NOAA Technical Report NMFS 117

May 1994

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ABSTRACT

We compare results of bottom trawl surveys off Washington, Oregon, and California in 1977, 1980, 1983, and 1986 to discern trends in population abundance, distribution, and biology. Catch per unit of effort, area-swept biomass estimates, and age and length compositions for 12 commercially important west coast groundfishes are presented to illustrate trends over the 10-year period. We discuss the precision, accuracy, and statistical significance of observed trends in abundance estimates. The influence of water temperature on the distribution of groundfishes is also briefly examined. Abundance estimates of canary rockfish, *Sebastes pinniger*, and yellowtail rockfish, *S. flavidus*, declined during the study period; greater declines were observed in Pacific ocean perch, *S. alutus*, lingcod, *Ophiodon elongatus*, and arrowtooth flounder, *Atheresthes stomias*. Biomass estimates of Pacific hake, *Merluccius productus*, and English, rex, and Dover soles (*Pleuronectes vetulus, Errex zachirus*, and *Microstomus pacificus*) increased, while bocaccio, *S. paucispinis*, and chilipepper, *S. goodei*, were stable. Sablefish, *Anoplopoma fimbria*, biomass estimates increased markedly from 1977 to 1980 and declined moderately thereafter. Precision was lowest for rockfishes, lingcod, and sablefish; it was highest for flatfishes because they were uniformly distributed. The accuracy of survey estimates could be gauged only for yellowtail and canary rockfish and sablefish. All fishery-based analyses produced much larger estimates of abundance than bottom trawl surveys—indicative of the true catchability of survey trawls. Population trends from all analyses compared well except in canary rockfish, the species that presents the greatest challenge to obtaining reasonable precision and one that casts doubts on the usefulness of bottom trawl surveys for estimating its abundance.

Introduction

The National Marine Fisheries Service (NMFS), NOAA, has conducted groundfish surveys in the northeastern Pacific Ocean for over 30 years. The earliest exploratory efforts, conducted under the agency's former title of the Bureau of Commercial Fisheries, aimed at providing information on little used or unknown resources. Fishing gear development was also an important objective during many early surveys. When foreign fishing fleets began to harvest substantial quantities of groundfish off the Pacific coast during the late 1960's, we designed and implemented surveys to determine the status of the primary target species, Pacific hake, *Merluccius productus*, and to monitor changes in population characteristics. In 1976, NMFS increased the scope of the Pacific hake surveys and made a commitment to build a comprehensive groundfish database from intensive and extensive bottom trawl and hydroacoustic surveys to monitor long-term changes in groundfish distribution, abundance, and biological features. Scientists incorporate survey results with analyses of commercial fishery data to develop periodic stock assessments and provide these assessments to the Pacific Fishery Management Council (PFMC) as advice for its annual management recommendations.

Major triennial surveys of west coast groundfish resources were conducted by NMFS in 1977, 1980, 1983, and 1986. Detailed information on the latter three surveys was published in a series of data reports (Weinberg et al., 1984; Coleman, 1986 and 1988). Gunderson and Lenarz (1980) discussed studies based on data from the 1977 survey. Dark et al. (1983) compared the results of the 1977 and 1980 surveys for selected rockfish species. Further comparisons were delayed until sufficient data allowed examination of longer term population trends. Although the four years of information now available allow for comparisons, results of additional surveys will add measurably to the understanding of the variability common to groundfish communities. A better grasp of this variability is particularly important now that the west coast groundfish industry is capable of easily meeting or exceeding annual optimum yields. The development of new fisheries, the addition of significant new fishing effort, and the evolution of harvesting technology have created major management challenges for the PFMC and have increased the demand for resource information.

This report compiles and compares the results of groundfish surveys conducted in 1977, 1980, 1983, and 1986 and examines population trends during this period. Specific objectives of the study were to 1) determine trends in distribution and abundance of major groundfish species, 2) characterize estimates of length composition and age composition of populations of key species, 3) evaluate recruitment and year class strength, and 4) examine changes in sea temperature and possible effects on groundfish distribution.

Methods

The survey objectives and design in 1977 were somewhat different from those of the 1980, 1983, and 1986 surveys, but not so different as to preclude meaningful comparisons. The 1977 bottom trawl and hydroacoustic survey was conducted from Port Hueneme, Calif. (lat. 34°00'N), to Cape Flattery, Wash. (lat. 48°30'N), to obtain information on the distribution, abundance, and biological characteristics of a variety of important rockfishes, *Sebastes* spp., inhabiting the 91–457 m (50–250 fm) zone (Gunderson and Sample, 1980). Subsequent surveys were aimed primarily at determining the distribution, abundance, and biological features of Pacific hake and two rockfishes: yellowtail rockfish, *Sebastes flavidus*, and canary rockfish, *S. pinniger* (Dark et al., 1983; Weinberg et al., 1984; Coleman, 1986 and 1988). The 1980 and 1983 surveys were conducted between Monterey Bay, Calif. (lat. 36°48'N), and central Vancouver Island, British Columbia (lat. 49°15'N), between depths of 55 and 366 m (30–200 fm). The 1986 survey covered much of the same area, except that no sampling was conducted north of the U.S.-Canada border. Only that portion of the survey area common to all four years (Fig. 1) was considered in our analyses and comparisons. All surveys were conducted from July to October, when Pacific hake and rockfish movements are thought to be minimal. Therefore, the probability of censusing fish schools more than once as the vessels passed through the survey area was minimized.

The sampling design was shaped mainly by the need for multispecies assessments and our desire to estimate abundance with the greatest possible precision. We allocated bottom trawl samples over the survey area in proportion to the abundance of commercial landings of Pacific hake and key rockfishes. Because sample variability is correlated with the mean catch per unit of effort (CPUE), more samples were assigned in areas of anticipated high abundance to reduce variance. In 1977, 1980, and 1983, the survey area was subdivided into different sampling strata using historical commercial catch data for Pacific hake (Edwards et al., 1981) and several valuable rockfish species. We allocated samples along transects drawn approximately perpendicular to the 55 m (30 fm; 91 m or 50 fm in 1977) isobath. Varying the distance between transects allowed us to raise or lower the intended sampling density for a stratum.

The 1977 survey area comprised 14 latitudinal sampling strata for rockfish, each of which was sampled at either "low" (transects every 18.5 km) or "high" (transects every 9.3 km) densities. Because abundance of target species was known to vary over the depths surveyed, the survey area was also stratified into four 91-m depth zones (91–183 m, 184–274 m, 275–366 m, and 367–457 m), which also influenced the location of bottom trawl stations on a given transect. The number of trawl stations on a transect within a depth stratum was proportional to the length of the transect segment within the stratum. Stations were then placed randomly along transects with the proviso that no two stations could occur within 3.7 km (2 nmi) of one another.

We modified the experimental design of 1977 for the 1980 survey to better accommodate the changes in study objectives. The southern boundary of the survey area was moved northward from Port Hueneme to Monterey Bay to describe an area that included most of the adult Pacific hake, canary rockfish, and yellowtail rockfish populations. The bathymetric boundaries were changed to 55–366 m to better reflect the depth distribution of the target species. The area was also restratified using commercial catch data to define important canary and yellowtail rockfish areas. This resulted in three levels of sampling density and three depth strata (91–183 m, 184–219 m, and 220–366 m). We established a minimum sampling intensity of one trawl haul per 130 km^2 because past survey experience had shown that this level of sampling effort produced reasonably precise Pacific hake biomass estimates in areas of moderate abundance. This "low" sampling density was achieved by spacing transects 22.2 km apart. Sampling intensity was doubled to create "medium" density strata (transects 11.1 km apart) where high Pacific hake abundance was expected (lat. 42°00'–45°00'N). Sampling was doubled again to create "high" density strata (transects 5.6 km apart) in the rockfish areas (lat. 42°50'–44°18'N and 46°10'–47°20'N) because of the high variability associated with rockfish catches.

