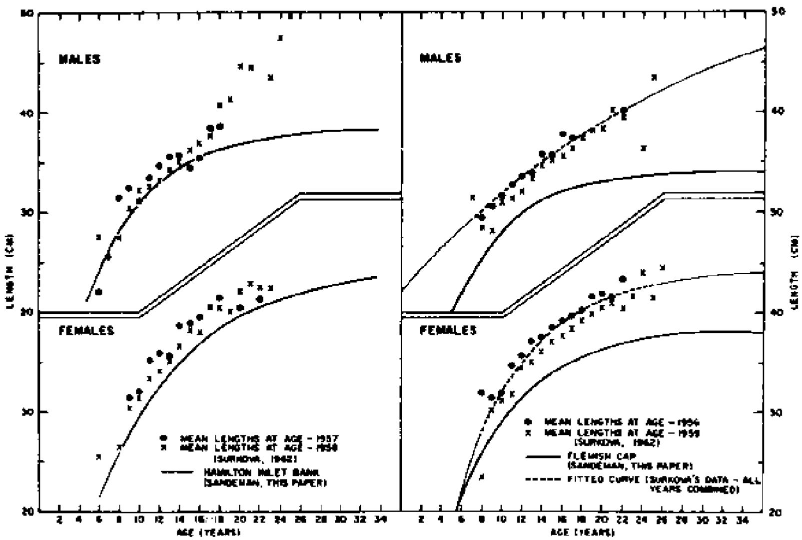

Figure 2: Growth rates of beaked redfish from Hamilton Inlet Bank (left) and Flemish Cap (right) showing growth curves derived by Sandeman (1969) and mean lengths at age determined by Sekova (1962). (Reproduced from Sandeman 1969b.)

the Gulf of Maine. McKone and Legge followed the exceptionally strong year-classes of 1956 and 1958 using both research frequencies and estimates of numbers at age derived from combining the frequencies with annual age length keys. They were able to follow these year classes from 1972-1979 and concluded that otoliths were satisfactory for ageing redfish. Mayo and his co-workers validated the use of otoliths on young fish (up to age 7). They followed the seasonal formation of hyaline and opaque edges on otolith sections and compared mean length at age with observed modes of length frequencies of the 1971 year-class for the period 1971-1978.

Natural mortality

No precise estimates of natural mortality rate (M) are available for any redfish stock in the Northwest Atlantic. However, it is known that the natural mortality rate for a long lived, slow growing fish such as redfish must be very low related to faster growing species such as cod and herring. For both of these latter fish, a coefficient of 0.2 has been assumed. Westrheim et al. (MS 1972) estimated M to be 0.12 for Pacific ocean perch and Sandeman (MS 1973) considered that for Northwest Atlantic redfish, M is between 0.1 and 0.05. Because of the lack of any other evidence, a natural mortality rate of 0.1 has been assumed, for assessment purposes, for a number of years. It is most probable that M lies below this level although a suitable alternative has not been determined at this time. Mayo et al. (MS 1983) assumed a level of 0.05 for Gulf of Maine redfish.

Food and feeding

The food and feeding of redfish off Canada's east coast has not been studied extensively. One of the main problems is that when these fish are brought to the surface, their stomachs are quite often either wholly or partially everted making any quantitative analysis difficult. Lambert (1960), Yanulov (1962) and Kashintsev (1962) found that redfish are pelagic and bathypelagic feeders, consuming a variety of fish, euphausids, amphipods, copepods and shrimp. Their studies showed that as redfish grow in size, fish such as capelin and myctophids become more important dietary items. The diet of redfish in various locations around Newfoundland was found to vary but it was thought that this was related to prey availability. Both Yanulov and Kashintsev found differences in feeding rates with season. In spring, during the pre-hatching and hatching period, almost nothing is eaten by either males or females. Feeding rates start off low during the post-hatching period but increase considerably by the end of the summer and the maximum rates are reached during the fall-winter period. By the second half of March, feeding has again ceased.

Parasites

The best known parasite of redfish is the ectoparasitic copepod <u>Sphyrion lumpi</u> which was first described on a North American redfish by Wilson (1919, 1931) from the Gulf of Maine area. Nigrelli and Firth (1939) described the apparent pathological effects of the parasite on redfish and described the range of infestation in the Gulf of Maine area (rates of 5-10%). Templeman and Squires (1960) presented the results of an extensive survey for incidence of infestation by this parasite in all of the areas off the east coast of Canada. They found that pockets of infestation existed off Labrador (rates of 5-15%) and on the southeast edge of the Grand Bank (rate of about 1-10%). The parasite could be attached at any point on the body but tended to concentrate in the cloacal region on redfish from Canadian waters in contrast to the Gulf of Maine redfish where the parasite was more commonly located near the base of the first spine of the dorsal fin.

Species mix

It may seem that a discussion of the species of <u>Sebastes</u> present in the Northwest Atlantic should come at a much earlier point in a review paper of this type. However, this is a complicated and, up until recently, a very confused area of research and most of the previously described investigations did not deal with a specific species, but a species mix. As was noted earlier, Storer (1856), described a redfish species in the Gulf of Maine and called it <u>Sebastes fasciatus</u>. This nomenclature was largely ignored after that and the redfish in the Northwest Atlantic were assumed to be <u>S. marinus</u>, the same species as that in the Northeast Atlantic.

Around 1940, Lundbeck (see Kotthaus 1961) noted that besides <u>S. viviparous</u>, there existed, in the Northeast Atlantic, the common redfish, <u>S. marinus</u>, and another deep water type, the beaked perch. In 1951, this deep water variety was described by Travin (Templeman 1959) and named <u>S. mentella</u>, a new species. In the Northwest Atlantic, Templeman and Sandeman (1957) first noted that there were apparently two different types of redfish in the waters around Newfoundland, <u>S. marinus</u> and <u>S. mentella</u>. Templeman (1959) indicated that in the area from off Baffin Island and West Greenland, south to the Gulf of Maine the mentella-type redfish predominated. He noted that the marinus-type was found in shallower water, grew larger and became sexually mature at larger sizes than the mentella-type but occurred in much fewer numbers. The taxanomic status of these two 'types' was discussed extensively during the 1959 Redfish Symposium in Copenhagen (see eg Mead and Sindermann 1961).

Although Templeman and Sandeman (1959), Sandeman (1961, 1969b) and Templeman (1967) did note that the North American mentella-type was, or could be, different from the oceanic eastern Atlantic form, up until the early 1970's, only two species of redfish were thought to exist in the Northwest Atlantic (S. marinus and S. mentella) and research was carried out accordingly. However, in 1968, Soviet scientists began publishing information concerning a third species, S. fasciatus (Barsukov 1968, 1972; Barsukov and Zakarhov 1972; Litvinenko 1974). These authors stated that S. mentella was more prevalent in the north, and less toward the south. Templeman (1976) acknowledged these studies and used the classification of S. mentella to include the true S. mentella as well as the 'American form of the sharp-beaked redfish', S. fasciatus (Storer).

Beginning in the late 1970's, detailed studies of the species problem was initiated in Newfoundland. Ni (1981a, 1981b) used the extrinsic gas bladder musculature and meristics and morphometrics to separate S. mentella and S. fasciatus in the northeastern Grand Bank area. In 1982, Power and Ni described the gas bladder musculature of S. marinus and indicated that it could be used to separate this species from the beaked species. Ni (1982) described the meristic variation in the North American beaked redfish from Baffin Island and West Greenland to the Nova Scotia Shelf. His findings agreed with the earlier work by the Soviets that there was a gradual transition from S. mentella in the north to S. fasciatus in the south. His findings are summarized in Fig. 3. In 1984, Ni described the meristic differences between S. marinus and the beaked redfish of the Northwest Atlantic. He pointed out that it is easier to separate S. marinus from the beaked redfish than to separate S. mentella and S. fasciatus. Litvinenko (1979) described the redfish from the Gulf of Maine as S. fasciatus.

Robins et al. (1980) described S. fasciatus, S. mentella and S. marinus as different species, but considerable discussion has continued as to whether these are true species or not (e.g. Payne and Ni 1982; Kenchington 1983; Ni 1983; Kenchington 1986). Robins et al. (1986) again treat the three types as separate species. They also address the problem of common names. S. marinus is called 'golden redfish', S. mentella is named 'deep-water redfish' and S. fasciatus is designated 'Acadian redfish'. The authors note that these will be included as separate species in the upcoming (1990) fifth edition of "A List of Common and Scientific Names of Fishes from the United States and Canada".

The sharp-beaked redfish are flame red in color while the golden redfish are more orange or yellow-red. This latter species has a relatively smaller eye and the bony protrusion on the lower jaw is usually blunt or weak. It is usually found in depths of less than

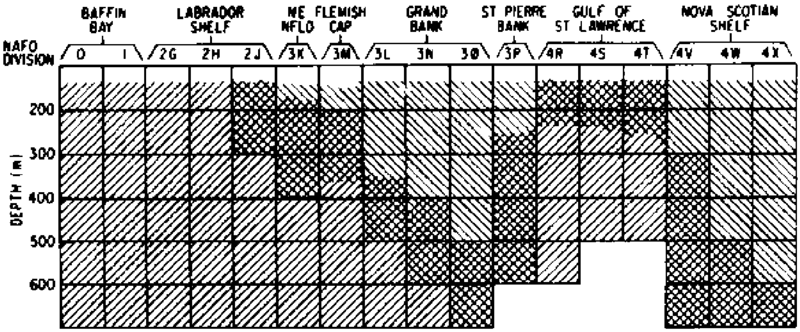

Figure 3: The distribution of *S. mentella* and *S. fasciatus* in division-depth blocks. The lines with positive slope represent *S. mentella* and negative slope represent *S. fasciatus*. Cross hatching represents a mixture of the two species (reproduced from Ni 1982).

about 275 m. The sharp-beaked redfish has a relatively large eye and the bony protrusion on the lower jaw is long and well developed. It is very difficult to discern between *S. mentella* and *S. fasciatus* based on morphological characters and in the field the two are generally treated as 'beaked redfish' without further separation.

Oceanic redfish

There is one other group of redfish of Genus *Sebastes* that has been found off Labrador. These are pelagic fish that have been taken on long lines over the ocean depths. Templeman (1967) described catches of these fish taken at the mid-mouth of the Labrador Sea. The water depth is 3060-3660 m in this area. He noted that these fish were heavily infested with the parasite *Sphyrion lumpi* and were probably part of an oceanic population that had been previously shown to exist in a large eddy system extending from Iceland and Greenland to the Labrador and northeast Newfoundland shelves. This stock does not appear to have any commercial importance in North America, and no recent work has been carried out in this area.

The Fishery

The fishery for redfish in the Northwest Atlantic is primarily based on catches of the sharp-beaked redfish, *S. mentella* and *S. fasciatus*. *S. marinus* are present in only relatively small numbers and are not considered to be important to the fisheries.

Historical catches

In North America, redfish catches have been recorded from the Gulf of Maine (NAFO Subarea 5) from as early as 1916 when 53 mt were taken by United States fishermen (Templeman 1959). There was a considerable increase in this fishery in the mid-1930's when landings jumped from

519 mt to 23,162 mt between 1934 and 1936. At this time, the fishery also expanded somewhat into the area of the Nova Scotia Shelf (NAFO Subarea 4). With time, the landings from the area north of the Gulf of Maine increased and surpassed those from this area. A fishery began in the Gulf of St. Lawrence (NAFO Subarea 4) in 1951 but effort was soon diverted to the Grand Bank area (NAFO Subarea 3) resulting in a decrease in catches from Subarea 4. Commercial landings were first reported from Subarea 2 in 1958 when 77,000 mt were caught (ICNAF 1970). Within the NAFO Convention Area (formerly ICNAF), catches of redfish peaked in 1959 with a total of 389,000 mt being landed. They then fluctuated around about 200,000 mt until the mid-1970's when total landings began to decrease under various quota regulations. Landings in the 1980's have been in the vicinity of 125,000 mt annually.

In the earliest years of the redfish fishery off North America, the United States fleet accounted for 100% of the landings. But, during the mid-1940's, they were joined by fishermen from Canada. In the early 1950's European vessels (Iceland and Germany) began fishing for redfish on this side of the Atlantic and in 1956 the USSR began sending vessels over. Soviet landings quickly grew such that in 1958-1960 they were the greatest for any single country. In recent years, landings by the United States have dropped drastically under strict management practices. From the late 1960's to the present, catches by Canada and the USSR have consistently accounted for greater than 70% of the total redfish landings from the NAFO Convention Area.

Stocks or management units

Discussions of redfish stocks in the Northwest Atlantic have always been associated with the management of the fishery. In 1961, Mead and Sindermann suggested that, for management purposes, three stocks of redfish could be identified in the Northwest Atlantic. These were: Flemish Cap, ICNAF (now NAFO) Subarea 2 + Division 3K and 3L, and Division 3O + 3P + Subareas 4 and 5. They noted that the latter two stocks intermingled in Division 3N but suggested that the situation in this area was not clear. Travin et al. (1962) concluded, on the basis of parasite and morphometric differences, that Subarea 3 could be divided into a northern stock (Division 3K + northern 3L), a Flemish Cap stock and a south Newfoundland stock (Divisions 3N, 3O and 3P). They also concluded that intermingling occurred in Division 3N. Bainbridge and Cooper (1971) concluded that three stocks, as defined by Mead and Sindermann, existed based on the distribution of larvae.

Assessment of redfish began in the mid 1970's. Sandeman (MS 1973) referred to the redfish in the Gulf of St. Lawrence as a 'stock' when discussing management options. Parsons and Parsons (MS 1973) separated redfish from NAFO Divisions 3O and 3P based on differences in growth rates described by Sandeman (1969b). They also separated redfish in Divisions 3L and 3N from those in Divisions 3O and 3P based on the conclusions of Mead and Sindermann (1961) and Bainbridge and Cooper (1971). The data from Divisions 3L and 3N were combined since there was inadequate evidence to indicate separate stocks. Pinhorn and Parsons (MS 1974) presented an assessment of another 'stock', that in NAFO Subarea 2 + Division 3K and in the same year, Parsons and Parsons (MS 1974a) assessed the status of the redfish on Flemish Cap. Mayo and Miller (MS 1975) presented a preliminary assessment of the redfish in NAFO Divisions 4V, 4W and 4X combined. In the same year, Mayo (MS 1975) presented a preliminary assessment for Gulf of Maine redfish

(Subarea 5). This was treated as a single stock because of jurisdictional considerations between Canada and the United States. Thus, excluding the Baffin Bay-West Greenland area, a total of 8 stocks were defined (see Fig. 1): NAFO Subarea 2 + Division 3K (Labrador-northern Newfoundland), Divisions 3L + 3N (north and east Grand Bank), Division 3M (Flemish Cap), Division 3O (southwest Grand Bank), Division 3P (south coast of Newfoundland), Divisions 4R, 4S and 4T (Gulf of St. Lawrence), Divisions 4V, 4W and 4X (Nova Scotia Shelf) and Subarea 5 (Gulf of Maine).

The separation of the Northwest Atlantic redfish into these stocks, or perhaps more properly, management units, has continued to the present although some of these separations have been questioned. Koeller and LeGresely (MS 1981) regarded the redfish on the southern slope of Laurentian Channel in the Gulf of St. Lawrence as a separate stock. Nikolskaya (MS 1981) concluded that the redfish in Division 3L differ from those in Divisions 3N and 3O based on growth rates, maximum age and dominant sizes and ages but Atkinson and Power (MS 1986), after reviewing available data, concluded that the situation in Division 3N is still unclear. They did note that it was unlikely for serious problems to arise in the management of Division 3O separate from Divisions 3L and 3N.

Attempts at stock definition in the early 1960's were confounded unknowingly by the existence of the two species of sharp-beaked redfish. Most recently Ni (1982), based on meristic taxa, proposed 5 management stocks off the Canadian coast. These were 1) the Baffin Bay-Labrador stock, 2) Flemish Cap stock, 3) Grand Bank stock and 4) Gulf of St. Lawrence stock and 5) Nova Scotia Shelf stock. His separation of the Grand Bank and Scotian Shelf stocks was not based on any meristic differences, but upon different management jurisdictions within the Canadian Department of Fisheries and Oceans. It seems unlikely that the stocks, as they now exist for management purposes, will be changed in the forseeable future although no other evidence is available to indicate that the separation is valid.

Management

As noted earlier, management advice was first provided for the redfish stocks off the east coast of Canada in the early to mid 1970's. This advice was assessed by ICNAF (established in 1949) which was responsible for the management of all stocks in the Northwest Atlantic lying outside the waters of the coastal states. With the extension of jurisdiction to 200 miles by both Canada and the United States in 1977, ICNAF was replaced by two organizations. ICNAF itself was replaced by NAFO which now has jurisdiction over stocks lying outside coastal economic zones and also provides advice, when requested, for those stocks which overlap the economic zone of the coastal state (Canada) and the Convention area. The United States is not a Contracting Party of NAFO. The second organization established is the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) which is wholly Canadian and is responsible for providing management advice for those stocks lying completely within Canada's 200 mi. economic zone. Today, only 2 redfish stocks are managed through NAFO; the Flemish Cap stock which lies completely within the NAFO Convention area and the stock in Divisions 3L and 3N which overlap Canada's economic zone and the Convention area.

The initial assessments provided were based on general production analyses (e.g. Parsons and Parsons MS 1973; Parsons and Parsons MS 1974a; Pinhorn and Parsons MS 1974; Mayo and Miller MS 1975), often in association with yield-per-recruit and catch curve analyses (Parsons and Parsons MS 1974b). Quotas were imposed on these stocks based on both the results of these early assessments and average historical catches, but often tempered by 'gut feelings' of stock status or condition. During this period, the reference level for fishing was MSY or maximum sustainable yield. For yield-per-recruit analyses, Fmax (that level of fishing mortality that results in the maximum yield-per-recruit) was used as the reference point. The year of quota imposition and the corresponding quotas were as follows:

Stock	First Year of quota	Quota (MT)
2+3K	1974	30,000
3LN	1974	20,000
3M	1974	40,000
3O	1974	15,000
3P	1974	23,000
4VWX	1974	40,000
SA 5	1973	30,000

Assessments of redfish in the Gulf of St. Lawrence were reviewed within ICNAF (e.g. Berthome and Forest MS 1976) but the imposition of quotas was the sole responsibility of the coastal state, Canada. In 1976 an initial TAC (total allowable catch) of 30,000 mt was established for this resource.

As stated previously, management was originally based on a combination of MSY, Fmax , historical average catches and 'gut feelings'. Beginning in the mid- to late 1970's, some modifications were made to these concepts. For general production models, the reference level of MSY was replaced by 'yield at 2/3 MSY effort' as it was thought to be safer than MSY in that it represented a level more to the left of the downside of the equilibrium curve. The reference of Fmax was replaced by F0.1, that level at which the change in yield-per-recruit with respect to changes in mortality rate is one-tenth of that of the fishery beginning on a virgin stock. These changes were implemented to promote stock rebuilding and improved catch rates as extensive over-fishing of most of the commercial species off Canada's east coast in the early- to mid-1970's had resulted in depressed stocks. They remain in effect today (in most cases) as reference levels when carrying out assessments of redfish off eastern Canada.

Since 1975, assessments of the 7 redfish stocks have been carried out annually using general production analyses (e.g. Parsons and Parsons MS 1973, MS 1974a; Pinhorn and Parsons MS 1974; Mayo and Miller MS 1975; McKone MS 1979; Atkinson MS 1983; Atkinson MS 1985) as well as sequential population analyses (cohort, VPA) (e.g. Parsons and Parsons MS 1975; Atkinson et al. MS 1980; McKone et al. MS 1980; Maguire et al. MS 1983). General production analyses have been used most frequently although the assumption of equilibrium is knowingly violated. Sequential population analyses have generally not been satisfactory because of a lack of a sufficiently long time series of commercial catch-at-age data coupled with low levels of fishing mortality. The most recent (1986) TAC's and the basis for them are as follows:

Stock	TAC (MT)	BASIS
2+3K	35,000	Retained starting 1980, based on yield at 2/3 effort MSY.
3LN	25,000	Retained starting 1980, based on yield at 2/3 effort MSY.
3M	20,000	Retained starting 1979, based on yield at MSY.
30	20,000	Retained starting 1978, based on yield at MSY.
3P	18,000	Retained starting 1980, based on F0.1 catch of 18,000 MT.
4RST	55,000	Based on F0.1 strategy with some modifications based on ecomonics.
4VWX	30,000	Retained starting 1980, based on yield at 2/3 effort MSY.

Research and the Future

Much of the research on redfish off the east coast of Canada was done when the existence of the two species, S. mentella and S. fasciatus, was unknown. Much of this work needs to be redone and studies in this direction are beginning. The differences in growth rates noted by Sandeman (1969b) may be, in part, due to different proportions of the two species present in his samples from different areas. For example, examination of the depths from which Sandeman's samples were taken, and comparison with Ni's (1982) findings, would suggest that Parsons and Parsons' (MS 1973) basis for separation of Division 30 and 3P redfish (different growth rates) is merely a reflection of sampling differences. It appears that S. fasciatus may have been sampled from Division 30, while a mixture was sampled from 3P. This needs to be reexamined.

There appears to be a cline from north to south with regard to the extrusion time of larvae. Ni and Templeman (1985) noted that the sequence of larval release off the south coast of Newfoundland appeared to be S. mentella, S. marinus then S. fasciatus. If this is the case, then the different relative abundance of the species may account for some of the previously noted differences in release times.

The age and growth (and hence natural mortality) of these redfish still requires a great deal of work. Age determination and validation is ongoing both through otolith interpretation and the use of radioisotopes. For this work to be valid, there must be a separation of the two sharp-beaked species.

The diel movements of these fish are well documented. These movements have serious implications when conducting trawling surveys for redfish.

The phenomenon is being studied through the use of hydroacoustics. Preliminary data analyses have not yielded any solutions, but instead, indicate that a solution to the problem may be more complicated then a simple quantification of movement related to time of day in that there may be depth, light and fish density relationships involved.

Investigations are also underway into the use of hydroacoustics for estimating biomass of redfish. Besides the technological problems involved in working in water depths up to 750 m, such things as species identification and target strength need to be resolved.

The assessment methodology presently in use for the evaluation of the status of the redfish stocks has many shortcomings. While sequential population analysis may become more useful as the time series of data is increased and accumulated fishing mortalities become high enough for matrix conversion, problems related to ageing may still remain. General production models usually assume that the stock is in equilibrium (losses due to mortality, either natural or fishing, are balanced by recruitment). These assumptions are clearly violated in many of these redfish stocks where recruitment is highly variable. Using running averages of effort (Gulland 1961) is one way of handling this situation but is in many ways inadequate. Investigations are now underway into the use of a non-equilibrium production model (after Rivard and Bledsoe 1978) in the assessment of these redfish.

Another point that has been raised in recent years is that of the species mix in the commercial catches. Suggestions have been made that the two sharp-beaked species should be separated for management purposes. Whether this is possible or practical remains to be seen. It is first necessary to learn and understand a great deal more about the distribution of the two species with regard to area, depth and season. An easy, reliable method for species identification in the field, for both fisheries personnel and fishermen, will have to be developed. In the end, it may not be practical to separate quotas or other management policies based on the distributions of these species.

Today, the redfish fishery off the east coast of Canada is in a healthy state. Markets have improved steadily in recent years and in 1985, the Canadian catch of 72,200 mt represented a landed value of 15.5 million dollars and translated into a total product value of 53.9 million dollars. There is still room for expansion, as the 1985 landings only represented about 50% of Canada's total allocation from the redfish quotas. Continued monitoring of these fisheries coupled with ongoing research will ensure the viability of these fish and their fishery on into the future.

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A history of California rockfish fisheries

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Abstract

Rockfish have been caught off California since prehistoric times. While 60 species are recorded in California waters, less than 20 species make significant contributions to landings by the diverse gears that are used in the fisheries. This paper reviews dynamics in the size and composition of the fishing fleets and landings. Recent events in the fisheries are compared with the history, and important management and research problems of the present are discussed.

History of Landings

Californians have captured rockfish for centuries. California Indians consumed rockfish in prehistoric times (Fitch 1972). Rockfish had attained commercial importance in California by 1875 (Phillips 1957). By the turn of the century, annual landings had reached about 750 mt and there were about 1,500,000 people in the state. Now, with 25,000,000 people, landings of rockfish have increased to 20,000 mt, a 60% gain in landings per capita. The California Department of Fish and Game began compiling fish receipt data in 1916 (Heimann and Carlisle 1970; Figure 1). These data include most landings, but some small landings do not enter normal market channels and are not included.

The landings were fairly stable, generally between 2,000 and 4,000 mt, until the Second World War first interfered with the fishery and then created a large demand. Until 1943, most rockfish were caught by hook-and-line gear; only 5% were landed by trawlers. In late 1943, a boat moved from Astoria, Oregon, to Eureka and used a high-rise trawl called a "balloon trawl" (Phillips 1949). The balloon trawl was very

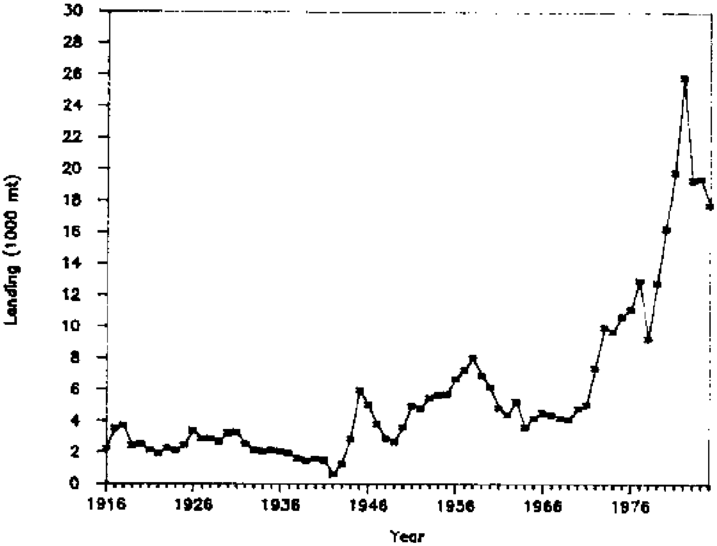

Figure 1. California commercial landings of rockfish, 1916–1985.
Source: 1916–1968 (Heimann and Carlisle 1970),
1969–1970 (Bell 1971),
1971 (Oliphant et al. 1973),
1972–1974 (McAllister 1975, 1976),
1975 (Pinkas 1977),
1976 (Oliphant 1979),
1977–1980 (Frank Henry, personal communication), and
1981–1985 (PacFIN).

effective in capturing rockfish. Use of the balloon trawl spread rapidly and trawl-caught rockfish have dominated the landings since 1944. A peak occurred in landings in 1945 because of the demand from army camps on the West Coast. Landings declined at the end of the war when the camps were phased out.

I did not find explanations for fluctuations in landings between 1950 and 1970. During the past 15 years, landings have increased considerably as the result of better market demand, net design, acoustics, and navigation. Landings peaked in 1982. In that year, many boats from Oregon and Washington fished in northern and central California. These vessels made large landings of widow rockfish (*Sebastes entomelas*) as well as other species of rockfish. In addition to the expanded trawl effort in the 1980's, gill-net vessels also have increased effort.

Since 1983, widow rockfish landings and, to some degree, landings of other species have been constrained by Pacific Fishery Management Council regulations.

The hook-and-line fishery in the early days was fairly primitive. Most trips lasted less than a day and often the crew size was one. Most fishing took place close to port and in water less than 100 fathoms (Scofield 1947). Landings were dominated by black rockfish (*S. melanops*) in northern California, bocaccio (*S. paucispinis*) and chilipepper (*S. goodei*) in central California, and vermilion rockfish (*S. miniatus*) in southern California. After the advent of the balloon trawl, canary rockfish (*S. pinniger*) replaced black rockfish in northern California and bocaccio and chilipepper replaced vermilion rockfish in parts of southern California. Catches of widow rockfish were minor before 1979 when vessels with midwater trawls began targeting on them. In very recent years, bank rockfish (*S. rufus*) have become more important in landings.

Trawl fishery

It is not very meaningful to discuss solely the California trawl fleet, because many vessels fish in more than one state during the year. The fleet is very dynamic. Of the 600 trawlers that participated in the California, Oregon, and Washington fishery for groundfish between 1981 and 1984, only 400 participated in the 1984 fishery. Of the 200 that didn't, records are incomplete for about half (E. Ueber, personal communication). We do know that about 50 sank or burned, 30 fished in other areas or for other groups of fish, and 30 didn't operate because of bankruptcy or other problems.

Most trawl-caught rockfish enter the fresh fish market as fillets. In recent years, widow rockfish, bocaccio, chilipepper, and bank rockfish have dominated the trawl landings. The ex-vessel price of most trawl-caught rockfish is $0.275/lb. The trawl landings of rockfish in California are worth about $10,000,000.

Gill-net fishery

Another important gear for rockfish in southern and central California is the gill net. This gear is prohibited in northern California. Landings by this gear are not as dominated by widow rockfish, bocaccio, and chilipepper as trawl landings are. Yellowtail rockfish (S. flavidus) and blue rockfish (S. mystinus) are also important.

In 1985, almost 900 vessels were licensed to use gill nets (E. Ueber, personal communication). While I do not have accurate data, probably several hundred gill-net vessels landed rockfish in California.

Our data for California gill-net landings are incomplete, but the catch of rockfish was more than 2,700 mt in 1985. Gillnetted fish tend to be worth more than trawl-caught fish. I estimate that 1985 landings were worth several million dollars to the fishermen. While some gillnetted rockfish are filleted, many enter the market as whole or dressed fish.

A number of problems are associated with the gill-net fishery in California. Besides the usual gear conflicts, there are major incidental kills of seabirds and marine mammals. Because of the problems, there is considerable public support to either ban the gear altogether or severely restrict it.

Hook-and-line fishery

Rockfish are still commercially caught by hook-and-line fishermen in California. While this fishery captures the same species as the other gears, there is a greater tendency to fish for specialized markets such as the Chinese restaurant trade. The brown rockfish (S. auriculatus) and several closely related species are preferred for this market. Fishermen receive as much as $3.00/lb for fish in good condition. Sometimes the fish are kept alive until just before cooking.

I don't have a firm estimate of the number of hook-and-line vessels fishing for rockfish in California. It is approximately 300. 1985 landings were about 1,000 mt. I estimate that these landings were worth 1 to 2 million dollars. Most hook-and-line caught rockfish enter the market as whole or dressed fish.

Recreational fishery

Rockfish are very important for recreational fisheries. Besides being good eating, rockfish can be as large as 28 lbs (such as the cowcod, S. levis), can be very colorful (such as the starry rockfish, S. constellatus), and can be very attractive when viewed underwater (such as the treefish, S. serriceps). While catches are usually dominated by one or two species, we have sampled more than 12 species on a single party-boat trip. The variety is appealing to some anglers.

While the California recreational fishery probably is worth more than commercial fisheries of most nations, it is not very well documented. This is because it is difficult to adequately sample recreational landings. Statistics have been collected from the party-boat fishery through a logbook system since 1936 (Collyer 1949, Young 1969). Since 1981, the entire fishery has been sampled by a phone interview and field sampling program (U.S. Department of Commerce 1986).

The party-boat fishery is concentrated in southern California. Prior to the 1950's, rockfish did not support a major targeted fishery in southern California. Anglers preferred the then abundant barracuda (Sphyraena argentea). Barracuda numbers declined and rockfish became very important in the party-boat fishery. The party-boat fishery for rockfish is still minor in northern California.

In 1985, recreational anglers landed almost 8,000,000 rockfish in California (U.S. Department of Commerce 1986). The fish weighed about 4,000 mt. Rockfish comprised almost 1/3 of all recreational fish landed in the state and are the most important group of species. Forty-six species of rockfish were sampled from recreational catches in 1984. However, three species--blue rockfish, black rockfish, and yellowtail rockfish--represent about 30% of the landings. Boat anglers make more than 90% of the landings. Landings from party boats and private boats are about equal.

Economists have yet to agree on how to determine the value of a recreational fishery. One method is to appraise all costs associated with fishing trips. Using this approach, economists estimated that the California recreational fishery for all species is worth about a billion dollars (D. Huppert, personal communication). This is not equivalent to the commercial fisheries values, because there are many factors included in the recreational value not included in the ex-vessel value of commercially landed fish. Still it appears that the recreational value significantly exceeds the commercial value. Agencies recognize this when making management decisions.

Status of fishery

Most stocks of traditional rockfish species in California are at or below the MSY level. Some, such as bocaccio, may be overfished. Present regulations consist of a quota on widow rockfish, 40,000-lb trip limits on commercially caught fish, and a 15-fish bag limit for recreational fish. There are also various gear and area restrictions. The objective of many of the area regulations is to reduce gear conflicts, particularly between recreational and commercial fishermen.

While most of the traditional species are fully utilized, two appear not to be. Recent analysis indicates there is some room for expansion in landings in chilipepper. In addition, bank rockfish landings have increased in recent years. They occupy a habitat that had only been lightly fished previously.

There are two other abundant, lightly exploited species. The splitnose rockfish (S. diploproa) is quite abundant. However, it is a very long-lived species and, while the fishery probably could be expanded some, care is needed in such an expansion because the species could easily become overfished. It is a marginal commercial fish because it produces low fillet yields and is fairly small. Shortbelly rockfish (S. jordani) is very abundant and short-lived. The species probably could support a fishery about the size of the other species combined.

However, it is quite small (maximum size about 30 cm) and must be processed rapidly.

Species targeted by recreational fisheries in southern and central California appear to be fully utilized. Some of the expansion of the recreational fishery has come at the expense of the commercial fishery. Several nearshore species--e.g., black, blue, and yellowtail rockfish--appear to be lightly fished in northern California. Recreational fishing in this area is limited because of the distance from population centers.

Discussion

During historical times the commercial fishery has passed through several phases (Figure 1). Between 1916 and 1947, landings were generally between 2,000 and 4,000 mt. During the Second World War, fishing techniques and markets improved and landings increased to between 4,000 and 8,000 mt until 1971. Since then, techniques and markets have again improved and landings are now about 20,000 mt. The status of exploited species indicates that landings will be between 10,000 and 30,000 mt until other species are harvested. If an increase occurs, it would be a repeat of history. The previous major increases involved changes in the relative importance of species. A future major increase also is likely to involve changes in species composition of landings. Shortbelly and splitnose rockfish are likely to contribute to increased landings. As in the past, improved market conditions are a prerequisite to increased utilization of these two species.

History may also be repeated in the recreational fishery. Significant expansion of recreational landings of rockfish in southern and central California is not likely to occur without reduction of commercial landings.

Management and researchers involved with California rockfish fisheries face several major problems including conflicts between recreational and commercial fisheries. I have already mentioned the gill-net problem. There also appears to be some overcapitalization. The industry, researchers, and managers have been discussing various forms of limited access management, but implementation of such management appears to be years, if not decades, off. Fluctuations in year-class strength cause the fishery to be somewhat unpredictable. Research aimed at this problem is discussed in another paper (Kendall and Lenarz 1987). Researchers are also attempting to develop optimal management strategies that account for the multispecies aspects of the fishery. Finally, monitoring the fishery is quite expensive. We are working on procedures to make sampling more efficient.

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The rockfish fisheries off western Canada, 1860-1985

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Abstract

A production history of the rockfish fisheries off western Canada is reported, based primarily on published reports of appropriate agencies. Subjects discussed were: 1) participating nations; 2) production records; 3) principal species; and 4) new fisheries.

Introduction

This report chronicles the history of the rockfish fisheries off British Columbia since 1860, based primarily on published reports.

Primary data source was Forrester *et al.* (1978), which provided the only published account of the early fishery for rockfishes, as well as available production records through 1970. Subsequent production records were obtained from publications of the Canadian Department of Fisheries and Oceans (DFO), the International North Pacific Fisheries Commission (INPFC), and the Washington State Department of Fisheries (WDF).

The INPFC groundfish statistical areas were used, because they best fit the various data sets. Catch records by area began in 1956, and are continuous to date. Two such areas, Vancouver and Charlotte, encompass the coast of British Columbia (Fig. 1). Unfortunately the southern third of the Vancouver area encompasses the northwest coast of Washington State. This overlap produces some unresolvable problems in segregating national production, particularly after Canada and the United States promulgated their individual 200-mile economic zones in 1977. Prior to 1977, Canadian vessels rarely sought rockfish in that portion of the Vancouver area which now lies in the U.S. 200-mile economic zone. However, during the same period, U.S. vessels regularly sought rockfish throughout the Vancouver area, as well as the southern portion of the Charlotte area.

Fisheries

Domestic

The first domestic commercial fishery which included rockfish took place off Victoria (S. Vancouver Island) "about 1860" (Lord 1866). This was a hook and line fishery, from canoes or other small vessels, to supply the local Victoria market with flatfish (including halibut), greenling, and rockfish.

Records of the domestic commercial fishery began in 1917 (Forrester *et al.* 1978; Table 29), and continue to date, in increasingly detailed form.

Non-domestic

Non-domestic rockfish fisheries were initiated by U.S. trawlers during the early 1950s, prior to 1956 (Forrester *et al.* 1978), and continued into 1981 (Table 1). Other national fleets which targetted on rockfish were those from the USSR (1965-68), Japan (1966-77), and Poland (1975-76).

Table 1. Historical record of national fisheries for rockfishes off British Columbia, 1956-85.

Time	Canada	U.S.	USSR	Japan	Poland
1956-64	+	+	-	-	-
1965	+	+	+	-	-
1966	+	+	+	+	-
1967-68	+	+	+	+	-
1969-74	+	+	+	+	-
1975-76	+	+	+	+	+
1977	+	+	+	+	-
1978-81[a]	+	+	-	-	-
1981[b]-85	+	-	-	-	-

[a] March 31, 1981.
[b] April 1, 1981.

Major restraints were imposed on the non-domestic fisheries in 1971 and 1977.

On March 10, 1981, Canada proclaimed fisheries closing lines on the east and west coasts which designated exclusive Canadian fishing zones (Anon. 1971). On the west coast, the closing lines excluded from Queen Charlotte Sound, Hecate Strait, and Dixon Entrance all non-domestic fisheries, except those of the United States.

On January 1, 1977, Canada promulgated its 200-mile economic zone (Anon. 1976), and thereafter all of the non-domestic fisheries were gradually phased out. The U.S. rockfish fishery was the last to be terminated, on March 31, 1981.

Production

Domestic (1917-85)

Historically, the domestic fishery for rockfish has been arbitrarily segregated into five eras: 1) paleozoic (1917-42); 2) boom I (1943-46); 3) neo-paleozoic (1947-61); and boom II (1977-85), (Table 2).

Table 2. Production[a] eras for the rockfish fishery of British Columbia, 1917-85.

Era	Years	Annual landings (t)	
		Mean	Range
Paleozoic	1917-42	160	49-113
Boom I	1943-46	1,332	1,010-1,610
Neo-paleozoic	1947-61	366	189-703
Renaissance	1962-76	2,261	743-4,289
Boom II	1977-85	11,504	7,952-17,640

[a] Sources:
1917-70 Forrester, Beardsley, *et al.* (1978)
1971-76 Forrester, Bakkala, *et al.* (1983)
1977-80 Smith (1978, 1979, 1980, 1981)
1981-84 Leaman (1982,1983,1984,1985)
1985 Leaman (personal communication)

Mean annual landing was 160 t (range = 49-313 t) during 1917-42; rose briefly to 1,332 t (1,010-1,610 t) during 1943-46; declined to 336 t (189-703 t) during 1946-61; rose to 2,261 t (743-4,289 t) during 1962-76; then rose more sharply to 11,504 t (7,952-17,640 t) during 1977-85.

Principal gear was probably some form of hook and line during 1917-42, and primarily on-bottom trawl thereafter.

Rockfish landings have never been reported by species on a regular basis. Sampling programs to estimate species composition began in 1971 (Forrester and Smith 1973). Pacific ocean perch (*Sebastes alutus*) were first reported in the landings of 1953 (op. cit.).

National (1956-85)

All-nation. During 1956-85, the all-nation catch of rockfish in the Vancouver-Charlotte region rose, irregularly, from 5,059 t in 1956 to a peak of 66,419 t in 1966; declined to 17,041 t in 1971; then more-or less stabilized at 14,600-31,700 t/y, through 1985 (Fig. 2; Table 3).

The principal species throughout the study period was Pacific ocean perch, *S. alutus*.

Canada. During 1956-76, Canadian landings were generally well below 5,000 t/y, but thereafter rose steadily to 17,140 in 1985 (Fig. 2; Table 3). Pacific ocean perch landings exhibited a similar pattern. Landings remained below 4,000 t/y through 1979; rose sharply to 5,290 t in 1980; then levelled off at 5,100-6,700 t/y through 1985. The sudden increase in 1980 was due in part to exploitation, for the first time, of a "new" stock in South Hecate Strait. This stock was discovered and surveyed in 1973 (Westrheim 1974). Subsequently biomass surveys were undertaken in 1974, 1978, and 1981, the results of which were summarized by Leaman and Stanley (1985).

The continued increase in production of other rockfish, reflects in part the limited supply of Pacific cod fillets due to a substantial, coastwide decline in Pacific cod abundance.

United States. During 1956-80, the U.S. fishery for rockfish in the Vancouver-Charlotte region ranged from 3,600-13,800 t/y, with peaks in 1963 (10,544 t), 1969 (13,756 t), and 1972 (8710 t) (Fig. 2; Table 3). Pacific ocean perch landings followed a similar pattern through 1977, with a range of 1,300-8,200 t/y, and peaks in 1963 (7,151 t) and 1966 (8,247 t). However, landings dropped sharply from 1959 t in 1977 to 900 t in 1980; and 238 t in 1982.

USSR. The USSR fishery which targetted on rockfish in the study area began in 1965 and terminated in 1968 (Fig. 2; Table 3). Peak catch was 47,952 t in 1966, and in the other three years, 11,500-17,800 t/y. During 1969-73, annual by-catches ranged from 10 to 1030 t/y, largely from the Pacific hake (*Merluccius productus*) fishery. Pacific ocean perch catches followed a similar pattern--peak catch of 34,700 t in 1966 and 8,300-12,900 t/y for 1965 and 1967-68. By-catch during 1969-73 was 10-750 t/y.

Japan. The Japanese fishery which targetted on rockfish in the study region began in 1966 and terminated in 1977 (Fig. 2, Table 3). Catches ranged from 3000 to 22,900 t/y, with peaks in 1968 (16,472 t), 1972 (11,003 t), and 1974 (22,883 t). Thereafter, an annual by-catch of 23-110 t was produced, largely by the line fishery for sablefish (*Anoplopoma fimbria*). Pacific ocean perch catches followed a similar pattern--2,100-14,700 t/y during 1966-77, with peaks in 1968 (14,772 t), 1982 (10,347 t), and 1974 (10,843 t). Annual by-catch during 1978-82 was 0-21 t.

Poland. The Polish fishery targetted on rockfish only in 1975 (12,873 t) and 1976 (3,931 t) (Fig. 2, Table 3). principal species caught were *S. entomelas* and *S. flavidus* (Ketchen 1980b). Pacific ocean perch catches were negligible--<48 t in 1967; <17 t in 1968.

Other Rockfish

Canadian and U.S. production records mark the increasing importance of rockfish other than Pacific ocean perch, particularly after 1970 in the U.S. fishery, and after 1975 in the Canadian fishery (Fig. 2, Table 3). Unfortunately species composition of rockfish catches by other national fleets are not available on a consistent basis.

Species Composition

There are approximately 34 species of rockfishes off British Columbia (Hart 1973). Estimates of species composition of other-rockfish landings from the Vancouver-Charlotte region were reported for Canadian and U.S. vessels

Table 3. Annual production (t)[a], by nation, of rockfish (RKF) and Pacific ocean perch (POP)[b], from the Vancouver-Charlotte Region, 1956-85.

Year	Canada		USA		USSR		Japan		Poland[e]		Total	
	RKF	POP	RKF	POP	RKF[c]	POP[d]	RKF	POP	RKF	POP	RKF	POP
1956	239	154	4820	2240	-	-	-	-	-	-	5059	2394
1957	215	91	3909	2034	-	-	-	-	-	-	4124	2125
1958	426	319	3596	1306	-	-	-	-	-	-	4022	1625
1959	544	247	5290	2581	-	-	-	-	-	-	5834	2828
1960	445	357	5385	2927	-	-	-	-	-	-	5830	3284
1961	267	124	6538	3561	-	-	-	-	-	-	6805	3685
1962	860	534	9366	5160	-	-	-	-	-	-	10226	5694
1963	815	454	10544	7151	-	-	-	-	-	-	11359	7605
1964	930	471	8052	5555	-	-	-	-	-	-	8982	6026
1965	1781	1395	9584	6585	16896	12200	-	-	-	-	28261	20180
1966	2696	2366	12565	8247	47952	34700	3206	3206	-	-	66419	48519
1967	743	391	9297	6193	17824	12900	13047	12874	-	-	53784	32406
1968	1314	876	10805	5725	11503	8300	16472	14772	-	-	44025	29690
1969	2439	1504	13756	5707	132	100	13093	11686	-	-	29420	18997
1970	2915	2099	11633	5971	378	270	7628	7164	-	-	22554	15504
1971	2285	1337	8939	3990	1030	750	4787	4326	-	-	17041	10403
1972	4113	2327	8696	3871	499	360	11003	10374	-	-	24311	16932
1973	2820	1398	8160	2609	10	10	9991	3598	-	-	20981	7615
1974	2658	1529	6127	2443	?	?	22883	10843	-	-	31668	14815
1975	3253	2040	4179	1310	?	?	10169	5428	12873	<48	17601	8778
1976	4289	1745	5485	1323	?	?	7750	3531	3931	<17	17524	6599
1977	7952	2716	*8710	1959	?	?	3047	2140	-	-	19709	6815
1978	10472	3864	6771	1285	-	-	110	21	-	-	17353	5170
1979	8781	2819	6771	1136	-	-	74	2	-	-	15626	3957
1980	9766	5290	5479	900	-	-	23	1	-	-	15268	6191
1981	9960	5103	4668	280	-	-	26	-	-	-	14654	5383
1982	11076	5983	6770	238	-	-	40	-	-	-	17886	6221
1983	12674	5653	-	-	-	-	-	-	-	-	-	-
1984	15210	6698	-	-	-	-	-	-	-	-	-	-
1985	17641	6111	-	-	-	-	-	-	-	-	-	-

[a] Sources: 1956-70: Forrester, Beardsley *et al.* (1978).
1971-76: Forrester, Bakkala *et al.* (1983).
1977-82: INPFC (1981a and b, 1982, 1983, 1985a and b).
1983-84: Leaman (1984, 1985).
1985 Leaman (personal communication)

[b] Ketchen (1980a).

[c] "Intermediate" estimates of Ketchen (1981a; Table 8).

[d] Estimated by applying the ratio of the 1967-77 Japanese ratio of POP/RKF (=0.724).

[e] Ketchen (1980b, p. 23).

during 1967-75 (Fraidenburg *et al.* 1977), and for Canadian vessels during 1978-85 (Smith 1978, 1979, 1980, 1981; Leaman 1982, 1983, 1984, 1985, 1986).

During 1967-75, the top seven species comprised 98.7 percent of the cumulative Canada-U.S. landings (Table 4). Principal species were *Sebastes flavidus* (48.4 percent), *S. pinniger* (24.0 percent), and *S. brevispinis* (15.0 percent).

During 1978-85, the top seven species comprised 93.6 percent of the cumulative Canadian landings (Table 4). Principal species were *S. brevispinis* (28.4 percent), *S. reedi* (18.9 percent), *S. flavidus* (16.3 percent), and *S. pinniger* (15.8 percent).

New Fisheries

Two new fisheries for rockfishes, with a high dollar value, have developed recently, and deserve at least a passing comment at this time. The first to develop, about 1977, was a line fishery in our inside waters (east of Vancouver Island) which targets primarily on *S. maliger* to satisfy a growing live-fish market in Vancouver. Dr. Richards will be reporting on this fishery later in the program. The second began late in 1982, and involves freezing-at-sea of trawl-caught rockfishes, mostly red, primarily for export to Japan.

Table 4. Species composition (percent) of Canadian and U.S. landings of other rockfish from Vancouver-Charlotte Region, 1967-75 and 1978-85.

1967-75[a] (Canada-U.S.)		1978-85[b] (Canada)	
Species	Percent	Species	Percent
S. flavidus	48.4	*S. brevispinis*	28.4
S. pinniger	24.0	*S. reedi*	18.9
S. brevispinis	15.0	*S. flavidus*	16.3
S. paucispinis	8.0	*S. pinniger*	15.8
S. reedi	1.7	*S. proriger*	6.4
S. babcocki	1.2	*S. aleutianus*	4.6
S. entomelas	0.4	*S. paucispinis*	3.2
Other[c]	1.3	Other[d]	6.4
Total	100.0	Total	100.0

[a] Fraidenburg *et al.* (1977).

[b] Smith (1978, 1979, 1980, 1981); Leaman (1982, 1983, 1984, 1985); Leaman (personal communication).

[c] Unspecified.

[d] 15 species of *Sebastes* and 2 species of *Sebastolobus*.

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The history of the rockfish fisheries in Alaskan waters

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Abstract

Rockfish (Sebastes sp. and Sebastolobus sp.) catch records were consolidated from several data sources using a Lotus 123 spreadsheet to provide a comprehensive summary of Alaskan rockfish landings from 1956 to 1985. Reported landings are presented by fishery, species group, and geographic area for the period 1956 through 1985. A brief history of earlier fisheries is also presented.

Rockfish catches peaked in 1965 with reported foreign landings of Pacific ocean perch (POP) (Sebastes alutus) in excess of 510,000 metric tons (mt). Harvests declined substantially to an all species catch of 4,352 mt in 1985. POP accounted for 77% of all reported rockfish landings with 65% from the Gulf of Alaska and 34% from the Bering Sea/Aleutian Islands region. Landings of other rockfish species were evenly divided between the Gulf of Alaska and the Bering Sea/Aleutian Islands region. Foreign landings comprised over 99% of the total reported rockfish landings since 1956 with domestic and joint venture landings comprising 0.3% and 0.2% respectively. Domestic landings increased from only 2% of the total harvest and 3% of the Gulf of Alaska harvest as recently as 1983 to 41% of the total harvest and 89% of the Gulf of Alaska harvest in 1985.

Regulations effecting harvest levels and fishery allocations are briefly discussed.

Introduction

Rockfish (Sebastes sp. and Sebastolobus sp.) have been harvested from Alaskan waters since the early 1900's (Rigbly 1984). There are several reports available that provide good information on various segments of the rockfish fishery in recent years. These reports include

Lynde 1986, Berger, et al. 1986, and Rigby 1984. However, there is no single document available which contains comprehensive catch data from all rockfish fisheries in Alaskan waters.

This report attempts to fill that gap by providing a consolidation of rockfish catch information from the foreign, joint venture, and domestic fisheries in Alaskan waters from 1956 through 1985. A brief overview of earlier fisheries is also presented.

Methods

Data from this report was obtained from available documents on Alaskan groundfish fisheries, including the three reports mentioned above. Information from these sources was combined with catch data from Pacific Coast Fisheries Information Network (PACFIN) reports and in-season catch summaries from the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS) to produce a consolidated rockfish catch database for the years 1956 through 1985. A Lotus Development Corporation 1-2-3 spreadsheet, graphics, information management program was run on a Compaq microcomputer for consolidation and graphic presentation of the data.

The catches were compiled by management area (Figure 1), fishery, and species group. Because some of the earlier data lacked area resolution, only four management areas were used for this report. The three primary management areas in the Gulf of Alaska, Eastern, Central and Western Gulf were reported independently while the Bering Sea and Aleutian Islands areas were combined. The data is separated into three fisheries, the foreign, joint venture, and domestic fisheries. Species composition is difficult to determine from the available data, particularly prior to the late 1970's and so only two species groups, the Pacific ocean perch (POP) category, which includes <u>Sebastes alutus</u> and four associated species, and "other rockfish" which includes all other species of <u>Sebastes</u> and two species of <u>Sebastolobus</u> are utilized in this report.

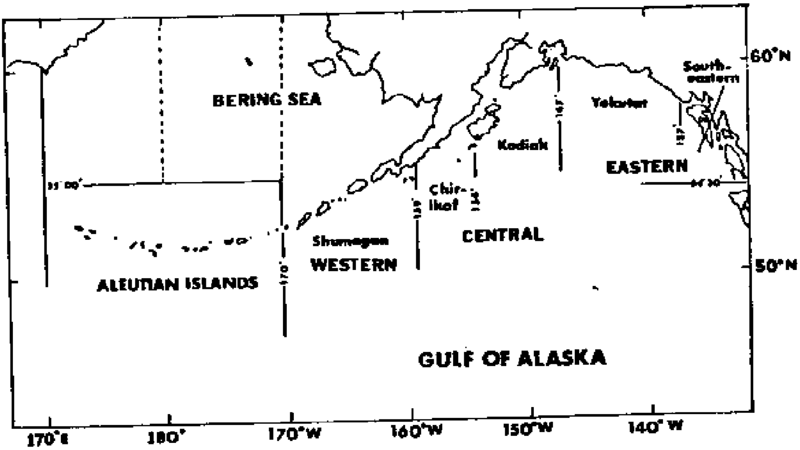

Figure 1. North Pacific Fisheries Management Council management areas within the Gulf of Alaska and Bering Sea.

Historic Fisheries

Prior to the 1960's rockfish landings were primarily of fish that were harvested as bycatch in the directed fisheries for halibut and other species, primarily sablefish (*Anoplopoma fimbria*) and salmon (*Onchoryncus* sp.). Reported rockfish landings from the early fisheries averaged 163 mt between 1939 and 1946 and peaked in 1945 with a harvest of 452 mt. One earlier odd year (1918) produced 154 mt (Rigby 1984). Reported domestic landings were negligible between 1946 and 1970. No species composition data is available from these fisheries, but it assumed that the yelloweye rockfish (*Sebastes ruberrimus*) was the dominant species landed.

Recent Fisheries (1956-1985)

The more recent fisheries are documented back to 1956 since that was the first year of data included in Lynde (1986). Although there were established domestic fisheries dating back to earlier years, it was not until the foreign trawl fleets entered Alaskan waters in the 1960's that the rockfish fishery fully developed. Joint venture fisheries, in which domestic vessels land fish directly to a foreign processor vessel, occurred beginning in the late 1970's after the passage of the Magnuson Fisheries Conservation and Management Act (MFCMA) restricted foreign fishing activity. However, by 1985 the domestic rockfish fishery had largely displaced both the foreign and joint venture fisheries.

Foreign fisheries

The foreign fisheries peaked in 1965 at over 510,000 mt (Figure 2) and declined rapidly thereafter. By 1985 only 131 mt were reported landed by foreign fleets. Reductions in landings prior to 1976 were likely the result of stock reductions. The rapid decline in harvest between 1976 and 1985 can be attributed to regulations imposed on the foreign fisheries after the passage of the MFCMA. Foreign removals of all species of rockfish from 1956 through 1985 totalled over 2.6 million mt and accounted for over 99% of all rockfish taken from Alaskan waters during that period.

Over 77% of the foreign rockfish harvest was reported as POP although accurate species composition data is not available prior to the implementation of the foreign observer program in 1973. Because of inconsistancies in the early catch reports, the actual percentage of POP was possibly even higher. Also, since most of the rockfish harvest was from the deep water trawl fishery, it is likely that at least some of the unspecified rockfish reported from the fishery between 1967 and 1973 (Figure 2) were species which are now included in the five species POP category.

Most of the POP harvest was reported from the Gulf of Alaska regulatory areas which accounted for 66% of the landings (Figure 3). Unspecified rockfish landings were evenly distributed between the Gulf of Alaska and the Bering Sea/Aleutian Island regions with 51% of the harvest reported from the Bering Sea/Aluetian Island area (Figure 4).

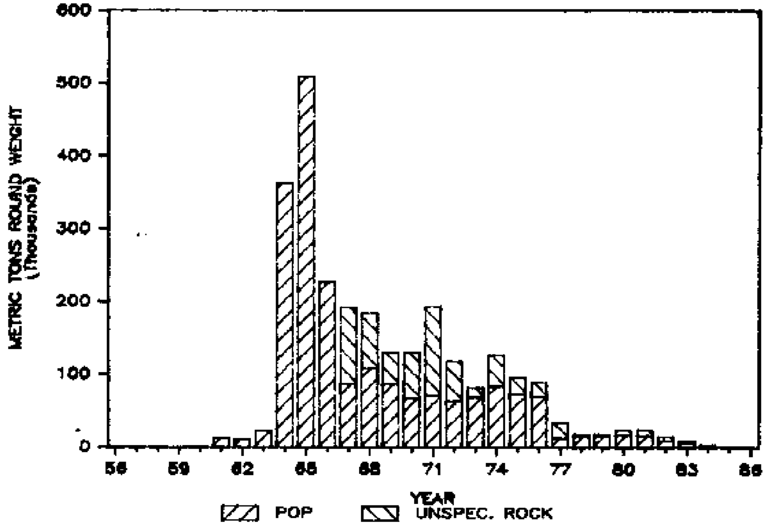

Figure 2. Foreign rockfish landings from Alaskan waters, 1956 through 1985 showing reported catches of Pacific ocean perch (POP) and unspecified rockfish.

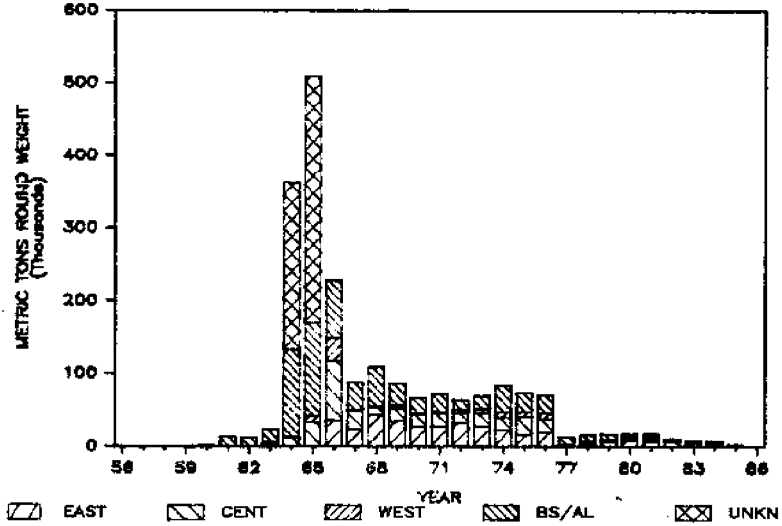

Figure 3. Distribution of foreign rockfish landings reported from Alaskan waters, 1956 through 1985 in three Gulf of Alaska regulatory areas, the Bering Sea/Aleutian Islands region and unknown Gulf of Alaska areas.

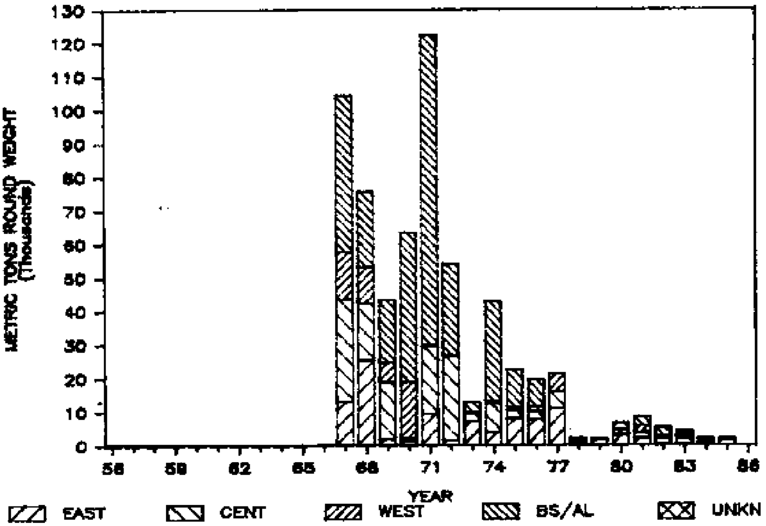

Figure 4. Distribution of foreign unspecified rockfish landings from Alaskan waters, 1956 through 1985 in three Gulf of Alaska regulatory areas and the Bering Sea/Aleutian Islands region.

Joint venture fisheries

Joint venture harvests of rockfish were first reported from Alaskan waters in 1978 with one mt of unspecified rockfish reported. Landings were small until 1983 when 2,420 mt were harvested, peaked in 1984 at 2,657 mt, and then dropped to 772 mt by 1985 (Figure 5). Much of the harvest reduction in 1985 was because of restrictions placed on the joint venture fisheries as the domestic fisheries developed. Reductions in allowable harvest as a result of biomass estimates generated from the 1984 triennial survey data also contributed to the decline.

Between 1978 and 1985 the joint venture fisheries reported total rockfish landings of 6,008 mt. This accounts for only 0.2% of all rockfish harvested from Alaskan waters from 1956 through 1985 and 5% of the landings since the joint venture fisheries began in 1978.

Rockfish in the POP category accounted for 87% of the reported joint venture harvest. The remaining 13% were classified in the unspecified rockfish category and could include species in the POP category as well.

Most of the joint venture rockfish harvest was reported from the Gulf of Alaska which accounted for 79% of the total landings. Over 77% of the POP and 90% of the unspecified rockfish harvests were reported from the Gulf of Alaska regulatory areas. The Western Gulf was the primary area of joint venture rockfish harvest with nearly 69% of all joint venture landings reported from that area.

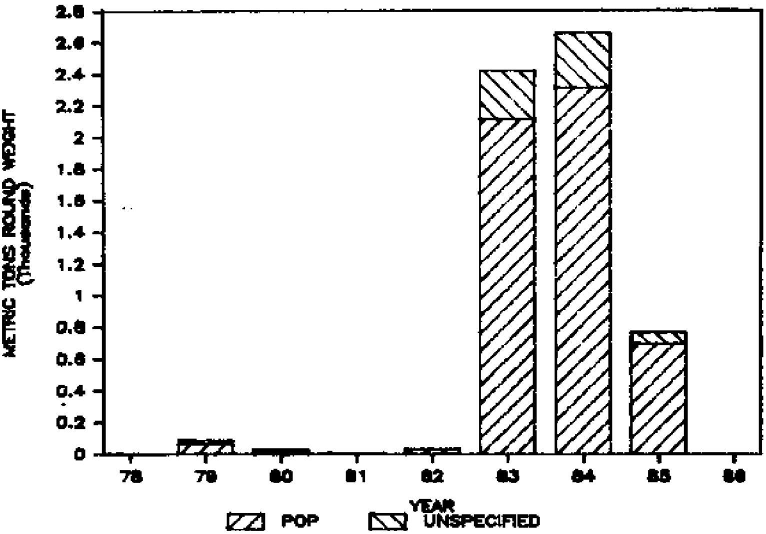

Figure 5. Joint venture rockfish landings from Alaskan waters, 1978 through 1985 showing reported catches of Pacific ocean perch (POP) and unspecified rockfish.

Domestic fisheries

Although domestic catches were reported from earlier years, only 12 mt of rockfish were reported between 1956 and 1970. A reported harvest of 620 mt of unspecified rockfish from the Eastern Gulf in 1970 was the highest on record until 1984. With the exception of the 1970 landings, the harvest was small until 1975 when slightly over 200 mt was reported. From 1971 through 1983 harvests were very stable averaging 312 mt, but the catch increased rapidly to 2,326 mt in 1984. In 1985 the domestic harvest increased again to 3,449 mt (Figure 6) and is expected to continue to increase at the expense of the foreign and joint venture fisheries.

Domestic rockfish harvests between 1956 and 1985 totalled 9,336 mt which is only 0.3% of all rockfish landed during that time period. The species groupings were fairly evenly distributed with 33% reported as POP, 26% as other rockfish, and 41% as unspecified rockfish (Figure 6). However, most of the unspecified rockfish was reported from the Eastern Gulf and is assumed to be primarily of species in the other rockfish management category. POP landings were not reported in the domestic fishery until 1981.

Over 75% of the total domestic rockfish harvest was reported from the Gulf of Alaska regulatory districts with 60% from the Eastern Gulf alone. No domestic rockfish landings were reported from the Western Gulf until 1983 and were minimal in all regulatory areas with the exception of the Eastern Gulf prior to 1984. The Bering Sea/Aleutian Islands region accounted for over 33% of the total POP landings, but only 7% of the other rockfish and 2% of the unspecified rockfish landings.

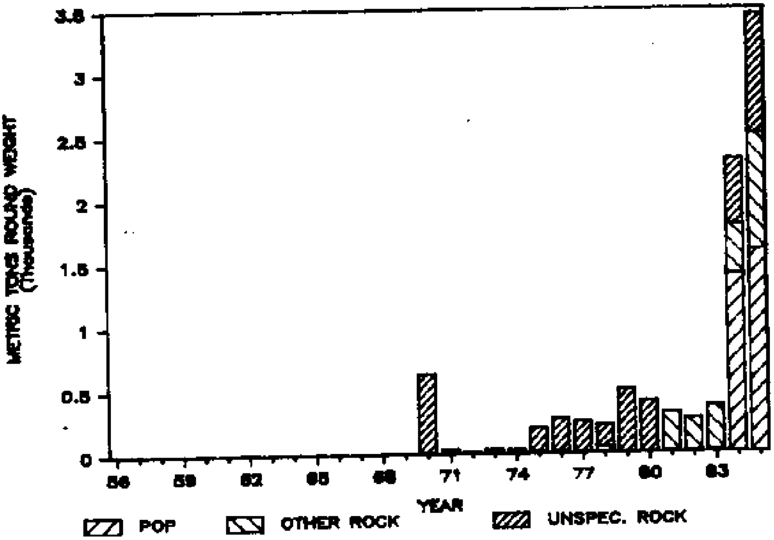

Figure 6. Domestic rockfish landings from Alaskan waters, 1956 through 1985 showing reported catches of Pacific ocean perch (POP), other rockfish, and unspecified rockfish.

Discussion

It is obvious from this review that foreign fleets have dominated the Alaskan rockfish fishery. As mentioned earlier in this report, foreign fisheries took over 99% of the rockfish harvested from Alaskan waters in the past 30 years. Even since 1978, when the Gulf of Alaska Groundfish Fisheries Management Plan was adopted, the foreign fleets harvested nearly 90% of all reported rockfish landings (Figure 7).

All rockfish species are currently considered depressed in Alaskan waters and, because of this, harvest has been greatly restricted in recent years. Much of the depressed stock condition can be directly attributed to the extensive foreign harvests between 1964 and 1976. In fact, the rockfish fishery was essentially over before the implementation of FCMA in 1976.

The total harvest for all rockfish species reached 4,352 mt from Alaskan waters in 1985. This is only 3% of the estimated maximum sustainable yield (MSY) which was set at 157,200 mt for all rockfish species in Alaskan waters. The estimated MSY level has been exceeded only six times in the past 30 years including the peak harvests of 1964 and 1965 (Figure 8) and the harvest has not reached anywhere near that level since 1971. This suggests that the MSY estimate is probably too high for these species and should be reevaluated. Use of newer biological information such as older ages and slower growth would tend to reduce the yield estimates substantially for these species. The total harvest has also been substanially below optimum yield (OY) levels set for these species in recent years. It is unclear if this indicates that quotas are not attainable at current stock levels or if there are other factors influencing rockfish harvest.

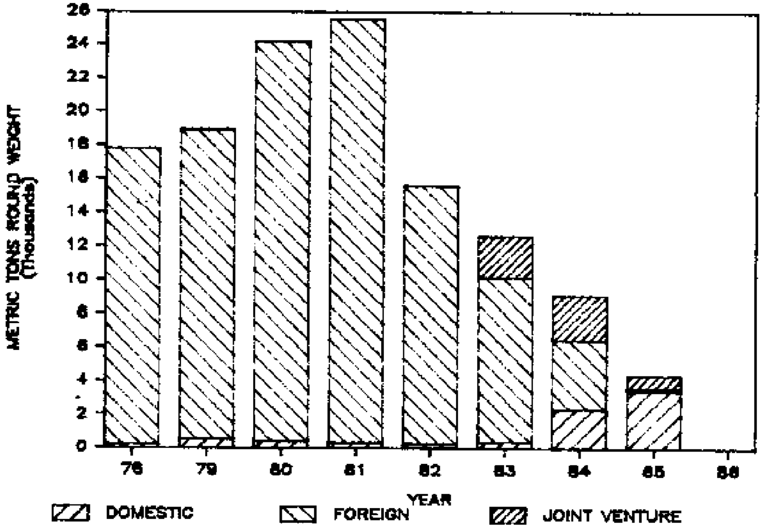

Figure 7. Rockfish landings from Alaskan waters, 1978 through 1985 showing catch by fishery.

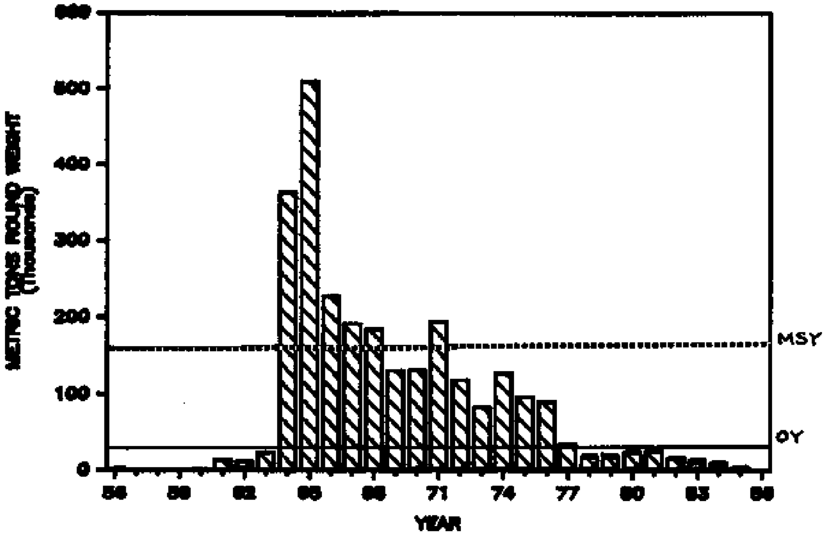

Figure 8. Harvest of all rockfish from Alaskan waters from 1956 through 1985 showing the 1985 MSY and OY estimates in relationship to actual harvest.

After the consolidated rockfish landing spreadsheet was completed information was received that some of the data in the HAL database (Lynde 1986) may not be totally accurate (personal communication R. Majors, National Marine Fisheries Service, Northwest and Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115). Verification from the Northwest and Alaska Fisheries Center is suggested for actual catch values for specific fisheries and species groups between 1956 and 1980. If erroneous data is found, the discrepancies are expected to be relatively minor and should not effect the trends indicated in this report.

The consolidated rockfish catch spreadsheet can easily be changed to make corrections to the existing data or to include additional data. It will run on any IBM compatible computer with at least 640K of internal memory using the LOTUS 1-2-3 softwear program. Copies of the spreadsheet can be made available on request from the author of this report.

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Session II -- Life History and Reproduction

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Movement studies of nearshore demersal rockfishes in Puget Sound, Washington

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ABSTRACT

An underwater tagging program was initiated to determine if habitat influences the movement patterns of copper, quillback and brown rockfishes. A total of 222 rockfishes were tagged on three reef types: high relief rocky reef, high relief artificial reef, and low relief rocky reef. Rockfishes confined their activities to smaller areas (80% within 20 m^2) on high relief reefs than on the low relief reef (68% within 400 m^2). Most of the copper and quillback rockfishes left the low relief reef in the fall after residing there during the spring and summer and some (7 of 61 tagged fish) moved offshore to the deeper artificial reef. In translocation experiments (up to 400 m) from reef to unstructured (flat-bottomed) areas, all of the 43 displaced copper and quillback rockfishes returned to the high relief reefs but none of the 14 displaced rockfishes returned to the low relief reef. Translocations from one reef type to another demonstrated that copper and quillback rockfishes returned to high relief reefs when displaced to a low relief area but did not return to the low relief reef when displaced to high relief reefs.

INTRODUCTION

Rockfishes, genus Sebastes, are an important component of the recreational and commercial fisheries along the west coast and therefore it is important to understand their life history characteristics to facilitate management. One important aspect of rockfish biology, their movement patterns, is quite variable among the 100 species of found worldwide (Love 1980, Barsukov 1981). Sedentary rockfishes could be overexploited by heavy fishing if there is no localized movement (Love 1980). Existing information regarding the

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movement patterns of nearshore demersal rockfishes presents an unclear picture. Most nearshore demersal rockfishes are considered to be sedentary, some may be perennial residents of reefs and not move more than 50 m after establishing adult residences (Larson 1980a, Love 1980). Tagged demersal rockfishes are generally recaptured in the same area of the reef where they were originally caught, thus demonstrating their sedentary nature (Mathews and Barker 1983). Diver surveys also indicate that rockfishes are quite sedentary (Moulton 1977, Larson 1980b). Additional evidence that adult rockfishes are sedentary comes from the observation that heavily fished areas can be rapidly depleted of rockfishes, suggesting that little adult movement occurs to replenish reefs (Barker 1979).

It is important to note that most studies describing demersal rockfishes as sedentary have been conducted on high relief reefs and such behavior may not characterize rockfishes in other habitats. There is evidence that the same species of rockfishes reported as sedentary may be mobile. Moulton (1977) documented decreasing densities of copper, _Sebastes caurinus_, and quillback, _S. maliger_, rockfishes on reefs in winter and spring. More dramatic movement of these sedentary rockfishes is exhibited when adult rockfishes quickly colonize artificial reefs (Solonsky 1985). Movement up to 1.6 km by black-and-yellow, _S. chrysomelas_, gopher, _S. carnatus_, and brown, _S. auriculatus_, rockfishes has been documented from low relief rocky reefs to higher relief artificial reefs and Matthews (1985, 1986) proposed that they have a lower affinity for low relief reefs, resulting in roaming to locate better habitats.

This difference in movement raises the question of whether the tendency of rockfishes to move depends on habitat type. Therefore, to learn more about the movements of copper, quillback, and brown rockfishes in relation to habitat, an underwater tagging study was designed to determine: 1) Does home range size vary with habitat type? and 2) Are rockfishes more likely to return to certain habitats than others after experimental displacement?

MATERIALS & METHODS

Study sites

Study sites typifying three habitat types: high relief rocky reef, high relief artificial reef, and low relief rocky reef were selected within central Puget Sound (Fig. 1). The high relief rocky reef, Orchard Rocks, is located on the southeastern side of Bainbridge Island approximately 600 m offshore. The entire Orchard Rocks reef covers an area of approximately 5 ha. The portion of the reef used as the study site is 15 m deep and consists of large boulders and rocky ledges that rise up to 5 m off the bottom. The reef has a surface canopy of _Nereocystis luetkeana_ and a dense understory of _Agarum fimbriatum_ and _Pterygophora californica_ . The high relief artificial reef, built in 1980, is located 5 km south of Bainbridge Island off Blake Island. The reef consists of concrete rubble, slabs, rectangular boxes, and tires forming vertical relief up to 4 m off the bottom and covers an area of approximately 2500 m^2 (Laufle 1982). The low relief rocky reef is 400 m inshore of the Blake Island artificial reef; the two reef types are separated by a steeply sloping bottom of

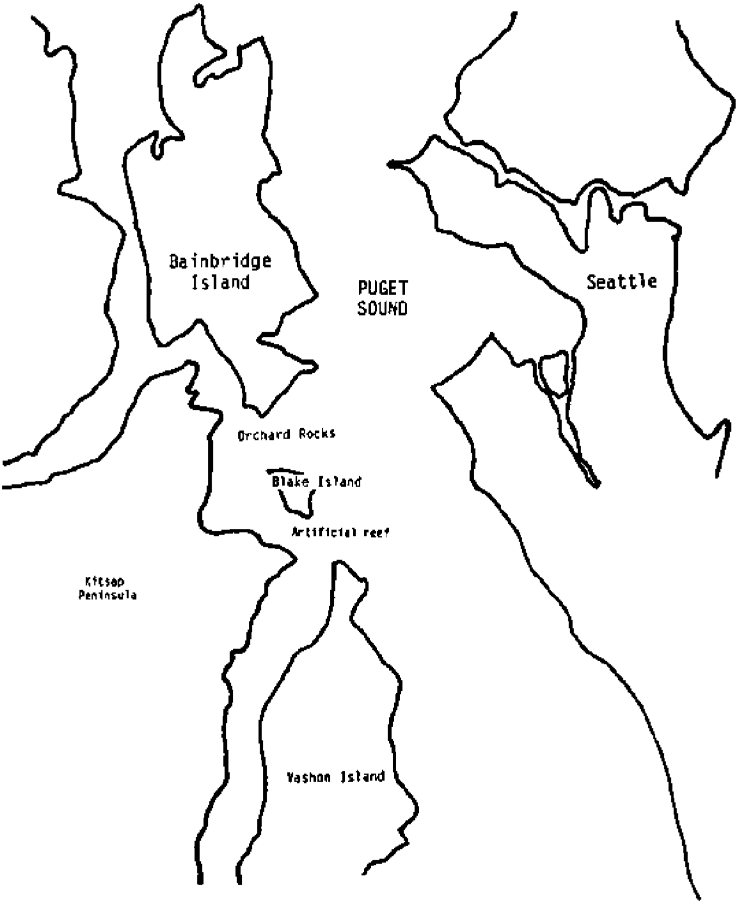

Figure 1. Map of central Puget Sound, showing Orchard Rocks and Blake Island reef sites. Low relief rocky reef is approximately 400 m inshore of Blake Island artificial reef.

sand. The low relief reef is quite extensive (approximately 10 ha) forming the entire inshore region of southwest Blake Island. The low relief reef is 10-15 m deep, has a dense canopy of Nereocystis and consists of flat, featureless rock with only a few isolated areas of vertical relief (1 m) off the bottom.

Underwater tagging

Rockfishes were tagged, measured and released without ever being removed from the water, using a technique developed by Debra Murie and co-workers (University of Victoria, Victoria, B.C.). A fish anesthetic (methomidate hydrochloride) which was transported in a 10 liter plastic water bottle at a concentration of 2 g/l. A 1 m section of surgical tubing and a 1 m clear plastic tube was added to the shut-off valve of the water container enabling a diver to approach and administer a small dose (150 ml) of the drug to an individual rockfish. Once a fish was slowed down by the drug (approximately 10-30 sec), it was captured with a hand net and tagged with a Dennison tagging gun and a Floy spagetti tag. A piece of flexible numbered white plastic (10mm X 10mm X 1mm thick) marked with indelible black ink was added to each spagetti tag for greater visibility. The white plastic was attached to the tag by drilling a hole, which was the same diameter as the Floy tag, through the piece of white plastic and then burning the end of tag to prevent loss of the white plastic. The addition of the numbered plastic to the spagetti tag enabled divers to individually identify rockfishes underwater from a distance of 1-2 m. Fish were tagged, measured (TL) on an underwater slate, and immediately released. Fish were observed after release to ensure that they had recovered from the anesthetic, generally about 1-2 min. The entire tagging process from capture to release took approximately 2 min and a maximum of 13 individual rockfish have been tagged on a single dive. For each reef the mean size of tagged fishes was computed for the three species.

Analysis of Movements

Divers surveyed the reefs and adjacent areas to locate tagged fish and their exact position on the reef was recorded. Thus, recapture data began immediately with subsequent dives after the fish were tagged, in contrast to conventional tagging studies where researchers must wait for tags to be returned. Dive lights were used to illuminate holes and crevices. The number of observations of tagged rockfishes were then tallied and home range areas estimated. In addition, adjacent areas were surveyed to determine if localized roaming occurs. Home range was defined as the area in which the animal normally lives (Brown and Orians 1970), and for rockfishes includes feeding and resting areas. A series of progressively larger rectangular areas were marked on three discrete areas on each reef and on subsequent dives a search was made within the marked off areas to locate tagged fishes and note their exact location. For example, a 20 m^2 area was marked off and if on diving surveys 100 of 150 observations of tagged fish were made within the 20 m^2 area, then the home range estimate would be 66.6% of observations within a 20 m^2 area. This technique is different from the convex polygon method employed by many researchers (Stickel 1954, Miller and Menzel 1986). Our relocation information, however, provided more precise locations of tagged fish when compared to trapping results or triangulation location estimates utilized from telemetry studies. Therefore, it is a useful comparative estimate of the home ranges utilized by rockfishes on the three reefs.

To determine the affinity of rockfishes for the 3 reef types, a series of translocation experiments were performed. To establish their residency on the reefs, tagged rockfishes that had been resighted a minimum of 5 times over a 2 month period were candidates for translocation experiments. Fishes were recaught using the anesthetic technique. A minimum amount of anesthetic was used and, whenever possible, an attempt was made to capture the fish without the drug. Once caught, the fish was placed in a opaque canvas bag. Fishes were moved either by divers on the bottom or by boat to release sites. In either case, fishes were always released on the bottom by divers and were checked to ensure that they generally appeared healthy, with no swimbladder problems. The first set of translocations involved moving the fishes 50-400 m from reef to non-reef (sand) sites. In the second set of translocations, fishes were moved from one reef type to another: low relief rocky reef to high relief artificial reef, high relief artificial reef to low relief rocky reef, and high relief rocky reef to low relief rocky reef. The translocation experiments were carried out with copper and quillback rockfishes.

RESULTS

From June through October 1986, a total of 222 copper, quillback, and brown rockfishes were tagged on the three reefs (Table 1). On the high relief reef, 79 rockfishes were tagged: 22 brown, 29 copper, and 28 quillback. On the artificial reef 82 rockfishes were tagged: 36 copper and 46 quillback. Sixty-one rockfishes were tagged on the low relief rocky reef: 41 copper and 20 quillback.

On the high relief rocky reef, tagged copper rockfish averaged 25.8 cm (range = 18-34 cm), quillback rockfish averaged 25.4 cm (range = 18-32 cm), and brown rockfish averaged 29.5 cm (range = 24-40 cm). On the artificial reef copper rockfish were a mean size of 25.0 cm (range = 17.5-31 cm) and average size of quillbacks were 19.4 cm (range = 17-25 cm). On the low relief rocky reef copper rockfish averaged 23.0 cm (range = 18-31 cm) and quillback rockfish averaged 18.2 cm (range = 14-22 cm).

The tagged rockfishes (information on copper and quillback was similar and therefore pooled) on the high relief rocky confined their activities to small areas; 98 of 113 observations (87%) were within a 13 m^2 area while the remaining 15 observations (13%) were within 80 m^2 (Table 2). Similarly, on the artificial reef, 77 of 97 observations (79.4%) found the tagged rockfishes within a 20 m^2 area and the remaining 20 (20.6%) observations were within 80 m^2. On the low relief rocky reef, larger areas had to be surveyed to locate tagged fishes and 64 (68%) observations were made within 400 m^2 and 30 (32%) within 1500 m^2.

Table 1. Number of rockfishes tagged from 6/86-10/86 on the three reefs in Puget Sound, Washington.

	High relief rocky reef	High relief artificial reef	Low relief rocky reef
Brown rockfish	22		
Copper rockfish	29	36	41
Quillback rockfish	28	46	20
Total	79	82	61

Grand total = 222 rockfishes

Table 2. Home range estimates for copper and quillback rockfishes on three reefs in Puget Sound, Washington. Observations of locations of tagged rockfishes within marked off areas were summed for each reef and percentages reported. Number of observations will total more than the number of fishes tagged as fishes were sighted more than once.

High relief rocky reef	High relief artificial reef	Low relief rocky reef
87% within 13 m^2	79.4% within 20 m^2	68% within 400 m^2
13% within 80 m^2	20.6% within 80 m^2	32% within 1500 m^2
113 observations of tagged fishes	97 observations of tagged fishes	94 observations of tagged fishes

No tagged rockfishes were located away from tagging sit on the high relief rocky and artificial reefs. However, by the end of September, the low relief rocky reef was virtually devoid of rockfishes. An offshore movement of rockfishes occurred as seven (6 copper and 1 quillback) of the 61 tagged copper and quillback rockfishes from low relief rocky reef were resighted on the artificial reef, 400 m offshore. These tagged rockfishes left the low relief rocky reef and travelled over sand to the artificial reef where they are currently residing.

Of the 24 rockfishes (11 copper and 13 quillback) that were moved up to 400 m from the high relief rocky reef, 22 (9 copper and 13 quillback) returned to within 10 m^2 of the their original home site and 2 (copper) returned to an adjacent ridge on the reef, approximately 30 m from removal site. Sixteen of nineteen displaced fishes (7 copper and 9 quillback) from the artificial reef returned to within 18 m^2 of the removal site and 3 (1 copper and 2 quillback) have been sighted on concrete pipe 25 m away from the original site.
None of the fourteen rockfishes (10 copper and 4 quillback)

translocated from the low relief rocky reef have been resighted.

On the reef-reef displacement experiments, 5 rockfishes displaced (3 quillback and 2 copper) from the high relief rocky reef to the low relief rocky reef (400 m) returned to the removal site (within 10 m^2). Five (3 quillback and 2 copper) of the six (4 quillback and 2 copper) displaced from the high relief artificial reef to the low relief rocky reef (400 m) returned to within 15 m^2 of removal site. Of six rockfishes (4 copper and 2 quillback) displaced from the low relief rocky reef to the artificial reef, 3 copper rockfish returned to the low relief area (within 400 m^2) and the 2 quillback rockfish stayed on the artificial reef.

DISCUSSION

Although these data and experiments are preliminary, they indicate that rockfishes confine their activities to small areas and will return to home sites on high relief reefs. This information suggests that demersal rockfishes have a preference for high relief habitat and may result in less movement. Rockfishes on low relief rocky reefs have larger home range areas, suggesting that a resource may be in short supply and the fishes may move over larger areas in order to locate prey or hiding places. Larson (1980b) reported that the home range size of black-and-yellow and gopher rockfishes increased with depth, presumably due to a decrease in prey availability requiring rockfishes to move over a larger area to locate prey. In addition, the rockfishes on the low relief rocky reef occupied that habitat from June-October and subsequently vacated the reef. Thus, this site may be only marginally suitable on a seasonal basis. The mechanisms utilized by rockfishes to locate new habitat or relocate home sites are unknown but it is unlikely that they rely solely on familiarity with the immediate area. Copper and quillback rockfishes on high relief reefs were able to relocate their home sites after having been displaced over 400 m, which is well beyond their observed home range. Rockfishes may be utilizing some homing mechanism although we can not exclude the possibity of random search to relocate their home sites. Displaced yellowtail rockfish, S. flavidus, returned to home sites after being moved up to 22.5 km (Carlson and Haight 1976). Furthermore, brown rockfishes displaced from fishing piers in San Francisco Bay have returned to home sites after being displaced 25 km, considerably beyond their familiar area (W. Lenarz, Southwest Fisheries Center, NMFS Tiburon, Ca. 94920, pers. comm.).