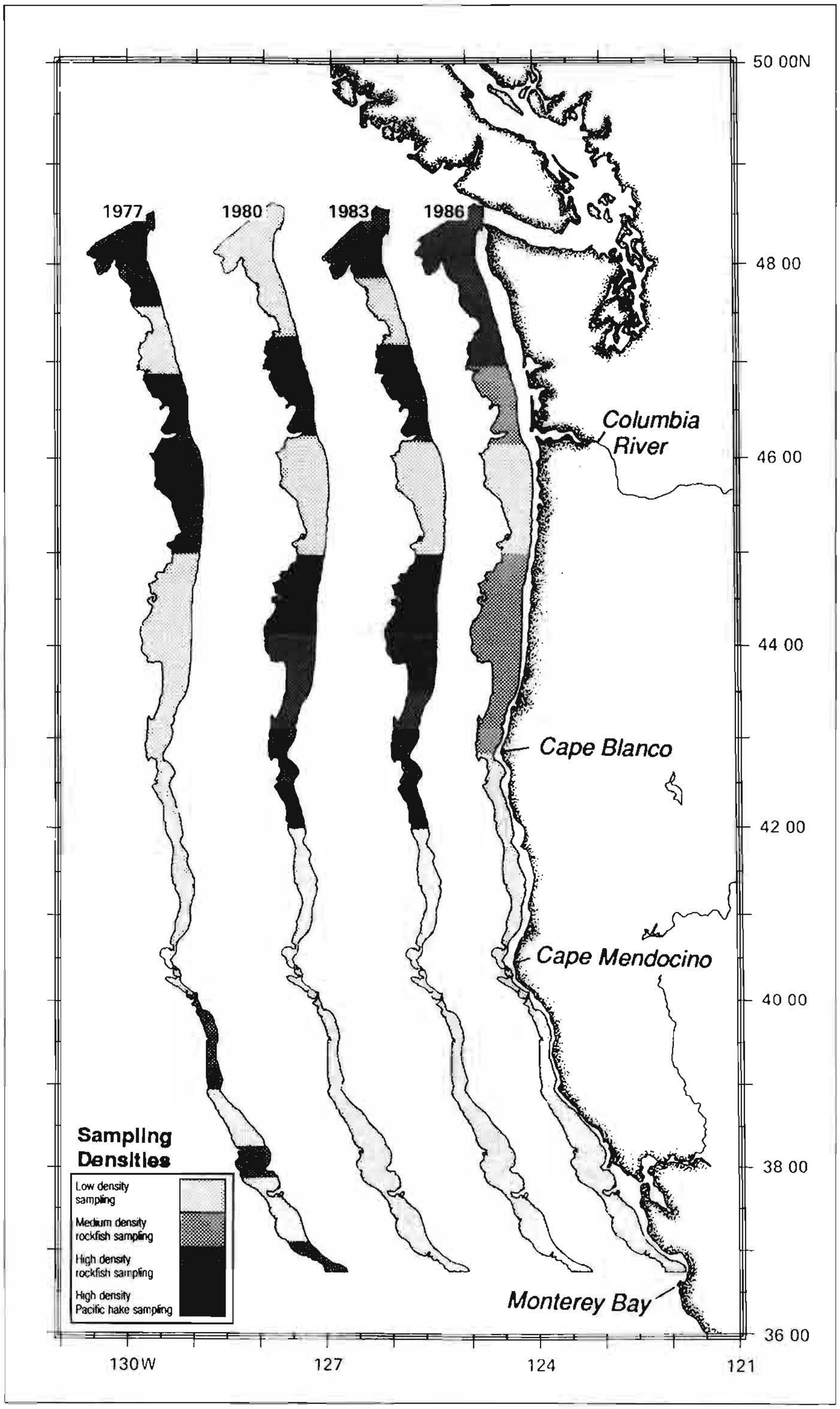

Figure 1

Survey boundaries and relative sampling densities established for the 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

The 1983 survey design was identical to the 1980 design, except for the addition of stations in a small area off northern Washington. These stations were added to improve estimates of shelf rockfish abundance in an area of growing commercial importance.

In 1986 we restratified the survey area again and allocated sampling effort differently to improve further the precision of canary and yellowtail rockfish abundance estimates. Stratification of the survey area was based on previous survey results and commercial CPUE data[1] for these two rockfish species. Optimum stratification was selected from among three possible schemes suggested by the geographic distribution of CPUE. Variation in CPUE was expressed in a linear model using year, area, and depth as components of variation to determine the scheme that best isolated areas of disparate rockfish densities. The criteria for selection of an optimum stratification were minimization of within-stratum variation in CPUE for canary and yellowtail rockfish and maximization of between-strata variation. The analysis resulted in six geographic strata (Fig. 1) and four depth intervals (55–91 m, 92–183 m, 184–219 m, and 220–366 m), instead of the eight geographic strata and three depths used in 1980 and 1983.

We considered various allocation schemes for distributing samples among strata. Monte Carlo simulations using canary and yellowtail rockfish CPUE data from previous surveys were used to estimate the probability of detecting different magnitudes of changes in abundance of the two species. The results of these efforts indicated that an allocation proportional to the product of stratum size and the standard deviation of CPUE for the stratum ("approximate Neyman allocation"), which simultaneously minimized the variances of both canary and yellowtail rockfish abundance estimates, would perform best. The resulting allocation scheme, tempered by the condition that all strata contain at least three samples, was adopted for the 1986 survey. The stations allocated to each stratum were systematically placed along east-west transects spaced 3.7 km apart. Beginning at the shallow end of the southernmost transect, stations were placed at equal intervals along the cumulative length of the transects in that stratum. This resulted in different sampling densities for each stratum that were strictly proportional to the station allocation. More detailed descriptions of the triennial survey sampling designs were presented by Gunderson and Sample (1980), Dark et al. (1983), Weinberg et al. (1984), and Coleman (1988).

Bottom trawl vessels ranged in size from the chartered vessel *Commando* (19.8 m) to the NOAA ship *David Starr Jordan* (52.1 m). Four trawlers were employed in 1977, and two in each of the later surveys. We did not have the opportunity to conduct comparative fishing power studies, so we took special efforts to ensure that trawl gear and trawling procedures were standardized to minimize differences in fishing power among vessels. Additionally, in 1980, 1983, and 1986, the two vessels sampled alternate transects throughout the survey area so that differences in fishing power would not affect inter-areal comparisons of results. There were minor differences in trawl door weights and tail chain lengths to accommodate specific vessel configurations, but all vessels used Noreastern trawls that were otherwise rigged identically (Gunderson and Sample, 1980). These trawls were constructed with 8.9-cm (3.5-in) nylon mesh in the intermediate and codend; codends were also lined with 3.2-cm (1.25-in) mesh to retain juvenile groundfish. An exception occurred in 1986 when one vessel fished alternately with two Noreastern trawls, one constructed of nylon and the other of polyethylene materials. Polyethylene construction was employed because it was reputed to be more durable and was expected to result in less time lost to gear damage. The trawls were otherwise identical except that the wings of the polyethylene trawl were slightly modified to reduce snagging. The relative fishing efficiency of the two trawls is presently being evaluated in more detail. The area swept by the two trawls differed by about 8%, therefore all catches by polyethylene trawls were standardized to nylon trawl catches prior to distribution and abundance calculations (Coleman, 1988). In situ measurements indicated that the nylon trawl had an average wing-tip to wing-tip distance of 13.4 m (remeasured at 12.8 m in 1986) and a footrope to headrope distance of 8.8 m (7.2 m in 1986). Scope ratios used by all vessels were similar and towing speeds were held as close as possible to 1.5 m/second.

If rough seabeds prevented trawling at a designated site, an alternative station site was selected nearby. If no suitable alternative sites were found, the station was considered to be untrawlable and the vessel proceeded to the next station. Vessels trawled for 30 minutes at each station. Catches were sorted and weighed by species, and subsampled for a variety of biological data. We measured fork length of fish in random samples of target species. Procedures used for representative sampling of catches were described in detail by Gunderson and Sample (1980).

Sea surface temperatures were collected at most stations with bucket thermometers. The bottom temperature data used in this study were, in most cases, collected with expendable bathythermographs (XBT's), but the expanded collection of bottom temperature infor-

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[1] Tagart, J. V., Washington Department of Fisheries, Natural Resources Building, Olympia, WA 98504. Personal commun., May 1986. Golden, J. T., Oregon Department of Fish and Wildlife, Hatfield Marine Science Center, Newport, OR 97365. Personal commun., May 1986.

mation in 1986 was possible through the use of a temperature sensor mounted on the headrope of the trawl. The headrope sensor was calibrated with independent XBT observations and proved to be accurate. In 1977, a minimum temperature recording headrope thermometer was used during most hauls. The data collected from the headrope thermometers exhibited so much variation that meaningful trends in distribution were obscured. Because of this imprecision and the absence of measurements north of lat. 44°N, we excluded the 1977 bottom temperature data from the analysis.

Relative population densities of target species based on survey CPUE data are presented in charts by year, depth zone, and 0.5° latitudinal blocks. The chart for each species was constructed by calculating the mean CPUE in each latitude/depth block in each year. The mean CPUE values for 1977 were then ranked in descending order, and the top 10% of the nonzero values were assigned to represent the highest density category. The next highest 30% of the values represent the moderate density category, and the remaining 60% represent the lowest density category. Blocks without catch or samples are also indicated. These CPUE categories were used for all subsequent years; therefore, all density values are relative to 1977.

Biomass estimates for each depth and geographic stratum were derived using the following standard area-swept equation:

$$\hat{B}_i = \frac{A_i}{a_i}\left(\overline{CPUE_i} \times \frac{1}{q}\right),$$

where $\hat{B}_i$ = estimated biomass in the i^{th} area/depth stratum, A_i = total area in the i^{th} stratum, a_i = area swept during a standard trawl haul, $\overline{CPUE_i}$ = mean CPUE (kg/km) in the i^{th} area or depth stratum, and q = the catchability coefficient of the sampling trawl (assumed $q = 1$). The variance about biomass estimates was estimated by

$$var(\hat{B}) = \sum\left(\frac{A_i}{a_i}\right)^2 var\left(\overline{CPUE_i}\right)$$

where

$$var\left(\overline{CPUE_i}\right) = \frac{1}{n_i(n_i - 1)} \sum\left(CPUE_{ij} - \overline{CPUE_i}\right)^2.$$

Ninety percent confidence intervals were calculated using

$$\hat{B} \pm t_{(.90,n_e)}\sqrt{var(\hat{B})}$$

where n_e = effective degrees of freedom.

Although trawl catches tend to be non-normally distributed, in most cases our sample sizes were sufficiently large that we could reasonably assume that our estimator, $\overline{CPUE_i}$, behaved according to the Central Limit Theorem (Fisher, 1921) and was, for practical purposes, normally distributed. Therefore, the assumption of normality underlying the use of the variance and confidence interval formulae above was considered satisfied.

The length composition of a population within a stratum was estimated by weighting sample length frequencies from each haul by the CPUE of that haul, summing the weighted length frequencies over all hauls in a stratum, and then applying that weighted stratum length frequency to the estimated population numbers in the stratum. Stratum length compositions were converted to estimated stratum age compositions by using age-length keys constructed for each International North Pacific Fisheries Commission (INPFC) area (Fig. 2). Our use of distinct age-length keys minimized any bias that might be introduced by different age-length relationships among INPFC areas.

Several data limitations affected the analysis of the survey data. Because research objectives in 1977 differed somewhat from those established in subsequent years, some data from the four surveys were not exactly comparable. As previously mentioned, bottom trawl sampling in 1977 occurred between 91 and 457 m (50 and 250 fm), whereas in later surveys sampling was conducted between 55 and 366 m (30 and 200 fm). Therefore, we excluded samples collected deeper than 366 m in 1977 from these analyses. Samples collected at 55–91 m in 1980, 1983, and 1986 could have been excluded to achieve consistency, but we included them rather than sacrifice a large amount of information. Extrapolation of 1977 abundance estimates to the 55–91 m (30–50 fm) interval based on proportions found in that interval in 1980–86 was unacceptable because that would have required assumptions that probably are not valid. Alternatively, results of the four surveys were compared with the caveat that 1977 absolute abundance estimates are conservative relative to those from later years for species that occur mainly in the shallower portions of the survey area (e.g. Pacific hake; English sole, *Pleuronectes vetulus*; lingcod, *Ophiodon elongatus*; canary rockfish; and yellowtail rockfish). The 55–91 m zone represents 34, 32, 26, and 15% of the area between 55 and 366 m in the Monterey, Eureka, Columbia, and U.S. portion of the Vancouver (U.S.-Vancouver) INPFC areas, respectively. As noted previously, depth strata employed in the designs of the four surveys differed as research objectives changed. Depth strata were combined to allow the best interannual comparability of results for this analysis. Two common depth zones (55–183 m and 184–366 m) were ultimately used for abundance analysis of all species except shelf (canary and yellowtail) rockfish. Three common depth zones (55–183 m, 184–219 m, and 220–366 m) were used for these two species. Because of the different depth stratification in 1977, common depth zones for that survey year were 91–183 m, 184–274 m, and 275–366 m for shelf rockfish and 91–183 m and 184–366 m for all other species.

We present biomass estimates to provide insight on the relative magnitude of various groundfish populations, but a caution is warranted. A catchability coefficient of unity (i.e. all fish in the trawl path are caught) was assumed in the estimation of biomass. Actual catchability coefficients are unknown, but they are certain to vary within and among species. Biomass estimates generated from bottom trawl surveys also reflect an assumption that the trawl is capable of sampling the entire habitat of the target species. The Noreastern trawl rigged with rollers was selected as our standard sampling gear in 1977 because it could be fished over a wide range of seabed types and was considered at that time to be an effective rockfish trawl. We have elected to continue using this trawl, even though trawls that appear to be more efficient at catching rockfish are now available. This decision was made to preserve data comparability and because the Noreastern trawl as equipped has suited the multispecies aspects of the survey. However, the trawl is a compromise and is prob-