The method described of underwater tagging has many advantages over conventional tagging. As opposed to traditional tagging studies where the goal is to tag as many fish as possible, and rely on the recreational and commercial fisheries to supply the tag recoveries, this tagging program was designed to tag fewer fish but closely follow their movements through SCUBA surveys. By resighting the fish through SCUBA surveys, the tag return information begins immediately without waiting the months or years it often takes for tag recoveries to filter in from the fisheries. Furthermore, by capturing and returning fishes to the exact spot where they are encountered, the problems of returning fish over the side of a boat with uncertainty of whether they return to the bottom or find their home site are reduced. Moreover, traditional tag-recapture studies are often hampered by low returns. For example, Mathews and Barker (1983) tagged 342 quillback rockfish in northern Puget Sound but only recovered 11 tags. By comparison, at the end of 4 months we have over 300 observations of the locations of tagged rockfishes .

The adaptive significance of different movement patterns related to habitat is a stimulating research area. Southwood (1962) maintained that the primary evolutionary advantage of migratory movement lies in enabling species to keep pace with changes in their habitat. One might thus expect a higher level of migratory movement in those species associated with a less predictable environment. Demersal rockfishes may be sedentary on suitable habitat (high relief reefs) but may be more mobile on less suitable habitats. Viewing movement as an indicator of habitat suitability may explain the exodus of rockfishes from the low relief rocky reef at the end of the summer. This low relief reef may be unsuitable during the fall and winter, perhaps owing to the reduction in the only structure on the reef, the surface canopy of Nereocystis.

These preliminary observations and experiments provide some interesting new information on how habitat type may influence rockfish movement. Movement in rockfishes may be quite small in comparison to long distance migrations made by other fishes. However, management of these fishes may necessitate an understanding of how rockfishes may be moving in response to quality or seasonality of their habitat. For example, heavy fishing pressure on high relief reefs could subject rockfishes to overexploitation, especially when movement from nearby low relief reefs occurs. Therefore, as a management tool some high relief reefs could be set aside as rockfish preserves and closed to fishing. Future movement work planned to more completely understand rockfish movement includes ultrasonic tracking to closely follow day-night and seasonal migrations, longer distance translocations to determine from what distance rockfishes can relocate their homesites, following tagged fishes from the low relief rocky reef to determine if they return to the reef after their fall and winter exodus, replicating experiments on additional reefs, and additional reef-reef displacement experiments to further understand rockfish preference for habitat type.

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Ocean climate influences on groundfish recruitment in the California Current

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1. Introduction

In this study, patterns of rockfish (genus Sebastes) recruitment variation are shown to be similar to patterns of variation in physical parameter values which describe the rockfishes' environment. The patterns of similarity occur at interannual and longer scales in the 1965 - 1980 period. Although it is important to obtain detailed knowledge of the rockfishes' complete reproductive cycle, including physiological and behavioral adaptations of the young-of-the-year, the approach used here does not depend on having this knowledge.

Studies that link groundfish recruitment success to variation in the physical environment are not new (Ketchen 1956, Templeman 1972, Cushing 1973, Parrish et al. 1981). A number of interesting relationships have been at least partially illuminated. It is hoped that the present investigation will augment the ongoing exploration process that will lead to scientifically based resource management methods.

The focus of the present study is on the large amplitude recruitment fluctuations that remain apparent years and even decades later in the data obtained from commercial fishery samples. The course of the investigation was determined by the following considerations and assumptions.

1. Because of specific adaptations, rockfish population size and structure reflect physical environmental events occurring during the life history

of the population's members (Darwin and Wallace 1858). It is unlikely that co-occurring species can react identically to the range of physical variability occurring in the California Current environment.

2. Probable recruitment success of discrete cohorts of a given species of rockfish can be inferred from catch-age (catch-at-age) composition data derived from otolith (sagittae) readings for a population subset (Hightower and Lenarz 1986, Henry 1986). Imprecision in determining the calendar year of otolith initiation (fishes first year) increases- as specimen age increases (Boehlert and Yoklavich 1984).

3. Time series of physical environmental measurements exist that delineate events of diel to decadal time scales. These may have amplitudes of several standard deviation units and may extend over tens of degrees of latitude. (Mooers and Robinson 1984, Norton et al. 1985, Chelton et al. 1982). This study is focused on events of interannual and longer time scales because these events are easiest to define and rockfish recruitment variability at these scales is evident in catch-age composition data.

4. Because of uncertainties in aging and the lack of knowledge concerning the effects of environmental change on all stages of rockfish development, the best chance of showing relationships will be found by examining physical conditions during the first year of the fishes' life (Hjort 1914, Hunter 1982). Extremes in first year success (as determined from catch-age composition data) and physical events are important as possible single factor maxima that stand above "noise" that obscures underlying relationships. The rockfish parturition date is taken as January first. So, the calendar year is taken as the fishes' first year.

5. The effects of variation in any particular physical parameter on the young-of-the-year is unknown. So, the approach used in this study is to describe each year in terms of several physical parameters. Because of the reduction of quantitative time series into three bins ("+," "0" and "-"), short time series and qualitative nature of some of the data sets, pattern matching is emphasized.

The major data relationships are seen in Table 1 which organizes the information into binned data series to emphasize common patterns. The physical data are binned by numerical magnitude into three groups relative to the long term means. In general, the bins are labeled "+" for above average or positive anomaly, "0" for a defined average range where random anomaly might be assumed and "-" for below average or negative anomaly. Extremes are labled "++" and "=." Widow (S. entomelas) and chilipepper(S. goodei) rockfish recruitment and zooplankton abundance data series are given in Table 1 with the highest values indicated by "W," "C" and "Z" respectively. Asterisks show extremes and lowercase letters indicate above average values. The "x" symbol indicates low values of recruitment or abundance. For all series "n" means that the data for this period is not available. Relationships between high first year survival (population recruitment) and various physical parameters are shown for widow and chilipepper rockfish (RF) in Table 1. Row 12 of Table 1 gives a summation of the physical parameters and may be taken as a combined physical indicator. Note that widow RF and chilipepper RF have most successful recruitment under different environmental conditions. Widow RF recruitment appears enhanced during "warm" years which have positive values in row 12 and chilipepper RF have their best recruitment during "cool" years that have negative values in row 12 of Table 1.

Sections two and three of this report are intended to explain and give additional background on the physical and biological data series used in Table 1. Sections four and five expand and discuss the results given by Table 1.

2. Biological Data Series

A zooplankton abundance data series is presented with the widow and chilipepper RF recruitment time series to allow consideration of the young-of-the-year rockfishes' biological environment. All biological systems are affected by physical environmental changes. Comparison of the three series (rows 1,7 and 11 in Table 1) supports this.

Widow rockfish (S. entomelas). Widow RF recruitment data (row 1, Table 1) were obtained from the cohort analysis of the 1980 - 1985 catch-age composition data from commercial fishery sampling in Washington, Oregon and California (Hightower and Lenarz 1986). These are summarized in Figure 1. Greatest population recruitment was in 1968 and 1970. The recruitment level shown for 1971 and 1969 may be overestimated because of imprecision in aging 10 and 12 year old fish, i.e. peak spreading. Widow RF are a component of the recreational fishery as far south as Santa Barbara (Love 1981), but the peak commercial catch has been off Oregon with only occasional commercial catch south of San Francisco.

Since 1978 widow RF have become the object of a targeted single species fishery. Unlike fishing methods for other RF species (e.g. chilipepper), which are by daytime bottom trawl, the adult widow RF are more vulnerable to nighttime mid-water trawling. Dense vertically-oriented schools form at night and disperse at dawn, when widow RF become incidental in the daytime bottom trawl fishery (Wilkins 1986). The dense single species aggregations were discovered in 1978. By 1980 annual harvest increased 20 fold to 21 thousand metric tons. The "boom" years of 1980 through 1983 were sustained by the highly successful 1968 and 1970 year classes. As these cohorts were exhausted in the absence of succeeding good year classes, the fishery

Table 1. Comparison of sequences of annual values for widow and chilipepper rockfish recruitment (rows 1 and 11), indicators of the physical environment (rows 2, 3, 4, 5, 7, 8, 9, 10) and a composite physical parameter derived by adding rows 3, 4, 5, 6, 8, 9 and 10 (row 12). Years from 1965 to 1980 are entered across the top. Row designations as follows: row 1(Widow RF), widow rockfish recruitment time series; row 2(EN/AL), occurrence of California Current warming event types, EN = El Nino and AL = Aleutian Low induced coastal warming; row 3(1st dif. 25m T), large scale coastal (32 - 50 degrees north) first difference winter temperature anomaly at 25m; row 4(AL index), Aleutian Low atmospheric pressure indicator, "+" means greater development; row 5(B. C. SST), British Columbia Sea Surface Temperature (SST); row 6(N. Transport) index of tendency to anomalous northward transport in the California Current; row 7 (Zooplank.), zooplankton abundance indicator; row 8(Downwelling), winter coastal downwelling indicator at 42 degrees north; row 9(Cen. Cal. SST), composite central California SST indicator; row 10(SF Sea Level), San Francisco sea level height anomaly; row 11(CP RF), relative chilipepper rockfish recruitment; row 12 (Sum), composite physical parameter. In the biological time series, capital letters mean largest values with the asterisks indicating maxima. Lower case letters (w, z, c) indicate above average values. The "0," "x" and "n" symbols are for average and low values and no data respectively. Blank means data inconclusive (row 11). Numerical values for physcial parameters were divided into three bins: "+" above average, "0" for average, "-" below average, "++" and "=" indicate extremes. Split symbols, e. g. "+/-", mean above the mean for at least 3 months at the start of the year, remainder "-." Note that the winter events or values shown in rows 2, 3, 4 and 8 that take place in two calender years are placed in the second calendar year. Widow rockfish (row 1) have most successful recruitment during "warm" years which have "+" values in row 12. Chilipepper rockfish appear to have better recruitment during "cool" years which have "-" values in row 12.

Year	1965	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Widow RF (1)	n	n	n	W	w	* W	w	x	x	x	x	x	0	W	x	w
EN/AL (2)		EN		AL		AL EN			EN				AL EN	AL (en)		AL
1st dif. 25m T (3)	=	+	0	+	-	+	=	-	+	-	+	-	++	-	-	++
AL Index (4)	=	-	0	++	-	++	+	-	0	-	-	=	+	++	-	+
B.C. SST (5)	0	+/0	+	+/-	-	+/-	=	=	+/-	0	-	-	+/0	++	0	++
N.Trans-port (6)	-/+	+	+	0	+	+/n	-	-/+	+/-	-	=	-/+	+	++	+/n	n
Zoo-plank. (7)	z	z	z	z	0	0/z	Z	z/x	* x	0	0	n	n	x	* x	n
Downwell-ing (8)	-	-	-	-	0	++	-	=	-	-	-	=	-	++	=	++
Cen. Cal. SST (9)	-/+	+	+	+	+	+	0	+	+/-	-	=	-/+	+	+/-	0/+	+/
SF Sea Level (10)	0	0	0	+	++	+/-	=	-	+	-	-	=	-/+	+	0/+	+
CP RF (11)	c				c		C	x	C	c	* C	0	x	x	c	n
Sum (12)	-5	+2	+2	+4	+1	+7	-7	-6	+1	-6	-7	-8	+5	+8	-1	+9

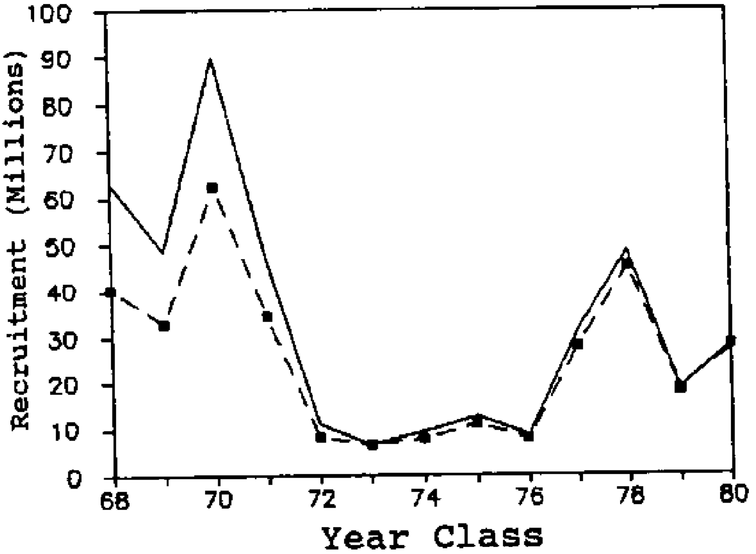

Figure 1. Cohort analysis estimates of widow rockfish recruitment at age 5 for the 1968 - 1980 year classes. Instantaneous rate of natural mortality was set at 0.15 (broken line) and 0.20 (solid line). The last three year classes may not be fully recruited to the fishery. Analysis and table from Hightower and Lenarz (1986).

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slumped (Wilkins 1986, Gunderson 1984). Figure 1 shows poor widow RF recruitment for five consecutive years from 1972 through 1976. These were cool California Current years with mild winters (Table 1, rows 4, 5, 8). The 1976-1977 winter brought a climatic shift to conditions that were again favorable to widow RF recruitment.

Chilipepper rockfish (S. goodei). Chilipepper rockfish has commercial importance mainly in central California. Annual catch is 2,000 metric tons, all south of the northern California border. Except for zonal distribution, its ecology and also its morphology appear similar to Pacific ocean perch (S. alutus) (Adams 1980). Catch-age composition data submitted to the Pacific Fisheries Management Council by Henry (1986) are summarized in Table 2. Table 2 was abstracted to give row 11 of table 1. Table 2 lists the eight most important cohorts contributing to the total California commercial trawl catch between 1978 and 1983. Each column lists year classes in descending importance to the total catch. The number in parentheses is the number of thousands of fish in the most numerous cohort. Relative abundance of the seven other most important cohorts is indicated as percent of the most abundant contributor.

Table 2. Summary of the chilipepper catch-age data for 1978 - 1983. The eight most important year classes contributing to the total California commercial trawl catch are listed for each year. Each column lists year classes in descending importance to the total catch. The number in parentheses is the number of thousands of fish in the most numerous cohort sampled by the commercial fishery. Relative abundance of the seven other most important cohorts is indicated as percent of the most abundant contributor. For the entire series, the major contributing cohorts in descending order are given in column 7.

Year	1978		1979		1980		1981		1982		1983		Total	
Rank	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%
1	69	(230)	73	(540)	75	(750)	75	(630)	73	(330)	71	(400)	75	(2536)
2	73	80	75	74	74	68	73	70	75	94	75	98	73	84
3	71	78	71	43	73	55	74	60	74	72	73	60	74	61
4	70	62	72	43	72	49	72	27	71	45	79	40	71	54
5	68	57	76	43	71	35	76	27	76	39	76	38	76	36
6	72	55	74	33	76	31	71	25	72	21	74	35	70	28
7	67	39	70	32	69	20	70	21	79	18	77	23	69	26
8	74	39	68	26	70	17	77	10	70	18	70	18	68	16

An average or better year class will enter the list of eight most numerous year classes in its third, fourth or fifth year. It will be found in the four most abundant year classes for three or more years (e.g. 1974). Finally, the cohort will drop from the list of most numerous year classes as its numbers are depleted by fishing (e.g. 1972). Relative year class strength can be estimated from the time dependent ranking of cohorts and the persistence of its residence among the top catch contributors (Table 2). The results of quantitative catch-at-age analyses (Deriso et al. 1985) are comparable to the results developed below (Henry 1987).

For the entire series, the major contributing cohorts in descending order are: 1975, 1973, 1974, 1971, 1976, 1970, 1969, 1968 (column 7, Table 2). The 1975 year class became the second most important cohort in its fourth year and remained a top contributor for the entire period. This was an unusually successful recruitment year and was the most abundant year class in the record high landings of 1980. The 1973 cohort was not sampled until its sixth year, but its place as second overall suggests that it also was an unusually abundant cohort. The 1974 year class was optimally sampled by the 1978 through 1983 period and there is probably some spreading of the 1973 and 1975 modes into 1974 because of aging imprecision. There is insufficient information to conclude that the 1974 period was much better than a high average year in terms of recruitment. The 1971 cohort appears strong in that it was a major contributor to the fishery throughout the period even though it was not sampled until its eighth year. The increase in importance of the 1971 cohort from sixth in 1981 to first in 1983 may be the result of deeper trawling necessitated by the 1982 -83 El Nino conditions. The 1976 cohort became important in its third year, but its ranking in the catch has always been lower than fourth. Aging imprecision probably lead to the overestimation of this year class because of its proximity to the very strong 1975 year class. There may have been a moderately good year class in the 1968 - 1970 period, possibly 1969. The cohorts of 1972, 1977 and 1978 are weak, in this order of decreasing abundance. The 1979 cohort is unusually numerous compared to the two predecessors (Henry 1986). It was seventh in importance in its third year and fourth the following year (Table 2).

Results of fishery-independent trawl surveys by the Northwest and Alaska Fishery Center/NMFS suggest that the 1965, 1969, 1974 and 1975 chilipepper RF year classes have been more successful than average (Coleman 1986). This is in general agreement with the results presented by Henry (1986) and has been used to complete the 1965-70 section of the chilipepper recruitment time series.

Zooplankton abundance. Continental shelf rockfish are known to feed on zooplankton (Brodeur and Pearcy 1984). Overall zooplankton abundance in the California Current south of San Francisco as given by Chelton et al. (1982) is summarized in row 7 of Table 1. The years thought to be most successful for both widow and chilipepper RF were average zooplankton years. This may represent a balance in caloric competition at the planktonic level. That is, a balance between having low enough planktonic predation to survive and having high enough planktonic food to grow may be important in rockfish planktonic stages. The zooplankton index is not included in the combined physical parameter (Table 1, row 12).

3. Physical Parameters

The physical parameters used in this study were chosen for completeness in the 1965 - 1980 period, for possible generality in reflecting physical conditions in areas of greatest chilipepper and widow RF abundance, and for general availability. The following subsections will give additional detail on the abstracting and binning of the physical data sets used in Table 1. Table 1 row headings are included with the subsection headings.

California Current Warming Events(EN/AL). Although the *Sebastes* environment in the California Current region is over the continental shelf and slope, the forces that affect this environment may originate thousands of kilometers distant in the tropical and north Pacific (Quinn 1978, Uda 1962, Norton et al. 1985, Mysak 1986). Row 2 in Table 1 indicates the occurrence of two warming event types (EN = El Nino, AL = Aleutian Low Intensification). The observed coastal impacts of the El Nino and Aleutian Low warming occur in fall and winter thus extending over two calendar years (Breaker and Mooers 1987), e.g. 1972-73 or 1976-77. In Table 1 the notation for these events are placed in the second year, 1973 and 1977 respectively.

The California Current System (CC) is a broad eastern boundary system of weak but persistent north to south surface flow off the west coast of the United States (Hickey 1979). The CC inner boundary is the coast and the outer boundary is a broad transition zone 3-400 km offshore The origins of two California current warming event types are diagramed in Figure 2. El Nino effects are carried into the CC region from the tropics by poleward traveling coastally trapped downwelling wave packets which depress the thermocline and cause coastal warming. (Huyer and Smith 1985, Chelton and Davis 1982, Enfield and Allen 1980, Picaut 1985, Mysak 1986). These El Nino perturbations that originate as equatorially trapped Kelvin waves (Cane 1983) are denoted by the solid arrows in Figure 2. Coastal bathymetric and bathythermal irregularities cause the eastern boundary trapped waves to leak energy to the west as downwelling baroclinic Rossby waves. (Rienecker and Mooers 1986, Mysak 1986)

The second warming event type is associated with an intensification of the Aleutian Low Pressure System and its counterclockwise circulation (around "L" in Figure 2).

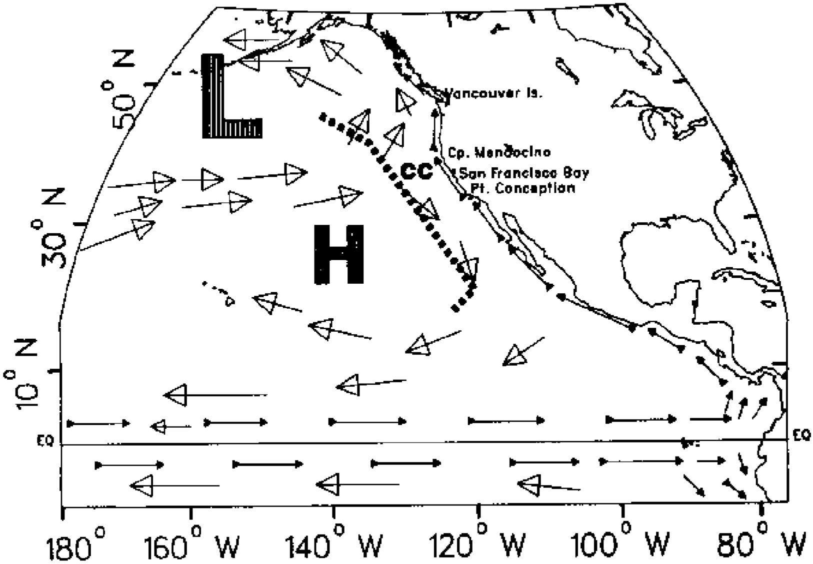

Figure 2. Origins of two California Current (CC) warm event types. The outer boundry of the CC transition zone is indicated by the dotted line. El Nino effects are brought to the CC region by poleward traveling coastally trapped waves originating as equatorially trapped Kelvin waves (small solid arrows). Intensification of the Aleutian Low atmospheric pressure system (block L) affects the CC throughout its range by intensification of winds that oppose its normal flow to the south (open arrows). As the low expands, the eastern limb of the cyclonic circulation brings anomalous south to north winds to the coast which enhance winter downwelling. The atmospheric pressure pattern shown in this diagram is representative of the early March mean.

Intensification of the Aleutian Low pressure system is a deepening or increasing magnitude of negative pressure anomalies in the lower atmosphere (Wallace and Gutzler 1981). This has effects throughout the north Pacific. The California Current is affected throughout its range by anomalous winds that oppose its normal flow to the south. As the Low expands, the eastern limb of the cyclonic circulation brings south to north winds along the coast. Then local and remote wind forcing combine to augment processes that depress the thermocline in the California Current and warm the coastal ocean, but this effect is usually limited to the upper 150m (Norton et al. 1985, 1987).

There is a tendency for deep Aleutian lows to develop during El Nino years when there is extensive equatorial warming as in the winters of 1969-1970 and 1976-1977 (Wallace and Gutzler 1981), but sometimes the low does not intensify even when there is extensive equatorial warming as in 1965 and 1972 (Douglas et al. 1982). The Aleutian Low may also intensify without apparent tropical warming as in 1967-1968 and 1979-1980 (Norton et al. 1985).

Patterns of dependence among physical parameters. Patterns of dependence among physical parameters are shown in Table 3. This table shows the association tendency among the physical parameters discussed in this study. The three interannual event types distinguished in this paper are shown. During an El Nino year (Table 3, col. 1), the warming effect on the California Current (CC) may be called the "California El Nino." During the California El Nino the sea level height and northward transport anomalies increase (Huyer and Smith 1985). Along parts of the coast there is northward surface flow as a persistent year-round feature (Bird et al. 1984, Hickey 1979.)

The Aleutian Low Index (AL Index in Table 1) may be above or below average during a California El Nino and coastal downwelling may be above or below average(Tables 1 and 3). Since the California El Nino brings warm water into the coastal zone, the north to south flow tendency of the CC is decreased. During Aleutian Low warming (Table 3, col. 2), the Aleutian Low index will increase indicating intensification of the north Pacific Low pressure system. Unusually strong coastal downwelling is common during an Aleutian Low warming. Other effects will be similar to those of the California El Nino. One of the several definite relationships shown in Table 3, is the connection between winter downwelling (row 3), onshore transport of surface water and increased transport to the north. If coastal wind stress is from south to north along the coast, surface water will be transported onshore (row 6) and downwelling will occur. As an adjustment to redistribution of water, northward flow will be increased (row 5). Increased northward flow is the result of onshore flow, which may result from California El Nino, Aleutian Low or local forcing. Onshore flow may be important in producing conditions leading to increased widow RF first year survival. During the CC cool event (Table 3, col. 3), all the parameters will tend to reverse (become "-") in value except transport to the south, which will increase. Onshore transport usually brings warmer water to the coast. Consequently, SST (row 1) and sea level (row 4) will be increased. Table 3 represents an idealized view of the relationships among physical parameters presented in Table 1.

The relationships among the physical parameters involve the change from one point to another on a functional surface which results in increased or decreased variable value. Many combinations of binned variable

Table 3. Idealized representation of three California Current Interannual Events (columns) in terms of common parameter anomalies (measurements). The rows are: Sea Temperature, row 1; Aleutian Low index, row 2; winter downwelling, row 3; Sea Level height anomaly, row 4; Northward Transport tendency, row 5; Onshore Transport, row 6 and CC southward flow. The warming events will have positive anomaly measurements except for California Current transport to the south which will be reduced. Anomalies will have reverse tendency during cool events (col. 3). The "+/-" entries reflect opposite possibilities. The California El Nino may occur with or without Aleutian Low induced warming (row 2) and enhaced winter downwelling may or may not occur during Aleutian Low warming events (row 3).

Event > Measurement		California El Nino warming	Aleutian Low warming	California Current cool event
Sea Temp.	(1)	+	+	-
AL Index	(2)	+/-	+	-
Downwelling	(3)	+/-	+/-	-
Sea Level	(4)	+	+	-
N. Transport	(5)	+ (north)	+	-
Onshore Trans.	(6)	+	+	-
Cal. Cur.	(7)	-	-	+ (south)

values are possible in a given event type, even when scaled to long term means (Table 1). Observed combinations will depend on the event intensity and the state of the CC and north Pacific atmosphere when the signals arrive. For instance, the 1972-73 El Nino was intense in the tropics, but an intensified Aleutian Low did not develop, and northward flow tendency increased during the 1972-1973 winter. Then flow shifted strongly to the south in late 1973 (Chelton et al. 1982, Huyer et al. 1978).

First difference 25 meter temperature(1st dif. 25m T). The first difference of the standardized temperature anomaly at 25 meters depth for a 200 km wide coastal strip extending from 30 to 50 degrees north latitude is shown in row 3 of Table 1. Data in this area were also averaged for a period from October through March (Norton et al. 1987). The year designation is the same as for the associated January. First differences are the average standardized temperature anomaly for a given year minus the value from the preceding year. This procedure emphasizes interannual change. A "+" entry means the current year is warmer than the preceding year and "++"("=") means that the warming was maximum (minimum) or within 10% of the maximum (minimum) value. Note that the first difference coastwide standardized anomaly is positive for every warming event in the 1965-80 series (Table 1). That is, each of the "EN" and "AL" years produced a signal in the coastwide anomaly that indicates warming over the preceding year(Table 1, rows 2 and 3).

Aleutian Low (AL Index). Aleutian Low Intensification (Table 1, row 4) was measured directly by the negative mean monthly anomaly of the 500 millibar atmospheric height at 45 degrees north latitude by 165 west longitude ("L" in figure 2). The sign of the anomaly is reversed and bins assigned according to the conventions of Wallace and Gutzler (1981). A "+" notation in row 4 indicates intensification of the Aleutian Low Pressure System over the mean. The "++" notation indicates a particularly intense Aleutian Low. The "0" means average Aleutian Low development. An Aleutian Low that is more intense than average will also be larger than average. As it expands, the Eastern Pacific High is shifted southward and winds from the south become more common over the CC System (Figure 2). The deepest Aleutian Lows were coincident with the best years for widow RF recruitment.

British Columbia Sea Surface Temperature (B. C. SST). British Columbia SST (row 5 in Table 1) was derived from monthly mean temperature anomalies (from a 30 year monthly mean) at Race Rocks on the southern tip of Vancouver Island (Tabata 1985). Symbols were assigned to divide the data into three bins as follows: "+," anomaly greater than +.25 degree Celsius; "0" for anomalies of absolute (unsigned) value less than .25; "++" and "=" indicate extreme values. In some cases it was not possible to unambiguously state that the entire year was above or below average. So, "+/-" means that the first part of the year (at least three months) was above average temperature and the last part of the year (at least three months) was below average temperature. Note that "-" values typical of the 1971 - 1976 period correspond to the best recruitment years for chilipepper RF.

Northward California Current Transport (N. Transport). An integrated index of northward CC flow (row 6, Table 1) in an area 200-400 kilometers from shore extending from 26 to 38 degrees north is extracted from Chelton et al. (1982). The symbols "+" and "n" mean northward transport and no data respectively. Fortunately, this unique time series is nearly complete in the 1965 to 1980 interval of interest. Although its exact meaning might be subject to considerable interpretation, agreement in independent measurements over the continental shelf and slope (Huyer et al. 1978, Mclain and Thomas 1983, McLain et al. 1985) suggest that this transport tendency index has some applicability in assessing the rockfishes' environment. In general it appears that, northward transport has favored widow RF recruitment and southward transport has favored chilipepper RF recruitment.

Winter Season Downwelling Index (Downwelling). An annual index of coastal downwelling (row 8, Table 1) during the winter season at 42 degrees north was derived by Norton et al. (1985) by accumulating the monthly mean upwelling index values of Bakun (1973) and reversing the sign. The convention of plus and minus symbols is similar to the parameters already discussed. In terms of percent of the highest value, the bins were assigned as follows: 0-25%, "=;" 25-60%, "-;" 60-80%, "0;" 80-95%, "+;" 95-100%, "++." The numerical average value was at about 68% of the maximum value. The three extreme downwelling years, 1970, 1978 and 1980 were favorable to widow RF recruitment.

Central California Sea Surface Temperature (Cen. Cal. SST)

The central California SST indicator (row 9 of Table 1) was derived from monthly mean anomalies at the Southeast Farallon Islands, 46 km west of San Francisco and at Pacific Grove at the southern end of Monterey Bay 100 km south of San Francisco (Anon. 1981). These two stations represent different coastal environments and the combined data is presented as a temperature indicator closely associated with the chilipepper environment. Combination of the data allowed a complete data set to be derived from two nearly complete data sets. Binning conventions are generally the same as for British Columbia sea surface temperature (above). The most extremely negative value in 1975 corresponds to the most successful (known) chilipepper year class, but this relationship does not appear to hold for all other chilipepper year classes.

San Francisco Sea Level (SF Sea Level). The detrended San Francisco sea level was adapted from McLain (1983) for row 10 of Table 1. Sea level anomaly is an indicator of coastal current tendencies and integrated sea temperature (higher sea level anomaly suggests more northward flow and higher integrated temperature anomaly of the water column) (Chelton and Davis 1982, Norton et al. 1985). The division of the anomaly range into three bins and extremes was based on taking the range of anomalies less than 5 cm absolute value as average or "0." Extremes and anomalies within 10% of the extremes are given "++" and "=" symbols. In several cases, negative anomaly corresponds to good chilipepper RF first year survival and positive anomaly appeared to favor enhanced widow RF first year survival. The role of sea level extremes does not imply a direct relationship between sea level at San Francisco and rockfish recruitment.

4. Results

The individual measurements of the physical environment have been combined in a simple straightforward way by first dividing the data series values into three categories or bins to show patterns. Then the binned values were added together to give an overall representation of the pattern. The result of this process is given in row 12 of Table 1. This combined parameter was then compared to the recruitment data for widow and chilipepper rockfish (table 1, rows 1 and 11). The major results of these pattern comparisons are listed below.

1. Different physical conditions are required for optimum widow and chilipepper RF recruitment. Certain intermediate years, in terms of the combined physical parameter (Table 1, row 12), may support moderate recruitment in both species.

2. Widow RF recruitment is favored by winters with deep Aleutian Lows, violent winter storms on the coast, above average sea temperatures, enhanced northward flow in the the California Current and anomalously high coastal sea level. Widow RF recruitment seems to be facilitated by the common large scale warming events (Table 1, row 2). However an El Nino alone, unaccompanied by anomalously deep Aleutian Low development as in 1966 and 1973, does not appear to favor enhanced widow RF recruitment. The Aleutian Lows that expand over the coast and bring frequent 'winter storms with strong winds from the south to intensify coastal downwelling seem more important than the Californai El Nino in enhancing widow RF recruitment (Table 1).

3. Chilipepper RF fish recruitment appears to be facilitated by cool water, and increased southerly CC flow conditions as described ideally in table 3, column 3, or more realistically in table 1 under 1971 and 1975. Exceptionally good chilipepper recruitment does not occur in years of exceptionally good widow RF recruitment.

4. The coastal ocean from central California to Vancouver Island has undergone three climatic shifts in the 1965 - 1980 period. First, there was a warm period of five years which included two California El Ninos and two Aleutian Low events. In 1970 the two warm event types combined to create conditions that appeared exceptionally favorable to widow RF recruitment. After 1970 a shift to an ocean climate of cool sea temperatures and increased southerly flow in the CC occurred. This cool period lasted until 1976 and included all the most numerous chilipepper RF cohorts contributing to the 1978 to 1983 catch. In 1976 the ocean climate shifted back to the warmer regime. Again young-of-the-year widow RF survival appears to have been enhanced as CC warming events became more frequent.

The catch-age composition data suggest that 1969 and 1971 were moderately good recruitment years for widow RF. These were also at least moderately good years for chilipepper RF recruitment. It is probable that because the very successful 1968 and 1970 widow RF cohorts were not aged until they were over ten years old, there is some peak spreading due to aging imprecision. The 1969 year class would be most likely to be overestimated if aging imprecision is Gaussian, since it is between the two most numerous cohorts. However, if it is more likely that annular otolith rings will be missed more frequently than erroneously added, then the 1971 year class would be the most likely to be overestimated because it follows the most numerous cohort. The 1969 year class will be second most likely to be overestimated. Combining this reasoning about aging imprecision with the findings that chilipepper RF recruitment is facilitated during cool events (Table 3), can lead to the not unreasonable conclusion that the apparent ambiguity in recruitment data for 1971 is the result of overestimation of the size of the 1971 widow RF cohort. The physical environment of 1971 appears favorable to chilipepper RF recruitment (Table 1).

Environmentally, 1969 and 1971 were very different. If better than average recruitment was to occur in both chilipepper and widow RF in the same year, it would be expected to occur in a year such as 1969 when the sum of physical parameters is not conspicuously in the minus or plus domain. The catch-age composition data for chilipepper RF does not give definite information about the strength of this year class compared to the strong year classes of the 1970s. It is likely that the 1969 widow RF year class was also overestimated, but the extreme positive sea level anomaly suggests that this year was more favorable to enhanced widow RF recruitment. High coastal sea level is consistent with increased northward flow along the coast. This is confirmed by the northward flow index (Table 1, rows 6 and 10). Increased northward flow may be the factor in common with Aleutian Low warming events that facilitate widow RF recruitment (Table 3). Chilipepper RF recruitment may have been enhanced in 1969 relative to 1968 and 1970 and may have been poor compared to 1973 and 1975.

Results of the Northwest and Alaska Fishery Center's 1980 Bottom Trawl Survey show that the 1965 chilipepper RF cohort was especially numerous (Coleman 1986). This is consistent with the relationships which are also evident during the 1971 - 75 period (Table 1).

The 1972 year class is conspicuously weak in the chilipepper catch-age composition data of Henry (1986), but the environmental data appears favorable to a strong chilipepper year class. The inshore CC was affected by the 1972-73 El Nino in the spring of 1972 (Enfield and Allen 1980, Chelton and Davis 1982, Huyer and Smith 1985) and this may have had an impact not reflected in the physical parameters presented. Likewise the 1976-77 El Nino may have curbed survival of the 1976 year class of chilipepper RF. The 1965 and 1969 chilipepper year classes, however, appear as though they may be exceptions to the reasoning just used to explain poor recruitment in 1972 and 1976.

5. Discussion

The combined physical parameter developed above gives a numerical value to the ideal California Current event types : Aleutian Low induced warming, California El Nino coastal warming and California Current cool events (Table 3). The larger unsigned values belong to years with warm or cool events undiluted by opposite event types (Table 1). The best years for chilipepper and widow rockfish recruitment occur when the value of combined parameter is at or near its maximum unsigned value. Negative anomalies favor recruitment in chilipepper rockfish, while positive anomalies favor widow rockfish recruitment (Table 1). This result, suggests that the present approach may be appropriate, but it does not necessarily mean that the most important physical terms have been included in the analysis. Future research must be sensitive to other parameters' ability to match patterns of fish stock recruitment and add dimension to descriptions of the fishes' environment.

The simple system used here allows some knowledge of the biological systems to be gained without knowing exactly how the biological systems are affected by the physical environment or even what particular aspect of the physical environment is most important. Also, the assumption that the biological system is reacting in a simple straightforward way need not be abandoned. The assumption that can be avoided in using the multidimensional approach is that the rockfish systems react directly to physical parameters as we happen to measure them, e.g. temperature, sea level, etc.

Species distinction has been shown to be important. If, for instance, recruitment of chilipepper and widow RF were summed, it would be much more difficult to form associations with physical environmental patterns. Another species distinction is that the value a particular physical data set will have in helping to understand recruitment will depend on the species involved. The data presented in table 1 are somewhat more successful in describing the widow RF recruitment data set than in describing the chilipepper recruitment data set. Widow RF recruit best under the Aleutian low, El Nino and downwelling conditions. The only apparent exception is 1971, the year following the most numerous year class in the record. This may not be an exception because 1971 is the year class most likely to have its size overestimated because of the tendency to miss annular rings in aging older fish.

Figure 3 summarizes some of the points made above. It is a scale-less grid or coordinate system with two main axes. The vertical axis represents advective current flow in the CC system. Increased northward flow is toward the top of Figure 3, while increased flow to the south is represented by the space below the horizontal axis. Negative atmospheric pressure anomaly or an intensified Aleutian Low Pressure System is toward the right on the horizontal axis. Positive anomaly representing a less developed Aleutian Low is to the left. The right side of the horizontal axis is further divided into two areas. When the winter-time Aleutian Low extends over the coastal

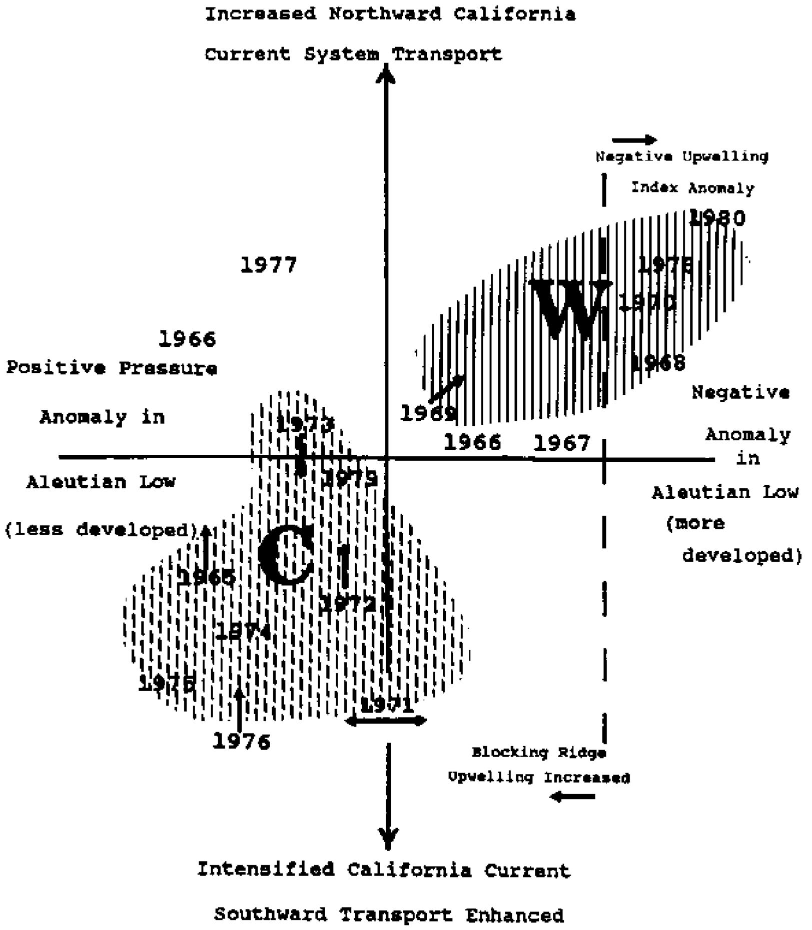

Figure 3. Coordinate system organizing rockfish recruitment data and physical parameter tendencies into four quadrants. The verticle axis represents advective current flow in the CC system. Increased northward flow is toward the top and increased southward flow is represented by the space below the horizontal axis. Negative atmospheric pressure anomaly in an intensified Aleutian Low is to the right. The positioning of the year designations was done on the basis of the combined parameter (table 1, row 12). Arrows associated with the date give inferred direction of change during the year. Years that favor chilipepper rockfish are in the the lower left quadrant (broken hatching) and years that favor widow rockfish recruitment are in the upper right quadrant (solid hatching).

When the winter-time Aleutian Low extends over the coastal California Current System, it frequently results in increased winter downwelling (Figure 3, right of dotted line). The area in the upper right quadrant between the main vertical axis and the dotted vertical ancillary axis would contain years when the Aleutian Low did develop but was blocked from the coast by a high pressure ridge as in the 1976-1977 winter (1977 in Table 1). The 1967 - 1968, 1977 - 1978 and 1979 - 1980 winters (1968,1978 and 1980 respectively in Table 1) would be to the right of dotted line in the upper right quadrant. The upper left quadrant is the area of California El Ninos that occur without Aleutian Low intensification. El Nino years of 1966 and early 1973 would be in this quadrant. Columns 1 and 2 in Table 3 would represent the area above the horizontal axis in the left and right quadrants respectively. If the event types occurred together in a combined event as in 1969 - 1970, the year would be placed in the upper right quadrant. The high downwelling value for 1970 moves the year further to the right past the dotted line. These years are usually warm with elevated coastal sea level and increased onshore transport in the coastal ocean's surface layers (table 3).

The space below the horizontal axis in Figure 3 corresponds to the cool CC years when transport to the south is enhanced. (table 3, col. 3). The lower left quadrant would contain the cool years of the early and mid-1970's. Aleutian Low enhancement is not as frequent or intense during cool periods, so few years will be characteristic of the lower right quadrant. In the 1965-80 series, 1971 is a possible example. The lower left quadrant contains 1965(early), 1972(early), 1973(late), 1974, 1975, 1976(early), and 1979 which were definitely cool and largely devoid of warming event influence as these influences are described in this study.

Years that appear to favor chilipepper recruitment are in the lower left quadrant and those that favor widow rockfish recruitment are in the upper right quadrant of Figure 3. The best widow rockfish years are to the right of the dotted line indicating that the best widow rockfish recruitment years have intense coastal winds which bring warming of the surface layers of the coastal ocean and leading to northward transport. Increased onshore, cross shelf, transport will accompany increased northward transport. This will carry pelagic larvae and weakly swimming early juvenile stages toward shore.

This possible mechanism for increased widow RF recruitment fits the generalities proposed by Parrish et al. (1981) that explain fish species distributions along the Washington, Oregon and California coasts. They state that the California Coast between Cape Mendocino and Point Conception is unfavorable to recruitment of species with pelagic eggs and larvae because of the vigorous surface offshore transport that accompanies the nearly year around upwelling circulation (Parrish et al. 1981, Bakun and Parrish 1980). At present there is no way of knowing if onshore transport is the important environmental factor in widow RF recruitment, but the data suggest an important winter mechanism that has dynamics in common with northward and onshore CC System transport. If widow RF depend on winter onshore transport to maintain early life stages in favorable environments for settling and the onshore transport is wind driven (apparently the more the better, table 1), then it is not surprising that the commercial fishery for widow RF does not extend south of San Francisco, and that the targeted fishery of the early 1970s was centered off Oregon where winter winds from the seasonally intensified Aleutian Low are a conspicuous feature of the mean annual cycle. It may be that the prolonged upwelling season and associated offshore transport, or divergent flow, characteristic of the central California Coast carries planktonic stages of widow RF larvae offshore into environments hostile to survival and growth. If planktonic stages of widow RF are characteristically in the surface layers, then it is probable that this is the mechanism inhibiting population maintenance off central California.

It is clear the chilipepper rockfish which have maximum abundance on the central California coast are dependent on different conditions than those favoring excellent widow rockfish recruitment. Chilipepper rockfish recruitment is favored by cool years, but the fact that there was good recruitment in 1973 suggests that the cool conditions of the later part of 1973 were more important to young-of-the-year survival than that year's warm initial months. That is, the later part of 1973 appears to fit the pattern that would favor chilipepper RF recruitment. It may be that the character of the winter months at the beginning of the chilipepper rockfishes' first year is less important in determining chilipepper RF survival than they appear to be in determining widow RF survival. The fact that chilipepper rockfish are most successful on the central California coast suggests that they have specific adaptations in their early life history that allow them to avoid being swept offshore in larval and planktonic juvenile stages by the surface offshore transport that accompanies the characteristic upwelling circulation.

Other rockfish species. Preliminary studies of the kind described above are being conducted on yellowtail (*S. favadus*) and canary (*S. pinniger*) rockfish. Data from the 1960-70 period, suggest that yellowtail rockfish recruit better during El Nino years. Years with and without intensified Aleutian Low development may be equally favorable. This would place yellowtail RF in the upper two quadrants of Figure 3 indicating that their recruitment is enhanced by any event forcing northward CC flow. Canary rockfish appear to have better recruitment when there is more southward transport. So, the years favoring canary rockfish recruitment would fall below the horizontal axis in Figure 3. More definite conclusions regarding these species will have to await more complete and accurate recruitment time series.

Fisheries management and investment planning. Understanding the probabilistic nature of recruitment periodicity is essential to resource managers as well as investors looking for maximum return on their investment. Knowing the climatic regime that favors or inhibits recruitment in a targeted species, could lead to better knowledge of how sustainable a fishery might be and what limitations on exploitation may be necessary to maintain a sufficient stock of adults to take advantage of good recruitment conditions when they occur.

Since several time series of physical parameters exist of five to ten decades length, it may be possible to treat these as proxi-variables of recruitment and get quantitative information on expected variability in recruitment.

Widow rockfish boom and bust. The knowledge of the spectacularly good widow rockfish recruitment of 1968 and 1970 followed by very poor recruitment from 1972 through 1976 suggests an explanation for the boom and bust history of the targeted widow RF fishery (Gunderson 1984). It is possible that the discovery of the midwater widow RF fishery in the late 70's was the result of the excellent recruitment conditions of 1968 and 1970. Suddenly, eight years later, there was a large exploitable biomass of widow rockfish which had not been noticed before because it was not there. After the abundant widow rockfish resource was discovered, the fishery increased twentyfold in two years based on the unusually good 1968 and 1970 year classes. The decline in the fishery that began in 1982 was the result of depletion of the two strong year classes. The cool, strong CC years that followed 1970 inhibited widow rockfish recruitment, providing no additional input to the fishery resource in the early 1980's. It will be interesting to note how successful the 1980 widow rockfish year class will be. According to the data presented in table 1, 1980 should be a very good year and initial catch-age composition data suggest that it is a numerous cohort (Figure 1). Data at full recruitment are not presently available.

The combined physical and biological data presented in this report suggest that the bio-economic boom to bust event chronicled by Gunderson (1984) for widow rockfish is perfectly natural considering the pulsed recruitment common in this species and the climatological background of the event. When more is known of the physical conditions favoring the 1968 and 1970 year classes, it will be possible to analyse the historical records and determine expected frequency of proper conditions for exceptionally good recruitment.

Acknowledgements

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Status of early life history studies of northeast Pacific rockfishes

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Abstract

Rockfishes (Sebastes spp.) are highly unusual in that they have internal fertilization of a large number of eggs (>10^5) and give birth to planktonic larvae at the first feeding stage. Following the planktonic larval stage, juveniles develop in a variety of habitats, depending on the species. Some remain pelagic for several months, while others become demersal at a small size. Since about 70 species of rockfish occur in the northeast Pacific, identifying the larvae and juveniles is a major problem. Recent studies have greatly enhanced our ability to identify these young stages, which allows us to contemplate using them to address fishery-related problems. Current studies are focused on relating the abundance of larvae and juveniles of rockfish to the adult populations, to measure both adult biomass and recruitment. These studies show promise, but the unusual biology of the genus limits somewhat the potential of such studies for fishery management purposes.

Early Life History Pattern

Rockfishes have an unusual reproductive pattern with important implications for their ecology and fisheries on their populations. Most fish that reproduce in marine waters lay free-floating planktonic eggs that are fertilized and undergo embryonic development as independent organisms in the open sea. Hatching is followed by a yolk-sac period about one-half as long as incubation, during which the larva develops eye pigment and feeding mechanisms. In rockfishes, however, fertilization occurs internally and the eggs develop and hatch inside the ovary of the female. It has recently been found that the embryos ingest ovarian fluid as a supplement to the yolk (see Boehlert, Kusakari, and Yamada, this volume). When the larvae are extruded after several weeks, they have little yolk left and are ready to begin feeding. These larvae are about 3-7 mm standard length (SL), comparable in size to first-feeding larvae of species with planktonic eggs.

Mortality of planktonic fish eggs, due primarily to predation, is high for the few species that have been studied in enough detail to make reliable estimates. Generally more than 50% of the pelagic eggs spawned by a fish die before hatching (Hempel 1979). Mortality of yolk-sac larvae in the field is even more difficult to examine but predators that feed on eggs probably also consume yolk-sac larvae. Thus, less than 20% of eggs spawned may survive through the yolk-sac period to become free-feeding larvae. Boehlert et al. (this volume) estimate that there is about 25% mortality of young in rockfishes between fertilization and parturition. Thus, the number of surviving first-feeding larvae in rockfishes is about 75% of the number of eggs that undergo ovulation, rather the 20% or less of that number in fishes spawning pelagic eggs. Also, the reproductive pattern of rockfishes reduces the amount of dispersion of planktonic stages by ocean currents.

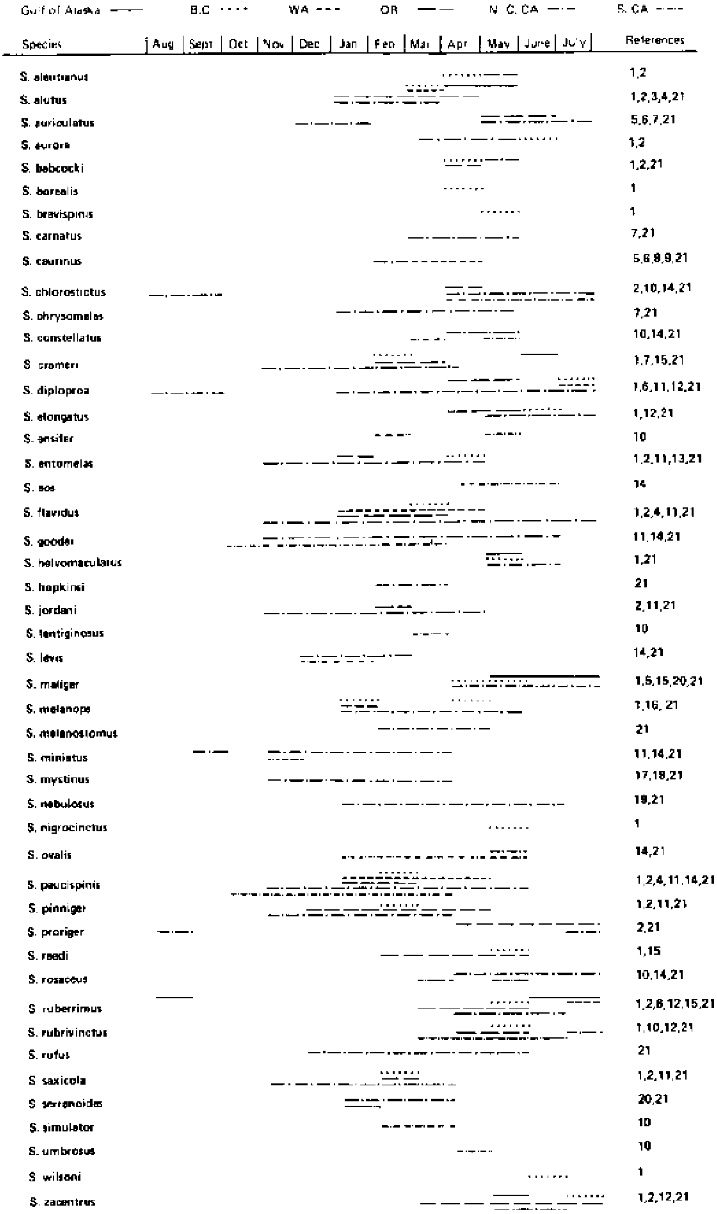
Fecundity of rockfishes is high (10^4-10^6 eggs per female) and is only slightly lower than it is in fishes spawning pelagic eggs. In fish with more extensive protection of the young, or those that produce considerably larger eggs, fecundity is reduced substantially. It would seem that rockfishes have not achieved the concomitant reduction in fecundity generally associated with increased parental contribution to the welfare of individual progeny. The evolutionary advantage of gestation in rockfishes is unclear, but apparently it is not completely explained by protection of the egg and early larval stages. Internal fertilization may allow distinct but similar species to co-occur with little chance of cross-fertilizing their gametes. Behavioral or other prezygotic barriers would prevent copulation among closely related species. This reproductive strategy may have contributed to the genus becoming so speciose in the North Pacific.

Seasonality of Reproduction

Reproductive events in rockfishes follow this sequence: spermatogenesis, vitellogenesis, mating, ovulation, fertilization, embryonic development, hatching, and larval extrusion. Males mature up to several months before the females, and mating may precede fertilization by several months. Embryonic development takes about 40-50 days, and the larvae hatch about 1 week prior to extrusion. Although most rockfishes release larvae during the first 6 months of the year, there is quite a bit of variation among the species, and within a species among years.

When comparing information on seasonality of reproduction, the methods and criteria used and the sample sizes must be evaluated. Most work to date has been done off British Columbia and north/central California. Wyllie Echeverria (in press) has summarized information on reproductive seasonality of 34 species of northeast Pacific rockfish. The duration of larval release varies from 1 to 9 months among the species studied, and a few species demonstrated two periods of release during the year (Table 1). In general, species can be grouped into those that extrude larvae in winter and those that extrude larvae in spring-summer.

Table 1.--Periods of release of rockfish larvae. Based on Wyllie Echeverria (in press).



Species	References
S. aleutianus	1,2
S. alutus	1,2,3,4,21
S. auriculatus	5,6,7,21
S. aurora	1,2
S. babcocki	1,2,21
S. borealis	1
S. brevispinis	1
S. carnatus	7,21
S. caurinus	5,6,8,9,21
S. chlorostictus	2,10,14,21
S. chrysomelas	7,21
S. constellatus	10,14,21
S. crameri	1,7,15,21
S. diploproa	1,6,11,12,21
S. elongatus	1,12,21
S. ensifer	10
S. entomelas	1,2,11,13,21
S. eos	14
S. flavidus	1,2,4,11,21
S. goodei	11,14,21
S. helvomaculatus	1,21
S. hopkinsi	21
S. jordani	2,11,21
S. lentiginosus	10
S. levis	14,21
S. maliger	1,5,15,20,21
S. melanops	1,16, 21
S. melanostomus	21
S. miniatus	11,14,21
S. mystinus	17,18,21
S. nebulosus	19,21
S. nigrocinctus	1
S. ovalis	14,21
S. paucispinis	1,2,4,11,14,21
S. pinniger	1,2,11,21
S. proriger	2,21
S. reedi	1,15
S. rosaceus	10,14,21
S. ruberrimus	1,2,6,12,15,21
S. rubrivinctus	1,10,12,21
S. rufus	21
S. saxicola	1,2,11,21
S. serranoides	20,21
S. simulator	10
S. umbrosus	10
S. wilsoni	1
S. zacentrus	1,2,12,21

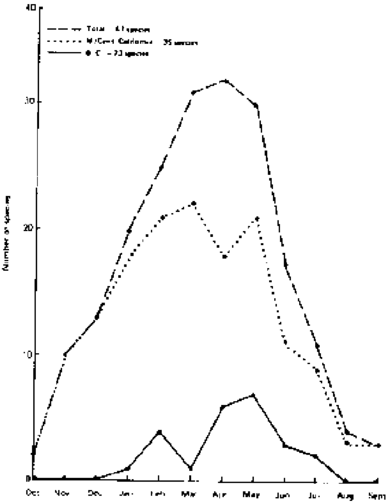


Figure 1.--Number of rockfish species releasing larvae off north / central California and British Columbia by month. Based on Wyllie Echeverria (in press).

Parturition seems to occur earlier in the year in the southern part of the species' range, although data sufficient for such a comparison is available for few species. Annual differences in timing of release of larvae seem to be environmentally determined. In some species studied by Wyllie Echeverria (in press), parturition during the anomalous El Nino year of 1983 was delayed compared to the other years from 1981 to 1985.

Summarizing the data presented by Wyllie Echeverria (in press), there seems to be a slight tendency for rockfishes in the north (British Columbia) to release young later in the year (April-June) than those off north/central California which release young mainly from January to May (Fig. 1). Also, a longer period of release is apparent off north/central California than off British Columbia (Table 2). The median period of release off British Columbia is 1 month, whereas off north/central California it is 3 months. These differences could partially be due to differences in sampling density.

Table 2.--Duration of parturition period of rockfishes by area and number of species (based on Wyllie Echeverria, in press).

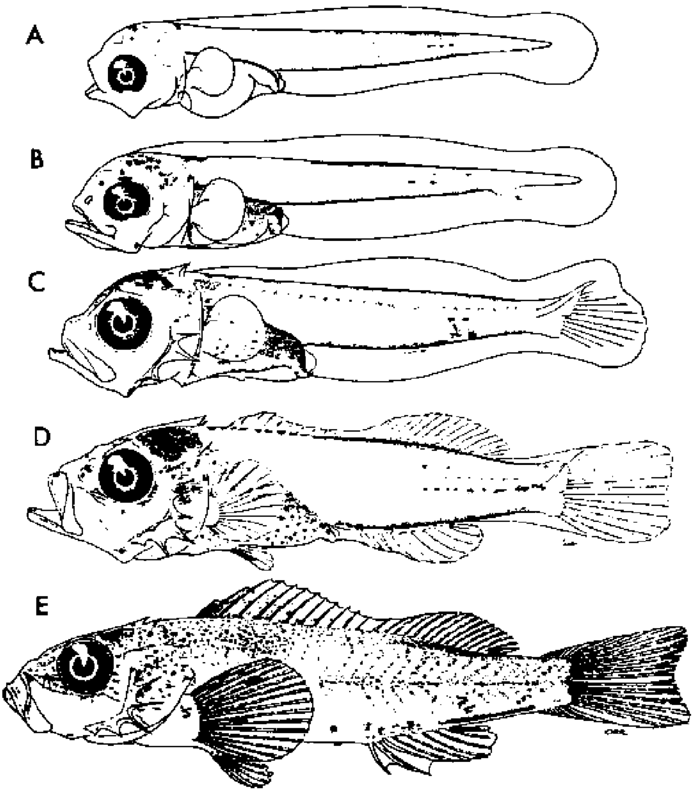
	Area					
Number of months	G of A	BC	Wa	Or	N/C Ca	S Ca
	number of species					
1	3	21	2	6	3	2
2	1	2	1	6	5	5
3	2		2	1	8	1
4				4	2	2
5				2	7	1
6					5	2
>6					5	
total	6	23	5	19	35	13*

*3 species have split season with no release in March or April.

Larval Development

Rockfish larvae are about 3-7 mm SL at birth and have pigmented eyes and a functional mouth (Fig. 2). The trunk and tail is surrounded by an undifferentiated finfold and larval pectoral fins are present. Pigment generally consists of small discrete melanophores in characteristic positions. Although there is considerable interspecific variation in melanophore amount and placement, from nearly absent in *S. helvomaculatus* to a dark banded pattern on the body of *S. aurora*, in almost all species some pigment is found on the gut and there is usually a series of postanal ventral midline melanophores. Depending on the species, melanophores may also occur on such places as the jaws, top of head, nape, pectoral fins, dorsal postanal midline, or midlaterally on the caudal peduncle and near the tip of the notochord. Superficial pigment is added in definitive patterns as the juvenile period is approached.

Figure 2.--Development of *Sebastes dalli* (from Moser and Butler 1981). A. 5.1 mm larva; B. 6.2 mm larva; C. 7.1 mm larva; D. 10.1 mm larva; E. 21.7 mm pelagic juvenile.



With development, the body deepens somewhat and the head enlarges. In postflexion larvae head length is about 28-48% of the body length, preanal length is about 42-66% of the body length, and the maximum body depth is about 21-42% of the body length (Table 3). Head spines start to develop early in the larval period, and soon reach their maximum number and relative size. A full or nearly full complement of spines develops during the larval period, but some are usually lost during the juvenile period to produce the adult pattern that is a specific character. The first head spines to form are the pterotics, several of the preoperculars, and the parietals. Spines continue to be added and to increase in size as the larvae develop. The parietal spines, some of the preopercular spines, and the supraocular ridge become serrate in some species. The parietals and central preoperculars are the longest spines, the parietals reaching 27% of the head length in *S. helvomaculatus* (Richardson and Laroche 1979). Fin ray formation follows this sequence: caudal, pectorals, pelvics, dorsal, and anal. Fin rays are generally not particularly elongate, although there is variation in the length of the pectoral rays with *S. paucispinis* pectorals reaching 37% body length in postflexion larvae (Moser et al. 1977). Pelvic rays develop uniquely early in 5-mm larvae of *S. paucispinis*, and reach the same elongate proportion as the pectorals.

Table 3.--Morphometric characters of postflexion larvae of 16 species of northeast Pacific rockfishes, expressed as ranges of percent standard length (SL).

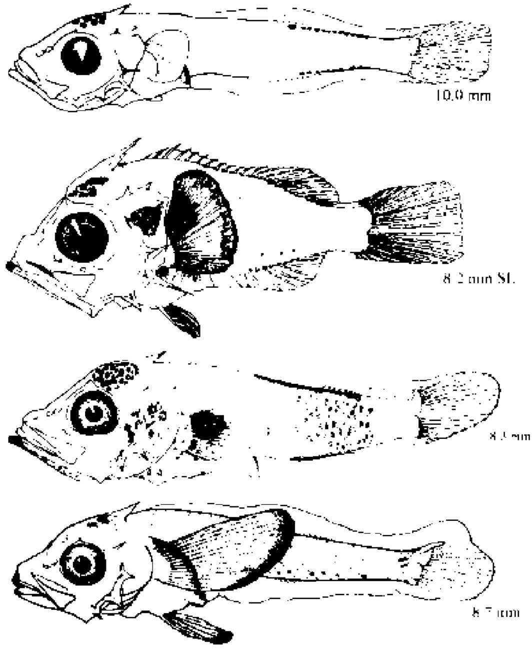
Species	Head length	Body depth	Preanal length	References*
S. auriculatus	30 - 38	22 - 29	47 - 53	20
S. aurora	33 - 40	26 - 34	56 - 66	18
S. caurinus	29 - 36	21 - 29	42 - 54	20
S. crameri	37 - 43	30 - 35	55 - 65	19
S. dalli	28 - 33	22 - 28	48 - 56	16
S. entomelas	34 - 39	25 - 30	55 - 61	9
S. flavidus	35 - 43	25 - 31	54 - 61	8
S. helvomaculatus	40 - 44	33 - 34	59 - 60	19
S. jordani	31 - 36	22 - 26	46 - 54	15
S. levis	34 - 38	33 - 36	57 - 63	15
S. macdonaldi	34 - 41	33 - 36	55 - 64	15
S. melanops	35 - 43	26 - 33	54 - 62	8
S. melanostomus	39 - 44	37 - 42	55 - 63	14
S. paucispinis	36 - 39	28 - 31	51 - 61	15
S. pinniger	38 - 48	34 - 42	52 - 63	19
S. zacentrus	40 - 46	33 - 36	54 - 62	9

*Numbers key to references in Literature Cited.

Larval Identification

Two approaches, or a combination of both, are used to establish the identity of larval fish. The direct approach involves rearing larvae from known parents. The indirect, or series approach, involves finding specimens in field samples that are large enough to have definitive adult (mainly meristic) characters, but small enough to retain some larval characters (such as pigment). A series of similar looking but smaller specimens is accumulated from field samples until the smallest larvae can be recognized. With northeast Pacific rockfishes, yolk-bearing larvae of 50 species have been reared, but only seven species have been reared to caudal fin formation, and only one species has been reared through the larval period. The caudal fin formation larvae are helpful, but not completely definitive, in establishing the identity of field-caught specimens, and the yolk-bearing larvae offer little help at the level to which they have been studied. Thus, with rockfishes larval identification has depended mainly on establishing series. A few species such as *S. jordani*, *S. paucispinis*, *S. aurora*, and *S. melanostomus* have proven to have very distinctive larvae at all stages of development (Fig. 3) but most, particularly before notochord flexion, seem to look very similar. In several descriptions based on the series approach, larvae smaller than 8-10 mm SL could not be recognized with confidence.

Figure 3.--Flexion stage larvae of (top to bottom) *S. jordani* (from Moser et al. 1977), *S. melanostomus* (from Moser and Ahlstrom 1978), *S. aurora* (from Moser et al. 1985), and *S. paucispinis* (from Moser et al. 1977).



Descriptions of larvae and pelagic juveniles of various rockfishes are slowly accumulating in the literature, making it reasonable to contemplate using the planktonic stages in field samples for fisheries studies. Among northeast Pacific rockfishes, illustrations have been produced for yolk-sac or preflexion larvae of 50 species, complete larval series of 8 species, and pelagic juveniles of 39 species (Table 4).

Table 4.--Key to sources of illustrations of rockfish larvae from the northeast Pacific Ocean. Numbers key to references in Literature Cited.

Area of occurrence Species	Larval Stage					Juvenile Stage	
	Yolk sac	Preflexion	Flexion	Postflexion	Transformation	Pelagic	Benthic
West Coast of North America							
S. aleutianus	4, 24					7	7
S. alutus	3, 4, 24					7	7
S. atrovirens							
S. auriculatus	3, 15, 20	20	20	7		7	7
S. aurora		18	18	18	18	18	18
S. babcocki	3, 4, 24			7		7	7
S. borealis							7
S. brevispinis	3, 4, 10					7	
S. carnatus	12, 15						
S. caurinus	3, 10, 15, 20	20	20	7		7	7
S. chlorostictus	12, 15			7	7	7	7
S. chrysomelas							
S. ciliatus	6						
S. constellatus	12, 15, 17		17	17			
S. crameri	24			19	19	7, 19	7, 19
S. dalli	12, 15, 16	16	16	16		16	
S. diploproa	3, 25			7		7	7
S. elongatus	12, 15, 25			7		7	7
S. emphaeus				7		7	7
S. ensifer	12, 15						
S. entomelas	6, 17			9	9	7, 9	7, 9
S. eos	12, 15						
S. flavidus	3			8	8	7, 8	7, 8
S. gilli	15						
S. glaucus							
S. goodei	11, 15					7	
S. helvomaculatus	25			19	19	7, 19	7
S. hopkinsi	12, 15						
S. jordani	10, 11	2, 15		2, 15	2, 15	2, 7, 15	7
S. lentiginosus							
S. levis	2, 12, 15		2, 15	2, 15	2, 15	2, 15	
S. macdonaldi	2, 12, 13, 15	2, 13, 15	13	2, 13, 15	2, 13, 15	2, 13, 15	13
S. maliger	3, 25			7	7	7	7
S. melanops	10			8	8	8	7, 8
S. melanosema							
S. melanostictus							
S. melanostomus	14, 15			14	14	14	7, 14
S. miniatus	15					7	7
S. mystinus	4, 22			7		7	7
S. nebulosus							7
S. nigrocinctus						7	7
S. notius							
S. ovalis	12, 15, 17	17					
S. paucispinis	2, 11, 12, 15	1, 2, 12, 15	1, 2, 12, 15	1, 2, 12, 15	2, 12, 15	7, 12	7
S. phillipsi							
S. pinniger	15, 21			19	19	7, 19	7, 19
S. polyspinis	10					7	
S. proriger	25			7		7	7
S. rastrelliger						7	7
S. reedi	24					7	7
S. rosaceus	12, 15					7	7
S. rosenblatti	15						
S. ruberrimus	3, 5, 6, 25					7	7
S. rubrivinctus	17						
S. rufinanus							
S. rufus	15, 17	17	17				
S. saxicola	11, 24			7		7	7
S. semicinctus	12, 15						
S. serranoides	17	17					
S. serriceps	15						
S. simulator							
S. umbrosus	12, 15						
S. variegatus	6, 10			7			7
S. wilsoni				7		7	7
S. zacentrus	4, 6, 10, 25			9	9	7, 9	7, 9
Gulf of California endemics							
S. cortezi	15	15		15		15	
S. exsul							
S. peduncularis							
S. sinensis							
S. spinorbis							
S. varispinis							

Westrheim (1975) concluded, based on work with preextrusion larvae of 31 species, that "interspecies similarities and intraspecies differences in morphometric and meristic characteristics of preextrusion Sebastes larvae delineated in this study clearly preclude accurate identification, based only on these criteria, of Sebastes larvae caught at sea." He also found that larvae of several species reared to yolk exhaustion changed significantly in pigment pattern from preextrusion larvae. The yolk-sac period in most fishes is characterized by changes in pigment pattern as embryonic pigment migrates and is increased to form the larval pigment pattern. The larval pigment pattern is still not well established in yolk-exhaustion rockfish larvae, so it does not appear possible to anticipate what more advanced plankton-caught larvae of a particular species will look like based on pigment observed in reared preextrusion or yolk-exhaustion larvae.

In spite of these problems there are indications that more detailed studies of reared yolk-sac larvae of rockfishes may be helpful for identifying field-caught specimens. Examining the published illustrations of yolk-sac larvae of 46 species of rockfishes, we established 26 loci where pigment was observed (Fig. 4). We then scored each species based on the presence or absence of pigment at these loci. We found that only two pairs of species could not be separated on the basis of this pigment criterion. There may be problems in comparability of the illustrations because of different illustrators, intraspecific pigment variations, different stages of development, and uncertainty with some adult identifications. However, this excercise indicates that there indeed may be enough interspecific difference in pigment to warrant further study.

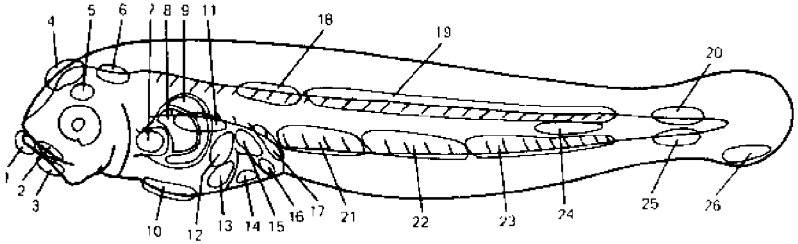
Also, we noted, in the published illustrations and on specimens of several species at our disposal, considerable variation in the appearance of the melanophores that are present on or near the hindgut. The number, size, and location of these seem to be rather consistent within a species, and there is considerable variation among species. Further study will be required to test the utility of this pigment for species separation.

While some changes in pigment occur between hatching and yolk exhaustion, we were struck in the several series we examined by the consistency of pigment in some areas. This indicated that the problem of comparing illustrations and descriptions of preextrusion and yolk-exhaustion larvae may not be severe enough to negate their value completely.

Besides pigment, yolk-bearing larvae have other characters that may be profitable to evaluate. Morphometric characters such as size at stage of development, body depth, and preanal length may prove important. All of the illustrations summarized by Westrheim (1975) were produced by sketching pigment onto a basic template drawing of a rockfish yolk-sac larva. Thus, no morphometric comparisons can be made of these illustrations. Further, the pectoral fins were not included on these illustrations, so the pigment characters of the pectoral fin can not be evaluated for these larvae.

Western Pacific rockfishes, which are larger at extrusion than those in the eastern Pacific, have been reared in large numbers through the juvenile stage for release to enhance natural production (see Moser and

Figure 4.--Pigment loci on yolk-sac larvae of rockfishes. In the body of the table, "1" means pigment present, "2" means pigment absent.



Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Pigment Loci																									
S. entomelas	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
S. ciliatus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2	2	1	2	1	2	2	1	2	1
S. crameri	1	1	1	1	1	1	1	1	1	1	1	2	2	1	2	2	2	1	1	1	1	2	2	1	2	1
S. mystinus	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	2	2	1	1	1
S. alutus	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	1	1	1	2	2	1	1	1
S. semicinctus	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	2	1	2	2	2	1	1	1
S. rubberrimus	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	2	1	1	1	1	2	2	1	2	1
S. hopkinsi	1	1	1	1	1	1	1	1	1	1	2	1	1	1	1	2	2	1	2	1	1	2	2	1	1	1
S. variegatus	1	1	1	1	1	1	1	1	1	1	2	1	1	2	1	2	2	1	1	1	1	2	2	1	2	1
S. brevispinis	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	1	1	1	1	2	2	1	2	1
S. reedi	1	1	1	1	1	1	1	1	1	1	2	2	1	1	2	1	2	1	1	1	1	2	2	1	2	1
S. aleutianus	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	1	1	2	1	2	2	1	2	2
S. helvomaculatus	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1	2	2	1	1	1
S. carnatus	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	2	1	2	1	2	2	2	1	1	1
S. flavidus	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1	1	2	2	1	2	1
S. zacentrus	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	2	2	1	2	2	1	2	2	2	2	2
S. paucispinus	1	1	1	1	1	1	1	2	2	1	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
S. rosaceus	1	1	1	1	1	1	1	2	2	2	2	1	1	2	1	1	2	1	1	1	2	2	2	1	1	1
S. cortezi	1	1	1	1	1	1	2	2	1	2	2	1	1	1	2	1	2	1	1	1	1	2	2	1	2	1
S. rufus	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1	2	1	2	1	1	1	2	1	1	1
S. saxicola	1	1	1	1	1	2	1	1	1	1	2	1	1	1	1	1	2	1	2	1	2	2	2	1	1	1
S. proriger	1	1	1	1	1	2	1	1	1	1	2	1	1	2	2	2	2	1	1	2	1	2	2	1	2	2
S. elongatus	1	1	1	1	1	2	1	1	1	1	2	1	2	2	1	1	2	1	1	1	2	2	2	1	1	1
S. diploproa	1	1	1	1	1	2	1	1	1	2	2	1	1	1	2	2	2	1	1	1	1	2	2	1	2	1
S. babcocki	1	1	1	1	1	2	1	1	1	2	2	1	2	2	1	2	2	1	2	1	2	2	2	1	2	2
S. macdonaldi	1	1	1	1	1	2	2	2	1	1	2	1	2	2	1	1	2	1	1	1	1	2	2	1	1	1
S. jordani	1	1	1	2	1	1	1	1	1	1	2	1	1	1	2	1	2	1	2	1	1	2	2	1	1	1
S. serriceps	1	1	1	2	1	2	1	1	1	1	2	1	1	2	1	2	2	1	1	1	1	2	2	1	2	1
S. ovalis	1	1	1	2	1	2	2	1	1	1	2	1	1	1	1	2	2	1	2	1	1	2	2	1	1	1
S. goodei	1	1	1	2	1	2	2	2	2	1	2	2	2	1	2	2	2	1	1	1	1	2	2	1	1	1
S. dalli	1	1	1	2	2	2	1	1	1	1	2	1	1	1	1	2	2	1	2	1	2	2	2	2	1	1
S. gilli	1	1	1	2	2	2	2	1	1	1	2	1	1	2	2	2	2	1	2	1	1	2	2	2	2	1
S. constellatus	2	1	1	1	1	1	1	1	2	2	2	1	1	2	1	1	2	1	1	1	1	2	2	1	1	1
S. ensifer	2	1	1	1	1	1	1	1	2	2	2	1	1	2	1	1	2	1	1	1	2	2	2	1	1	1
S. pinniger	2	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1	2	1	2	1	1	2	2	1	2	1
S. rosenblatti	2	1	1	1	1	1	1	2	2	2	2	1	1	2	1	2	2	1	1	1	2	2	2	1	1	1
S. eos	2	1	1	1	1	1	1	2	2	2	2	1	1	2	1	2	2	1	1	1	2	2	2	1	1	1
S. umbrosus	2	1	1	1	1	1	1	2	2	2	2	1	2	2	1	1	2	1	1	1	1	2	2	1	1	1
S. chlorostictus	2	1	1	1	1	1	1	2	2	2	2	1	2	2	1	2	2	1	1	1	2	2	2	1	1	1
S. maliger	2	1	1	1	1	2	1	1	1	2	2	2	1	1	1	1	1	2	2	1	2	2	2	1	1	1
S. miniatus	2	1	1	2	2	2	1	1	1	1	2	2	1	1	1	2	2	1	1	1	1	2	2	1	2	1
S. caurinus	2	1	1	2	2	2	2	1	1	2	2	1	2	2	2	2	2	2	2	1	2	2	2	1	1	1
S. levis	2	1	1	2	2	2	2	2	2	1	2	1	1	1	1	2	2	1	1	1	1	2	2	1	1	1
S. auriculatus	2	1	2	2	2	2	1	1	1	2	2	1	1	1	1	2	2	2	2	1	2	2	2	1	1	1
S. melanostomus	2	2	2	1	2	2	1	2	2	2	2	2	2	1	1	1	2	1	1	1	1	2	1	1	1	1

Butler in press). However, only one eastern Pacific species (*S. dalli*) has been reared beyond caudal fin formation (Moser and Butler 1981). Among the other most successful eastern Pacific rearings, *S. rufus* lived to 46 days, *S. constellatus* to 38 days (Moser and Butler in press), and *S. caurinus* to 35 days (Stahl-Johnson 1985). Eastern Pacific rockfishes seem amenable to standard techniques developed in other marine fish, but concentrated efforts are needed to obtain healthy full-term larvae from females, and to have proper rearing conditions available for this work. Further progress in rockfish larval identification is largely dependent on rearing developmental series of a wide variety of species.

Larval Distribution

Largely because of identification problems, occurrences of rockfish larvae from ichthyoplankton surveys in the northeast Pacific are usually reported at the generic level (*Sebastes* spp.). Lisovenko (1964) discussed purported catches of *S. alutus* larvae made in the Gulf of Alaska in 1963, at a time when the population of *S. alutus* was much larger than at present. The proportion of *S. alutus* and other rockfishes in these catches is unknown, since no description of *S. alutus* is available, and Lisovenko (1964) did not provide diagnostic characters for the larvae he identified as *S. alutus*.

No field work has been designed specifically to collect rockfish larvae. Occurrences of particular species have been reported in the descriptions of the few species described from field collections (Table 5). These distributional data probably are more indicative of where sampling was conducted, and what samples were examined, than the actual distribution of the larvae. However, the larvae occur to considerable distances offshore (up to 306 km from shore), and several species were not reported nearshore (6 of the 14 species were not found closer to shore than 24 km). Most larval occurrences were in the first 6 months of the year, with the period of occurrence of 7 of the 14 species including April. The season of three species extended to August.

Table 5.--Occurrences of larvae of rockfishes in the northeast Pacific Ocean reported by species.

	Major Features of Occurrences				
Species	Size (mmSL)	Area	Distance from shore (km)	Season	References*
S. aurora		San Francisco-central Baja CA	110-170	Apr-June	18
S. cortezi		Gulf of CA		Mar	15
S. crameri	9-10	Newport, OR	83-93	Apr-May	19
S. entomelas	10-15	off Oregon	9-306	Apr-May	9
S. flavidus	10-20	off Oregon	24-266	Apr-May	8
S. helvomaculatus	8-20	Newport, OR	83-120	July-Aug	19
S. jordani		San Francisco-San Diego	inshore	Jan-Feb	15
S. levis		California Bight		Jan-June	15
S. macdonaldi		central Baja CA		Mar	15
S. melanops	10-20	off Oregon	5-266	Apr-May	8
S. melanostomus	large	Los Angeles to Baja CA	5-220	Apr-Aug	14
S. paucispinis		CA to Baja CA	nearshore	Jan-Feb	15
S. pinniger	9-20	Newport, OR	83-120	Mar-June	19
S. zacentrus	7-10	off Oregon	46-148	Aug	9

* Numbers key to references in Literature Cited.

Collections of larvae identified as Sebastes spp. (rockfish) from the eastern Bering Sea, the northern Gulf of Alaska, and from off the Washington, Oregon, and California coast have been documented (Table 6). The following summarizes what we know about the distribution of rockfish larvae in these areas. Information based on the occurrences of larvae identified as rockfishes is of limited value, because several species are likely to be included in the collections, and each presumably has a specific pattern of distribution that overlaps those of other species.

Rockfish larvae are vulnerable to collection in plankton nets over a relatively narrow length range. Moser and Butler (in press) found that among over 11,000 rockfish larvae from California Cooperative Oceanic Fisheries Investigations (CalCOFI) plankton collections nearly 50% were less than 5 mm SL, and more than 90% were less than 7 mm SL. In plankton samples taken off Washington, Oregon, and northern California from March through November, little difference in mean size of the larvae was found; they ranged from 4.29 mm in November to 5.61 mm in March-June, and 5.22 mm in August (Northwest and Alaska Fisheries Center (NWAFC) files). Apparently, there is a severe mortality of larvae less than 7 mm, or their avoidance ability increases dramatically at that size. Notochord flexion and the concomitant development of the caudal fin occurs at about 7-8 mm in most species, so increased escapement of larger larvae is probable. Lengths of rockfish larvae have not been reported from other studies, but based on the above nearly all are probably less than 10 mm. Larger larvae and pelagic juveniles of at least some species are collected in neuston nets, where in eight surveys off Washington, Oregon, and northern California the mean length of the 1,112 rockfishes caught was 19.25 mm (NWAFC files).

One consequence of the small size of rockfish larvae in plankton collections is that the larvae are close in time and position to where they were released from the females. Thus, distribution of larvae can probably be used to give a fairly accurate idea of where and when release occurs. Off southern California most rockfish larvae are found in winter; off Washington, Oregon, and northern California most are in spring and summer; and in the Gulf of Alaska and in the Bering Sea most are in summer. Thus, it seems that release of larvae occurs progressively later in the year proceeding from south to north. This agrees with information already cited on seasonality of reproduction based on studies of gonads. The shift in timing of larval release may reflect the seasonal development of oceanographic conditions conducive to producing food suitable for the larvae.

Juvenile Identification

The transition from larval to juvenile stage often is defined to occur when counts of fin rays, gill rakers, and lateral line pores reach adult levels. This stage occurs in many species of rockfish at about 20 mm. Some species do not become juveniles until about 30 mm. Using this definition, many specimens reported as juveniles in the literature and this paper are actually large larvae.

Until the last decade the majority of specimens of juvenile rockfish were identified as Sebastes spp. Several workers have advanced the

Table 6.--Summary of data on *Sebastes* spp. larval collections from major ichthyoplankton programs in the eastern Bering Sea and the northeast Pacific Ocean.

Area	Reference	Years sampled	Months sampled	No. of cruises	collecting stations	*Sebastes* spp. occurrences
Eastern Bering Sea	Waldron [1981]	1955-79	All, mostly Spring--Summer	43	2,435	At 89 stations on 10 cruises, in spring and summer mainly near shelf break, mostly south of 60° N.
	Walline 1981	1979	June-July	1	114	In over 50% of oblique bongo tows throughout sampling area-mainly near shelf break south of St. Matthew's Island.
	Haryu et al. 1985	1970-79	June-August	14	418	592 larvae caught, throughout the southeastern Bering Sea.
Gulf of Alaska	Kendall and Dunn 1985	1972, 1977-79	All except Dec and Jan	11	707	Found late spring through early fall, peak in summer, shift inshore as season progressed.
Washington-Oregon-N. California	NWAFC files*	1980-84	Mar-June, Aug, Oct-Dec	8	873	Nearly equally abundant spring and summer. less abundant in fall, mainly offshore beyond Continental Shelf.
Oregon	Richardson et al. 1980	1972-75	March-April	6	306	Mainly beyond Continental Shelf.
California-Baja California	Ahlstrom et al. 1978**	1950-75	All	157	26,619	Most in winter, decrease abundance in southern part of area, mostly nearshore.

* Kendall, A.W. Jr. pers. comm. Dec. 1986.

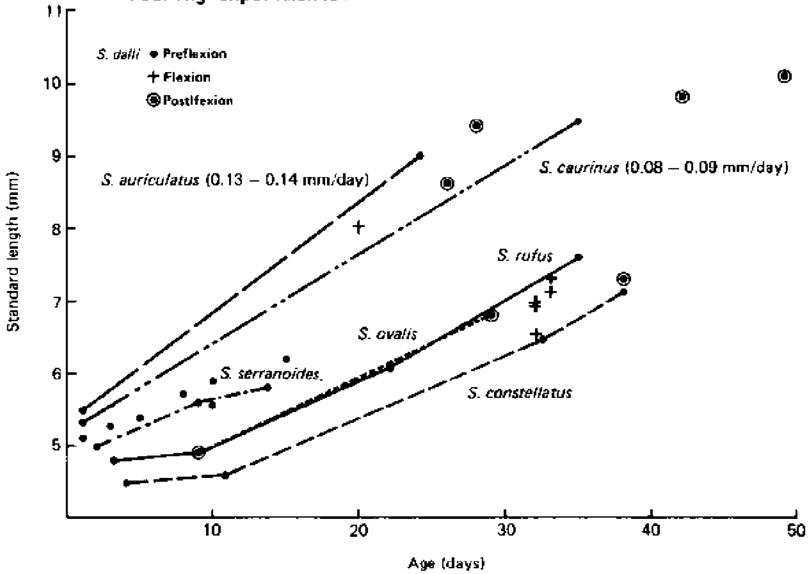
** Loeb et al. 1983 contains more detailed analysis of data from 1975. Other references cited therein contain additional analysis of CalCOFI data.

state of the art so now we can identify most juveniles captured off Washington, Oregon, and California. We were able to identify more than 99% of specimens of juvenile rockfish collected by midwater trawl off central California. Important papers on identification are Laroche and Richardson (1979 and 1980), Moser and Ahlstrom (1978), Moser et al. (1977), Moser and Butler (1981), Moser and Butler (in press), Moser et al. (1985), and Richardson and Laroche (1979). The preceding studies used material collected at sea or from rearing studies. Investigators employing scuba have conducted several nearshore studies of juvenile rockfish off California. Anderson (1983), who includes photographs of 17 species, is the most complete source on identification of juveniles in nearshore areas. The Tiburon Laboratory has developed a key that uses pigmentation patterns and meristics. Laroche is preparing a well-illustrated identification guide. Pelagic juveniles of 37 species will be illustrated in the laboratory guide being prepared by Matarese et al. (in press).