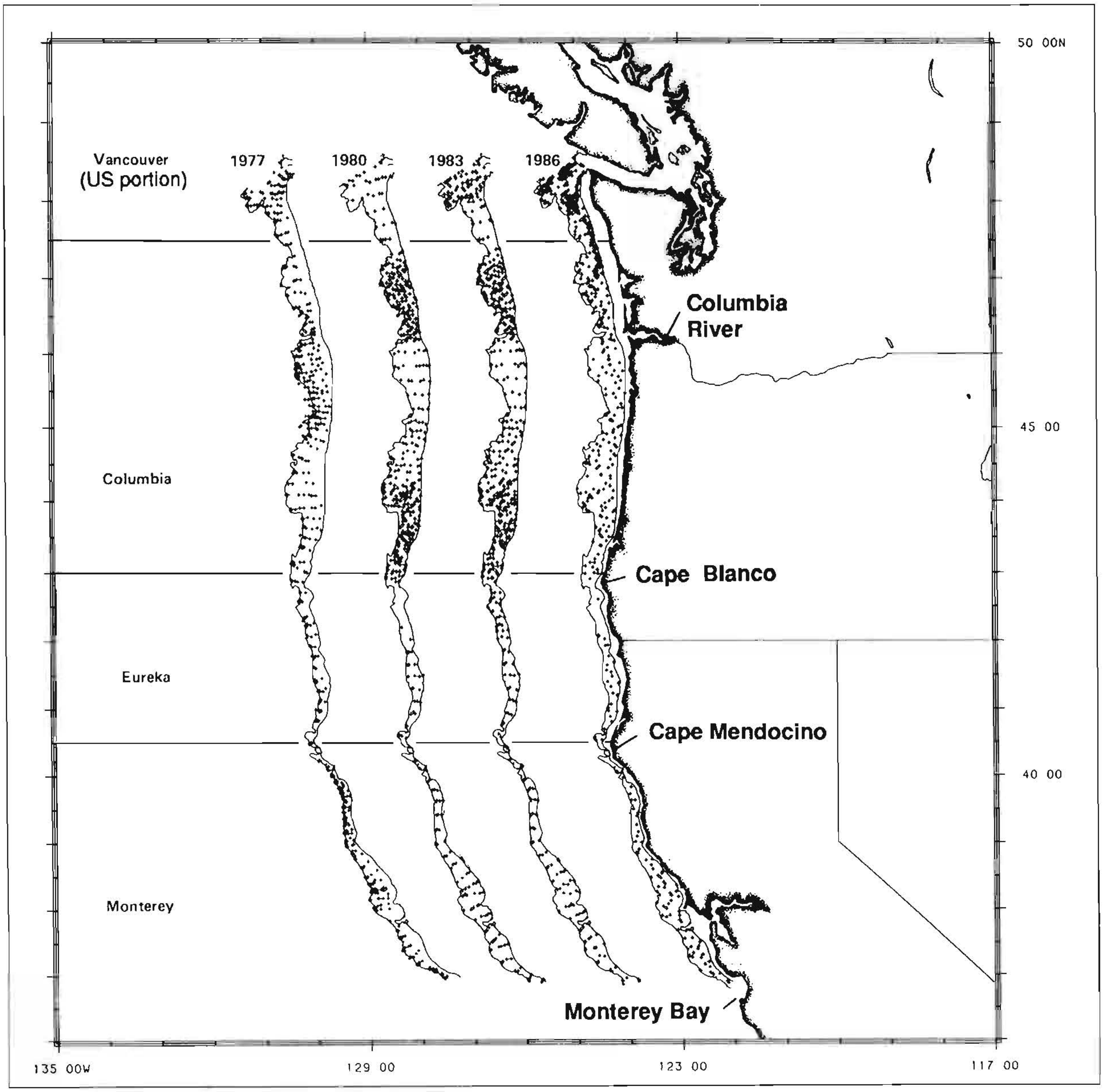

Figure 2
Distribution of successful bottom trawl hauls during 1977, 1980, 1983, and 1986 National Marine Fisheries Service surveys.

ably inefficient for some species. For instance, Demory et al.[2] reported that a few comparisons between a trawl rigged with discs and another rigged with rollers on the footrope indicated that the roller-equipped trawl was only 25% as efficient in capturing Dover sole, *Microstomus pacificus*. Also, some rockfishes and sablefish, *Anoplopoma fimbria*, range into midwater areas and are not completely available even to this relatively high opening bottom trawl. Herding by trawl components located outside the wing tips of the net (e.g. bridles, doors, and warps; Carrothers, 1981; Main and Sangster, 1983) will tend to compensate for the effects of unavailability and escapement. Lacking information on herding in species of concern and assuming that escapement and unavailability can be significant, we view our biomass estimates as conservatively biased. Biomass estimates probably best serve as indicators of changes in relative abundance and are used in this study to examine trends in population size.

Finally, procedural changes could account for some of the interannual variability in age compositions observed during the study period. Age determination methods at the Alaska Fisheries Science Center (AFSC) have evolved slowly since 1977 as new techniques have been studied and accepted. During 1977–80, groundfish species treated in this report were aged using otolith surfaces. Otoliths were only sectioned or broken and burned to meet special requests or to resolve specific questions about ages derived from surface readings. Since 1983, greater and more systematic use of the break-and-burn technique has been employed, because surface ageing methods were shown to underestimate the age of older fish (Beamish, 1979 a and b; Chilton and Beamish, 1982). All Pacific ocean perch, *Sebastes alutus*, ages are now determined from broken-and-burned otoliths. All other species are aged using whole (surface) or broken-and-burned otoliths. The specific method applied is left to the discretion of the otolith reader, although most otoliths from older specimens were subjected to both techniques. Within- and between-reader variability is continuously monitored and maintained at the lowest possible levels. The extent of age-determination bias will be discussed species by species.

Results

Samples Collected

Survey areas encompassed 28,529 km^2 (8,318 nmi^2) in 1977 and 39,463 km^2 (11,506 nmi^2) in each of the other years. The 1977 survey area was smaller because a narrower depth interval was sampled. The 1980 and 1986 survey areas were slightly smaller than planned because adverse weather precluded sampling between lat. 42°00' and 42°50'N in 1980 and between lat. 42°07' and 42°50'N in 1986. A total of 485 to 515 bottom trawl hauls were successfully completed each year in the four INPFC statistical areas combined (Table 1, Fig. 2). INPFC areas (Fig. 2) are commonly used by the PFMC in the management of groundfish resources. Sampling was emphasized in the Monterey area in 1977 to estimate bocaccio, *Sebastes paucispinis*, and chilipepper, *S. goodei*, abundance. The shift of additional sampling effort to more northern areas in 1980, 1983, and 1986 reflected our desire to more precisely estimate canary and yellowtail rockfish abundance in that region.

Length data were collected for 12 species (Table 2) and age data for nine species (Table 3). Length and age data were collected on a priority basis and therefore more data are available for key species. Only a portion of the age structures collected have been processed to obtain ages. For example, age determinations were only available for Pacific hake and canary rockfish in 1983 and for Pacific hake only in 1986 because of the lack of reader expertise in ageing some species and because of incomplete validation of ageing methods for others.

Groundfish Distribution, Abundance, and Biological Parameters

General Distribution and Abundance — The importance of each INPFC area in terms of the relative abundance of groundfish present during the survey periods was examined by using mean CPUE as an index of density (Table 4). On average, density of all groundfish species combined was greatest in the U.S.-Vancouver area (lat. 47°30'N to U.S.-Canada border) followed by the Monterey, Eureka, and Columbia areas (Table 4). Mean CPUE in the U.S.-Vancouver area was 1.9 times greater than that of the Columbia area. Average groundfish density in the Monterey area, nearly as great as that in the U.S.-Vancouver area, was 1.7 times greater than that observed in the Columbia area. Overall, density in the shallow depth zone (55–183 m) was slightly greater than in the deep zone (184–366 m), and the density in 1977 was greater than in later survey years. The considerable interannual and bathymetric variability in CPUE among areas was due mainly to the distribution of Pacific hake, a large and dynamic component of the west coast groundfish complex.

An examination of the catch rates of predominant species by INPFC area (Table 5) revealed latitudinal patterns of distribution that have persisted through the years. Spiny dogfish, *Squalus acanthias*, Pacific hake,

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[2] Demory, R. L., J. T. Golden, and E. K. Pikitch. 1984. Status of Dover sole (*Microstomus pacificus*) in INPFC Columbia and Vancouver areas in 1984. *In* Pacific Fisheries Management Council, Status of the Pacific coast groundfish fishery and recommendations for management in 1985, Appendix 11, 33 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

Table 1

Numbers of successful bottom trawl hauls and areas surveyed in groundfish surveys off Washington, Oregon, and California during 1977, 1980, 1983, and 1986.

		International North Pacific Fisheries Commission area									
		U.S.-Vancouver		Columbia		Eureka		Monterey		Total	
	Depth zone (m)	Area surveyed (km^2)	Hauls	Area surveyed (km^2)	Hauls	Area surveyed (km^2)	Hauls	Area surveyed (km^2)	Hauls	Area surveyed (km^2)	Hauls
1977	91–183	2,840	32	10,536	106	2,408	19	5,134	82	20,915	239
	184–366	1,187	38	3,996	122	1,080	36	1,554	128	7,820	324
	Total	4,027	70	14,532	228	3,488	55	6,688	210	28,735	563
1980	55–183	3,537	17	15,642	288	2,717	24	8,543	56	30,436	385
	184–366	1,200	9	4,018	62	1,076	9	1,626	20	7,923	100
	Total	4,737	26	19,660	350	3,793	33	10,169	76	38,359	485
1983	55–183	3,537	46	15,642	237	4,089	40	8,543	55	31,811	378
	184–366	1,200	24	4,052	73	1,076	20	1,626	20	7,954	137
	Total	4,737	70	19,694	310	5,165	60	10,169	75	39,765	515
1986	55–183	3,546	171	15,665	187	4,089	27	8,437	60	31,739	445
	184–366	1,125	18	3,542	28	1,076	4	1,615	12	7,360	62
	Total	4,671	189	19,207	215	5,165	31	10,053	72	39,100	507

and Pacific ocean perch were consistently important species in the U.S.-Vancouver area. Pacific hake and Pacific ocean perch continued to dominate in the Columbia area, but sablefish and Dover sole began to assume a higher rank in the species composition. Although Pacific ocean perch was prominent in the Columbia area in 1977 and 1980, its importance fell noticeably in later years. Canary and yellowtail rockfish were relatively abundant in the two northern areas, but their CPUE declined noticeably in the Eureka and Monterey areas, where they were not among the important components. In the Eureka area, Pacific hake ranked high, reflecting its coastwide dominance. Dover sole became relatively more important there. Splitnose rockfish, *Sebastes diploproa,* and stripetail rockfish, *S. saxicola,* emerged as important components in the Eureka area. Finally, stripetail rockfish became a major component of the groundfish community in the Monterey area, as did splitnose rockfish, chilipepper, and bocaccio.

In the survey area as a whole, Pacific hake was the dominant species in all years. Spiny dogfish CPUE also ranked high each year, but annual variability in CPUE was evident among other species. Sablefish was among the four most abundant species in 1980, 1983, and 1986 but ranked 13th in 1977. Shortbelly rockfish, *S. jordani,* was prominent in 1977 and 1986 but was not among the species composing 80% of the total groundfish CPUE in 1980 and 1983. Likewise, splitnose rockfish was relatively abundant in 1977, 1980, and 1986 but was not among the most abundant species in 1983.

Trends in Species of Major Commercial Importance

Pacific hake — Pacific hake is the largest single groundfish resource found off Washington, Oregon, and California. Biomass estimates have usually been in excess of one million metric tons (t) (Stauffer, 1985). The species first became the subject of foreign fisheries in the mid-1960's, and since 1978 it has supported a substantial joint venture fishery. Domestic fisheries have existed since the early 1960's but, except for the first 2–3 years of operation, have only accounted for a small portion of the total catch. Total catches from 1980 to 1987 have ranged from 73,151 to 160,448 t, and only recently have approached optimum yield levels of 175,000 to 195,000 t (PacFIN 1986–88[3]).

Pacific hake were usually present in all depth strata throughout the survey area but were most densely distributed on the continental shelf between 55 and 183 m; intermediate densities occurred in the 184–366 m zone (Fig. 3). From 1977 to 1986, Pacific hake CPUE decreased from south to north. Averaged over all years, mean CPUE was 93.2 kg/km in the Monterey area, 76.2 kg/km in the Eureka area, 33.4 kg/km in the Columbia area, and 32.2 kg/km in the U.S.-Vancouver area. The greater densities in the southern areas reflect the presence of abundant prerecruit and recruiting stock components. High densities (112.3 to more than 453 kg/km) occurred over larger regions in 1983 and 1986. In

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[3] Pacific Fisheries Information Network (PacFIN). 1981–88. U.S. catches 1981–88. PacFIN, Pacific States Marine Fisheries Commission, Metro Center, Suite 170, 2000 S.W. First Avenue, Portland, OR 97201.

Table 2

Number of length samples taken from bottom trawl catches in 1977, 1980, 1983, and 1986 by species, depth zone, and International North Pacific Fisheries Commission statistical area. See text for scientific names.

		U.S.-Vancouver				Columbia				Eureka				Monterey			
		1977	1980	1983	1986	1977	1980	1983	1986	1977	1980	1983	1986	1977	1980	1983	1986
Pacific hake	S[1]	615	977	977	7,425	5,594	6,495	18,416	10,843	1,188	946	5,493	2,977	3,649	4,744	3,604	10,399
	D[2]	167	248	551	1,096	1,561	648	4,913	663	760	336	1,497	539	3,834	1,138	894	924
Sablefish	S	—	243	189	1,721	732	890	1,860	1,820	86	211	372	40	1,121	457	245	570
	D	—	—	360	155	852	414	1,649	694	12	—	855	—	580	—	303	—
Yellowtail rockfish	S	488	500	820	1,318	1,195	1,544	2,306	1,585	106	100	207	178	321	28	159	271
	D	—	—	—	—	178	68	83	42	—	—	—	—	—	—	—	—
Canary rockfish	S	—	348	1,007	1,676	186	819	1,644	1,344	813	130	63	25	83	—	407	67
	D	—	—	104	—	—	58	52	—	126	—	—	—	—	—	—	—
Bocaccio	S	—	—	141	66	34	63	29	4	—	26	12	42	575	345	19	149
	D	—	7	—	—	28	—	23	35	—	12	37	—	374	201	410	19
Chilipepper	S	—	—	—	—	—	—	—	—	24	67	20	—	2,543	581	894	1,720
	D	—	—	—	—	—	—	50	—	—	—	—	—	2,553	697	562	127
Pacific ocean perch	S	69	184	274	212	307	27	17	—	—	—	—	—	—	—	—	—
	D	1,765	1,566	1,286	732	3,728	1,609	1,365	257	213	41	187	37	—	—	—	—
Lingcod	S	—	—	—	35	—	—	70	186	—	—	—	—	33	—	—	—
	D	—	—	—	1	—	—	—	6	—	—	—	—	—	—	—	—
English sole	S	—	177	204	3,487	—	379	740	3,322	—	—	127	34	—	90	179	321
	D	—	—	—	—	—	—	—	38	—	—	—	—	—	—	—	—
Dover sole	S	—	63	48	1,927	—	743	1,452	2,962	—	—	379	250	—	81	—	1,038
	D	—	318	115	740	—	219	516	882	—	—	396	377	—	272	363	701
Rex sole	S	—	179	—	3,076	—	411	1,182	3,080	—	—	—	39	—	265	—	—
	D	—	97	—	564	—	13	182	346	—	—	105	—	—	—	72	275
Arrowtooth flounder	S	—	607	127	5,287	—	155	—	1,048	—	—	—	19	—	—	—	—
	D	—	61	36	739	—	106	—	125	—	—	—	—	—	—	—	—

[1] Shallow (91–183 m in 1977; 55–183 m in 1980–1986).

[2] Deep (184–366 m).

1983, the highest densities (>453 kg/km) of juveniles were found off the extreme northern portion of California and southern Oregon. In 1977, 1980, and 1986, the CPUE in the Monterey area was 74, 747, and 104%, respectively, of the CPUE in the Eureka area, whereas in 1983 it was only 40%. This northward displacement in 1983 may have been a response to unusually warm water in the central California region. Bottom temperatures in the Monterey area (lat. 36°30'–39°30'N) averaged about 1.5°C warmer in 1983 than the average combined temperatures from other survey years; temperatures similar to the mean from other survey years were not encountered until sampling proceeded north of about lat. 41°00'N. A large concentration of young Pacific hake was found in 1983 between lat. 40°00' and 42°30'N. This suggests that young fish departed from areas where they normally reside and migrated northward until they encountered more suitable cooler temperatures.

Estimated biomass was generally least in the U.S.-Vancouver area because of the small size of the area and the lower densities observed there (Fig. 4). Bio-

Table 3

Number of age samples taken from bottom trawl catches in 1977, 1980, 1983, and 1986 by species, depth zone and International North Pacific Fisheries Commission statistical area. See text for scientific names.