Larval and Juvenile Growth

Little is known about growth of rockfish larvae and juveniles. Under laboratory rearing conditions, change in length with time has been noted for larvae of seven northeast Pacific species. Only S. dalli lived beyond 40 days and a length of 10 mm. There is quite a wide variation shown in growth with some larvae reaching 9 mm in 24 days, while others were only a little over 7 mm after 38 days (Fig. 5). Since larval rearing has not been routinely successful in rockfishes, it is unknown how closely these growth rates reflect those found in the wild, or how much variation is due to different responses to rearing conditions.

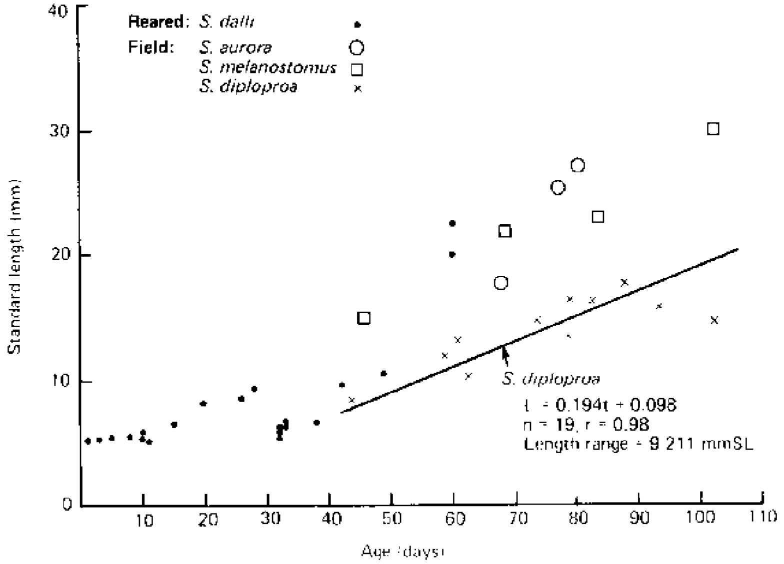
Figure 5.--Growth of northeast Pacific rockfishes based on several rearing experiments.



Boehlert (1982) and Boehlert and Yoklavich (1983) held field-collected pelagic juvenile *S. diploproa* and benthic juvenile *S. melanops* under a variety of *laboratory conditions* of food, temperature, *and photoperiod* and noted effects on growth using stepwise multiple regression. Growth rate generally increased with increased ration; it was maximal at intermediate temperatures in *S. diploproa*, but continued to increase at higher temperatures in *S. melanops*. The temperature of maximal growth increased with fish *size in S. diploproa*. Growth rates observed in the laboratory under satiation *rations were* similar to those reported in the field (Boehlert and Yoklavich 1983).

Daily growth increments have been observed on the otoliths of a few juveniles of two species found in albacore stomach contents. The juveniles ranged in length from 15 to 31 mm and in age from 47 to 101 days. The growth rate, determined by otolith aging, of 21 field-collected juvenile (9.0-42.7 mm) *S. diploproa* (Boehlert 1982) was considerably less than that of the *other two* species so studied (Fig. 6). When these juvenile data are graphed along with data from reared *S. dalli*, a coherent picture emerges suggesting slow growth from 5 *to 10 mm* followed by more rapid growth through 30 mm, although *S. diploproa* growth seems to continue at a slower rate (Fig. 6). *Median fin formation* occurs in these species at about 10 mm and possibly the enhanced mobility this provides facilitates the observed increase in growth rate starting at this age.

Figure 6.--Growth or reared *Sebastes dalli* and size-at-age of field-collected juvenile *S. aurora, S. diploproa*, and *S. melanostomus*. Based on Boehlert (1982), Moser and Ahlstrom (1978), Moser and Butler (1981), and Moser et al. (1985).



Life History Patterns of Juveniles

The life histories of rockfish are diverse and complex. It appears that some species may spend nearly their entire lives in a very restricted area. In other cases it appears that life histories may be as complex as those of salmon.

Turner et al. (1969) found 12-mm *S. dalli* in crevices and caves in proximity to adults, and proposed that the young were released there. The authors did not describe identification procedures. It is possible that identification was incorrect, since larval and juvenile descriptions were not published until 1981 by Moser and Butler. However, there are no records in the literature of pelagic larvae or juveniles of *S. dalli*.

Work conducted by the Tiburon Laboratory indicates that the life history of *S. auriculatus* is quite complex. Gravid females occur in San Francisco Bay, but much more often in offshore waters as deep as 80 m. Most *S. auriculatus* in San Francisco Bay are immature. Pelagic juveniles occur offshore April through June. Benthic juveniles are found in nearshore waters and are abundant in San Francisco Bay. Tagging studies have shown that juveniles spend up to several years within a very restricted home range while in the bay. The fish then gradually move into deeper waters and offshore. Fish tagged as juveniles in the bay have been recaptured several years later more than 80 km away in offshore waters.

While rockfishes possess a range of life history strategies, many species appear to have a juvenile stage which is either pelagic or associated with drifting objects such as kelp. However, in addition to *S. dalli* there are other exceptions to the general rule that rockfishes have an open ocean juvenile stage. Pelagic juveniles of the subgenus *Sebastomus* (e.g. *S. constellatus*, *S. chlorostictus*, and *S. rosaceus*) as well as *S. alutus* and *S. rufus* are noticeably missing or rare in pelagic collections. *S. atrovirens*, *S. carnatus*, *S. caurinus*, and *S. chrysomelas* recruit to the kelp habitat as large larvae (Anderson 1983). These four species first associate with the kelp canopy and then gradually migrate to the bottom. Thus, their strategy may be a variation of the strategy of species associated with drifting objects as juveniles.

The first review of rockfishes associated with drifting objects is by Mitchell and Hunter (1970). They found juvenile *S. diploproa*, *S. paucispinis*, *S. rubrivinctus*, *S. serranoides*, and *S. serriceps* associated with drifting kelp off southern California and Baja California. This stage is particularly important in the life history of *S. diploproa* (Boehlert 1977). Juvenile *S. diploproa* were associated with drifting kelp throughout the year. Peak abundance was in May-June. The juveniles appeared to leave the drifting kelp habitat and settle to the bottom between May-June and November-December. Juveniles are about 1 year old when they reach the bottom. Pelagic sampling gear rarely captures juveniles of this abundant species. Boehlert (1977) also presented information on *S. paucispinis*, *S. rubrivinctus*, and *S. serriceps*. *S. caurinus* and *S. nigrocinctus* were associated with a drifting glass float found in Queen Charlotte Sound (Hitz 1961). Data presented in the paper suggest that specimens identified as *S.*

caurinus could have been *S. maliger*. Since Boehlert's work, the literature contains little about juvenile rockfishes associated with drifting objects. It may prove to be an interesting subject to study north of southern California.

Pelagic sampling gear has captured juveniles of many rockfish species. The two most extensive studies are by Pearcy and Laroche (Table 7) and Adams, Lenarz, Moreland, and Wyllie Echeverria (Table 8). Pearcy and Laroche captured 15 species of juvenile rockfish off Oregon and Washington using purse seines. *S. entomelas*, *S. flavidus*, *S. melanops*, and *S. mystinus* were abundant in their collections. Peak catches for 12 of the 15 species were in June. Catches of *S. diploproa*, *S. nigrocinctus*, and *S. proriger* were low and peaked in September. They do not report juvenile *S. alutus*, which is a common species in their area. Adams et al. captured 22 species of juvenile rockfish off central California with a midwater trawl. They captured significant numbers of *S. auriculatus*, *S. entomelas*, *S. flavidus*, *S. goodei*, *S.*

Table 7.--Catches of juvenile rockfishes by purse seine sets off Oregon and Washington, 1979-1984. Mesh size was 3.2 cm (stretched). (N = number of juveniles, Y = number of years of occurrence) (Personal communication W. Pearcy and W. Laroche, Oregon State University, Newport, Oregon).

Month	May		June		July		August		September	
Number of Sets	124		335		119		67		152	
Species	N	Y	N	Y	N	Y	N	Y	N	Y
S. crameri	0	0	2	2	0	0	0	0	0	0
S. diploproa	0	0	1	1	0	0	0	0	13	1
S. emphaeus	1	1	0	0	0	0	0	0	0	0
S. entomelas	9	1	283	5	0	0	0	0	0	0
S. flavidus	0	0	589	6	0	0	0	0	0	0
S. goodei	1	1	1	1	0	0	0	0	0	0
S. jordani	9	2	73	6	1	1	0	0	0	0
S. maliger	0	0	1	1	0	0	0	0	0	0
S. melanops	1	1	369	5	0	0	0	0	0	0
S. mystinus	1	1	432	3	2	1	0	0	0	0
S. nigrocinctus	0	0	0	0	0	0	0	0	18	2
S. paucispinis	0	0	14	3	0	0	0	0	0	0
S. pinniger	1	1	8	1	0	0	0	0	0	0
S. proriger	0	0	0	0	0	0	0	0	14	1
S. saxicola	0	0	17	1	0	0	0	0	0	0

Table 8.--Catches of juvenile rockfishes by midwater trawls off of central California. A 25-m head rope length trawl with a 1.3-cm stretched mesh cod end was used. Towing depth varied from 10 to 100 m. April was sampled 1985 and 1986. Late May and June were sampled 1983-1986. (N = number of juveniles, O = number of occurrences, Y = number of years of occurrence). (Personal communication P. Adams, W. Lenarz, S. Moreland and T. Wyllie Echeverria, Southwest Fisheries Fisheries Center, Tiburon, California).

Month		April			Late May-June	
Number of Tows		48			357	
Species	N	O	Y	N	O	Y
S. auriculatus	205	12	1	532	83	2
S. caurinus [1/]	0	0	0	9	6	1
S. crameri	0	0	0	15	10	2
S. diploproa	1	1	1	3	3	1
S. entomelas	0	0	0	15,335	99	4
S. flavidus	0	0	0	893	86	4
S. goodei	460	21	2	603	57	3
S. hopkinsi	1	1	1	1,374	41	3
S. jordani	134	17	2	84,828	180	4
S. levis	0	0	0	1	1	1
S. melanops	0	0	0	99	23	3
S. miniatus	1	1	1	0	0	0
S. mystinus	11	7	2	2,817	47	3
S. nigrocinctus	0	0	0	3	2	1
S. paucispinis	7	6	2	1,029	81	3
S. pinniger	16	8	2	242	65	3
S. rastrelliger	0	0	0	1	1	1
S. saxicola	16	10	2	65	22	3
S. semicinctus	0	0	0	10	7	2
S. serranoides	0	0	0	12	5	2
S. serriceps	0	0	0	3	3	1
S. wilsoni	4	3	1	20	8	3

[1/] Specimens classified as *S. caurinus* could also be *S. carnatus*, *S. chrysomelas*, or *S. maliger*.

hopkinsi, *S. jordani*, *S. mystinus*, *S. paucispinis*, and *S. pinniger*. Peak catches of most species occurred in late May-June, but *S. auriculatus*, *S. goodei*, and *S. saxicola* are more abundant in April. They did not capture *S. rufus*, which is abundant in their area. In addition to the list of species collected as juveniles in Tables 7 and 8, *S. helvomaculatus* is reported by Richardson and Laroche (1979), *S. macdonaldi* by Moser (1972), *S. melanostomus* by Moser and Ahlstrom (1978), and *S. zacentrus* by Laroche and Richardson (1980).

Studies have found newly transformed benthic juveniles of many species both in nearshore and offshore waters. Anderson (1983) provides data on the timing of settlement in the nearshore habitat off central California for 15 species (Table 9). His data indicate that *S. entomelas*, *S. goodei*, *S. jordani*, and *S. paucispinis* only occasionally used this study area. The remaining 11 species regularly used the area. He also obtained a few specimens of *S. semicinctus* and *S. rosaceus*. Feder et al. (1974) report juvenile *S. atrovirens*, *S. miniatus*, *S. mystinus*, *S. paucispinis*, and *S. rastrelliger* in kelp beds off southern California. Hobson (pers. commun. Sept. 1986, Southwest Fisheries Center, Tiburon, California) has found significant numbers of *S. caurinus*, *S. flavidus*, *S. melanops*, and *S. mystinus* in kelp beds of northern California. Turner et al. (1969) found juvenile *S. auriculatus*, *S. caurinus*, *S. dalli*, and *S. serranoides* associated with man-made reefs in nearshore waters off southern California.

Sherwood and Mearns (1981) captured large numbers of juvenile *S. saxicola*, *S. diploproa*, and *S. jordani* using a bottom trawl off southern California. Moser and Ahlstrom (1978) captured benthic juvenile *S. melanostomus* off southern California. Chen (1971) captured juvenile *S. rosenblatti* and *S. umbrosus* on the bottom off southern California.

Table 9.--Number of juvenile rockfish in nearshore waters (<25 m) off central California (Anderson 1983).

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S. atrovirens	0	0	0	0	0	56	50	88	47	90	35
S. carnatus - *S. chrysomelas*	0	0	0	2	82	312	91	43	20	7	0
S. caurinus	0	0	46	95	207	115	7	67	27	4	0
S. entomelas	0	0	0	0	11	17	5	0	0	0	0
S. flavidus	0	0	9	14	141	119	76	32	22	51	1
S. goodei	0	0	0	0	6	0	1	1	0	0	0
S. jordani	0	0	0	0	5	6	2	0	0	0	0
S. melanops	0	0	3	6	113	68	44	20	9	20	0
S. miniatus	18	6	4	5	7	6	28	19	16	3	0
S. mystinus	0	0	13	101	326	129	77	40	36	9	0
S. paucispinis	2	2	6	18	59	14	10	8	8	4	0
S. pinniger	0	0	15	154	130	111	17	35	38	22	0
S. saxicola	0	0	14	3	59	117	214	100	109	0	0
S. serranoides	0	0	4	19	144	82	42	49	11	10	7

Love and Lee (1974) report on *S. rubrivinctus* caught by bottom trawl off Santa Barbara. Lenarz et *al.* (pers. commun. Sept. 1986, Southwest Fisheries Center, Tiburon, California) captured juveniles of 11 species with a bottom trawl off central California (Table 10). *S. saxicola* was particularly abundant. Apparently, midwater trawl gear does not adequately sample *S. crameri*, *S. saxicola*, and *S. semicinctus* in April-June off central California (Tables 8 and 10). Benthic juveniles of *S. flavidus* and *S. melanops* were collected off Oregon by Laroche and Richardson (1979); *S. entomelas* and *S. zacentrus* by Laroche and Richardson (1980); and *S. crameri*, *S. helvomaculatus*, and *S. pinniger* by Richardson and Laroche (1979). Carlson and Haight (1976) report that juvenile *S. alutus* begin settling in Alaskan fiords when they reach around 40-55 mm in length. *S. alutus* do not appear to settle until their second year of life.

May, June, and July are important months for juvenile rockfishes off Washington, Oregon, and California, when the young fish are important forage items for other fish (Merkel 1957) and for birds (Wiens and Scott 1975) and are at peak abundance in midwater catches (Table 7 and 8). Also, most major species transform to benthic juveniles during this time. Anderson (1983) reports peak catches of small benthic juvenile *S. flavidus*, *S. melanops*, *S. mystinus*, *S. paucispinis*, and *S. serranoides* during June (Table 9). These catches suggest that June is the peak month of transfer from the pelagic to nearshore stage for these species. Hobson (pers. commun. Sept. 1986, Southwest Fisheries Center, Tiburon, California) has found during the past 10 years that *S.*

Table 10.--Catches of juvenile rockfishes by 30 bottom trawls off of central California during June 1984. A 12-m head rope length trawl with a 1.3-cm stretched mesh cod end was used. Bottom depths were less than 200 m. (N = number of juveniles, O = number of occurrences) (Personal communication W. Lenarz, S. Moreland and T. Wyllie Echeverria, Southwest Fisheries Center, Tiburon, California).

Species	N	O
S. auriculatus	1	1
S. constellatus	1	1
S. crameri	17	4
S. flavidus	5	3
S. hopkinsi	12	2
S. jordani	3	2
S. paucispinis	1	1
S. pinniger	10	3
S. saxicola	201	12
S. semicinctus	7	3
S. wilsoni	2	2

flavidus, S. melanops, and S. mystinus first begin recruiting to nearshore habitats of northern California between late May and late June. Hobson's observations also provide some insight into other aspects of the juvenile stage. He has observed that the size of newly recruited juveniles is noticeably larger in some years than others. This suggests that size is not the only factor that triggers transition from one juvenile stage to another. He also has observed that during some years recruitment of these species to the nearshore habitat is concentrated into a period of less than a month, whereas during other years it is spread over several months.

Juvenile Field Studies

A study of rockfish recruitment was initiated in 1983 by the Tiburon Laboratory. Reports are available on progress through 1985 (Lenarz and Moreland 1985, Hobson et al. 1986). This section reviews these reports and adds some information obtained in 1986.

The study has three major objectives. The first is to develop methods for predicting year-class strength for economically important species of rockfish. Most species of rockfish are not recruited to fisheries until the age of 4-10 years. The study attempts to estimate year-class strength in the first year of life, and thus give fishermen and managers a basis for planning. The goal is to detect severalfold changes in year-class strength. Such precision has been shown to be appropriate for management purposes (e.g. Lenarz 1971). The study area originally included the coastal and offshore waters between Point Sur and Cape Mendocino, California. Beginning in 1986, the offshore work was limited to the area between Monterey and Bodega Bay. The study emphasizes seven species of rockfish that are important in the area: S. entomelas, S. flavidus, S. goodei, S. jordani, S. melanops, S. mystinus, and S. paucispinis.

The second objective is to gain a better understanding of factors that affect strength of recruitment, the most important factor underlying the success of fisheries. Although there must be a relationship between recruitment strength and the quantity and quality of eggs or larvae produced by adults, that relationship is obscured by poorly understood environmental factors. The Tiburon Laboratory is studying annual changes in reproductive physiology of adults, the relationship between oceanic conditions and recruitment success, and the fine-scale timing of reproductive success (daily ages of juveniles).

The third objective is to develop a better understanding of the ecological niches of juveniles of important species. About 60 species of rockfish occur in California and about 20 species are fairly abundant in the study area. These closely related species are similar in appearance in the juvenile stage. The ecology of some juvenile rockfishes is fairly well known during the nearshore stage, but little is known about the ecology of any species during the pelagic juvenile stage. We are studying feeding habits and environmental factors that affect distribution of pelagic juveniles, as well as adding to the existing knowledge of the nearshore stage.

Samples in the offshore area are collected with a midwater trawl that is slightly modified from the gear used by Mais (1974). The net has a 25-m headrope and 1.3-cm mesh liner in the codend. Tows 15 minutes in duration are made during darkness. Daylight tows were tried and discontinued because of low catches. Standard warp is 30 m for tows in depths less than 92 m and 90 m in deeper waters. Replicate tows are made at some stations for comparative purposes. Most of the work is conducted from late May through the end of June, but some work is done in April.

Analysis of replicate midwater tows made at some stations indicated that only one tow per station was necessary. The 90-m warp catches were larger than the 30-m warp catches, but the differences were not statistically significant. The power of the test was low because of small sample sizes. However, catches at these two depths were significantly correlated. We are collecting more data on depth distribution.

Midwater catches were lowest in 1983 and highest in 1985. Catches were similar in 1984 and 1986. An analysis of variance produced significant differences between 1984 catches and 1985 catches of *S. flavidus*, *S. goodei*, *S. jordani*, and *S. paucispinis*, but not *S. entomelas*.

Previous to 1986 one set of midwater trawl stations was occupied between Point Sur and Cape Mendocino. The 1985 season demonstrated to us that settlement can occur in late May-early June. We thus narrowed the area to Point Sur to Bodega Bay and will attempt to sample all stations three times during the season. The highest replicate will be used for the index of abundance.

Results from *Oncorhynchus tshawytscha* and nearshore *Ophiodon elongatus* stomach content analyses are promising. We believe that we may be able to eventually replace midwater trawl surveys with stomach content analyses to produce routine indices of abundance for important species of juvenile rockfish.

Scuba surveys are made in shallow nearshore waters of northern California's Sonoma and Mendicino coasts. The laboratory conducts scuba surveys to about 35 m every 2 to 3 weeks as weather permits. Two or three divers equipped with marking slates note numbers of juveniles during timed segments along random courses in representative habitats.

The nearshore studies are providing data on two species that do not appear to be sampled well by the midwater trawl survey, *S. melanops* and *S. mystinus*. In addition, the nearshore results are similar to the offshore results for *S. flavidus*. Statistically significant differences were found in 1983, 1984, and 1985 for *S. flavidus*, *S. melanops*, and *S. mystinus*.

The Laboratory began work on adult reproductive physiology and daily age determinations during the past year. It is premature to present a progress report on these two studies.

The Tiburon Laboratory plans to follow the basic field plan for the next several years. We intend to make statistical comparisons of the midwater trawl and stomach content data in a few years. We will drop the midwater trawl work if the stomach data appear to be adequate. We are attempting to obtain another vessel during May-June to examine some questions we have on the relationship between oceanic conditions and the distribution of the juvenile rockfishes.

It will be a number of years before we know how well the indices of abundance perform as predictors of year-class strength. However, there is already some evidence that indices will produce satisfactory results for *S. paucispinis*.

Implications for Management

Adult biomass estimation

The lack of pelagic eggs in rockfishes has several consequences for fisheries scientists. The use of surveys of pelagic eggs to estimate spawning biomass of fish populations is becoming a standard practice in several fisheries. This technique has been considered for several decades, and now is reaching a level of sophistication that makes it the method of choice for population estimates in several cases. Since rockfishes do not have pelagic eggs, this method cannot be considered for these fish. The pelagic larvae of fish can be used to estimate spawning biomass, but as the time between spawning and collecting increases, the effects of mortality and dispersion make the estimates less and less reliable. This method could be considered for rockfishes known to have very distinctive early larvae (e.g. *S. jordani* and *S. paucispinis*); however, early larvae of most rockfishes all look quite similar and it may not be possible to identify them routinely in plankton samples. To use eggs or larvae for a population estimate, details of reproductive parameters such as fecundity and distribution of spawning must be known rather precisely. This information is being accumulated for rockfishes, but is not yet generally available for these applications.

Larval identification

Since there are so many rockfishes in the northeast Pacific, and since larvae of few of them appear to be readily identifiable, their use in recruitment studies seems doubtful in the near future. Larval series (illustrations of a yolk-sac and/or preflexion larva, a flexion larva, and a postflexion larva) are only known for 9 of the 71 species. Among these are four species with distinctive larvae (*S. aurora*, *S. jordani*, *S. melanostomus*, and *S. paucispinis*), but the others may be confused with species that have not yet been described. Descriptions of larvae of other species are accumulating slowly, and rearing of northeast Pacific rockfish larvae has proven difficult so far. A further complication to the larval identification problem is that most of the rockfish larvae collected in plankton surveys are too small (<8 mm) to have distinctive meristic characters. The critical stages for establishing series, those between flexion larvae and pelagic juveniles (which have distinctive pigment patterns and adult meristic characters), are very rare indeed in plankton collections. It should be noted in particular that development of *S. alutus*, the most common and heavily fished rockfish in the Gulf of Alaska and Bering Sea, remains undescribed between the yolk-sac larvae and pelagic juvenile stages. While the use of rockfish larvae in fisheries studies is not impossible, scientists and managers should realize their limitations and gear expectations accordingly.

Longevity

The adult life histories of rockfishes are as varied as the early life histories. In this section we will discuss longevity, its effect on management, and implications for using estimates of year-class strength made during the year of birth.

S. jordani is a very abundant unexploited species (Lenarz 1980). It is relatively short-lived (rarely older than 10 years). This species could probably sustain relatively high rates of exploitation. Consequently, a fishery would probably be supported by one to several year classes. Early estimation of year-class strength is important for such a fishery because a year class only produces significant contributions to landings for a few years at most.

S. entomelas is a moderately-lived species (fish older than 30 years uncommon). The species supports moderate levels of exploitation (Hightower and Lenarz 1986). Strong year classes occur every few years. Uncertainty in the strength of incoming year classes has resulted in errors of about 25% in estimation of acceptable biological catch for the Pacific Fisheries Management Council.

S. alutus is a very long-lived species (oldest specimens approach 100 years). This species can only support low rates of exploitation (Ito et al. 1986), and stocks are depleted in most if not all areas. Fish do not fully recruit to the fishery until age 10 or more, and strong year classes occur only about once per decade. The ability to detect such year classes at an early age would provide managers and industry with a valuable planning tool.

While there is a wide range of longevity in rockfish, it appears that in general, management and industry would benefit from estimates of year-class strength at an early age. We hope to make such estimates from pelagic and nearshore surveys of juvenile rockfish densities.

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Addendum

MacGregor, J. S.
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This paper was published too late to be included in our review. It contains an analysis of occurrences of rockfish larvae collected in the CalCOFI program, and discusses distributions of *S. jordani*, *S. paucispinis*, *S. macdonaldi*, and *S. levis* specifically.

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Post-larval copper rockfish in the Strait of Georgia: Habitat use, feeding, and growth in the first year

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Many demersal marine fishes have pelagic larvae which subsequently settle into benthic habitats. The pelagic-demersal transition is a critical event for these young fishes, as many have specific habitat requirements. Some of these species are able to discriminate among micro-habitats at the time of the pelagic-demersal transition (Marliave 1977). After initial settlement, young-of-the-year (YOY) fishes may select habitats based on factors such as food availability (Jones 1984), shelter availability (Shulman 1984, 1985, Ebeling and Laur 1985), predator density (Shulman 1985) and presence of conspecifics (Sweatman 1983). The pelagic-demersal transition may result in high mortality, depending on the success with which the young fish locate suitable shelter and appropriate prey.

Copper rockfish (Sebastes caurinus) is found in shallow rocky-reef habitats from California to Alaska (Hart 1973). It release pelagic larvae, which subsequently recruit to shallow reef environments (Carr 1983). Throughout most of its range, copper rockfish is one of a number of rockfish species found in nearshore waters. However, in the Strait of Georgia, British Columbia, rockfish diversity is low, and copper rockfish is the most common shallow water (< 20 m) species. As a result, copper rockfish is an important component of nearshore reef communities of the Strait of Georgia, and is exploited by both recreational and commercial fisheries (Richards 1986).

The process of recruitment is poorly understood for most rockfishes; although, for temperate reef fishes, macrophytes apparently are important features in post-larval habitats. In the Labrid species Pseudolabrus celidotus, for example, recruitment was consistently higher in certain habitats, defined principally by macrophyte type (Jones 1984). In California, several post-settlement rockfishes first appear in kelp canopies, followed by ontogenetic shifts to more benthic habitats (Carr 1983); similarily, Boehlert (1977) found that pre-juvenile splitnose rockfish (S. diploproa) frequent patches of floating kelp prior to their demersal transition. In the study reported here, we examined patterns of habitat use by post-larval YOY copper rockfish in the Strait of Georgia, including changes in density, size distributions, and feeding habits over time. The primary objective was to identify which shallow reef environments might be especially valuable to copper rockfish in their first year.

Study Area

The study was conducted off Snake Island, a small island (0.52 km by 0.24 km) located in the Strait of Georgia on the east coast of Vancouver Island (Fig. 1). This site was chosen because of the diversity of benthic habitats available, and becasue of its relative isolation. The nearest land mass is a small island 2.3 km away, which is separated from Snake Island by a channel with depths over 100 m. The nearest headland is 2.4 km distant, with deep intervening channels.

Habitats were categorized on the basis of the presence or absence of dominant macrophytes. They are: kelp forest (KF), Agarum slope (AG), eelgrass bed (EG), or sand (SN) (Table 1). In the following sections we identify habitats by their two letter designators, and, in the case of the KF habitat, the bottom and canopy are separately identified as KF-bottom and KF-canopy.

Methods

Fish densities were estimated while SCUBA diving. Visual counts were made by swimming along randomly placed 25-m transect lines in each of the four habitats in each of three time periods. Ten replicate transects comprised each habitat/time sample. Fish were recorded if they were observed in the water column within 1 m of either side of the transect line. In areas with dense algal cover, such as rocky slopes covered with Agarum, divers searched the algae to flush any hidden individuals. In the KF habitat, where stands of Nereocystis formed an extensive canopy, initial counts were made within 1.5 m of the bottom, followed by a second count in the kelp canopy. The two counts were combined for the KF transect total. Copper rockfish were identified as YOY, juvenile or adult, based on size.

Transect counts were conducted August 15-22, September 24-27, and October 17-22, 1985. Transects in each habitat were surveyed on at least two different days in each time period. All dives were performed between 0900 and 1300. Algal cover in each habitat was estimated in August and September from four randomly placed 15-m transects. In addition, while counting fish in the KF habitat, divers recorded the number of Nereocystis stipes within the 2-m wide transect band.

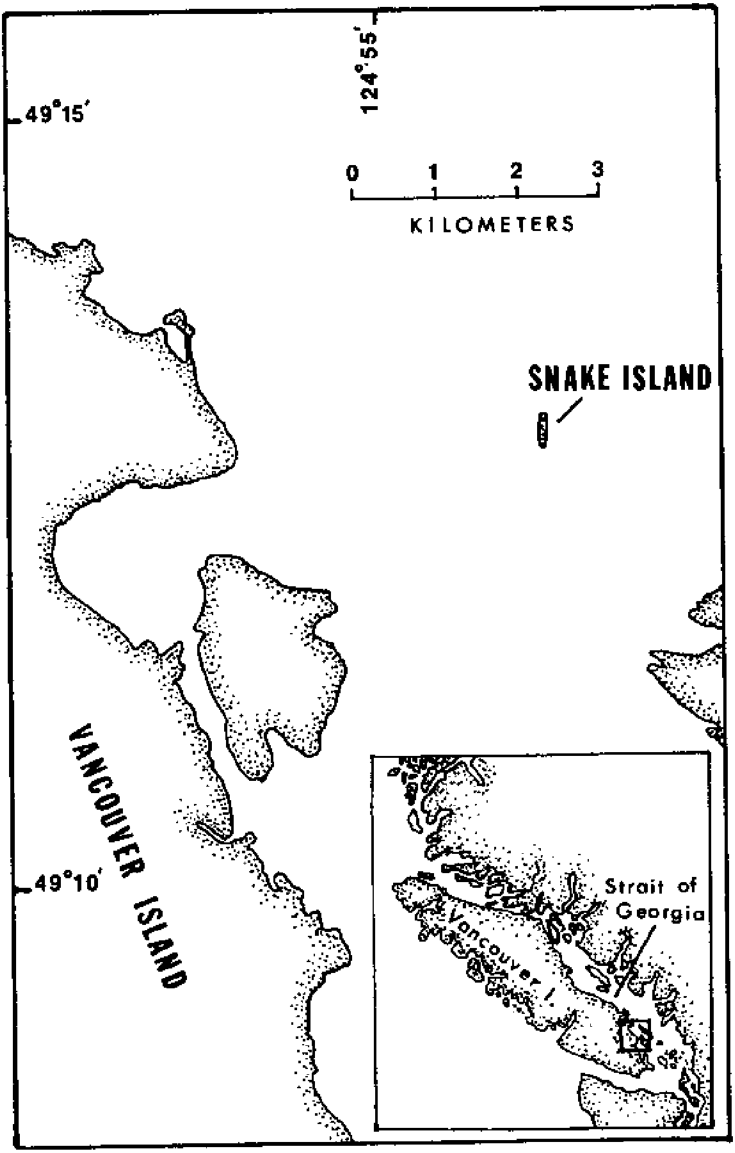

Figure 1. The Snake Island study site in the Strait of Georgia, British Columbia, Canada.

Table 1. The major habitats at the Snake Island study site. Depths are relative to mean sea level.

1. Kelp Forest (KF) 5 - 11 m. An area characterized by dense stands of the giant kelp *Nereocystis leutkeana*, with a canopy extending to the sea surface. The understory is dominated by the kelp *Agarum fimbriatum* (75% cover).

2. Agarum Slope (AG) 6 - 14 m. Rocky slopes dominated by the understory kelp *Agarum fimbriatum* (86% cover). Occasional broken rocks provide additional vertical relief.

3. Eelgrass Bed (EG) 7 - 11 m. Areas where the perennial eelgrass *Zostera marina* occurs in dense stands, rooted in sandy substrate. Individual plants reach a height of 1.6 m. The bottom is gently sloping. Algal drift material is common.

4. Sand (SN) 8 - 30 m. Areas of sandy substrate with no rooted macrophytes. The bottom is sparsely covered with algal drift dispersed from the rocky areas (31% cover with drift algae, mostly *Agarum*).

YOY copper rockfish were collected after density counts had been completed in each time period. Divers armed with small-mesh hand nets captured fish in the order in which they were encountered, selecting no more than a few fish from a single school. In August, fish from the KF habitat were collected from canopy and bottom locations. By September, densities in the KF and SN habitats were too low to continue sampling. Fish were placed on ice immediately after capture, and were frozen within a few hours. Later, the frozen fish were thawed in ice water, damp-dried with paper towels, measured for fork length to the nearest mm, and weighed to the nearest centigram. Otoliths (saggitae) were removed and stored in alcohol, and stomachs were removed and fixed in 10% formalin.

Settlement date was estimated by counting daily otolith increments. A distinct mark, which is structurally identical to the metamorphic mark documented by Victor (1983), occurred in most otoliths, and is assumed to mark the time of the pelagic-demersal transition (Figure 2). In July 1986, a recently metamorphosed YOY copper rockfish was collected in the Strait of Georgia, near Nanaimo. The otoliths from that fish clearly show a recently formed clear area with no peripheral increments (Figure 2). We regard this as a provisional validation of the metamorphic mark, pending further studies. Otoliths were mounted on microscope slides and viewed at 400x magnification through an oil immersion lens. Otoliths from specimens collected in August were read whole, whereas otoliths from later specimens were mounted on microscope slides with clear fingernail hardener and ground down on 600 grit sandpaper. The number of increments peripheral to the metamorphic mark was assumed to equal the number of days since settlement.

Food habits were quantified by examining stomach contents of each fish under a binocular dissecting microscope. Individual prey items were sorted into homogeneous taxonomic groups, and counted. Percent volume of each prey group was estimated by spreading prey items to a uniform thickness over a background grid of 1 mm squares, then counting the area covered. In the case of larger prey items, such as shrimp, the area covered was multiplied by their estimated thickness relative to

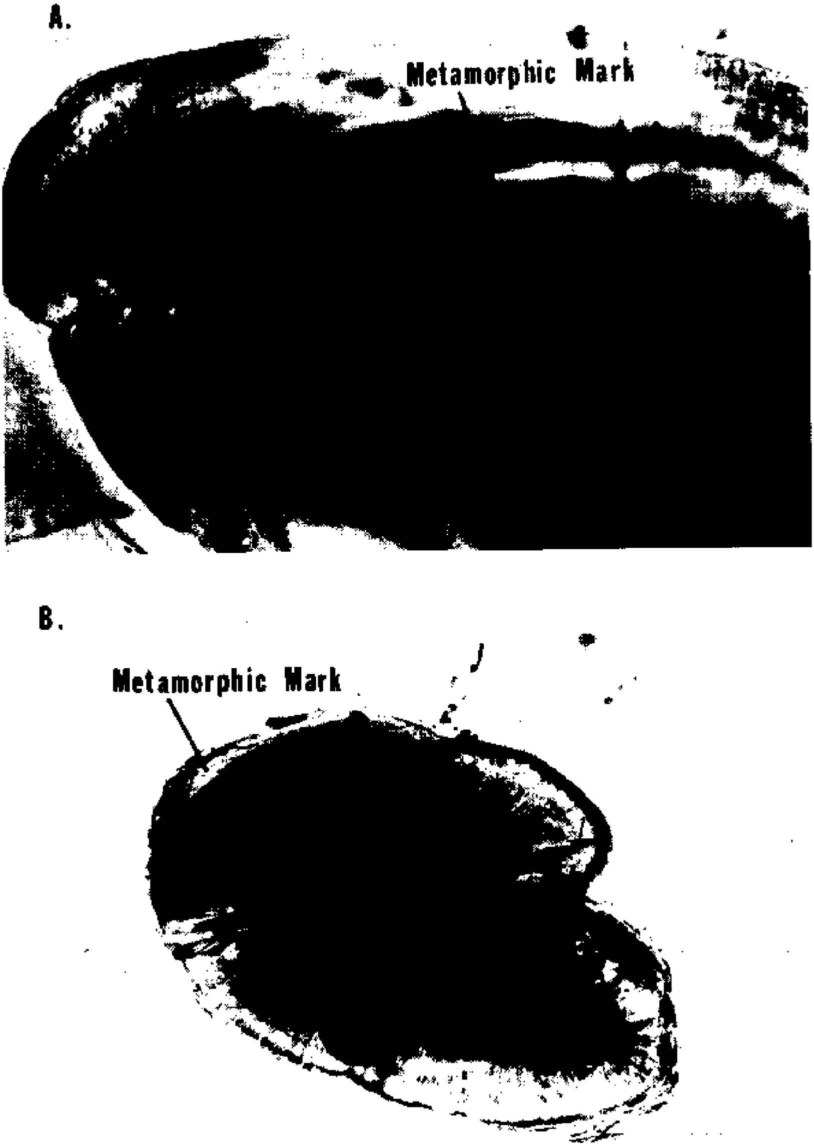

Figure 2. A. Otolith from a fish collected in September 1985, showing metamorphic mark. B. Otolith from a fish collected in July 1986 showing recently formed metamorphic mark.

the thickness of smaller items. The mean percent volume (%V) was calculated as the average of all values for individual specimens in each sample. The percent occurrence of prey catagories in each sample is the percent of specimen stomachs in which the prey catagory was found.

Transformations of density and size data did not produce distributions with homoscedastic variances. Hence we used a nonparametric test (Kruskal-Wallis) to compare densities and sizes among habitats within a time period, and among time periods within a habitat. We used the Wilcoxon two-sample test in all cases where there were only two medians to compare.

Results

Spatial and temporary variation in density.

YOY copper rockfish were the most abundant fish encountered on transects. Older juvenile and adult copper rockfish also occurred, but at a maximum density of 1.8 fish/transect (AG habitat in September). No other rockfish species occurred on transects. Lingcod, probably the major predator on YOY copper rockfish, had a maximum density of 0.8 fish/transect in the AG habitat in September and in the EG habitat in October.

The distribution of YOY copper rockfish varied considerably among habitats (Figure 3). In August, densities were highest in the KF habitat, somewhat lower in the EG and AG habitats, and lowest in the SN habitat. By September, densities in the KF and SN habitats had declined to near zero, but remained relatively high in EG and AG habitats. The trend continued in October, with low densities in KF and SN habitats, and relatively high densities in EG and Ag habitats. Differences in density were significant ($p<.001$) across habitats for each month, although there were no significant differences between the AG and EG habitats in August and October, based on pairwise comparisons. In September, the density of YOY copper rockfish was significantly greater ($p<.008$) in the EG habitat than in the AG habitat.

There were also significant changes in density of YOY rockfish over time in each habitat, with the exception of the AG habitat. Density peaked in the EG habitat in September ($p<.05$), whereas density decreased dramatically in the KF and SN habitats after August ($p<.001$). During August, most YOY copper rockfish in the KF habitat were associated with the kelp canopy. However, in September and October YOY copper rockfish were only found on the floor of the kelp forest. A notable decrease occurred in the density of Nereocystis plants during the study, as the mean number of stipes in the KF habitat (in stipes/transect) decreased from 29 in August, to 17 in September and 8 in October ($p<.001$, Kruskal-Wallis test).

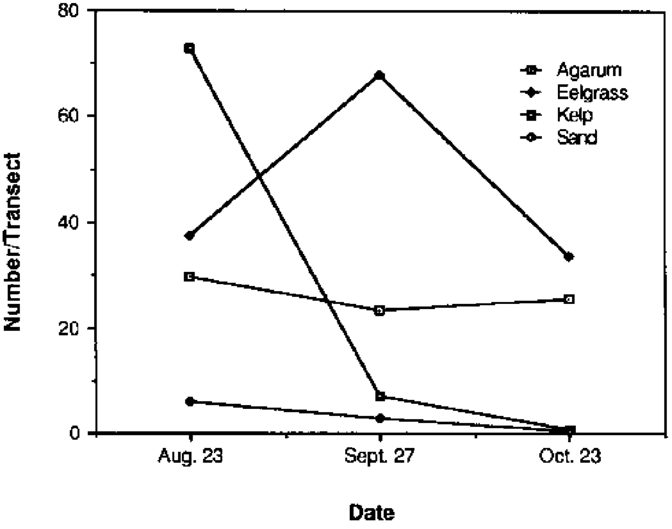

Figure 3. Density, in number per transect (50 square meters), of YOY copper rockfish in four habitats over three months at the Snake Island study site in the Strait of Georgia.

Spatial and temporal variation in size.

Size differences were apparent for YOY copper rockfish collected from different habitats in each time period (p<.001, Table 2). In August, when YOY copper rockfish occupied all four habitats, the largest fish were collected from the KF-bottom habitat, followed by EG, KF-canopy, SN and AG habitats. Fish in the KF-bottom habitat were significantly larger than fish in other habitats by pairwise comparison tests. In September and October fish in the EG habitat were marginally larger than fish in the AG habitat (p<.05 and p=.05, respectively).

The largest size increase for YOY copper rockfish occurred over the August - September period (p<.001 for both EG and AG habitats). Size increases between September and October were significant for the EG habitat (p<.01), but not for the AG habitat. Growth rates between August and October averaged 0.15 and 0.16 mm/day in the AG and EG habitats, respectively.

Settlement Date.

The number of otolith increments peripheral to the metamorphic mark in August and September specimens provided the distribution of settlement dates in Figure 4. Settlement appears to have occurred in one major episode during the first week of August. The daily nature of the otolith increments is verified by comparison of settlement dates from August and September specimens. The distributions of settlement dates back-calculated from the two sampling periods are virtually identical (Figure 4); thus, the number of increments added between the collection dates in August and September is approximately equal to the number of calendar days in that interval.

Table 2. Sample sizes (N), mean length and standard error (SE) in mm for YOY copper rockfish collected at Snake Island. Habitat abbreviations are given in Table 1.

TIME/HABITAT	N	LENGTH	SE
August			
AG	89	36.5	0.4
KF-bottom	49	42.2	0.7
KF-canopy	99	38.2	0.3
EG	61	38.8	0.7
SN	66	37.3	0.6
September			
AG	59	44.6	0.7
EG	83	46.4	0.6
October			
AG	29	45.6	1.2
EG	57	48.4	0.6

Food habits.

Recently settled copper rockfish juveniles fed on a variety of planktonic zooplankton, epi-benthic crustaceans, and benthos- or macrophyte-associated mobile invertebrates (Tables 3 and 4). Harpacticoid copepods, gammerid amphipods, caprellid amphipods, mysids and shrimp were especially important prey groups. Generally they appear to feed opportunistically.

In August, pelagic planktonic prey were an important component of the diet of fish in KF (calanoid copepods) and AG (crab zoea) habitats. With those exceptions, prey were predominately epibenthic or demersal. Harpacticoid copepods were the most commonly found prey in the diet in August, especially in habitats outside the kelp forest; and were the most important (in %V) single prey group in AG and SN habitats.

Time series of diet compositions were available for fish from AG and EG habitats. Some prey groups were consistently used, but there also were some ontogenetic shifts in feeding habits (Tables 3 and 4). In the AG habitat, harpacticoid copepods remained important prey in September (11 %V) and October (19 %V), although a shift to larger prey was evident by the increase in shrimp in September (31 %V) and October (18 %V), and mysids in October (28 %V). In the EG habitat, shrimp were a main diet component in August (26 %V), and continued to be important in September (30 %V) and October (45 %V). After August, fish in the EG habitat were feeding almost exclusively on large epi-benthic or benthic crustaceans (shrimp, gammerid amphipods and mysids).

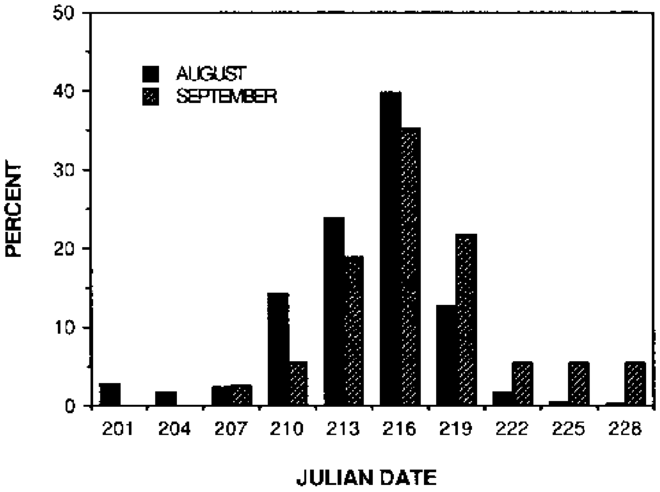

Figure 4. Back-calculated date of settlement for YOY copper rockfish at the Snake Island study site collected in August (n=348) and September (n = 37), based on number of otolith increments. Distributions shown are based on total numbers in each three day interval, beginning on Julian Day 200 (July 20). Maximum settlement is in the interval beginning August 4.

Table 3. Frequency of occurrence of major taxonomic groups of prey found in YOY copper rockfish stomachs. KFB: KF-bottom habitat, KFC: KF-canopy habitat; other habitat abbreviations are given in Table 1.

PREY GROUP	AUGUST					SEPTEMBER		OCTOBER	
	AG	EG	KFB	KFC	SN	AG	EG	AG	EG
SAMPLE SIZE	32	32	32	31	32	43	41	28	34
Calanoid Copepod	.16	.11	.13	.80	.03	.18		.15	
Harpacticoid Copepod	.93	.93	.58	.52	.96	.50	.06	.63	.25
Crab Zoea	.16								
Gammerid Amphipod	.13	.14	.29	.16	.31	.26	.70	.44	.33
Caprellid Amphipod	.06	.29	.45	.42	.37	.03		.07	.04
Stomatopod	.03	.04		.03	.03			.04	.08
Mysid	.19	.11	.19	.06	.10			.37	.54
Shrimp	.03	.18	.13		.10	.38	.42	.22	.54
Polychaete		.11	.29	.10	.21	.06	.18		.04

Table 4. Percent volume, expressed as the mean proportion of the total stomach volume in each prey catagory, for YOY copper rockfish sampled from each habitat at the Snake Island site in each month. KFB: KF-bottom, KFC: KF-canopy; all other habitat abbreviations are given in Table 1.

PREY CATAGORY	AUGUST					SEPTEMBER		OCTOBER	
	AG	EG	KFB	KFC	SN	AG	EG	AG	EG
SAMPLE SIZE	32	32	32	31	32	43	41	28	34
Calanoid copepod	.02	.01	-	.25	-	.02		.01	
Harpacticoid copepod	.28	.14	.11	.08	.28	.11	-	.19	.01
Crab zoea	.13								
Gammerid amphipod	.04	.03	.11	.05	.06	.21	.29	.09	.16
Caprellid amphipod	.04	.12	.23	.25	.21	.01		.02	-
Stomatopod	-	.02		-	-			-	.01
Mysid	.07	.06	.19	.01	.04			.28	.15
Shrimp	.02	.26	.15		.10	.31	.30	.18	.45
Polychaete		.11	.08	.05	.01	.06	.05		.06
Unident.	.39	.25	.12	.30	.27	.28	.33	.22	.14

Discussion

There was probably little mixing of YOY copper rockfish among habitats during the initial post-larval summer period, as there were significant among-habitat differences in mean fish size in August. Subsequent changes in density could result from additional recruitment from plankton, migration of post-larval juveniles from nearby sites, dispersion among habitats, mortality, or any combination of these factors. It is unlikely that settlement from the plankton continued at Snake Island after the start of the study, as the otolith ages and length frequencies of the samples give no indication of new settlement. It is also unlikely that densities were affected by migration from other reef areas, because of the relative isolation of Snake Island. Therefore, we assume that all density changes reflected movements among habitats and/or mortality.

Ontogenetic shifts in habitat use occur in response to changing resource values, such as shelter from predation or prey availability (Werner and Gilliam 1984). Bluegill sunfish switch foraging habitats when the relative food values of the habitats change (Werner et al. 1983a), although these fish may forage in less prey-rich habitats with more shelter when in the presence of predators (Werner et al. 1983b). Jones (1984) found that post-larvae of a temperate reef fish preferentially used habitats with high algal biomass and increased prey density, although he recognized the difficulty in separating the effects of food availability and protection from predators. Predation is undoubtedly a factor in habitat resource value in the Strait of Georgia. Potential predators in the study area include lingcod (Miller and Geibel 1973) and adult copper rockfish (Prince and Gotshall 1976, Moulton 1977), and various bird species (Carr 1983).

Post-larval rockfish juveniles have been observed to shift habitats as they grow (Carr 1983), with associated changes in feeding habits (Singer 1985). Copper rockfish in the Strait of Georgia follow a similar pattern, although we observed them to initially occupy a greater diversity of habitats than observed in California (Carr 1983). The scope of our study did not allow the controlled field experiments necessary to quantify the relative importance of prey vs. predators as factors in habitat selection. However, we did examine prey use by habitat, over time. During the three months of this study, YOY copper rockfish consistently exploited certain prey types within a habitat. For example, fish in the AG habitat ate harpacticoid copepods throughout the study, even though in October the fish were larger than in earlier samples. We suspect, therefore, that the reduction in use of kelp forest habitats between August and September was a result of reduced shelter availability and/or reduced density of all prey types, and was not a result of changing preferences by growing fish.

In the Strait of Georgia, post-larval copper rockfish initially utilize a variety of reef-associated habitats. Kelp forests are an especially important habitat during this phase. However, the relative food and shelter values of shallow reef habitats change seasonally with the production cycles of the dominant macrophytes and their associated invertebrate populations. Within the first few months of settlement YOY copper rockfish shift to demersal habitats with perennial macrophytes. For YOY copper rockfish the availability of reef areas with both summer kelp forests and winter perennial macrophytes is a feature that potentially enhances first year survival. Such areas may, therefore, be especially valuable as nursery areas, and could possibly contribute disproportionately large numbers of individuals to older age classes.

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Reproductive mode and energy costs of reproduction in the genus *Sebastes*

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The genus *Sebastes* has historically been considered to be ovoviviparous, with all energy for embryonic development coming from the yolk present at fertilization. Recent studies have shown that embryos of two species receive nutrition in addition to that supplied in the yolk. Embryonic catabolism (estimated from *in vitro* oxygen consumption) required a significant portion of the yolk energy; combined with energy content of the larva at birth, total energy was much greater than the initial egg energy. One can access the accuracy of *in vitro* embryonic oxygen consumption by determining the excess respiration by pregnant females above that of males and immature females. In *Sebastes schlegeli*, this excess oxygen consumption is significant. The additional oxygen consumed by gestating females is greater than that predicted for oxygen consumption of the embryos early in gestation but less later in gestation, suggesting that *in vitro* estimates are approximately 80% high. We discuss the implications of these estimates to earlier calculations of viviparity. Energy taken up through ingestion and absorption of ovarian fluid in the hindgut, however, still confirms viviparity.

Introduction

Live-bearing fishes are characterized by a wide range of energetic relationships between maternal and embryonic systems. The genus *Sebastes* has historically been considered to be ovoviviparous, and that no additional nutrition is provided to the embryo during gestation (Scrimshaw 1945; Amoroso 1960). The reasons for this description have been based upon inference, however, since initial egg size is small, larvae are small at birth, and fecundity is very high (Phillips 1964; Moser et al. 1977; Boehlert et al. 1982). Recently, however, energetic studies have demonstrated that embryos of two rockfish species receive some form of nutrition during later stages of gestation and are thus viviparous (Boehlert and Yoklavich 1984; Boehlert et al. 1986). The source of nutrition was postulated to be a nitrogenous substance derived from resorption of unfertilized ova through ingestion of ovarian fluid and subsequent uptake in the hindgut.

The work demonstrating viviparity compared indirect with direct calorimetry of embryos during development. The indirect calorimetry used *in vitro* oxygen consumption to determine catabolic needs in development. Oxygen consumption *in vitro* increases with increasing developmental stage either linearly (*S. melanops*, Boehlert and Yoklavich 1984) or exponentially (*S. caurinus*, Dygert 1986; *S. schlegeli*, Boehlert et al. 1986). An important assumption of all previous work is that *in vitro* oxygen consumption is closely related to that *in vivo*. Many studies have estimated embryonic oxygen consumption of live-bearers *in vitro* (Moser 1967; Webb and Brett 1972; Berglund et al. 1986), but few have considered oxygen consumption rates *in vivo*. Boehlert et al. (1986) questioned the accuracy of *in vitro* oxygen consumption rates and suggested that they may be higher than *in vivo* rates, thus inflating estimates of catabolic energy use. In this paper we discuss the manner in which viviparity was demonstrated in *S. melanops* and *S. schlegeli* and then, by considering the relative increase in oxygen consumption by gestating female *S. schlegeli* as compared with spent or immature females or males (Webb and Brett 1972), provide insights to the accuracy of the *in vitro* measurements.

Materials and Methods

Methodology used in the embryonic energetics studies has been described in Boehlert and Yoklavich (1984) for *S. melanops* and Boehlert et al. (1986) for *S. schlegeli* and will be only briefly described here. Developmental stages of embryos were classified according to a modification of Oppenheimer (1937) and Yamada (1963) (Kusakari unpublished). Gestation time and duration of different stages of development were determined from samples of embryos taken from females held in the laboratory. Fish were catheterized at various intervals and an analytical relationship between the stage of development and the duration of each stage was developed. From this relationship stage of development was converted to time since fertilization.

Oxygen consumption was determined for embryos at several stages of development in a Gilson differential respirometer at 10°C using standard techniques (Umbreit et al. 1972). At the end of each experiment, the embryos were counted and used for dry weight and carbon and nitrogen determinations; some embryos were preserved for determination of developmental stage. Ash-free dry weight (AFDW) was determined from groups of 35-100 embryos. Caloric content was determined from percent carbon using the nitrogen-corrected equation of Salonen et al. (1976).

For experiments on respiration rates of adult *S. schlegeli*, fish from captive populations were used. Two days before beginning experiments, fish were weighed, measured, and sex determined after anesthetization in MS-222. Females were catheterized, developing embryos removed and staged, and estimates of time since fertilization (as a function of developmental stage) were calculated following techniques of Boehlert et al. (1986).

Fish were starved at least 2 d before respiration experiments. The resprirometer consisted of a cylindrical fish chamber constructed of acrylic tubing 20 cm in diameter with a volume of 13.2 liters. The respirometers were held in a 1.8 x 1.1 x 0.65 m tank which was partially covered with black plastic during experiments. Fish activity and oxygen content of the outflowing water were monitored at 5-10 min intervals. Flow-through methodology was used and oxygen concentrations determined with a polarographic oxygen electrode. Oxygen consumption rates (ml O_2/h) were determined by multiplying the change in oxygen concentration of inflowing and outflowing water by the flow rate. For each animal, a mean value was computed from two replicates. Our estimates may be considered "routine" metabolic rate (Fry 1971). Control experiments were run with empty respirometers and the drop in oxygen content was negligible.

Specimens in our experiments were divided into two groups based upon reproductive status. The first group was composed of males, immature females, and spent females and the second group females with gestating embryos at different stages of development. Respiration rates as a function of weight for the first group were fitted to a curve which could then be used as a predictive model of "normal" or non-gestating respiration rates. The estimates of this curve could then be applied to the second group; the difference between observed and predicted respiration rates was attributed to oxygen consumption by embryos within the female system plus associated costs of live-bearing.

Results and Discussion

Stage duration calculations show that early stages are passed through rapidly and that later stages, which encompass more significant morphological change, take considerably longer. The integrated relationships suggest that fertilization to birth takes 37 d for _S. melanops_ (Boehlert and Yoklavich 1984) and 51.5 d for _S. schlegeli_, which has a significantly larger egg (Boehlert et al. 1986). Comparisons of these estimates with data from individual females show agreement but may be somewhat variable under natural conditions. Oxygen consumption, which was determined for both species from embryos at several developmental stages, increased with time since fertilization; the relationship was nearly linear for _S. melanops_ (Boehlert and Yoklavich 1984) and was exponential for _S. schlegeli_ (Fig. 1). For embryos in later stages of development, many hatched from the delicate chorion and limited swimming activity occurred in the respirometer flasks. This may result in inflated values of oxygen consumption for late stage embryos.

The curves, fitted to the oxygen consumption as a function of time since fertilization, were integrated to estimate the total oxygen consumed during gestation. This value can be converted to calories using an oxycalorific equivalent (Lasker 1962) to determine the total catabolic energy expenditure during gestation. A comparison of these data with the actual energy contained in the embryos (Table 1) suggests that additional energy must be used during gestation. If _Sebastes_ was strictly ovoviviparous, the sum of final embryonic

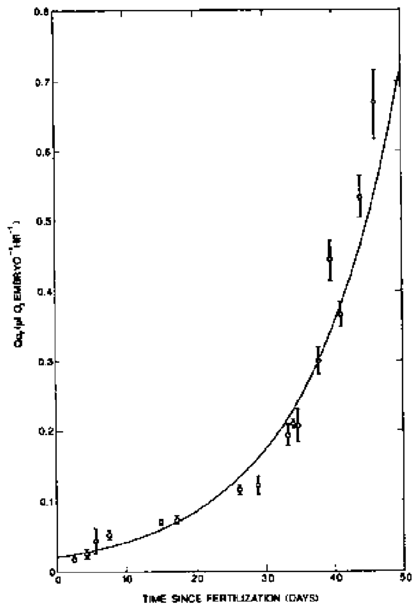

Figure 1. Oxygen consumption in embryonic _Sebastes schlegeli_. Each point (±2 SE) represents the mean of three or four replicates with embryos from the same female (from Boehlert et al. 1986).

Table 1. Changes in the energy content of individual embryos of _Sebastes_ from direct estimates of caloric content compared to catabolic energy utilization estimates (from Boehlert and Yoklavich 1984; Boehlert et al. 1986).

	Sebastes schlegeli	_Sebastes melanops_
Initial caloric content	1.59	0.43
Final caloric content	1.48	0.35
Catabolic calories	1.40	0.28

caloric content and catabolic energy utilization during gestation should equal the initial caloric content. The sum is significantly greater for both species, but more so for _S. schlegeli_.

The relative changes in these values during gestation is graphically illustrated for _S. schlegeli_ in Figure 2. The catabolic and direct comparisons of energy utilization diverge relatively early in _S. schlegeli_, and the results are clearly indicative of additional nutrition provided to the embryos during gestation. The catabolic energy utilization suggests that the percentages of original yolk energy remaining at birth would be 36% for _S. melanops_ and only 12% for _S. schlegeli_ (Table 1; Fig. 2).

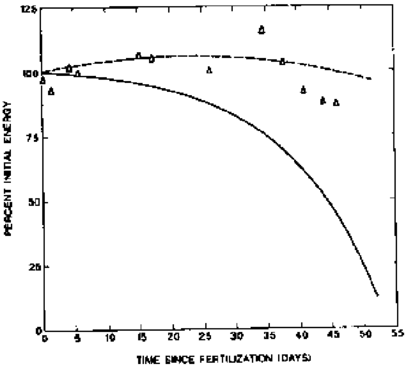

Figure 2. Summary of the energetics of development in embryonic *Sebastes schlegeli*. The y-axis is the percent initial energy, where 100% represents 1.59 calories. The solid line represents expected energy remaining with time based on subtraction of cumulative catabolism. The dashed line and data points represent actual caloric content of embryos at different stages (from Boehlert et al. 1986).

As mentioned earlier, overestimating embryonic respiration could also result in overestimates of catabolic energy utilization. There are two major factors which may be possible sources of error. First, activity by later stage embryos when removed from the maternal system may increase oxygen consumption. As an example, "active" respiration rates for Pacific sardine larvae may be from 1.3 to 3.5 times those of "inactive" rates (Lasker and Theilacker 1962). Second, oxygen tension in the Gilson respirometer is initially at saturated, atmospheric levels (Umbreit et al. 1972) whereas oxygen tension inside the ovary may be low; low ambient oxygen can lower respiration rate in embryos (Carlson and Seifert 1974). It is therefore possible that the rate of development of embryos *in vivo* may be under the control of oxygen availability and that the long gestation times and stage durations may be a result. Although there is no evidence for this in *Sebastes*, Triplett (1960) noted more rapid development *in vitro* for embiotocid embryos.

Respiration measurements on adult *S. schlegeli* were thus used as a check on *in vitro* measurements. Gestating fish were typically much more robust at a given length than were male, immature female, or spent females. The weight increase of gestating females over non-gestating *S. schlegeli* is most marked after about 32 cm SL and the divergence between the two curves increases with increasing length, most likely due to the rapidly increasing fecundity with length. We determined oxygen consumption rates for 23 non-gestating fish, including 19 males, 2 immature females, and 2 spent females for comparison with rates for 17 pregnant females with embryos between stages 1 and 30. Respiration rates typically increased with increasing body weight for non-gestating and gestating fish (Fig. 3). Data from non-gestating fish were fitted to the curve

$$Q = 46.734\ W^{0.7515} \qquad n = 23 \qquad r^2 = 0.524 \quad , \qquad (1)$$

where Q = oxygen consumption rate (ml O_2/h) and W = body weight (kg). At a given body weight, respiration rates were much higher for females with developing embryos. Data from these females were fitted to the curve

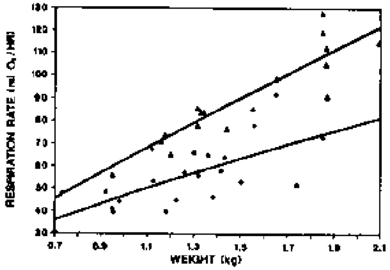

Figure 3. Oxygen consumption rates (ml O_2/h) as a function of fish body weight for Sebastes schlegeli. Triangles represent values from gestating females, and diamonds for males, immature females, and spent females; lines represent fitted curves (from Boehlert et al. in prep.).

$$Q = 62.383\ W^{0.9014} \qquad n = 17, \qquad r^2 = 0.81 \quad . \qquad (2)$$

These two curves (Fig. 3) are significantly different (analysis of covariance, $P < 0.01$). Differences are even more profound when comparisons are made for fish of equal length due to a much greater weight-at-length for pregnant females.

"Excess respiration" may be defined here as the amount of oxygen consumed by a gestating female in excess of that predicted for a non-gestating fish of the same length (Equation 1). This value will be the sum of embryonic respiration requirements and additional live-bearing costs, which include work associated with increased cardiac and branchial pumping and the added costs of ionic and osmotic regulation as more blood passes the gills. Calculation of this value is confounded by the weight of the female fish and the stage of development of the embryos. For this reason we standardized the measured oxygen consumption rates of gestating females (using the weight exponent in Equation 2) to a uniform weight of 1.5 kg. This value corresponds to a fish of 35.6 cm SL, with estimated post-fertilization fecundity of 126,921 embryos (Boehlert et al. 1986) and estimated total embryonic oxygen requirement (fecundity times in vitro embryonic oxygen consumption) which varied with stage of embryonic development from 3.13 to 74.86 ml O_2 h^{-1}. A fish of this length in non-gestating condition would have a corresponding weight of 1.3 kg with a respiration rate of 56.92 ml O_2 h^{-1} (Equation 1). The mean excess respiration of these adjusted data is 33.39 ml O_2 h^{-1} and values show a positive relationship with total embryonic oxygen demands. Subtracting the embryonic respiration rate from the excess respiration, however, results in values which show a negative relationship with the time since fertilization (Fig. 4). This relationship suggests that the added oxygen consumption of gestating females is high early in gestation and decreases, eventually becoming negative with further embryonic development (Fig. 4). The value approaches zero at about 30 d, near the time when the mouth opens and ovarian fluid is apparently consumed (Boehlert et al. 1986). Embryos at this stage are characterized by pigmented eyes, nearly complete lens, and fully formed otoliths, rectum, and urinary bladder (Kusakari unpublished).

If we assume that activity in post-30 d embryos is a major cause of increased in vitro embryonic respiration rates, we can estimate the pattern of respiration without these data. Refitting the curve for

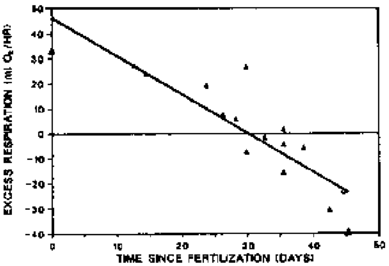

Figure 4. Elevation of respiration rate above that attributed to embryonic respiration in gestating female *Sebastes schlegeli* as a function of time since fertilization. All values are standardized to a weight of 1.5 kg for the gestating female (from Boehlert et al. in prep.).

embryonic oxygen consumption (Fig. 1) with only those values less than 30 d since fertilization allows recalculation of total respiration, which would be 0.70 catabolic calories per embryo. Compared to the estimated *in vitro* catabolic utilization of 1.40 cal (Table 1), the values of *in vivo* embryonic respiration may be inflated by as much as 85%.

Respiration rates may be indirectly estimated by another method as well. Boehlert et al. (1986) suggested that the additional nutrition for embryos comes from resorption of those embryos dying early in gestation. If we assume that this is the only source of energy, then from an energy standpoint the ovaries are a closed system. This would assume that the maternal system only provides exchange of respiratory gases and metabolic waste products. This idea is supported by observed ingestion of yolk proteins by late stage embryos during a time when such materials are not present in the plasma of females (A. Takemura and K. Takano pers. commun.). The energy decrease in the ovary during gestation for the 1.5 kg female *S. schegeli* is about 95.2 kcal. This is based upon the reduction in fecundity (by embryo death) and the decreased energy content per newly hatched larva as compared to a newly fertilized egg (Table 1). Partitioned over the embryos which survive, this amounts to some 0.75 cal each, which is close to the *in vivo* catabolic estimate derived above.

From these results, it would appear that the *in vitro* estimates of catabolic energy utilization by embryos of *S. schlegeli* (Boehlert et al. 1986) are high. If the value is indeed near 0.75 cal, the catabolic curve for *S. schlegeli* (Fig. 2) would show about 53% of the initial energy remaining at birth, still below that estimated by direct calorimetry. Other evidence also supports viviparity. First, uptake of substances by the hindgut occurs in late stage embryos of both species studied (Boehlert and Yoklavich 1984; Boehlert et al. 1986). Further, in individual *S. schlegeli* embryos, ash-free dry weight increases with time since fertilization, and significant decrease in carbon and increase in nitrogen (as a percentage of AFDW) occur during gestation (Fig. 5). The increasing AFDW and increasing percent nitrogen combine to result in a marked increase in nitrogen over the course of development, unlike most oviparous fishes, which show significant decreases in nitrogen over development (Rogers and Westin 1981).

The ovarian oxygen demand from embryonic respiration represents a significant proportion of the gestating female's excess respiration.

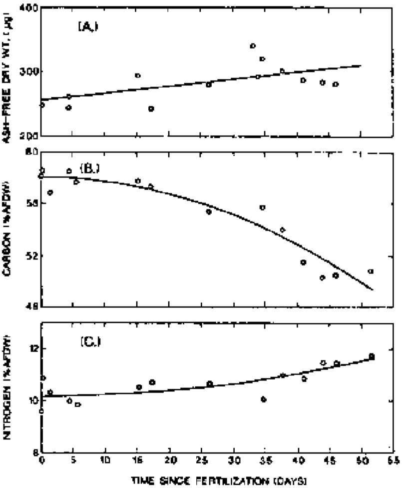

Figure 5. Changes in embryonic ash-free dry weight (AFDW) (A), carbon (B), and nitrogen (C) as a function of time since fertilization (days). Carbon and nitrogen are both expressed as percentages of ash-free dry weight (from Boehlert et al. 1986).

The other part of this excess is apparently associated with costs of live-bearing, including supply of respiratory gases and removal of waste products. That the total "excess" respiration of females during the gestation period remains fairly constant, however, suggests there is some "upper limit" for oxygen consumption. Metabolic scope may be defined as the difference between the maximum active metabolic rate supportable by aerobic metabolism and standard metabolic rate (Fry 1971); this topic has recently been reviewed by Priede (1985). Although the added weight and respiratory demands of developing embryos will contribute to a general decrease in the metabolic scope, other factors must also be considered, including general swimming activity and energy for digestion (specific dynamic action, SDA; Beamish 1974). Vahl and Davenport (1979) demonstrated an increase of 60% in the metabolic rate in *Blennius pholis* associated with a large ration and attributed this increase to apparent SDA; they suggested that in this fish and other species a single large ration may decrease the scope for activity by some 50% for several hours. Priede (1985) suggested that many fish species must time their feeding activity to keep the metabolic rate within the limits of metabolic scope. Over the extended period of gestation, *Sebastes* may need to make accommodations for the reduced metabolic scope associated with the increased respiratory load. *Sebastes* females store significant amounts of fat which are apparently depleted during the gestation period (Guillemot et al. 1985). Interannual variability in environmental factors may result in variability in the level of nutrition provided to embryos in other viviparous fishes (Trexler 1985). The effects of fish size, food availability, and physical factors thus have important implications to reproduction in the genus *Sebastes*.

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Use of a length frequency simulator to explore the information content in length data for a long-lived species, silvergray rockfish *(Sebastes brevispinis)*

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Abstract

Length data for silvergray rockfish (*Sebastes brevispinis*) is examined with a population model which incorporates stochastic variation in recruitment and length. The model, which predicts length frequency composition, is useful both for graphically estimating total instantaneous mortality from actual samples and for examining the information that can be gained from length data for long-lived species with low growth rates. The modelling exercises indicated that the expected length distributions were relatively insensitive to year-class variability. The distributions were sensitive to variation in instantaneous total mortality, partial recruitment and growth, but the shape and location of the right-hand descending limb was a still better indicator of total instantaneous mortality than mean or median length. Theoretical distributions representing different mortality rates were compared with two actual samples. Graphically determined estimates of Z based on length corresponded well with estimates derived from the age composition.

Introduction

Fishery stock assessment is often limited by a lack of information on age composition. Direct ageing of hard parts is either not possible, as is the case for many tropical species, or it is too costly in personnel-time to age enough samples for catch-at-age analysis. This lack of information has led investigators to develop methods for estimating vital rates or age composition from length data. Techniques have been proposed for estimating age composition directly from length frequencies given estimates of growth rates (Schnute and Fournier 1980), for using length data directly in catch-at-length models (Jones 1984), or for using length data to estimate vital rates (Beverton and Holt 1956; Hoenig, Lawing and Hoenig 1983; Pauly 1984).

These analytical techniques work best for short-lived, fast growing species for which there is contrast in size between the dominant age classes (Pauly 1984). They typically rely on the assumption of constant recruitment and equal growth by all members of a cohort. They also tend to assume knife-edge recruitment.

The Department of Fisheries and Oceans, Canada is responsible for assessment of all species of rockfish (genus *Sebastes*) on Canada's Pacific coast. This currently encompasses approximately 16 commercially important stocks (Leaman 1985; Stanley 1985). While length and otolith samples are routinely collected from commercial and research catches, ageing of the otoliths by the cross-section technique (Chilton and Beamish 1982) is too time consuming to develop extensive catch-at-age time series for more than one or two stocks. We therefore have turned to length frequency analysis as a means of gaining insight into the dynamics of many of the rockfish stocks. Unfortunately, rockfish represent the antithesis of an ideal candidate for length frequency analysis. They are long-lived with slow growth and do not fully recruit to the fishery until they are in the asymptotic phase of their growth. For example, aged samples of male silvergray rockfish (*Sebastes brevispinis*) shown in Figure 1 indicate full recruitment at between 25 and 30 years of age. Mean size at age for the same silvergray rockfish, presented in Figure 2, shows that the more than 60 exploited cohorts are compressed within 20 cm of growth. The mean lengths of the fully recruited cohorts are distributed within 7 cm. The limited growth during adult life and a mean standard deviation in length at age of 2.63 cm removes much of the contrast in length among ages.

Given the inadequacy of existing models for length frequency analysis of rockfish, I have utilized a simple graphical technique for estimating the total instantaneous mortality rate (Z) from length frequency information. The present paper documents the procedure using data for male silvergray rockfish. The technique involves generating an expected length frequency, given estimates of von Bertalanffy growth parameters and total mortality, and comparing the expected results with sample results. The key features are the stochastic parameterizations of mean length at age, individual length about mean length, and year-class strength.

Methods

The simulator

Theoretical length frequencies are generated from an adapted version of a simulator provided in Breen and Fournier (1984). The simulator generates expected numbers at age for a given total mortality rate. These are then corrected to recruited numbers at age with partial recruitment factors. A random number generator randomly selects individual specimens from the recruited population and converts the observation from age to length. Each length is stochastically estimated based on the von Bertalanffy equation. The simulator initially generates a set of mean lengths at age, with the mean length at each age randomly determined as:

$$l_i = L_\infty(1-e^{-k\ (i-t_0)})e^{\varepsilon_i} \qquad (1)$$

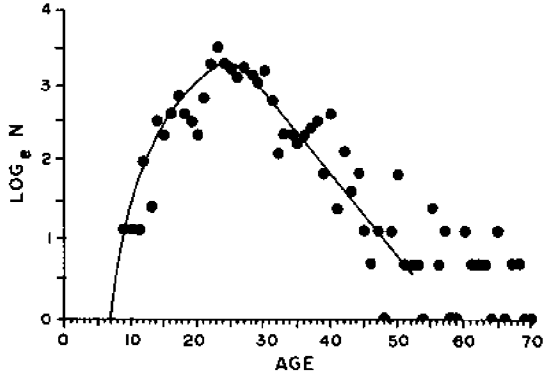

Figure 1. Log$_e$ frequency of male silvergray rockfish by age. Samples from commercial landings, 1977-81, southern and central coast of B.C. (INPFC statistical areas: Vancouver and Charlotte).

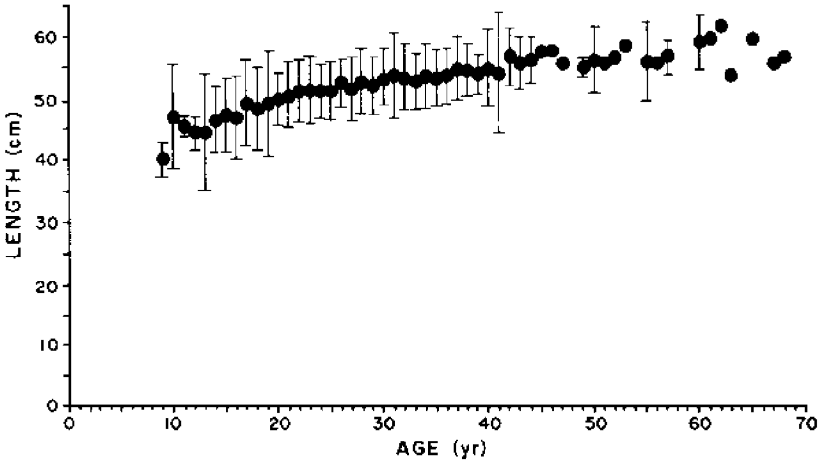

Figure 2. Mean length at age of male silvergray rockfish. Bars indicate 95% confidence limits of sample distribution. Samples from commercial landings, 1977-81, southern and central coast of B.C. (INPFC statistical areas: Vancouver and Charlotte).

where l_i is mean length at age i and $_i$ is a random normal deviate with a mean of zero and a specified standard deviation. Individual length (l_j) is also randomly determined as:

$$l_j = l_i \, e^{\varepsilon_j} \tag{2}$$

The simulator mimics real samples in that it can produce individual lengths or mean lengths that exceed the given value for L . The simulator allows the user to vary sample size and simulate variable recruitment by randomly varying population proportions by age according to the formula:

$$P_i = P_1 \, e^{\tau_i - Z_i} \tag{3}$$

where P_i is the relative abundance at age i, P_1 is the abundance in age class 1, Z is instantaneous total mortality, and $_i$ is a random normal deviate with mean zero and a provided standard deviation. I modified the published simulator to include the partial recruitment feature, and to produce length observations rounded to the nearest whole centimeter. To summarize, the model produces a theoretical length frequency given the information shown below in Table 1.

Table 1. Principal parameters used in the length frequency simulator (adapted from Breen and Fournier 1984).

1. n, the sample size.
2. Z, the instantaneous total mortality rate.
3. Partial recruitment factors by age.
4. von Bertalanffy growth parameters: t_0, k, L_∞.
5. Standard deviation (ε_i) of mean length about predicted mean length at age i from the von Bertalanffy equation.
6. Standard deviation (ε_j) in individual length about mean length.
7. Permitted random variation (τ_i) in population proportions for each age i, to simulate recruitment variability.

I estimated partial recruitment parameters from a set of silvergray commercial samples which had been collected between 1977 and 1981. These were aged using the cross-section technique. Log_e frequency at age is shown in Figure 1. Total instantaneous mortality (Z), for the calculation of partial recruitment, was estimated as the slope of the predictive regression of $\log_e$ frequency against age (Ricker 1975). For calculation of partial recruitment, I restricted the range of ages used in the regression to include only those ages which had undergone fishery exploitation. Silvergray rockfish have been exploited significantly in B.C. since the mid-1950s and the most recent collection in this set of data was from 1981, so I used the 25 age classes starting with the first age, 28, that was unquestionably part of the linear segment of the descending limb. The chosen points and regression lines are shown in Figure 1. Also shown is an eye-fitted $\log_e$ frequency curve for age classes younger than 28. Partial recruitment was determined as the ratio of the transformed $\log_e$ frequency from the eye fitted curve (<28 years) to the transformed $\log_e$ frequency predicted from the regression on age-classes starting at 28. The same data sets were used to estimate the standard deviation of mean length about age and the standard deviation in length about mean length. Growth parameters (t_0, k, L_∞) were taken from Archibald et al. (1981).

Estimation of Z

The model's accuracy in estimating Z was examined with two recently aged samples. Z was first estimated graphically from length data by overlaying the observed length frequency of a sample on a selection of expected distributions derived from different values of Z. One of the samples was obtained from the northwest coast of Vancouver Island, the other was collected in Moresby Gully, a more northerly region of the B.C. coast. Two sets of length frequency distributions were therefore derived from the corresponding growth rates of silvergray rockfish for these two regions (Archibald et al. 1981). For comparability, I equalized the scale of expected and actual distributions by decreasing the numbers at length in the expected distributions by the ratio of numbers observed to the theoretical sample size of 10,000.

Z was also estimated from the age composition of these samples. The sample sizes were too small to employ the regressions method used in the calculation of partial recruitment so Z was estimated as the reciprocal of mean age from the fully recruited age classes (Pauly 1984).

Results

The age and length information used for calculating partial recruitment and variation in mean length and individual length at age is provided in Table 2. The effects of changing the parameters of Table 1 on expected length composition are illustrated in Figures 3 through 8. In all the figures, the comparative or "standard" length composition is for males based on the set of growth parameters representing southern and central stocks of silvergray rockfish from the coastal waters of British Columbia (Archibald et al. 1981). Unless noted, the standard distribution represents a sample size of 10,000, a Z value of 0.15, the partial recruitment factors of Table 2, and a standard deviation of length about mean length of 2.63 for all ages. I found no correlation between age and the variability in individual length about mean length (Table 2). No variation in population proportion among ages was included in the standard distribution ($\tau_i = 0$). The standard distribution shown in the comparisons was one example of a random distribution based on a standard deviation in length about mean length of 0.26. Changing the random seed with this level of variation in mean length had

Table 2. Length and age information and partial recruitment factors for silvergray rockfish (*Sebastes brevispinis*) based on commercial samples collected between 1977 and 1981 from central and southern B.C. waters.

Age	n	Mean length (cm)	s	Partial recruitment	Age	n	Mean length (cm)	s	Partial recruitment
9	2	40.0	1.41	0.01	40	12	55.0	3.07	1.00
10	2	47.0	4.24	0.02	41	3	54.3	4.93	1.00
11	2	45.5	0.71	0.03	42	7	57.0	2.31	1.00
12	6	44.3	1.37	0.05	43	4	56.0	2.16	1.00
13	3	44.7	4.73	0.07	44	5	56.6	1.95	1.00
14	11	46.5	2.58	0.09	45	2	58.0	0.0	1.00
15	9	47.6	3.00	0.12	46	1	58.0	-	1.00
16	12	47.2	3.38	0.16	47	2	56.0	0.0	1.00
17	16	49.6	3.46	0.21	48	0	-	-	1.00
18	12	48.8	3.35	0.26	49	2	55.5	0.71	1.00
19	11	49.5	4.25	0.34	50	5	56.4	2.70	1.00
20	9	50.1	2.15	0.43	51	1	56.0	-	1.00
21	16	50.6	2.68	0.52	52	1	57.0	-	1.00
22	26	51.5	2.49	0.61	53	1	59.0	-	1.00
23	32	51.6	2.73	0.71	54	0	-	-	1.00
24	26	51.6	2.18	0.81	55	3	56.3	3.21	1.00
25	24	51.6	2.32	0.90	56	1	56.0	-	1.00
26	22	52.9	1.97	0.98	57	2	57.0	1.41	1.00
27	25	51.8	2.55	1.00	58	0	-	-	1.00
28	23	52.9	2.63	1.00	59	0	-	-	1.00
29	20	52.4	2.33	1.00	60	2	59.5	2.12	1.00
30	24	53.6	2.45	1.00	61	1	60.0	-	1.00
31	15	54.0	3.48	1.00	62	1	62.0	-	1.00
32	7	53.6	2.76	1.00	63	1	54.0	-	1.00
33	9	53.2	2.28	1.00	64	0	-	-	1.00
34	9	53.9	2.67	1.00	65	2	60.0	0.0	1.00
35	8	53.5	2.27	1.00	66	0	-	-	1.00
36	9	53.9	2.26	1.00	67	1	56.0	-	1.00
37	10	55.0	2.58	1.00	68	1	57.0	-	1.00
38	11	54.8	2.09	1.00	69	0	-	-	1.00
39	5	54.4	1.67	1.00	70	0	-	-	1.00

little impact on the expected distributions. The expected length frequencies for Z values of 0.05, 0.15, and 0.30 are shown in Figure 3. Figure 4 shows a comparison between the standard curve and the expected distribution given no variation in mean length or individual length.

The impact variable recruitment on length distributions is shown in Figures 5 and 6. Figure 5 shows the effect of allowing random variation in populations proportions. τ_i values were set at 2.0. The actual proportions at age for this example are provided in Table 3. Figure 6 illustrates a deterministic approach towards variable recruitment, where I arbitrarily chose one year-class (15-yr old or 20 yr-old), and multiplied its abundance by 10.

The effect of altering the partial recruitment factors is shown in Figure 7. The partial recruitment factors of Table 2 show a gradually increasing value from ages 9 to 27, with low levels (<0.26) persisting until the final 10 years (18-27). For comparison, a distribution was generated from a set of factors with full recruitment reached by 20 years and partial recruitment increasing in increments of 0.10 between ages 11 and 20. The effect of sample size on variability in length frequency distributions is shown in Figure 8 for 2 different random samples of 250 specimens. They are presented to show the extent to which small samples can imply dominant length modes which do not really exist.

Figures 9 and 10 show male length frequencies for one sample from the northwest coast of Vancouver Island and one from Moresby Gully superimposed on the expected length frequencies for Z values of 0.05, 0.15 and 0.30 for these two areas.

The Z estimates, graphically estimated from the length frequency overlays and from the age composition, are summarized in Table 4. The age composition is presented in Table 5.

Discussion and Conclusion

The simulator

The length frequency simulator serves two purposes in being an experimental model and an analytical tool for estimating total mortality rates. If one assumes constant natural mortality, varying the parameters provides insight into how much information can be expected from a limited amount of length data for a long-lived species with determinant growth. Figure 3, for example, indicates that, in spite of the relative lack of contrast in size at age, it is possible to characterize mortality rates from length data.

One of the principal characteristics of the simulator is the stochastic parameterization of length. There can be a tendency to assume that the presence of larger fish near the size of L_∞ indicates the continued abundance of older fish. This in turn implies a low historical value for F, the rate of instantaneous fishing mortality. Figure 4 shows the extent to which variability about mean length and mean length at age can flatten and extend the descending right-hand limb and incorporate greater abundance of

Table 3. An example of percent age composition of the recruited population with a ξ_i value of 2.0.

Age	%	Age	%	Age	%
9	0.06	29	1.03	49	0.00
10	9.06	30	1.80	50	1.35
11	0.28	31	0.40	51	0.02
12	0.04	32	0.12	52	0.01
13	0.06	33	7.41	53	0.03
14	2.94	34	0.15	54	0.01
15	0.09	35	0.60	55	0.00
16	0.01	36	0.26	56	0.06
17	0.03	37	0.01	57	0.02
18	2.22	38	0.00	58	0.18
19	14.39	39	0.20	59	0.01
20	0.55	40	0.33	60	0.01
21	0.08	41	0.07	61	0.00
22	0.05	42	0.01	62	0.00
23	47.88	43	0.00	63	0.00
24	0.14	44	0.00	64	0.00
25	2.32	45	0.06	65	0.00
26	0.18	46	0.13	66	0.01
27	0.01	47	0.34	67	0.00
28	4.90	48	0.04	68	0.03

Table 4. Comparison of length frequency and age frequency estimates of instantaneous total mortality (Z) for two commercial samples of male silvergray rockfish.

Sample	n	t_0	k	L_∞	Z	
					Length frequency	Age frequency
Kains Is.	57	-4.13	0.088	57.0	0.05-0.10	0.09
Moresby Gully	125	-4.13	0.101	54.9	0.10	0.08

Table 5. Numbers at age for two samples of male silvergray rockfish.

Age	Sample		Age	Sample	
	NW Vancouver Is.	Moresby Gully		NW Vancouver Is.	Moresby Gully
10	0	0	40	2	4
11	2	1	41	0	0
12	1	0	42	0	4
13	1	0	43	1	1
14	2	0	44	0	1
15	1	5	45	0	2
16	1	3	46	1	2
17	4	3	47	1	4
18	0	3	48	0	3
19	2	1	49	1	1
20	1	0	50	4	1
21	2	1	51	1	2
22	1	0	52	0	1
23	0	2	53	0	1
24	1	2	54	1	0
25	3	5	55	0	0
26	1	4	56	0	0
27	0	1	57	0	0
28	1	2	58	0	1
29	1	3	59	0	0
30	3	1	60	1	2
31	1	5	61	0	0
32	7	8	62	0	0
33	4	9	63	0	1
34	0	10	64	0	0
35	2	1	65	0	0
36	0	5	66	0	1
37	0	9	67	0	1
38	1	4	68	0	1
39	1	2	69	0	1

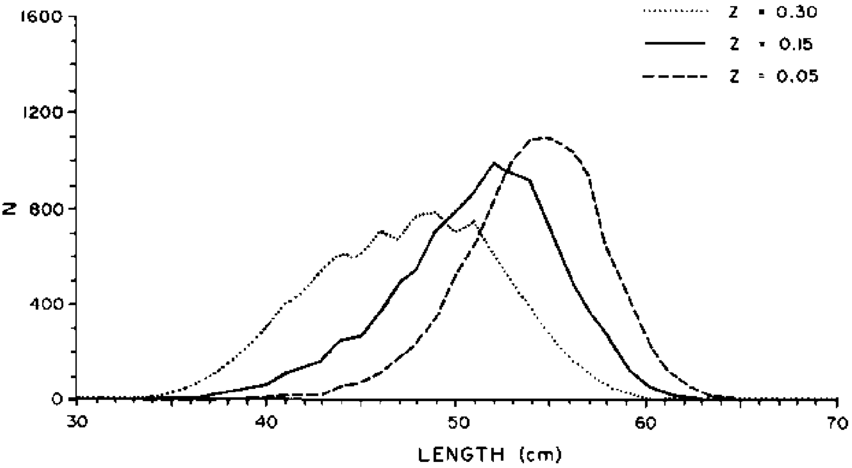

Figure 3. Expected length frequencies of male silvergray rockfish for instantaneous total mortality rates of 0.05, 0.15 and 0.30.

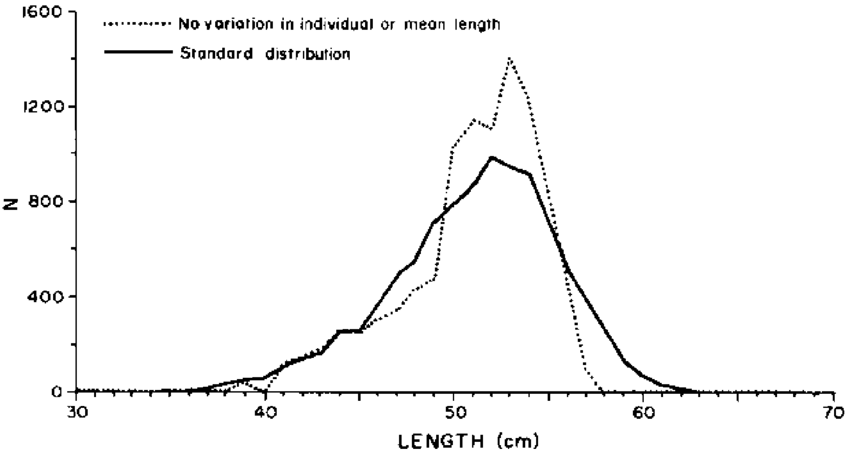

Figure 4. Expected length frequency with no variation in individual length or mean length at age in comparison with variation in both parameters.

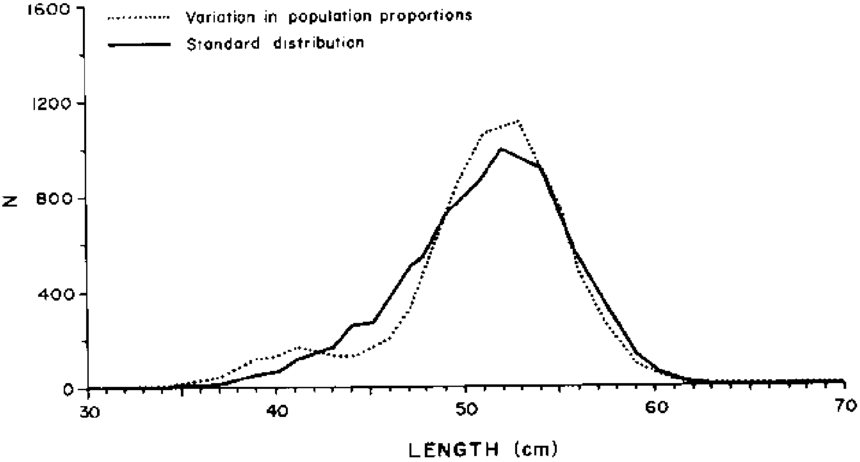

Figure 5. Expected length frequencies for varying (τ_i = 2.0) and non-varying population proportions.

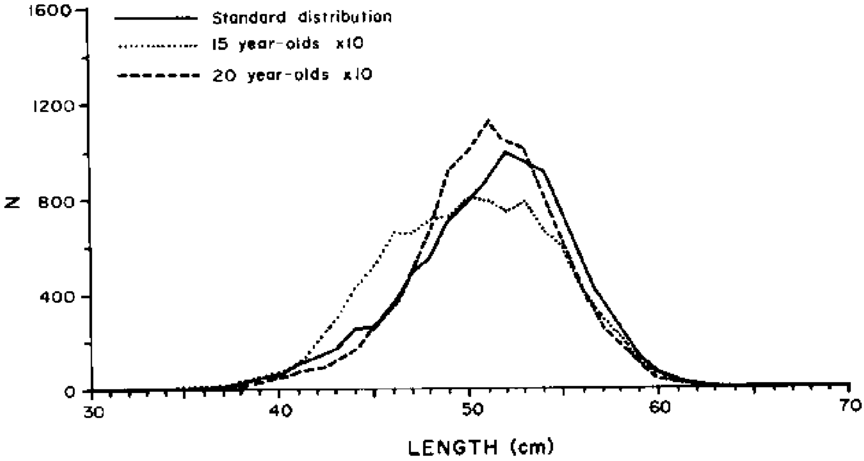

Figure 6. Expected length frequencies where population size at age is increased by 10 times for 15 year-olds or 20 year-olds.

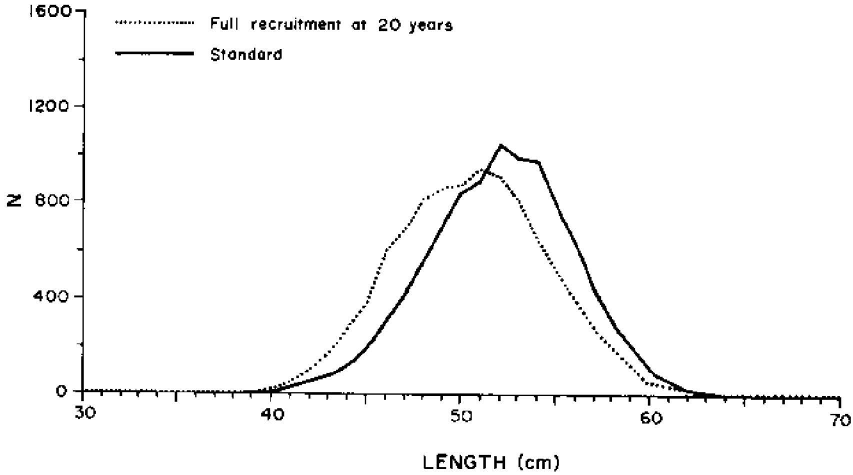

Figure 7. Expected length frequencies for "standard" partial recruitment factors (full recruitment at 28 yr) and "test" partial recruitment factors (full recruitment at 20 yr).

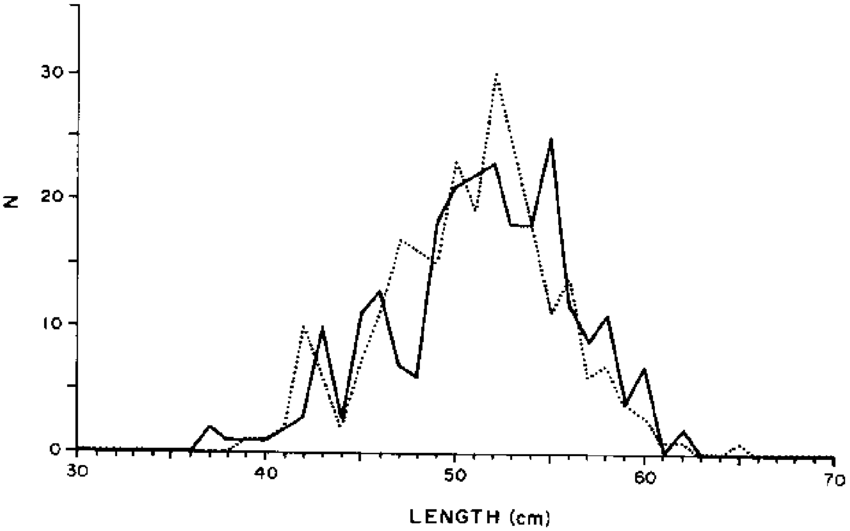

Figure 8. Expected length frequencies for two random samples of 250 specimens.

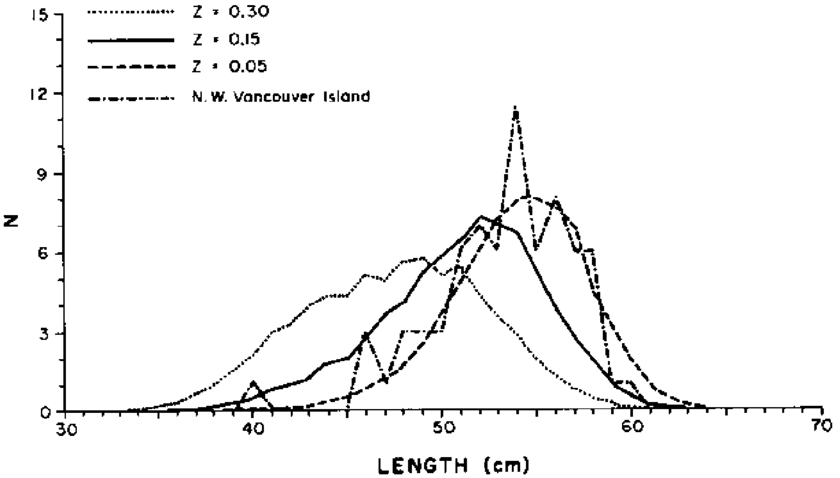

Figure 9. Comparison of a length frequency sample of male silvergray rockfish from the Northwest coast of Vancouver Island with expected length frequencies corresponding to Z = 0.05, Z = 0.15 and Z = 0.30.

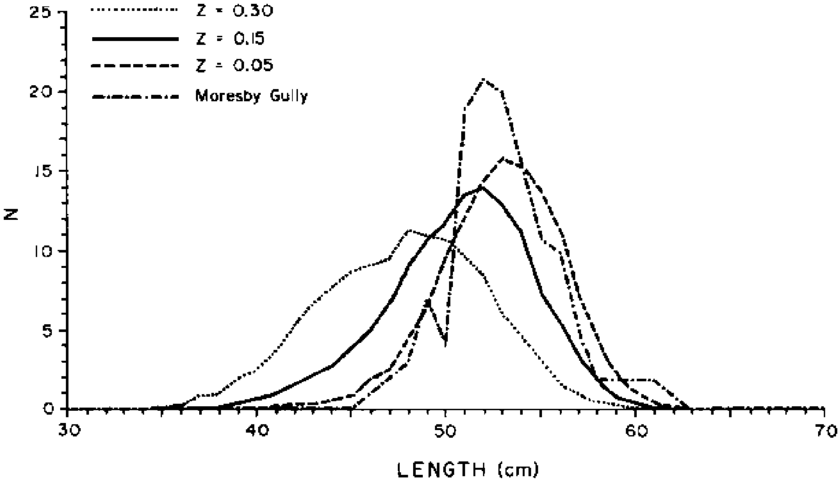

Figure 10. Comparison of a length frequency sample of silvergrey rockfish from Moresby Gully with expected length frequencies corresponding to Z = 0.05, 0.15 and 0.30.

larger, but not necessarily older, fish.

The slow growth of older fish combined with variability in length creates a smoothing effect which tends to obscure the impact of year class variability on length frequencies. The example of randomly varying recruitment incorporates a wide variation in proportion at age as shown in Table 3; but the resulting length frequency distribution shown in Figure 5 barely differed from the standard form.

Figure 6, which shows the effect of varying only one year-class, implies that for a genuinely large incoming year-class to be discernible in length data, it would apparently have to be much greater than 10 times the average level of recruitment. Interestingly, while the large 15-yr old and 20-yr old year class spikes flatten and shift the length frequency distribution to the left as expected, the shape and location of the descending right-hand limb is largely unaffected. This suggests considerable stability in this portion of the distribution and that attempts to infer the magnitude of total instantaneous mortality should concentrate on this feature of the distribution. The mean or median length may be a less conservative indicator of the proportional contribution of older fish and therefore mis-represent a change in the mortality rate. The stability of the distribution with respect to randomly varying proportion at age is further testimony to the smoothing effect of the variability in size and minimal growth among recruited ages. Conversely, the model indicates that if length frequency data indicate distinct modes, the modes are more likely to be sampling artifacts from too few observations (Figure 7), or a result of some other factor like segregation by size or age in the fished schools.

Varying the partial recruitment factors appears to mimic a change in the mortality rate (Figure 8). This emphasizes the need for accurate calculation of these parameters which can be difficult if the aged samples cover a period when a particularly large year-class is passing through the partially recruited ages. Although not presented here, a similar impact on the length distribution is incurred by varying the growth parameters. One might assume these to be relatively stable for rockfish but there is evidence of lability in these parameters with respect to Pacific ocean perch (<u>Sebastes alutus</u>) (B. M. Leaman pers. comm.). There is also evidence of systematic variation in L_∞ as shown in the two published values included in Table 5. Rockfish species in B.C. waters tend to show a south to north cline of decreasing L_∞ (Archibald et al. 1981).

Estimation of "Z"

The length and age based techniques produced similar estimates of Z. Both length distributions appear to lie between the distributions corresponding to mortality rates of 0.05 and 0.15 in approximate agreement with age-derived estimates of 0.09 and 0.08 for the Vancouver Island and Moresby Gully samples respectively. The Vancouver Island sample falls within the Z=0.05 distribution except for the absence of large specimens (≈60 cm). The dominant size classes of the Moresby sample more closely resemble the Z=0.15

distribution, however, the overall distribution, is closer to the Z=0.05 example. These two samples are typical for silvergray rockfish in British Columbia waters.

While perhaps more objective, the numerical techniques for estimation of vital rates (reviewed by Pauly 1984) have difficulty accomodating the slow, determinant growth and longevity of rockfish. The simulation-graphical method represents an alternative and perhaps more practical means for estimating vital rates. It also is a useful tool for examining what kind of conclusions can be drawn from rockfish length frequency information.

Additional work will include continued comparison with aged samples, preferably with more contrast, and refining the parameter estimates required for the model. As the analyses and comparisons will always be conducted on recruited ages, performance of the simulator would be improved by using a more general growth model (Schnute 1981).

The objectivity in estimating Z might be improved by using an analytical procedure for comparing the fit of the actual with the theoretical distributions. The parameterization of Z will be altered to incorporate additional information on variation in F.

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Age and growth of yelloweye rockfish (*Sebastes ruberrimus*) landed in southeastern Alaska

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Abstract

The rate of growth of yelloweye rockfish (Sebastes ruberrimus) was examined using length-at-age data from three areas in southeastern Alaskan waters. Otoliths were collected from landed commercial catches in Sitka (Central Southeast Outside area or CSEO) and Ketchikan (Southern Southeast Outside area or SSEO). Age-frequency data from Ketchikan were biased towards large fish because processors would not permit otoliths to be removed from round fish. Filleted and head-and-gutted fish were usually over six pounds. Ages were determined using the break-and-burn method. The maximum age observed was 114 in the SSEO samples and 97 in the CSEO samples. Older fish were more abundant in the SSEO areas. A log-transformed allometric growth model was fit to the length-at-age observations, and area and sex strata were compared using analysis of covariance. Growth rates were not significantly different between sexes in any of the areas compared, although the relatively high variability in the length-at-age data may have masked minor differences in growth rate. Sexes were analyzed separately in the comparisons among areas. Because rates of growth between the two areas from SSEO were not significantly different, data from these two areas were pooled for comparison with the central area. Length-at-age data with age greater than 30 years were used to compare growth rates between CSEO and the pooled SSEO areas as the SSEO data were biased toward older fish. No significant difference was found in growth rates between these two areas. The two areas were pooled to describe growth rates by sex. Using additional information from a small sample of young fish from all areas, von Bertalanffy growth curves were fit to the data for each sex.

Age distributions were different between sexes and areas. Male yelloweye rockfish have a strong early mode which declines rapidly, while

female yelloweye are more evenly distributed over the entire age distribution. This trend was seen in all areas and in a small sample of age data collected during a research survey in the CSEO area during 1981.

Introduction

During the past six years a domestic longline fishery for yelloweye rockfish (S. ruberrimus) has been rapidly developing in the southeastern Gulf of Alaska (Bracken and Ito 1985; Bracken and O'Connell 1986). Little specific life history information is available on this species. Yelloweye rockfish or Pacific red snapper are distributed over rocky bottom from Baja California, Mexico to Prince William Sound, Alaska (Phillips 1957; Rosenthal 1980). Yelloweye rockfish are a large red rockfish reaching a maximum length of 91 cm (Hart 1973). They are ovoviviparous and give birth to young from April through June in southeastern Alaska (O'Connell 1986).

The only published information on age and growth of yelloweye rockfish is based on surface aging of otoliths (Rosenthal et al. 1982). Recent research indicates that surface-aging techniques may underestimate ages of rockfish, particularly in older year classes, and that reading of otolith sections via the break-and-burn method is a more valid approach to evaluating the impact of fisheries and developing sound management regimes for long-lived species. The intent of this paper is to present age and growth information on yelloweye rockfish landed in the commercial fishery in the southeastern Gulf of Alaska.

Materials and Methods

Otoliths were collected from commercial landings of rockfish in Sitka and Ketchikan during 1983 and 1984 from three areas of Southeast Alaska (Figure 1). Area A comprises the Central Southeast Outside (CSEO) management area and areas B and C comprise the Southern Southeast Outside (SSEO) management area. Fishermen used longline set gear and fished over rocky bottom between 20 and 80 fathoms. Commercial landings were sampled for length, sex and stage of maturity and otoliths were collected when possible. Fork length was measured on round fish to the nearest centimeter. Processors would not allow round fish to be sampled for otoliths so only fish that were filleted or headed and gutted were sampled. In Ketchikan these were predominately large fish. Otoliths were aged at the Alaska Department of Fish and Game's (ADF&G) Kodiak Aging Laboratory using the break-and-burn method (Beamish and Chilton 1982). A small sample of break-and-burn age data collected in Sitka during 1981 was made available by the University of Alaska, Juneau (UAJ) for comparing growth rates and age distributions over time (Haldorson 1986, UAJ, unpubl. data). The fish in this sample were collected using jigging machines during research surveys (Rosenthal et al. 1982). The otoliths were aged at UAJ. Some length-at-age data for young fish from the 1980-1982 surveys were used to fit the von Bertalanffy model. These fish were aged using surface-aging methods. The method of collection and aging are described in Rosenthal et al. (1982).

Because samples were collected from commercial fisheries targeting on large individuals, growth data for young fish with relatively rapid growth rates were not available for most areas. For this reason, von Bertalanffy growth curves could not be fit to the yelloweye growth data

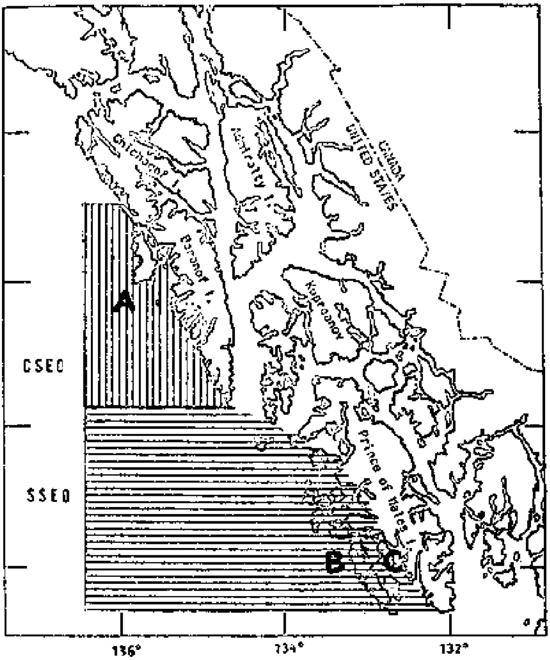

Figure 1. Commercial fishing sites and management areas in the Southeast Alaska rockfish fishery.

from the commercial catch samples without additional constraining assumptions on at least one of the parameters. A simpler allometric growth model ($y = ax^b$) described the limited amount of curvature in the growth data as well as the von Bertalanffy model and facilitating the comparison of the rates of growth among areas, since only two parameters were involved. The length-and-age observations were log transformed because the variance of these data tended to increase with increasing age in several of the area strata. An analysis of covariance was applied to the log-linear allometric model, $\ln(\text{length}) = \ln(a) + b(\ln(\text{age}))$, to compare the rates of growth among areas and between sexes.

Least-squares regression procedures were used to estimate the log-linear allometric growth model parameters. The multivariate secant iterative method was used to obtain least squares estimates of the nonlinear and von Bertalanffy parameters. The effects of logarithmic transformations on the length-at-age residuals were examined using the Kolomogorov-Smirnov test for departures from normality as well as tests for kurtosis and skewness.

Results

A century of year classes is represented in the age sample (Figure 2). The fish sampled for otoliths from the commercial catch ranged in age from 13 to 114 years (1871 year class).

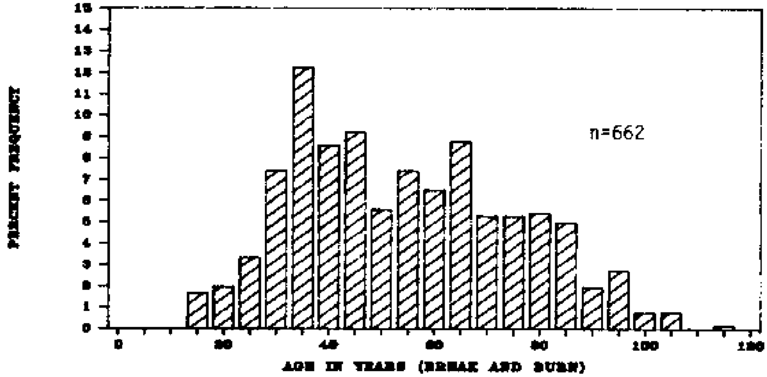

Figure 2. Age distribution of S. ruberrimus from Southeast Alaska commercial rockfish landings, 1983 and 1984, sexes combined.

The length-at-age data combined for all areas and both sexes show the lack of curvature in the samples (Figure 3). This is due to the absence of young fish in the commercial catch.

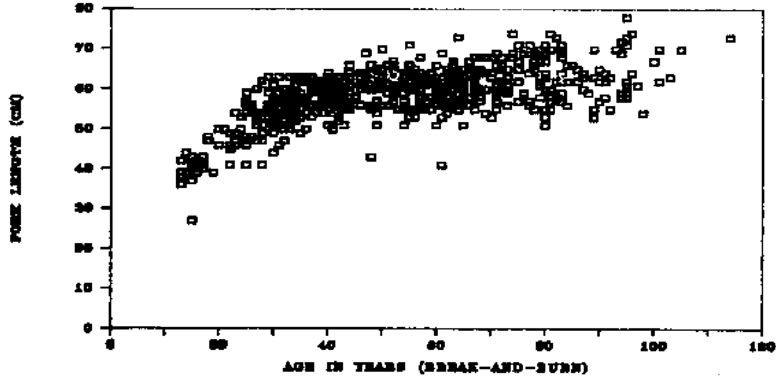

Figure 3. Length-at-age observations of S. ruberrimus sampled from the Southeast Alaska rockfish fishery.

Growth Rate Comparisons

Yelloweye rockfish landed in the CSEO (area A) and SSEO (areas B and C) commercial fisheries were sampled for differences in growth between sexes by area of catch. Analysis of covariance on the log-linear allometric model was used to compare growth rates between sexes and areas.

Sex

The ANCOVA technique tests for differences in slope between independently fitted lines then, if slopes are not different, tests for differences in intercepts given the same slope. In general, growth rates are similar for males and females in areas A, B, and C (Figure 4). No significant differences were found in either slope or intercepts between sexes for any of the three areas although when plotted separately the allometric model indicates slightly faster growth for males (Table 1). Length-at-age observations for sexes were not pooled as the relatively high variability in the length-at-age data may have masked minor differences in growth rates and other rockfish growth studies have found significant differences in male and female growth rates in some species (Miller and Giebel 1977; Six and Horton 1977; Boehlert 1980; Fraidenburg 1980; Wilkens 1980).

Table 1. Analysis of covariance statistics for differences in growth rates between sexes by district.

Area	Number	Slope F Value	Slope Prob> F	Intercept F Value	Intercept Prob> F
A	146	2.16	.1438	1.08	.2998
B	149	.79	.3770	.84	.3598
C	367	.02	.8889	.28	.5984
A/Survey	74	1.28	.2614	.80	.3739

Area

The two southern areas sampled, areas B and C, were tested for differences in growth rates for each sex separately. No significant difference in slope or intercept for either sex was determined so these two areas were pooled to comprise the SSEO data (Table 2).

Table 2. Analysis of covariance statistics for differences in growth rates between districts B and C, by sex.

Sex	Number	Slope F Value	Slope Prob> F	Intercept F Value	Intercept Prob> F
Male	254	3.6	.0589	3.74	.0543
Female	262	.21	.6502	.74	.3917

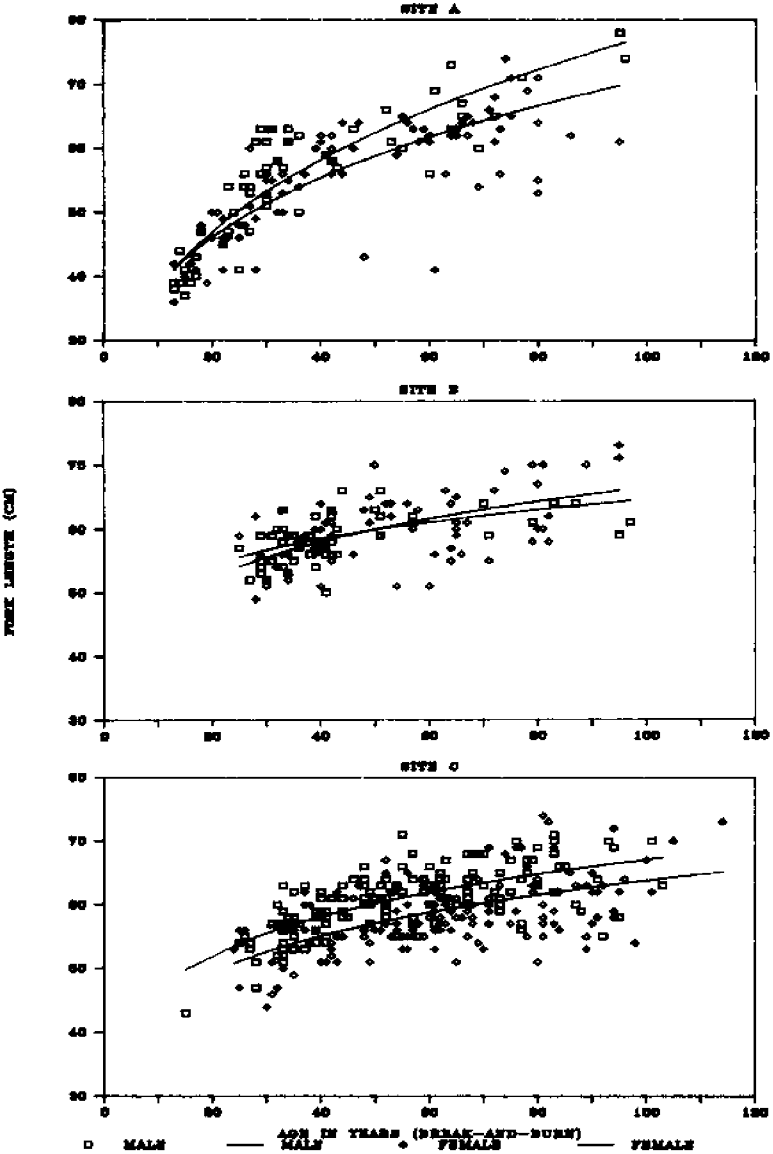

Figure 4. Length-at-age observations and allometric growth models for S. ruberrimus, by commercial fishing site.

Table 3. Analysis of covariance statistics for difference in growth rates between areas SSEO and CSEO, ages 30 years and older, by sex.

Sex	Number	Slope		Intercept	
		F Value	Prob> F	F Value	Prob> F
Male	257	3.66	.0569	2.74	.0988
Female	310	.06	.8063	.15	.6972

In order to generally describe yelloweye rockfish growth over a broad age range, a small sample of length-at-age data for young fish (less than 20 years) from a previous study (Rosenthal et al. 1982) was combined with the pooled length-at-age data for all ages from this study. The ages of the young fish were determined using surface-aging techniques which is assumed to be reliable for young ages. Von Bertalanffy growth parameters were estimated using the pooled data (Figure 6). Growth of yelloweye rockfish increases steadily until about 30 years of age where it levels off, although fish continue to live for many decades.

The only published length-at-age data for yelloweye rockfish is based on surface-aging techniques and therefore not directly comparable to ages from this study (Rosenthal et al. 1982). UAJ provided us with a small sample of break-and-burn otoliths collected in the CSEO area during 1980 and 1981 (Figure 7). An ANCOVA comparison of their study determined no significant differences in either slope or intercept (Table 4).

Table 4.

Sex	Number	Slope		Intercept	
		F Value	Prob> F	F Value	Prob> F
Male	89	3.38	.0697	3.35	.0705
Female	131	3.47	.0648	3.16	.0778

Age Distributions

Although there were no significant differences in growth rates between areas there were some notable differences in age distributions, both by area and sex.

Fewer young fish were represented in the SSEO data than in the CSEO data. This is most likely due to market differences between Sitka and Ketchikan during 1983 and 1984. Most small yelloweye were discarded at sea in the Ketchikan fishery so the shore-based delivery samples consisted of otoliths from fish that were being filleted or headed and gutted in port. These were usually larger fish. In order to compare growth rates over similar ranges of ages, only fish 30 years and older were used to compare growth rates between CSEO and SSEO (Figure 5). If plotted separately the allometric growth curves indicate a slight tendency toward slower growth in the southern area, particularly for males. However, ANCOVA results were nonsignificant for both males and females (Table 3).

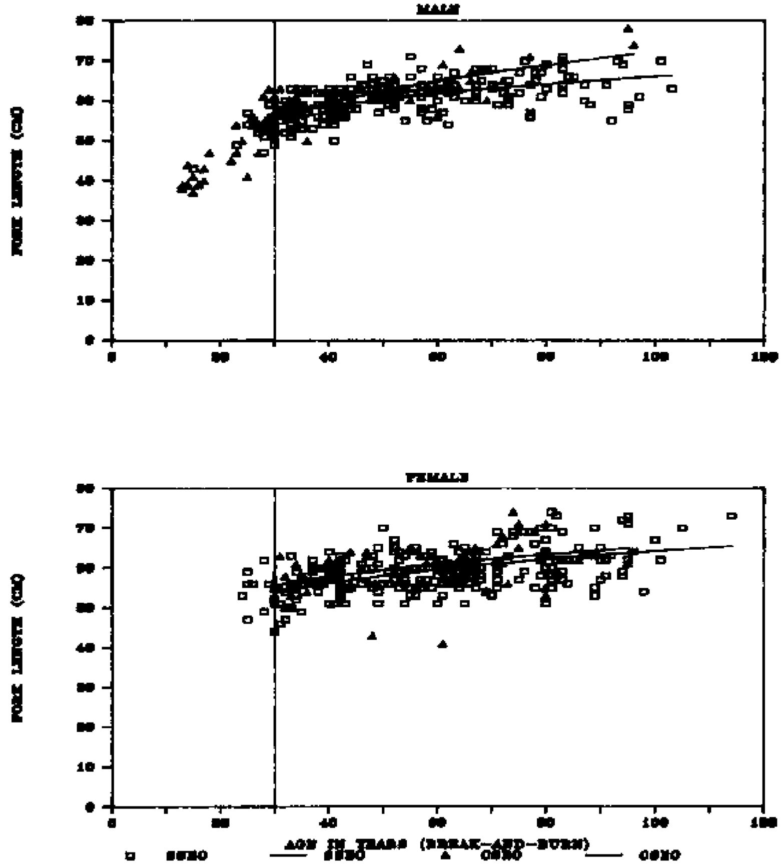

Figure 5. Length-at-age observations and allometric growth models for S. ruberrimus 30 years and older; comparisons between CSEO and SSEO by sex.

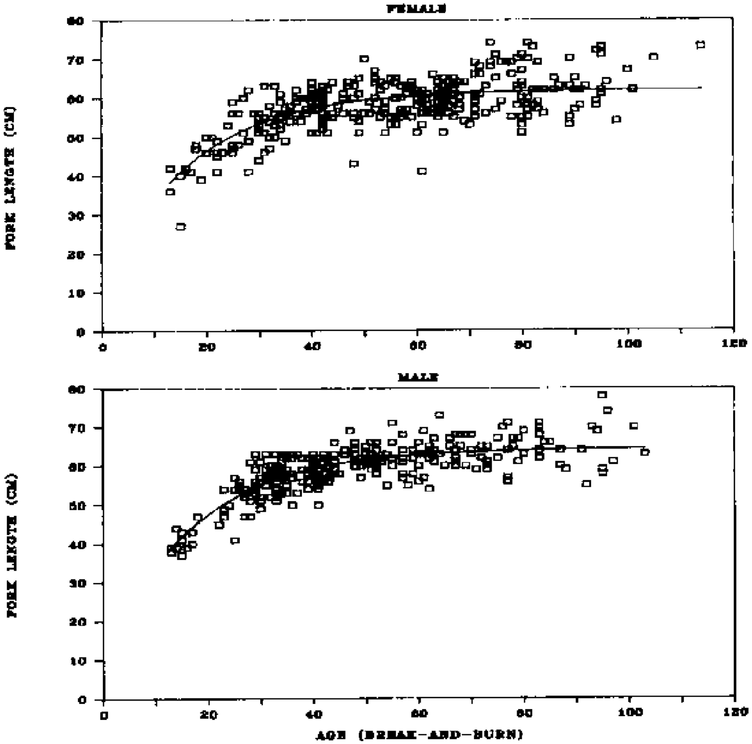

Figure 6. Von Bertalanffy growth models, by sex, for S. ruberrimus, Southeast Alaska, (ages younger than 20 from surface-aged survey data).

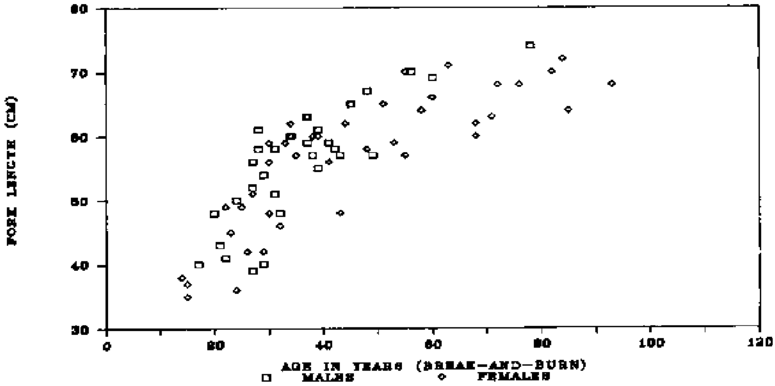

Figure 7. Length-at-age observations of S. ruberrimus sampled from 1981 survey, CSEO.

Sex

In both areas and in the 1981 survey data, distributions of male and female age frequencies were markedly different. There were far fewer old males than old females. Males ranged in age from 13 to 103 years. The male age distribution show a stong mode prior to 40 years, with the frequency declining rapidly as age increased. Females ranged in age from 13 to 114 years. The female age distributions are more equally distributed over a very broad range of ages.

Area

There were no differences in age distributions evident between area B and area C so the data was pooled. In SSEO ages ranged from 15 to 114 years with most ages greater than 30 (Figure 8). Yelloweye rockfish appear to be fully recruited into the fishery by age 35. Young ages (less than 30 years) are not adequately represented in the SSEO samples due to sampling limitations. Based on five year increments the model age group for males was 31-35 years and for females, 61-65 years. Males exhibited a strong mode in distribution at 31-35 years, then decreased in frequency as age increased. Females were more evenly distributed over all ages with modes at 41-45, 51-55, 61-64 and 81-85 (Figure 8).

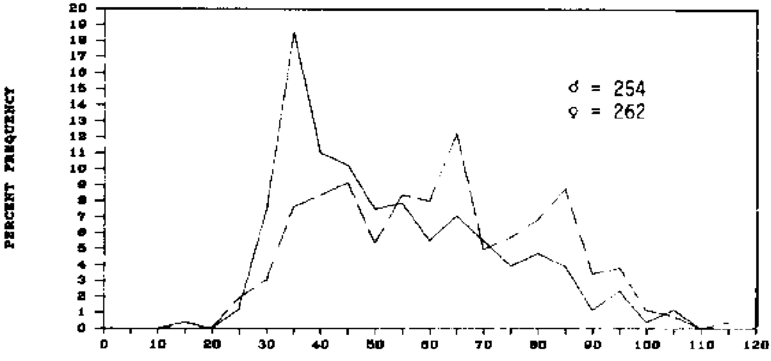

Figure 8. Age distribution of S. ruberrimus from SSEO, by sex.

In CSEO sample ages ranged from 13 to 95 years. Yelloweye rockfish from CSEO appear to be fully recruited by age 30. Males again display a strong mode at relatively young age groups, 26-30 years, then decline in frequency over the rest of their distribution. Females were more evenly distributed than males displaying modes in occurrence at 16-30, 41-45, 56-60, and 71-80 years of age (Figure 9).

CSEO had a lesser percentage of very old fish than did SSEO, particularly fish greater than 75 years. Modes in age distribution do not correspond between the two areas. The differences in distributions between areas is apparent, with the CSEO female distribution, in particular, having fewer old fish (Figure 10).

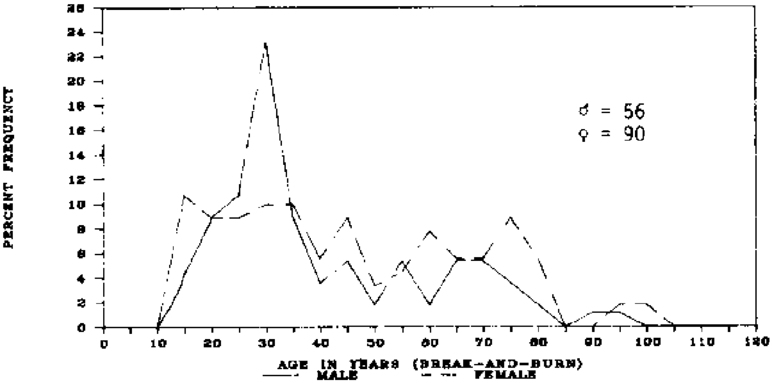

Figure 9. Age distribution of S. ruberrimus from CSEO, by sex.

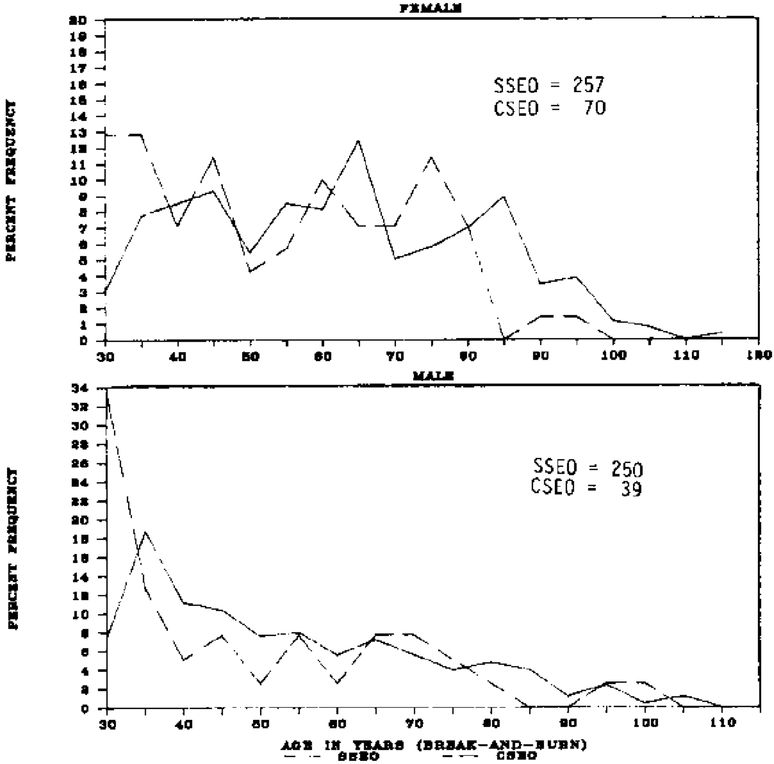

Figure 10. Age distribution of S. ruberrimus 30 years and older, by area and sex.

1981 Survey Data

The 1981 survey data from CSEO ranged from 12 to 99 years with most ages less than 50 years. Males again had a young mode; however, the mode was more widely distributed, from 26 to 45 years with a gradual decline. No males were aged at 61 to 75 years although there were small modes at 55-60 and 76-80 years. Females were more evenly distributed with a broad mode at 26-30 years, gradually declining to 45 years, and smaller peaks at 51-55, 66-75 and 81-85 years (Figure 11).

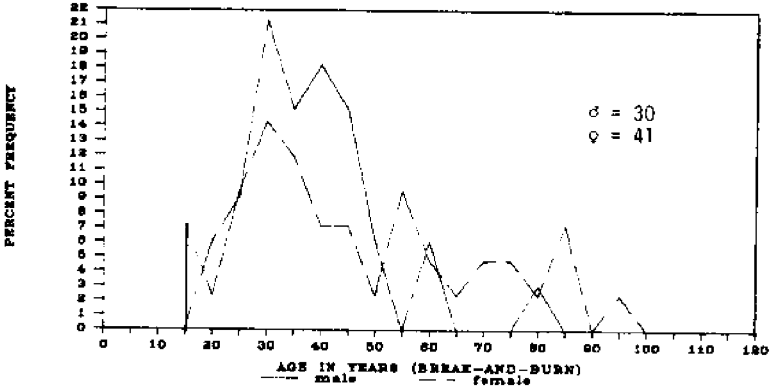

Figure 11. Age distribution of S. ruberrimus from 1981 survey, by sex.

A comparison of the 1984 longline data from CSEO from this study with the 1981 survey data, adjusted for differences in years collected, shows some differences in age distribution by sex. Males between 35 and 50 years of age were relatively abundant during the early survey but are poorly represented in the later sample, where the mode occurs at 26-30 years and then rapidly declines. The female distributions are less divergent although a lesser percentage of fish between 31 and 50 years and very old fish are present in the 1984 longline samples than in the 1981 survey survey data.

Discussion

Based on the fish landed in the commercial fishery, yelloweye rockfish growth in southeast Alaskan waters is typical of growth in other rockfish species. The initial period of growth increases steadily, then levels off to a fairly constant rate for many decades. In this species the growth rate levels off at approximately 30 years of age. It is unfortunate that no very young ages (less than 10 years) are available in this analysis as the von Bertalnaffy growth model, fitted to the available data, may not describe the growth of the younger fish. However, very small yelloweye rockfish are rarely recruited to the longline fishery.

Growth rates were similar for males and females in all three areas, although male yelloweye rockfish show a slightly faster growth rate than females when the data are fit to a log-linear allometric growth model. Differences in growth rates between sexes have been reported for some species of rockfish. In most cases where growth rate differs females grow at a faster rate than do males (Miller and Giebel 1973; Six and Horton 1977; Boehlert 1980; Fraidenburg 1980; Wilkens 1980). Growth rates are not always different and different studies do not always find the same results. Fraidenburg (1980) found that female yellowtail rockfish (S. flavidus) had a faster growth rate than male yellowtail rockfish, while Rosenthal(1982) reports male yellowtail rockfish from southeast Alaska with a faster growth rate than female yellowtail rockfish. Several species of rockfish from California have no differences in growth rates by sex (William Lenarz, NMFS, 10/86 pers. commun.)

Differences in growth by latitude have been observed for some rockfish species; however, the trends are not always similar (Archibald, Shaw and Leaman 1981). Westrheim (1973) found Pacific Ocean perch (S. alutus) to have a slower growth rate in northern latitudes while olive rockfish (S. serranoides) and splitnose rockfish (S. diploproa) are reported to have faster growth rates in northern latitudes (Love 1980, Boehlert and Kappenman 1980). No significant differences in growth rates between yelloweye rockfish from CSEO and SSEO were found. If growth was plotted separately for the two areas, fish from CSEO exhibit slightly faster growth rates. It is possible that the slightly faster growth in CSEO may reflect a short-term density dependent response to fishing pressure. The CSEO area has been subject to intensive domestic fishing pressure since 1981, while the domestic fishery in the SSEO area did not begin in earnest until 1984. Yelloweye rockfish in CSEO may have a lower relative abundance due to fishing mortality and therefore may exhibit increased growth. It should be noted that the differences were not significant and that the two areas are fairly close geographically (55°30' vs 57° N latitude), so it seems likely that differences in growth between these two areas would be due to regional differences in abundance of yelloweye rockfish and prey items rather than to different life history strategies.

Age frequency distributions determined from the samples of fish delivered to shore-based plants in CSEO and SSEO were different. This is due at least in part to the differential discarding of small fish due to differences in market preferences in the two ports. This is one of the problems with relying on the fishery to select samples. However, besides the sampling biases there appears to be real differences in age distributions as well. The similarity in age distributions between the commercial fishery samples from CSEO and those of an earlier survey sample indicates that at least in the CSEO area the fishery can supply age-frequency samples that are representative of the underlying population.

Male and female age distributions are markedly different in all areas, and in both this study and the 1981 survey. The reason for this difference in distribution is not known. It may be due to behavior differences between the sexes, perhaps associated with territoriality.

Finally, the use of the break-and-burn method for aging rockfish has not been validated for this species. Growth rates estimated from this study using ages determined at the ADF&G Aging Laboratory are similar to those of an earlier study using ages determined at UAJ. This helps support the validity of the break-and-burn technique and indicates that between-reader variablity may be low, at least between these two readers. If there were problems with consistency or accuracy of an individual reader, significantly different growth rates would be expected.

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A comparison of age estimates derived from the surface and cross-section methods of otolith reading for Pacific ocean perch (*Sebastes alutus*)

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Abstract

A sample of Pacific ocean perch (Sebastes alutus) otoliths, which had been aged in the mid-1970s using the surface reading technique, was re-aged by examining the cross-section. The objective was to examine whether the agreement for younger ages was sufficient to justify using catch-at-age data based on a time series of surface readings. Results indicated slightly biased but close agreement to age 14 (as determined by surface reading) in males and 15 in females. Otoliths estimated to be 17 or greater by the surface method showed very poor correlation with cross-section determinations.

Introduction

The application of the cross-section technique to ageing of rockfish otoliths (Chilton and Beamish 1982) has led in some cases to a reassessment of rockfish (genus Sebastes) biology. The greater apparent lifespan has altered estimates of size at age and significantly lowered estimates of natural mortality rates (Archibald, Shaw and Leaman, 1981). These lower estimates have, in turn, led to a more conservative perspective toward rockfish management (Leaman and Beamish 1984).

While the change in technique has hopefully led to improved management, it has also raised the problem of how, or even whether, to make use of the extensive catch-at-age time series which had been developed for rockfish through use of the original surface technique.

This problem was addressed by Archibald, Fournier and Leaman (1983) in their catch-at-age analysis of the Pacific ocean perch (Sebastes alutus) stock in Goose Island Gully by first conducting a preliminary comparison of surface versus cross-section readings.

They concluded that there was satisfactory agreement through age 16, and so utilized these younger ages while treating the remaining age classes as 17+ in their catch-at-age model (Fournier and Archibald 1982). This conclusion was supported by earlier work of Westrheim (1973) who showed that the large 1952 year-class for Queen Charlotte Sound could be followed as a distinct age mode with surface readings until the age of 17.

This comparison should have involved re-aging a sub-set of otoliths from the 1963 to 1977 surface-read material which had been used in the analysis. This would have incorporated any additional bias contributed by the individuals who were responsible for ageing the 1963 to 1977 data, and would have accurately reflected the surface readings prior to a general "awareness" about the greater lifespan. However, all the original otoliths were thought at the time to have been destroyed in a warehouse fire. Therefore a new sample was aged with the surface technique prior to being re-aged with the cross-section technique. Archibald et al. (1983) decided to engage the services of an individual who had little experience or familiarity with fish ageing to conduct the surface determination. In this way, they avoided using the experienced technicians who had participated in the transition of procedures and whose surface readings had begun to reflect the added expectation of greater ages.

We subsequently have found a small sample of the original otoliths which had been surface-aged as part of the 1963 to 1977 data set. As we were never fully satisfied with the original comparison and because the population analysis based on these surface readings remains the only catch-at-age analysis of rockfish in B.C. waters, we had this old material re-aged using the cross-section technique.

Our purposes in conducting the comparison were to: 1) examine the validity of using surface readings for the previous assessment; 2) determine whether 17+ was the most appropriate cutoff age for lumping the older age classes; and 3) resolve whether we could append additional years of catch-at-age data based on the cross-section technique to the original catch-at-age time series based on surface readings.

Methods and Results

The original otoliths that we re-discovered had been sorted by sample and sex and stored in a glycerin-and-water mixture in glass vials. The otoliths within the vials were grouped corresponding to the 1-centimeter length intervals of the sampled fish. With nothing to distinguish one otolith from another within a length interval, we could only identify a known-age otolith if it were the only otolith corresponding to a length interval or, if all the otoliths in an interval had been assigned the same age. The latter case was obviously more common the fewer the otoliths in the interval and therefore tended to correspond to length intervals nearer the extremes of the length distribution. Numbers of otoliths by length of the whole fish are shown in Table 1. The original method of surface reading was described in Westrheim (1973). The cross-section method that we used to re-age the sample is described in Chilton and Beamish (1982).

Table 2 and Figures 1 and 2 present mean cross-section age by surface age. Tables 3a and 3b present the overall distribution of readings. Figures 3 and 4 show the converse of Figures 1 and 2, mean surface age corresponding to each cross-section age.

Cross-section readings for each age group of otoliths, as grouped by surface ages, showed considerable variability but limited bias for the younger age groups. Cross-section readings for males tended to be lower for ages 6 to 8 and higher for ages 9 to 15, although when treated as individual samples, only the mean difference for age 12 was significantly different from 0 (=0.05). The mean difference between readings (cross-section minus mean surface) was $\leq$ 1.0 for ages 6 to 14, then increased to 1.3 for 15-yr olds and 2.1 for 16-yr olds. Beyond 16 there was virtually no agreement, and beyond 23 there was virtually no correlation.

Mean cross-section age for females was less than the surface age for each age group younger than 16, except for the 6 and 10-yr olds. Only the mean difference for 12-yr olds was significantly different from 0. The mean difference for all ages in this range was $\leq$ 0. Cross-section readings averaged 18.8 for the 16-yr-old group of surface readings. As with males, there was little agreement beyond 16, and beyond 20 there was virtually no correlation.

Table 1. Length frequency by sex for the re-aged sample of Pacific ocean perch from Goose Island and Mitchell's gullies.

Length (cm)	Male	Female
31	28	14
32	29	19
33	24	27
34	23	31
35	10	25
36	14	16
37	10	17
38	12	22
39	10	19
40	21	26
41	21	25
42	26	21
43	17	14
44	11	15
45	5	11
46	0	21
47	0	11
48	0	6
49	0	1
50	0	1
51	0	0
52	0	1
Total	261	343

Discussion

The linear relationship between the two ageing techniques for ages 6 to 14 in males and 6 to 15 in females indicate that Archibald et al. (1983) were justified in using the surface readings for their assessment. While there was apparent bias, though not significant in most ages, the differences were minimal relative to the requirements of the model. The biases could be assumed to have been constant over the 15 years of the time series and, since the model only attempts to detect general changes in stock abundance, a bias of consistently less than 1 year per age group would have had little impact on the overall conclusions about biomass trends.

The results indicate that 15+ or 16+ would be a more appropriate cutoff age for lumping the older age classes in future assessments. This parameterization was examined in the initial assessment but

Table 2. Mean cross-section age for otoliths grouped by surface-read ages; Pacific ocean perch from Goose Island and Mitchell's gullies.

Surface age (yr)	Cross-section age					
	Males			Females		
	n	$\bar{x}$	s	n	$\bar{x}$	s
6	2	6.00	0.00	4	7.00	2.00
7	14	6.93	0.83	5	6.40	0.55
8	17	7.41	1.54	9	7.67	1.50
9	13	9.15	1.41	17	8.76	1.25
10	33	10.30	1.07	26	10.46	1.42
11	21	11.33	1.06	38	11.00	1.45
12	21	13.00	2.05	45	11.40	1.14
13	9	13.78	1.30	29	12.41	2.43
14	14	15.29	2.92	26	13.73	2.29
15	8	17.12	6.06	25	14.76	1.88
16	5	21.40	2.07	19	18.84	7.52
17	10	21.80	7.19	5	20.80	6.83
18	10	22.70	3.62	10	25.20	9.75
19	9	26.56	3.88	5	23.00	2.45
20	10	32.40	10.47	11	24.64	4.08
21	12	35.00	13.54	11	34.18	15.05
22	14	33.79	14.51	14	34.07	15.09
23	10	44.50	14.26	14	31.79	8.49
24	11	41.73	13.14	11	36.09	16.58
25	7	50.71	17.81	6	49.83	8.35
26	5	52.80	19.88	7	46.57	10.15
27	4	42.50	5.26	4	41.50	18.05
28	1	40.00	-	1	71.00	-
29	0	-	-	1	34.00	-
30	1	49.00	-	-	-	-

Table 3a. Distribution of age estimates derived from surface and cross-section techniques. Otoliths were from male Pacific ocean perch from Goose Island and Mitchell's gullies. Older cross-section estimates which did not fit on table are shown in brackets at the bottom of the matching surface age column.

Cross-section age (yr)	Surface age (yr)																								
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6	2	4	6																						
7		8	3	2																					
8		1	6	1	1																				
9		1	1	6	5	1						1													
10				2	17	4	1																		
11				1	3	5	2		1	1															
12			1	1	7	9	8	1	1																
13						2	2	4	2																
14							6	1	1	1		1													
15							1	2	5	3															
16								1	1		0		1												
17										1		1													
18													0												
19									1	1	1			0											
20							1		1		1	1	2		0	1			1						
21									1		1				1	0									
22												1					0								
23											1	1	3	2	1		1	0							
24											1		3	2			2		1						
25												2		1	2	2	2			1					
26														1		1					1				
27															1							0			
28																	1						0		
29																								0	
30												1	1	2		2			1						0
31										1							2	1							
32															1	1	1			1					
33												1													
34																	1		(44)						
35															1	1	2	1	(44)			1			
36																		1	(50)						
37																		3	(53)	(45)	1				
38																(42)		(53)	(53)	(46)					
39															1	1		(65)	1	(63)	(65)	(43)			
40															(43)	(44)	(47)	(73)	(63)	(67)	(67)	(65)	1		
41															(54)	(71)	(79)	1	1	(72)	(69)	(47)			(49)

Table 3b. Distribution of age estimates derived from surface and cross-section techniques. Otoliths were from female Pacific ocean perch from Goose Island and Mitchell's gullies. Older cross-section estimates which did not fit on table are shown in brackets at the bottom of the matching surface age column.

Cross-section age (yr)	Surface age (yr) 6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
6	3	3	2					1																
7		2	2	3	1	1																		
8			4	4		1	1	1																
9				6	6	1		1																
10	1			2	6	9	6	2																
11			1	2	7	15	17	5	3	1	1													
12					4	7	15	4	4															
13					2	2	5	4	4	2	2								1					
14						1		6	9	9	1	1												
15						1	1	3	5	10	5													
16								1		1	2													
17								1				1	1											
18													0											
19										1			2	0										
20												1		1	1									
21										1	4	1	2	1	2	1	1							
22																	0		1					
23									1		2				2			2						
24													1	2	2	2	1	2	0					
25											1				1	2	5	1	2	0		1		
26													2	1			1		1		0			
27															1		1					0		
28													1			1		2					0	
29															1			1				1		0
30																								
31																								
32												1				1								
33																	1	1						
34															1				1					1
35																1				1	1			
36																		1			(45)			
37																1			2	(50)	(48)			
38																	(43)	(41)		(51)	1			
39																	(51)	1	(54)	(51)	(59)			
40																(57)	(58)	(43)	(62)	(51)	1	(48)		
41											(45)		(51)			(68)	(69)	(49)	(62)	(61)	(61)	(64)	(71)	

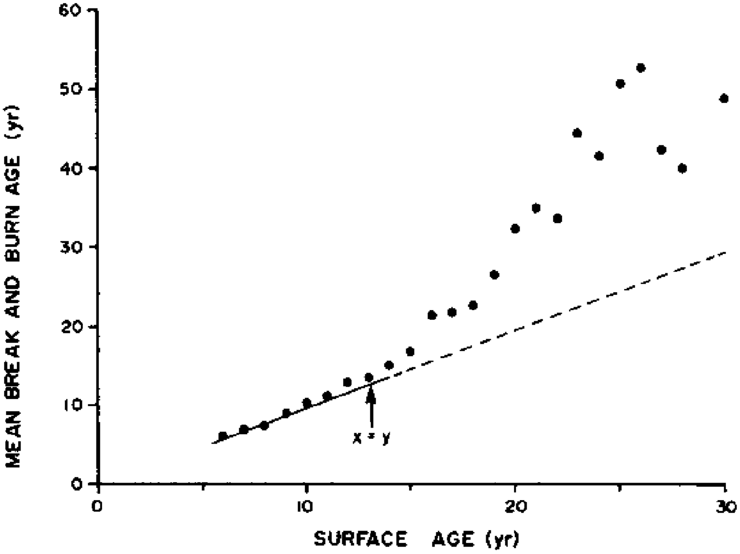

Figure 1. Mean cross-section age for male Pacific ocean perch plotted against surface age.

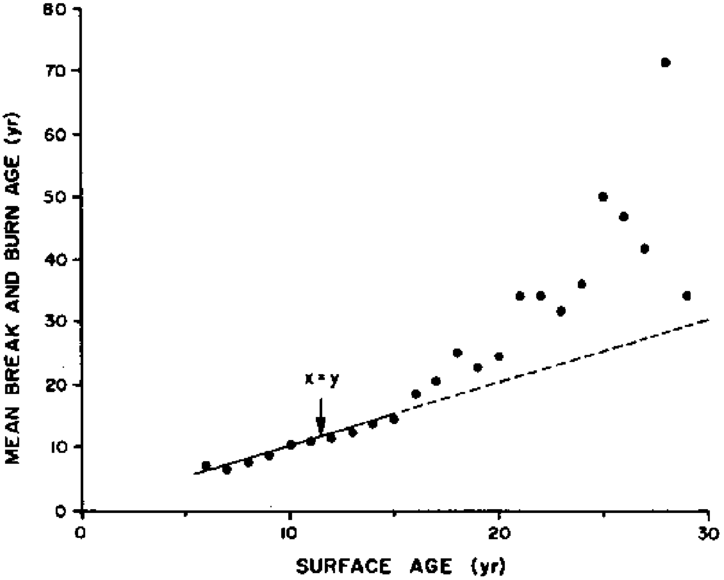

Figure 2. Mean cross-section age for female Pacific ocean perch plotted against surface age.

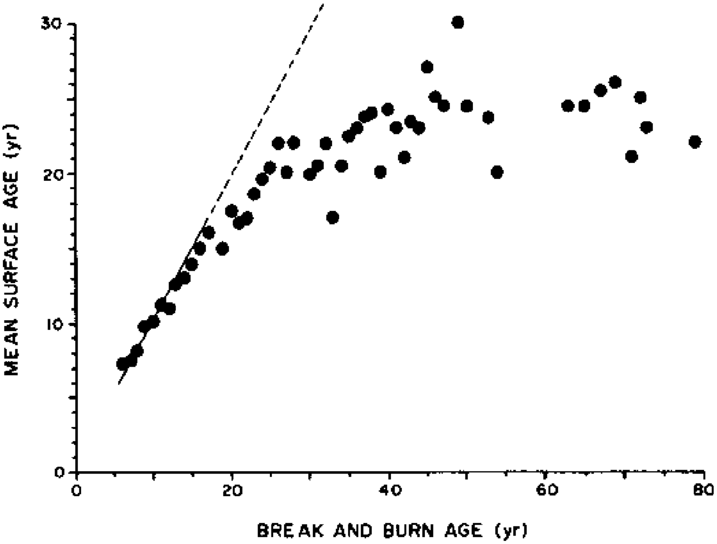

Figure 3. Mean surface age for male Pacific ocean perch plotted against cross-section age.

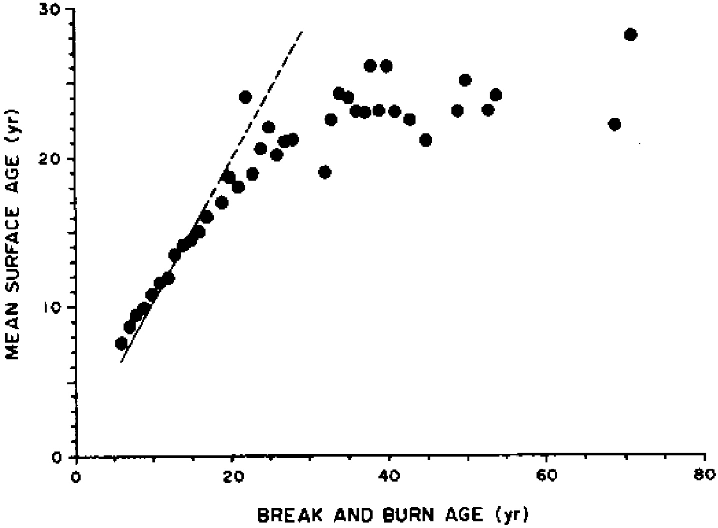

Figure 4. Mean surface age for female Pacific ocean perch plotted against cross-section age.

produced results very similar to the published results which used 17+ as the final age group (B. M. Leaman pers. comm.).

I had intended to use the results to generate a correction matrix for converting the original surface-aged material including older ages to their equivalent cross-section distribution. I could then append any additional years of cross-section catch-at-age information to the original "corrected" data set derived from surface estimations. However, the older ages provided too little information for predicting cross-section ages. While surface ages of 16 to 23 were correlated with increasing mean cross-section age, the percent agreement was almost nil (Tables 3a and 3b) and the variability in cross-section readings was large (Table 2). Surface determinations older than 20 provided virtually no information about expected cross-section age. Furthermore, although the distribution of cross-section ages for each of the younger age groups (6-15) was significantly skewed to the left, in many cases the bias was not large and the variance could be accomodated in the Fournier and Archibald model by virtue of the model's parameterization of ageing error. Finally, using the results from this comparison to convert an entire catch-at-age series would have incorporated the typical problems of extrapolation from age-length keys (Westrheim and Ricker 1978).

The issue of whether cross-section catch-at-age information could be appended to surface-read information was resolved by examining Figures 1 to 4. Figures 1 and 2 indicate, as stated earlier, reasonable agreement of mean cross-section to surface readings to ages 14 in males and 15 in females. The converse relationship of mean surface reading to each cross-section age, which is shown in Figures 3 and 4, indicates reasonable agreement ($\leq$ 1 year mean difference) to age 17 in males and females. The general agreement persists to a greater age in this configuration because the distribution of cross-section ages for each surface age contains the occasional old individual. This effect is not seen in the distributions of surface readings corresponding to each cross-section age (Tables 3a and 3b). Results therefore indicate that additional catch-at-age derived from the cross-section ageing technique can be appended to time series derived from surface readings. The imprecision in agreement between the two techniques however, implies that while sequential population analyses based on mixed catch-at-age data should identify general biomass trends, it will have considerable difficulty in correctly characterising year-class variability.

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Long-term cycles of growth in *Sebastes*: Extracting information from otoliths

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Time series of information about fish populations are useful in understanding their natural fluctuations and responses to variation in physical factors. Most time series on fish, however, concern population size, typically estimated from historical catch records. We describe a technique by which growth information can be extracted from otoliths of long-lived species such as Sebastes through sectioning and careful measurement. As an example, data from recently collected Sebastes diploproa and S. pinniger are used to describe growth at ages 1 through 6 during several decades of this century. We describe the technique and its limitations, and make suggestions for application of the resulting data.

Introduction

The study of long-term changes in marine fish populations has recently received a great deal of attention. Understanding the responses of fish populations to physical and biotic variability can lead to predictive capability; indeed, many current studies in fisheries oceanography examine the causes of past population change with the goal of modeling future trends in populations. Obviously such information can be most useful for purposes of fisheries management.

Several categories of long-term change in marine fish populations have been investigated. Population or stock size has generally been estimated from historical catch records of fisheries, and data from many decades are available, as for some Pacific salmonid stocks (Mysak et al. 1982) and several North Atlantic fisheries (Cushing 1982). Species assemblages and biotic interactions have been described on the decade scale by current work of the California Cooperative Oceanic

Fisheries Investigations (Loeb et al. 1983; H. G. Moser, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038 pers. commun.), and on the century scale by Soutar and Isaacs (1974) for the same region.

Methods of data collection for developing time series either come from continuous data collection or extraction of naturally stored information. The former often occurs over generations of biologists. Since starting a new series may not allow achievement of objectives for 30 or more years, available time series (which are often collected for other purposes) are used. In some cases, however, naturally stored information can be used to extract historical population information. A classic example of this approach is the study of cycles of population abundance for *Engraulis*, *Sardinops*, and *Merluccius* by Soutar and Isaacs (1974). By measuring the abundance of scales in anoxic sediments, they were able to define natural cycles of abundance of these species for 150 yr. Information is also stored in the otoliths of individual fish (Radtke 1984). The study of age in fishes and the use of otoliths for back calculation are simple examples of extraction of historical information, and others have used isotopic composition to define thermal habitats occupied by individual fish (Mulcahy et al. 1979).

The study of growth in fishes has typically been concerned with relatively short-term growth of cohorts or populations, most often with fished stocks. Differences in growth may exist between stocks (Templeman and Squires 1956; Borisov 1979), geographical regions (Boehlert and Kappenman 1980), and among years (Margetts and Holt 1948). Such growth differences may be genetically based (Borisov 1979), the result of density dependence (Margetts and Holt 1948), or caused by several environmental factors, most importantly temperature (Brett 1979). Unfortunately, comparisons of growth with time often come from different studies, frequently made difficult by changes in sampling, ageing methodology, or interpretation (Boehlert and Kappenman 1980).

Because estimates of fish growth are generally made at a single point in time, time series on the order of several decades do not exist for any species. Since otoliths act as recording chronometers, however (Radtke 1984; Campana and Neilson 1985), back calculation techniques allow one to establish growth patterns early in the life history of fishes, even in older fish. Extreme longevity has recently been confirmed in the scorpaenid genus *Sebastes* (Bennett et al. 1982), and ages in excess of 80 yr have been reported for several species (Archibald et al. 1981; Boehlert and Yoklavich 1984; Leaman and Beamish 1984). Thus otoliths of these species hold the potential to derive estimates of growth from several decades ago. In this paper we describe a modification of back calculation techniques, from which historical growth patterns can be obtained, and we apply this technique to two species, the splitnose rockfish, *Sebastes diploproa*, and the canary rockfish, *S. pinniger*.

Materials and Methods

Otolith samples were collected during rockfish surveys conducted by the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, during 1977 (Boehlert 1980), 1980 (Boehlert and

Yoklavich 1984), and 1983 (Wilson 1985). Collection techniques followed Gunderson and Sample (1980). Since one objective was to represent as many years of growth as possible, we based otolith selection upon age alone; old fish in this study thus greatly outweigh their relative abundance in a random sample. Otoliths were sectioned and age determined as outlined in Boehlert and Yoklavich (1984).

Back calculations and measurement of growth increments were limited to the first 6 yr of growth. This limit was imposed because otolith increments become smaller with increasing age; eventually, linear growth stops and the otolith begins to thicken (Bennett et al. 1982; Boehlert 1985). We used two different techniques for otolith measurement. For *S. diploproa*, whose otoliths are typically more opaque and increments smaller, we measured from dorsal to ventral distal edges of annuli 1-6. In the faster-growing *S. pinniger*, in which otoliths are clearer, we measured from the focus to the dorsal distal edge of each increment (Fig. 1).

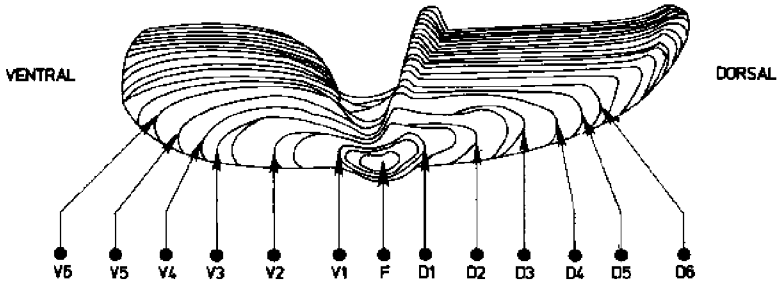

Figure 1. Schematic drawing of an otolith section from *Sebastes* showing the axes of measurement used in the current study. Measurements for *S. diploproa* were from dorsal to ventral distal margins (i.e., V2 to D2); measurements used for *S. pinniger* were from focus to dorsal distal margin) (i.e., F to D2).

Data analysis and interpretation

Available data included sex, length, date of collection, location information, total age, and widths of the measured annuli for ages 1-6. The growth increment (GI(I), where I = 1 to 6, determined by subtraction of measurements of adjacent annuli rather than the full measurement], was used so that growth in a given year was not cumulative and therefore did not reflect past growth. Age was subtracted from year of collection to determine the year of birth. For each fish, each growth increment (1-6) was associated with a specific "year of growth." Data on 6 yr of growth were therefore available for each fish with the exception of those younger than six at the time of sampling. As an example, a fish collected in 1980 and aged as 40 yr was born in 1940; growth measurements from this individual were therefore available for years 1940 through 1945. Table 1 demonstrates a subset of the data array available for this series.

Table 1. A subset of the data array for growth increments used in the present study. The numbers under growth increment represent the years of birth for these growth years. The first growth increment is defined to occur in the year of birth, the second growth increment in the following year, and so forth.

Growth year	Growth Increment, GI					
	1	2	3	4	5	6
1940	1940	1939	1938	1937	1936	1935
1941	1941	1940	1939	1938	1937	1936
1942	1942	1941	1940	1939	1938	1937
1943	1943	1942	1941	1940	1939	1938
1944	1944	1943	1942	1941	1940	1939
1945	1945	1944	1943	1942	1941	1940
1946	1946	1945	1944	1943	1942	1941

The majority of specimens used in the study were males. To increase the sample size, however, otoliths were collected from both males and females. Since growth, particularly after sexual maturity, differs between sexes for these two species (Boehlert and Kappenman 1980), it was necessary to test for differences in the growth measurements to allow a combination of growth data from males and females independent of the years tested. We separated the data by sex and then aggregated the data for each growth increment such that each year of birth had a single, mean value. Differences in growth between sexes were tested by comparing the respective growth increments with a paired t-test for all years where both male and female data were available. The results of this test showed that no differences were evident between sexes for either species.

Yearly means of GI(I)'s were calculated and these were the values upon which further calculations were made. A long-term average and standard deviation were calculated for each series of yearly mean growth increments and the standardized growth anomalies A(I) were calculated as follows:

$$A(I) = \frac{[GI(I) - (\text{mean } GI(I))]}{(SD\ GI(I))}$$

These anomalies have a mean of zero and a standard deviation of one, allowing comparison of the growth anomalies in different growth years without concern for the effects of growth increment magnitude. Comparisons between species would also be facilitated by this conversion.

Results and Discussion

A total of 802 *S. diploproa* (651 males and 151 females) and 942 *S. pinniger* (616 males and 326 females) were used in this study. The *S. diploproa* ranged in age from 1 to 86 yr and had a birth date distribution from 1896 to 1979 (Fig. 2A). Specimens of *S. pinniger* ranged in age from 2 to 60 yr and had a corresponding birth date

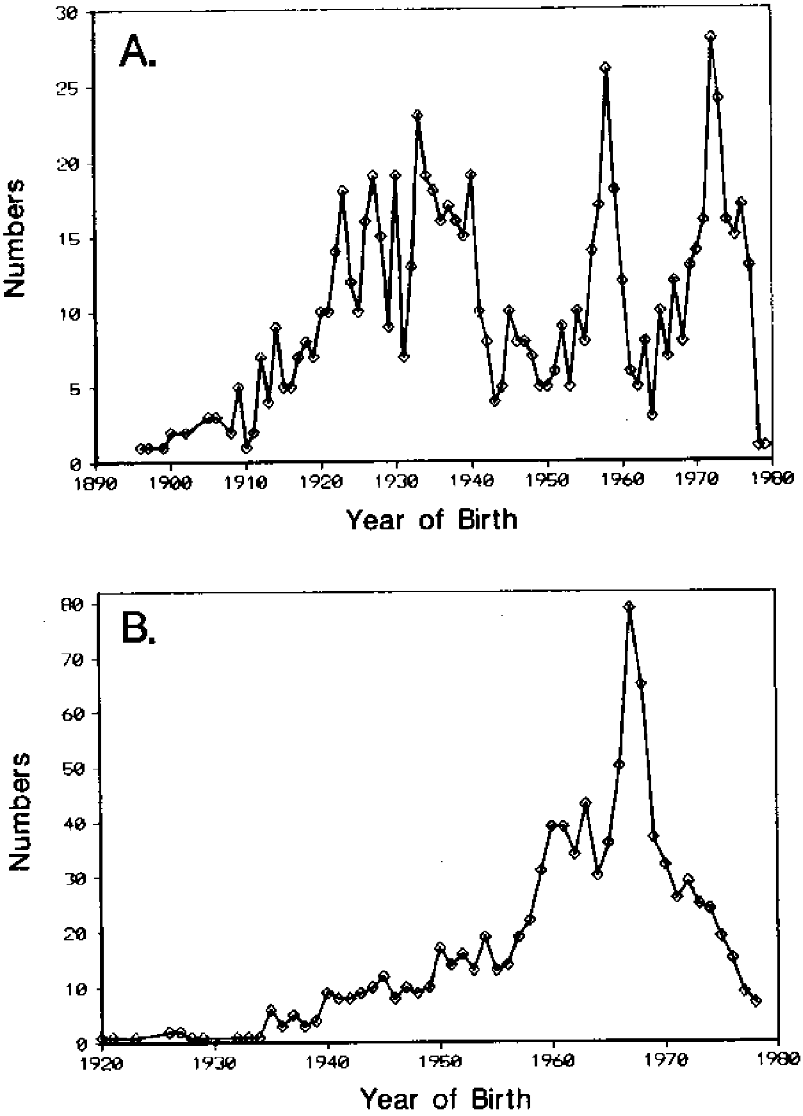

Figure 2. Distribution of the years of birth of specimens used in the present study. Males and females are combined. A. *Sebastes diploproa*. B. *S. pinniger*.

distribution from 1920 to 1978 (Fig. 2B). The total numbers of growth increments available were 4,714 for *S. diploproa* and 5,600 for *S. pinniger*. In the discussion of the results to follow, several sources of error contribute to the variability of these results. From a methodological standpoint, three errors are quickly apparent. First, minor changes in the location of the section of the otolith (Fig. 1) may result in slightly different increment measurements; we expect this to introduce relatively minor errors, however, since the sectioning technique (Boehlert and Yoklavich 1984) was consistent throughout the study. The second source of error occurs in the estimate of total age. Errors in this estimate will result in assignment of the incorrect year of birth and subsequent years of growth for each growth increment (Table 1). Finally, errors in annulus selection while making measurements on the section can occur. None of these errors are expected to be systematic, however, and their cumulative effects should not significantly mask trends in the data.

A concern from a biological standpoint is the implicit assumption that there is no linkage of longevity and growth. That is, if long-lived individuals are characterized by either faster or slower growth rates during the first 6 yr of life than individuals with shorter lifespans, we can encounter problems when comparing young with old fishes. A genetic basis for such a difference in growth and age at sexual maturity has been suggested for cod (Borisov 1979). An investigation into the biochemical genetics of *S. diploproa* using electrophoresis at 29 loci showed no variation associated with age (Wishard and Boehlert, unpubl. data). Although negative results cannot rule out a difference, our growth results do not show a consistent trend which would support a genetic basis for growth differences.

As one would expect from growth data, there is definite variability in the growth anomalies for both species (Figs. 3,4). No clear trends in either faster or slower growth over the full time series are apparent for either species. The 5-yr running averages, however, show an interesting pattern. In *S. diploproa* (Fig. 3), most of the age classes show a trend of positive anomalies before about 1925, and negative anomalies from about 1955 to 1970; positive anomalies after 1970 are also apparent in most of the records. The relationships among the age classes are also of interest. Generally, there is a relationship among anomalies 2-6 for this species, but the anomaly for year 1 is uncorrelated with growth in any other year. *Sebastes diploproa* is a deeper living member of this genus as adults, but the first year is spent in surface waters (Boehlert 1977); thus the factors which are important in growth in the first year may differ from those which determine growth in subsequent years. Temperature, which can have an important impact on juvenile rockfish growth (see summary in Boehlert and Yoklavich 1983), may differ between deep and shallow water (Kruse and Huyer 1983).

For *S. pinniger*, the record is somewhat shorter but shows interesting trends (Fig. 4). For age classes 1-4, there appears to be a positive anomaly through about 1952 followed by a period of negative growth until about 1970. Age classes 5 and 6, however, seem to show the opposite trend during these periods. All age classes show concordance, however, in the pattern of positive anomalies after about 1970. This same trend, although much weaker, was observed for *S. diploproa* (Fig. 3).

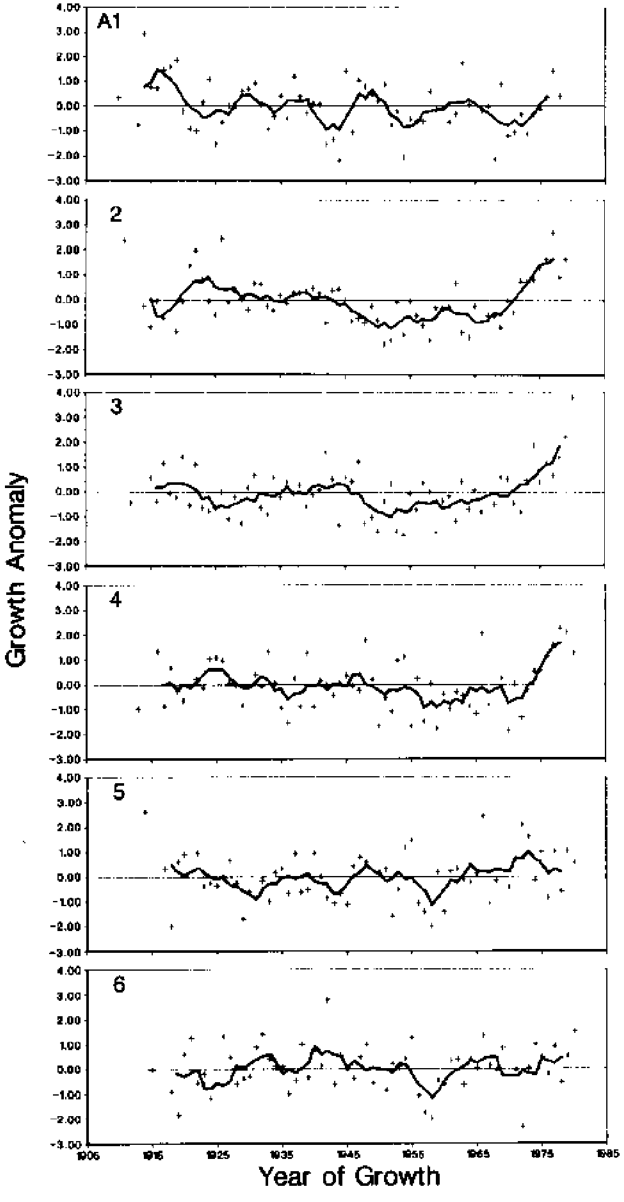

Figure 3. Plot of growth anomalies in years of growth 1-6 for *Sebastes diploproa*. The data points represent the yearly growth anomalies. The curve represents the 5-yr running average of these data. Only years where mean growth increment was based upon four or more observations were used in these figures.

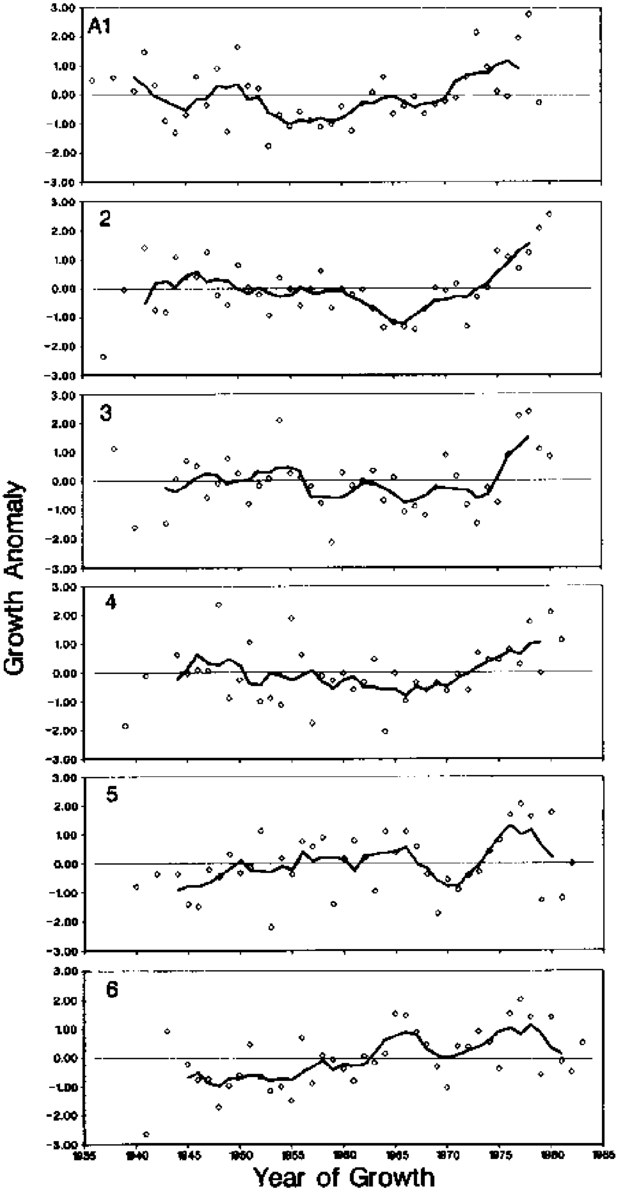

Figure 4. Plot of growth anomalies in years of growth 1-6 for *Sebastes pinniger*. The data points represent the yearly growth anomalies. The curve represents the 5-yr running average of these data. Only years where mean growth increment was based upon four or more observations were used in these figures.

The technique which we describe in this paper allows development of time series of growth for long-lived species of fishes. The results we have presented for these two species will need further statistical analysis to discern trends in the data and to investigate the possible sources of variation in growth patterns. For example, time series analysis may show relationships with physical factors, as described by Chelton et al. (1982) and Mysak (1986). Biological causes for growth variation may also be implicated. In this regard, it is significant that the apparent increase in growth after 1970 (Figs. 3,4) is temporally related to the depletion of coastal stocks of *Sebastes* as described by several papers in this volume. Does this hint at density dependent growth patterns? Future research on this data base will address these questions.

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Population parameters for rougheye rockfish (*Sebastes aleutianus*)

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Introduction

Rockfish (genus Sebastes) are an important component of the marine community in the northeastern Pacific Ocean (Love and Westphal 1981). Major catches have occurred in the foreign high seas fisheries in the Gulf of Alaska and Bering Sea (Bakkala et al. 1979). Thirty-two species of rockfish have been identified from groundfish catches from the Eastern Bering Sea and Aleutian Islands regions (Ito 1986a). The demersal fish catches of California, Washington and Oregon are dominated by rockfish (Gunderson and Lenarz 1980). Canadian rockfish catches have been important (Carter and Leaman 1981). Finally, a steadily growing fishery has been established in southeastern Alaska for several species of nearshore rockfish (L. Haldorson, pers. comm.).

Historically, fishing patterns for demersal fishes have severely depleted stocks and altered the structure of their populations (Love 1980). The demersal fisheries in the Gulf of Alaska and Bering Sea have changed significantly and are now managed under the implementation of the Magnuson Fishery Management and Conservation Act (Major 1986, Preface). Although overall production has increased, the catch of only pollock has increased steadily. Catches from most other species groups, notably the rockfish, have declined sharply. Annual landings of rockfish taken from the Gulf of Alaska have declined from 385,481 to 3,221 mt from 1965 to 1985. U.S. and Canadian rockfish stock levels are very low (J. Fujioka, pers. comm.). This is attributed to the over-exploitation of stocks during the 1960-1970's. The current status of the Gulf of Alaska Pacific ocean perch (POP) complex and "other rockfish" stocks is depressed. Pacific ocean perch stocks in the Eastern Bering Sea and Aleutian region have remained stable but low for many years (J. Fujioka, pers. comm.).