		U.S.-Vancouver				Columbia				Eureka				Monterey			
		1977	1980	1983	1986	1977	1980	1983	1986	1977	1980	1983	1986	1977	1980	1983	1986
Pacific hake	S[1]	263	348	377	73	1,216	1,784	1,306	669	503	289	477	252	684	1,101	689	359
	D[2]	75	120	208	120	648	314	773	169	—	102	587	173	228	490	103	260
Sablefish	S	—	—	75	—	—	—	459	68	—	—	85	—	—	—	94	—
	D	—	—	126	—	—	—	520	—	—	—	351	—	—	—	78	—
Yellowtail rockfish	S	437	305	465	135	722	872	1,154	197	65	87	141	—	—	—	87	—
	D	—	—	—	—	96	—	—	—	—	—	—	—	—	—	—	—
Canary rockfish	S	177	301	281	234	509	647	1,070	365	—	90	—	—	78	—	296	—
	D	—	—	104	—	34	20	—	—	126	—	—	—	—	—	—	—
Bocaccio	S	—	—	126	66	—	14	—	4	—	—	—	—	132	116	—	—
	D	—	—	—	—	—	—	25	—	—	—	—	—	136	66	326	—
Chilipepper	S	—	—	—	—	—	—	—	—	—	67	—	—	1,147	196	386	—
	D	—	—	—	—	—	—	50	—	—	—	—	—	775	324	317	—
Pacific ocean perch	S	294	88	161	—	591	—	—	—	—	—	—	—	—	—	—	—
	D	149	214	429	—	92	283	500	—	—	—	—	—	—	—	—	—

[1] Shallow (91–183 m in 1977; 55–183 m in 1980–1986).

[2] Deep (184–366 m).

mass estimates were generally larger in the Columbia area, usually because of the greater habitat area there. The greatest biomass was often found in the Monterey area where estimates were also most variable. For instance, in 1980, 77% of the biomass was found in the Monterey area, but in 1977, only 27% was found there. These latitudinal shifts in distribution were probably related to oceanographic changes, food availability, and population age composition. Pacific hake populations are stratified latitudinally by age and size; the youngest, smallest fish inhabit the southern portion of the species range (Nelson and Larkins, 1970; Dark, 1975). In years when strong year classes are recruited, the distribution usually shifts southward, as in 1980 and 1986. As expected, 90% confidence intervals (Table 6, Fig. 4) were relatively narrow but increased as estimated biomass increased. Standard normal variates (*Z*-statistics) were calculated to compare INPFC area and total survey area biomass estimates for all possible pairs of years. These were tested for significance at the 98% level. (A Bonferroni inequality (Miller, 1981) must be assumed due to the multiple nature of the tests; therefore, the actual probability is equal to $(n \times p) = 6 \times 0.02 = 0.12$. Thus the tests used will be conservative in the rejection of the null hypotheses.) Significant differences in total biomass estimates were found between 1977 and all other years and between 1983 and 1986 (Table 7).

Major changes in Pacific hake abundance occur because of wide variations in year-class strength (Stauffer, 1985). Such fluctuations were observed during the period of the four surveys. Biomass estimates based on bottom trawl catches (a small portion of the total biomass estimate) ranged from 65,983 t in 1977 to 239,153 t in 1986, almost a fourfold increase (Table 6). This resource is commonly dominated by only a few year classes (Bailey and Francis, 1985). The variability of recruitment to the stock, therefore, has a large impact on overall biomass estimates. Sampling variability can also be a significant source of variation in abundance estimation. Pacific hake are more uniformly distributed than many other species so variances of biomass estimates tend to be smaller. Coefficients of variation (CV) for biomass estimates in the entire survey area ranged from about 12 to 22% over the four surveys (Table 6), which represents some of the smallest values observed among the species considered in this study.

Table 4

Mean catch per unit of effort of all groundfish species combined (kg/km trawled) by year, International North Pacific Fisheries Commission (INPFC) statistical area, and depth stratum.

INPFC area	Depth (m)	1977[1]	1980	1983	1986
U.S.-Vancouver	55–183	429	230	182	165
	184–366	181	150	191	122
	55–366	305	190	187	144
Columbia	55–183	137	64	104	138
	184–366	128	74	134	99
	55–366	133	69	122	118
Eureka	55–183	77	91	192	372
	184–366	42	66	105	207
	55–366	59	76	142	289
Monterey	55–183	175	314	108	204
	184–366	188	116	258	121
	55–366	181	215	183	163
Mean of all areas	55–183	200	115	143	176
	184–366	166	82	146	144
	55–366	183	97	145	161

[1] The shallow stratum in 1977 was 91–193 m.

Larger Pacific hake tend to be found over the continental shelf in waters less than 184 m deep. However, the size to depth relationship is not strong and considerable variability exists. Interannual variability is the most notable feature of the length data. The length composition in 1977 was generally unimodal and characteristic of a mature population, with little evidence of abundant, newly recruited hake (Fig. 5). Length distributions in subsequent years were dominated by large numbers of fish between 32 and 43 cm, representing strong year classes just recruiting to the fishable population. In 1983, this mode of small hake predominated in the Columbia area, and small fish were even found in the Vancouver area. This unusual presence of small hake in the northern part of the survey area may have been due to a broader distribution typical of extraordinarily large year classes or may have been related to major oceanographic changes resulting from the 1982–83 El Niño.

The population age compositions (Fig. 6) have the following characteristics suggested by the length data. Females generally reach older ages and the interannual variability of the age composition can be dramatic. The 1977 age composition consisted of individuals ranging from 1 to 15 years old; 4- and 7-year-old fish of the 1973 and 1970 year classes, respectively, prevailed (Fig. 6). The 1977 year class emerged prominently in 1980 when large numbers of age-3 fish in the Monterey and Eureka areas accounted for about 67% of the estimated population that year (Nelson and Dark, 1985) (i.e. their latitudinal distribution may overlap the southern portion of the survey area to a different extent in different years). The age composition in 1983 was also characterized by a large age-3 component (1980 year class) that overwhelmed all other age groups. While the 1977 and 1980 year classes appear to be of similar magnitude based on bottom trawl data, the 1980 and 1983 hydroacoustic surveys indicated that the 1980 year class at age 3 was about 1.9 times larger than the 1977 year class at the same age.[4] This may partly account for its presence in northern areas in 1983 where the 1977 year class did not occur. The 1986 age composition shows the 1984 year class, though large, to be smaller than either the 1977 or 1980 year classes. However, the availability of 2- and 3-year-olds may differ enough due to incomplete recruitment to preclude a meaningful comparison. Assessment of survey and fishery data confirms the high abundance of both the 1984 and 1980 year classes (Hollowed et al., 1988).

Changes in the age composition of the population introduced major changes in the distribution of the resource. Much of this variation can be explained by the recruitment of a succession of weak or average year classes punctuated occasionally by strong year classes,

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[4] Williamson, N., Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115. Personal commun., April 1984.

Table 5

Dominant groundfish species composing approximately 80% of the total catch per unit of effort (CPUE) in each International North Pacific Fisheries Commission statistical area by year.

		U.S.-Vancouver			Columbia			Eureka	
Year	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
1977	Spiny dogfish	59.2	19.4	Pacific hake	22.4	16.8	Pacific hake	30.6	51.6
	Canary rockfish	31.2	29.6	Lingcod	17.0	29.6	Dover sole	6.4	62.4
	Pacific hake	25.7	38.0	Pacific ocean perch	14.2	40.4	Splitnose rockfish	3.3	68.0
	Pacific ocean perch	25.3	46.3	Yellowtail rockfish	12.1	49.5	Darkblotched rockfish[1]	2.9	73.0
	Pacific herring[1]	24.9	54.5	Sablefish	10.5	57.4	Sablefish	2.3	76.8
	Arrowtooth flounder	24.4	62.5	Arrowtooth flounder	10.2	65.1	Spiny dogfish	2.0	80.2
	Silvergray rockfish[1]	22.4	69.8	Dover sole	10.0	72.6			
	Yellowtail rockfish	20.8	76.7	Canary rockfish	5.3	76.6			
	Lingcod	9.8	79.9	Sharpchin rockfish[1]	3.7	79.4			