Rockfish research has traditionally been underfunded; consequently the majority of the research attention given to Sebastes focuses on the species of greatest commercial importance such as the Pacific ocean perch (Westrheim 1973). Basic biological information including age structure and reproductive biology is not available for many of the fifty species of rockfish which inhabit the western coastal water of North America (Love and Westphal 1981). Acquiring this information is important because new interest in demersal fish stocks has been generated by the decline of the POP stocks and increasing management controls on traditional fisheries such as salmon and halibut (Archibald et al. 1981). Rockfish populations are managed as an aggregate. For example, POP (Sebastes alutus) is managed with 4 other species of Sebastes (aleutianus, borealis, polyspinis, and zacentrus). as the "pop complex", or red rockfish, that inhabit the slope and shelf depths. Also, other rockfish caught in the high seas fishery are lumped together for management purposes in a category called "other rockfish" (Carlson et al. 1986). While new demersal fisheries may not key in on many of the rockfish species, they will be caught incidentally.

The purpose of this study is to perform a comprehensive analysis of the basic age, growth, and mortality parameters of the rougheye rockfish (Sebastes aleutianus) in southeastern Alaska. This study examines one adult and two juvenile populations in southeastern Alaska. Otolith meristic measurements are investigated for age prediction as an alternative to direct ageing.

A description of age structure of rockfish stocks would provide information about stock dynamics, growth, mortality and sustainable yield (Leaman and Beamish 1984). Intensification of Gulf and Bering Sea fisheries makes management and conservation of the demersal stocks a complicated task (Carlson et al. 1986). Often, rockfish stock information is limited and of poor quality making it difficult to formulate yield options (Leaman and Stanley 1985). Limited funding to the management agencies inhibits their ability to monitor age structure because ageing rockfish is extremely labor intensive. Therefore an ageing method which is precise and not time consuming is needed to construct the correct models for understanding these long-lived stocks and insuring adequate management and yields to prevent overharvesting.

Very little information on adult rougheyes and virtually none on juveniles exists in the literature. This species is of interest for two reasons. First, it is managed as part of the POP complex (Carlson et. al. 1986) in the Gulf of Alaska and Bering Sea and has even been misidentified as POP in commercial catches (Ito 1986b). Second, it is thought to be the the oldest living rockfish (Chilton and Beamish 1982), being aged to 140 years. This species is caught incidentally in the Bering Sea trawl fishery (Bakkala et al. 1979) and is of minor commercial importance in the Gulf of Alaska (Alton 1981). It is also landed by the Canadian trawl fishery in significant numbers (Carter and Leaman 1981) and is incidentally caught by the sablefish and halibut longline fisheries in the waters of southeastern Alaska (Haldorson, pers. comm.). The estimated catches of rougheye from the eastern Bering Sea as reported from U.S. observer data has declined from 1,044 to 99 t from 1977 to 1984 (Ito 1986b), following the overall decline of all rockfish catches during the same period. A similar pattern of decline exists for the Aleutian Islands region, from 1,128 to 24 t from 1977 to

1984.

In order to assess the usefulness of otolith meristic measurements for ageing fish, estimates of otolith growth in thickness, length, width and weight are considered. Currently the preferred ageing structure for Sebastes is the sagittal otolith (Patten 1973). The age is determined by visually counting the alternating hyaline/opaque rings called annuli. These rings are observed from the surface, from a sectioned piece or by breaking and burning the otolith. A controversy currently exists as to which reading method gives the most accurate and consistent age estimate (Leaman and Beamish 1984). Surface counts have been found to underestimate ages of many long-lived species (older than 15 years). The break and burn or section methods may reflect the true age of the fish more accurately than the surface method, but both are time-consuming and require a highly skilled technician. For some species of Sebastes, an experienced otolith ager can only age 6-8 fish/hr using the sectioning method, and 10-15/ hr using the break and burn method (Boehlert 1985). In addition, it is difficult to acquire inter- and even intra- agency agreement as to how to interpret the annuli on the otolith of older (>15 yr.) specimens.

Otolith length and width are positively correlated to fish length (Boehlert 1985). For Pacific halibut, otolith weight is the best predictor of fish length and fish weight (Quinn et al. 1983). Often when a fish approaches an asymptotic length, the otolith ceases to grow longer and wider, but does continue to grow thicker and therefore increase in weight (Boehlert 1985). This increase in thickness accounts for more accurate ageing of otoliths that are sectioned or broken and burnt. Additional rings are added to the middle surface after the otolith stops growing in length and width. Boehlert (1985) developed predictive relationships of age for two species of rockfish using multiple regression techniques, being one of the first to suggest this approach.

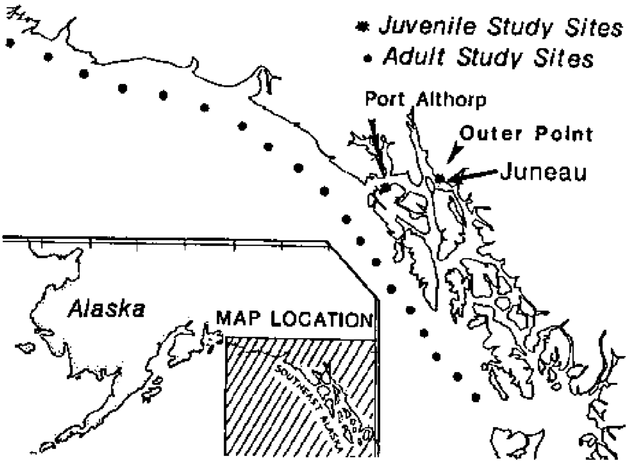
Methods and Materials

Field data collection

The primary juvenile site was Outer Point on Douglas Island (Figure 1). This population was sampled three times during 1982 and 1983. The sampling dates were: Sept. 21, 1982; Mar. 23 and April 7, 1983. The samples were collected by the NOAA research vessel, John N. Cobb. Fish were caught with a 400 mesh Eastern otter trawl equipped with weighted wooden doors. One or two tows were made per day dragging between 50 to 75 fathoms for approximately 30 minutes. A total of 200 fish were collected from the hauls at the Outer Point location. Specimens were brought back to the laboratory and frozen before processing.

The second juvenile population was sampled from Port Althorpe located on the outer coast of Chichagof Island (Figure 1). The sampling date was July 15, 1983. The NOAA research vessel MURRE II, a 25.9 m. power barge collected the samples. The equipment used was a standard 12.2-m nylon flat shrimp side trawl with 2.54-cm 2- mesh and weighted wooden doors. The net was towed once for approximately 30 minutes at 50 fathoms. 70 specimens were collected. Fish were frozen on board before being brought back to the laboratory by other scientific personnel.

Figure 1. Study sites for rougheye rockfish.



The adult population was sampled from the outside waters of Southeast AK from the areas between Yakutat and Sitka (Figure 1). Samples were collected by the Japanese longline vessel, RYUSHO MARU NO. 15. The survey period was between August 22 and September 10, 1982. Longline gear was used for sampling and consisted of 45 hooks per hachi tied to a 100 meter groundline with a 1.2 meter gangion spaced 2 meters apart . 160 hachi were set per sampling site. The gear was fished for 5 to 6 hours and set in direct angles to the contour line to cover a depth range from 100 to 1000 meters. Hooks were baited with squid.

The samples were processed fresh on board by the crew of the vessel. Fish were measured for fork length to the nearest cm and sexed, and both sagittal otoliths were taken. The otoliths were cleaned and stored in 50% ethanol in small vials. 300 specimens were processed and an additional 75 fish were frozen whole and returned to the laboratory.

Processing of samples consisted of determining sex if possible, measuring fork length to the nearest cm, and collecting both sagittal otoliths. The otoliths were cleaned and stored in small vials containing 50% ethanol or glycerin.

Laboratory processing of otoliths

Ageing. The juvenile populations were aged by both the surface method described by Westrheim (1973) and a modified break and burn method described by Chilton and Beamish (1982). The adult population was aged with the modified break and burn method only.

The surface method of ageing otoliths involves placing the otolith in a small black-bottomed dish and counting the rings under a dissecting microscope. For this study the lid of a 100 ml. sampling jar was used as a sampling dish. A small amount of water, enough to submerge the otolith, was placed in the dish so that reflected light adequately illuminated the otolith. A 100 powered Leitz dissecting microscope was used to count the otolith rings. All surfaced aged otoliths were aged two separate times before a final age was assigned as suggested by Chilton and Beamish (1982).

The break and burn procedure (Chilton and Beamish 1982; Boehlert and Yokalovich 1982) was modified by breaking the otolith in half by hand because sectioning equipment was not available. Each half of the otolith was slightly burnt with an alcohol burner and placed in modeling clay so the burnt section faced up. A small amount of glycerin was applied to the burnt surface with a small paint brush. The rings were counted by using a Wild dissecting microscope at 30 - 100 power with fiber optics. Each otolith was aged twice at separate intervals before a final age was assigned. The sex and fork length of each specimen was not known while it was being aged. When one otolith would not yield a consistent age, the other one was broken and burnt and aged. The same age had to be determined two separate times before a final age was assigned to the specimen.

Validation of rockfish ages and ageing techniques is very difficult (Chilton and Beamish 1982). The ageing technique used in this study was validated by taking a subsample of otoliths previously aged to the Pacific Biological Station in Nanaimo, B. C. and to the NMFS Montlake Laboratory in Seattle, Washington for comparison of ages. The two agencies interpret annuli differently, especially when using the break and burn method. Our technique agreed with the method of interpretation of annuli as was done at the Nanaimo laboratory.

Meristic measurements of otoliths. Meristic measurements were made on all groups of otoliths. A handheld micrometer was used to measure one otolith from each pair. Each otolith was measured for length, width and thickness to the nearest .01 mm. When part of the otolith was broken or chipped, it was not used for a measurement. Each otolith was measured once. All otoliths were placed in an oven for 5 hours at 120 degrees C before they were weighed to the nearest .01 g with an Sartorius electronic balance.

Analytical methods

Data was entered and managed on a Compaq microcomputer. Data summaries and statistical analyses were performed using SYSTAT software. Standard regression techniques (Sokal and Rohlf 1969) and exploratory data analysis (Tukey 1977) were used to investigate the data . Models were derived to estimate age from various otolith morphometrics using stepwise multiple regression techniques. Models were derived for both sexes combined and for each sex separately for the adult population. Models were derived for only both sexes combined for each of the two juvenile populations.

Distribution and regression analysis. First, the shape of each variable's distribution was examined to see if the data needed to be transformed. The data were examined with exploratory data techniques (Tukey 1977) and analyzed graphically. Each variable was plotted in a stem and leaf diagram to look for symmetry and to get the letter values (lvals) of the distribution. The lvals (median, hinge, eights, sixteenths, and extremes) were summarized and the midpoints were calculated. If the stem and leaf diagram showed skewness and if the midpoints (mids) fluctuated or showed an upward or downward trend, then the data were transformed. Transformations were made until the distributions appeared symmetrical and the mids were stable.

The second step of regression analysis consisted of looking for multicollinearity problems. First, the independent variables were plotted against each other and the resulting scatterplots were examined. Next, a Pearson correlation matrix of the variables was calculated.

The data was then entered into a series of stepwise multiple regression models. The best model was chosen by comparing each test statistics and by residual analysis. Residual analysis helped to assess if problems had occurred with model or error specification, and if heteroscedasticity had occurred. A scatterplot of the residuals versus the dependent variable was analyzed for such patterns. Also, outliers or hi leverage points were identified. Residuals were plotted in a stem and leaf diagram to further investigate departures from underlying assumptions.

The regression models derived for each population were compared using analysis of covariance (Kleinbaum and Kupper 1978). First, the two juvenile population were compared using a dummy variable regression model that indexed location. Next, the data from the two juveniles was pooled and was compared to the data from the adult population.

Growth analysis: Growth of individual fish was modeled with a von Bertalanffy growth curve, using non-linear least squares to obtain parameter estimates, as described by Gallucci and Quinn (1979). The data from the adult population was analyzed for both sexes combined and for each sex separately. Pooled data consisting of all three populations with both sexes combined and with both sexes separately was also analyzed. The analysis of covariance procedure was used to see if any difference was apparent in the generated growth equations. The pooled juvenile data set was not used alone because no asymptotic length was found in the data set.

Mortality estimation. Catch curve regression analysis (Ricker 1975) was used to estimate survival and total mortality rates. Estimates were made for each sex separately and for both combined. Jensen (1985) showed that catch curve regression analysis was preferable to other methods, when variation was small to moderate. The major assumptions are that the overall mortality rate does not change over time, that recruitment is the same for each year class, and that past some critical age the survival rate is uniform (Ricker 1975).

Logarithms of the percentage representations of each age class were plotted against age. Next, linear regression analysis was used to calculate the slope of the descending right arm of the catch curve, which is the estimate of the instantaneous mortality rate (Z). For the adult population, this curve started at age 40 for both sexes alone and combined. For the juveniles, the curve started at approximately age 5.

Survival (S) was estimated by the equation: S = exp(- Z). Its standard error was estimated by S s.e.(Z) from the delta method (Seber 1982, p. 7-9).

Results - Prediction of Age

Adult population

Summary Statistics. A total of 378 specimens, 178 female and 200 male, were collected for this population. Ages ranged from 10 to 95 years, with the mean at 33.8. The majority of the fish aged for each sex were between 20 and 40 years. The mean age for females was 32.7 years and for males was 34.8 years. 14.8 percent of the total population was at least 50 years or older. The age frequency distributions for both sexes were similar. Fork length distribution for the sample ranged from 28 to 74 cm with a mean at approximately 44 cm for both the entire sample and for each sex. Most fish sampled were between 40 - 50 cm.

Descriptive and Predictive Relationships. The stem-and-leaf and the letter value ("lval") diagrams indicated the following transformations should be made on the data. The distributions of age, otolith width and otolith thickness were made more symmetrical by converting them to natural logarithms. Since transformations only slightly improved the distribution of length, both the raw and transformed data were used separately in regression analysis. Transformations did not improve the distribution of otolith length.

As an example of this approach, "lval" diagrams for the age distribution in the raw and natural logarithm form are shown in Table 1. The mids are rising for the raw data, indicating need for a transformation. For the log-transformed data, the mids are very stable, indicating that the transformation improved the symmetry of the distribution.

Table 1. "lval" diagrams for distributions of age and ln(age), adult population, sexes combined.

Age:	N = 377				MIDS	SPREAD
	188		33		33	19
	94h	23		42	32.5	
	48	20		52	36	
	24	15		62	38h	
	12	14		67	40h	
	1	10		95	52h	

The mids are rising indicating the need for transformation.

ln(age):					
		3.49		3.49	.09
	3.14		3.73	3.43	
	2.90		3.95	3.42	
	2.71		4.12	3.41	
	2.60		4.20	3.40	
	2.30		4.55	3.43	

The mids are stable and the spread is much smaller than for age.

To assess multi-collinearity problems, bivariate plots of the independent variables revealed that strong positive linear relations exist. All independent variables had correlation coefficients above 0.783. Of the independent variables, the most highly correlated were otolith thickness and otolith weight. This result indicates that care must be taken in selection of the independent variables in multiple regression. Too many variables may result in bias of the regression coefficients (Sokal and Rohlf 1969).

The data were fitted to several multiple regression models to explore the relationship between age and the independent variables. The independent variables were entered into the stepwise model in the following order: length, ln(o.weight), ln(o.thickness), ln(o.width) and o.length where ln denotes natural logarithm and o. denotes otolith. The dependent variable was ln(age). A separate model was also calculated using ln(length) and the above mentioned variables in the same order.

Multiple regression models for the adult population were calculated for both sexes combined and for each sex separately. The main emphasis and most effort was applied to the models of both sexes combined, because management strategies often involve port sampling where the fish have been eviscerated. Therefore, lengths are taken and otoliths are collected without knowing the sex.

For sexes combined, all of the independent variables were entered into a multiple regression model (Table 2). The ln(o.width) and o.length variables were not found to be significant in the overall multiple regression model. This all-variable model explained 74.1 percent of the variation in age as measured by the coefficient of multiple determination, R^2. The midpoints of the residuals were all near 0 (0,.01,0,.06,.01) and the plot of the residuals versus ln(age) showed no distinct pattern.

All variables but otolith width were then entered into a stepwise model (Table 2). All variables except otolith length were found to be significant. This model described 74.3% of the variation in age. The mids of the residuals were steady near 0 (0,0,.01,.03,.03) and no obvious pattern was seen in the residual scatterplot.

In a effort to minimize the effects of multi-collinearity, the data were also fitted to several other multiple regression models. This was done in an attempt to find a model which adequately describes age from the fewest number of independent variables. A total of 20 different models using various combinations of raw and transformed variables were calculated in this analysis.

The R^2 value was very consistent (between .680 - .741) for all models and the F statistic was always highly significant (P=.000). Therefore, the deciding factors which distinguished the best models were the models that had the fewest number of independent significant variable coefficients, and residual analysis. The final model chosen to describe and predict age from length and otolith meristic data for the data set that includes both sexes combined, had only two variables: length and ln(o.weight). This model predicts 71.6% of the variation in age. The "lval" diagrams of the residuals showed no trends (Table 2). A plot of predicted and observed age showed that the model was realistic in spite of the variability in the data (Figure 2).

Table 2. Regression coefficents and associated test statistics, adult population, sexes combined.

A. All variables: N = 297

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	3.016	0.783	.000	.741	.000
length	0.012	0.004	.001		
ln(o.weight)	0.484	0.130	.000		
ln(o.thick)	0.570	0.210	.007		
ln(o.width)	-0.220	0.270	.416		
o.length	0.021	0.012	.000		

B. Stepwise procedure: N = 298

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	2.456	0.400	.000	.743	.000
ln(o.weight)	0.418	0.101	.000		
length	0.011	0.004	.001		
ln(o.thick)	0.595	0.204	.004		
o.length	0.023	0.012	.050		

C. Final model: N = 333

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	3.567	0.220	.000	.716	.000
ln(o.weight)	0.691	0.063	.000		
length	0.013	0.004	.000		

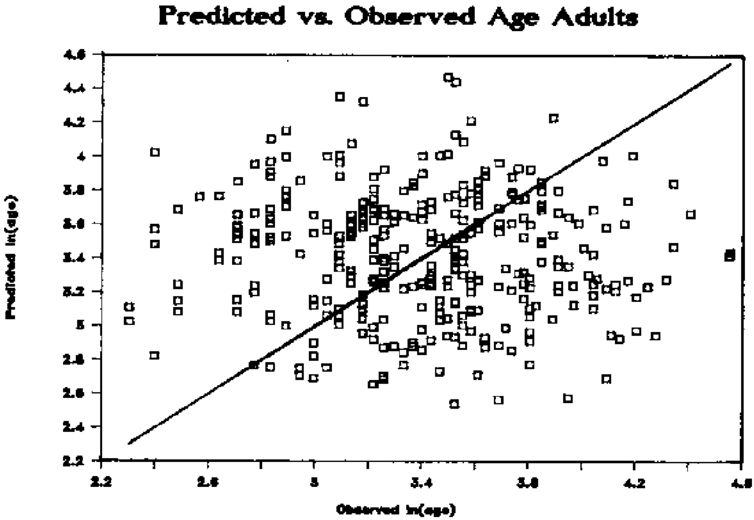
D. Summary of midpoint values of residuals for final model

			Mids
167	0.00		0.00
84	-0.15	0.19	0.02
42	-0.27	0.26	0.005
22	-0.33	0.34	0.005
11	-0.39	0.44	0.03
1	-0.81	0.63	0.09

For adult females, an analogous pattern of analysis ensued. The best model had significant values for length and ln(o.weight) and described 73.6% of the variation in age (Table 3). The scatterplot of the residuals versus ln(age) showed no obvious patterns. The midpoints of the residuals were steady at 0 (.05,.00,.01,.01,.05).

For adult males, the best model used only length and o.weight (Table 3). This model predicted 69.4% of the variation in age and had a significant F statistic. The residual analysis revealed two possible outliers, but the scatter was random. The the midpoints were steady at 0.

Figure 2. Predicted versus observed age for the adult population, combined sexes.



Juvenile population - Outer Point

Data analyses for juvenile populations were similar to the procedures for the adults, except that data were only analyzed for both sexes combined, because sex could not be determined on many of the specimens collected at both sites.

Summary statistics. A total of 174 fish (of which 71 were females, 76 were males and 29 were of unidentified sex) were sampled from the Outer Point population. Ages ranged from 2 to 18 years, with the mean at 7 years. Most of the fish sampled were 5 and 6 years old. The fork length distribution ranged from 6 to 37 cm, with a mean length at 23.6 cm. The majority of fish sampled were 20 cm or greater.

Descriptive and predictive relationships. The analysis of the distributions of the variables indicated that all of the variables except otolith thickness needed a natural logarithm transformation.

The variables were analyzed for possible multi-collinearity problems. Bivariate plots of the independent variables and examination of the correlation coefficients revealed that some of the variables were very highly correlated, and some were not. The least correlated were otolith thickness and length (.648) and the most correlated were otolith width and otolith weight (.926).

For this population, ln(age) was the dependent variable. The best model included only ln(length) and ln(o.weight), (Table 3). It predicted 77.6%

Table 3. Best multiple regression models

A. Adult population, females: N = 156

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	2.858	0.339	.000	.734	.000
length	0.024	0.005	.000		
ln(o.weight)	0.498	0.099	.000		

B. Adult population, males: N = 177

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	2.110	0.142	.000	.694	.000
length	0.015	0.004	.000		
o.weight	1.735	0.199	.000		

C. Outer Point juvenile population, sexes combined: N = 127

Variable	Coefficient	S.E.	P	Multiple R^2	F
constant	0.936	0.653	.154	.776	.000
ln(o.weight)	0.600	0.099	.000		
ln(length)	0.705	0.149	.000		

D. Althorpe Bay juvenile population, sexes combined: N = 29

Variable	Coefficient	S.E.	P	F
$length^{1/2}$	0.609	0.189	.002	.000
ln(o.weight)	30.705	7.490	.001	

E. Combined juvenile populations: N = 127

Variable	Coefficient	S.E.	P	F
ln(length)	0.915	0.024	.000	.000
ln(o.weight)	0.468	0.036	.000	

of the variation in age and the F statistic was significant. The residual scatterplot revealed no patterns and the mids were centered around 0 (.01,.005,.010,.005,.04).

Juvenile population - Althorpe Bay

Summary Statistics. A total of 29 fish were sampled from Althorpe Bay. The sex of the majority of these fish could not be determined. The ages ranged from 2 to 12 years with a mean at 6 years. The fork lengths ranged from 7 to 32 cm. The mean length was 22.6 cm.

Descriptive and predictive relationships. Analysis of the distributions of the variables revealed that the following transformations were needed. Length was transformed by square roots. Otolith width, thickness and otolith length were transformed by natural logs. Age and otolith weight were left in the raw data form.

The variables were analyzed for multi-collinearity problems. All independent variables were very highly correlated. The highest correlation were between otolith weight and length (.985) and otolith length and otolith weight (.985). The lowest correlation was for otolith weight and otolith thickness (.913). These independent variables had higher correlation coefficients overall than the other two populations.

The best multiple regression model included the transformed length and otolith weight variables, but did not include a constant (Table 3). This model described 97.7% of the variation in age. This high value stems from using few data points that did not contain many missing values. The F statistic was significant. The residual scatterplot indicates that the variance does increase with increasing age. The midpoint values fluctuated around 0.

Comparison of populations

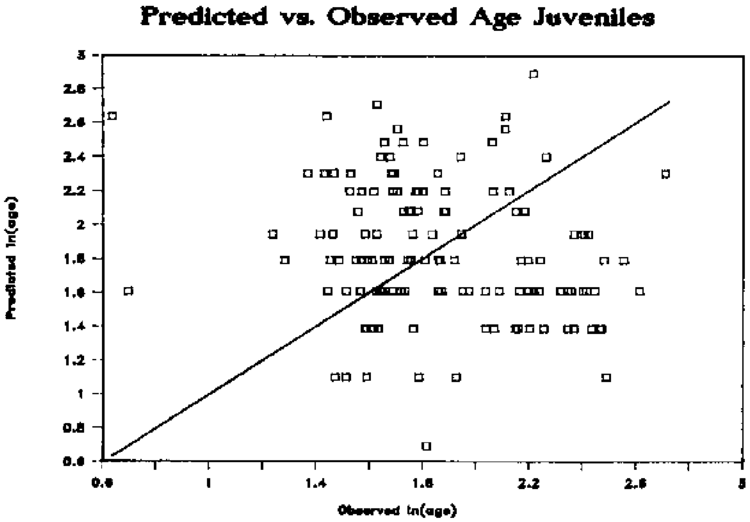
The final regression coefficients from each of the models from all three populations studied were compared using analysis of covariance (Kleinbaum and Kupper, 1978). The juvenile data were compared first. The data from both locations were pooled and a dummy variable regression technique was used to compare data sets by looking for significance of the resulting regression coefficients.

The results are shown in Table 4 and show that the overall regression coefficients of ln(length) and ln(o.weight) were significant (P =.000 for both). The location term was not significant (P =.275) indicating that both data sets had the same intercept. The test for equal slopes and then therefore for coincident lines indicated that the length component of the data was not different between the two populations (P =.374). The otolith weight component had a significance level of (P =.077) which was judged to be insignificant. Thus, the data could be pooled and then compared to the adult data set.

A stepwise multiple regression analysis was then performed on the pooled juvenile data set. The only regression coefficients that were significant when all variables were entered into the model were the ln(length) and ln(o.weight) (Table 3). The scatter of residuals was random; however two outliers were observed. These data points were rechecked and were found to be valid data points. A plot of predicted and observed age shows that the model is realistic (Figure 3).

The next step was to compare the pooled juvenile data set to the adult data set using analysis of covariance (Table 4). The regression coefficients for ln(length) (P=.000) and ln(o.weight) (P=.026) were significant. The location variable was also significant (P=.043) indicating that the intercepts of these two data sets were not the same. The interaction term of location with ln(length) was not significant (P=.329) while the interaction with ln(o.weight) was (P=.001). Therefore, since the intercepts were not the same and one of the slope components are also different, we concluded that these two data sets should not be pooled.

Figure 3. Predicted versus observed age for the pooled juvenile population, combined sexes.



In summary, the best overall model for the populations studied consists of an adult and a juvenile curve. The best equation for the adult population is :

ln(age) = 3.567 +.013 length +.691 ln(o.weight)
s.e. .220 .004 .063

The range of length values is 28 to 74 cm, and for otolith weight is 0.128 g to 0.980 g.

The best equation for the combined juvenile populations is :

ln(age) = .915 ln(length) + .468 ln(o.weight)
s.e. .024 .036

The range of length values for the juvenile population is 6.0 to 37.0 cm and for otolith weight is 0.033 g to 0.270 g.

Results - Growth Analysis

Analyses were performed on the adult and the pooled juvenile and adult data set. Only results from the pooled data set are presented, because the goal was to obtain a growth curve for all ages. Analyses were performed for females, males, and sexes combined (Table 5). The L-infinity estimate was the greatest for the females (58.0 cm), and similar for the males (53.4 cm) and for both sexes combined (54.7 cm). These values were less than the maximum value recorded in the data set, indicating that length is highly variable at older ages. The estimate of the growth parameter K was 0.04 for females, and was the about the same for the males and combined data (0.05). The t_0 estimate for sexes combined (-4.21 yr) is similar to the estimate for males (-4.09 yr) and is higher

Table 4. Analysis of covariance results for comparing populations.

A. Comparison of juvenile populations: N = 126

ANALYSIS OF COVARIANCE

Source	SS	DF	MS	F-ratio	P
ln(length)	0.688	1	0.688	17.757	.000
ln(o.weight)	1.470	1	1.470	37.961	.000
location	0.047	1	0.047	1.204	.275
location* ln(length)	0.124	1	0.124	0.795	.374
location* ln(o.weight)	0.031	1	0.031	3.191	.077
Error	4.684	120	0.039		

B. Comparison of combined juvenile with adult population: N = 420

ANALYSIS OF COVARIANCE

Source	SS	DF	MS	F-Ratio	P
ln(length)	1.221	1	1.221	21.181	.000
ln(o.weight)	0.286	1	0.286	4.970	.026
location	0.237	1	0.237	4.111	.043
location* ln(length)	0.055	1	0.055	0.954	.329
location* ln(o.weight)	0.708	1	0.708	12.292	.001
Error	23.861	414	0.058		

than the one for females (-5.56 yr). Standard errors were similar for the three groups and were small in comparison to the estimates.

Analysis of covariance was used to compare the curves generated for each sex of this pooled data set. The F statistic ($F(59,575)=0.625$) was not significant ($P>0.5$) and therefore no difference was found between the curves generated for each sex.

Thus,the best model which describes describes growth is from the pooled juvenile and adult data:

$L_t = 54.74 [1 - \exp(-0.0503 (t- (-4.21)))]$ with $R^2 = .886$.

s.e. 0.72 0.0025 0.46

A plot of the data and this von Bertalanffy equation is shown in Figure 4.

Table 5. Estimates of von Bertalanffy growth parameters, combined adult and juvenile data.

A. Sexes Combined: N = 578 R^2 = .886

Parameter	Estimate	S.E.	T-value	95% C-I
L-infinity	54.74	0.72	75.9	53.33 - 56.15
K	0.0503	0.0025	19.7	.0464 - .0553
t_0	-4.21	0.46	-9.1	-5.12 - -3.30

Resid DF : 575 Resid SS : 9630.90 Resid MS : 16.74

B. Females: N = 246 R^2 = .887

Parameter	Estimate	S.E.	T-value	95% C-I
L-infinity	58.03	1.42	40.9	55.25 - 60.81
K	0.0425	0.0035	12.0	.0356 - .0494
t_0	-5.56	0.82	-6.7	-7.18 - -3.93

Resid DF : 243 Resid SS : 3769.54 Resid MS : 15.51

C. Males N = 276 R^2 = .854

Parameter	Estimate	S.E.	T-value	95% C-I
L-infinity	53.44	0.95	56.0	51.58 - 55.30
K	0.0525	0.0039	13.4	.0449 - .0578
t_0	-4.09	0.75	-5.5	-5.56 - -2.63

Resid DF : 273 Resid SS : 5244.02 Resid MS : 19.20

Results - Mortality

Estimates of instantaneous mortality Z and survival S for adults are:

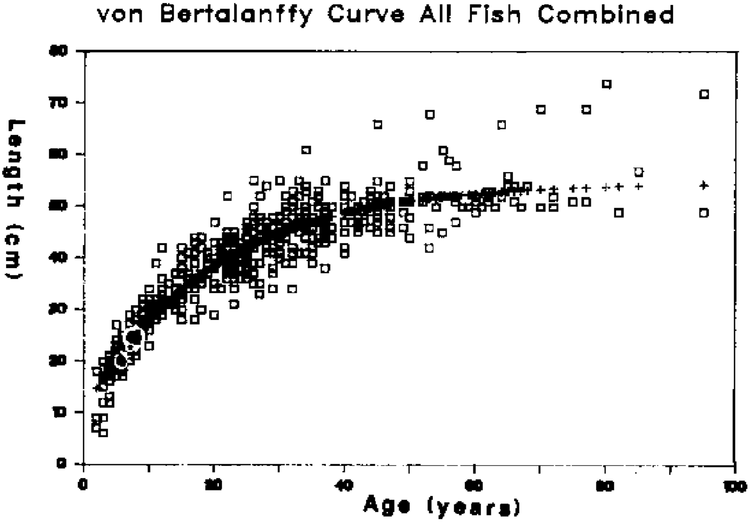
	Z	s.e.(Z)	S	s.e.(S)
sexes combined:	0.037	0.007	0.966	0.007
female:	0.028	0.010	0.973	0.010
male:	0.030	0.005	0.971	0.005

Estimates of instantaneous mortality Z and survival S for the pooled juvenile data are:

	Z	s.e.(Z)	S	s.e.(S)
sexes combined:	0.261	0.028	0.771	0.022
female:	0.208	0.037	0.813	0.030
male:	0.219	0.053	0.803	0.043

The catch curve for the adult population is shown in Figure 5, having been smoothed by a nonlinear data smoother from SYSTAT. The variability in logarithmic frequency at older ages is apparent and is due to small sample sizes at these ages. The irregularity in the curve is probably due to recruitment trends over time.

Figure 4. Growth data and the von Bertalanffy fit for all rougheye rockfish data.



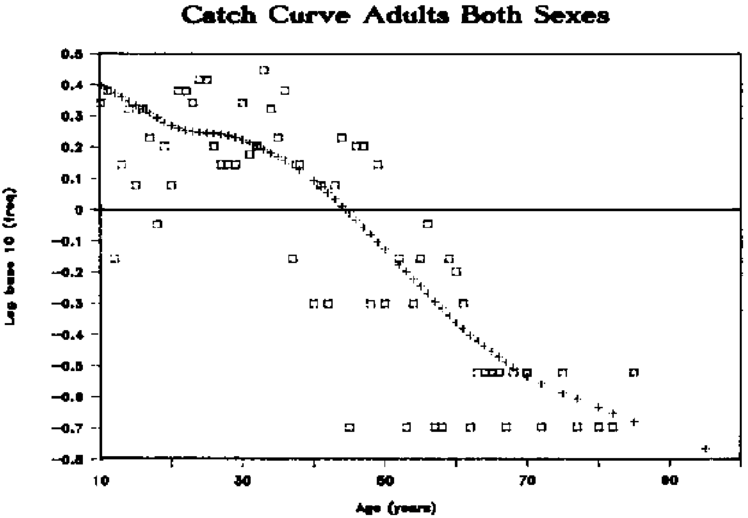
These values of survival represent all forces of mortality, which we presume includes natural mortality, incidental mortality from longlines, and probably minor directed mortality at the time of study. The method assumes that recruitment has been constant over the age span considered, but we have no information about recruitment.

Discussion

Ageing of long-lived species such as Sebastes is a difficult but necessary task to insure proper management of these populations, usually accomplished by reading the rings on otoliths. Although this methodology does give the necessary information, several problems with it still remain to be solved. Primarily, these problems involve lack of agreement and objectivity in interpretation of annuli among agers (both within and between agencies) (Boehlert, 1985) and that it is time-consuming and expensive. Therefore, other means of extrapolating this information accurately in addition to otolith reading are desirable, such as using otolith meristics in addition to fish length. Otolith meristics measurements have been correlated with fish length and age for many species of fish including rockfish (Boehlert 1985).

In this study, we found that otolith meristics and fish length were useful predictors of age for rougheye rockfish, after traditional ageing techniques established a baseline relationship of length, age, and otolith measurements. Multiple regression models for the three populations used otolith weight and fish length as the best predictor variables for fish age.

Figure 5. Catch curve for adult rougheye rockfish, sexes combined.



The advantages of using such a predictor model are many for long-lived species such as the rougheye rockfish. After initial ageing has been done by traditional methodology, a less-skilled technician could accurately make reproducible otolith meristic measurements that could be used to predict age. If agencies could agree on baseline age-length keys for specific stocks, then a higher agreement of the age structure could be reached because these meristic models require no subjectivity. Finally, since these models rely on measured variables instead of "interpretation" of rings, they lend themselves to automation .

The major disadvantage of using predictor variables is that such relationships are subject to error and may change over time and area. This technique may be more suited to older adult populations than to juvenile populations, because ageing juveniles is much easier and quicker than ageing adults. Consequently, readers tend to agree on these ages and can reproduce their results more often.

The rockfish literature does not contain much information on growth and mortality for the rougheye rockfish, perhaps the longest living member of the family Scorpaenidae. The oldest specimens aged in this study were 95 years old. The maximum length recorded was 74 cm. The von Bertalanffy growth parameters estimated in this study are in agreement with other species of rockfish. For example, estimates of growth parameter K ranged from 0.04 to 0.05. These values are in the range of values for other members of this family (Archibald et al. 1981, Westrheim and Harling 1975). The t_0 values are comparable to other values for rockfish (between -4.09 and -5.56).

Total instantaneous mortality rates (Z) were estimated for the both sexes of adults and juveniles. The estimates for the adults ranged from 0.03 to 0.04 and are comparable to estimates made by Archibald et al. (1981) for the rougheye rockfish off of the coast of British Columbia which ranged from 0.01 to 0.04. These rates are similar to those for other members of the Pacific ocean perch complex. The instantaneous mortality rates for the juvenile populations were much higher than for the adults. These values ranged from 0.21 to 0.26.

Management of fisheries of long-lived species, such as Sebastes is very complex for many reasons. These populations are usually multi-species, targeted on by multi-national fisheries using a variety of gear types and are often caught incidentally. Additionally, acquiring adequate and accurate stock characteristics such as growth parameters, mortality coefficients, population estimates and stock identification information is often difficult and expensive to attain as discussed earlier. Intensification of fisheries and the lack of resiliency of these populations once they have been over exploited complicate the issue even further.

The importance of longevity has been addressed recently in the literature as the result of the older ages discovered by the break and burn technique of ageing demersal fishes (Leaman and Beamish 1984). This concept needs special attention since a better understanding of these stocks and subsequent management decisions may help avoid the prolonged periods of low yield or terminations of fisheries after exploitation. Further study is needed concerning stock-recruitment relationships and variation in yearclass strength in multi-age populations of rockfish. Annual recruitment may be a very small proportion of the virgin stock biomass and this fact can easily complicate the attempts to management the fishery. Managing these long-lived species which have evolved strategies that insure a long reproductive period rather than maximizing the population growth rate must be done as carefully and efficiently as possible.

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Results from tagging black rockfish (*Sebastes melanops*) off the Washington and northern Oregon coast

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Introduction

Recent reductions in sport and commercial salmon seasons and harvest quotas have resulted in increased fishing pressure directed toward black rockfish (Sebeastes melanops) stocks off the Washington coast. Black rockfish are the primary species harvested by the expanding coastal bottomfish charterboat fishery, comprising over 90% of the total catch. Recreational harvest of black rockfish off the Washington coast increased from 79,000 fish in 1980 to over 226,000 fish in 1984 (Washington Department of Fisheries 1980, 1984). Black rockfish are also harvested by the shallow-water trawl fishery and are increasingly being targeted by commercial jig fishermen. The harvest of rockfish (primarily S. melanops) in Washington coastal waters by the commercial jig fishery increased from 8,779 pounds in 1975 to 191,082 pounds in 1985.

Concurrent with this increasing utilization has been a growing concern among user groups, primarily the charterboat industry, regarding the future availability of coastal black rockfish stocks and potential harvesting conflicts between fisheries. Although a limited amount of black rockfish tagging had been conducted prior to this study in Puget Sound, the Strait of Juan de Fuca and off the Oregon coast (Barker 1979; Coombs 1979), little research had been undertaken concerning migration and stock integrity of black rockfish off the coast of Washington. A tagging study intitiated in 1981 by the Washington Department of Fisheries in conjunction with the Washington State Charter Boat Association (WSCBA) has continued through 1985 to begin development of this information. This study was supplemented in 1984 by a cooperative effort with the University of Washington which released tagged fish off Neah Bay, Washington during 1984 (Kuzis 1985).

Methods and Materials

Tagging was conducted aboard a variety of vessels, primarily the WDF 56 ft. patrol/research vessel G.H. CORLISS and a number of 42-55 ft. charter vessels donated by the WSCBA. Several smaller vessels (14-24 ft.) were employed in the 1984 nearshore tagging in the vicinity of Neah Bay. Personnel consisted of staff from the WDF Marine Fish Program assisted by numerous volunteer workers. Personnel from the University of Washington Fisheries Cooperative Research Unit participated in 1984 tagging efforts. Typical operation required a two to three-man tagging crew and eight to fifteen anglers capturing fish for tagging. Fish were caught using rod and reel with one to three single-hook jigs per line.

After capture, fish were inspected for air bladder inflation, measured, tagged and immediately released. Fish which suffered severe air bladder inflation or other physical trauma which made survival doubtful, were not tagged. No fish were artificially decompressed. To avoid problems with too rapid decompression, fish schools were usually hydroacoustically located within 20 fathoms of the surface prior to targeted fishing.

Fish were tagged with a three-inch Floy FD-68B T-end anchor tag inserted between the pterygiophores in the dorsal musculature with a Dennison tagging gun. Tags were serially numbered and carried the printed legend "WN. DEPT. FISH OLY WN." Approximately 6% of the fish were double tagged to provide insight into potential tag shedding.

During the first three years of the study, approximately 20% of the tagged fish were injected intraperitonealy with a solution of oxytetracycline hydrochloride (OTC) at a dosage rate of 50 milligrams per killogram of body weight. OTC is incorporated into bony tissues leaving a check on the otolith which is visible under ultraviolet lighting. Comparison of otolith growth subsequent to the OTC check with time at liberty can provide insight on the validity of current ageing theory. Seven tagged fish were retained in an an aquarium with an open ocean circulation system during 1981 and 4 fish in a net-pen during 1982 to evaluate tagging mortality and tag loss.

As an incentive to fishermen to return tagged fish, WDF offered a $2.00 reward for each returned tag plus a randomly selected bonus reward of $10.00 for 5% of the released tags and $50.00 for 1% of the released tags. The study was well publicized and posters were placed throughout coastal ports harvesting black rockfish. In addition, the Westport Charter Association began conducting an annual "Snapper Derby" in 1981 which offered a $50.00 reward for the return of a tagged fish caught by a derby ticket holder. Charter offices in the ports of Neah Bay and Ilwaco began participating in the derby during 1985.

Results

Tagging conducted during 1981 through 1985 has resulted in the release of 14,795 tagged black rockfish off the coast of Washington and northern Oregon. Mean length of tagged fish was 41.1 centimeters. Tag releases and recoveries by year are shown in Table 1.

YEAR RELEASED	NUMBER TAGGED	RECOVERIES BY YEAR 1981	1982	1983	1984	1985	1986	TOTAL	%REC.
1981	4,739	19	53	50	32	8	2	164	3.5%
1982	2,544		5	27	6	2	1	41	1.6%
1983	2,033			23	17	14	1	55	2.7%
1984	675				3	8	3	14	2.1%
1985	4,804					153	57	210	4.4%
TOTAL	14,795	19	58	100	58	185	64	484	3.3%

Table 1. Tag Releases and Recoveries by Year

Tags were released from four major areas along the Washington and northern Oregon coast (Figure 1). Tag release and recovery information, by area, is given in Table 2.

RELEASE AREA	NUMBER RELEASED	NUMBER RECOVERED	% REC.
WESTPORT	7,518	345	4.59%
SEALION ROCK	1,723	15	0.87%
TILLAMOOK HEAD	2,637	61	2.31%
NEAH BAY	2,917	63	3.27%
TOTAL	14,795	484	3.27%

Table 2. Tag Releases and Recoveries by Area of Release

Tagging was conducted exlusively in the Westport area during 1981. Tags were released in all areas except Tillamook Head during 1982. All areas except Sealion Rock were addressed during 1983 and 1985. Neah Bay was the only area where tags were released during 1984.

Over half the tags have been recovered by the charter fishery. Approximately 25% of the tag returns were from Washington and Oregon trawl fisheries (Table 3).

FISHERY	TAGS RECOVERED	PER CENT OF TOTAL
CHARTER	248	51.9%
OREGON TRAWL	86	18.0%
PRIVATE BOAT	63	13.2%
WASHINGTON TRAWL	35	7.3%
COMMERCIAL JIG	24	5.0%
SALMON TROLL	15	3.2%
SHORE ANGLERS	5	1.0%
SCUBA DIVERS	2	0.4%
TOTAL	478	100.0%

TABLE 3. Tag Recoveries by Fishery of Recovery

Movement

Tags with known recovery location were returned from 464 fish. Of these, 321 (69.2%) were recovered within 10 miles of the release site while 143 (30.8%) were recovered more than 10 miles from the release site. Fifty-six fish (12.1%) were recovered more than 50 miles from the release site. One fish tagged off Tillamook Head, Oregon was recovered 345 miles away off Cape Mendocino, California. Since different patterns of movement appear to be demonstrated by fish tagged in different areas, it is helpful to consider each tagging area separately.

Neah Bay area. None of the recoveries from this area occurred more than 10 miles from the release site.

Sealion Rock area. Four of the tags from this area were recovered between 10 and 80 miles south of the release site at a mean distance of 34 miles. Eleven tags were recovered on site.

Westport area. Movement indicated by recoveries from this area was again primarily southward. Ninety-six tags were recovered between 10 and 64 miles to the south at a mean distance of 41.6 miles. Many of these recoveries (54) occurred in the vicinity of a sunken grain freighter referred to by local fishermen as the "Wheatship". This wreck is the site of a nearshore trawl fishery targeting black rockfish. Nine tags were recovered between 12 and 69 miles to the north at a mean distance of 28 miles. Recovery location of less than 10 miles from the release site was recorded for 220 (68%) of the tags from this area.

Tillamook Head area. Twenty-nine tags from this area were recovered within 10 miles of the release site. Of the tags which were recovered at distances greater than 10 miles from the release site, the majority were to the north. Twenty-eight tags were recovered from 17 to 72 miles to the north. Twenty-seven of these recoveries were from the "Wheatship" area and one from the area off Westport. Three tags were recovered to the south, two at 24 miles and one at a distance of 345 miles off Cape Mendocino, California.

Oxytetracycline injection

During the first three years of the study, 1,978 tagged fish were injected with OTC. Thus far, 23 injected fish have been returned. Time at liberty has ranged up to 997 days. Leaman and Nagtegaal of Department of Fish and Oceans in Nanaimo, British Columbia have analyzed and photographed otoliths from 13 of these fish, employing both surface ageing and break and burn techniques. The OTC mark has generally been well-defined and results to date have been consistent with the formation of one annulus per year at liberty. The annulus appears to have been formed soon after the OTC mark which Leaman suggests is indicative of fall formation of the annulus or a suppression of growth resulting from the stress of tagging and injection. Results from this facet of the study should become more informative as fish with greater time at liberty are recovered.

There appears to be a substantial mortality associated with OTC injection. Analysis of tag returns for injected and non-injected fish released during the same day have shown injected fish to be recovered at only 67% of the level of return of non-injected fish. Five black rockfish being retained in an aquarium were injected with OTC at the same dosage rate used for tagged fish. All five fish remained alive after 60 days. It is possible that the apparent mortality indicated by differential tag returns results from physical injury sustained during injection rather than from the effects of the OTC.

Tag loss

<u>Holding experiments</u>. All seven tagged fish held in an aquarium during 1981 were alive after a period of 1 month. One tagged fish died after 34 days and another after 48 days. Both fish had areas of necrotic tissue surrounding the isthmus, possibly an infection resulting from handling the fish by the lower jaw during tagging. During this time, one of the 12 non-tagged fish held in the aquarium also died. This fish, as well as other non-tagged individuals in the aquarium, had lesions on the head and body, suggesting that conditions in the aquarium may have contributed to the observed infection and subsequent mortality. One unobserved mortality occurred among the group of tagged

fish sometime after the second month in the aquarium. Four of the tagged fish remained alive after seven months when the experiment was terminated. No tags were lost from any of the fish. Four tagged fish held in a net-pen during 1984 were all healthy, with tags intact, after 47 days when they disappeared through an apparent act of vandalism (Kuzis 1985).

Double tagging. Unfortunately, a number of failed and replaced tags were recorded in the data during 1981 in such a manner that they were indistinguisable from double tagged releases. Double tagged returns from 1981 were therefore not included in the analysis. A total of 865 double tags were released during 1982-1985. Ten of these fish have been recovered with time at liberty ranging from 20 to 419 days. Four of the fish had shed one tag (20% of the total returned tags). If consideration is limited to tags at liberty over 200 days, estimates of tag shedding increase substantially. Three of the four fish recovered after 200 days had shed one tag (37.5% of the total return). These are minimal estimates of tag shedding since fish losing both tags are not considered here. Future double-tagged returns should indicate whether the tag shedding rate continues to increase after 200 days.

Discussion

Movement

Tag recovery is almost certainly influenced by localized concentrations of fishing effort as evidenced by the large number of tags recovered in the "Wheatship" fishery. Accepting that an analysis of movement of tagged fish will be biased by the spatial distribution of the fisheries, it is still possible to offer a few general hypotheses concerning movement of black rockfish stocks along the coast of Washington and northern Oregon:

Fish off the northern Washington coast and outer Strait of Juan de Fuca exhibit no significant movement.

Fish appear to move from the central Washington coast southward to the Columbia River but not into waters off Oregon.

Movement displayed by fish off the northern Oregon coast is primarily northward to the Columbia River. Overall hypothesized movement is depicted in Figure 2.

Several observations are germane to this speculation:

1) Fifty-six tags from the Westport releases were recovered near the Columbia River. No tags were recovered more than 10 miles south of the Columbia River. It would be reasonable to expect more southerly recoveries if the movement indicated by these returns were sustained for greater distances.

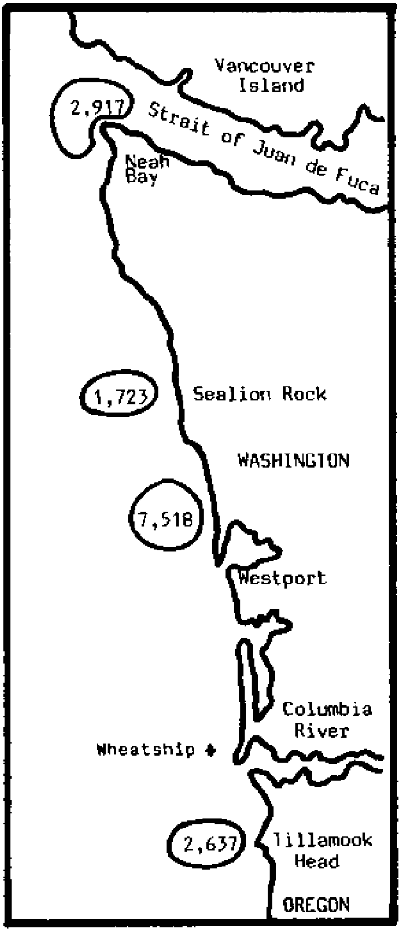

Figure 1. Tag releases by area.

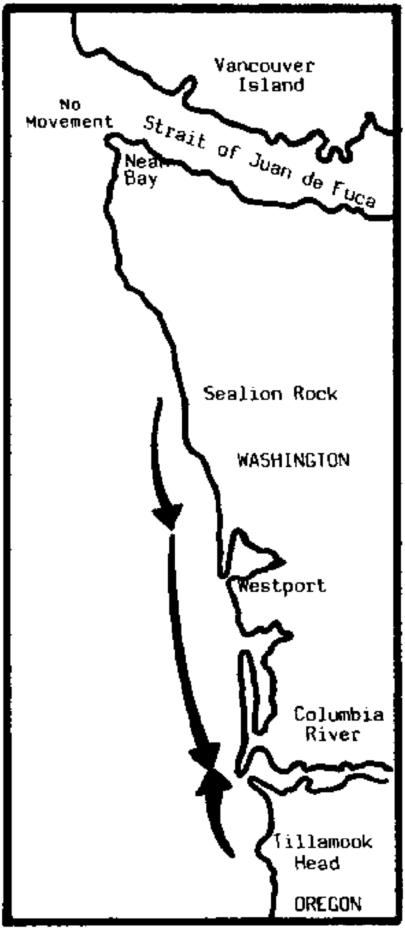

Figure 2. Hypothesized Movement of black rockfish off the Washington and northern Oregon coast.

2) The large majority of tags (88%) which displayed movement from the Tillamook Head area were recovered to the north off the Columbia River.

3) Substantial fisheries for black rockfish occur off central Oregon. Black rockfish harvest out of Garibaldi and Newport alone was estimated at 43,398 fish for the months of July and August of 1985 (Butler 1986). Despite this harvesting capability, only three tagged fish from this study have been recovered south of the Tillamook Head release site (two 24 miles south off Tillamook Bay and one 345 miles to the south off northern California).

4) An Oregon black rockfish tagging study released 3,850 and 3,908 tagged fish out of Garibaldi and Newport, Oregon respectively during the spring of 1985. As of December, 1985, 114 tagged fish had been recovered, none more than 8 miles from the release site (Butler, 1986). Since that time, two fish tagged off Newport were recovered at the "Wheatship". One Garibaldi tag was recovered to the south off Newport (Jerry Butler, Oregon Department of Fish and Wildlife, personal communication).

One possible explanation for the observed movement is a cyclical migration in response to long-shore flow and food availability. Black rockfish feed almost exclusively in the water column (Leaman 1976, Steiner 1978). The food demands of large aggregations of black rockfish may cause them to actively seek out prey over considerable distances.

Tag loss

The rate of tag shedding appears to accelerate with time. One possible cause of this phenomenon is the biological growth which occurs on tags. Despite the fact that tags treated with algicide were employed during most of the study, the majority of tags returned were heavily encrusted with various flora and fauna. Tags at liberty for less than 2 months have been recovered with encrusting growth up to 2 centimeters in diameter. One tag at liberty for 1,047 days was host to a cluster of mussels ranging up to 5 centimeters. The drag created by such growth could easily contribute to the tag pulling from the tag wound. This growth could also disguise the tag and contribute to nonreporting of recaptured fish.

Current Work and Recommendations

As the importance of black rockfish to Washington coastal fisheries grows, the need for management information will also increase. Washington Department of Fisheries (WDF) is currently conducting a multi-stage, mark-recapture tagging study which will be analyzed according to Jolly (1965) and Seber (1965) to obtain estimates of the exploitation rate of black rockfish off the Washington coast. WDF has also begun acoustical stock assessment work on coastal black rockfish populations. Collection of catch and effort data from fisheries for black rockfish and biological sampling of the catch has been intensified to more clearly document harvest and catch composition by area. Results of this work will further illuminate tag return analyses. It would also be useful to evaluate the retention rate of tags other than the T-end anchor tag.

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Results of a bottom trawl survey of Pacific ocean perch off Washington and Oregon during 1985

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Abstract

The fishery on depleted stocks of Pacific ocean perch (*Sebastes alutus*) off Washington and Oregon has been regulated by limiting foreign landings to incidental catch since 1977 and imposing trip limits on domestic fishermen since 1978. These limits have been imposed in an attempt to rebuild the stocks to a point where they can produce maximum sustainable yields. Cohort analysis has suggested that such rebuilding might be accomplished in approximately 20 years. Industry and managers have pressed for a reassessment of the resource to evaluate the effectiveness of catch limits toward achieving the rebuilding goal. The resource was assessed with a bottom trawl survey in the spring of 1979 to determine abundance, distribution, and population biology of the stocks. A comparable survey was conducted during the spring of 1985 to examine population changes during that 6-year period.

The 1985 Pacific ocean perch survey essentially replicated the one conducted in 1979, although some changes were necessary to standardize sampling gear and depth coverage which were inconsistent during the 1979 survey. Abundance estimates were calculated from catch data from 214 successful trawl hauls. Pacific ocean perch biomass was estimated to be 2,028 metric tons (t) in the U.S. portion of the Vancouver (U.S.-Vancouver) International North Pacific Fisheries Commission (INPFC) statistical area and 6,606 t the Columbia INPFC area. The precision of the 1985 estimates was improved over the 1979 results, probably due to steps taken to standardize data collection and a more uniform distribution of the population. Population size compositions were bimodal in both INPFC areas. The distribution in the U.S.-Vancouver area was quite broad with relatively even numbers of fish at all lengths. The Columbia area population exhibited modes at 27-31 cm and 36-40 cm.

The abundance of Pacific ocean perch, as determined from the results of these trawl surveys, has apparently declined by 63% in the U.S.-Vancouver area and by 18% in the Columbia area between 1979 and 1985. The size and age composition of the populations in both areas show slightly more young fish in 1985 (25-31 cm and 4-6 years old), suggesting some improvement in recruitment in recent years. Continued juvenation of the population due to fishing is also apparent, especially in the U.S.-Vancouver area.

Introduction

Commercial fishing for Pacific ocean perch (Sebastes alutus) in the northeast Pacific Ocean began in 1946. Catch levels were incidental until 1951. Thereafter the fishery, which began off the coasts of Washington and Oregon, expanded into the Canadian waters of Queen Charlotte Sound. Until 1966 commercial harvests continued to be made chiefly by the U.S. trawl fleet with the remainder landed by the Canadian trawl fleet (Alverson and Westrheim 1961; Major and Shippen 1970). Trawlers from the U.S.S.R. began fishing this species in 1959 in the Bering Sea. The activities of the Soviet Pacific ocean perch (POP) fishery gradually moved eastward and southward, entering the waters off British Columbia, Washington, and Oregon in early 1965. The Japanese trawl fleet also developed a fishery on this species which followed a similar expansion pattern approximately 1 year behind the Soviet fleet (Westrheim et al. 1972; Gunderson et al. 1977; Quast 1972). Production of this fishery in the International North Pacific Fisheries Commission (INPFC) Vancouver and Columbia statistical areas combined in 1966 exceeded 27,600 metric tons (t), more than three times the largest previous harvest of 8,921 t made 1 year earlier. The catch peaked in 1967 at 37,459 t and remained high in 1968 at 21,979 t. The effects of the high exploitation rates during these 3 years (as high as 68% in the Columbia area) began to show in 1969 as the catch in these two areas fell nearly 85% to 5,906 t. Catches remained low through 1976, when foreign fleets were prohibited from fishing for POP in these areas.

The condition of Pacific ocean perch stocks off British Columbia, Washington, and Oregon have been assessed periodically since the intense exploitation of 1966-68. The mean exploitable biomass in the Vancouver area during 1966-68 was estimated to be 34,000 t by dividing mean landings (13,419 t) by the estimated exploitation rate (0.39) (Westrheim et al. 1972). Subsequent biomass estimates in the Vancouver area, based on declining mean weighted catch per unit of effort (CPUE) for the Washington-based fleet, were 18,700 t during 1969-71 (Technical Subcommittee 1972) and 16,700 t during 1972-74 (Gunderson et al. 1977). The CPUE rose slightly in 1975-77, raising the biomass estimate to 17,800 t, although this estimate is probably biased toward the high side by the fleet's recent switch to a more efficient trawl (Fraidenburg et al. 1978). Columbia area biomass estimates since 1966 have been calculated by dividing landings by estimated exploitation rates and indicate that the biomass has declined from 23,000 t during 1966-68 to 7,300 t during 1969-72 and 4,300 t during 1973-74 (Gunderson et al. 1977). Fraidenburg et al. (1978) estimated the biomass in 1977 at between 8,000 and 9,600 t using an area-swept extrapolation of commercial CPUE data, although this estimate is suspected to be high since the commercial fishery operated in areas of high abundance.

Research surveys have provided information defining migration, seasonal availability, growth, maturity, reproductive patterns, and other biological characteristics of POP (Gunderson 1971, 1972, 1974). A coastwide survey of rockfish resources was conducted in 1977 (Gunderson and Sample 1980) with the objective of defining the distribution and measuring the abundance of the major species taken in bottom trawls. The relative imprecision of biomass estimates derived for POP from that survey and the possibility that recent strong year classes had significantly increased the stock size prompted requests from the fishing industry and resource managers for better assessments of the status of this resource. In response, the National Marine Fisheries Service (NMFS) coordinated, with the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fisheries (WDF), a cooperative assessment survey of the POP stocks off Washington and Oregon in March-May 1979 (Wilkins and Golden 1983). That survey provided more precise biomass estimates which were similar to those calculated from the 1977 survey. The 1977 coastwide survey was repeated (with some modification of the survey design) in 1980 and 1983, yielding two more fishery-independent assessments of the resource (Weinberg et al. 1984; Coleman 1986). The Canadian perch stocks were surveyed in the fall of 1979 (Lapi and Richards 1981) and again in the fall of 1985. The results of these surveys indicate that those stocks declined by approximately 56% over that period (B.M. Leaman, Pacific Biological Station, Nanaimo, B.C., Canada, personal communication). Virtual population (Gunderson 1979, 1981; Ito et al. 1986) and stock reduction analyses (Ito et al. 1986) have been performed for these stocks also.

All resource assessment results plainly show a dramatic decline of Pacific ocean perch abundance during and after the intensive fishing in 1966-68 (Fig. 1). Fishery managers acted to conserve the resource by restricting foreign catches of this species to incidental levels in 1977 when Canada and the United States extended their fishery jurisdiction. The sizeable fleet of U.S. trawlers fishing in Canada were excluded from the Queen Charlotte Sound grounds in 1977 and, consequently, the groundfish stocks off the Washington and Oregon coasts were subjected to increased fishing when these vessels moved their operations south. Landing limits for ocean perch have been in effect for Oregon and Washington trawlers since late 1978 (Table 1) to reduce fishing mortality and promote the Pacific Fishery Management Council's (PFMC) goal of rebuilding the ocean perch stocks off Washington and Oregon. Gunderson (1979) estimated through cohort analysis that by limiting acceptable biological catches to 600 t and 950 t in the U.S. portion of the Vancouver (hereafter referred to as U.S.-Vancouver) and Columbia areas, respectively, these stocks could be rebuilt in approximately 20 years to a level at which they could produce maximum sustainable yields (Pacific Fishery Management Council 1980).

The 1985 NMFS Pacific ocean perch survey was initiated to determine how the stocks off Washington and Oregon have responded to 6 years of restrictive catch regulations aimed at rebuilding population size. The primary objective of the survey was to obtain abundance, distribution, size composition, and age composition estimates that could be compared with results of a similar survey conducted in 1979 (Wilkins and Golden 1983). This paper presents a brief explanation of the differences between the 1979 and 1985 surveys, including the results of an adjunct study conducted to evaluate the relative fishing power of the standard

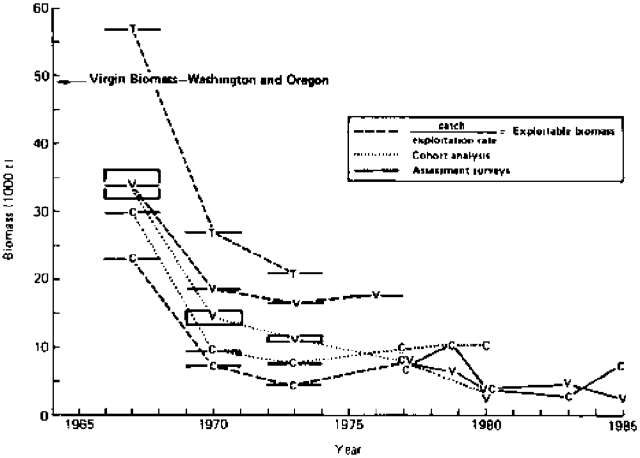

Figure 1.--Summary of various estimates of biomass for the stocks of Pacific ocean perch in the International North Pacific Fisheries Commission Vancouver (V) and Columbia (C) areas. The different methods used to derive biomass estimates are indicated by different line patterns.

Table 1.--Summary of management regulations of the Pacific ocean perch fishery in the International North Pacific Fisheries Commission Vancouver and Columbia areas (U.S. waters only). Weight restrictions are in metric tons.

Effective date	Area	Effect of Regulation
October 26, 1978	Washington	Trip limit of 4.54 t or 25% of catch (whichever greater)
	Oregon	Trip limit of 9.07 t
January 1, 1981	Washington and Oregon	Trip limit of 4.54 t or 10% of catch (whichever greater)
February 1, 1982	Washington and Oregon	Trip limit of 2.27 t or 10% of catch (whichever greater)
November 10, 1983	Columbia area	No landings permitted
January 1, 1984	Washington and Oregon	Trip limit of 2.27 t or 10% of catch (whichever greater)
August 16, 1984	Columbia area	No landings permitted
January 1, 1985	Washington and Oregon	Trip limit of less than 20% of catch
April 28, 1985	Washington and Oregon	Trip limit of 2.27 t or 20% of catch (whichever less)

Noreastern survey trawl versus that of the Mystic trawl which was used in 1979 in the southern portion of the survey area. The focus, however, is on the comparison of the results of the two surveys and the effectiveness of the stock rebuilding program.

Methods

Survey design.

The 1985 survey was conducted using the same basic survey design used for the 1979 survey (Wilkins and Golden 1983) to allow for the most direct comparison of results. The stations at which trawl hauls were made off the Washington coast were identical for both surveys. Those 1979 stations off the Oregon coast were standardized to the survey design for 1985 to allow for the best synoptic survey and to simplify comparisons with any future assessments. Consequently, the differences between the survey designs were that the 1985 survey covered the depth range of 165-475 m from 44°37'N lat. to the U.S.-Canada border, whereas the 1979 survey covered from 165 to 420 m between 44°37' and 46°21'N lat. and from 165 to 475 m between 46°21'N lat. and the U.S.-Canada border.

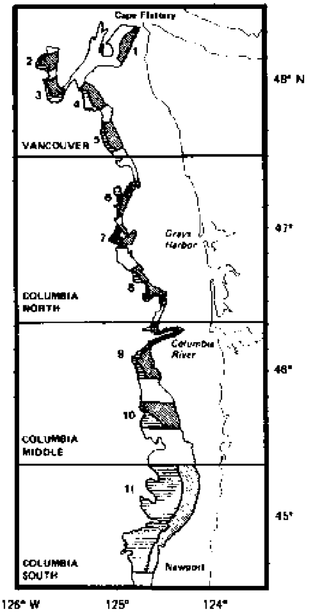

Figure 2.--The survey area, subareas, and high density sampling strata used in the design of the 1985 Pacific ocean perch survey.

The depth range to be sampled was chosen after analyzing CPUE trends in the commercial fishery during spring months (March-May), the season when Pacific ocean perch are most available. This analysis showed that CPUE could be expected to be higher between 165 and 320 m than in the 321 to 475 m depth range, so the areas were stratified by depth accordingly.

It became apparent from the CPUE analysis that large catches of POP were coming from localized grounds within the survey area. Eleven such subareas were delineated within the survey bounds (Fig. 2). Relatively more sampling effort was expended in the high density strata and the shallow depth zone in an attempt to reduce the sampling variance and improve the precision of the abundance estimates.

Approximately 250 stations could be sampled with the resources available for this survey. These samples were allocated among high density strata proportionally to their area (km^2) and the desired sampling density (Table 2). Sampling density was established by examining historical CPUE values and predicting levels of precision for abundance estimates in

Table 2.--Descriptions, sample densities, and mean Pacific ocean perch (POP) catch per unit effort (CPUE) for strata used in the analysis of results of the 1985 POP survey. All catch rates in the Columbia South subarea have been adjust to the Noreastern trawl. Strata are shown in Figure 2.

Stratum	Depth (m)	Area (km^2)	Allo-cated tows	Allo-cated tows/km2	Suc-cess tows	Suc-cess tows/ km^2	POP CPUE (kg/km)
U.S.-Vancouver	165-475	1584.4	95	1/17	80	1/20	23.9
High density	165-319	560.4	54	1/10	49	1/11	36.6
High density	320-475	215.9	20	1/11	19	1/11	17.0
Low density	165-319	700.8	12	1/58	9	1/78	6.0
Low density	320-475	107.3	9	1/12	3	1/36	6.0
Columbia North	165-475	800.6	53	1/15	43	1/19	36.2
High density	165-319	355.8	28	1/13	27	1/13	62.1
High density	320-475	180.6	14	1/13	14	1/13	2.6
Low density	165-319	175.7	7	1/25	1	1/176	89.6
Low density	320-475	88.5	4	1/22	1	1/89	6.4
Columbia Middle	165-475	1967.7	52	1/38	44	1/45	19.3
High density	165-319	692.4	31	1/22	27	1/26	49.6
High density	320-475	281.7	11	1/26	9	1/31	5.4
Low density	165-319	584.6	5	1/117	5	1/117	1.7
Low density	320-475	409.0	5	1/82	3	1/136	4.3
Columbia South	165-475	2620.5	47	1/56	47	1/56	6.2
High density	165-319	1039.3	22	1/47	22	1/47	6.0
High density	320-475	1581.2	25	1/63	25	1/63	6.4
Columbia Total	165-475	5388.8	152	1/35	134	1/40	26.2
High density	165-319	2087.5	81	1/26	76	1/27	48.6
High density	320-475	2043.5	50	1/41	48	1/43	4.2
Low density	165-319	497.5	12	1/41	6	1/83	16.4
Low density	320-475	760.3	9	1/84	4	1/190	4.8

different portions of the survey area. The positions of the stations in a given stratum were assigned on evenly spaced tracklines drawn perpendicular to the depth contour so as to provide a systematic coverage of the depth range within the stratum (Wilkins and Golden 1983).

Vessel, gear, and sampling methods.

Survey operations were conducted aboard the 26.5 m chartered trawler, Marathon. The standard trawl deployed throughout the survey was the Noreastern trawl equipped with roller gear, 1.5 x 2.1 m steel V doors, 55 m triple bridles, and a 32 mm mesh codend liner. The average horizontal and vertical openings of this net during fishing have been previously measured acoustically to be 13.4 m and 9.1 m, respectively (F. Wathne, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, Seattle, WA, personal communication).

Trawl hauls were made at the predetermined stations along the designated depth contour. The trawl was towed for 30 minutes at a speed of approximately 5.5 km/h after allowing it to settle on the bottom. Catches were brought aboard, sorted by species, weighed, and counted. Biological data were collected from random samples of species of interest in the catch, including fork lengths of POP and other commercially important species. Otoliths were collected from POP for age determination.

Comparative fishing experiment.

A major problem with the analysis of the 1979 survey results stemmed from the use of three different types of trawls during the field work. This predicament came about because the two vessels chartered by the ODFW lacked sufficient power to pull the Noreastern. The Noreastern trawl was used in the U.S.-Vancouver and Columbia North areas (46°21'N lat. to the U.S.-Canada border), a modified 400-mesh Eastern trawl in the Columbia Middle area (45°22' to 46°21'N lat.), and a Mystic trawl in the Columbia South subarea (44°37' to 45°22'N lat.). A comparison of fishing powers among the three trawl types was not possible in 1979.

A comparative fishing experiment was implemented as part of the 1985 survey with the objective of relating the effectiveness of the Noreastern and Mystic trawls for capturing Pacific ocean perch. The comparative trawling was conducted in the Columbia South area where the Mystic trawl was used in 1979. No comparisons were attempted between the Noreastern and 400-mesh Eastern trawls due to the lack of time and the absence of documentation on the modifications that had been made to the 400-mesh Eastern trawl used in 1979. The Mystic trawl used in the comparative fishing power experiment was the same type as that used in the Columbia South subarea during the 1979 POP survey and was deployed using the same doors used with the Noreastern, a pair of 73 m bridles, and no codend liner. Anecdotal sources estimate the average horizontal and vertical openings for the Mystic to be 8.5 m and 6.7 m, respectively (J.T. Golden, Oregon Department of Fish and Wildlife, Newport, OR, personal communication), although it was not measured during this survey. The predetermined stations in this subarea were sampled by alternating the trawl type used at consecutive stations. This is an adaptation of the "alternate row" comparison experiment (Wakabayashi et al. 1985), allowing fishing power data collection without the large cost in time and logistic effort needed for side-by-side fishing comparisons. Catch rates for POP were then analyzed to test whether the population of CPUE values observed from hauls made with one trawl was distinct from the population of CPUE values from hauls made with the other trawl (Geisser and Eddy 1979). Two models were constructed, one asserting that the two populations of CPUE values were indistinguishable and the other asserting that they were distinct. Model selection was based on which better predicted the data (i.e., the model with the smallest discrepancy between the observed values from predicted values, in this case the sample mean, was selected). If the distinct population model is selected, a fishing power correction needs to be applied. This coefficient is calculated from the ratio of the catch per effort of one net to the catch per effort of the other net (catch per effort in this case is calculated by dividing the sum of the catch from all hauls of one net by the sum of the effort (km trawled) expended by that net).

Analytical procedures.

Procedures used to analyze data from the 1979 survey were applied to the 1985 survey data and are explained in detail by Wilkins and Golden (1983). Results are presented by INPFC statistical areas (U.S.-Vancouver, 47°30'N lat. to U.S.-Canada border; Columbia, 44°37' to 47°30'N lat.) because the resource is managed by these areas. Some portions of the analyses are presented by subareas of the Columbia area to facilitate comparison between the results of the 1979 and 1985 surveys. Catch rates of POP (kg/km trawled) and their variances were calculated from catch and haul information and used to derive estimates of population biomass and numbers within strata (INPFC areas, subareas, and depth zones) with associated 90% confidence intervals. The population, size compositions were estimated by extrapolating length data, appropriately weighted by catch rates, to the estimated population number. Size compositions were then converted to age compositions by means of age-length keys constructed separately for the Vancouver and Columbia INPFC areas from age data collected during the survey.

The method used for ageing Pacific ocean perch has changed since structures collected in 1979 were read. Formerly, age determination for rockfish involved discriminating annuli on otolith surfaces (Westrheim 1973) which underestimates the age of older fish. The currently accepted method is sectioning or breaking the otolith and identifying annuli on the new surface (Beamish 1979a,b; Chilton and Beamish 1982; Bennett et al. 1982) which seems to provide more accurate age and growth information, especially in older fish. These two techniques may provide readings that will result in different growth curves since the ages of fish determined to be over 20 years old by surface ageing have usually been underestimated (Beamish 1979b). Otolith samples from the 1985 survey were read using the current methodology, so thorough comparisons between age composition estimates from the two surveys will not be possible.

Results

Successful trawl hauls were completed at 214 of the 247 planned stations. Catches ranged from 2.3 to 6,643.0 kg and consisted of 89 fish species. Pacific ocean perch was the most abundant species in the survey area with a mean CPUE of 25.2 kg/km trawled (13.3% of the total mean CPUE). Rockfish as a group comprised 56% of the survey catch. Pacific ocean perch was the dominant species in this group, comprising 23.9% of the rockfish catch. Catch rates of POP were usually higher in high density strata and in the shallow depth zones (Table 2). The dominance of rockfish, particularly POP, indicates some degree of success in delineating the survey area.

The distribution of POP catches is shown in Figure 3. The mean catch rates were highest for the shallow depth strata (165-320 m) with mean CPUEs of 31.5, 47.8, and 40.8 kg/km for the U.S.-Vancouver, Columbia, and combined shallow survey areas, respectively. By comparison, the deeper strata (321-475 m) had mean catch rates of 14.8, 4.5, and 8.4 kg/km in the U.S.-Vancouver, Columbia, and combined areas, respectively. In the Columbia area POP catch rates increased from south to north (Table 2).

In the Columbia South subarea 23 Noreastern and 24 Mystic trawl hauls were completed and used in the examination of relative fishing power. The analysis determined that the CPUEs were significantly different, which implies the need for a correction factor to equate results from the two trawl types. When analyzed by depth zone the results showed that a correction factor was not warranted in the shallow zone (11 hauls for each trawl) where the Mystic outfished the Noreastern by a factor of 1.42. In the deep zone (12 Noreastern and 13 Mystic hauls), the Mystic outfished the Noreastern by a factor of 4.50 and the need for a correction factor was indicated. The Mystic trawl was found to be approximately 2.64 times as effective as the Noreastern at capturing

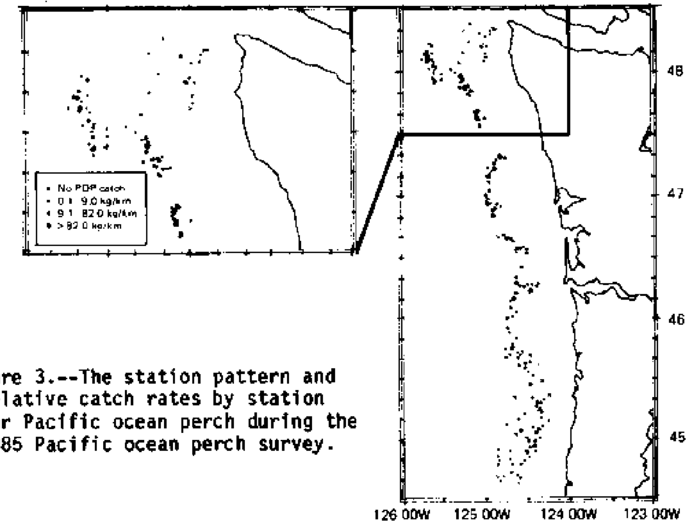

Figure 3.--The station pattern and relative catch rates by station for Pacific ocean perch during the 1985 Pacific ocean perch survey.

POP when tows from all depths were considered (Table 3). This factor accounts for the difference in path width of the trawls as well as for their relative catching efficiencies. The results of the fishing power analysis for all species of fish and invertebrates found to require correction factors are presented in the appendix.

The data set used for the comparative analysis was rather small for obtaining precise results, so we compared the fishing power of the two nets on a group of slope rockfish species which co-occur with POP (the "slope complex"). If we can assume that the species of the slope complex, which occupy similar habitats and have similar distributions, also behave like POP when fished by the two types of trawl, we should expect to obtain comparative fishing power results which are similar to those found for POP. Species were included in this complex on the basis of recurrent group analysis of catch data from all hauls in the current survey (Fager 1957; Fager and Longhurst 1968) and included sharpchin (Sebastes zacentrus), rosethorn (S. helvomaculatus), silvergray (S. brevispinis), redbanded (S. babcocki), splitnose (S. diploproa), greenstriped (S. elongatus), and darkblotched (S. crameri) rockfishes, Pacific ocean perch, and shortspine thornyhead (Sebastolobus alascanus). Results of this analysis were similar to that for POP alone; a correction factor of 2.60 was needed. Similar results were also found when catch data for all rockfishes (Genus Sebastes and Sebastolobus) were combined (Table 3). The correction factor for POP derived for samples from all depths (2.64) was selected as the most appropriate measure of the relative fishing power of the

Table 3.--Summary of results of fishing power comparison (FPC) for rockfish between the Noreastern (NE) and Mystic trawls in the Columbia South subarea. Catch rates and fishing power conversion factors are calculated by dividing total catch by total effort.

Species	Depth zone	FPC needed	Catch rates NE	Catch rates Mystic	Conversion factor NE to Mystic	Conversion factor Mystic to NE
Pacific	165-319 m	No	7.67	10.86	0.71	1.42
ocean	320-475 m	Yes	4.62	20.83	0.22	4.50
perch	165-475 m	Yes	6.12	16.14	0.38	2.64
Slope	165-319 m	Yes	31.65	84.13	0.38	2.66
complex*	320-475 m	Yes	20.27	52.33	0.39	2.58
	165-475 m	Yes	25.85	67.28	0.38	2.60
All	165-319 m	Yes	33.68	85.87	0.39	2.55
rockfish	320-475 m	Yes	24.30	64.00	0.38	2.63
	165-475 m	Yes	28.90	74.28	0.39	2.57

*Slope complex was comprised of rockfish species which co-occur with Pacific ocean perch and included Pacific ocean perch, shortspine thornyhead, rosethorn, sharpchin, splitnose, silvergray, redbanded, greenstriped, and darkblotched rockfish.

two trawls. The difference in results using data from the two depth zones is probably due to the small sample of hauls. Using the selected correction factor it was possible to calculate an abundance estimate in terms of Mystic trawl catch rates that is compatible with results from the 1979 survey in the Columbia South area. Similarly, an abundance estimate could be derived in terms of Noreastern trawl catch rates which would correlate with those derived for the other 1985 survey areas.

It was not possible to compare the Noreastern trawl with the modified 400-mesh Eastern trawl used in the Columbia Middle area during the 1979 survey, so no attempt was made to adjust catch rates for comparability. We were forced to assume that the nets were equally efficient at catching perch and calculated abundance estimates separately for each gear based on their respective horizontal fishing dimensions.

Estimates of POP stock biomass, population numbers, and associated 90% confidence intervals are presented by subarea and depth zone in Table 4. These estimates are based on the depth coverage of 165-475 m and trawl catch rates adjusted to Noreastern trawl catch rates using a correction factor of 2.64. Eighty-four percent of the estimated POP biomass in the survey area occurred in the shallow depth zone. Only in the Columbia South subarea, which accounted for 14% of the total perch biomass, was abundance greater in the deep stratum than in the shallow stratum. This subarea is unique because the deep stratum is 52% larger than the shallow stratum. In all other subareas the shallow strata were 85-390% larger than the deep strata. The total POP biomass within the survey bounds was 8,633 t (+/- 24%); 23.5% of the estimated biomass (2,028 t +/-57%) was found in the U.S.-Vancouver area and 76.5% (6,606 t +/- 27%) in the Columbia area. Confidence intervals around the biomass estimates ranged from +/- 24% to +/- 94% for various survey subareas, a marked improvement in precision over the 1979 survey results. Discussion of the comparison between these two surveys is presented later in this report.

Table 4.--Pacific ocean perch (POP) abundance estimates from the standardized analysis of the 1985 POP survey (based on Noreastern catch rates and survey depths of 165-475m). Confidence intervals are expressed as a percentage of the biomass estimate.

Area	Biomass (t)	90% Confidence limits (t)			Population (no.x1000)	Mean weight (kg)	Mean length (cm)
		LOWER	UPPER	% of B			
U.S.-Vancouver							
165-319 m	1709.5	574.2	2844.8	(± 66%)	2484	0.7	34.5
320-475 m	318.0	145.7	490.4	(± 54%)	413	0.8	37.9
165-475 m	2027.5	880.6	3174.5	(± 57%)	2897	0.7	35.0
Columbia North							
165-319 m	2739.4	1889.2	3589.5	(± 31%)	3390	0.8	37.2
320-475 m	76.0	50.6	101.3	(± 33%)	87	0.9	39.9
165-475 m	2815.3	1964.8	3665.8	(± 30%)	3477	0.8	37.2
Columbia Middle							
165-319 m	2327.9	783.5	3872.4	(± 66%)	2989	0.8	36.7
320-475 m	242.5	14.6	470.4	(± 94%)	185	0.7	37.0
165-475 m	2570.5	1020.6	4120.3	(± 60%)	3174	0.8	36.7
Columbia South							
165-319 m	465.9	202.4	729.5	(± 57%)	884	0.5	31.8
320-475 m	754.2	384.1	1124.4	(± 49%)	957	0.8	37.8
165-475 m	1220.1	774.8	1665.4	(± 36%)	1841	0.7	34.9
Columbia Total							
165-319 m	5533.2	3783.7	7282.8	(± 32%)	7263	0.8	36.3
320-475 m	1072.7	635.4	1510.0	(± 41%)	1377	0.8	37.7
165-475 m	6605.9	4813.2	8398.6	(± 27%)	8640	0.8	36.5
Total Survey Area							
165-319 m	7242.7	5201.5	9283.9	(± 28%)	9747	0.7	35.8
320-475 m	1390.7	938.6	1842.8	(± 33%)	1790	0.8	37.8
165-475 m	8633.4	6550.0	10716.9	(± 24%)	11537	0.7	36.1

Estimated population size composition curves for Pacific ocean perch from the 1985 survey are shown in Figure 4. Catches of the Noreastern and Mystic trawls in the Columbia South area were examined for evidence of differential size selectivity of ocean perch which could bias estimates of population size composition. Separate estimates of population size composition were made from length frequency data collected with each of the two trawls. There was an indication that the Mystic was more efficient at catching larger fish, but the size range of fish caught by each net was very similar (Fig. 5) despite the 32 mm mesh liner in the Noreastern codend (vs. the 108 mm mesh codend material of the Mystic). The results of relative fishing power and size composition analyses suggested that the two nets were performing similarly in

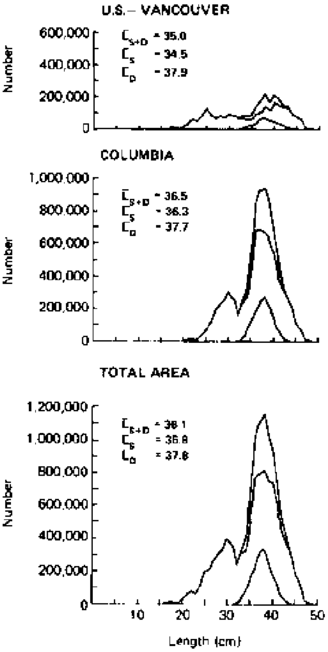

Figure 4.--The population size composition and mean lengths ($\bar{L}$) of Pacific ocean perch estimated from results of the 1985 Pacific ocean perch survey by depth zone and International North Pacific Fisheries Commission area and for the total survey area. (Lower curve = 320-475 m depth zone, middle curve = 165-319 m depth zone, and upper curve = 165-475 m depth zone).

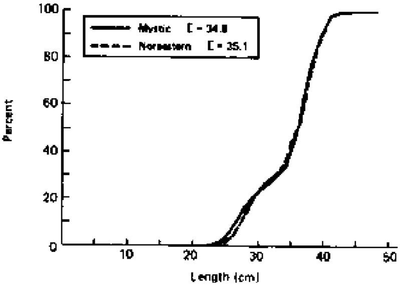

Figure 5.--Size selectivity of the Noreastern and Mystic trawls shown by cumulative percent size composition estimated from the catches of each trawl during comparative fishing in the Columbia South subarea.

the shallow stratum and that the major difference appeared to be their relative efficiency for catching larger fish (>34 cm), which make up virtually the entire deep stratum population. Since no difference in size selectivity was seen between the two nets, population size composition was estimated using length frequency data from all hauls. The population in the U.S.-Vancouver area was characterized by a rather even distribution of lengths between 24 and 45 cm. The length distribution in the Columbia area was bimodal with a major mode at 37-39 cm and a smaller mode at 27-31 cm. Virtually all perch caught in the deep strata were over 33 cm, while those caught in the shallow strata spanned the entire range of lengths.

The sex ratio for Pacific ocean perch within the survey bounds was 53.78% males. Examination of sex ratios by INPFC area revealed a considerably lower percentage of males in the U.S.-Vancouver area than in the Columbia area with estimates of 48.25 and 55.63% males, respectively. Sex ratio estimates for all subareas and depth zones are presented in Table 5. The deep zone in the U.S.-Vancouver area had a higher proportion of males than the shallow zone (51.57 vs. 47.70% males, respectively). The opposite trend was seen in the Columbia area where the fish in the shallow and deep zones were 56.42 and 51.46% males, respectively.

Table 5.--Sex ratios (% males) of Pacific ocean perch populations in the International North Pacific Fisheries Commission Vancouver and Columbia areas (U.S. waters only) from results of the 1985 Pacific ocean perch survey by subarea and depth zone. Values in parentheses represent results which have been adjusted for comparison with 1979 results (depths to 420 m and catch rates adjusted to the Mystic trawl in the Columbia South subarea).

Area and depth zone	1979	1985	
U.S.-Vancouver area			
165-319 m	46.54	47.70	
320-475 m	46.67	51.57	
165-475 m	46.57	48.25	
Columbia North subarea			
165-319 m	51.70	54.19	
320-475 m	43.03	36.05	
165-475 m	51.13	53.74	
Columbia Middle subarea			
165-319 m	44.17	58.73	
320-475 m	33.05	48.02	(48.77)
165-475 m	43.96	57.66	(58.15)
Columbia South subarea			
165-319 m	53.17	57.17	(57.16)
320-475 m	46.26	54.06	(53.42)
165-475 m	49.80	55.56	(55.14)
Columbia area			
165-319 m	49.63	56.42	(56.55)
320-475 m	45.91	51.46	(52.61)
165-475 m	48.54	55.63	(55.53)
Total survey area			
165-319 m	48.45	54.20	(54.58)
320-475 m	46.13	51.48	(52.49)
165-475 m	47.84	53.78	(54.09)

Ages of Pacific ocean perch were estimated by reading the broken and burned otoliths of 1,635 specimens (500 from the U.S.-Vancouver area and 1,135 from the Columbia area). Ages ranged from 2 to 71 years in the Vancouver area and from 3 to 76 years in the Columbia area. The age composition figures for both areas (Fig. 6) show important contributions to the population from the 1979-80 year classes (5-6 years old). The 1981 year class is also relatively important in the U.S.-Vancouver area. The Columbia area population is also supported strongly by the 1970-75 year classes (10-15 years old). The growth curves and von Bertalanffy growth parameter estimates for both areas were nearly identical (Table 6, Fig. 6), and indicated that virtually all growth in length is completed in the first 15 years.

Comparison of 1979 and 1985 survey results.

The primary objective of the current survey was to assess the distribution, abundance, and biological features of the POP resource so that results would be comparable to those from a similar survey conducted in

Table 6.--Estimated von Bertalanffy growth parameters for Pacific ocean perch sampled during the 1979 and 1985 Pacific ocean perch surveys. Samples collected in 1979 were aged by surface readings of otoliths and those collected in 1985 were aged with the break-and-burn method.

Year/area	Male			Female		
	L_{inf}	k	t_0	L_{inf}	k	t_0
1979						
U.S.-Vancouver	42.11	.176	-1.15	45.21	.146	-1.45
Columbia	40.75	.187	-1.09	43.23	.164	-1.32
1985						
U.S.-Vancouver 38.66	38.66	.205	- .80	41.73	.171	-1.02
Columbia	38.86	.224	- .32	41.64	.183	- .97
Total area	38.84	.215	- .55	41.65	.183	- .82

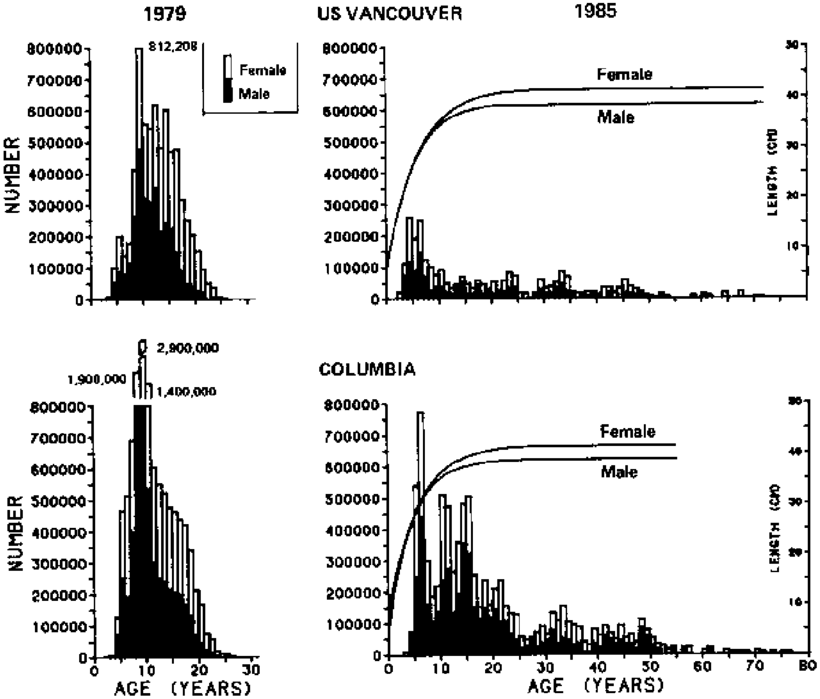

Figure 6.--Age composition of Pacific ocean perch populations estimated from results of 1979 and 1985 assessment surveys by International North Pacific Fisheries Commission area and sex. Growth curves are also presented for the 1985 results.

1979. Inconsistencies in the 1979 sampling resulted from three agencies conducting different portions of the field work. The most serious of these involved the use of three different trawls by four different vessels and variable depth coverage (165-475 m off Washington and 165-420 m off Oregon). The 1985 survey was designed to standardize the survey in all areas and to partly compensate for the differences between the two surveys to allow the most valid comparisons. For comparison with the 1979 results, catch rates of the Noreastern trawl were adjusted to Mystic trawl catch rates in the Columbia South subarea using a correction factor (2.64) relating their respective efficiencies for catching POP. Also, hauls deeper than 420 m in the Columbia Middle and South subareas were excluded from the data when calculating the 1985 abundance and size composition estimates so that results would relate to the same portion of the resource.

The apparent abundance of the Pacific ocean perch resource in the survey area declined by 33% in biomass and 37% in numbers between 1979 and 1985 (Table 7, Fig. 1). The largest decline (63% less biomass and 57% fewer fish) was seen in the U.S.-Vancouver area. Stocks in the Columbia area decreased by 18% in biomass and 29% in numbers of fish. Although these differences appear large, they were not significantly different. Standard normal variates were calculated by:

$$Z = \frac{(B_{85} - B_{79})}{Var(B_{85}) + Var\ (B_{79})} .$$

Test statistics for the U.S.-Vancouver and Columbia areas were -1.48 and -0.66, respectively, neither of which exceeds the test value of 1.96 (alpha = 0.05). The large variances associated with the 1979 abundance estimates tend to dampen the sensitivity of this statistical test. Although the observed changes in stock size were not statistically significant, the sensitivity of the tests used to determine significance, particularly in the U.S.-Vancouver area, is questionable.

The depth distribution of the population was similar in both survey years. Approximately 85-95% of the estimated population occurred in the shallow zone. The depth distribution in 1985 was more uniform than in 1979 when examined by 20 m depth intervals (Fig. 7). The population was also distributed more evenly latitudinally in 1985 (Fig. 8). The Columbia North and Middle subareas each contained only 12% of the population in 1979 while in 1985 they contained 26 and 23% of the population. The Columbia South and U.S.-Vancouver subareas contained 42% and 34% of the population, respectively, in 1979 and 32% and 19% of the population, respectively.

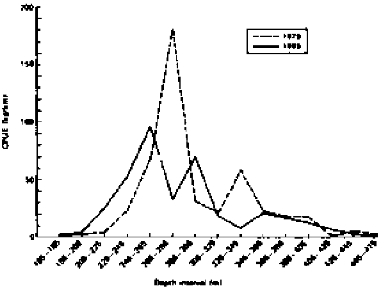

Figure 7.--The depth distribution of Pacific ocean perch in 1979 and 1985 (survey results) shown by mean catch per unit effort by 20 m depth intervals.

Table 7.-- Pacific ocean perch abundance estimates from an analysis of the 1979[1] and 1985[2] survey data.

Area	Biomass (t)	90% Confidence limits (t)			Population (x1000)	Mean weight (kg)	Mean length (cm)
		lower	upper	% of B			
U.S.-Vancouver							
1979							
165-319 m	4573.3	443.6	8703.0	(± 90%)	5281	0.9	
320-475 m	956.3	83.2	1829.5	(± 91%)	1466	0.7	
165-475 m	5515.8	1397.6	9633.9	(± 75%)	6736	0.8	37.7
1985							
165-319 m	1709.5	574.2	2844.8	(± 66%)	2484	0.7	34.5
320-475 m	318.0	145.7	490.4	(± 54%)	413	0.8	37.9
165-475 m	2027.5	880.6	3174.5	(± 57%)	2897	0.7	35.0
Columbia North							
1979							
165-319 m	1794.5	128.2	3460.8	(± 93%)	2037	0.9	
320-475 m	123.4	0	398.0	(± 223%)	143	0.9	
165-475 m	1917.9	249.6	3586.2	(± 87%)	2180	0.9	38.6
1985							
165-319 m	2739.4	1889.2	3589.5	(± 31%)	3390	0.8	37.2
320-475 m	76.0	50.6	101.3	(± 33%)	87	0.9	39.9
165-475 m	2815.3	1964.8	3665.8	(± 30%)	3477	0.8	37.2
Columbia Middle							
1979							
165-319 m	1905.1	0	4239.2	(± 123%)	3044	0.6	
320-420 m	45.2	6.6	83.9	(± 86%)	61	0.7	
165-420 m	1950.3	0	4284.7	(± 120%)	3105	0.6	35.2
1985							
165-319 m	2327.9	783.5	3872.4	(± 66%)	2989	0.8	36.7
320-420 m	136.8	0	335.8	(± 145%)	185	0.7	37.2
165-420 m	2464.7	918.6	4010.8	(± 63%)	3174	0.8	36.7
Columbia South							
1979							
165-319 m	2968.1	853.9	5082.3	(± 71%)	5695	0.5	
320-420 m	3691.3	1082.9	6299.7	(± 71%)	5416	0.7	
165-420 m	6659.4	3359.1	9959.7	(± 50%)	11112	0.6	34.6
1985							
165-319 m	1229.2	533.9	1924.6	(± 57%)	2323	0.5	31.8
320-420 m	2143.6	1114.6	3172.5	(± 48%)	2724	0.8	35.0
165-420 m	3372.8	2153.1	4592.5	(± 36%)	5046	0.7	35.0
Columbia Total							
1979							
165-319 m	6667.7	3266.4	10069.0	(± 51%)	10776	0.6	
320-420 m or 475 m	3859.9	1269.8	6450.0	(± 67%)	5620	0.7	
165-420 m or 475 m	10527.6	6323.9	14731.3	(± 40%)	16397	0.6	35.2
1985							
165-319 m	6296.5	4441.3	8151.8	(± 29%)	8701	0.7	35.6
320-420 m	2371.5	1339.8	3403.2	(± 44%)	3015	0.8	37.8
165-420 m	8668.0	6577.6	10758.5	(± 24%)	11716	0.7	36.1

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[1] 1979 estimates based on survey depths of 165-475 m north of the Columbia River and 165-420 m south of the Columbia River; Noreastern trawl catch rates were used north of the river, 400 Eastern trawl catch rates between the river and 45°22' N lat., and Mystic trawl catch rates south of 45°22' N lat.

[2] This analysis of the 1985 data incorporates adjustments to make the results as closely comparable to the 1979 results as possible. Survey depths used in the analysis were 165-475 m north of the Columbia River and 165-420 m south of the river. Noreastern trawl catch rates were used in all areas except the Columbia South where Noreastern trawl catch rates were adjusted to Mystic trawl catch rates by multiplying them by 2.64. Consequently, the Columbia Total estimates also reflect the use of Mystic trawl catch rates in the Columbia South area.

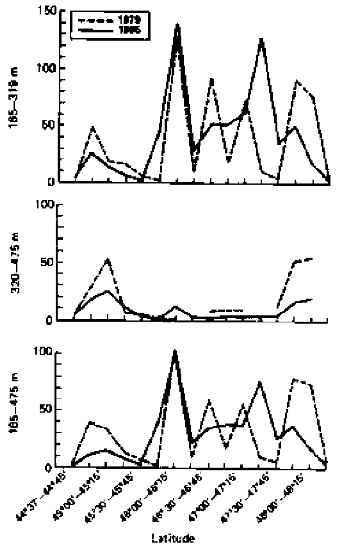

Figure 8.--The latitudinal distribution of Pacific ocean perch in 1979 and 1985 (survey results) shown by mean catch per unit effort by 15 minute latitude intervals.

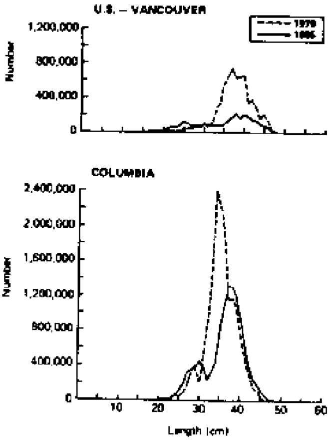

Figure 9.--The population size composition of Pacific ocean perch in 1979 and 1985 (survey results) in the International North Pacific Fisheries Commission Vancouver (U.S. portion) and Columbia areas. The 1985 results have been adjusted to Mystic catch rates in the Columbia South subarea and depth coverage to 420 m off Oregon for comparison with the results of the 1979 survey.

in 1985. The more uniform distribution of the population and more consistent sampling procedures were undoubtedly major factors in the improved precision of the 1985 abundance estimates.

Major differences are evident between the population size composition estimates from the two surveys (Fig. 9). The majority of the 1979 population in the U.S.-Vancouver area composed a mode at 34-42 cm. The 1985 population was spread more evenly between 22 and 46 cm. The population size composition in the Columbia area was bimodal in 1985 with a major mode at 34-42 cm and a smaller mode at 27-31 cm. The large mode of 34 cm fish seen in 1979 appears to be still relatively strong 6 years later as larger (36-41 cm) fish. Slightly more small fish (20-30 cm) were seen in both areas during 1985 than in 1979, suggesting that recruitment in recent years may be better than it was in the late 1970s. Larger fish dominated the size composition in the deep strata consistently in both years and all areas, a pattern seen in many rockfish species.

The proportion of males in the population increased notably from 47.84% in 1979 to 53.78% in 1985. This change in sex ratio was consistent in all strata (Table 5). The proportion of males in the shallow zone of the Columbia area was higher than in the deep zone, although the opposite trend was found in the U.S.-Vancouver area. This pattern occurred during both survey years.

The age composition of the population looks quite different between the two survey years, although the use of different ageing methods confounded the comparison. The maximum ages estimated from the 1985 otolith sample were much older than those estimated from the 1979 sample (76 vs. 26 years). Results from the 2 years can only be compared to about age 15, since there is relatively good agreement between surface- and section-aged observations from the same otolith up to that point (Beamish 1979b). The abundance of the older age classes, even within this range, is usually overestimated by using surface-aged data. The 1985 age composition in the U.S.-Vancouver area shows slightly more young fish (4-6 years) than in 1979, although the older fish are much less abundant. Young fish (5-6 years) are also slightly more abundant in the Columbia area in 1985, but the strong year classes of the early 1970s (ages 10-15 in 1985) still make up a significant part of the population. The growth curves were not compared between years because the 1979 surface-aged data would be misleading.

Discussion

The most difficult problem faced in the comparison of the 1979 and 1985 survey results was relating abundance estimates which had been derived from catch rates of two or three different types of trawls. Since no information is available to relate the fishing power of the Noreastern trawl to that of the 400-mesh Eastern trawl used in the Columbia Middle subarea in 1979, the comparison of catch rates in that subarea is unreliable. The results of the comparative fishing experiment in the Columbia South subarea indicated that the Mystic trawl, with only one-half the mouth opening area of the Noreastern, was over two and one-half times as effective at catching POP. Similar relative fishing power factors were calculated for the slope complex and for all rockfish species combined. Further, despite the small-mesh codend liner used only with the Noreastern, there was no detectable difference in the size composition of perch caught by the two nets.

The difference between the catch rates of these nets may be related to the way the width of the effective fishing path is estimated. While the fishing path of a trawl is usually assumed to be the distance between wingtips of the net itself, some studies (Carrothers 1981; Foster et al. 1981; Harden Jones et al. 1977; Main and Sangster 1983) recognize that a considerable herding effect may result from the mud clouds created by the trawl doors and dandylines and that a more appropriate measure of the effective fishing path might be the distance between the trawl doors or some function of that distance. The dandylines used with the Mystic trawl were 33% longer than those used with the Noreastern. Generally, longer dandylines will allow the doors to spread wider, although direct measurement would be necessary to determine the effect. The doorspread would also likely be affected by the relative resistances of the two nets moving through the water. Presumably the smaller Mystic net, with no small-mesh codend liner, would encounter significantly less resistance, allowing the doors to spread wider. These factors probably increased the Mystic trawl's effective path width, which may partly explain that net's greater fishing power, even though its actual dimensions are smaller than the Noreastern's.

The validity of these relative fishing power estimates should be further examined. Pacific ocean perch and many other rockfish species are noted for having very contagious distributions and, consequently, large variances are usually associated with mean catch rates for these species and wide confidence intervals accompany abundance estimates. Additionally, comparative fishing experiments require the results of many trawl hauls in order to dampen the effects of this variability. The experiment conducted in 1985 involved relatively few tows covering a wide depth range over which abundance varied substantially. More samples would probably have reduced the effect of distribution and yielded a more representative comparison of fishing power. Although the comparative fishing data is relatively limited, it allows us to compare the results of the two surveys in the Columbia South subarea.

The weakest assumption made during the analysis was that the net was capturing all fish encountered by the net mouth. This weakness is common to all trawl surveys and will continue to be until reliable relationships between fish behavior and sampling gear can be established. We have also assumed that the stocks were fully available in the survey area during the survey period, which is usually a weak assumption. Consequently, the results of resource trawl surveys must be considered to be conservative and should be viewed as such by resource managers.

The length composition of Pacific ocean perch samples from hauls made with each type of trawl were similar enough to conclude that the various components of the population (sex, size, and age groups) were being sampled in the same proportions by both gears. Estimates of size and age composition and sex ratio are probably not affected by pooling the biological data collected by both types of gear.

Abundance estimates were more precise in 1985 than in 1979. The distribution of the population was more uniform in 1985 (Figs. 7, 8). Some sources of sampling variability were also removed by conducting the survey with one vessel, a standardized trawl, and a standardized survey pattern throughout the study area. These two factors were probably responsible for much of this improved precision.

Biomass, population, and size composition (population number at each size class) are all calculated by the same area-swept algorithm and subject to the same assumptions. The catch rates and biological data are assumed to truly reflect the abundance and composition of the population being sampled and the fishing gear is assumed to be sampling the population consistently. The variance and confidence intervals calculated for these estimates should accurately reflect the sampling variance, including the distributional variability of the population.

The accuracy of resource surveys can usually be appraised only by comparing their results with those from assessments which use other methods and data bases. Fortunately, the POP resource in the INPFC Vancouver and Columbia areas has been monitored fairly closely since the mid-1960s and many independent assessments of the resource are available for various times during that period. In addition to surveys, abundance has been estimated by calculation of exploitable biomass (dividing catch by the estimated exploitation rate), extrapolation of commercial CPUE data to an "area-swept" estimate, cohort analysis, and most recently by stock reduction analysis. Abundance estimates from major assessment efforts are summarized in Figure 1. By all indications, the resource was sharply reduced by intense fishing in 1965-67 and continued to decline through the mid-1970s until foreign landings were prohibited.

The declines have slowed since then but continue despite restricted landings aimed at allowing the stocks to rebuild. Continuing declines were expected through at least 1975 because of the potential loss of reproductive capacity of the population (Quast 1972; Westrheim et al. 1972).

The cohort analyses performed by Gunderson (1979, 1981) predicted that Pacific ocean perch stocks could be rebuilt if harvests were limited to low levels for approximately 20 years. Using the assumptions from those analyses and landing statistics, the stocks in the U.S.-Vancouver and Columbia areas should have increased by 80% and 43%, respectively, between 1979 and 1985. The survey results show the opposite trend. The differences between predicted biomass and survey biomass estimates was significant (alpha = 0.05 and test value = 1.96) in both INPFC areas. The U.S.-Vancouver stock declined from 5,516 t to 2,208 t instead of rebuilding to a predicted level of 9,936 t (Z = -12.38). The Columbia stock declined from 10,528 to 8,668 t instead of increasing to 15,081 t (Z = -5.13). Results of a new cohort analysis and stock reduction analysis (Ito et al. 1986) support the conclusion that the stocks have not rebuilt and are possibly smaller than when the rebuilding plan was implemented. Gunderson assumed that recruitment to these stocks would be constant and equal to the mean recruitment of the 1956-68 year classes (3,297 and 2,236 t in the Vancouver and Columbia areas, respectively). Stock reduction analysis (Ito et al. 1986) indicates that these recruitment estimates were too high and determined average recruitment to these stocks to have been about 2,000 t annually in each area. The natural mortality estimates used in Gunderson's calculations may also have been overestimated since recent evidence shows POP to be a much longer-lived species than previously believed (Beamish 1979b; Chilton and Beamish 1982). The natural mortality rate is probably closer to 0.05 than the 0.15 or 0.10 Gunderson used for the Vancouver and Columbia areas, respectively (Archibald et al. 1981, 1983; Shaw and Archibald 1981; Ito et al. 1986).

Another reason stocks have failed to rebuild is that fishing mortality probably has been underestimated. The POP fishery has long been subject to significant discards of fish smaller than the market will accept. Enforcement of trip limits aimed at reducing landings have probably aggravated this problem. Discard rates of domestic trawlers have only recently been researched and evaluated and seem to be quite variable depending on the season and the fishing strategy being pursued. Data collected by observers aboard domestic bottom rockfish trawlers off Newport, Oregon, indicate discard rates of approximately 24.8% in weight and number for POP during fourteen trips in July through September, 1985 (Pikitch, this volume). The within-trip discard pattern suggested a tendency for all POP to be retained near the beginning of the trip until the limit was approximately met, after which nearly all were discarded. Discard rates were lower for the periods October-December 1985 and January-June 1986 and also for other fishing strategies (midwater, nearshore mixed species, and deepwater Dover sole fisheries) due to lower POP catch rates. The survival of discarded rockfish is negligible due to physiological damage from expanding air bladders when the fish are brought to the surface. Consequently, when adjusted for discard rates, removals from the population could actually exceed reported landings by more than 20% for some segments of the trawl fishery.

Rebuilding in the U.S.-Vancouver area may also have been thwarted when Canadian fishery managers allowed an experimental overharvest of Pacific ocean perch in the Canadian zone of the Vancouver area between 1980 and 1983 (Stocker 1981). The purpose of this policy was to evaluate the stock's sensitivity to large relative, though small absolute, changes in landings. Researchers believed that due to the already severe depletion of the stock, "the penalty for error in such a system would be much lower than in other *S. alutus* stocks, while the potential benefits to our understanding of stock dynamics may be large." Results of Canadian trawl surveys show that the POP stocks in the Canadian sector of the Vancouver area have apparently declined by 56% between 1979 and 1985 (B.M. Leaman, Pacific Biological Station, Nanaimo, B.C., Canada, personal communication). Although this experiment was limited to Canadian waters, it is possible that it has contributed to the apparent 63% decline in the resource's abundance in the U.S. portion of the Vancouver area.

The effects of discard rates, overestimated recruitment, and the Canadian overfishing experiment would lead one to expect less stock rebuilding than predicted by Gunderson's cohort analyses. On the other hand, overestimating natural mortality for the cohort analyses would have led to an underestimate of the stock's potential to rebuild itself, but would have also led to underestimates of fishing mortality (since $F = Z - M$) and, consequently, underestimates of exploitation rates. The net result could likely be consistent with the declines in abundance shown by the survey results. The most probable rebuilding scenario examined by Ito et al. (1986) indicated that it would take at least 50 years for the stocks in the Vancouver and Columbia areas to rebuild to a level (25,000 t in each area) at which they could produce maximum sustainable yield.

In conclusion, all evidence suggests that the Pacific ocean perch resource off Washington and Oregon remains in poor condition and has even taken a serious turn for the worse in the U.S.-Vancouver area. The apparent 63% decline in biomass in the U.S.-Vancouver area between 1979 and 1985 was substantiated by a corresponding 56% decline in the Canadian portion of that area. The survey results and those of recent cohort and stock reduction analyses show that landing restrictions have not resulted in increased stock size as predicted, but the stocks appear to be declining further despite the regulations. Biomass levels are currently only about 5-10% of the virgin biomass in both areas and recruitment failure at these low levels is a strong possibility (Ito et al. 1986). Without increased catch restrictions and favorable recruitment, this resource may well decline to the point where interspecific competition and economic costs of rebuilding programs will seriously impede rebuilding these stocks to productive levels.

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Appendix.--Summary of results of fishing power comparison between the Noreastern and Mystic trawls in the Columbia South subarea during the 1985 Pacific ocean perch survey. Only species determined to require fishing power correction factors are included in this summary. Catch rates (kg/km trawled) and fishing power conversion factors are calculated by dividing the sum of the catch by the sum of the effort.

	Catch rates (kg/km)		Conversion factor	
Species	NE	Mystic	Mystic to NE	NE to mystic
Rockfish				
Pacific ocean perch	6.12	16.14	0.38	2.64
Rougheye rockfish	0.95	4.40	0.22	4.61
Shortspine thornyhead	8.16	18.53	0.44	2.27
Splitnose rockfish	4.25	19.28	0.22	4.54
Other roundfish				
Eulachon	0.24	0.01	17.95	0.06
Sablefish	23.81	77.60	0.31	3.26
Flatfish				
Dover sole	7.46	25.50	0.29	3.42
Rex sole	2.98	5.43	0.55	1.83
Slender sole	0.40	0.06	7.01	0.14
Cartilaginous fish				
Longnose skate	0.65	3.08	0.21	4.76
Spiny dogfish	0.06	0.24	0.27	3.66
Spotted ratfish	0.12	0.69	0.18	5.66
Invertebrates				
Brisaster latifrons	0.73	0.01	86.63	0.01
Orange-pink sea urchin	11.95	0.06	202.63	0.005
Sea cucumber	0.68	0.002	403.51	0.002
Squid	0.05	0.005	10.03	0.10
Starfish	0.39	0.02	23.44	0.04

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Rockfish in the Aleutian Islands: Results from the 1980 and 1983 U.S.-Japan cooperative demersal trawl surveys

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Abstract

The Aleutian Islands region is an important habitat for the rockfish resource found along the Outer Continental Shelf and upper slope of the North Pacific Ocean and the Bering Sea. The dominant rockfish species found to inhabit the Aleutian Islands from trawl surveys is the Pacific Ocean perch (Sebastes alutus) followed in lesser concentrations by northern rockfish (S. polyspinis), shortraker rockfish (S. borealis), rougheye rockfish (S. aleutianus), and shortspine thornyhead (Sebastolobus alascanus).

In 1980, the National Marine Fisheries Service of the United States and the Far Seas Fisheries Research Laboratory of the Fisheries Agency of Japan conducted the first comprehensive resource assessment survey of the Aleutian Islands to collect information on the distribution and abundance of the principal groundfish species and to provide estimates of biomass and the biological stock parameters for each species. The survey area included the Continental Shelf and upper slope both north and south of the Aleutian Islands from Unimak Pass to Stalemate Bank with the sampling depth ranging from 31 to 919 m. Successful sampling was completed by three vessels at 319 trawl stations.

The survey was repeated in 1983 using a sampling plan which was developed to improve the precision of the biomass estimates based upon the the distribution and abundance of the principal species as determined by the 1980 survey. The 1983 survey had the same geographic and bathymetric coverage as in 1980 with 377 successful demersal trawl stations completed by three vessels chartered by the two nations' management agencies.

Biomass estimates were standardized to the U.S. Noreastern trawl for comparing survey results between years and provided Pacific ocean perch

estimates of 122,000 t and 152,000 t for 1980 and 1983, respectively. The 1980 and 1983 biomass results for other rockfish species closely associated with Pacific ocean perch were 9,000 and 17,000 t for northern rockfish; 8,000 t and 40,000 t for shortraker rockfish; and 16,000 t and 23,000 t for rougheye rockfish. Biomass estimates for shortspine thornyhead which inhabit the Continental Slope waters were 10,000 t for both survey years.

Introduction

The Northwest and Alaska Fisheries Center (NWAFC) of the U.S. National Marine Fisheries Service (NMFS) and the Far Seas Fisheries Research Laboratory of the Japan Fisheries Agency (JFA) conducted the first comprehensive systematic resource assessment survey of the Aleutian Islands during July-November 1980. The survey objectives were to collect information on the distribution and abundance of the principal groundfish and invertebrate species, to establish estimates of total trawlable or available biomass by species, and to define the biological stock parameters of each species and to ascertain how they change with time. Designed to be repeated every 3 years, the survey has established a time series of data to be used in management of the groundfish resource of the Aleutian Islands region and assessment of stock conditions in future years. This report summarizes the 1980 and 1983 survey results for the five dominant shelf and slope rockfish species.

The Aleutian Islands region is an important rockfish habitat area of the North Pacific Ocean and the eastern Bering Sea. This resource, which is primarily found along the Outer Continental Shelf and upper slope regions, is dominated by Pacific ocean perch (POP) (*Sebastes alutus*), followed in lesser concentrations by northern rockfish (*S. polyspinis*), shortraker rockfish (*S. borealis*), rougheye rockfish (*S. aleutianus*), and shortspine thornyhead (*Sebastolobus alascanus*). With the exception of northern rockfish, these species are captured in North Pacific waters from central California northward through the Gulf of Alaska, the Aleutian Islands, and the Bering Sea. Northern rockfish, with a more limited distribution, are found in the Gulf of Alaska from Yakutat westward to the Aleutian Islands and north to the Bering Sea. Nine species of rockfish were encountered during the 1980 and 1983 Aleutian Islands trawl surveys (Table 1).

Table 1.--Total weight* (lbs.) of the rockfish species encountered during the 1980 and 1983 cooperative U.S.-Japan groundfish trawl surveys.

Species	Year 1980	Year 1983
Pacific ocean perch	116,057.0	187,268.0
Northern rockfish	6,850.6	40,005.4
Rougheye rockfish	11,139.0	13,577.8
Shortraker rockfish	9,411.1	71,988.8
Shortspine thornyhead	17,172.5	8,750.3
Dusky rockfish	1,424.2	581.6
Yelloweye rockfish	47.5	14.3
Harlequin rockfish	3.5	9.3
Sebastolobus macrochir	4.5	31.1

*Catch weights are standardized by trawl width to the U.S. Noreastern trawl.

Rockfish resources have supported major Japanese and Soviet trawl fisheries in the Aleutian Islands, and to a lesser extent in the Bering Sea, since 1962. Foreign reported commercial catches in the

Aleutian Islands of species of the Pacific ocean perch complex peaked in 1965 at 109,000 metric tons (t) (Table 2) and have declined steadily since. For 1986 the domestic quota in the Aleutian Islands and Bering Sea International North Pacific Fisheries Commission (INPFC) management area for species of the POP complex is set at 6,8000 t and these species now support one of the few fisheries fully utilized by domestic trawlers in the Bering Sea-Aleutian Islands and the Gulf of Alaska management regions.

Table 2.--Annual foreign catch (t) of rockfish of the Pacific ocean perch complex[a] from the eastern Bering Sea and the Aleutian Islands.

Year	Eastern[b] Bering Sea	Aleutian[c] Islands	Year	Eastern Bering Sea	Aleutian Islands
1962	19,900	200	1974	14,000	22,500
1963	24,500	20,800	1975	8,600	16,600
1964	25,900	90,300	1976	14,300	14,250
1965	16,800	109,100	1977	4,600	13,200
1966	20,200	85,900	1978	2,400	10,500
1967	19,600	55,900	1979	1,700	8,800
1968	31,500	44,900	1980	1,100	8,200
1969	14,500	38,800	1981	1,200	4,000
1970	9,900	66,900	1982	200	5,600
1971	9,800	21,800	1983	200	700
1972	5,700	33,200	1984	300	625
1973	3,700	11,800			

[a] May include *Sebastes alutus*, *S. polyspinis*, *S. aleutianus*, *S. zacentrus*, and *S. borealis*.

[b] Source: Bakkala et al. (1980) for catches through 1977, catches for 1978-84 are from U.S. observer program blend estimates (Nelson et al. 1979, 1980, 1981b, 1982, 1983a; Berger et al. 1984, 1985b).

[c] Source: Bakkala et al. (1980) for catches through 1977.

The earliest fishery investigations of the resources of the Aleutian Islands were conducted by the U.S. Fish Commission steamer Albatross in 1896. The Soviet Union implemented several scientific expeditions into the island chain during the 1960s to compile information on the seasonal changes in the hydrography of the region and to organize future fisheries for flounders, rockfish, and Atka mackerel. The Japan Fisheries Agency (JFA) also performed several limited-scale otter trawl surveys of the Aleutian Islands in the early 1970s primarily to collect information on the biological characteristics of the groundfish species.

Survey Methodology

Since neither the National Marine Fisheries Service nor the Japan Fisheries Agency had conducted an extensive trawl survey of the Aleutian Islands prior to 1980, little data were available to provide information on groundfish and invertebrate distributions needed to formulate an effective sampling plan. For this reason a sampling plan was developed which assured a wide geographic and bathymetric coverage of the survey area with maximum sampling density in the time allotted (Wilderbuer et al. 1985). The Continental Shelf and upper slope regions north and south of the Aleutian Islands from Stalemate Bank to Unimak Pass were divided into sampling sections 30 minutes of longitude wide. Each sampling section was further divided into six depth intervals:

1-100 m (1-54 fathoms)
101-200 m (55-108 fathoms)
201-300 m (109-162 fathoms)
301-500 m (163-273 fathoms)
501-700 m (274-382 fathoms)
701-900 m (383-492 fathoms)

One trawl station was assigned to each depth interval of each sampling section. In sampling sections where the depth intervals were over 5 nautical miles (nmi) wide, additional sampling was designated as follows:

5 to 10 nmi wide - 1 additional station
11 to 15 nmi wide - 2 additional stations
16 to 20 nmi wide - 3 additional stations

The total survey area extended over three International North Pacific Fisheries Commission (INPFC) statistical areas: The southern portion of the southeastern Bering Sea area; the Aleutian Islands area including Bowers Ridge; and the western portion of the Shumagin area. The survey was analyzed and is presented by these three distinct areas with the Aleutian Islands region further divided at 180 degrees longitude into the northwest, northeast, southwest and southeast subareas (Fig. 1). The survey area north of 53 degrees N latitude is the Bowers Ridge subarea.

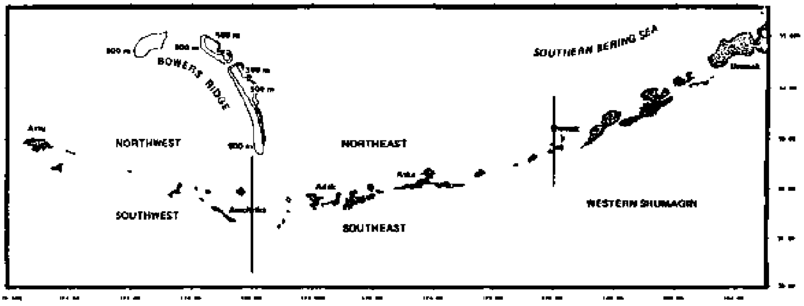

Figure 1.--Survey area and anlytical subareas of the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

Three vessels were chartered by the two research agencies to perform the survey in 1980. Both U.S. vessels, the Half Moon Bay and the Ocean Harvester are 32.9 m (108 ft) west coast type combination crabber/trawlers which completed 129 and 89 on-station bottom trawls, respectively. The Hatsue Maru No. 62, a 46.6 m (153 ft) land-based stern trawler, was the principal participant during the survey completing 217 demersal trawl stations.

All bottom trawling by the U.S. chartered vessels was conducted with a Noreastern trawl (27.4/32 trawl) with roller gear. The headrope and footrope were 27.4 and 32 m long, respectively, with vertical and horizontal openings of 6.1 and 17.9 m, respectively. The Noreastern trawl was fished with 1.8 x 2.7 m steel V-type otter boards and triple 54.9 m dandylines; the codend was lined with 1-1/2 inch stretched mesh nylon webbing.

Two Japanese commercial trawls were used by the Hatsue Maru No. 62 during the survey. A 31.8 m headrope trawl (32/44 trawl) was fished during the first half and was later replaced by a 54.8 m headrope trawl (55/65 trawl) during the second half. Both trawls were equipped with roller gear constructed of 57 cm diameter car tires in the central portion and 53 cm diameter gum and steel bobbins along the wings. Vertical openings of the trawls used during the first and second halves of the survey were 5.2 m and 4.5 m, respectively.

The average horizontal opening for the Japanese trawl was estimated at 21.6 m during the first leg and 28.5 m during the second leg. Both trawls were rigged with 82 m dandylines (a single 32 m section branching into two 50 m bridles) and fished with 2.2 m x 3.4 m otter boards weighing approximately 2,400 kg.

The groundfish survey was repeated in 1983 by the two research agencies with the following changes. In an attempt to improve the precision of the survey estimates, a sampling plan was developed based upon the distribution and abundance of the principal species as determined by the 1980 Aleutian Islands survey. Sampling density was increased in areas of highest fish abundance. Analytical areas were selected based upon the abundance of the principal species encountered during the 1980 survey, and sampling densities were allocated based on the variance of the abundance estimates using the Neyman allocation method (Cochran 1977). The resulting 1983 sampling distribution was then partitioned into the same longitudinal depth strata used in 1980.

Two NOAA research vessels, the Miller Freeman and the Chapman, and the Japanese stern trawler the Daito Maru No. 38, were used to conduct the 1983 Aleutian Island survey. The Daito Maru No. 38, a 51.8 m (170 ft) Hokuten trawler and the principal participant in the survey, completed 263 survey stations. Both U.S. vessels had a more limited participation. The Miller Freeman, a 65.6 m (215 ft) stern trawler, completed 99 survey stations while the Chapman, a 38.5 m (126 ft) research vessel, completed 63 survey stations. The sampling effort (number of successful stations) was 319 in 1980 and 377 in 1983 (Table 3).

All bottom trawling by the U.S. research vessels was conducted with the Noreastern trawl (27.4/32 trawl) with roller gear, the same gear used in 1980. A large Japanese commercial trawl was used by the Daito Maru No. 38 during the survey. The headrope and footrope were 45.0 and 58.0 m long, respectively, with a vertical opening of 5.0 m and a horizontal net opening of 28.3 m. The trawl was equipped with roller gear constructed of 35 and 53 cm gum bobbins and 30 and 41 cm gum discs. It was fished with 80 m dandylines and 2.25 x 3.45 m otter boards.

All research catches from the 1980 and 1983 surveys were processed using standard sampling techniques designed to assure random sampling of the principal species in the catch (Hughes 1976). Biomass estimates were calculated from the area-swept techniques (Alverson and Pereyra 1969) using only catches from successfully completed survey stations. Fishing power differences between the U.S. and Japanese

Table 3.--Number of successfully completed bottom trawl survey stations, by subarea and depth, during the 1980 and 1983 cooperative U.S.-Japan resource assessment surveys of the Aleutian Islands region.

Area and Subarea	Depth (m)	1980	1983
Southwest	1-100	1	4
	101-200	21	36
	201-300	19	23
	301-500	22	13
	501-900	6	14
	1-900	69	90
Southeast	1-100	7	3
	101-200	26	30
	201-300	16	42
	301-500	15	13
	501-900	7	10
	1-900	66	84
Northwest	1-100	1	5
	101-200	6	13
	201-300	15	13
	301-500	8	7
	501-900	4	19
	1-900	34	57
Northeast	1-100	6	8
	101-200	21	46
	201-300	17	21
	301-500	12	10
	501-900	5	17
	1-900	61	103
Bowers Ridge	1-100	--	--
	101-200	2	2
	201-300	5	2
	301-500	4	5
	501-900	19	11
	1-900	30	20
Southern Bering Sea	1-100	11	15
	101-200	12	14
	201-300	5	8
	301-500	5	3
	501-900	3	3
	1-900	36	41
	Total	292	377
Western Shumagin	1-100	8	*
	101-200	9	
	201-300	3	
	301-500	4	
	501-900	3	
	1-900	27	
	Grand Total	319	377

* Not sampled during the 1983 Aleutian Islands survey.

vessels and gear were analyzed using catch data from 26 pairs of U.S. and Japanese trawl stations conducted within a 2-week time period and classified as comparative trawl hauls. Relative fishing power correction factors were calculated from the ratio of the mean catch per unit effort (CPUE) of the two trawls and were applied to species catch rates which varied between the U.S. Noreastern trawl and the Japanese commercial trawl.

Fishing power differences between the U.S. and Japanese trawls in 1983 were analyzed as in 1980 with the 1983 relative fishing power correction factors calculated from 42 paired survey stations classified as comparative trawl hauls. Since the Noreastern trawl was fished on the U.S. vessels during both survey years, CPUEs were standardized to the Noreastern trawl to provide a comparison between the 1980 and 1983 surveys.

Results

Pacific ocean perch was found to be the most abundant rockfish species inhabiting the Aleutian Islands region, comprising 73 and 62.5% of the estimated biomass of the dominant rockfish species from the 1980 and 1983 surveys, respectively (Tables 4, 5). Following in magnitude of the rockfish resource were shortraker rockfish, rougheye rockfish, and northern rockfish. Shortspine thornyhead had the lowest estimated biomass of the dominant rockfish species averaged over both survey years.

Table 4.--Estimated biomass (t) by subarea of the major shelf rockfish species encountered during the 1980 and 1983 cooperative U.S.-Japan groundfish trawl surveys of the Aleutian Islands.

	Species									
	Pacific ocean perch		Shortraker rockfish		Northern rockfish		Rougheye rockfish		Shortspine thornyhead	
Subarea	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
Southwest	21,174	26,852	1,416	7,431	2,331	6,030	2,828	4,937	5,412	2,908
Southeast	31,043	41,772	1,969	5,374	6,058	4,136	6,842	3,804	392	1,433
Northwest	16,222	2,425	1,763	3,157	118	5,322	1,441	1,295	2,374	2,058
Northeast	46,872	16,235	2,384	10,622	546	802	4,514	7,605	773	1,199
Bowers Ridge	46	3,915	271	760	0	376	174	2,940	1,359	1,758
Southern Bering Sea	6,812	61,703	448	12,813	121	568	440	2,830	574	873
Total	122,169	152,902	8,251	40,157	9,174	17,234	16,239	23,411	10,884	10,229

Pacific ocean perch.

Distribution and abundance. Pacific ocean perch were found to be distributed throughout the survey area in 1980 and 1983, occurring in concentrations on the average 10 times more dense than the other dominant rockfish species (Tables 6, 7). Highest average CPUE values were found in the eastern Aleutian Islands during both survey years, with less consistent density estimates resulting from the western

Table 5.--Estimated biomass (t) by depth interval of the major shelf rockfish species encountered during the 1980 and 1983 cooperative U.S.-Japan groundfish trawl surveys of the Aleutian Islands.

	Species									
	Pacific ocean perch		Shortraker rockfish		Northern rockfish		Rougheye rockfish		Shortspine thornyhead	
Depth (m)	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
1-100	332	450	43	74	59	10,776	1,051	90	61	22
101-200	43,004	98,001	92	179	8,785	6,092	863	2,829	171	20
201-300	63,715	52,347	485	1,070	313	230	2,083	5,988	393	238
301-500	15,056	2,100	6,797	34,776	11	136	11,938	14,298	1,475	2,688
501-900	62	4	844	4,058	6	0	304	206	8,784	7,261
Total	122,169	152,902	8,251	40,157	9,174	17,234	16,239	23,411	10,884	10,229

Table 6.--Mean catch per unit effort (kg/ha) by subarea of the major shelf and slope rockfish species encountered during the 1980 and 1983 cooperative U.S.-Japan groundfish trawl surveys of the Aleutian Islands.

	Species									
	Pacific ocean perch		Shortraker rockfish		Northern rockfish		Rougheye rockfish		Shortspine thornyhead	
Subarea	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
Southwest	8.97	12.66	0.60	3.50	0.99	2.84	1.23	2.12	2.29	1.37
Southeast	14.81	20.90	0.93	2.68	2.89	2.06	3.26	1.90	0.19	0.71
Northwest	11.56	1.62	1.26	2.11	0.08	3.55	1.03	0.86	1.69	1.37
Northeast	20.83	7.36	1.06	4.82	0.24	0.36	2.01	3.45	0.34	0.54
Bowers Ridge	0.05	3.81	0.27	0.74	0.00	0.36	0.18	2.96	1.37	1.71
Southern Bering Sea	5.38	48.81	0.35	10.13	0.10	0.44	0.35	2.23	0.45	0.69
Overall	19.09	15.13	0.70	3.97	0.89	1.70	1.62	2.32	1.43	1.01

Aleutians. Sampling in the southern Bering Sea subarea resulted in the largest variation of estimates between years indicating sampling problems (Table 8). Pacific ocean perch were encountered in highest densities between 101 and 500 m in both survey years. Only trace amounts of POP were found in continental slope waters deeper than 500 m.

Survey catches indicate POP are found to occur together with the dominant Aleutian Islands rockfish species. Catches from waters less than 100 m deep are characterized by a POP-northern rockfish assemblage, in 101-500 m depths a POP-rougheye-shortraker assemblage, and a POP-rougheye-shortraker-shortspine thornyhead assemblage at depths greater than 500 m.

Table 7.--Mean catch per unit effort (kg/ha) by depth of the major shelf and slope rockfish species encountered in the Aleutian subareas during the 1980 and 1983 U.S.-Japan groundfish trawl surveys of the Aleutian Islands.

	Species									
	Pacific ocean perch		Shortraker rockfish		Northern rockfish		Rougheye rockfish		Shortspine thornyhead	
Depth (m)	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
1-100	0.17	0.28	0.02	0.05	0.03	6.72	0.54	0.06	0.03	0.01
101-200	19.38	42.35	0.04	0.08	3.96	2.63	0.39	1.22	0.08	0.01
201-300	49.24	40.54	0.37	0.83	0.24	0.18	1.61	4.64	0.30	0.18
301-500	9.32	1.30	4.21	21.60	0.01	0.08	7.39	8.88	0.91	1.67
501-900	0.02	0.00	0.32	1.23	0.00	0.00	0.12	0.06	3.06	2.21
Overall	19.09	15.13	0.70	4.06	0.89	1.70	1.62	2.31	1.43	1.01

Depth strata did include trace amounts.

Table 8.--Sampling error[a] (expressed as percentage of the mean biomass) by subarea of the major shelf rockfish species encountered during the 1980 and 1983 cooperative U.S.-Japan Aleutian Island demersal trawl surveys.

	Species									
	Pacific ocean perch		Shortraker rockfish		Northern rockfish		Rougheye rockfish		Shortspine thornyhead	
Subarea	1980	1983	1980	1983	1980	1983	1980	1983	1980	1983
Southwest	120	95	60	100	171	85	47	44	89	35
Southeast	156	65	61	110	199	325	85	172	88	59
Northwest	92	95	103	135	170	265	56	105	50	40
Northeast	66	76	89	186	92	111	86	139	87	310
Bowers Ridge	56	25	481	170	b	1150	c	944	67	55
Total Aleutian subareas	57	39	38	67	125	70	44	59	50	18
Southern Bering Sea	219	113	205	308	118	109	231	375	89	37
Total Survey Area	51	76	36	48	119	68	40	53	51	16

[a] Derived from 95% CI, where sample error = (Biomass(upper)-mean estimate)/mean estimate.

[b] No catch.

[c] Only one catch in this subarea, no variance computation.

To examine the variability in Pacific ocean perch CPUE from both surveys, an Analysis of Variance (ANOVA) was performed using the method of Rubin (Rubin 1982) to test for between-subarea effects and between-year effects in catch rate differences. Results indicate that for POP CPUE grouped by geographical subarea and year no significant differences exist between subareas and between years (Table 9). This indicates that either no statistically significant density difference exists for POP between analytical subareas and years, or that the trawl surveys were unable to detect any statistically significant changes that do exist.

Table 9.--Results of two-way Analysis of Variance for Pacific ocean perch catch per unit effort (CPUE) from two survey years using Rubin's method.

Description	Null Hypothesis (H_0)	Calculated F statistic	Probability of obtaining a smaller F statistic if H_0 is true	95% statistical significance
Analysis of CPUE by geographical subarea and year - fixed depth (12 strata)	Mean CPUE are equal for all subareas	0.02275	1.66%	non-significant
	Mean CPUE are equal for both years	0.02096	11.39%	non-significant
Analysis of CPUE by depth interval and year: - fixed geographical area ([illegible] strata)	Mean CPUE are equal by depth interval	0.07342	15.22%	non-significant
	Mean CPUE are equal for both years	0.00074	2.17%	non-significant

The analysis was repeated using POP CPUE data calculated for each depth interval pooled over the entire survey area and year (Table 9). Results show that the main effects due to depth distribution and year are also not statistically significant.

Although a cursory inspection of the estimated CPUE values appear quite different by depth, the large variances associated with the estimates and the small survey sample sizes mask the ability to detect statistically significant differences between depth stratum effects and the main effect due to year.

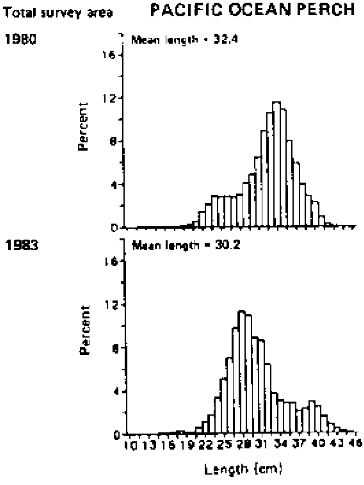

Figure 2.--Estimated size composition of Pacific ocean perch from the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

Size and age composition. The size and age structure of the Aleutian Islands POP stock is examined using figures presenting the size and age composition weighted by relative population density resulting from the 1980 and 1983 surveys (Fig. 2). For POP, size composition is also presented by subarea and depth for both survey years (Figs. 3, 4). Only age structures from POP collected during the 1983 survey have been

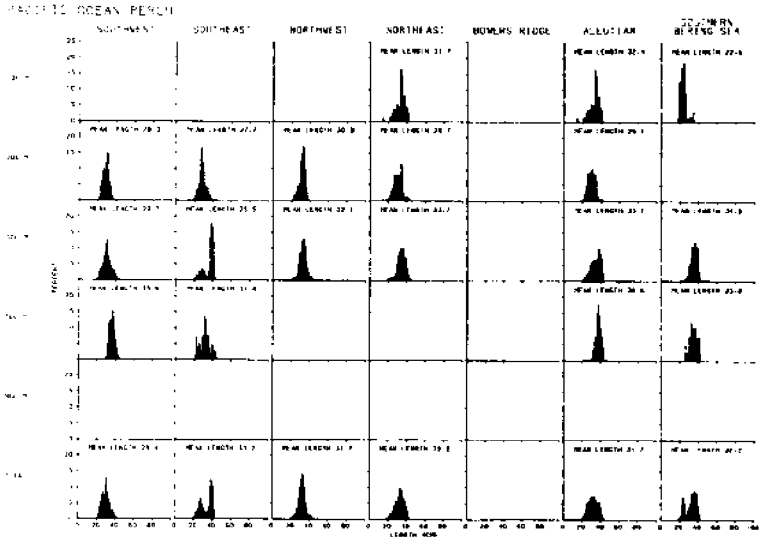

Figure 3.--Size composition of Pacific ocean perch by subarea and depth zone from the 1980 cooperative U.S.-Japan Aleutian Islands groundfish survey.

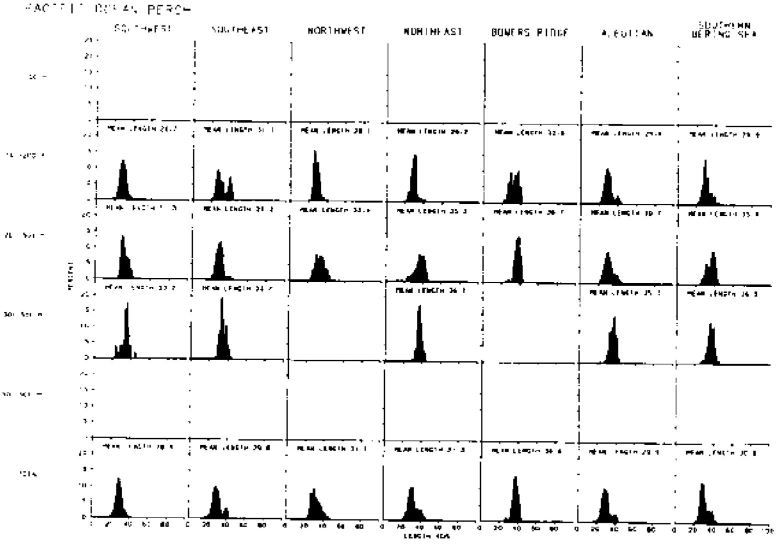

Figure 4.--Size composition of Pacific ocean perch by subarea and depth zone from the 1983 cooperative U.S.-Japan Aleutian Islands groundfish survey.

analyzed and are available for this report. The comparison of size composition of POP for the total survey area between years shows a decrease in mean length from 32.4 cm in 1980 to 30.2 cm in 1983 (Fig. 2). The dominant length mode of 33-35 cm contributed over 30% of the total stock in 1980 acompanied by a notable recruitment of smaller 22-26 cm perch. By 1983 these small perch believed to be the 1976 year class as shown by the 1983 age composition (Fig. 5), grew to occupy the dominant length mode of the stock (27-30 cm) comprising nearly 30% of the stock available to the demersal trawl. Only a trace amount of smaller fish (16-20 cm) were encountered in 1983, an indication that the 1976 year class is strong relative to the later year classes.

Survey results from both years indicate that the size structure of POP is different between the north and south side of the Aleutian Islands (Figs. 3, 4). The size composition of the southwest and southeast subareas contained mostly POP from the 1976 year class, resulting in smaller dominant mode lengths and mean lengths.

This was particularly noticeable in 1980, where the dominant length mode (33-35 cm) of larger fish was encountered in the northwest and northeast subareas, but was a less important component of the size composition of the south side of the Aleutian chain. The largest size POP were found in the Bowers Ridge subarea during the 1983 survey.

The distribution of size composition by depth shows POP are encountered in larger size with increasing depth, similar to many shelf and slope species. Without exception, mean lengths were larger in the 301-500 m depth interval than in the 101-200 m depth interval for all subareas in both survey years. Recruitment processes occurred in the 101-200 m depth interval throughout the 1980 survey but were only found to develop in shallow waters of the northeast subarea, and to a lesser extent the southeast and southwest subareas, in 1983.

Age data for Pacific ocean perch from NMFS resource assessment surveys are available from otolith readings. A sample of 1,519 otoliths from the 1983 Aleutian Islands survey were processed by the NWAFC age determination unit using the break-and-burn technique. The resulting age-length key was applied to POP size composition data from the total survey area in 1983 to calculate age composition (sexes combined). Figure 5 shows the estimated age composition of POP from the 1983 Aleutian Islands survey.

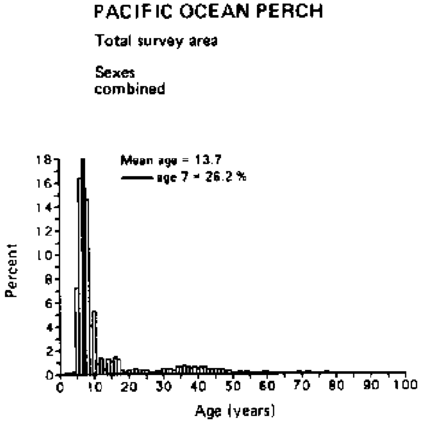

Figure 5.--Estimated age composition of Pacific ocean perch from 1,519 otoliths collected during the 1983 cooperative U.S.-Japan Aleutian Islands survey.

Pacific ocean perch ranged from age 1 to 98, with the dominant mode at age 7. Age 7 POP are the 1976 year class which comprised 26% of the estimated POP stock in 1983 and had an average length at age of 26.3 cm. Considering this and examining the size composition of POP in 1983 (Fig. 4), it appears age 7 POP were abundant throughout the survey area (except at Bowers Ridge), particularly at depths below 100 m.

Shortraker rockfish.

Distribution and abundance. Shortraker rockfish exhibit a widespread distribution throughout the Aleutian Islands and were encountered in all geographical subareas both survey years (Tables 4-7), but were found in much less dense concentrations than POP. The Bowers Ridge subarea produced the lowest average CPUE for shortraker rockfish both years. Similar to POP CPUE estimates, the largest variation in estimates between survey years for shortraker rockfish occurred in the southern Bering Sea subarea, an indication of further sampling problems (Table 8). By depth, shortraker rockfish were primarily distributed between 301 and 500 m and were commonly caught with POP and rougheye rockfish. Shortraker rockfish were found to decrease in abundance at depths less than 300 m, and also at depths greater than 500 m.

Size composition. The estimated size composition for shortraker rockfish captured throughout the survey area in 1980 and 1983 are presented in Figure 6. A broad length range was encountered both survey years with the mean length increasing from 41.4 cm in 1980 to 44.4 cm in 1983. The 1980 length composition was broadly unimodal with a nearly normal distribution of lengths about the mode at 37-46 cm. The increase in mean length in 1983 primarily resulted from an increase in shortraker rockfish larger than 65 cm as the length distribution broadened with modes at around 35 and 51 cm. The dominant length mode ranging from 33 to 39 cm in 1983 suggests some recruitment of smaller shortraker rockfish did occur after 1980.

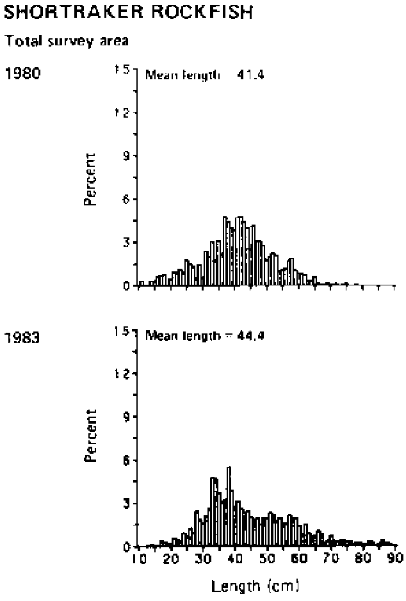

Figure 6.--Estimated size composition of shortraker rockfish from the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

Rougheye rockfish.

Distribution and abundance. Rougheye rockfish occured throughout the Aleutian Islands and were captured in all geographical subareas both survey years (Tables 4-7). Average CPUE values suggest that rougheye rockfish occur in much less dense concentrations than POP but are found in densities similar to shortraker, northern, and shortspine thornyhead rockfish. As with POP and shortraker rockfish estimates, the southern Bering Sea subarea produced the most variable results between survey years.

Rougheye rockfish were found to be distributed throughout all depths sampled both years with highest concentrations encountered in the 301-500 m depth interval where they are commonly caught with POP and shortraker rockfish. The survey estimate for rougheye rockfish in the Bowers Ridge subarea in 1983 (Table 8) shows unusually high confidence intervals about the biomass estimate, indicating severe sampling problems or a low level of density for rougheye rockfish in this subarea.

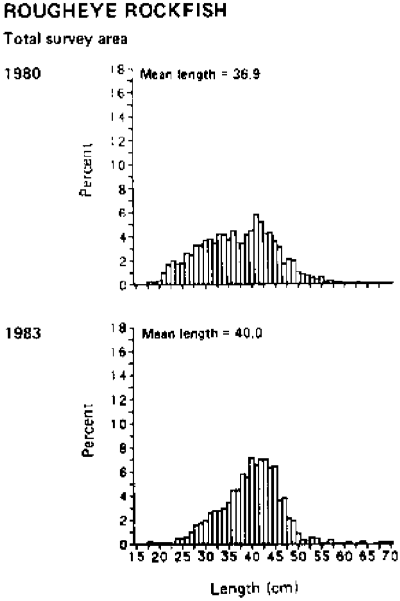

Figure 7.--Estimated size composition of rougheye rockfish from the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

Size composition. Survey results indicate the size structure of rougheye rockfish changed in the survey area between 1980 and 1983 (Fig. 7). Mean fish lengths increased from 36.9 cm in 1980 to 40.0 cm in 1983 as the features of the length distribution changed from broadly bimodal in 1980 (32 cm, 42 cm) to a more restricted unimodal distribution around 40.0 cm in 1983. The broad range of partially recruited rougheye rockfish less than 40.0 cm in length in 1980 appear fully recruited to the demersal trawl in 1983 contributing to the steepness of the dominant mode.

Northern rockfish.

Distribution and abundance. Northern rockfish are generally well distributed throughout the Continental Shelf and upper slope of the Aleutian Islands and are commonly encountered with POP (Tables 4-7). Preferring shallow waters of the Continental Shelf, highest densities of northern rockfish were found in waters less than 300 m deep. They were encountered in much lower densities in slope waters deeper than 300 m, and were absent in catches from depths greater than 500 m. Northern rockfish were not found at Bowers Ridge in 1980 and their presence in the 1983 survey at Bowers Ridge produced the highest variance by subarea of the dominant rockfish species from both surveys (Table 8). Since Bowers Ridge includes only depths greater than 100 m and was not allocated a dense sampling coverage (Table 3), the surveys did not adequately sample for northern rockfish in this subarea.

Size composition. The mean length of northern rockfish decreased from 32.2 cm in 1980 to 28.6 cm in 1983 as the size composition changed from being skewed toward larger fish in 1980 to smaller fish in 1983 (Fig. 8). Survey results indicate that some measure of recruitment to demersal trawl sampling did occur for northern rockfish after 1980 as

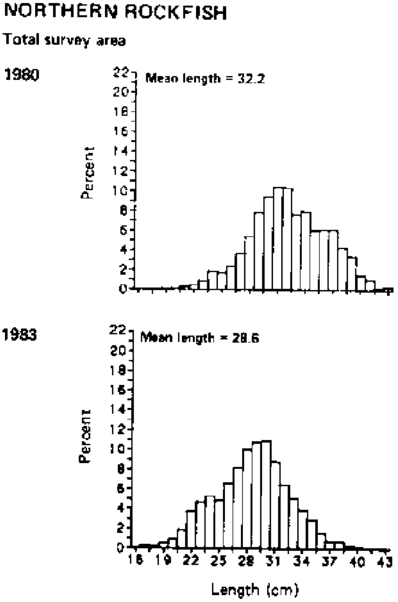

Figure 8.--Estimated size composition of northern rockfish from the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

fish in the length category less than 26 cm became a more important component of the size structure of the stock in 1983 compared to the size composition from the previous survey.

Shortspine thornyhead.

Distribution and abundance. Shortspine thornyhead were found on the Continental Shelf and slope in all subareas surveyed in 1980 and 1983 (Tables 4-7). Highest densities were found to occur in the western Aleutian subareas and Bowers Ridge with decreasing densities encountered in the eastern Aleutian Islands. Survey results indicate a broad depth range throughout the Aleutian Islands with highest densities occurring at depths deeper than 300 m. Shortspine thornyhead usually are present in catches with POP, rougheye, and shortraker rockfish but rarely are taken with northern rockfish due to the thornyhead's preference for deeper water.

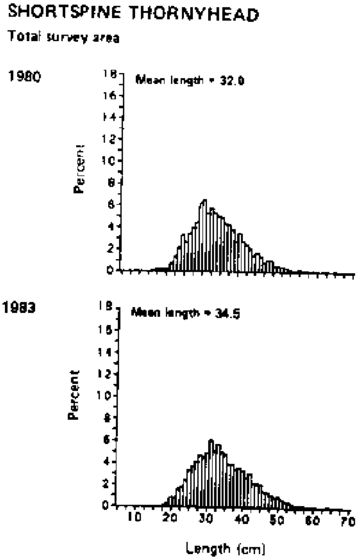

Figure 9.--Estimated size composition of shortspine thornyhead rockfish from the 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys.

Size composition. The change is size composition of shortspine thornyhead between 1980 and 1983 is characterized by slow growth with little recruitment (Fig. 9). The weighted length distribution from both survey years is unimodal with very similar symmetry about the mean length which increased from 32.0 cm in 1980 to 34.5 cm in 1983.

Discussion

To effectively discuss and evaluate the results of sampling marine rockfish populations with demersal trawl gear, consideration should include the results of other investigators who have dealt with similar problems in other geographical areas.

When the jurisdiction of fisheries management was extended to 200 miles off the U.S. coastline with the enactment of the Magnuson

Fishery Conservation and Management Act (1976), several pilot rockfish surveys were initiated to study the ability of trawl surveys to define and effectively sample shelf and slope rockfish resources (Gunderson and Nelson 1977). These surveys occurred in Monterey Bay, California and Queen Charlotte Sound, British Columbia and provided estimates of average CPUE and biomass. The resulting estimates showed very large variances for bank rockfish (Sebastes rufus) (Monterey Bay), and for canary rockfish (S. pinniger) and redstripe rockfish (S. proriger) (Queen Charlotte Sound). As in other trawl surveys (Grosslein 1969), variances associated with biomass estimates for many flatfish and roundfish species were reasonable (less than + 50% of the mean), but because of the prominent dense schooling behavior of most rockfish species, the precision involved in providing their abundance estimates is often poor.

This problem was taken into consideration when allocating sampling effort for the large-scale 1977 west coast whiting and rockfish trawl survey (Gunderson and Sample 1980) by scheduling more sampling in areas containing known rockfish populations as indicated from commercial rockfish landings. The survey was repeated in 1980 and 1983 with further use of commercial fishery catch data of canary rockfish and yellowtail rockfish (S. flavidus) to modify the allocation of survey effort (Weinberg et al. 1984).

Because of the high variability of rockfish bottom trawl survey estimates, the 3 years of west coast survey data were analyzed to determine if demersal trawl surveys could detect real interannual changes in rockfish population abundance (Knechtel 1986). Knechtel used a statistical test based on a method developed by Rubin (Rubin 1982) to estimate the probability of trawl surveys to detect specified interannual changes of canary rockfish population abundance using Monte Carlo simulations of 400 replicate sets of surveys. His results indicate that with a survey sample size of 500 stations allocated using a Neyman allocation the probability of detecting canary rockfish population changes that differ by a factor of 2 between survey years is only 56-60% and for a total sample size of 1,000 stations with the same allocation method the probability increases moderately to 82-86%. The method of survey station allocation was also found to be an important aspect of survey quality with the optimum allocation formula or Neyman allocation (using CPUE variance information from previous surveys) performing significantly better in simulations at detecting large population changes.

In the case of the Aleutian Islands surveys, the objective in 1980 was to perform an initial groundfish survey using a broad geographic and bathymetric sampling plan which was modified in 1983 to reduce the variances of the abundance estimates of the five most abundant species encountered in 1980. Although POP were among the five most abundant species in 1980, the 1983 survey allocation was also influenced by various roundfish species distributions (pollock, Theragra chalcogramma; Pacific cod, Gadus macrocephalus; sablefish, Anoplopoma fimbria; Atka mackerel, Pleurogrammus monopterygius) and was not designed to provide the optimum sampling allocation to produce the most precise rockfish biomass and density estimates.

Similar to the results of other bottom trawl surveys for rockfish, the 1980 and 1983 Aleutian Islands survey results show high variances for rockfish biomass estimates (Table 8). This is primarily due to the contagious spatial distribution characterized by most rockfish species resulting in their nonuniform distribution over the fishing grounds and also because of the general untrawlability of their habitat. This is reflected in the distribution of catch rates for POP from the surveys (Fig. 10) where results indicate that large catches of POP are uncommon events with POP frequently absent from the catch or only encountered in small amounts. These uncommon or rare catches can increase CPUE and biomass estimates and their variability within survey subareas and should be viewed with caution in consideration of the high variability of the estimates, the small survey sample sizes, and the multispecies allocation of survey effort.

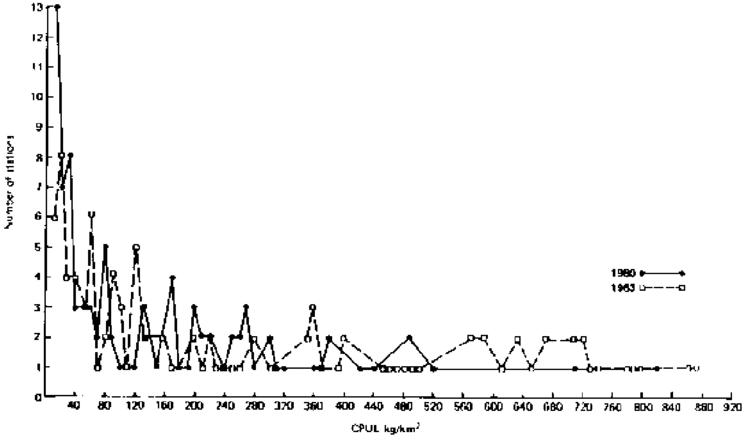

Figure 10.--Frequency distribution of Pacific ocean perch CPUE (kg/km²) from the 1980 and 1983 cooperative Aleutian Islands surveys. (Zero catches not included.)

An effective evaluation of trawl survey results and limitations to the data must also include a discussion of the factors which affect the accuracy and precision of bottom trawl surveys. Since this subject has been described in detail in other papers (Wakabayashi and Bakkala 1985 West 1985), only factors of interest pertinent to the 1980 and 1983 Aleutian Islands surveys will be discussed here.

In order to obtain valid estimates of density and abundance from demersal trawl surveys, certain assumptions concerning trawling and fish behavior must be met. The species of interest must be available, vulnerable, and selected by the trawl, and the sampling gear must sample the total geographic and bathymetric range inhabited by the species. The 1980 and 1983 cooperative U.S.-Japan Aleutian Islands surveys were constrained by money available for sampling, manpower to effectively staff research cruises, the availability of suitable fishing vessels and knowledgeable trawl masters at the time of charter, and seasonal weather conditions throughout the Aleutian Archipelago, all of which may severely limit sampling time and reduce sample sizes.

Because of the time and money constraints, survey effort may have been inadequate to effectively sample rockfish such as shortspine thornyhead since their total depth range may lie outside the 1-900 m depth range sampled. Rockfish movements in and out and within the survey area, the complete lack of winter sampling, diurnal fish behavior, and rockfish habitat unavailable to bottom trawling also limit the effectiveness of demersal trawl survey results. Also, without the participation of the large Japanese vessels and their commercial trawls, the Aleutian Islands rockfish resource would not have been adequately sampled.

Both Japanese vessels employed a large, wide commercial flatfish trawl with a relatively small vertical opening compared to overall net size, whereas the U.S. vessels used the high opening, four-panel Noreastern rockfish trawl. In both cases, rockfish concentrations encountered in the survey area which school in a highly vertical fashion would not be completely sampled by a demersal trawl. Interestingly, for four of the five dominant rockfish species encountered, the Japanese flatfish trawl was more efficient. (The U.S. Noreastern trawl was only more efficient for rougheye rockfish).

These differences in trawl efficiency may be a reflection of the varying sampling distributions between the U.S. vessels and the Japanese vessels. Japanese research vessels conducting cooperative research within the fishery conservation zone of the United States are prohibited from operating within 3 miles of the coast. Consequently, the JFA-chartered trawlers were allocated a larger portion of deeper sampling stations than the U.S. vessels during both survey years which provided better coverage of the depth distribution of most shelf and slope rockfish species. Other physical characteristics of the larger, heavier Japanese flatfish trawl and the amount of available horsepower may have better enabled the gear to maintain correct fishing posture in areas of strong tidal curents or steep bottom contours (characteristic of the Aleutian Islands).

Two very different estimates of POP biomass resulted from the southern Bering Sea subarea in 1980 and 1983, both with very high variances (Table 8). The sampling error of POP was highest in this subarea during both survey years although it decreased in 1983 to nearly half of the 1980 value. The large POP biomass estimate in 1983 and its accompanying wide confidence interval for this subarea indicate some sampling problems. The large 1983 estimate resulted from two large catches of POP from the Daito Maru No. 38, while the remainder of the sampling stations produced either an absence of or trace amounts of POP. This catch pattern is typical of survey results obtained from sampling rockfish concentrations with demersal trawls. Increased sampling is scheduled for the southern Bering Sea subarea in 1986.

The sampling error of the biomass estimates for the total survey area increased between 1980 and 1983 for Pacific ocean perch, shortraker rockfish, and rougheye rockfish, and decreased for northern rockfish and shortspine thornyhead. Generally, the decreases in sampling error were large while the three species which broadened their confidence intervals did so only moderately.

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Comparing abundance and productivity estimates of Pacific ocean perch in waters off the United States

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Introduction

The Pacific ocean perch (Sebastes alutus) resource in waters off the United States has historically been divided into four broad stocks/regions for management purposes: eastern Bering Sea, Aleutian Islands, Gulf of Alaska, and West Coast. Through the years, these populations have been assessed using a wide variety of stock assessment techniques. These techniques, however, have usually been applied only to one particular region at any given time. This piecemeal approach has made it difficult to obtain a clear overall picture of abundance and productivity. This paper examines, in very general terms, the major types of stock assessment methods that have been used to monitor Pacific ocean perch. More specifically, simple comparisons are made of the abundance and productivity estimates of Pacific ocean perch among the four major geographic regions in U.S. waters.

Distribution and Regions Involved

Pacific ocean perch are widely distributed throughout the North Pacific Ocean and Bering Sea. Along the North American coast, this species can be found 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. Throughout its geographic range, this species is generally associated with gravel, rocky, or boulder type substrate found in and along gullies, canyons, and submarine depressions of the upper continental slope.

For comparative purposes, the Pacific ocean perch resource in waters off the United States was divided into four broad regions: eastern Bering Sea, Aleutian Islands, Gulf of Alaska, and West Coast (Fig. 1). These regions correspond with the broad management areas employed by the regional fishery management councils. The North Pacific Fishery Management Council, charged with the management of Alaska's offshore fisheries, views the Pacific ocean perch resource in the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska regions as separate stocks. The Pacific Fishery Management Council manages Pacific ocean perch as two discrete stocks within the West Coast region.

Catch History

In all regions, Pacific ocean perch were the target of an intense fishery during the 1960s and early 1970s, primarily by Japanese and Soviet distant-water fishing vessels. Both nations employed trawlers of varying sizes and designs as their primary method of harvest. Many of the smaller vessels functioned as catcher boats for large motherships, while the larger trawlers generally operated independently by processing and freezing their own catch. Also, the use of support vessels (hospital ships, refrigerator and personnel transports, etc.) permitted the fishing fleets to operate at sea for extended periods of time. Although Japan and the Soviet Union were the primary exploiters of this resource throughout the 1960s and 1970s, relatively minor catches were also taken by other nations such as Poland, the Republic of Korea, Taiwan, Canada, and the U.S.

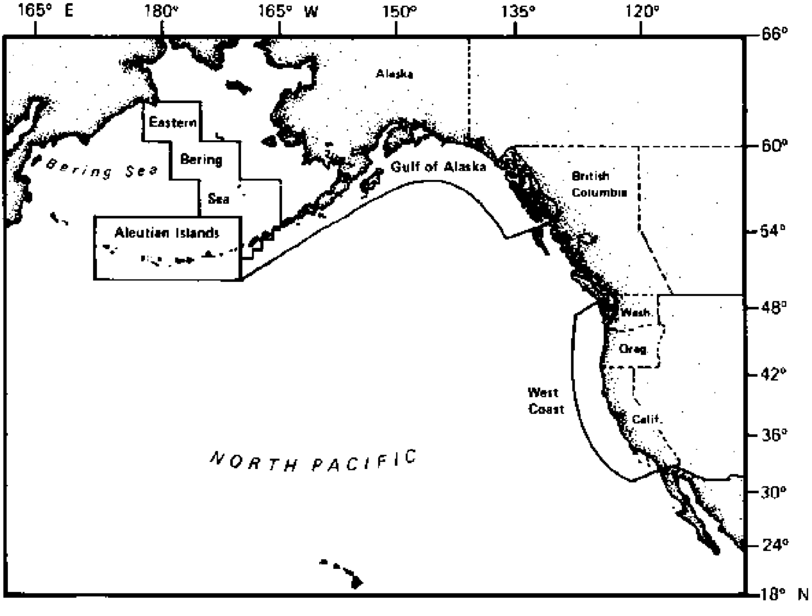

Figure 1.--The four regions used for comparing abundance and productivity estimates of Pacific ocean perch in U.S. waters.

As depicted in Figure 2, growth of the Pacific ocean perch fishery was rapid. By 1965, total removals (all regions combined) mushroomed to over 483,000 metric tons (t), but soon declined almost as rapidly as they had increased. In 1984 total catches were but a small fraction of the 1965 peak catch. The pie diagram in Figure 2 shows the maximum recorded catches by region, providing an indication of the relative productivity of Pacific ocean perch in U.S. waters. The Gulf of Alaska appears to be the most productive region, followed in descending order by the Aleutian Islands, eastern Bering Sea, and West Coast regions.

Stock Assessments

The condition of the Pacific ocean perch resource has been monitored periodically with a variety of stock assessment techniques. The more common approaches have included catch per unit effort analysis, trawl surveys, cohort-type analyses, and more recently, stock reduction analysis. Each method has its own inherent advantages, disadvantages, and biases associated with its use. 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. Therefore, it is prudent to examine stock changes by more than one method.

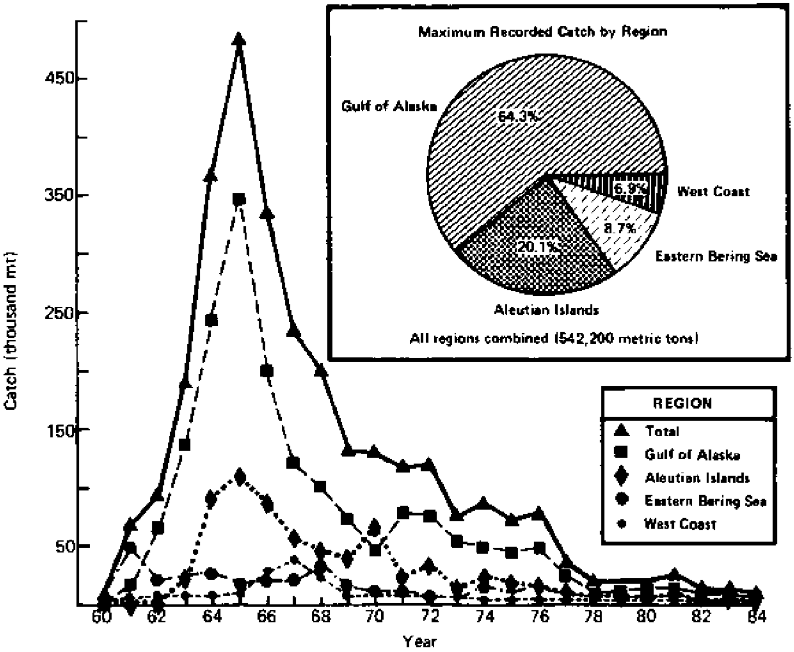

Figure 2.--Catch trends of Pacific ocean perch by region, 1960-84. Inset: Maximum recorded catch of Pacific ocean perch by region.

The Northwest and Alaska Fisheries Center (NWAFC) and others have conducted numerous assessments of Pacific ocean perch in waters off the United States. Each assessment has varied in its methodology and complexity. Some of these assessments have been very detailed and involved, requiring a thorough understanding of population dynamics to fully comprehend the assessments. It is beyond the scope of this paper, however, to describe in detail the methodology and results of each and every stock assessment. Rather, this report will summarize, in a very general manner, the major types of stock assessment methods that have been used and then discuss significant results of selected assessments.

Catch per unit effort (CPUE) analysis

Assessments of Pacific ocean perch have frequently been based on changes in catch per unit of effort (CPUE) in the commercial trawl fisheries. Commercial catch and effort statistics supplied by Japan have been the primary data source for most CPUE-type analyses of Alaskan stocks (e.g., Balsiger et al. 1985; Chikuni 1975; Ito 1986). On the other hand, CPUE assessments of West Coast stocks (e.g., Westrheim et al. 1972; Gunderson 1977) have relied mainly on catch and effort data from Canadian and U.S. trawlers. The majority of these assessments have indicated sharp declines in abundance throughout the 1960s and 1970s, during the period when Pacific ocean perch was a primary target species by distant-water fishing fleets.

In recent years, however, commercial CPUE data have become increasingly difficult to interpret as an index of stock abundance. Errors associated with CPUE-type assessments have been related primarily to the estimation of effective fishing effort. Standardizing and partitioning total trawl effort into effort directed solely toward Pacific ocean perch has been difficult, due to the multi-species and multi-gear nature of the trawl fishery. Moreover, quota restrictions, effort shifts to different target species, and rapid improvements in fishing technology and fishing skill have confounded the analysis of CPUE data. These factors must be considered if CPUE is to reflect changes in stock abundance accurately.

Trawl surveys

Commercial fishery statistics are not the only data available for assessing the status of the Pacific ocean perch resource; data collected by research surveys have been used to provide fishery-independent assessments of the abundance, distribution, and biological characteristics of Pacific ocean perch. Recent trawl surveys conducted by the NWAFC provide exploitable biomass estimates of the major Pacific ocean perch stocks in U.S. waters.

Surveys conducted in Alaskan waters have mainly been based on cooperative efforts between the NWAFC and the Fisheries Agency of Japan. In the eastern Bering Sea region, cooperative trawl surveys were conducted in 1979, 1981, 1982, and 1985. These surveys produced a mean biomass estimate of approximately 20,000 t (Ito 1986). Similar surveys in the Aleutian Islands region in 1980 and 1983, produced a mean biomass estimate of about 113,900 t (Ito 1986). For the Gulf of Alaska region, the 1984 U.S.-Japan cooperative trawl survey estimated exploitable biomass at around 334,900 t (Carlson et al. 1986). Trawl surveys were also conducted in 1979 and 1985 to estimate the biomass of Pacific ocean perch within the West Coast region. The mean exploitable biomass in this region was estimated at roughly 13,400 t (Ito et al. 1986).

Trawl survey estimates of Pacific ocean perch biomass are usually characterized by large variances. In some instances the 95% confidence intervals have encompassed plus or minus 100% of the point estimate. Such large variances are probably due to the highly contagious distribution of this resource. Other factors such as inadequate sampling, inappropriate sampling gear, and fish behavior may also contribute to the wide confidence intervals about the point estimates.

Furthermore, trawl surveys probably underestimate the true population size of Pacific ocean perch. As pointed out by Bakkala et al. (1985), this species is known to occupy the water column above that sampled by most bottom trawls and also is known to inhabit areas of rough bottom which are usually avoided during surveys to prevent damage to the trawls. Unfortunately, that portion of the population unavailable to the trawl gear cannot be determined at this time.

Cohort-type analyses

Cohort-type analyses provide an alternative to commercial CPUE and trawl survey stock assessments. These techniques have been developed to circumvent the need for reliable effort statistics and to provide abundance estimates in terms of absolute values rather than as an index. Abundance estimates are presented in terms of historical population numbers and biomass at age. Age-specific rates of instantaneous fishing mortality are estimated as well. Conducting this type of an assessment requires historical catch-at-age data, an estimate of natural mortality, and an estimate of fishing mortality for each year class.

Gunderson (1979, 1981) was the first to apply cohort analysis to Pacific ocean perch populations. His assessment covered the major stocks within the West Coast region. Ito (1982) and Balsiger et al. (1985) also employed cohort analysis techniques to assess the status of the Pacific ocean perch resource in Alaskan waters. The results of all these assessments indicated that Pacific ocean perch stocks underwent precipitous declines in abundance during the period of heavy foreign exploitation.

A major problem with these cohort analysis assessments of Pacific ocean perch is that the age data used, derived from surface readings of scales and otoliths, are now thought to be incorrect. Ages derived by the relatively new "break and burn" technique of reading otoliths indicate much higher ages than previously thought (Beamish 1979; Chilton and Beamish 1982). Ages in excess of 80 years have been recorded for some specimens. Such longevity generally corresponds with natural mortality estimates much lower than those used in the previous cohort analyses (Archibald et al. 1981; Hoenig 1983; Shaw and Archibald 1981). A lower natural mortality would have the effect of decreasing the cohort analysis abundance estimates.

Stock reduction analysis

Stock reduction analysis (SRA) is a relatively new stock assessment method (Kimura and Tagart 1982; Kimura et al. 1984; Kimura 1985). Essentially, SRA is a solution to the set of catch equations that does not require age composition data; it is also flexible and it has the ability to incorporate different sources of information and examine them for consistency. Furthermore, SRA does not require effort data, a requisite in CPUE-type analyses. This method provides much useful assessment information, including estimates of instantaneous rates of fishing mortality, historical biomass, and maximum sustainable yield (MSY).

Balsiger et al. (1985) employed SRA techniques to assess the Pacific ocean perch resource in Alaskan waters; Ito et al. (1986) conducted a similar assessment of Pacific ocean perch populations of the West Coast region. According to these studies, the Gulf of Alaska contained the largest biomass of any region prior to the onset of exploitation. Virgin biomass in this region was estimated at about 1,450,000 t. In the Aleutian Islands and eastern Bering Sea regions, the estimates of virgin biomass amounted to about 560,000 t and 240,000 t, respectively. And in the West Coast region, virgin biomass totaled approximately 144,000 t.

Productivity, in terms of maximum sustainable yield, was also estimated by the SRA assessments. A range of MSY values was calculated for each region based on a variety of SRA model parameters. Employing a constant recruitment condition in the SRA model, MSY was estimated at 30,849 t for the Gulf of Alaska region; 11,865 t for the Aleutian Islands region; and 4,984 t for the eastern Bering Sea region. The estimate of MSY for the West Coast region amounted to 2,805 t. These estimates are thought to be fairly optimistic.

Abundance and Productivity Comparisons

As previously mentioned, historical catches by region (Fig. 2) provide an indication of the relative size and productivity of the Pacific ocean perch resource. Based on maximum recorded catches, the Gulf of Alaska appears to be the most productive region. This is not surprising as this region is the largest in terms of total area and suitable rockfish habitat. The Aleutian Islands is apparently the next most productive Pacific ocean perch region, followed by the eastern Bering Sea region and lastly by the West Coast region.

Although the catch statistics provide an indication of the relative stock size and productivity by region, they do not provide direct estimates of absolute abundance. Assessments based on cohort-type analyses, trawl surveys, and SRA express stock changes in terms of absolute values, thus permitting direct comparisons on a regional and annual basis. In this report, however, the results of the cohort-type analyses will not be used for comparative purposes. The abundance estimates from cohort analyses may not be indicative of the true abundance of Pacific ocean perch, as most of the historical age data used in these assessments are now thought to be incorrect.

Pacific ocean perch populations in waters off the United States apparently underwent sizeable reductions in biomass after the onset of exploitation (Fig. 3). Based on SRA assessments, virgin biomass for all U.S. stocks totaled 2,394,000 t. Recent trawl surveys (refer to the stock assessments section for the specific survey years used) indicate that total biomass has now dropped to a level of about 482,200 t, a reduction of approximately 80% from virgin levels. Throughout this decline, the Gulf of Alaska has remained the dominant region in terms of Pacific ocean perch biomass, followed in descending order by the Aleutian Islands, eastern Bering Sea, and West Coast regions.

There apparently has been a shift in the percentage composition of total biomass by region (Fig. 3). The eastern Bering Sea and West Coast regions comprised 10.0% and 6.0% of the total virgin biomass in U.S. waters, respectively. Results from recent trawl surveys, however, indicate that both regions now account for a much smaller portion of the total biomass -- 4.1% in the eastern Bering Sea region and 2.8% in the West Coast region. The Gulf of Alaska region, on the other hand, has increased its share of the total biomass. The Gulf region accounted for 60.6% of the total virgin biomass; now it accounts for 69.5% of the total biomass based on estimates from recent trawl surveys. The Aleutian Islands region has remained fairly constant in terms of its share of the total biomass.