	Monterey			Total survey area	
Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
Shortbelly rockfish	38.8	21.3	Pacific hake	25.5	13.9
Splitnose rockfish	23.5	34.3	Shortbelly rockfish	22.6	26.2
Pacific hake	22.8	46.9	Spiny dogfish	17.1	35.5
Chilipepper	17.1	56.4	Splitnose rockfish	14.8	43.6
Dover sole	12.9	63.5	Chilipepper	10.0	49.0
Spiny dogfish	12.5	70.3	Dover sole	9.7	54.3
Bocaccio	10.1	75.9	Pacific ocean perch	7.9	58.6
Stripetail rockfish	9.3	81.0	Yellowtail rockfish	7.4	62.6
			Lingcod	7.1	66.5
			Canary rockfish	6.9	70.2
			Arrowtooth flounder	6.8	73.9
			Bocaccio	6.6	77.5
			Sablefish	5.8	80.7

		U.S.-Vancouver			Columbia			Eureka	
Year	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
1980	Spiny dogfish	61.8	32.6	Sablefish	10.6	15.3	Splitnose rockfish	22.0	29.0
	Pacific hake	24.1	45.3	Pacific ocean perch	8.8	27.9	Pacific hake	15.9	49.9
	Pacific ocean perch	15.6	53.5	Pacific hake	8.6	40.4	Sablefish	10.2	63.4
	Arrowtooth flounder	10.8	59.2	Splitnose rockfish	4.6	47.0	Dover sole	5.2	70.3
	Dover sole	9.9	64.4	Dover sole	4.4	53.3	Darkblotched rockfish[1]	4.5	76.3
	Yellowtail rockfish	9.5	69.4	Arrowtooth flounder	4.4	59.6	Stripetail rockfish	4.1	81.8
	Sablefish	7.3	73.3	Lingcod	4.4	65.9			
	Splitnose rockfish	7.1	77.0	Sharpchin rockfish[1]	3.5	70.9			
	Redstripe rockfish[1]	7.1	80.8	Yellowtail rockfish	2.6	74.7			
				Darkblotched rockfish[1]	2.1	77.7			
				Yellowmouth rockfish[1]	1.8	80.2			

	Monterey			Total survey area	
Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
Pacific hake	118.8	55.3	Pacific hake	21.1	18.6
Sablefish	14.0	61.8	Sablefish	11.0	28.4
Stripetail rockfish	13.9	68.3	Splitnose rockfish	9.8	44.5
Chilipepper	12.6	74.1	Spiny dogfish	6.7	51.5
Bank rockfish[1]	11.0	79.2	Pacific ocean perch	6.5	58.2
			Dover sole	5.3	63.7
			Arrowtooth flounder	3.4	67.2
			Lingcod	3.0	70.3
			Stripetail rockfish	2.7	73.2
			Darkblotched rockfish[1]	2.7	75.9
			Yellowtail rockfish	2.6	78.6
			Sharpchin rockfish[1]	2.0	80.1

Table 5 (Continued)

	U.S.-Vancouver			Columbia			Eureka		
Year	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
1983	Spiny dogfish	33.5	17.9	Pacific hake	23.1	19.0	Pacific hake	52.1	36.6
	Pacific ocean perch	17.4	27.1	Dover sole	16.1	32.2	Spiny dogfish	29.8	57.5
	Redstripe rockfish[1]	16.5	35.9	Sablefish	15.4	44.9	Dover sole	18.2	70.3
	Pacific hake	16.3	44.6	Darkblotched rockfish[1]	9.3	52.5	Sablefish	10.1	77.4
	Silvergray rockfish[1]	15.5	52.9	Sharpchin rockfish[1]	6.3	57.7	Rex sole	4.2	80.3
	Canary rockfish	14.8	60.8	Arrowtooth flounder	6.2	62.8			
	Arrowtooth flounder	10.7	66.5	Pacific ocean perch	5.9	67.7			
	Sharpchin rockfish[1]	9.8	71.7	Rex sole	5.8	72.4			
	Sablefish	7.9	76.0	Splitnose rockfish	2.8	74.8			
	Dover sole	7.5	80.0	Lingcod	2.6	76.9			
				Yellowtail rockfish	2.5	79.0			

Monterey			Total survey area		
Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
Stripetail rockfish	30.5	16.6	Pacific hake	29.4	20.4
Bocaccio	23.7	29.6	Spiny dogfish	16.0	31.4
Pacific hake	20.9	41.0	Dover sole	14.9	41.7
Chilipepper	15.9	49.6	Sablefish	12.1	50.1
Dover sole	15.0	57.8	Pacific ocean perch	6.5	54.5
Spiny dogfish	13.4	65.1	Darkblotched rockfish[1]	5.8	58.6
Splitnose rockfish	10.8	71.0	Sharpchin rockfish[1]	5.3	62.2
Sablefish	9.3	76.1	Arrowtooth flounder	5.1	65.8
Shortbelly rockfish	8.6	80.8	Canary rockfish	4.6	69.0
			Rex sole	4.4	72.0
			Yellowtail rockfish	4.1	74.9
			Redstripe rockfish[1]	3.8	77.6
			Silvergray rockfish[1]	3.3	79.9

	U.S.-Vancouver			Columbia			Eureka		
Year	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
1986	Pacific hake	39.7	27.6	Pacific hake	44.4	37.6	Pacific hake	140.0	48.4
	Spiny dogfish	19.7	41.4	Sablefish	9.4	45.6	Dover sole	19.6	55.2
	Arrowtooth flounder	13.4	50.7	Dover sole	7.5	51.9	Darkblotched rockfish[1]	17.3	61.1
	Darkblotched rockfish[1]	8.8	56.8	Splitnose rockfish	6.8	57.7	Shortbelly rockfish	16.0	66.6
	Pacific ocean perch	7.5	62.1	Darkblotched rockfish[1]	5.3	62.2	Sablefish	12.9	71.1
	Sablefish	7.0	67.0	Pacific ocean perch	4.9	66.3	Bank rockfish[1]	10.7	74.8
	Walleye pollock[1]	6.3	71.3	Rex sole	4.3	69.9	Bocaccio	9.3	78.0
	Dover sole	6.3	75.7	Pacific sanddab[1]	4.0	73.3	Splitnose rockfish	7.5	80.6
	Canary rockfish	5.1	79.2	Arrowtooth flounder	3.5	76.3			
				Sharpchin rockfish[1]	3.5	79.2			

Monterey			Total survey area		
Species	CPUE (kg/km)	Cumulative percentage	Species	CPUE (kg/km)	Cumulative percentage
Pacific hake	71.1	43.6	Pacific hake	73.8	41.3
Dover sole	15.5	53.1	Dover sole	12.2	48.2
Sablefish	10.2	59.4	Sablefish	9.9	53.7
Chilipepper	9.1	65.0	Darkblotched rockfish[1]	8.7	58.6
Stripetail rockfish	7.8	70.0	Spiny dogfish	7.3	62.7
Spiny dogfish	7.3	74.2	Rex sole	4.6	65.2
Rex sole	5.4	77.5	Splitnose rockfish	4.5	67.7
Bank rockfish[1]	4.4	80.2	Arrowtooth flounder	4.3	70.1
			Pacific ocean perch	4.3	72.5
			Shortbelly rockfish	4.2	74.9
			Bank rockfish[1]	3.8	77.0
			Bocaccio	3.3	78.8
			Stripetail rockfish	3.1	80.6

[1] Scientific names not mentioned in text: Pacific herring, *Clupea pallasi;* silvergray rockfish, *Sebastes brevispinis;* sharpchin rockfish, *S. zacentrus;* darkblotched rockfish, *S. crameri;* redstripe rockfish, *S. proriger;* yellowmouth rockfish, *S. reedi;* bank rockfish, *S. rufus;* walleye pollock, *Theragra chalcogramma;* Pacific sanddab, *Citharichthys sordidus.*