Chikuni (1975) provided a rigorous assessment of Pacific ocean perch stocks of the North Pacific Ocean and Bering Sea regions. Based on a yield per recruit type of analysis, he estimated MSY for each stock as follows: Gulf of Alaska, 150,000 t; Aleutian Islands, 75,000 t; eastern Bering Sea, 32,000 t; and West Coast (which includes Canadian waters), 33,000 t. Clearly, sustained exploitation at these levels was not possible (Fig. 2). The Gulf of Alaska and Aleutian Islands regions have produced catches in excess of Chikuni's MSY estimates only three times. Similarly, the MSY estimates for both the eastern Bering Sea and West Coast regions have been exceeded only once during the 25 year period from 1960 to 1984.

More recent estimates of productivity from stock reduction analysis techniques indicate that MSY levels are much lower than those estimated by Chikuni (1975) (Fig. 4). In fact, on a regional basis, the SRA estimates of MSY are between 79% and 92% lower than those of Chikuni. For all regions combined, the SRA estimates of MSY totaled 50,503 t. This estimate is about a 82% lower than Chikuni's coastwide MSY estimate of 290,000 t.

Summary and Conclusions

The principal objective of this study was to conduct simple comparisons of abundance and productivity estimates of Pacific ocean perch among four major geographic regions in U.S. waters. First, commercial landings were presented which gave an indication of the relative size and productivity of Pacific ocean perch populations by region. Next, estimates of absolute abundance and productivity were provided. Most of the estimates that were used for comparative purposes were based on assessments conducted by the NWAFC. This study concluded that the Gulf of Alaska has been and continues to be the dominant region in terms of Pacific ocean perch abundance, followed in descending order by the Aleutian Islands, eastern Bering Sea, and West Coast regions.

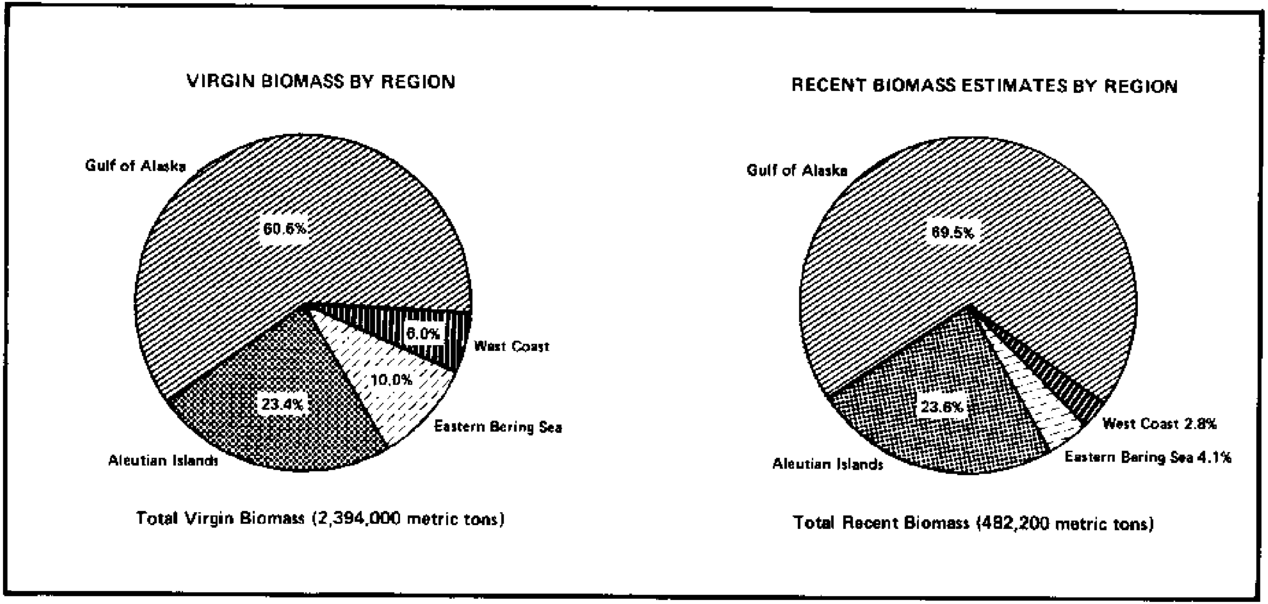

Figure 3.--Estimates of virgin and recent biomass by region.

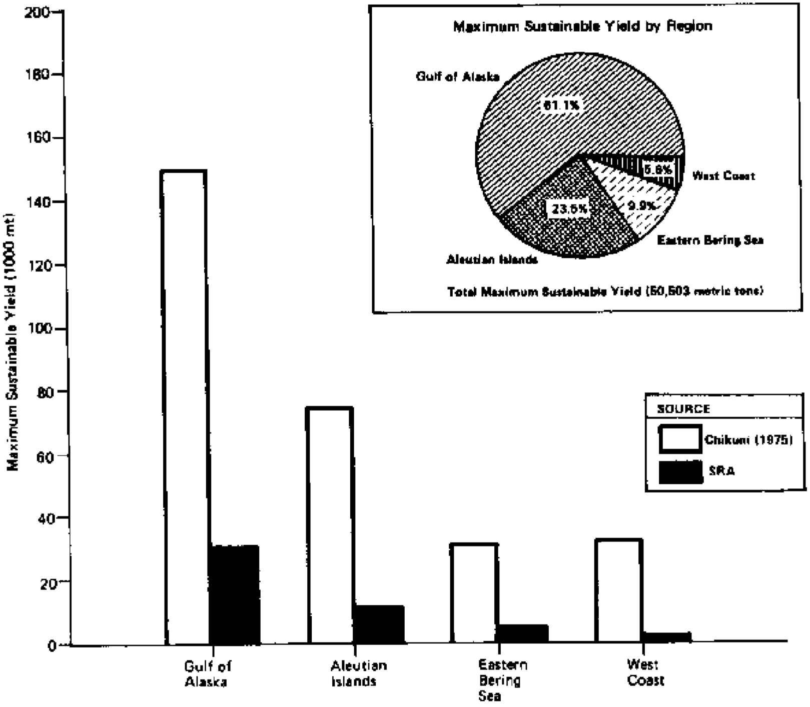

Figure 4.--Maximum sustainable yield comparisons by region. Inset: Stock reduction analysis estimates of maximum sustainable yield by region.

It is also apparent that Pacific ocean perch productivity is much lower than previously thought. Recent SRA assessments indicate that MSY may be 80% to 90% lower than previously published estimates (i.e., Chikuni 1975). This is not entirely surprising as new information on the biology and population dynamics of Pacific ocean perch have emerged since Chikuni estimated MSY. Chikuni estimated that Pacific ocean perch lived no more than 25 years and that instantaneous natural mortality ranged between 0.19 and 0.42. More recent information, however, suggest that Pacific ocean perch may attain ages in excess of 80 years and that instantaneous natural mortality is probably 0.05 or lower.

Evidently, with such long life spans and low rates of natural mortality, Pacific ocean perch are unable to cope with large removals from their populations. This species is also very slow growing and lacks the resilience of highly fecund groups such as the gadoids. Furthermore, ecological factors may have played a role in keeping the stocks at depressed levels. As the Pacific ocean perch populations declined due to excessive removals, its ecological niche may have been replaced by faster growing, highly fecund species, further reducing the reproductive potential of the Pacific ocean perch populations.

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The British Columbia inshore rockfish fishery: Stock assessment and fleet dynamics of an unrestricted fishery

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Introduction

The inshore rockfish fishery in British Columbia occurs predominantly in major area 4B, the Strait of Georgia and adjacent inside waters of Vancouver Island (Fig. 1). Most of the vessels use handline/troll or longline gear. (Landings by handline and troll gears are not distinguished in the sales-slip records). The fishery in its present form began to expand about 1977. At that time a market developed for live rockfish to supply restaurants and retail outlets, primarily in Vancouver's Chinatown. By 1984, annual landings in area 4B had increased by 5 times in weight, and by 15 times in value, relative to 1975 (Table 1). Here we describe the commercial fishery and present an overview of landing trends and fleet dynamics.

Species, Size and Age

Methods

We began to sample landed catch from the handline fishery in 1984 (Cass et al. 1986). Most fish are sold live, and as it was necessary to kill fish for sampling, we were forced to purchase our samples from local fish buyers. Fishermen generally stock-pile their catch in a submerged pen, until enough fish are accumulated to comprise a saleable quantity. Landings are then trucked by a fish buyer to Vancouver or to other local markets. As we were unable to locate fishermen who stock-pile their catch individually, samples included the catch from two or more vessels. Hence, we could not differentiate between gear types, specific locality or depth fished in our samples.

Results

Based on eight samples of the commercial catch to date (over 2000 fish), quillback rockfish (*Sebastes maliger*) is the major species and accounts for about 88% (by number) of the fish landed. Copper rockfish (*S. caurinus*) accounts for about 11%. Minor amounts (<1%) of yelloweye rockfish (*S. ruberrimus*), yellowtail rockfish (*S. flavidus*) and kelp greenling (*Hexagrammos decagrammus*) are also landed.

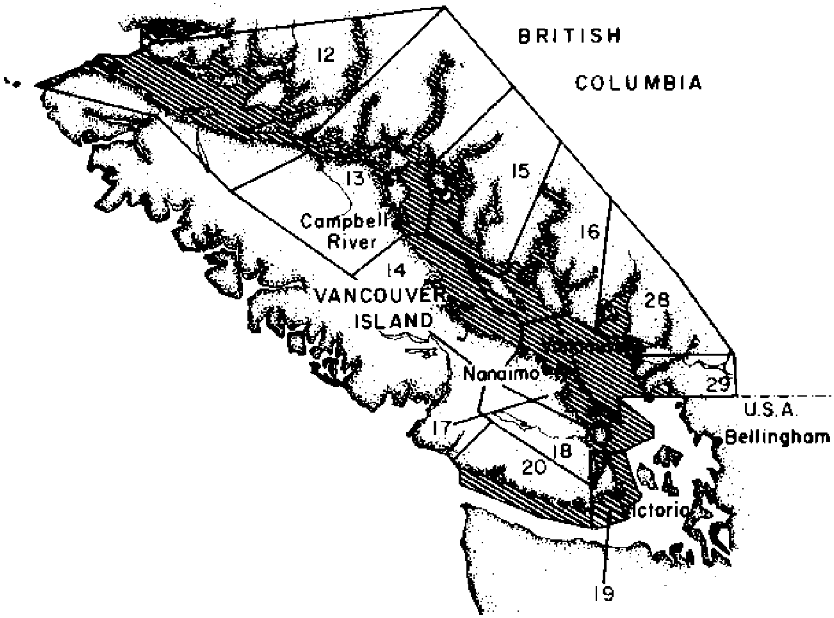

Fig. 1. Location of area 4B, between Vancouver Island and mainland British Columbia.

Table 1. Total landings (t), landed value (000's 1981 $), 20% qualified handline/troll LPUE (kg/day fished) and the percentage of total landings that were included by qualified handline/troll landings for the area 4B rockfish fishery for 1967-1984.

Year	Landings (t)	Landings ($)	Qual. LPUE (kg/d)	% land.
1967	91	21	25.2	34
1968	112	25	24.2	33
1969	118	52	36.8	48
1970	142	57	33.8	34
1971	117	53	37.7	34
1972	128	56	31.6	31
1973	131	55	31.6	24
1974	82	50	34.8	33
1975	73	46	33.1	34
1976	89	63	29.3	37
1977	191	158	43.9	48
1978	232	223	42.5	44
1979	320	345	41.0	44
1980	241	264	31.0	42
1981	278	389	45.4	52
1982	335	546	48.9	72
1983	331	610	43.5	79
1984	392	705	41.1	77

Size and species composition of the landed catch depend on depth of fishing. Quillback rockfish and yelloweye rockfish are found predominantly below 40 m and copper rockfish and kelp greenling predominantly above 40 m (Richards and Cass 1985, Richards et al. 1985). The median size of quillback rockfish and yelloweye rockfish tends to increase with depth (Richards 1986).

Fishermen reported, in a small questionnaire survey (n=7), that they prefer rockfish of about 0.7 kg (1.5 lb) in weight, and that they discard fish of less than about 0.2 to 0.5 kg. The average weight of quillback and copper rockfish in our commercial samples generally reflects these preferences (Table 2). Quillback rockfish in the samples were larger on average than copper rockfish. For both species, females were heavier than males.

To date, two of our samples have been aged from otoliths, by the break and burn method (Chilton and Beamish 1982). Ages in the samples ranged from 4 - 55 yr for quillback rockfish and from 3 - 35 yr for copper rockfish (Fig. 2). Copper rockfish appear to have a faster growth rate, mature earlier, and are caught at a younger age. The mean age of copper rockfish in the samples was about 11 yr compared to about 17 yr for quillback rockfish.

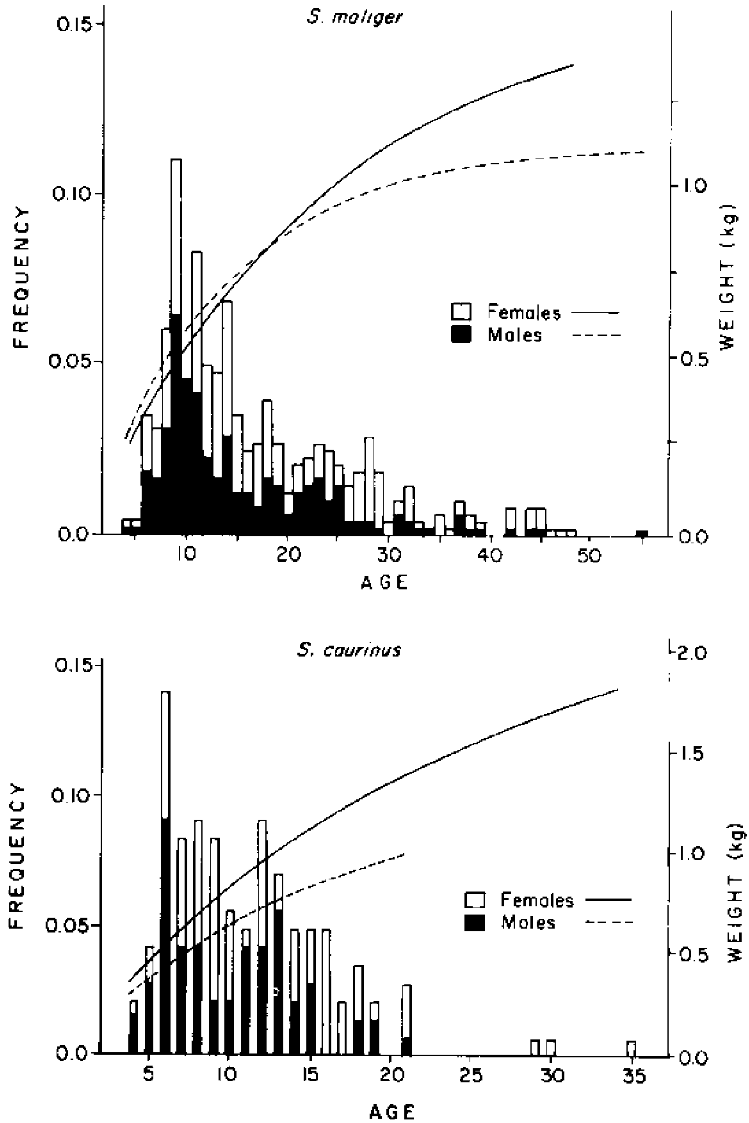

Fig. 2. Age distributions and von Bertalanffy growth curves for male and female quillback rockfish and copper rockfish sampled from the area 4B handline/troll fishery between July 1984 and January 1986. See Table 2 for sample sizes.

Analyses of Landing Trends

Methods

The analyses that follow are based on the sales-slip data files maintained by the Department of Fisheries and Oceans, Statistics Division. We had access to the data files for 1967-1984, and could follow the success of individual vessels beginning in 1979. There are several problems with the sales-slip data that could affect the outcome of the analysis. The most severe problem is an unknown but probably high rate of noncompliance with the fishery regulation to fill out sales-slips for these species. As there is no dock-side interview coverage for this portion of the non-trawl fleet, the landing records represent minimum estimates.

One landing was occasionally reported across two or more sales-slips. In these cases we chose to use the maximum reported effort for any landing by a vessel on a given day. Sales-slips were omitted from the analysis if the effort was listed as zero. This may have occurred if a landing was combined from two or more minor statistical areas and all of the effort was assigned to one of the areas.

We initially selected all landing records for a vessel on a given day if a rockfish landing was reported. Further analyses were generally performed on handline/troll landings, if rockfish comprised more than a specified percentage by weight (qualification

Table 2. Length, weight, age, and length and age at 50% sexual maturity for male and female quillback rockfish and copper rockfish sampled from the handline/troll fishery between July 1984 and January 1986. Sample size (N), mean, and standard error (SE) are given with each value.

	Males			Females		
	N	mean	SE	N	mean	SE
a) quillback rockfish						
length (cm)	1216	33.1	0.1	1310	34.1	0.2
weight (kg)	1216	0.75	0.01	1309	0.87	0.01
age (yr)	221	15.5	0.6	259	18.2	0.6
50% maturity age	221	13		259	11	
50% maturity length	1216	29.5		1310	28.1	
b) copper rockfish						
length (cm)	130	31.3	0.4	148	32.6	0.4
weight (kg)	130	0.57	0.02	148	0.67	0.03
age (yr)	69	10.0	0.5	74	12.1	0.7
50% maturity age[1]	107	6				
50% maturity length[1]	107	25.0				

[1] male and female values combined

level) of the landing. We found little difference in the time trend of LPUE (weight landed/days fished) using qualification levels of 20%, 40%, 60%, and 80%. The 20% qualification level was selected for reporting LPUE. For yearly analyses by vessel, only vessels that made three or more 20% qualified landings in that year were included.

Landings and LPUE

Until the early 1970's, there was a small trawl fishery for rockfish off the southwest coast of Vancouver Island. Annual trawl landings of rockfish averaged 98 t during 1954-1970. Since 1970 however, trawl landings have decreased to an annual average of 41 t. Handline/troll and longline landings of rockfish, which were historically less than trawl landings, averaged 65 t annually during 1954-1976. By 1984, annual handline/troll and longline landings of rockfish had increased to 343 t.

Rockfish landings by all gear types were relatively modest during 1967-1976 (73-142 t/yr), but then rose somewhat irregularly to a peak of 392 t in 1984 (Table 1). During 1967-1976, handline/troll LPUEs ranged from 24.2 kg/d (1968) to 37.7 kg/d (1971). During 1977-1984, the range was higher, from 41.0 kg/d (1978) to 48.9 kg/d (1982), except for 31.0 kg/d in 1980. LPUE dropped after 1982 to 41.1 kg/d in 1984.

The increase in LPUE during 1977-1984 can be accounted for by increased effort on rockfish as a target group. Previously, many of the rockfish were landed as incidentals by salmon troll and lingcod handline vessels. Lingcod stocks in the Strait of Georgia in particular have declined significantly in recent years (Cass 1985) and several former lingcod fishermen have switched to rockfish. This is shown in Table 1 by an increase in the proportion of total landings included by the 20% qualification level for handline/troll gear.

There are several possible explanations for the decrease in LPUE observed after 1982. The trend may simply be an artifact of poor data quality, for example. We do not know how the incidence of mis-reporting of sales-slips may have changed through time. However, we have two types of evidence to support the hypothesis that the decrease (approximately 15%) reflects a decrease in stock size. The first is anecdotal. Sport and commercial fishermen and fishery officers all report a decline in the size of rockfish stocks, and some changes have occurred in the local areas fished as a result. The second type of evidence is from our research program. In our experiments, we found LPUE for quillback rockfish, as measured by research angling, to be proportionally related to quillback density, as measured by visual observations from the PISCES IV submersible (Richards and Schnute 1986). Hence, a 15% decrease in LPUE in our research fishing would indicate a 15% decrease in stock size. Of course, the relationship between commercial handline/troll LPUE and stock size is less clear. We suspect that commercial LPUE is relatively insensitive to stock abundance, except at low stock levels.

Fleet patterns

The number of vessels reporting three or more 20% handline/troll landings of rockfish has decreased from 193 vessels in 1979 to 179 vessels in 1984 (Table 3). There is a high vessel turnover. Only 30-40% of the vessels remain in the fishery the year following their entry.

Vessels tend to be consistent between years in their relative success in the rockfish fishery. During 1979-1984, LPUEs for a vessel were highly correlated ($p<0.001$) in successive years. In addition, vessels that left the fishery after 1981, 1982 and 1983 had a significantly lower annual LPUE in their last year of fishing than did other vessels in that year ($p<0.05$, Wilcoxon two-sample test).

Vessels in the fishery range from small speed boats to former salmon trollers. Using 1983 as an example, median vessel length was 9.7 m (range 3.9-15.1 m, n=140), with modes in the vessel length distribution near 4 m and 10 m. LPUE was significantly correlated with vessel length ($r=0.21$, $p=0.01$), although the correlation was not high. As might be expected, the distribution of annual qualified landings by vessel was highly skewed (Fig. 3). The top 17 (12%, n=146) vessels accounted for 50% of the 1983 qualified landings.

The fishery occurs throughout area 4B, although the largest concentration of vessels is around Campbell River, minor statistical area (MSA) 13 (Table 3), an area of high tidal flow. In 1984, 50% of the rockfish handline vessels in the Strait of Georgia reported three or more qualified landings from MSA 13. MSA 13 alone accounted for 51% of the 4B all-gear rockfish landings in 1984. More recently, the fishery has begun to move further north to more exposed areas (e.g. MSA 12), perhaps associated with high competition for dwindling Strait of Georgia rockfish stocks. Based

Table 3. The number of vessels in the handline/troll fishery for rockfish between 1979 and 1984, the percentage of new vessels in the fishery in each year, the percentage of new vessels in one year that remained in the fishery the following year, and the percentage of vessels that fished in MSA 13. Only vessels that made three or more 20% qualified rockfish landings are included.

	Year					
	79	80	81	82	83	84
no. vessels	193	159	156	176	146	179
% new	-	61	59	53	40	37
% remained	32	30	37	35	45	-
% MSA 13	41	35	40	45	63	50

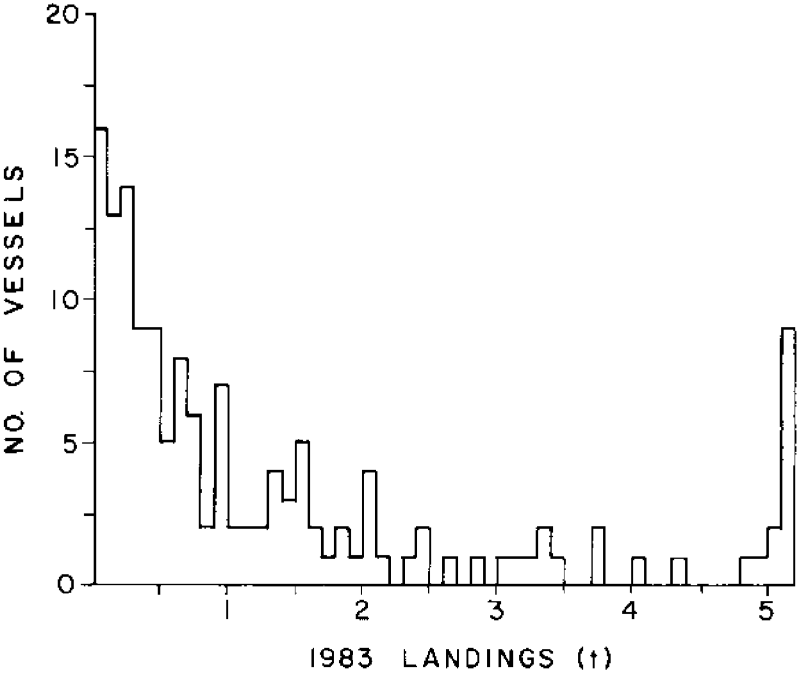

Fig. 3. Distribution of annual qualified rockfish landings (t) by vessel in the 1983 handline/troll fishery in area 4B. The last group includes all vessels that landed more than 5 t. Only vessels that made three or more qualified handline/troll landings of rockfish are included.

on preliminary 1985 data, over 20 vessels reported three or more qualified landings from MSA 12, an increase from 11 vessels in 1984 and one vessel in 1983.

Future of the fishery

It appears that decreases in the size of rockfish stocks have occurred in the Strait of Georgia over the past few years. In general, such decreases could be accounted for by either lack of recruitment or by overfishing. However, as rockfish are long-lived and recruit to the fishery over several years, recruitment failure is not a sufficient explanation for the observed decrease. The most likely explanation for this decrease is overfishing. Fisheries on long-lived species are often characterized by a period of high landings followed by a rapid decline in landings, associated with a decline in stock size (Leaman and Beamish 1984). This is the pattern that was observed, for example, in the Queen Charlotte Sound Pacific ocean perch (Sebastes alutus) fishery, and consequently, long-term (on the order of decades) rehabilitative measures became necessary (Archibald et al. 1983).

At present, there are no restrictions on the commercial fishery for rockfish in area 4B. We expect that rockfish stocks in the Strait of Georgia will eventually be reduced to levels at which they can no longer be economically fished, and that the fishery will then be re-directed to more remote areas. The point of economic extinction is somewhat vague as price has been increasing steadily. To prevent such a scenario, we have recommended a total allowable catch that is based on historical landings from the handline/troll and longline fishery. It is still uncertain what, if any, management action will be taken in the near future.

This analysis has been based on the commercial fishery only, as we are lacking a time series of landings and effort for the sport fishery. The sport fishery for rockfish has become an important alternative to the salmon sport fishery (McElderry et al. 1985). Approximately 85 t of rockfish were landed by the Strait of Georgia sport fishery in 1984 (T. Shardlow and T. Hoyt, unpub. data). This is over 20% of the landings by the commercial fishery. In 1986, an 8 fish/d bag limit on sport-caught rockfish was implemented coastwide. The limit is probably too high. It was originally imposed by management to control the landing and illegal sale of commercial quantities of rockfish under a sport licence.

Acknowledgments

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Identification of species assemblages and results of management applications for shelf and slope rockfishes off British Columbia

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Abstract

To cope with the management problems created by different productivity levels of rockfish stocks fished in the same areas, we analyzed commercial catch statistics to determine if there were assemblages that could function as management units. In particular, we wished to determine whether background variance of landings afforded management opportunities at the vessel, seasonal or annual level of aggregation. Cluster analysis of two years of landings data, prior to any management measures, identified both seasonal and annual assemblages but no consistency at the vessel level. For example, the majority of the catch of shelf rockfishes off northern Vancouver Island was caught as a consistent ratio of *Sebastes flavidus*:*S. brevispinis*:*S. pinniger*, whereas two separate seasonal ratios of *S. alutus*:*S. reedi*:*S. proriger* were identified off the west Queen Charlotte Islands. Such results suggested that yields of several species could be optimized through assemblage management, where single-species management had resulted in either unfilled quotas or over-exploitation of some species.

The assemblages identified were applied in the management of British Columbia's commercial fishery for three years. We present the results of this application and evaluate its success relative to the former single-species management. We also examine the persistence of the groups previously identified, during the assemblage management period, and indicate what consequences can result from management imprecision in achieving quotas for assemblages.

Introduction

The genus *Sebastes* (family Scorpaenidae) is the most speciose of the demersal fish genera in the northeast Pacific Ocean, with over seventy known species (Chen 1986). While all species are not spatially coincident, any area may have 10-30 species present throughout much of the year. Although these coincident species are congeners, their biological characteristics may vary widely (Archibald et al. 1981; Phillips 1964) and their equilibrium population levels may differ by tenfold or more (Leaman 1985). These differences combined with exploitation histories that have varied in both intensity and duration have created situations where different management strategies may be needed for co-occurring species.

Most of the Sebastes spp. exploited by trawl gear are aggregating forms. The reasons for this aggregating behaviour are not completely understood and any combination of predator protection, feeding facilitation, response to oceanographic or bathymetric features, or reproductive requirements might be plausibly invoked. In addition some species have strongly seasonal aggregating behaviour that may result from bathymetric migration, often further complicated by different patterns between the sexes (Leaman 1985). Natural aggregations may be further amplified in fisheries statistics by the limited availability of bottom suitable for trawling; indeed, most fishermen regard the name 'rockfish' as amply justified.

Within any management area, landings from rockfish fisheries in British Columbia are typically composed of a mixture of species in variable proportions (Tables 1,2). The composition of these mixtures is influenced by differential species abundance, bias in the distribution of fishing effort among species, and marketing constraints. Fishery landings therefore do not give a picture of the "true" community or assemblage, rather they present a variable subset of that community reflecting the biases of market demand, availability and vulnerability.

In the waters off British Columbia there are a number of fishing grounds where these scenarios occur. Available yield from stocks is quite disparate among and within areas (Leaman 1985; Stanley 1985) and often management of individual quotas for some species has resulted in either overfishing or regulatory closures that truncate fisheries for other species before their quotas are fully subscribed (Table 3). Such a system is clearly inefficient and improvements in management must deal with basic differences in biology among species, stocks at various levels of historical exploitation, and different patterns of aggregation throughout the year among the species landed from a given area. The manager may find that the window of control for the fishery prohibits single-species management due either to the impossibility of resolving single-species effort from catch statistics, or because the species are truly caught together.

What the manager needs is a method for optimizing yields from several stocks based on controlling the majority of their landings. Our objective was to analyze historical patterns of catch and effort to determine if management of shelf and slope rockfishes could be accomplished through treatment as assemblages, rather than as single species. In this paper we present the results of this analysis and their application to the management of British Columbia rockfish fisheries during 1983-1985.

Table 1. Commercial rockfish landings (t) off British Columbia by major area, 1977-1978.

	Major area									
	1978					1977				
Species	3C	3D	5A	5B	5E	3C	3D	5A	5B	5E
S. alutus	48.88	7.05	164.56	1,134.32	2,426.91	15.02	1.13	69.35	1,004.91	1,550.81
S. paucispinis	-	0.02	-	-	139.49	-	-	-	0.34	76.28
S. babcocki	0.81	0.38	17.68	54.98	5.09	0.33	-	0.73	19.47	2.28
S. brevispinis	1.03	20.78	373.39	350.23	139.88	18.01	10.31	85.69	111.97	20.33
S. entomelas	-	1.53	1.49	142.02	57.21	51.06	-	10.81	75.51	12.34
S. flavidus	45.04	36.84	406.98	1,237.29	1.57	236.61	7.52	303.96	709.38	3.72
S. paucispinis	3.81	19.15	74.88	58.43	14.31	28.97	10.14	17.41	24.50	1.37
S. pinniger	14.52	54.09	108.54	154.08	8.30	99.60	96.45	23.53	97.58	0.57
S. proriger	0.38	6.64	7.60	12.05	231.37	0.33	-	33.03	0.48	155.96
S. reedi	0.27	-	10.86	97.63	1,104.64	-	-	308.98	2.67	1,256.72
S. ruberrimus	1.37	0.62	0.80	1.25	-	0.07	-	0.27	-	-
S. zacentrus	-	-	0.45	-	3.64	-	-	0.47	-	2.67

Table 2. Percentage of major rockfish species[a] landed in various combinations, by year, in Area 5E 1977-1985.

Percentage of AL in following combinations:

Year	Alone	AL/PR/RE	AL/RE	PR/RE	AL/PR	With other rockfish
1977	55	21	13	0	2	9
1978	14	15	62	0	0	9
1979	11	24	37	0	0	28
1980	41	15	10	0	19	15
1981	46	20	30	0	0	4
1982	27	25	25	0	0	23
1983	2	27	51	0	1	19
1984	8	35	38	0	0	19
1985	28	35	21	0	10	6

Percentage of PR in following combinations:

Year	Alone	AL/PR/RE	AL/RE	PR/RE	AL/PR	With other rockfish
1977	2	87	0	0	7	4
1978	3	94	0	2	1	0
1979	0	100	0	0	0	0
1980	0	41	0	51	8	0
1981	0	90	0	10	0	0
1982	0	90	0	10	0	0
1983	0	74	0	21	5	0
1984	0	44	0	56	0	0
1985	0	49	0	35	9	6

Percentage of RE in following combinations:

Year	Alone	AL/PR/RE	AL/RE	PR/RE	AL/PR	With other rockfish
1977	0	76	24	0	0	0
1978	2	60	34	4	0	0
1979	0	81	19	0	0	0
1980	8	62	12	18	0	0
1981	0	56	24	18	0	2
1982	1	59	35	5	0	0
1983	4	50	26	20	0	0
1984	0	53	38	10	0	0
1985	1	69	10	19	0	1

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[a] Species: AL - *S. alutus*
PR - *S. proriger*
RE - *S. reedi*

Methods

The concept of describing groups of organisms as assemblages or by their degree of similarity is not a new one. Our approach departs from previous ones in the important regard that we required our assemblages to be functional in management. We stress that we did not set out to determine ecological linkages, which would require a long and detailed study. Our criteria for identification of functional assemblages were that:

(i) species must be coincident in landings from a given management unit;
(ii) this coincidence must persist over time useful in management (e.g. fishing season or year), i.e. species must co-vary in abundance in landings;
(iii) landings of a species in an assemblage must constitute the majority of its annual landings; and
(iv) the assemblages must be tractable under normal fishing patterns.

The latter three criteria are the primary departures from previous studies. For example, Day and Pearcy (1968), Fager and Longhurst (1968), Gabriel and Tyler (1980), and Tyler et al. (1982) have examined species groupings of the same general type we are considering but used much more temporally-limited data sets (often only single surveys). As such, the persistence of the relationships they described was inferred but not demonstrated, and their dynamics would be opaque to fishery managers (Wiens 1981). The same conclusion may apply to repetitive surveys made at specific times of year, that are not scaled to fishery results (Sissenwine et al. 1982). In part, this problem arises because some studies attempt to provide a management tool but their approaches carry the *a priori* assumption that species interactions are the driving force of group dynamics, while ignoring fishery effects (Mercer 1982).

Catch data from the British Columbia trawl rockfish fishery in seven areas (Fig. 1) during 1977-1978 were the subject of our analysis. The data were segregated into shelf (*S. brevispinis*, *S. entomelas*, *S. flavidus*, *S. pinniger*) and slope (*S. alutus*, *S. proriger*, *S. reedi*) forms. While catch statistics are not true measures of what species may co-occur, they do provide information on both association in landings and management opportunities (e.g. Tyler et al. 1984). Catches are subsamples of species groupings vulnerable to trawls and while the absence of a species does not necessarily infer its absence from the area, it does remove it from our management focus.

Nagtegaal (1983) reviewed some of the qualitative and quantitative methods that have been used to examine species associations. We chose cluster analysis (Borucki et al. 1975; Gabriel and Tyler 1980; MacDonald 1975; Sokal and Sneath 1963) as the most powerful and flexible method for our examinations.

A. Cluster analysis. The basic data element available for analysis was a vessel-area landing, for which a relative ratio index, R_{ij} was calculated for each species:

$$R_{ij} = C_{ij} / \sum_{i=1}^{N} C_{ij},$$

Table 3. Quotas (Q) and landings (C) of rockfish species by management area, 1979-1985. (values in tonnes).

Area/species	1979 Q/C	1980 Q/C	1981 Q/C	1982 Q/C	1983 Q/C	1984 Q/C	1985 Q/C
5E							
S. alutus	600/839	600/877	600/599	600/614	600/835	600/841	600/830
S. proriger	250/73	250/111	250/133	250/34	-/143	-/149	-/919
S. reedi	750/389	800/500	800/922	600/414	600/588	600/441	600/497
S. aleutianus	150/192	150/51	250/10	250/274	200/74	200/101	200/161
5A/B							
S. brevispinis	600/927	600/772	600/415	600/618	600/524	600/962	750/997
S. flavidus	3000/1526	3000/552	2000/281	1500/292	1500/323	1500/195	1500/341
S. pinniger	600/370	500/354	250/144	250/358	500/343	500/507	500/391
S. alutus	2000/1431	2000/1531	1500/1481	1000/856	1000/1246	800/860	850/839
S. proriger	225/8	225/-	250/-	250/3	-/37	-/40	-/117
S. reedi	450/10	450/28	50/5	-/228	250/608	250/344	350/304
3D							
S. brevispinis	150/264	200/400	200/251	200/126	250/564	250/462	350/812
S. flavidus	200/116	200/63	200/27	200/13	100/36	100/19	100/288
S. pinniger	500/351	500/323	350/114	350/215	450/712	450/882	500/727
S. alutus	10/44	-----with area 3C quota--------			250/463	250/337	350/340
S. proriger	50/1	50/-	50/-	50/-	-/22	-/29	-/78
S. reedi	50/-	50/-	50/-	50/1	-/20	-/114	-/412
3C							
S. brevispinis	100/1006	100/387	100/148	-/63	-/86	50/108	100/110
S. flavidus	100/344	100/657	100/2021	100/1552	-/17	100/20	200/94
S. pinniger	100/86	100/290	100/201	100/234	-/156	200/307	200/177
S. alutus	50/81	600/430	500/548	500/508	500/374	500/406	300/276
S. proriger	50/1	50/-	50/13	-/3	-/12	-/14	-/26
S. reedi	50/2	50/-	50/-	-/6	-/33	-/6	-/4

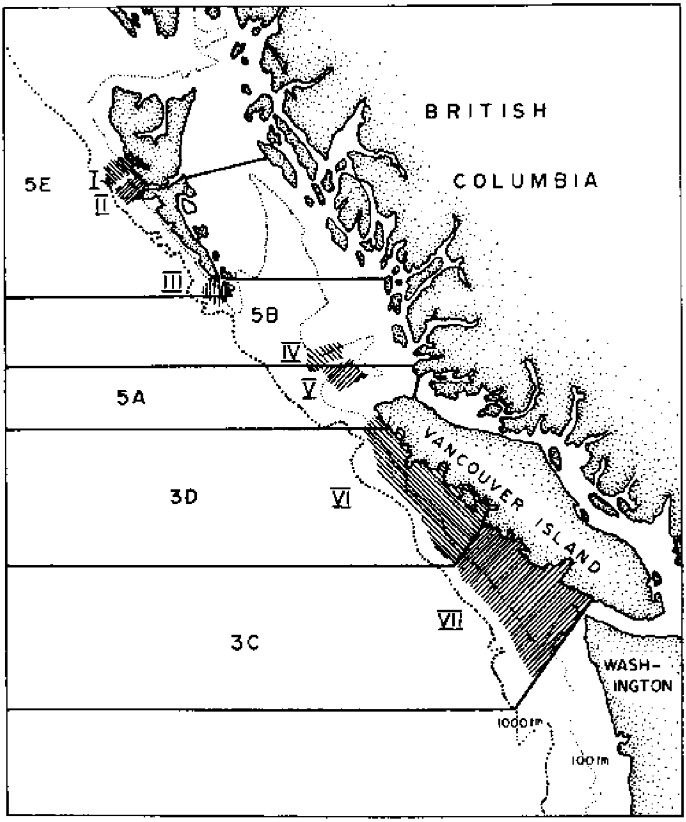

Figure 1. Areas for rockfish assemblage analysis (I-VII) and major statistical areas off British Columbia (e.g. 3C).

where C is catch and the species and landing indices are i and j, respectively. We used a Q-mode (entity) agglomerative cluster analysis, which groups elements according to the similarity of their species ratio (rather than R-mode (attribute) clustering which groups elements according to individual species similarity) for our preliminary examinations. This analysis produces a hierarchical classification of data in the form of a dendrogram, with one axis as a group classification and the other as an index of similarity between groups. A group-average fusion strategy was employed to link groups with a Canberra-metric similarity index. The latter was chosen to minimize the bias induced by differences in the gross level of catch among groups with similar proportions.

As a supplement to the cluster analysis we also calculated a relative catch index, L_{ig}, to identify those clusters representing the majority of the rockfish catch.

$$L_{ig} = C_{ig} / \sum_{g=1}^{K} C_{ig}$$

where C_{ig} is the catch of species i in cluster g. The denominator is the total rockfish catch of species i in all k clusters in the study area.

B. Catch proportion analysis. In addition to the cluster analysis we identified a proportion index to determine the proportions of rockfish species that were landed together.

$$P_{ig} = C_{ig} / \sum_{t=1}^{12} \sum_{g=1}^{K} C_{itg}$$

where C_{ig} is the catch of species i in combination g. The denominator is the total catch of species i in all combinations within the area for a year. The proportions were calculated for all possible combinations of commercial species within the study area. We also examined each species' catch by month relative to its annual catch for each area, to distinguish those species consistently caught together from those caught together only occasionally.

C. Covariation in species landings. Adherence to our criterion (ii), that species in an assemblage must co-vary in abundance, was examined with a Wilcoxon paired-sample test of percentage change in landings, by month, by species pair.

D. Application to management. Subsequent to these examinations, we analyzed a longer time-series of catch data (1977-1982) for monthly and annual patterns of R_{ij} and P_{ig}. Some of the assemblages identified by these analyses were presented as options to fishery managers and implemented during the 1983-1985 rockfish fisheries off British Columbia. The results of this implementation were evaluated in terms of the achievement of individual species quotas within an assemblage management fishery, and the persistence of the assemblage composition during this experimental management period.

Results

A. Cluster analysis. The results of the cluster analysis of the R_{ij} values are presented in tabular format (Table 4) for all seven areas but we present only two of the accompanying dendrograms, representing the best and worst cases (Figs. 2 and 3). It is obvious that the species composition of rockfish landings is highly variable when viewed at the level of individual landings. From an assemblage management perspective the worst-case scenario (Fig. 2) occurs when the arms of the dendrogram are all narrow and linked at a low level of similarity (<0.4). This implies that landings among vessels are extremely dissimilar throughout the year and the potential for assemblage management is low. Only Area VI (northwest Vancouver Island, May-December) displays these traits to any marked degree, and it is based almost entirely on major landings of single species, rather than completely different proportions of the same species mix. In the more typical dendrogram (Fig. 3), the group bases are linked at a high level of similarity (>0.8), either as a broad cluster of single species catches or multiple groups with extremely similar ratios.

It is clear that management opportunity afforded at the level of individual landings is limited by the variation in R_{ij}. However, major clusters based on temporal patterns were identified (Table 4), implying much greater stability in R_{ij} when landings are grouped over longer periods.

Examination of the L_{ig} index for the broader temporal clusters (Table 4) showed that these clusters also accounted for the majority of annual landings, hence would be useful in management. The exception to this general case concerned *S. flavidus* and *S. proriger*. For the former species the cluster analysis indicated that in the major areas of capture (IV and V) over 65% of the *S. flavidus* was caught by itself or in an assemblage where its $R_{ij} > 0.75$. At the same time we learned through a tagging study that *S. flavidus* was capable of extremely wide movements (Leaman, unpubl. data) and should be managed separately on a coast-wide basis. For *S. proriger*, while it was seldom caught alone, its R_{ij} averaged only 0.17 in those clusters accounting for the majority of its annual landings. Another result of the cluster analysis therefore, was the suggested elimination of *S. flavidus* and *S. proriger* from consideration for assemblage management.

Examination of the R_{ij} indices for the remaining shelf and slope forms, by month and management area indicated a relatively high degree of variation throughout the year for most areas (Table 4). We then turned to the P_{ig} index to determine if the majority of the variation occurred during the majority of the landings.

B. Catch proportion analysis. The general pattern of the monthly proportion index was for strong temporal segregation of index maxima between species, within the same management area. For example, the peak in P_{ig} for *S. alutus* in Area 5E during 1977-1982 was in April while the peak for *S. reedi* was in October (Fig. 4). Similarly, *S. pinniger* was dominant during May in Area 5B, while the *S. brevispinis* maximum occurred in August. In no area was there strong coincidence in the monthly proportions.

Taken by themselves, these results would suggest little opportunity for optimization within an assemblage management framework. However, when viewed in conjunction with the R_{ij} and L_{ig} results it is clear that achievement of species-specific management goals is possible, due to the temporal patterns of availability for individual species within the assemblages.

C. Covariation in landings. While the absolute magnitudes of landings by species do show differences, the patterns of change by month (% increase or decrease) exhibit some consistency (Fig. 5). For the examples in Table 5 only the 1977 *S. brevispinis* - *S. pinniger* Area 5A/B comparison showed a probability less than 0.5 ($0.3 > P_{.05(2),7} > 0.2$) in accepting the hypothesis of equivalent percent change in monthly landings of the two species.

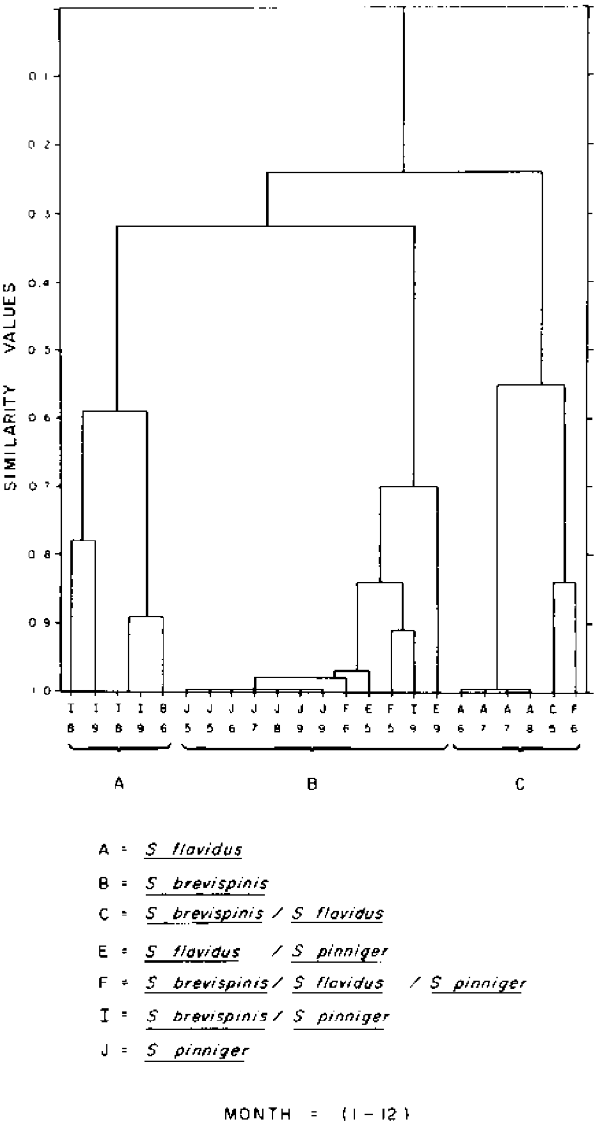

Figure 2. Similarity dendrogram from cluster analysis of shelf rockfish landings for Area VI, band on species composition and month caught.

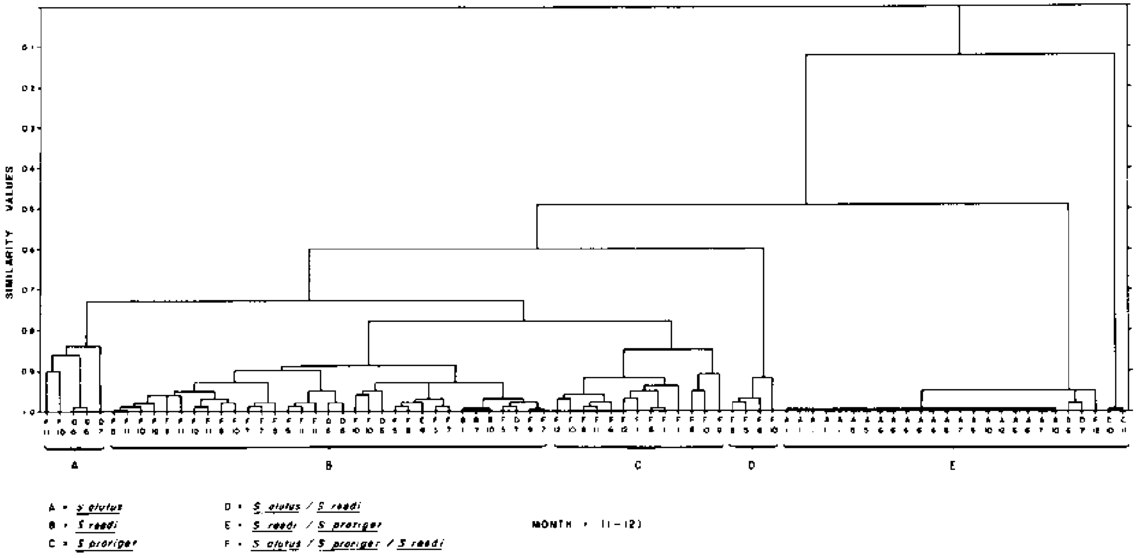

Figure 3. Similarity dendrogram from cluster analysis of slope rockfish landings for Area I, based on species composition and month caught.

Table 4. Relative catch indices and mean catch ratios for groups in cluster analysis, by study area.

Study area	species[a]	Group no.	Month	Relative catch index (L_{ig})	Mean catch ratio
I	Al/PR/RE	A'	Jun-Nov	.17/.02/.12	.51/.05/.43
	Al/PR/RE	B'	May-Nov	.23/.43/.46	.08/.06/.85
	Al/PR/RE	C'	Jul-Dec	.17/.28/.16	.23/.25/.48
	Al/PR/RE	D'	May-Oct	.01/.24/.09	.04/.50/.40
	Al/PR/RE	E'	Jan-Jun	.42/.03/.17	.97/.01/.01
II	Al/PR/RE	A_1'	Jul-Dec	.30/.41/.25	.48/.19/.33
	Al/PR/RE	A_2'	Jul-Dec	.23/.12/.62	.23/.07/.70
	Al/PR/RE	B'	Jan-Jul	.47/.47/.12	.96/.03/.04
III	Al/RE	A'	Jul-Dec	.46/.70	.79/.20
	Al/RE	B_1'	Jul-Dec	.33/.19	.90/.09
	Al	B_2'	Jan-Jun	.07	-
	Al/PR/RE	C'	Jul-Nov	.14/1.0/.11	.89/.01/.09
IV	BR/Fl/PI	A_1'	May-Jul	.01/.11/.15	.02/.78/.19
	BR/Fl/PI	A_2'	May-Jun	.08/.15/.12	.02/.93/.05
	BR/Fl/PI	A_3'	Aug-Oct	.14/.26/.04	.19/.79/.02
	BR/EN/Fl	A_4'	Sep-Oct	.07/.32/.11	.04/.20/.75
	BR/EN/Fl/PI	A_5'	Aug-Oct	.09/.09/.04/.08	.05/.11/.60/.23
	BR/Fl/PI	A_6'	May-Jul	.01/.04/.15	.01/.71/.27
	BR/Fl/PI	B'	May-Jun	.01/.02/.19	.25/.27/.47
	BR/Fl/PI	C_1'	Aug-Sep	.40/.12/.20	.51/.37/.08
	BR/Fl/PI	C_2'	Aug-Sep	.19/.04/.04	.95/.02/.02
	EN/Fl	D'	Aug-Sep	.59/.10	.57/.40
	PI	E'	May-Jun	.03	-
V	BR/Fl	A_1'	Jul-Oct	.13/.34	.23/.76
	BR/Fl/PI	A_2'	May-Jun	.01/.01/.08	.07/.65/.27
	BR/Fl/PI	A_3'	May-Sep	.01/.38/.05	.01/.97/.01
	BR/Fl/PI	B'	Aug-Oct	.83/.14/.71	.71/.22/.06
	BR/Fl/PI	C'	May-Nov	.01/.01/.17	.32/.04/.62
	BR/EN/Fl	D'	May-Jul	.01/1.0/.12	.06/.01/.89
VI	BR/PI	A'	Aug-Sep	.82/.07	.74/.25
	BR/Fl/PI	B'	Apr-Sep	.13/.38/.92	.02/.04/.93
	BR/Fl/PI	C'	May-Aug	.05/.62/.01	.13/.84/.02
VII	BR/EN/Fl/PI	A_1'	Aug-Sep	.03/.01/.01/.01	.16/.13/.46/.15
	EN/Fl	A_2'	May-Jul	.72/.86	.17/.82
	EN/Fl	B'	May	.26/.07	.50/.50
	Fl/PI	C_1'	Aug-Oct	.05/.75	.16/.83
	BR/Fl/PI	C_2'	Aug-Sep	.96/.01/.24	.31/.08/.46

[a] Al: *S. alutus* BR: *S. brevispinis*
PR: *S. proriger* EN: *S. entomelas*
RE: *S. reedi* FI: *S. flavidus*
PI: *S. pinniger*

D. Application to management. In addition to recommended species-specific quotas, managers were presented with quotas for shelf and slope assemblages by management area during 1983-1985. Assemblage quotas for Areas 3D and 5A/B relied on the temporal changes in R_{ij} and P_{ig} to achieve the appropriate mixture of individual species quotas while the Area 5E quota was divided into January-June and July-December allotments, to account for the seasonal bias in species availability (Fig. 4).

In general, the management precision of the assemblage quotas has been poor and quota overruns the rule, rather than the exception. The reasons for this are manifold and include a voluntary catch reporting system in British Columbia, rapid concentration of fishing effort, and either slow or no management action when quota limits were exceeded. Evaluation of assemblage management thus became somewhat confounded by imprecision in management of the assemblages. In Table 6 we have attempted to estimate what species and assemblage catches would have resulted from prompt management restrictions. Those figures in parentheses are the catches we would have achieved had we acted in such fashion, assuming that detection and response would normally operate in a monthly interval.

In the case of slope rockfish in Area 5E, assemblage management has acted to dampen major fluctuations in species composition of the total catch and prompt management action would have decreased overruns on the *S. alutus* yields (Fig. 6). However, it would also have reduced the catch of *S. reedi*. Achievement of the assemblage quota has thus been at the expense of the *S. alutus* stock. Since the seasonal patterns of R_{ij} for *S. reedi* and *S. alutus* have maintained themselves during assemblage management, it appears that improved distribution of species catches within the total assemblage can still be achieved through additional reduction of the spring fishery, with its higher landings of *S. alutus*, but maintaining the grouped-species quotas.

In some contrast with the above, assemblage management of shelf rockfish in Area 3D appears to have been less successful. While seasonal patterns of R_{ij} and monthly proportions have maintained themselves (Fig. 4) and quota overruns might have been decreased by more rapid management action (Fig. 7C), a component of the percentage overrun arose because management enacted fishing quotas 33% greater than allowable catches recommended by assessment biologists. However, even in consideration of this assemblage management has not introduced the stability noted for Area 5E.

It is possible to improve the performance of assemblage management in Area 3D through temporal segregation of the grouped quota, to take advantage of the higher proportion of *S. pinniger* in landings during the fall. Such segregation combined with prompt monitoring and management response would achieve more equitable balance than shown in Fig. 7B.

Discussion

Management of multiple species or stocks exploited by the same fishery is a problem that has plagued fishery biologists for some

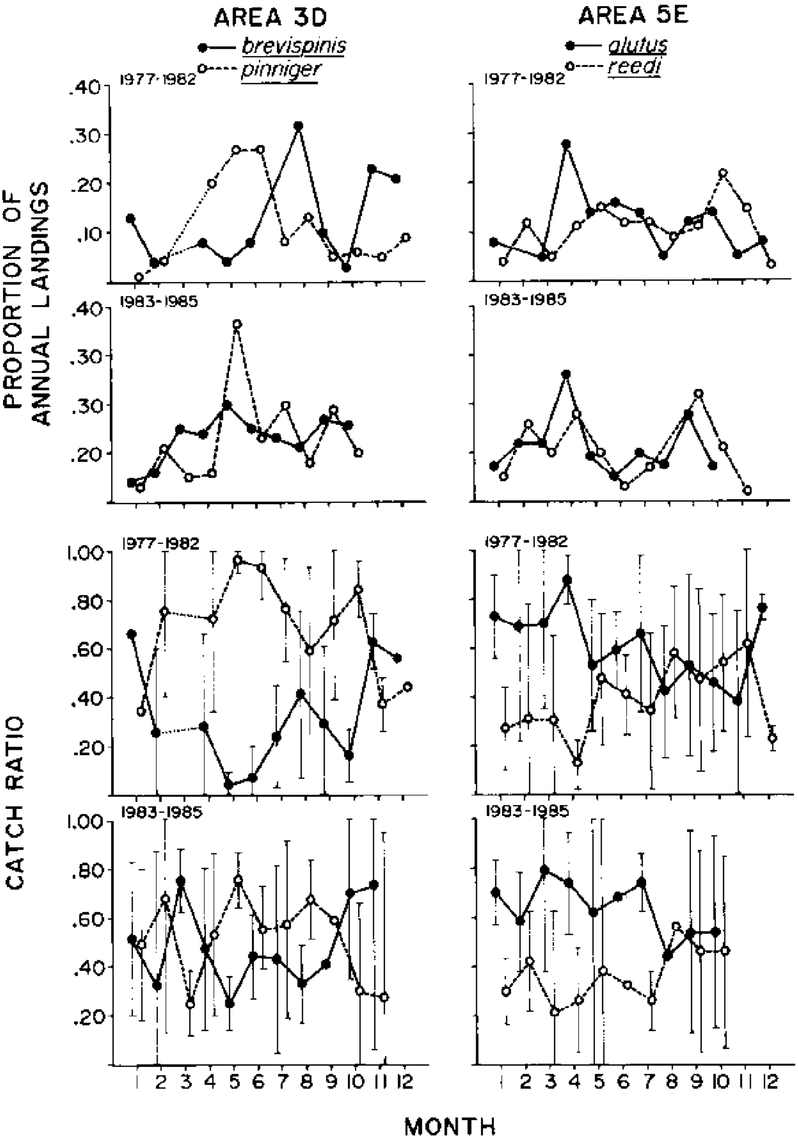

Figure 4. Monthly proportions and mean catch ratios of shelf rockfishes in Area 3D (left) and slope rockfishes in Area 5E (right), 1977-1982 and 1983-1985.

Table 5. Monthly landings (t) of rockfish species[a] in Areas 5E and 3D, 1977-1978, and tests of covariation. H_0: % change in monthly landings equal. H_1: % change in landings not equal.

1977	AL	RE	BR	PI
1	115.97	54.49	-	-
2	99.31	0.03	29.15	6.01
3	-	-	-	-
4	347.47	16.88	5.17	0.32
5	155.76	151.36	10.49	44.04
6	315.97	133.18	24.47	25.67
7	182.23	295.51	14.09	14.81
8	18.69	107.71	35.75	15.36
9	18.96	85.45	41.34	3.79
10	93.80	189.29	17.93	5.51
11	53.51	184.64	18.67	5.62
12	149.12	38.19	0.61	-
	Accept H_0:p>0.5		Accept H_0:p>0.2	
1978				
1	265.50	85.36	15.15	4.67
2	36.20	0.16	3.32	2.41
3	-	-	1.04	0.62
4	141.96	31.62	25.71	61.53
5	105.26	182.02	37.11	9.93
6	146.43	51.81	32.14	57.85
7	320.21	115.27	337.01	98.32
8	358.45	183.71	126.87	8.99
9	63.80	6.09	69.00	11.24
10	650.43	221.21	76.19	5.08
11	222.94	52.71	0.09	1.96
12	115.75	43.40	-	-
	Accept H_0:p>0.5		Accept H_0:p>0.5	

[a] species: AL-*S. alutus* BR-*S. brevispinis*
RE-*S. reedi* PI-*S. pinniger*

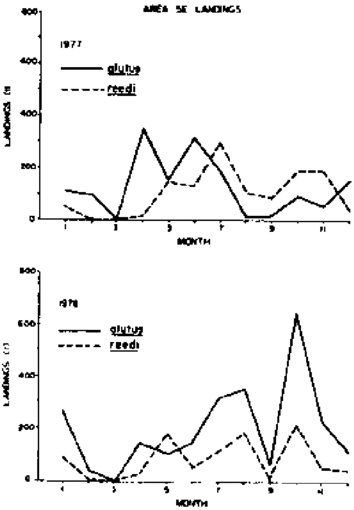

Figure 5. Monthly landings of slope rockfish in Area 5E, 1977-1978.

Table 6. Performance of assemblage rockfish management 1983-1985; values in tonnes. See text for explanation of values within vertical bars.

Area/species	Year 1983 Quota/catch		1984 Quota/catch		1985 Quota/catch	
3D						
S. brevispinis	200/564	253	250/462	195	350/813	507
S. pinniger	350/712	309	450/883	874	500/727	286
S. flavidus	150/36	14	100/19	19	100/288	222
Group quota (south)	600/836	576	500/801	799	500/1170	631
(north)	- 443		500/549	549	500/370	385
Total	600/1279		1000/1350	1348	1000/1540	1016
5A/B						
S. brevispinis	600/524		600/962		750/997	
S. pinniger	500/347		500/507		500/391	
Grouped quota	1100/871		1100/1469		1100/1388	
5E						
S. alutus	600/835	703	600/815	693	600/827	691
S. reedi	600/588	555	600/439	296	600/477	304
S. aleutianus	250/ 75	74	250/ 99	99	250/158	149
Grouped quota (spring)	500/998	832	500/816	550	500/995	676
(fall)	900/500	500	900/537	537	900/467	467
(total)	1400/1921	1332	1400/1353	1087	1400/1462	1143

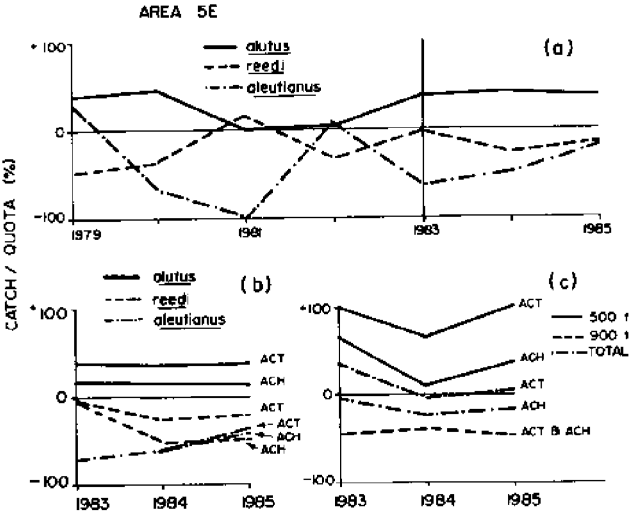

Figure 6. A. Individual (1979-1982) and assemblage (1983-1985) quota performance in Area 5E. B. Actual (ACT) and (ACH) achievable assemblage quota performance by species. C. Actual (ACT) and achievable (ACH) assemblage quota performance by opening.

time (Gulland 1983) and approaches have been of two general types. One method is to collect extremely detailed information on the biology and interactions of the species composing an assemblage, and build an analytic model which attempts to predict the effects of fishery and environmentally induced changes on these constituent parts (e.g. Andersen and Ursin 1977; Lett and Kohler 1976). Such a systems approach is inherently appealing to biologists because it offers the potential to actually understand the behaviour of a complex system. However, it is expensive in time and resources and extremely difficult to adequately model, at least with precision sufficient for quantitative prediction.

We make no pretense to such endeavour, rather have taken the second general approach, that of a more empirical nature wherein we attempt to deal only with the fishery induced changes and not with a detailed analysis of the internal dynamics of the assemblage. While such an approach will not substitute for that detailed understanding, it offers the potential to avoid catastrophic declines in one or more constituents while that knowledge is gained, by controlling a major external factor in these dynamics, i.e. the fishery.

Our program has also attempted to extend the normal empirical approach through a more comprehensive examination of assemblage composition as perceived through this major control variable. The advantages to using fishery based data are that assemblages can be examined over a longer time period than for research surveys and

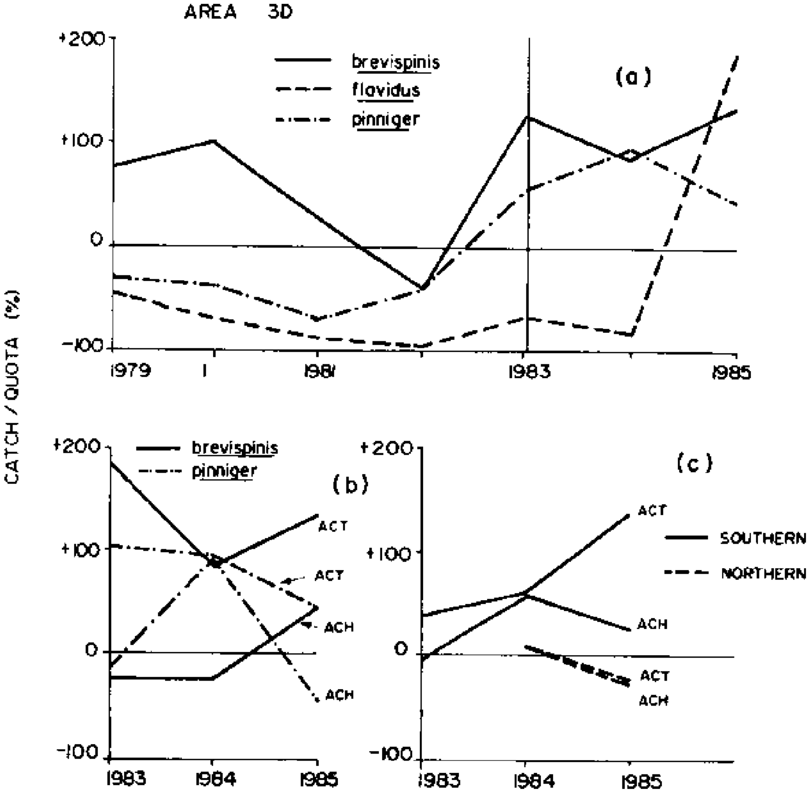

Figure 7. A. Individual (1979-1982) and assemblage (1983-1985) quota performance in Area 3D. B. Actual (ACT) and achievable (ACH) assemblage quota performance by species. C. Actual (ACT) and achievable (ACH) assemblage quota performance by sub-area.

that the data pertain directly to the management process. The disadvantages are that targetting and switching behaviour by fishermen may be imbedded in the data and be highly responsive to subsequent management actions, and that little understanding of internal assemblage dynamics is gained. This potential can be increased if assemblage management is undertaken on an experimental basis (Hobson and Lenarz 1977).

For the shelf and slope rockfishes off British Columbia, our analysis and management program has shown that:

- predictable assemblages of shelf and slope forms can be identified through fishery data;
- ratios of species in the assemblages are stable under experimental management and account for the majority of species' catches;

- separate species management goals are achievable with assemblage management, through manipulation of openings and quotas to take advantage of this seasonal and annual stability; and
- assemblage management based on such detailed examination can avoid the sacrifice of minor species for the sake of managing only the dominant species in an assemblage.

While we are encouraged by the modicum of success experienced with this approach we stress that it is only an interim measure and precursor to development of an understanding of the biological mechanics of these assemblages.

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Restricted year-class structure and recruitment lag within a discrete school of yellowtail rockfish

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Abstract.—Observations of a school of adult yellowtail rockfish *Sebastes flavidus* over an 11-year period in southeastern Alaska revealed negligible recruitment as the school dwindled in numbers and remaining individual fish grew in size.

Little is known about the patterns of recruitment of the yellowtail rockfish *Sebastes flavidus* along the Pacific coast of North America, where it ranges from San Diego, California, to Kodiak, Alaska. The recruitment observations described here are of a discrete school of yellowtail rockfish that occupied a sunken passenger liner at Point Lena, Lynn Canal, in southeastern Alaska. This school was also observed during a homing study by Carlson and Haight (1972), who showed that the species possessed the ability and inclination to return to a homesite when displaced as far as 22.5 km, displaced into other schools of yellowtail rockfish, or held for months in captivity. Return from certain sites involved changing directions several times or traversing deep straits or both. The difficulty of some returns and a lasting memory for the homesite indicate the fish possessed a strong association with it and are evidence for little natural emigration. In this paper, I describe what appears to be a long-term, pulse-like pattern of recruitment, and offer a hypothesis concerning initial establishment of adult schools.

Methods

Age-size composition and abundance were determined for a discrete school of yellowtail rockfish over 11 years by direct sampling and diver observations. This school occupied the wreck of a sunken passenger liner, 6,000 tonnes and nearly 100 m long, at 12–28 m depths at Point Lena, Lynn Canal, in southeastern Alaska. Adult yellowtail rockfish were captured by hook and line during 1969–1979, and the fork length of each fish was measured. Because these fish were also marked for the homing study by Carlson and Haight (1972), scales rather than otoliths were taken to determine age. Selected scales were pressed on plastic cards and viewed (83× magnification) on an Eberbach[1] projector.

Although otoliths are more appropriate for ageing older rockfish (Chilton and Beamish 1982), most of the age analyses took place during 1969–1971, when nearly all of the fish were young, generally less than 10 years old (Table 1). Kimura et al. (1979) stated that scales are reliable for ageing yellowtail rockfish through age 9, and scales were used to estimate ages of yellowtail rockfish to 14 (Phillips 1964) and from ages 8 to 15 (Six and Horton 1977). Furthermore, the mean lengths-at-age given by Westrheim and Harling (1975) for yellowtail rockfish ages 7–11 are generally within 3 cm of the values I found (Table 1). My age readings were consistent between years in terms of year classes represented and were, I believe, a valid reflection of the age structure of the school.

Annually, divers observed the school and visually estimated the size range of the fish and their overall abundance on 37 diving days during May–October between 1969 and 1979. Diver estimates

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

TABLE 1.—Ages and fork lengths of 408 yellowtail rockfish captured by hook and line at Point Lena, Lynn Canal, southeastern Alaska, from 1969 to 1979. No samples were taken in 1972, 1973, 1975, 1976, and 1978. Estimates of school size were made by scuba divers.

Sampling year	Age range (years)	Predominant ages (years)	Fork length (mm)		Number of fish sampled	Estimated number in school
			Range	Mean		
1969	7–10	7, 8	273–383	341	55	2,000–3,000
1970	7–16	8, 9	305–414	354	285	1,500–2,500
1971	9–11	9, 10	333–427	373	58	1,000–2,000
1974	13–14	13, 14	410–425	417	2	500–600
1977	10–18	16	340–443	408	7	100–200
1979	18	18	442	442	1	50–100

of the size range of fish in the school were subjective, but consistently showed a narrow size composition, and sizes were corroborated by actual capture and measurement of 408 fish (Table 1). Divers used the equivalent of transects (e.g., out each mast and from bow to stacks) over consistently used paths of known dimensions to count the numbers of rockfish in clusters and expanded these to estimate the total. Although the earliest diver observations recorded school size as "rough estimates," they verified the presence of a large school, at least in the thousands, certainly several times the 541 yellowtail rockfish from this school captured during the Carlson and Haight (1972) homing study.

Results and Discussion

Results indicate that recruitment to the school occurred over a short time span (1–2 years) and little or no additional recruitment occurred in the intervening 14–15 years. This school may have been newly established at the shipwreck homesite as early as 1967, as indicated by the size and relative abundance of a large school of yellowtail rockfish of relatively small size (estimated at 25–30 cm) that was observed by Louis M. Barr (Post Office Box 210361, Auke Bay, Alaska 99821, personal communication) while diving there in June 1967. There is evidence that yellowtail rockfish in Puget Sound shift from juvenile to adult areas with the onset of maturity around age 7 (Mathews and Barker 1983). In this study, the age structure of the rockfish in 1969 was dominated by the 1961 and 1962 year classes as 8- and 7-year-old fish. In 1970 and 1971, these year classes again predominated as 9- and 8-year-olds and 10- and 9-year-olds, respectively. No fish sampled were younger than age 7, and few fish older than age 11 were present (Table 1).

The 1960–1962 year classes were strong for other species of North Pacific marine fishes as well. For example, off Oregon–Washington, the 1961 year class of English sole *Parophrys vetulus* was abnormally strong, as were the 1960, 1961, and 1962 year classes of Dover sole *Microstomus pacificus* (Hayman et al. 1980). The 1961 year class was also unusually strong for Pacific halibut *Hippoglossus stenolepis* in the north Pacific Ocean (Deriso 1985), for Pacific hake *Merluccius productus* off Oregon–Washington (Bailey 1981), Pacific ocean perch *Sebastes alutus* off British Columbia (Leaman and Stanley 1985), and Pacific cod *Gadus macrocephalus* off British Columbia (Westrheim and Foucher 1985). The homing study by Carlson and Haight (1972) showed that yellowtail rockfish strongly identified with the site and returned to it when displaced, indicating little natural emigration. Yearly monitoring of the school by divers from 1969 to 1979 showed that progressively fewer, but larger, fish comprised the school. Age–size composition of 10 yellowtail rockfish taken during 1974–1979 from the small remaining school indicated that the 1961 year class remained predominant.

There are several possible explanations, not mutually exclusive, for the protracted lack of recruitment in this school of yellowtail rockfish. The explanation I favor is that the presence of large fish in established residence at this site prevented recruitment of the much smaller fish, who located in suitable areas elsewhere, and thereafter (as the demonstration of homing inclination and ability suggests for yellowtail rockfish inhabiting the wreck) identified with the other locations and did not emigrate.

This explanation is quite possible, particularly if the time frame is short (6 months or less) for shifting from juvenile (nursery) areas to adult habitat and if the larger adults represent potential predators or much more adept competitors for limited space, cover, and highly motile food sources. These larger fish could thus deter smaller fish from joining a school. The situation might progress to "a point of no return." The new recruits may be very sparse during the 2–3 years that the established adults grow to a size that excludes younger, smaller fish, even after the young fish attain maturity. Then, with a long-lived fish such as *Sebastes* spp., the established adult school remains intact until its members—all older, larger fish—approach the limits of longevity and are so reduced in number that they no longer deter recruitment. At this point, the next successful year class, upon attaining maturity, could recruit en masse, and the stage is set for a repeat performance of what we are seeing now.

Acknowledgments

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Recent exploitation patterns and future stock rebuilding strategies for acadian redfish, *Sebastes fasciatus* Storer, in the Gulf of Maine-Georges Bank region of the northwest Atlantic

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Abstract

The Gulf of Maine - Georges Bank stock of Acadian redfish, Sebastes fasciatus Storer, has been under moderate to intensive exploitation since the late 1930's. During the period of initial exploitation, annual commercial landings increased rapidly from less than 1,000 metric tons in 1935 to approximately 60,000 tons in 1941. Landings and effort subsequently declined through the 1940's and remained relatively stable from the mid-1950's through the late 1960's, averaging about 12,800 tons and 3,300 standard days fished, respectively. Additional effort by distant water fleets increased total landings to approximately 20,000 tons annually by the early 1970's. Except for a brief period between 1977 and 1979, landings have steadily declined since 1972, although domestic fishing effort has remained relatively high.

Estimates of exploitable biomass and relative abundance indices have consistently declined since the late 1960's. The most recent estimates suggest that stock abundance is currently lower than at any previously recorded level in the past 40 years. Age-specific stock size estimates derived from virtual population analyses (VPA) suggest that, except for a strong 1971 and a moderate 1978 year class, recruitment has been extremely poor throughout most of the 1970's and early 1980's. The VPA results also indicate that the instantaneous rate of fishing mortality (F) has exceeded F_{max} in most of the years since 1970 and has generally been between two and three times the $F_{0.1}$ level during this period.

Using the 1969 age-specific stock size estimates as a starting point, series of deterministic simulations were performed to evaluate the response of the stock under alternate levels of fishing mortality and different partial recruitment vectors. Recruitment effects were introduced in a form consistent with the pattern observed between 1969 and 1984. Additional sets of stochastic simulations were also performed using the most recent age-specific stock size estimates as a starting point to examine various stock rebuilding strategies with respect to fishing mortality and partial recruitment. A stochastic recruitment generator, based on a probability transition matrix approach, was incorporated to drive the model and to simulate different sets of recruitment conditions.

Results suggest that fishing mortality rates in effect during 1969 through 1984 were excessive given the sporadic nature of recruitment. In particular, high fishing mortality rates combined with an earlier age at full recruitment applied to the 1971 year class resulted in a rapid depletion of this cohort. Results for the 1978 year class, although incomplete as of 1984, suggest a similar pattern of exploitation. Future stock rebuilding strategies, based on 1985 stock sizes, are dependent almost entirely on recruitment success. A probable recruitment frequency of one strong year class per decade, as suggested by prior observations, combined with fishing mortality rates equal to $F_{0.1}$ (0.07) and an instantaneous natural mortality (M) of 0.05, will stabilize the stock only at minimal maintenance levels. Long-term increases in stock size may be achieved by significant alterations of the partial recruitment vector and/or an increase in recruitment frequency resulting from a positive stock-recruitment relationship.

Introduction

Three species of the genus *Sebastes* inhabit the western North Atlantic from the coast of Greenland to Georges Bank (Ni 1982, 1984). Off the New England coast, the Acadian redfish, *Sebastes fasciatus* Storer, (Robins et al. 1986) is most common in the relatively deep waters of the Gulf of Maine and on the northern and southeastern slopes of Georges Bank to depths of 400 m (Bigelow and Schroeder 1953). This species is characterized by a relatively long life span and extremely low growth and natural mortality rates. Ages up to 50 years with corresponding maximum lengths of 45-50 cm have been noted (Mayo 1980). Sexual maturity is attained by both sexes in 5-9 years at average lengths of 18-25 cm. An ovoviviparous reproductive cycle has evolved which enhances larval survival at a cost of greatly reduced individual fecundity. This strategy, in conjunction with a large number of mature age groups in the spawning stock, should provide a high degree of stability in reproductive potential and resilience to environmental or anthropic perturbations by distributing the reproductive burden over numerous year classes. Evidence of severe disruptions to the equilibrium of the stock, such as recruitment or growth overfishing, may appear only after a prolonged period of sustained intervention by either of the above influences.

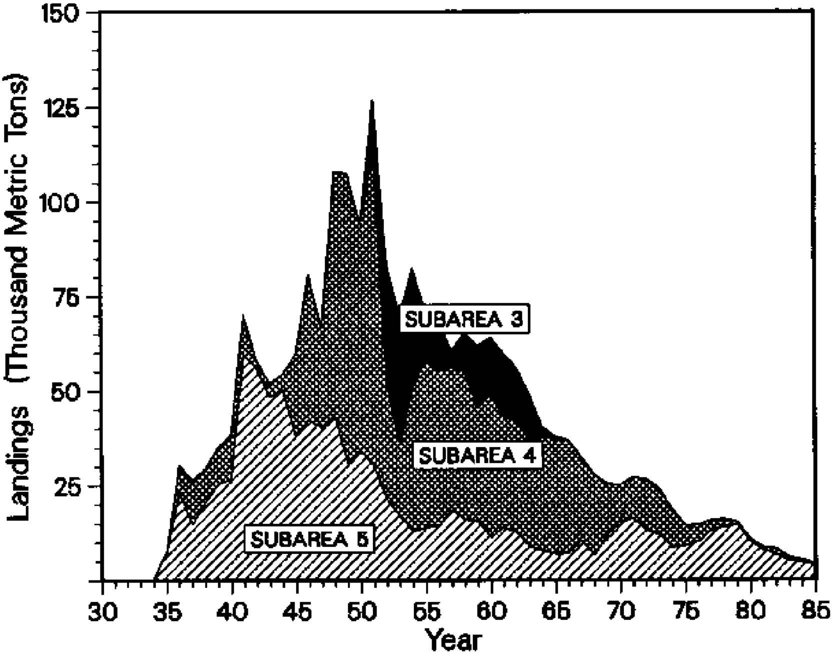

Figure 1. United States landings of redfish from Gulf of Maine - Georges Bank (Subarea 5), Scotian Shelf - Gulf of St. Lawrence (Subarea 4), and Grand Banks (Subarea 3).

Commercial exploitation of redfish within the Gulf of Maine - Georges Bank region has been moderate to intense throughout most of the past 50 years. Landings from this stock increased rapidly during the development of the fishery, from less than 1,000 metric tons (t) in 1934 to over 50,000 t per year between 1941 and 1944 (Figure 1). Landings subsequently declined sharply, despite continued high effort levels, until the early 1950's when effort was re-directed toward more distant grounds on the Scotian Shelf, in the Gulf of St. Lawrence, and on the Grand Banks off Newfoundland (Mayo 1980). In the late 1960's, Gulf of Maine - Georges Bank landings rose again in response to increased fishing effort from domestic and distant water fleets. During this cycle, landings peaked at approximately 20,000 t in 1971 and 1972 before declining to the current level of 4,300 t. Further details regarding the development of the New England redfish fishery including trends in historical landings may be found in Kelly et al. (1972), Mayo (1980), and Mayo et al. (1983).

Standardized commercial catch per unit effort (CPUE) has declined over the past two decades from a maximum of 6.4 t per day fished in 1966 to 0.9 t per day fished in 1985. During this same period estimated fishing effort increased from less than 2,000 days fished during the late 1960's to over 6,000 days fished in 1979 and 1980. Since 1981 annual effort has remained between 4,000 and 5,000 days fished despite continued reductions in landings. Precipitous declines in commercial catch rates, evident in the early 1970's, prompted several studies which were initially aimed at determining maximum harvest levels based on catch and effort analyses. Preliminary results (Mayo 1975), which suggested a maximum yield of 20,000 t from the entire Gulf of Maine - Georges Bank stock under equilibrium conditions, were later modified to approximately 14,000 t (Mayo 1980) when effort standardization techniques were incorporated in the analyses. In the first analytical assessment of this stock, Mayo et al. (1983) demonstrated a strong correlation between stock biomass and previously noted declines in commercial CPUE. This study further documented the presence of a strong 1971 year class and provided evidence linking a temporary reversal of the declining CPUE trend to recruitment of the 1971 year class to the fishery at ages 5, 6, and 7 between 1976 and 1978. Overall recruitment during the 1969-1980 period appeared to be extremely poor, causing the fishery to become increasingly dependent on the dominant 1971 year class.

Recent studies designed to examine long-term effects of various fishing mortality rates on projected stock sizes and resulting yields of redfish have been limited by the lack of information on the strength of incoming year classes. Recruitment effects had been incorporated in a deterministic manner by applying an average level equal to one of several possible outcomes based on prior observations as described by Mayo et al. (1983). A more appropriate solution to this problem may be based on theories that recruitment may fluctuate in response to some function of parental stock size, or in a cyclical manner consistent with known density-independent factors. Traditionally, recruitment variability in fisheries has been evaluated by fitting a family of curves which describe the dependence of recruitment on parent stock to a series of historical observations. Numerous applications of this method to model the responses of various animal populations have been summarized by Ricker (1954, 1975) and Cushing (1971, 1973).

An alternative technique to fitting stock-recruitment curves to such a series of paired observations involves the use of a probability transition matrix. This approach provides a means of utilizing raw stock size and recruitment data directly to calculate the probability of obtaining various levels of recruitment, given a range of possible parental stock sizes. Getz and Swartzman (1981) originally applied this method in a stochastic age-structured model to estimate recruitment for several species with up to seven recruitment levels and eight parental stock sizes. A modification of the Getz-Swartzman technique was applied by Swartzman et al. (1983) to the Northeast Pacific whiting fishery. More recently Overholtz et al. (1986) incorporated this form of recruitment estimation in a model of the Georges Bank haddock stock. The probability transition matrix consists of a series of discrete cells which contain pairs of observations for given levels of parental stock size and associated recruitment. The historical record of stock size and recruitment is used as a basis to compute the probability that a given level of recruitment will occur within a range of parental stock sizes. The accuracy of the recruitment probability schedules depends on the amount of historical information available but, as Getz and Swartzman (1981) note, the transition matrix approach provides a more natural utilization of the raw stock and recruitment data than a weakly correlated fit to a predetermined stock-recruitment curve. For long-lived species, the response time to any perturbation of the stock is greatly increased and the need for extensive historical data is even more critical.

In the present study, a limited series of parental stock and recruitment observations are incorporated in a stochastic simulation of the Gulf of Maine redfish stock. A probability transition matrix approach is employed to determine the probability of obtaining various levels of recruitment within specified limits of spawning stock size. Simulations were performed over 16 and 100 year time horizons to evaluate the effects of various fishing mortality rates and partial recruitment patterns on present and future stock sizes and yields. Sensitivity of the model to changes in the level of natural mortality is also examined.

Methods

Domestic and international landings data for this study were obtained from the commercial fishery data base system maintained at the Northeast Fisheries Center (NEFC), Woods Hole, Massachusetts and from fishery statistics compiled by the International Commission for the Northwest Atlantic Fisheries (ICNAF) and its successor, the Northwest Atlantic Fisheries Organization (NAFO). Estimates of catch at age and mean weights at age for the stock were computed from domestic length frequency samples weighted by area-specific monthly landings, and age/length keys based on otoliths collected by NEFC port samplers from 1969 through 1984. Numbers landed in the domestic fishery were computed by incorporating seasonal, areal, and sex-specific length-weight equations in the calculations. The total catch-at-age, including the international harvest, was estimated by simple expansion based on the ratio of total landings to domestic landings in each year. In most years the international fishery accounted for less than 5% of the total landings from this stock.

Estimates of instantaneous fishing mortality (F), stock size and biomass, and age 1 recruitment for the 1969-1984 period were obtained by Virtual Population Analysis (VPA) of the catch at age matrix employing an instantaneous natural mortality rate (M) of 0.05. Terminal F in 1984 (0.172) was derived from an iterative comparison of the functional relationship between estimates of fully recruited F obtained from a series of trial VPA's and corresponding annual fishing effort as described by Mayo et al. (1983). Partial recruitment was assumed to follow the pattern exhibited during the most recent years with full recruitment occurring at age 9. Spawning stock was computed by applying a maturity-at-age schedule to age-specific stock sizes for ages 5 through 9 inclusive. Total and spawning stock biomass estimates were derived from age-specific stock sizes by applying commercial mean weights at age.

To extend the series of stock and recruitment observations prior to 1969, age 2-5 stock sizes in 1969 were extrapolated back to age 1 for the years 1965 through 1968 assuming an exponential decrease in cohort size in each year equal to the instantaneous natural mortality rate. This procedure provided estimates of age 1 recruitment for redfish spawned during 1964 through 1967 to complement the recruitment estimates obtained from the final VPA for the 1968 through 1980 year classes. Spawning stock sizes for the years prior to 1969 were derived from a linear regression of 1969-1984 VPA spawning stock estimates on a series of corresponding stock abundance indices derived from NEFC autumn bottom trawl surveys for the Gulf of Maine region. The correlation between the two data sets was substantially improved by smoothing the trawl survey indices by the integrated moving average method as described by Pennington (1985). The resulting regression was highly significant ($r = 0.95$, $p < 0.01$).

Stock - recruitment relationships

The model described below is driven primarily by recruitment, which adds fish to the population at age 1, and natural and fishing mortality which account for losses. Age 1 recruitment, as determined from the VPA results, ranged from 0.4 million fish to 197.2 million fish with over 75% of the observations in the range of 0.4 to 5.9 million fish (Figure 2). Recruitment levels beyond the time period covered by the VPA are speculative in nature, and must be derived based on some objective criteria. Variability in recruitment may be related to changes in physical factors such as temperature or prevailing wind and current patterns, or to density-dependent mechanisms such as intraspecific competition during the larval and juvenile stages or changes in the rate of growth or maturation of the adults. In a density-dependent model, the strength of a recruiting year class is considered to be a function of some measure of parental stock size.

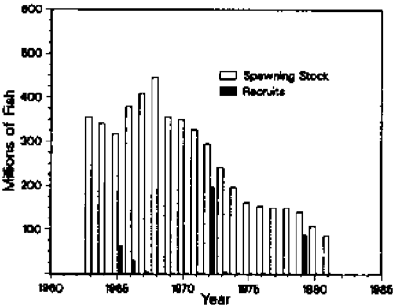

Figure 2. Redfish spawning stock and recruitment (millions of fish) from the Gulf of Maine - Georges Bank region.

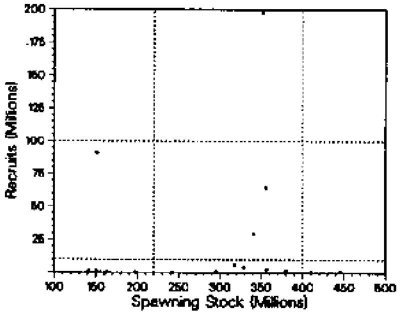

Figure 3. Probability transition matrix boundaries and distribution of redfish spawning stock and recruitment data.

Although mating of male and female redfish occurs during the calendar year prior to the release of larvae by the females, any relationship between spawning stock size and subsequent recruitment at age 1 must be lagged by one year. A scatterplot of 17 pairs of recruitment vs. spawning stock, representing the 1964 through 1980 year classes (Figure 3), illustrates that the recruitment pattern for Gulf of Maine redfish, based on these limited data, consists of a rather low base level interrupted by an occasional moderate to large year class. Further, this base recruitment level appears to be continuous at all spawning stock sizes, although a higher frequency of low recruitment occurs at relatively low stock sizes.

Model Description

Recruitment generator

Since recruitment to the fishable stock is a major driving force in any fishery simulation, the choice of an appropriate recruitment generator is critical to the final outcome. The technique described below was developed by modifying the Getz-Swartzman method to include a series of stochastic events within the context of the probability transition matrix to determine the level of recruitment and to select a single recruitment event from a distribution of possible values.

The 17 pairs of Gulf of Maine redfish data were first arrayed in a 3 X 3 contingency table with nine cells corresponding to low, moderate, and high spawning stock and recruitment levels. Transitions between levels were determined by the location of apparent gaps in the recruitment and spawning stock size continua. Within each spawning stock level, the cumulative probability that one of three recruitment levels would be selected was computed in accordance with the observed historical proportions. Stochastic variability was introduced by generating a random number between 0 and 1: this value determined the trial cell chosen based on which pair of cumulative probabilities bracketed the value. Thus, over a series of trials, the probability of selecting a particular recruitment level approximated the observed frequencies, although, on a single trial, any recruitment level could be selected. Within each recruitment cell, a distribution of recruitment scaling factors was constructed such that the highest recruitment frequency would occur at the midpoint of the interval. This was accomplished by first generating a series of three random numbers between 0 and 1. Over several trials, the means computed for each series form a uni-modal frequency distribution with a modal value of approximately 0.5 and a standard deviation of 0.166. A recruitment value was then obtained by multiplying the upper bound of the recruitment interval by the computed scaling factor, with an adjustment to the center of the interval. In this manner, the expected recruitment probability is initially determined by the level of spawning stock and, within a given range of spawning stock, a single recruitment event is drawn from up to three distributions in accordance with observed frequencies. Sample distributions of recruitment frequencies generated in this manner, based on 10,000 trials for each spawning stock level, are illustrated in Figure 4. Although the recruitment frequencies within each cell of the transition matrix are distributed

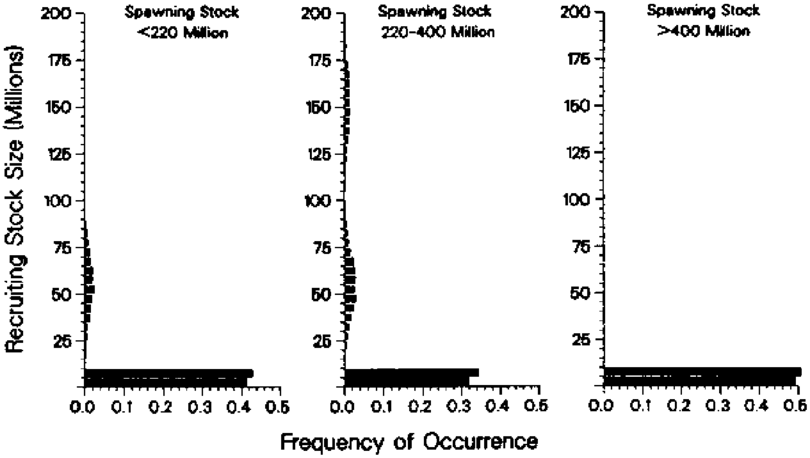

Figure 4. Distribution of probable recruitment frequencies in each cell of the probability transition matrix computed from 10,000 trials.

normally, recruitment over the entire range of observed values appears to be lognormal.

Stock and catch projections

Once a year class has recruited at age 1, the initial number of fish in each of 50 age groups present in the stock is discounted on an annual basis by the combined effects of natural and fishing mortality as follows:

$$N_{j+1,t+1} = N_{j,t} * \exp(-(F_{j,t}+M))$$

where: $N_{j,t}$ = the number of fish in age group j in year t,

$F_{j,t}$ = effective instantaneous fishing mortality on age group j in year t, and

M = instantaneous natural mortality.

Effective fishing mortality is defined as the product of the fully recruited F and an age-specific partial recruitment multiplier. The number of fish in each age group taken by the fishery in any given year is computed from the age-specific stock size estimates using the Baranov catch equation:

$$C_{j,t} = N_{j,t} * (F_{j,t}/(F_{j,t}+M)) * 1-(\exp(-(F_{j,t}+M)))$$

Spawning stock sizes were determined by applying an overall vector of maturity-at-age factors to the age-specific stock sizes. Total and spawning stock sizes were converted to biomass by applying a vector of average weights at age based on a von Bertalanffy growth curve taken from Mayo (1980), while catch biomass estimates were calculated from numbers caught using a mean weight at age vector derived from an average of the 1969-1984 commercial fishery data as described for the VPA procedure above. Effective fishing mortality on the incompletely recruited ages was adjusted in accordance with one of two possible partial recruitment vectors corresponding to either the pattern exhibited by the heavily exploited 1971 and 1978 year classes with full recruitment occurring at age 9 (Option 1), or the pattern observed over the 1969-1980 period with full recruitment occurring at age 14 (Option 2). Initial recruitment to the fishery occurred at age 5 in each case.

The model was employed to examine the effects of alternative harvesting strategies on both yield and stock size over short- and long-term time horizons by varying the level of fishing mortality and the partial recruitment pattern. Each simulation consisted of 30 trials over a specified time period of either 16 or 100 years duration. The 16-year simulations were designed to provide a short-term retrospective examination of recent changes in the population using 1969 stock sizes as a starting point. Results from this initial series were compared with those obtained from the VPA. Long-term simulations of various fishing options were performed using the relatively low 1985 stock size as a starting point to evaluate possible stock rebuilding strategies. Fishing mortality rates were fixed at various levels ranging from 0.01 to 0.17, including the $F_{0.1}$ and F_{max} levels. The sensitivity of the model to changes in natural mortality was also investigated.

Results

Catch-at-age for the years between 1969 and the mid-1970's was composed of a broad spectrum of year classes with ages between 10 and 20 years well represented. With the recruitment of the 1971 year class in 1976, 1977, and 1978, combined with minimal subsequent recruitment, the catch composition became increasingly dominated by this single year class through the early 1980's. Between 1978 and 1982, the 1971 year class accounted for over 50% of the total numbers landed, attaining a maximum representation of 63% in 1980 and 1981. In 1984, however, the 1978 year class recruited to the fishery in substantial numbers, accounting for approximately 48% of the total numbers landed, while the 1971 year class percentage declined to 26%.

VPA results suggest that F declined from approximately 0.20 during 1970-1973 to about 0.15 between 1974 and 1976, but increased thereafter to a level between 0.22 and 0.28 during the 1977-1981 period (Table 1). These recent levels of F are approximately three times the $F_{0.1}$ level (0.07) and 70-80% greater than the estimate of F_{max} (0.14) reported by Mayo et al. (1983). Exploitable (age 5+) stock size declined steadily from 487 million fish in 1969 to 166 million in 1975, increased to 313 million in 1976 when the 1971 year class recruited to the fishery, but has since declined sharply to an

Table 1. Estimates of instantaneous fishing mortality (F), and total stock, exploitable stock (ages 5+), and spawning stock obtained from virtual population analysis (VPA) of 1969–1984 catch-at-age data for Gulf of Maine – Georges Bank redfish (Stock sizes in millions of fish and biomass in thousands of tons).

Year	Instantaneous Fishing Mortality (F)	Total Stock Number	Total Stock Biomass	Exploitable Stock Number	Exploitable Stock Biomass	Spawning Stock Number	Spawning Stock Biomass
1969	0.120	520.0	139.4	486.6	136.2	356.0	117.5
1970	0.176	462.0	128.5	453.4	127.9	351.7	110.2
1971	0.196	393.5	134.0	387.0	133.7	328.8	121.0
1972	0.191	526.7	122.6	325.3	120.4	295.4	114.0
1973	0.225	459.5	99.1	254.9	94.9	242.5	92.4
1974	0.139	400.3	97.5	202.6	85.1	197.9	84.1
1975	0.158	353.4	92.3	166.3	74.3	162.9	73.5
1976	0.168	318.5	85.7	312.7	85.3	155.4	64.0
1977	0.223	274.0	80.7	271.7	80.6	151.2	59.9
1978	0.245	221.5	70.1	219.7	70.1	150.7	55.8
1979	0.285	261.0	62.2	168.6	61.2	141.0	54.4
1980	0.257	215.6	47.1	119.0	45.2	110.3	42.9
1981	0.260	186.1	44.1	89.0	36.5	88.1	36.4
1982	0.224	165.0	47.4	71.2	34.5	70.5	34.3
1983	0.205	145.1	43.1	140.2	42.9	63.2	29.6
1984	0.172	131.3	38.7	126.4	38.4	65.9	26.5
1985		112.7	32.6	107.8	32.3	71.7	25.2

estimated 108 million fish in 1985. Estimates of exploitable stock biomass are less variable, exhibiting a steady decline from 136,000 t in 1969 to 32,000 t in 1985. Similarly, estimates of spawning stock biomass declined from 118,000 t in 1969 to 25,000 t in 1985. Recruitment of the 1978 year class at age 5 in 1983 provided only marginal increases in exploitable stock size and biomass estimates, compared to previous increases generated by the 1971 year class during 1976-1979. Thus, the 1978 year class appears to be considerably weaker than its relatively strong predecessor.

Biomass and yield simulations

Simulated stock biomass and yield estimates obtained from the first series of trials, based on 1969 age-specific stock sizes, are given in Figure 5. During the first 16 years, fishing mortality rates were fixed at the levels indicated by the VPA results, while annual recruitment was generated by the model as a function of spawning stock size. Corresponding annual stock biomass estimates obtained from the VPA and observed yield levels are also provided as a reference to evaluate performance of the model. From years 17 through 100, F was held constant at various levels ranging from 0.01 to 0.17.

Results from the 16 year retrospective simulations for the 1969-1984 period agree closely with VPA stock size estimates and with empirical catch data. Recruitment estimates for the first four year were generated using probabilities associated with the mid-rang spawning stock sizes which, in theory, provide optimum conditions fo obtaining maximum recruitment levels. After 1972 the spawning stoc declined below the 220 million level resulting in lower overal recruitment. When averaged over 30 trials, simulated recruitmen values are considerably less variable than the observed levels. Mean

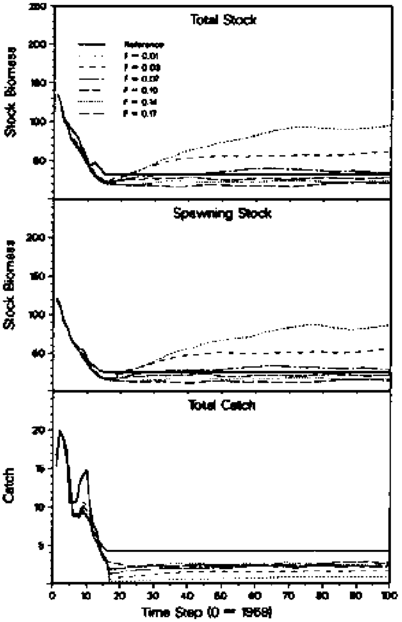

Figure 5. Results of 100-year stock biomass and yield simulations (thousands of tons) under six F levels with M = 0.05 and partial recruitment option 1.

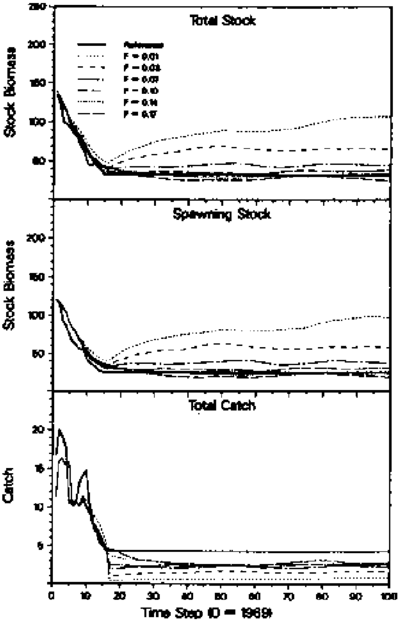

Figure 6. Results of 100-year stock biomass and yield simulations (thousands of tons) under six F levels with M = 0.05 and partial recruitment option 2.

annual recruitment levels generated from the model exhibited a slight downward bias resulting in lower annual stock size estimates when compared to actual stock sizes obtained from the VPA, particularly since the mid-1970's. The magnitude of the underestimate in total stock biomass ranged from 10 to 20% during this period, while spawning stock biomass was underestimated by about 5-10%. This downward bias in simulated average recruitment may have resulted from the adjustment of the modal probability within each cell of the transition matrix to the midpoint of the recruitment range when, in some cases, actual values fell closer to the upper limits.

Projections beyond 1985 indicate that stock levels will gradually increase when fishing mortality remains below 0.07. At the lowest F applied in these analyses (0.01), total stock biomass increases to approximately 95,000 t after approximately 55 years and remains at that level for the duration of the simulation. Spawning stock biomass also increases to about 85,000 t during the same time period. When F is held at 0.03, total stock biomass increases to a maximum level of 55,000 t after about 25 years and continues to rise thereafter to 60,000 t. Spawning stock biomass exhibits a similar trend, initially increasing to 50,000 t and then to 55,000 t at the end of the simulation. When F remains at 0.07 total stock and spawning stock biomass stabilize slightly above the 1985 reference levels; the three highest F's result in further declines before stabilizing at levels below the 1985 reference points. The yields to the fishery obtained at all fishing mortality rates are considerably less than the 1985 catch and range from less than 1,000 t at an F of 0.01 to approximately 2,500 t at F's between 0.10 and 0.17. During each of these simulations, spawning stock size remains well below the 220 million threshold needed to shift the recruitment probabilities into the next highest range.

The failure of the spawning stock to increase to former levels suggests that the recruitment simulation requires some refinement, or that the survival rate of a cohort from the age of recruitment to the time when the fish enter the spawning stock is insufficient to allow any significant accumulation. Two aspects of the population dynamics of this stock were further investigated: partial recruitment to the fishery, and natural mortality.

Alternate strategies

To decrease effective fishing mortality, the first series of simulations was repeated with a partial recruitment vector which approximated conditions evident throughout the 1970's in place of the initial vector which was based on the recruitment pattern exhibited by the heavily exploited 1971 year class from 1975 through 1984. The age of full recruitment was delayed from 9 to 14 years and the partial F on all ages from 5 through 13 was reduced. Natural mortality remained at 0.05. Results from the first 16 years of these analyses (Figure 6) provide better agreement with observed declines in stock size through the mid-1980's, although the delay in the age of full recruitment resulted in a slight overestimate of stock biomass during this period. Forward projections from 1985 reveal little improvement over the previous series since only extremely low fishing mortality rates allow any substantial recovery of the stock. Although total stock and spawning stock biomass increased by about 10% at the lowest F level, the spawning stock size still remained below 220 million fish throughout the entire period. Similar improvements are evident at F = 0.03 but little or no recovery above the 1985 level occurs when F exceeds 0.07. Yields are similar to those obtained from the previous series since the slightly higher stock sizes are offset by the lower effective fishing mortality.

The maturity-at-age schedule employed in the model incorporates a delay of 6 years between the initial age at recruitment (age 1) and the age at 50% maturity (age 7). An instantaneous natural mortality rate of 0.05 compounded over this 6-year period results in a 26% loss from each recruiting cohort before they can contribute substantially to the spawning stock, even if no fishing mortality occurs. Imposing fishing mortality rates between 0.10 and 0.17 to the partially recruited cohorts causes an additional loss of between 9 and 14% before the age of 50% maturity. Thus, approximately 35-40% of the

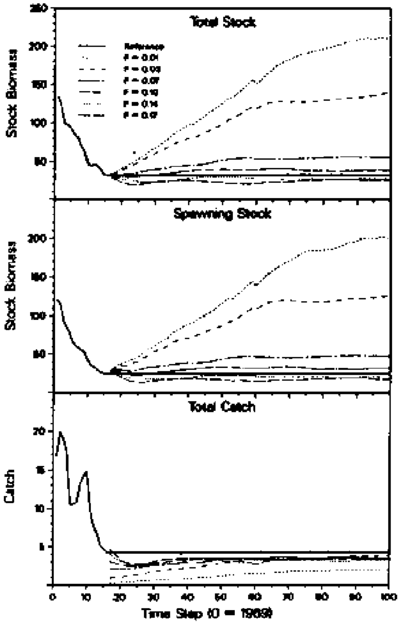

Figure 7. Results of 100-year stock biomass and yield simulations (thousands of tons) under six F levels with M = 0.025 and partial recruitment option 1.

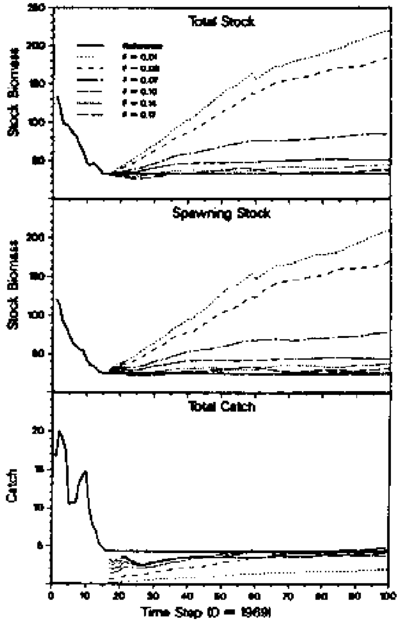

Figure 8. Results of 100-year stock biomass and yield simulations (thousands of tons) under six F levels with M = 0.025 and partial recruitment option 2.

recruitment is discounted before fish are added to the spawning stock when fishing mortality exceeds 0.10, if M is assumed to equal 0.05.

In the last two series of trials, each of the above analyses was repeated with natural mortality set at one-half of the original level. Simulations were performed using 1985 stock sizes as a starting point with the original and the modified partial recruitment vectors. The most dramatic improvement in stock biomass occurs at the two lowest F levels, although substantial increases are also evident when F equals 0.07, particularly if full recruitment is delayed until age 14 (Figures 7 and 8). When M is fixed at 0.025 the response of the stock to changes in partial recruitment is most sensitive at F's between 0.03 and 0.07, while only marginal improvements in stock size occur at higher fishing mortality rates. Similar yields to the fishery are obtained from all levels of F except 0.01; only marginal increases in catch occur when full recruitment is delayed.

Stock recovery

Under the fishing strategies employed during the first two series of trials with M equal to 0.05, stock biomass does not recover to 1969 levels with either partial recruitment vector (Figures 5 and 6). Under the best possible conditions, with F equal to 0.01 and partial recruitment delayed to age 14, total stock and spawning stock biomass increase to approximately 80% of the 1969 levels. With F equal to 0.03 stock biomass levels increase to only about 50% of the 1969 point. These asymptotic levels are attained between 35 and 60 years after initiation of the recovery process in 1985.

Results obtained from the last two series of trials with M equal to 0.025 (Figures 7 and 8) suggest that complete recovery of the stock to the 1969 level is achieved at fishing mortality rates between 0.01 and 0.03 under either partial recruitment option. Recovery times range from 30-40 years with F at 0.01 to 40-50 years with F at 0.03. With F equal to 0.07, stock biomass levels increase to between 40 and 60% of the 1969 point under the initial and the delayed recruitment options in about 40-45 years.

Discussion

The most significant outcome of these analyses appears to be the failure of the stock to return to recent historic levels unless natural mortality is considerably less than previously believed. Even when M is equal to 0.025 stock recovery was achieved only when fishing mortality remained below 0.07 for at least 30 years. As a consequence of these extremely low F levels, long-term yields to the fishery under the most optimal conditions of M and partial recruitment seldom exceeded the 1985 catch of 4,600 t. These results are remarkably similar to those presented by Archibald et al. (1983) for Pacific ocean perch, *Sebastes alutus*, in Queen Charlotte Sound. In practice, it is often extremely difficult to monitor fishing mortality rates at such low levels. At levels of F below 0.10, VPA results remain sensitive to the choice of terminal F for a greater number of years, and forward projections of stock size and yield are affected to a greater extent by natural mortality.

In any simulation the choice of model parameters and assumptions will influence results. The transition matrix approach is especially sensitive to the arbitrary placement of cell boundaries particularly when few stock and recruitment observations are used to construct the array. In the present case, boundaries were selected based on apparent gaps in the data, although several alternate schemes could have been chosen. The effects of choosing alternate cell definitions have not been investigated in this study. Within each cell, recruitment frequencies were generated with a central tendency at the cell midpoint instead of a uniform distribution. This procedure, which decreased the probability of obtaining recruitment values at the transition points in favor of those closer to the midpoint, was incorporated in the model primarily to reduce the impact of the extremely large value associated with the 1971 year class in the uppermost cell. Also, the upper bound of this cell was located close to the actual value under the assumption that a single extreme observation should not be taken to represent average conditions. These restrictions were imposed to provide a conservative approach to recruitment estimation given the uncertainty associated with the low number of observations.

The precipitous decline in stock size observed during the early 1970's suggests that recruitment frequencies generated within the optimum range of spawning stock were insufficient to offset declines due to the combined effects of natural mortality and relatively high fishing mortality rates. Similar declines were also generated during the course of this study by applying fishing mortality rates in excess of 0.10 to the recovered stock. Alternating 50 year sequences of low and high F's applied for 35 and 15 years, respectively, over a 300 year time horizon generated a series of stock declines similar to that observed during the 1969-1984 period. These simulations suggest that fishing mortality rates between 0.10 and 0.20, as observed during the 1970's, combined with a natural mortality rate of 0.05, were extremely high given the low recruitment levels observed during that period.

Recruitment probabilities incorporated in the model were based on a relatively short data series with respect to the longevity of the species and the overall history of the fishery. Admittedly, simulation results are affected by the scarcity of observations in the middle to high recruitment range, and it is quite probable that recruitment of moderate and strong year classes has been considerably less frequent during the past two decades compared to the 1940's and 1950's. In their analysis of recruitment in 18 worldwide stocks, Hennemuth et al. (1980) concluded that all but one of the data sets could be described by a lognormal distribution, based on the results of a series of Kolmogorov-Smirnov (K-S) one-sample goodness-of-fit tests. When applied to the 1964-1980 Gulf of Maine redfish recruitment data, this procedure provided sufficient cause to accept the null hypothesis ($p > 0.05$) that the log-transformed recruitment values represent a sample drawn from a normally distributed population.

An examination of the age-specific stock size estimates obtained from the VPA for 1969 reveals a more even distribution of middle aged fish between 9 and 22 years compared to the most recent years. Stock sizes for comparable age groups were approximately 2-10 times larger in 1969 vs. 1980, suggesting that total mortality during the 1950's and 1960's was considerably lower than recent values, or that the absolute size of recruiting cohorts was greater in the earlier years. Such a shift in recruitment distributions could account for the relatively poor response of the stock at moderate F levels and the extremely long recovery time required at low fishing mortality rates. If the recruitment distribution has been altered, and if the current pattern persists, the possibility of recruitment overfishing must be considered.

During the 17-year period from 1936 through 1952, landings from this stock frequently exceeded 30,000 t and, at times, approached 50,000 and 60,000 t annually as the large accumulation of virgin stock was harvested. Despite this relatively high initial exploitation rate, the fishery continued to provide consistent yields at an average level of about 15,000 t annually through the early 1960's. The production of medium to large year classes up to this time also appears to have continued at a moderate rate as indicated by the 1969 age-specific stock size estimates. For unexplained reasons, this stable recruitment pattern was severely disrupted during the 1960's and was replaced with the highly variable distribution evident during the past two decades. The effects of this alteration in recruitment frequency are clearly illustrated by trends in mean size of redfish taken in the commercial fishery since 1942 (Figure 9). The gradual decline in mean lengths between 1942 and 1965 follows the classic pattern exhibited during the initial "fishing up" process when accumulations of older fish are cropped. Sharp increases evident between 1966 and 1975, and, more recently between 1979 and 1982, indicate periods of relatively poor recruitment, while the intervening periods of rapidly declining mean sizes coincide with entry of the 1971 and 1978 year classes to the fishable stock.

It may be argued that such abrupt changes in population dynamics may be linked to environmental events rather than density-dependent processes. For example, Koslow (1984) has suggested that recruitment

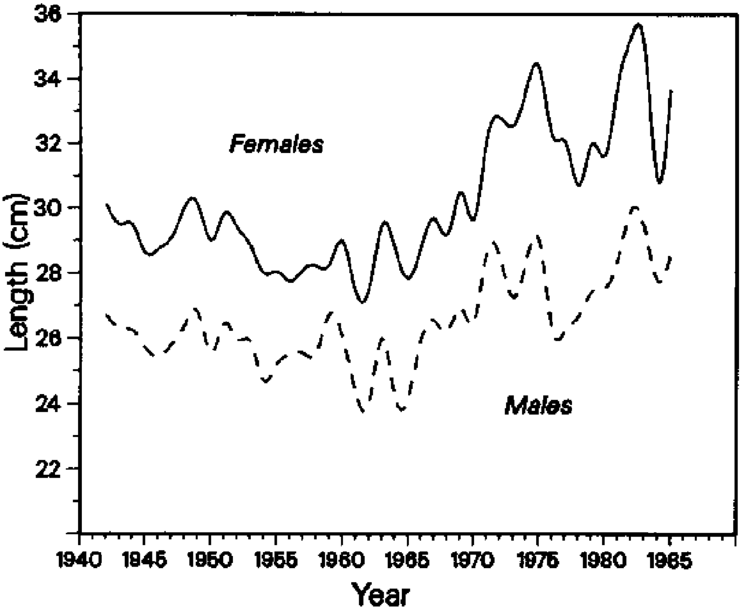

Figure 9. Trends in mean length (cm) of redfish landed in the Gulf of Maine - Georges Bank fishery from 1942 to 1985.

trends among several Northwest Atlantic species and stocks, including Scotian Shelf redfish, were correlated, and that much of the variability over time could be explained by changes in large-scale physical conditions prevalent throughout the region. Major recruitment events, such as strong late 1950's and early 1970's year classes, have also coincided among several species and stocks of *Sebastes* from the Grand Banks to the Gulf of Maine. However, recent assessments of Grand Banks and Gulf of St. Lawrence *Sebastes* stocks (Atkinson 1983, 1985a, 1985b; Rubec et al. 1985) have indicated relatively good recruitment levels and increasing overall abundance during the past 5 years, while corresponding results for the Gulf of Maine stock are contradictory.

Although environmental factors may have been partially responsible for the current recruitment pattern in the Gulf of Maine redfish population, the consequences of sustained heavy exploitation during the 1940's and early 1950's cannot be ignored. It is reasonable to assume that a long-lived species with a large number of year classes comprising the spawning stock may be relatively robust to perturbations for a considerable period of time, and that changes in the dynamics of the stock may not be readily apparent. Thus, it is conceivable that the effects of removing between 40,000 and 60,000 t of biomass per year from the spawning stock over a sustained period may not have become evident until the early 1960's. Similarly, the simulation results presented in this paper clearly suggest that attempts to restore a severely depleted stock to former levels will require extreme management measures over an extended time horizon of unprecedented dimensions.

Acknowledgements

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Incorporating reproductive value into Pacific ocean perch management

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Abstract

In this paper, I argue that there has never been a successful management program for a major commercial rockfish stock anywhere in the world. While management imprecision has obviously played a role, this failure may have been because those variables normally monitored are insensitive to changes in reproductive features that govern the commercial and evolutionary staying power of such stocks.

Multiple spawning species have evolved distinctive life histories which are presumably adaptive to uncertain reproductive success, and the rockfishes (genus Sebastes) contain some of the most extreme in this group. Pacific ocean perch (S. alutus) off British Columbia mature between 7-9 y and commonly have 30-60 subsequent spawnings in the absence of exploitation. Throughout much of this period (ages > 25 y), there is minimal or no individual growth and the biomass of a cohort is continually decreasing; reproduction is therefore the major expenditure for such non-growing fish.

The concept of reproductive value (RV), introduced by R. A. Fisher in 1930, affords a general structure for explicit consideration of such a life history. I examine the response of several RV measures (total RV, eventual RV, modified RV, and age/time-specific RV) to fishing pressure. On a cohort level, most RV measures exhibited greater sensitivity to exploitation than parameters normally measured (size, number, fishing mortality or fecundity at age). For example, introduction of fishing mortality of only 5 percent per year resulted in decreases of 15-30 percent in maximum cohort fecundity but 59-64 percent in RV at the age of maximum cohort fecundity. Even more dramatic were the coincident decrements (96-99 percent) in RV at the age of maximum individual fecundity. In the last portion of the paper, I suggest how reproductive value might be incorporated into the management process.

Introduction

Trawl fisheries for demersal fish have been a component of world fisheries for over 100 y but trawl catches of *Sebastes* spp. are a relatively recent phenomenon. Most major fisheries for these species in the northern hemisphere have had their genesis within the past 30 y, some only within the last decade. While these fisheries have been based on several different *Sebastes* spp., their histories have been remarkably similar.

In every instance of a major trawl fishery for rockfishes, the progress of the unrestrained fishery has been several years of relatively high catches preceding a rapid decline and subsequent years of very low catches (Figs. 1 and 2). Some familiar examples in the northeast Pacific are the fisheries for Pacific ocean perch (*S. alutus*) in the Gulf of Alaska, off the coast of Canada, and the Washington-Oregon region. In the Gulf of Alaska (Fig. 1), the catch peaked at over 348,000 t in 1965, subsequently underwent a precipitous decline to only 45,000 t by 1970 and is now less than 2% (approx. 5000 t) of the peak level (Balsiger et al. 1985). Similar declines were recorded for stocks off British Columbia and Washington-Oregon (Fig. 2); in all instances present catches are less than 10% of maximum levels. Even the recent fishery for widow rockfish (*S. entomelas*) off the Washington-California coasts has experienced similar, though less extreme, changes (Fig. 1).

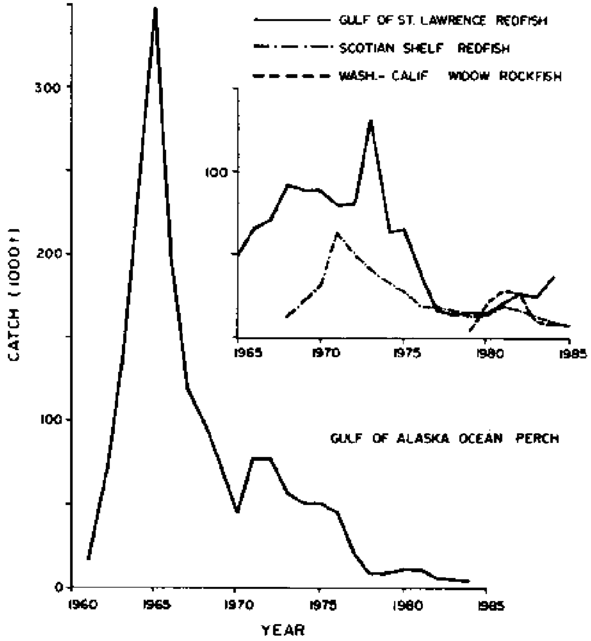

Fig. 1. Catch histories of several Pacific and Atlantic rockfish fisheries.

The progress of rockfish fisheries in the northwest Atlantic (Fig. 1) has produced catch histories of the same type observed in the northeast Pacific. Both the Gulf of St. Lawrence and Scotian shelf redfish (Sebastes spp.) fisheries have suffered declines of over 70% from historical catch maxima. While catches in the Gulf of St. Lawrence fishery have increased recently, the fishery has not reached the quota established by managers.

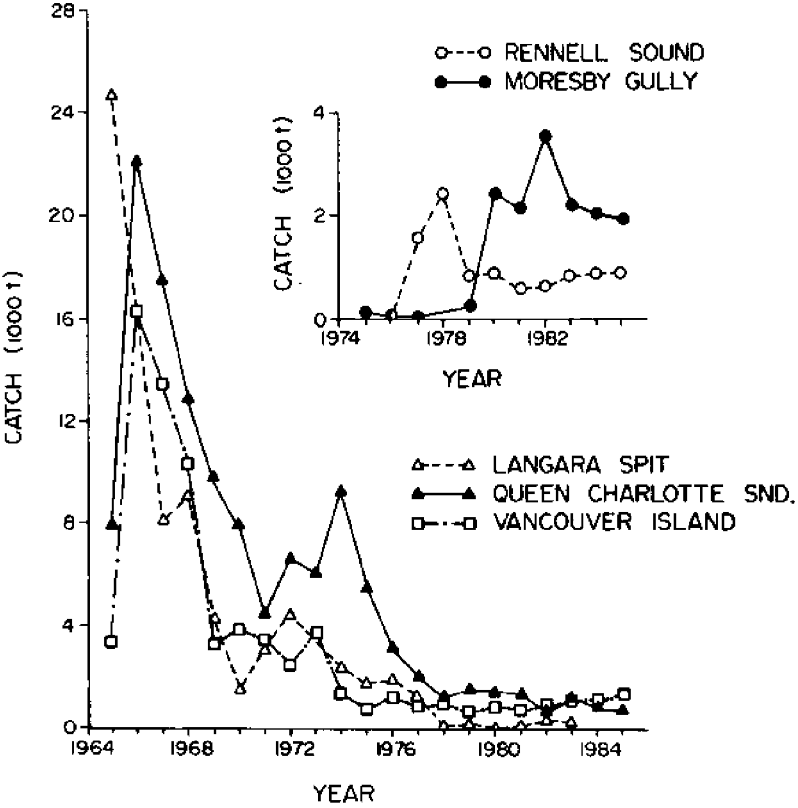

Fig. 2. Catch histories of Pacific ocean perch stocks off British Columbia.

The unquestioned cause of all of these declines was fishing mortality (F) far in excess of levels which might have provided sustainable fisheries. On the Pacific coast, these high F levels were generated by large distant-water fleets from Japan and the Soviet Union during the mid-1960s, prior to any effective regulatory environment in North America. Although both Canada and the U.S. declared 200-mi fishery management zones in 1977 and were able to reduce F levels experienced by these S. alutus stocks, that action was clearly too little and far too late. During this initial stage of the ocean perch fisheries then, the problem was not errors in management but an absence of management. Since 1977, none of the stocks of Pacific ocean perch has shown any evidence of rehabilitation.

Do we have any instances where a rockfish stock that has been the object of a major fishery has been successfully managed for sustained yield? I submit that, the absence of management aside, we have no examples of successful management of a major rockfish stock, and, in particular, no examples of successful recovery from overexploitation. Where we see some evidence of increased catches after major declines (e.g. Gulf of St. Lawrence redfish, Fig. 1), it is not the result of a directed management action so much as the appearance of the progeny of cohorts which were present in the population prior to the management action. In most instances these cohorts were largely eliminated by the fishery.

The tenet that we have never successfully managed a major rockfish stock might seem extreme but the lack of strong evidence to the contrary argues effectively that we have much to improve. I believe a large measure of our apparent inability to successfully manage rockfishes can be accounted for by three factors: first, recent results changing our perception of the biology of rockfishes (Archibald et al. 1981: Beamish 1979); second, the difficulty in adequately incorporating that knowledge into our population models; and, third, that the indices of stock status we use are insensitive to those population features governing evolutionary and commercial persistence. In the following sections I review these three points and suggest some alternative indices that can, after some initial effort, be routinely incorporated into stock assessments. I also examine the potential of incorporating some of these indices into the management of rockfishes, and their implications.

An altered perspective on rockfish biology

Our concepts of rockfish life history began to undergo dramatic changes beginning in 1979 when rockfish otoliths were examined in a different way. Otoliths had traditionally been aged by surface reading but the application of break and burn (Chilton and Beamish 1982) and thin sectioning techniques (Beamish 1979) led to new views of Pacific ocean perch lifespan. Archibald et al. (1981) applied these techniques to 10 Sebastes spp. and provided estimates of their growth and mortality rates in British Columbia waters. These ageing methods have yet to be validated for almost all the Sebastes spp. examined, with the exception of oxytetracycline validation of break and burn ageing for S. flavidus (Leaman and Nagtegaal, in press), and their results should be treated with appropriate caution. However, some indirect support for their validity does come from

Table 1. Estimates of instantaneous natural mortality (M = minimum Z from unexploited stocks) for some *Sebastes* spp. from British Columbia waters, estimated from break/burn ageing of otoliths. Also included are the best previous estimates of M obtained from surface ageing of otoliths, where available.

Species	Estimated M Break/burn ageing	 Surface ageing	Age range break/burn mortality estimate
Rougheye rockfish (*S. aleutianus*)	0.04	-	18-68
Pacific ocean perch (*S. alutus*)	0.05	0.15	15-77
Silvergray rockfish (*S. brevispinis*)	0.04-0.05	-	17-71
Darkblotched rockfish (*S. crameri*)	0.07	-	11-48
Widow rockfish (*S. entomelas*)	0.05	0.25	23-59
Yellowtail rockfish (*S. flavidus*)	0.07	0.25	17-53
Canary rockfish (*S. pinniger*)	0.03-0.04	0.20	15-76
Redstripe rockfish (*S. proriger*)	0.10	-	11-32
Yellowmouth rockfish (*S. reedi*)	0.08	0.20	18-52
Sharpchin rockfish (*S. zacentrus*)	0.07	-	15-46

analytic models of rockfish populations (Archibald et al. 1983; Kimura, pers. comm.).

The major results of Archibald et al. (1981) were a halving of estimated rates of mortality and a doubling of estimated life spans for these 10 Sebastes spp. (Table I). Another result was that the change in ageing technique produced almost no change in the estimated parameters of growth (L_∞,k). The latter occurred because the change in ageing technique affected primarily those individuals who had reached a large proportion of L_∞, even by surface age estimation. They considered this finding an almost minor result, yet in some ways it is equally as dramatic as the mortality rate changes, for it implies that several of the species do not grow over almost half of their life span or more (Fig. 3). More importantly, because the fish reproduce throughout their lives, it changes the dominance of the life cycle from somatic to gonadal production. This change should therefore require a change in our analytical approach to rockfish population dynamics to mirror this increased importance of reproduction.

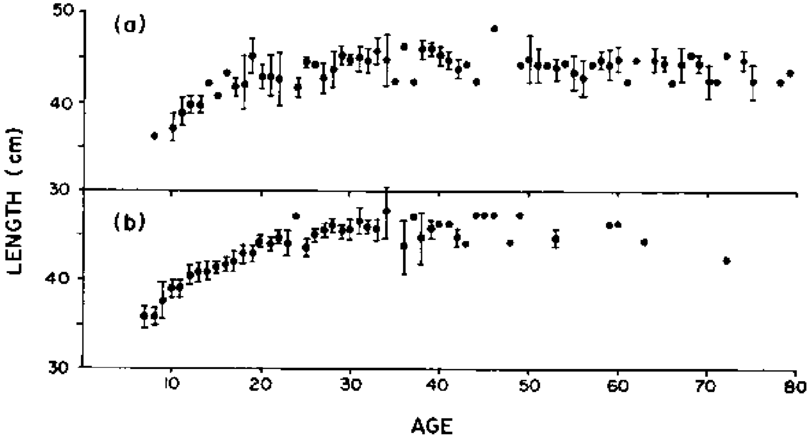

Fig. 3. Mean length at age (with 95% c.i.) for (a) a lightly exploited, and (b) a heavily exploited stock of Pacific ocean perch off British Columbia.

Incorporating reproductive biology into population models

The general and perhaps sole approach to incorporating reproduction into population models has been to formulate some relationship between adult spawners and reproduction. This may happen either directly, where adult spawners are linked to reproductive output, or indirectly, where spawners (biomass or numbers) are linked to recruits. The attraction of such stock-recruit relationships (SRR) is of course that they allow prediction of future values of recruitment, a deceptively attractive proposition. While there are a number of technical problems with SRRs (density effects, measurement precision, determining the true shape of the relationship with limited data) they can generally be overcome (Cushing 1977; Gulland 1983). What cannot be overcome or ignored is that the conceptual basis for the SRR is neither more nor less than a correlation analysis of, certainly in the case of rockfishes, two highly variable quantities. Its validity rests on the contrast and robustness of the observations from which it is constructed. In almost every instance, these observations for rockfish stocks are from an extremely rapid, one-way trend in the stock size of spawning adults, where we have few if any replicate observations, except at low stock abundance.

Prediction made with such SRRs becomes a process much more inductive than deductive. Nonetheless the temptation to produce multiple scenarios of future stock behaviour is one few of us can resist (Fig. 4). Unfortunately, such scenarios, though attractive to fishery managers, have yet to be proven and remain in the realm of informed speculation.

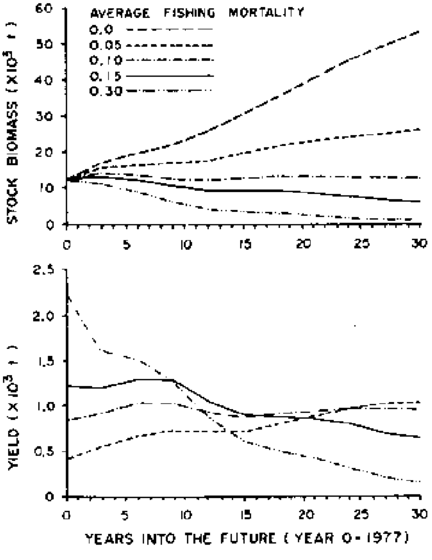

Fig. 4. Predicted stock rehabilitation trajectories for a heavily exploited stock of Pacific ocean perch off British Columbia (from Archibald et al. 1983).

Incorporating reproductive considerations into models of semelparous (single spawning) species has been relatively easy and led to the concept of 'replacement stock' for salmonids (e.g. Ricker 1975). This concept implies a management policy of ensuring sufficient spawning biomass or numbers for the cohort to reproduce itself in the next generation. For iteroparous (repeat spawning) species there is no such analogue within any given year. Instead, these species have evolved to take advantage of repeated spawnings to achieve the same objective of replacing the cohort. One component of their 'replacement stock' is therefore their total lifetime reproductive output. The other component is the fact that multiple cohorts spawn together, so that the total reproductive output in any year is the sum of variable reproductive effort from animals of different ages (hence sizes) and reproductive capacity. Clearly, both individual and demographic characteristics contribute to this replacement concept for iteroparous species.

It appears that the difficulty in incorporating reproductive biology into rockfish population models lies primarily with the construction of algorithms which reflect the underlying biology of how recruiting cohorts and the variations therein are generated. For rockfishes, we need to incorporate indices of population status or condition that are sensitive to changes in both stock biomass and its demography.

Reproductive indices

Ideally, we would like to employ an index that reflects a combination of age-specific reproductive effort and its contribution to overall stock reproduction, i.e. its reproductive value (RV). The concept of RV was introduced by Sir R. A. Fisher (1930) as the average number of young that a female of arbitrary age in a stable age distribution could expect to produce at that age and over the remainder of her life, relative to a female at birth. (Fisher's formulation of RV was actually more involved because he was assessing the genetic contribution to future generations). The importance of this concept was twofold, in that it incorporated the idea of fitness among different individuals (or more specifically, genotypes) and the variable distribution of reproductive effort with age. The latter presaged what would become a dominant area of research in population biology, life history theory.

The concept of reproductive value has enjoyed an active commentary in the literature (Charlesworth 1980) and several variants of Fisher's original index have been proposed. Three of these, eventual reproductive value (ERV) (Goodman 1967), age/time specific RV (Vandermeer 1968), and modified RV (Schaffer 1974) are of interest. Goodman's ERV is appropriate to populations of mixed-age reproducers because it is normalized by the reciprocal of the generation time. The latter quantity is taken to be the mean age of the parents (female) of a cohort at birth. Age/time specific RV is the total number of births by animals aged i and older per animal aged i. The major difference between this index and Fisher's RV is that it fluctuates with age distribution whereas Fisher's is stable. Modified RV was an attempt to deal with potential reproductive cost in that schedules of incremental fecundity were established wherein the increments were explicitly independent of previous reproductive effort. Most studies either ignore reproductive cost or implicitly assume it is zero. For iteroparous species this assumption is often a pragmatic necessity if reproductive effort for individuals cannot be assessed at each reproductive episode. Fecundity schedules calculated from simultaneous samples of different age groups will reflect prior reproductive expenditures, whose influences (if any) will be unknown. The indices I examined (Table 2) implicitly incorporate Schaffer's concept, i.e. reproductive cost is not ignored, it is simply unknown.

Table 2. Basic relationships used in the population simulations and the reproductive value (RV) indices examined.

Fecundity: $\text{Log } E = a + b_1 \text{ Log } L + b_2 \log W + b_3 \text{ Log } A$

Egg production: $P_i = \sum_j E_j N_{ij}$

Recruitment: $R_{i+6} = \alpha P_i e^{-\beta P_i} e^{\epsilon_i}$

Mortality: $N_{i+1,j+1} = N_{ij} e^{-Z_{ij}}$

Catch: $$C_{ij} = \frac{N_{ij} F_{ij}}{Z_{ij}} (1 - e^{-Z_{ij}}) \qquad [F_{ij} = F_i (PV_j)]$$

where i,j are year and age indices

E = fecundity
L = length
W = weight
A = age
N = number

R = recruitment
C = catch
Z = total mortality
F = fishing mortality
PV_j = partial vulnerability at age j

$$RV_{12} = \sum_{i=12}^{80} P_i$$

$$ERV_{12} = RV_{12}/\bar{A}$$

$$IRV_{12} = RV_{12}/N_{i,12}$$

$$IERV_{12} = ERV_{12}/N_{i,12}$$

Reproductive value for exploited Pacific ocean perch stocks

The estimation and utility of reproductive value in Pacific ocean perch was examined with a single cohort and a stochastic, multiple cohort simulation model. The basic relationships of the model (Table 2) included: age-specific fecundity estimation based on multivariate regressions of length, weight and age; population dynamics driven by a stochastic SRR with log-normal variation in recruitment and a lag of six years; cohort mortality through age-independent natural mortality; and fishing mortality applied through the normal catch equation. The latter incorporates partial recruitment factors by age. Exploitation effects were examined in 30 replicates of 200 y duration for each level of instantaneous fishing mortality (F). Stochastic standard deviation in the SRR was 0.55. All parameter values were obtained from a lightly exploited stock of S. alutus in British Columbia waters (Leaman et al. 1985; Leaman unpubl. data).

Results and Discussion

The cohort RV at each age for an arbitrary cohort is a continuously decreasing function with age (Fig. 5), regardless of fishing mortality. Maximum cohort fecundity occurs at approximately age 16 with no fishing mortality but decreases 26% and occurs four years earlier with introduction of F = 0.05. Reproductive value at the age of maximum cohort fecundity decreases by 68%. Cohort weight maximizes at age 14 with F = 0.0 and age 10 with F = 0.05. The reductions in cohort weight and reproductive value at the age of maximum cohort weight with F = 0.05 are 19% and 68%, respectively.

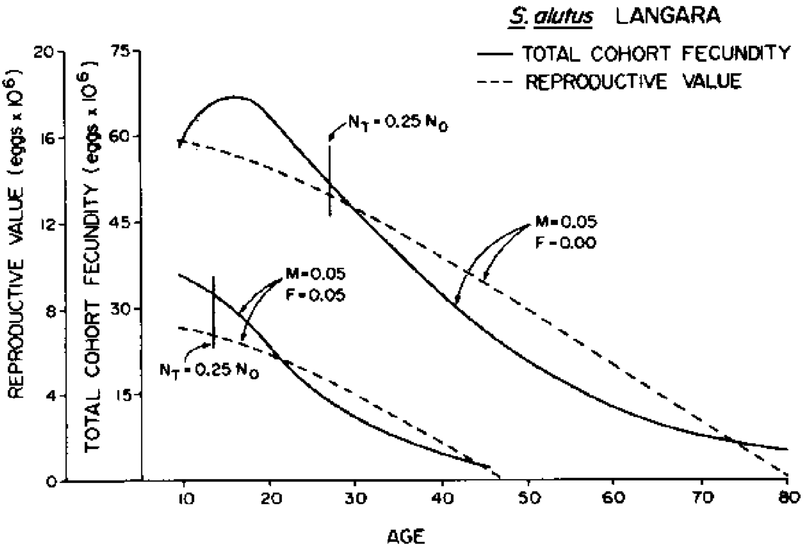

Fig. 5. Cohort fecundity and reproductive values at age for two levels of fishing mortality, in a Pacific ocean perch stock from northern British Columbia waters.

The RV index presented in Figure 5 is not the traditional RV index, which is discounted by the probability of survival to each age. That index performs in similar fashion, but due to the low natural mortality rate is a slightly convex function, with a maximum at age 34 for F=0.0. The value for this discounted index at the age of full recruitment (12 y) is 83% of the maximum. With F=0.05 the maximum of the discounted index occurs at age 30 and is reduced by 60% from the unexploited maximum, thus mirroring the magnitude of the changes in Figure 5.

For the multiple cohort model I examined reproductive value at age 12 for the cohort (RV_{12}) and by individual (IRV_{12}), as well as eventual reproductive value at age 12 for the cohort (ERV_{12}) and the individual ($IERV_{12}$), in addition to biomass and yield for F values between 0-0.12 (Table 3).

Table 3. Reproductive value indices, biomass, yield and mean age ($\bar{A}$) changes with fishing mortality (F), over 200 yr simulations.

F	Biomass (t)	Yield (t)	$\bar{A}$	RV_{12}	ERV_{12}	IRV_{12}	$IERV_{12}$
0.00	95520	0	24.01	1.40620	58.5713	5.8815	.2449
0.02	74110	750	19.63	0.97715	49.7763	3.8914	.1982
0.03	62600	1010	18.54	0.79714	42.9876	4.0823	.2201
0.04	58250	1290	17.23	0.70960	44.1939	3.1665	.1837
0.05	47600	1260	16.22	0.54336	33.5050	2.7606	.1701
0.06	41580	1330	15.49	0.46437	29.9870	3.1147	.2010
0.07	35760	1300	14.73	0.37836	25.6826	2.3062	.1565
0.08	29020	1150	14.17	0.29137	20.5625	2.3654	.1669
0.10	20420	930	13.16	0.18699	14.2106	1.9453	.1478
0.12	13510	680	12.56	0.11679	9.3001	2.0825	.1658

Maximum equilibrium yield occurred at F = 0.06 and biomass was approximately 44% of that when F = 0.0. Mean age of the stock decreased from a long-term average of 24 y at F = 0.0 to 15.5 y at F = 0.06. Changes in the RV indices in response to F (Fig. 6) vary considerably in their magnitude and consistency. Cohort RV_{12} response to F mirrors that of biomass but is considerably greater ($\bar{X}$ = + 10.1 %, S. E. = 0.59) at each level of F. The buffering effect of cohort variation is clearly evident when comparing response of RV_{12} to F for a single cohort vs. multiple cohorts. For the former, introduction of F = 0.05 reduces RV_{12} by 72% from the unexploited value, while for the latter the average decline is only 61% for the same F. The magnitude of the difference varies with the growth characteristics of individual stocks and ranges from 10-15% for stocks off British Columbia.

Examination of sizes at age for Pacific ocean perch stocks from 1963-1982 (Leaman unpubl. data) suggests some compensatory growth response to exploitation. Size at age 16 has increased 1.5-2.0 cm in heavily exploited stocks, however the modest increase in resultant fecundity at age (+10%) cannot compensate for the massive reductions (-80%) in RV for the same age.

Eventual RV_{12} also declines with exploitation although the total decline is less at F = 0.12 than for RV_{12} (-84% vs. -92%), as well as less with each F increment (Fig. 6). The relationships of the individual reproductive value indices (IRV and IERV) while showing more contrast between each other than the cohort indices, are less responsive to changes induced by fishing mortality. The erratic behaviour of some of these indices reflects the stochastic variation in recruitment. If values are averaged over several years the responses to F are more consistent.

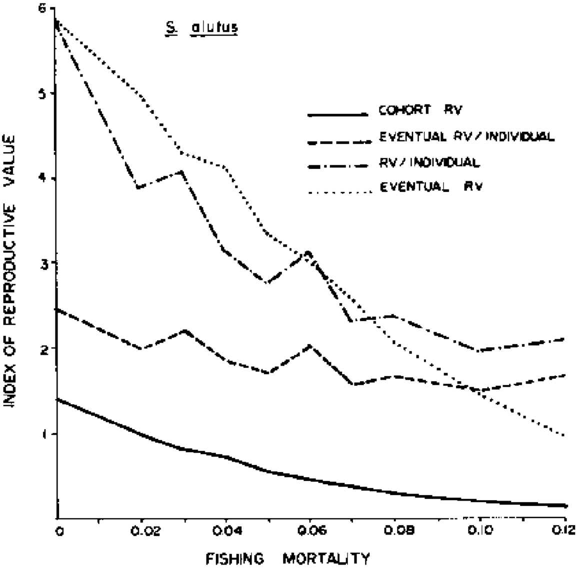

Fig. 6. Response of several reproductive value indices (at age 12) to fishing mortality, for a composite stock of Pacific ocean perch.

These reproductive value indices provide much more sensitive measures of stock status than those generated by simple biomass-based monitoring (e.g. CPUE or biomass). The highly determinant growth form of rockfishes noted earlier implies that these RV-based indices will more accurately reflect the demographic structure of stock biomass. While initially expensive to construct, due to the time and cost of fecundity estimation, they will be as robust as the fecundity-body relationships and should change in a uniform way with interannual fecundity variation. The routine monitoring of RV-based indices will require only a modest increase over the effort normally expended in catch sampling for age structure.

Our present management techniques for rockfish stocks rely on relatively insensitive feedback controls, that have yet to demonstrate significant successes. Clearly, the increased information content and sensitivity of RV-based indices affords us the opportunity to control fishing mortality effects which would not otherwise be evident. Reproductive value indices reflect the demographic structure of rockfish populations, that has evolved to meet the challenge of uncertain and infrequent reproductive success. That the unexploited maximum of discounted RV occurs at 34 y indicates the magnitude of this challenge. If the challenges which the life history of rockfishes have evolved to meet are still operative (and there is no reason to believe otherwise), then the conservation of reproductive value should be a primary management goal. However, it is less clear exactly how this should be achieved or to what extent. Our present perception of optimal policies is based on tenuous SRRs which may have limited applicability to stocks at low levels of biomass.

The incorporation of reproductive value into management will have to be an active and experimental process of long duration. A first step will be to reconstruct stock histories and examine the recruitment process in relation to reproductive value, followed by some analytic/simulation studies to examine the resilience of stocks, as has been done for biomass-based indices. While this will obviously take some time, it should direct our management models more toward biological principles and away from a simple faith that past recruitment patterns will repeat themselves, in spite of major fishery effects on stock composition.

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Impacts of management regulations on the catch and utilization of rockfish in Oregon

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Introduction

The U.S. West Coast groundfish trawl fishery exploits a diverse mixture of species, among which rockfish are an important component of the commercial catch. The fishery off California, Washington and Oregon is managed by the Pacific Fishery Management Council (PFMC) according to the Groundfish Management Plan (PFMC 1982) and its amendments. In recent years regulations have been in force which limit the amount each vessel can land of particular species and/or species groups annually and per fishing trip or other specified time period. Trip limit restrictions have sometimes been accompanied by limits on the frequency with which such trips can be conducted. The intent of these regulations is primarily to prevent overharvest and to attempt to maintain a year-round fishery. However, retention and landing of some species has been prohibited during portions of some years because annual landing limits were reached prior to the end of the year.

Because of the mixed-species nature of the fishery, it is possible that species groups managed by trip limits and/or annual quotas will continue to be caught incidentally after the trip or annual limits have been reached. Under current regulations the excess catch must be discarded and it is likely that few, if any, of these trawl-caught fish survive (Saila 1983). It is important to determine the extent of such regulation-induced discard in order to evaluate the effectiveness of the current management regime in limiting mortality of managed species groups, and to assess its biological and economic impacts.

In 1985 a study of the Oregon groundfish trawl fishery was initiated in which at-sea observations of the catch and its utilization are being recorded. In this paper I present preliminary results on the extent of regulation-induced discard, particularly of rockfish, observed during the first year of the study.

Methods

The data presented herein were collected aboard Oregon commercial groundfish trawl vessels operating out of the ports of Newport, Astoria and Coos Bay during the course of normal fishing operations. Participation in this study by skippers and/or owners of the vessels was voluntary. For each tow observed, the total weight was generally estimated visually by the skipper and/or a trained observer. After the contents of the net were released, a random sample of the catch was obtained, or in those instances in which the total tow weight was small, the entire catch constituted the sample. The sample was then sorted by species, and each species subsample was further sorted into utilized and discarded portions. The crew members also provided the observer with information on the reasons for discarding various portions of the catch. Reasons for discard include: market factors (a species may be unmarketable, or may have a limited market), fish size (only fish greater than a certain size may be marketable, or small fish may bring a lower price than large fish), and regulations (catch amount exceeds allowable trip limit or fish size less than minimum size limit). Discarded and utilized portions of each species subsample were then weighed and enumerated. Estimates of total numbers and weight utilized and discarded for a given species and tow were obtained by multiplying the number or weight, respectively, of that species in the sample by the ratio of estimated total tow weight to total (all species) sample weight.

Fishing strategies

There is much heterogeneity within the groundfish fishery in terms of the type of gear used, the locations fished, and the species composition sought. To examine differences in the impacts of regulations on the various fishing methods that are employed, each tow conducted was designated as belonging to one of the following four fishing strategies:

1) Bottom rockfish trawling (BRF): tows generally conducted using roller gear on the ocean bottom, with the primary target of the tows being one or more species of rockfish.

2) Midwater trawling (MID): tows conducted using midwater trawl gear above bottom; primary target species are widow rockfish (Sebastes entomelas) and Pacific hake (Merluccius productus).

3) Deepwater Dover sole trawling (DWD): tows conducted on-bottom in areas generally exceeding 100 fathoms depth, using mud-gear, roller gear or mud-roller combination gear. An important target species of this fishing strategy is the Dover sole (Microstomus pacificus), but sablefish (Anoplopoma fimbria) and thornyhead (Sebastolobus sp.) are also important components of the catch.

4) Nearshore mixed-species trawling (NSM): tows conducted using mud gear on-bottom in areas generally less then 100 fathoms depth; primary target species are a mixture of flatfish.

A second trawl fishery for shrimp (strategy five) also catches signficant quantities of groundfish incidentally. Although some shrimp trips have been observed during the course of the study, this paper is

Table 1. Trip limit restrictions pertaining to west coast groundfish between July 21, 1985 and June 30, 1986.

Species Group	Effective Date	Regulation
Pacific Ocean Perch	7/21/85 - 12/31/85	5,000 lbs. or 20% of the catch/trip whichever is less.
	1/1/86 - 6/30/86	10,000 lbs.or 20% of the catch/trip whichever is less.
Sebastes Complex	7/21/85 - 9/30/85	7,500 lbs./1/2 week or 15,000 lbs/week or 30,000 lbs./2 weeks.
	10/1/85 - 12/31/85	10,000 lbs./1/2 week or 20,000 lbs./week or 40,000 lbs./2 weeks.
	1/1/86 - 6/30/86	12,500 lbs./1/2 week or 25,000 lbs./week or 50,000 lbs./2 weeks.
Yellowtail Rockfish	7/21/85 - 12/31/85	3,000 lbs./1/2 week or 5,000 lbs./week or 10,000 lbs./2 weeks.
	1/1/86 - 6/30/86	5,000 lbs./1/2 week or 10,000 lbs./week 20,000 lbs./2 weeks.
Widow Rockfish	7/21/85 - 12/31/85	3,000 lbs./trip
	1/1/86 - 6/30/86	30,000 lbs./week
Sablefish	7/21/85 - 12/31/85	22" size limit with an incidental allowance of 5,000 lbs. of fish under 22" length.
	11/25/85 - 12/5/85	13% of catch.
	12/6/85 - 12/31/85	Prohibited.
	1/1/86 - 6/30/86	22" size limit with an incidental allowance of 5,000 lbs. of fish under 22" length.

limited to discussion of results of groundfish-directed trawling observations.

An attempt was made to obtain equal coverage of the four primary fishing strategies throughout the year. However, the voluntary nature of the observer program, and the fact that some fishing strategies are uncommon during some portions of the year, led to somewhat uneven sampling coverage.

Regulated species groups

During 1985-86 landings of five species and/or species groups were subject to trip limit restrictions. These were: Pacific ocean perch (Sebastes alutus), yellowtail rockfish (Sebastes flavidus), widow rockfish (Sebastes entomelas), sablefish (Anoplopoma fimbria) and the Sebastes complex. The Sebastes complex includes all rockfish except for widow rockfish, Pacific ocean perch, Sebastolobus sp. and shortbelly rockfish (Sebastes jordani). Thus, landings of yellowtail rockfish count towards allowable landings of Sebastes complex, as well as towards its own trip limit.

Because the regulations pertaining to each of these species groups varied during the course of the study, the data were further divided into three time periods:

A: July 21, 1985 through September 30, 1985;

B: October 1, 1985 through December 31, 1985;

and C: January 1, 1986 through June 30, 1986.

These time periods were chosen because they correspond roughly to periods during which the regulations for most species remained constant. A detailed description of the regulations in effect for each species and/or species group from July 21, 1985 through June 30, 1986 is provided in Table 1. Data were analysed by fishing strategy, time period, and species group.

Results

Between July 21, 1985 and June 30, 1986, a total of 483 groundfish-directed trawl tows were sampled. Table 2 provides a breakdown of tows sampled by fishing strategy and time period. Greater sample sizes were obtained for the DWD and BRF fishing strategies than for the NSM and MID strategies.

Table 2. Tows sampled by fishing strategy (BRF = bottom rockfish trawling; MID = midwater trawling; DWD = deepwater Dover sole trawling; NSM = near-shore mixed species trawling) and time period (A = 7/21/85 - 9/30/85; B = 10/1/85 - 12/31/85; C = 1/1/86 - 6/30/86) between July 21, 1985 and June 30, 1986.

Fishing Strategy	Time Period			
	A	B	C	Total A-C
BRF	46	35	114	195
MID	0	0	24	24
DWD	57	67	102	226
NSM	28	3	7	38
Total	131	105	247	483

The prevalence in the catch of species regulated by trip limits (regulated species groups) varied greatly among fishing strategies (Table 3). Regulated species groups comprised 85.3% of the BRF catch, 61.9% of the MID catch, 38.4% of the DWD catch and only 5.6% of the NSM catch. Species composition of the regulated-species component of the catch also varied by fishing strategy. Widow rockfish comprised 60.1% of the MID catch and 21.8% of the BRF catch, but did not contribute signficantly to the catches of either the DWD or NSM strategies. Yellowtail rockfish and other Sebastes complex species were most prevalent in the BRF catch, of somewhat lesser importance to the DWD catch, and of minimal importance to the MID and NSM strategies. The only strategy for which sablefish comprised a significant fraction of the catch was the DWD strategy. Pacific ocean perch comprised 4.6% and 4.2%, respectively of the BRF and DWD strategies, and less than 0.1% of the catches of the MID and NSM strategies.

Hypotheses concerning strategy-specific discard rates

Given the observed differences among fishing strategies in terms of the relative amount and species composition of the regulated component of their catches, it was expected that the frequency of occurrence, magnitude, and species composition of regulation-induced discard would also vary among the strategies. For example, because sablefish are only caught in large quantities during DWD fishing, regulation-induced discard of sablefish should occur most frequently for that strategy, and may not occur for the other strategies. In general, it would be expected that those strategies which catch the greatest quantities of regulated species groups and whose catches are most varied in species composition should experience the greatest impacts of the current management regime in terms of regulation-induced waste. Thus, the BRF strategy, for which a mixture of regulated species groups comprise the majority of the catch, should be most affected by trip limit restrictions. The DWD strategy should rank second in terms of regulation-induced discard. The MID strategy catches significant quantities of only one regulated species (widow rockfish), and fishermen employing this strategy can target on, or avoid, this species with a high level of accuracy. Thus it would be expected that the amount of regulation-induced discard occurring for the MID strategy should be less then that which occurs for either the BRF or DWD strategies. Because regulated species groups comprise only a minor portion of the NSM catch, regulation-induced discard should be low or non-existent for this strategy.

Further, there are two distinct ways in which trip limits can evoke waste. First, a regulated species may be the target of a given tow, and in an attempt to obtain the maximum allowable catch of that species, a fisherman may inadvertently catch an excess amount which must be discarded. This type of scenario would apply primarily to the MID strategy while in pursuit of widow rockfish. Alternatively, a non-regulated species or species group may be the objective of a given tow, but one or more regulated species may be caught incidentally in quantities in excess of allowable landings limits. This latter scenario would apply primarily to the BRF and DWD strategies. Undoubtedly, both of these scenarios (i.e. directed and non-directed effort for a regulated species) occur on some fishing trips.

Finally, the quantity of regulation-induced discard will vary over time as changes in regulations occur. Obviously, one would expect to see

Table 3. Catch in pounds and percent of catch of various species groups obtained by each fishing strategy (BRF = bottom rockfish trawling, DWD = deepwater Dover sole trawling, MID = midwater trawling, NSM = nearshore mixed species trawling). Data are from at-sea observations aboard Oregon commercial groundfish trawlers from July 21, 1985 - June 30, 1986.

Species Group	Catch by Fishing Strategy			
	BRF lbs. (%)	DWD lbs. (%)	MID lbs. (%)	NSM lbs.(%)
Widow Rockfish	129140 (21.8)	624 (0.1)	182879 (60.1)	53 (0.1)
Pacific Ocean Perch	26980 (4.6)	26135 (4.2)	0 (0.0)	3 (<0.1)
Yellowtail Rockfish	114959 (19.4)	658 (0.1)	5267 (1.7)	402 (0.9)
Other Sebastes Complex	226071 (38.2)	77986 (12.5)	115 (<0.1)	938 (2.2)
Sablefish	8394 (1.4)	134035 (21.5)	0 (0.0)	1031 (2.4)
All regulated species:	505544 (85.3)	239438 (38.4)	188261 (61.9)	2428 (5.6)
Other Rockfish	5329 (0.9)	52062 (8.3)	0 (0.0)	461 (1.1)
Other Fish	81069 (13.7)	318089 (51.0)	115792 (38.1)	37119 (85.1)
Invertebrates	435 (<0.1)	13995 (2.2)	32 (<0.1)	3597 (8.2)
Total	592378 (100.0)	623585 (100.0)	304085 (100.0)	43604 (100.0)

higher discard rates of sablefish during the time that landings of that species were prohibited, compared with other time periods when only landings of small fish (under 22") were restricted. In general, the lower the trip limit in effect, the greater the likelihood that incidental catches will exceed allowable landings limits, and thus, the greater the probability that regulation-induced discard will occur.

Quantity of regulation-induced discard observed

Tables 4 a-d provide a breakdown of total catch weights sampled, average catch/tow, marketable catch, and amount of the marketable catch discarded due to regulations; by fishing strategy, species group and time period. Estimates of marketable catch were obtained by subtracting amounts discarded due to market factors or fish size from total catch weight. This procedure may underestimate marketable catch because some of the fish for which discard was attributed to fish size may be marketable, but would yield a lower price than other fish on board. Under the present management regime there is an incentive for fishermen to discard smaller, lower valued fish in order to obtain maximum revenues within the allowable landed weight limit. Methods to detect and document such "higrading" of the catch are currently being explored. However, for most regulated species groups and fishing strategies the estimated marketable catch was very similar in magnitude to the total catch. A major exception occurred for the BRF strategy with respect to the Sebastes Complex catch during time period A. In that instance, less than half of the Sebastes complex catch was estimated to be marketable (Table 4a).

For all regulated species groups over all time periods and fishing strategies, a total of 74,039 lbs. of fish were discarded due to regulations out of a total marketable catch of 833,787 lbs. Thus, regulation-induced discard represented approximately 8.9% of the total marketable catch sampled. However, regulation-induced discard of individual species groups varied from 0% up to 100% of the marketable catch among fishing strategies and time periods. As expected, discard rates were generally highest for the BRF and DWD strategies, which caught significant quantities of several regulated species groups. Discard rates ranged from approximately 1 to 25% of the regulated species catch of these strategies (Tables 4a & b). For the MID strategy, regulation-induced discard was estimated at 10.8% of the marketable regulated species catch during time period C (the only period during which observations of this fishing strategy were made). The vast majority of the regulation-induced discard seen for this strategy was due to inadvertently large catches of widow rockfish (Table 4c). No regulation-induced discard was observed for the NSM strategy (Table 4d) which was not surprising given the low catch-rates of regulated species obtained by this strategy.

Some of the variation in discard rates could be explained by changes in regulations over time. For example, discard of sablefish was highest during time period B, when trip limit restrictions for that species were most severe. Interestingly, catch per tow of sablefish for the DWD strategy was also highest during time period B, perhaps indicating that a closer association between sablefish and Dover sole occurs during that time of year. Discard of yellowtail rockfish for the BRF strategy, which caught the greatest quantity of this species, was highest during time period B (Table 4a). During this time period the trip limit for yellowtail rockfish was lowest, both in absolute terms and as a fraction of allowable landings of Sebastes complex (Table 1). Average catch/tow of this species was also highest during time period B. For the BRF strategy, discard of widow rockfish was much higher under the 3,000 lb. per/week trip limit (64.1% of the marketable catch during time periods A and B combined) than under the 30,000 lb./week limit (2.5% of the catch during time period C). However, whereas the trip limit for widow rockfish remained at 3,000 lbs./trip during both time periods A and B, both catch per tow and discard rates were much higher during the former time period. While it would be expected that given a fixed trip limit, discard rate would increase as catch rates increase, it is unclear why the catch rates differed between time periods.

Discard rates of Pacific ocean perch; and Sebastes complex did not always vary in accordance with changes in regulations. Specifically,

Table 4a. Catch and regulation-induced discard of species and species/groups regulated by trip limits for the bottom rockfish fishing strategy by time period (A = July 21, 1985 - September 30, 1985; B = October 1, 1985 - December 31, 1985; C = January 1,1986 - June 30, 1986). Data are based on at-sea observations made aboard a sample of Oregon commercial groundfish trawl vessels.

Species Group	Time Period	Total Catch Sampled (lbs)	Average Catch Per Tow (lbs)	Marketable Catch (lbs)	Regulation-Induced Discard	
					Amount Discarded (lbs)	Percent of Marketable Catch Discarded
Widow Rockfish						
	A	22,447	488	22,282	17,945	80.5
	B	5,703	163	5,703	0	0.0
	C	100,990	886	100,948	2,552	2.5
Yellowtail Rockfish						
	A	11,156	243	11,156	0	0.0
	B	47,513	1358	47,512	6,302	13.3
	C	56,291	494	56,291	40	0.1
Sebastes Complex[1]						
	A	101,175	2,200	49,262	0	0.0
	B	90,749	2,593	79,942	6,390	8.0
	C	149,107	1,308	129,660	817	0.6
Pacific Ocean Perch						
	A	8,890	193	8,837	2,194	24.8
	B	19	1	19	0	0.0
	C	18,070	158	17,765	0	0.0
Sablefish						
	A	1,422	31	1,419	0	0.0
	B	130	4	33	33	100.0
	C	6,842	60	5,738	0	0.0
All Regulated Species Groups						
	A	133,934	2,912	81,800	20,139	24.6
	B	96,601	2,761	85,697	6,423	7.5
	C	275,009	2,412	254,111	3,409	1.3

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[1] Sebastes Complex includes yellowtail rockfish.

Table 4b. Catch and regulation-induced discard of species and species/groups regulated by trip limits for the deep water Dover sole fishing strategy by time period (A = July 21, 1985 - September 30, 1985; B = October 1, 1985 - December 31, 1985; C = January 1,1986 - June 30, 1986). Data are based on at-sea observations made aboard a sample of Oregon commercial groundfish trawl vessels.

					Regulation-Induced Discard	
Species Group	Time Period	Total Catch Sampled (lbs)	Average Catch Per Tow (lbs)	Marketable Catch (lbs)	Amount Discarded (lbs)	Percent of Marketable Catch Discarded
Widow Rockfish						
	A	574	10	574	0	0.0
	B	18	<1	18	0	0.0
	C	32	<1	32	0	0.0
Yellowtail Rockfish						
	A	0	0	0	0	0.0
	B	0	0	0	0	0.0
	C	658	6	658	359	54.6
Sebastes Complex[1]						
	A	20,599	361	19,444	0	0.0
	B	8,989	134	8,702	0	0.0
	C	49,056	481	44,623	6,026	13.5
Pacific Ocean Perch						
	A	1,673	29	1,652	0	0.0
	B	3,586	53	3,582	0	0.0
	C	20,877	205	20,828	0	0.0
Sablefish						
	A	21,346	375	17,538	426	2.4
	B	61,046	911	57,969	17,296	29.8
	C	51,643	506	46,668	0	0.0
All Regulated Species Groups						
	A	44,192	775	39,208	426	1.1
	B	73,639	1,099	70,271	17,296	24.6
	C	122,266	1,193	112,151	6,026	5.4

[1] Sebastes Complex includes yellowtail rockfish.

Table 4c. Catch and regulation-induced discard of species and species/groups regulated by trip limits for the midwater trawl fishing strategy during time period C (January 1, 1986 - June 30, 1986). Data are based on at-sea observations made aboard a sample of Oregon commercial groundfish trawl vessels.

Species Group	Time Period	Total Catch Sampled (lbs)	Average Catch Per Tow (lbs)	Marketable Catch (lbs)	Regulation-Induced Discard: Amount Discarded (lbs)	Regulation-Induced Discard: Percent of Marketable Catch Discarded
Widow Rockfish	C	182,879	7,620	182,879	20,000	10.9
Yellowtail Rockfish	C	5,267	219	5,267	320	6.1
Sebastes Complex[1]	C	5,382	224	5,375	320	5.9
Pacific Ocean Perch	C	0	0	0	0	0.0
Sablefish	C	0	0	0	0	0.0
All Regulated Species Groups	C	188,261	7,844	188,254	20,320	10.8

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[1] Sebastes Complex includes yellowtail rockfish.

regulations regarding Pacific ocean perch changed only slightly during the year of the study, yet significant discard was only observed during one time period during which catch/tow was high (Time period A, BRF strategy, Table 4a). Discard of Sebastes complex was primarily due to discard of yellowtail rockfish for the BRF strategy, but yellowtail rockfish did not comprise a large fraction of the Sebastes complex catch for the DWD strategy (Tables 4a and b). For the latter strategy, discard of Sebastes complex was highest during time period C, during which the highest trip limits for this species group were in effect, and catch rates were also highest in comparison with time periods A and B.

Table 4d. Catch and regulation-induced discard of species and species/groups regulated by trip limits for the nearshore mixed species fishing strategy by time period (A = July 21, 1985 - September 30, 1985; B = October 1, 1985 - December 31, 1985; C = January 1,1986 - June 30, 1986). Data are based on at-sea observations made aboard a sample of Oregon commercial groundfish trawl vessels.

Species Group	Time Period	Total Catch Sampled (lbs)	Average Catch Per Tow (lbs)	Marketable Catch (lbs)	Regulation-Induced Discard: Amount Discarded (lbs)	Regulation-Induced Discard: Percent of Marketable Catch Discarded
Widow Rockfish						
	A	53	2	53	0	0
	B	0	0	0	0	0
	C	0	0	0	0	0
Yellowtail and Rockfish						
	A	236	8	236	0	0
	B	0	0	0	0	0
	C	166	24	166	0	0
Sebastes Complex[1]						
	A	762	27	726	0	0
	B	126	42	84	0	0
	C	453	65	338	0	0
Pacific Ocean Perch						
	A	3	<1	3	0	0
	B	0	0	0	0	0
	C	0	0	0	0	0
Sablefish						
	A	958	34	779	0	0
	B	73	24	42	0	0
	C	0	0	0	0	0
All Regulated Species Groups						
	A	1776	63	1561	0	0
	B	199	66	126	0	0
	C	453	65	338	0	0

[1] Sebastes Complex includes yellowtail rockfish.

Discussion and Conclusions

It is clear that trip limits applied to individual species in a mixed species fishery lead to discard of some marketable fish. At least some discard of each of the regulated species groups was observed during the course of this study. Overall, regulation-induced discard accounted for 8.9% of the marketable catch of regulated species groups sampled. However, significant variation in discard rates was observed among species groups, fishing strategies, and time periods. On some occasions regulation-induced discard was extremely high, both as a percentage of the marketable catch and in absolute terms, whereas in other instances, no regulation-induced discard was observed.

Some of the variation in regulation-induced discard could be explained by differences in catch composition among fishing strategies, variations in trip limit regulations, and differences in regulated species catch rates among time periods. In general, it was found that highest discard rates tended to occur for those fishing strategies that caught mixed-species aggregations of fish with a large percentage of the catch consisting of species groups subject to trip limit restrictions. Greater discard rates also tended to be promoted by high catch rates and low trip limits for regulated species groups.

However, significant variation in catch and discard rates occurred which were not associated with changes in regulations or differences in fishing strategies. Other factors not considered in this paper undoubtedly play a major role in influencing the magnitude and variation in regulation-induced discard. Possible contributing factors include seasonal changes in species distributions and associations, individual differences in attitude and fishing strategy among fishermen, and trip length (ie. high catch rates per tow would be more likely to induce discard on long, relative to short, trips).

Further work is needed before the observations made in this study can be extrapolated to estimate the level of regulation-induced discard that occurred in the entire fishery during 1985-1986. Analyses of the levels of fishing activity employed in the fishery at-large by time period and fishing strategy are being conducted using logbook data, to permit such extrapolations to be made. However, given the variability in discard rates observed, such extrapolations will be rather approximate. Sampling rates are expected to be somewhat higher in future phases of this study than those reported here for the 1985-86 period, which should improve the precision of later estimates.

A question that inevitably arises but that is difficult to address is whether fishermen behave in a similar manner when an observer is aboard compared to other fishing trips. Factors that may tend to minimize changes in behavior due to the presence of an observer include:

1) There are no legal penalties associated with discard of fish-at-sea;

2) confidentiality of individual vessel catch utilization and discard practices is an important component of our agreement with the participants;

3) since economic compensation of skipper and crew is generally based on a percentage of profits (as opposed to time related

compensation), it is in the economic interests of the skippers to employ those strategies that are likely to yield the greatest profits; presumably such strategies are those that are used on a regular basis and;

4) participants appear to be sincerely interested in aiding efforts to document and evaluate effects of the current management regime.

Any deviations from normal fishing patterns that may have occurred would likely result in less, rather than more, discard then usual. Thus levels of regulation-induced discard observed in this study may underestimate overall discard rates.

Future consequences and evaluation of present management policies

Under current management policy, trip limits for regulated species can vary greatly both within and between years. This variation is due to changes in allowable annual catch levels, as well as variation in the number of vessels participating in the fishery. At present, fleet size is not regulated and varies in part due to changes in accessibility and profitability of alternative fishing opportunities (eg. shrimping, joint venture fishing). For a fixed level of annual allowable catch, an increase in the number of participants will likely lead to lower trip limits, and vice versa. Future changes in the number of species or species groups regulated by trip limits will also influence overall discard rates.

It is difficult to predict how allowable catch levels, fleet size, and regulations will change in the future, but it is clear that such changes will influence the extent of regulation-induced discard that will occur from year to year. Thus, the level of regulation-induced waste observed in this study may be greater or less than that which will occur in the future.

The waste of marketable fish due to regulations reduces the immediate value of the catch to individual vessels during trips where it occurs, and may also diminish future opportunities to catch and market fish for the fishery at large, and hence, the availability of fish to consumers. It also reduces the reliability of landings data as indicators of total fishery-induced removals. While it would certainly be desireable to prevent waste from occurring, the "costs" of the current management regime in terms of regulation-induced waste must be weighed against its benefits and should also be compared with the pros and cons of alternative management systems.

The West Coast groundfish trawl fishery is complex in terms of the number of species exploited, variation in the condition of individual stocks within the fishery, the variety of fishing strategies employed by the fishing fleet, and the multitude of management objectives sought to be achieved. Alternative management regimes which may be more effective at minimizing waste, may have other less desireable consequences. A fuller evaluation of the current management regime, as well as an evaluation of potential alternatives is now in progress.

Summary

Observations conducted aboard commercial fishing vessels during 1985 and 1986 indicate that the current West Coast groundfish management policy results in some discard of marketable fish. Regulation-induced discard averaged 8.9% of the marketable catch of regulated species groups sampled, but significant variation in discard rates was observed among species groups, fishing strategies and time periods. Higher discard rates tended to be promoted by low trip limits, high catch rates, and fishing strategies which caught a mixture of fish that included a large percentage of regulated species groups. Further work is in progress to more fully evaluate the current management regime in light of alternative management tools.

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Session VI -- Workshop on future rockfish research needs

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Workshop Summary

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The workshop on future research needs was conducted using the panel discussion format. The chairs of the individual symposium sessions, Grace Klein-MacPhee, H. Richard Carlson, Lewis Haldorson, Daniel H. Ito, and Steven K. Davis made up the workshop panel. Each gave a summary of the status of knowledge of rockfish, as reflected in the papers presented during his or her session; provided thoughts on what direction future research should take, and led the discussion of that particular panel subject. The following is a brief summary of the workshop discussions.

Rockfish fisheries conducted on the eastern and western costs of North America have a long history, although significant effort levels and high catches did not occur until about the 1940s. As a whole, the fisheries are experiencing declining catches and standing stocks. This has been due primarily to increasing effort and consumer demand for various rockfish. Researchers and managers must deal with a number of problem areas if they are to provide a fishery that is economically valuable in the long-term. These problem areas include:

> A lack of knowledge of the life histories of many rockfish species.
>
> The inability to measure a forecast recruitment.
>
> Unknown accuracies and precisions in biomass assessments.
>
> Management of multi-species fisheries.

By-catches of birds, marine mammals, and prohibited or fully utilized fish species.

Conflicts between various user groups.

Overlapping regulatory jurisdictions.

Perhaps the most important obstacle to overcome in providing effective management of the rockfish resources is that of declining budgets.

Knowledge of the early life histories of most of the commercially important rockfish species is severely lacking. If we are to begin to understand the dynamics of this resource, it is imperative that progress be made in areas such as species identification of early life stages, distribution and movement of larval and juvenile stages, and the factors affecting rates of mortality of these young fish.

The new aging techniques seem to have been accepted by most of those working in the field, but there is a need to insure continued validation of those techniques. The break and burn method is laborious and expensive, therefore, there is a need to investigate more efficient methods of estimating the age of rockfish. Areas that show some promise are the use of length frequency distributions, otolith morphometry, and regression techniques.

The species being investigated should be ranked in order of importance, and the validity of applying data available for similar species to those being studied determined.

There is a desire by the industry and managers to rebuild depleted rockfish stocks. Some measures have been taken to accomplish that objective, but accurate measurements of recruitment are needed to assess the success of those rebuilding programs. In addition to understanding the basic biology of the species involved and the development of good stock assessment techniques, the natural external factors affecting survival must also be understood to evaluate whether the management technique, natural factors, or a combination of both has caused the measured level of recruitment to the fishery. Since there are many natural factors, both biological and physical, affecting birth and survival, it may not be possible to accurately predict recruitment success, but it is important that the problem be investigated. Topics such as environmental affects of fecundity, larval survival windows, and the spatiality of recruitment are of particular importance.

Reviews of recent stock assessments show that many rockfish populations are much less productive than initially thought. A full review of assessment techniques is warranted to evaluate the need to increase their accuracy and precision. Critical questions that need to be answered are:

What is the degree of intra- and intersite variability of assessments?

Will there be problems with estimating the numbers of fish at age when the populations are low?

How accurate are current stock assessment models and trawl surveys at low stock or effort levels?

How to standardize data obtained using differing assessment techniques?

In addition to answering the above questions, there is a need to:

Incorporate new biological and physical data into assessment models when possible.

Examine robustness of existing models.

Modify existing assessment techniques, or develop new ones to deal with variability problems.

Investigate climatic affects on stock status.

Although there may be a need to slow down rockfish research as funding declines, there is also a need to get ahead of the boom-bust phenomenon that has been plaguing the rockfish fisheries. There are a number of things that can be done to either reduce the cost of research, or increase what can be done with existing funds.

Data sharing can be increased.

Managers and researchers need to interact more than they do now to increase the level of feedback.

Experimental fisheries should be used to test hypotheses.

There is a need to involve all users of the resource to a higher degree, so that they will assist in promoting programs to those that hold the purse strings.

The costs and benefits of rebuilding need to be assessed.

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