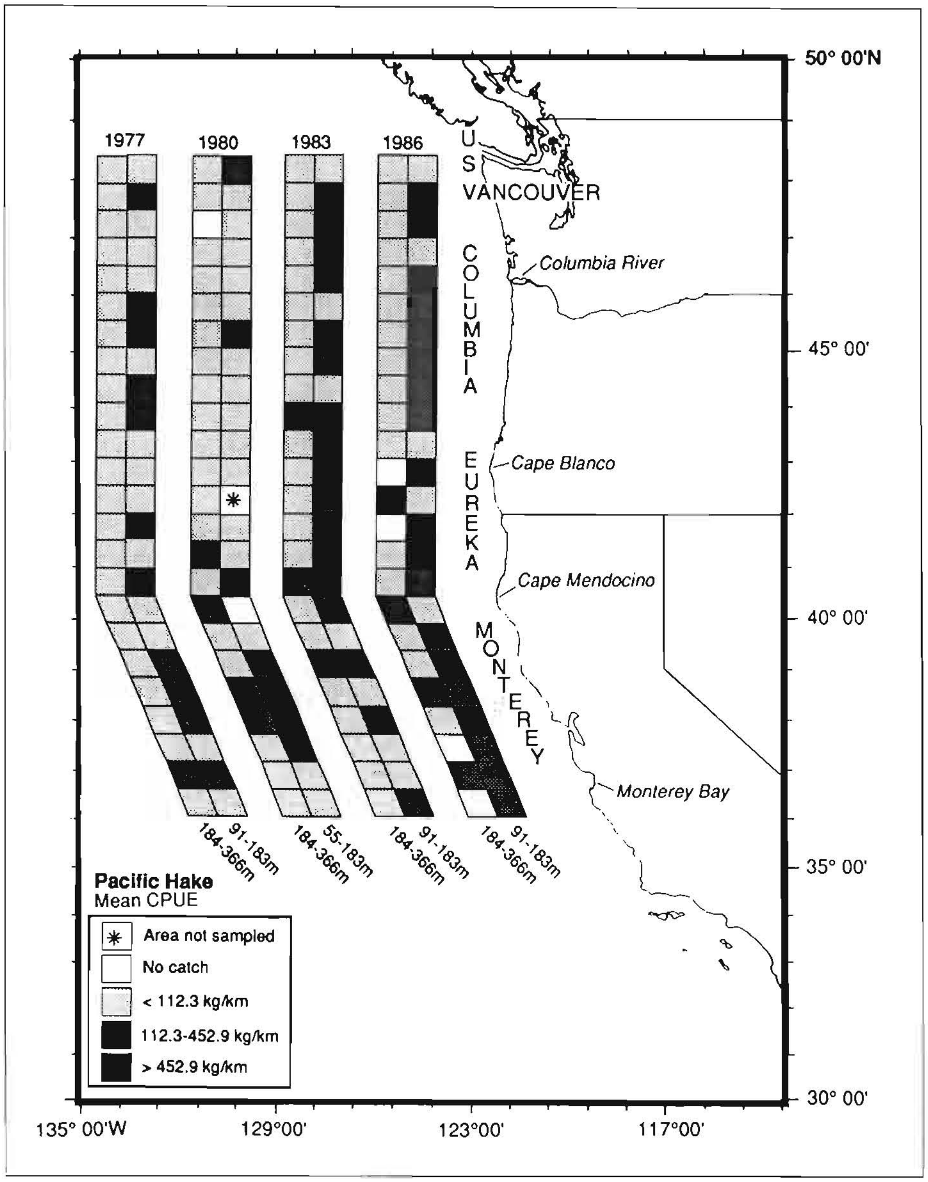

Figure 3
Distribution of Pacific hake, *Merluccius productus,* during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

such as those appearing in 1977, 1980, and 1984. The 1980 year class at age 3, for example, was estimated to be more than 15 times as large as the 1983 year class at age 3. The recruitment of the very large 1980 and 1984 year classes resulted in high catch rates over larger regions in 1983 and 1986 than in years without strong recruiting year classes. Young Pacific hake are usually most concentrated off northern California, but this pattern changed in 1983 when the population normally found off California was found farther to the north in the vicinity of the Oregon-California border. More typical distributions associated with populations having strong recruiting year classes were seen in 1980 and 1986 when large numbers of juvenile Pacific hake of the 1977 and 1984 year classes, respectively, occupied the Monterey, Eureka, and southern Columbia areas (Coleman, 1986 and 1988).

Survey results support historical data that indicate strong year classes tend to occur in a 3–4 year cycle. Francis[5] applied a variety of indices to chart the relative abundance of the 1960–84 year classes. The 1970, 1973,

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[5] Francis, R. C. 1985. Status of the Pacific hake resource and recommendations for management in 1986. *In* Pacific Fisheries Management Council, Status of the Pacific coast groundfish fishery through 1985 and recommended acceptable biological catches for 1986, 22 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

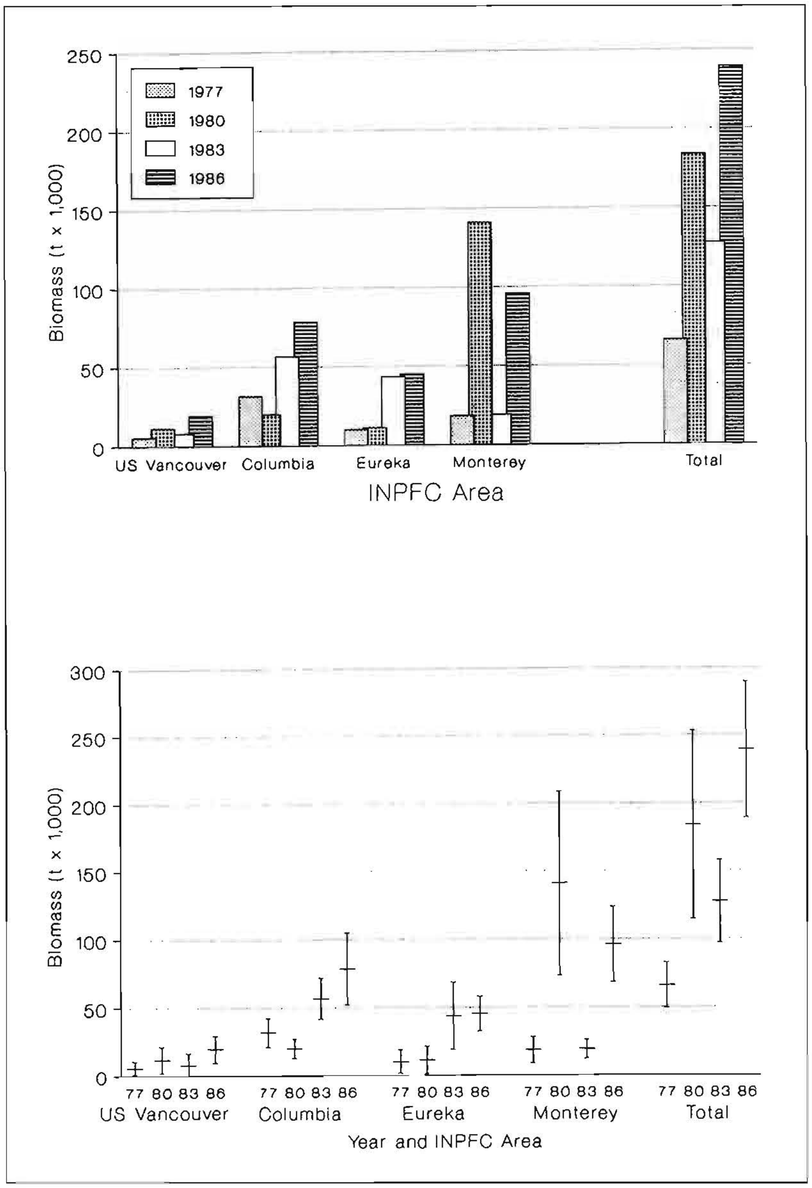

Figure 4
Estimates of Pacific hake, *Merluccius productus,* biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission area and year.

1977, and 1980 year classes were identified as strong by all indices. Survey results are consistent with these observations (Fig. 6). Bailey and Francis (1985) related year-class strength to oceanographic features present subsequent to spawning and postulated that warm water years associated with relatively weak upwelling are important to the production of large year classes.

Mean lengths at age tend to decrease over time (Fig. 7). The cause of this trend is uncertain, but two circumstances may have affected growth. Estimated total biomass (including estimates from hydroacoustic surveys) in 1980, 1983, and 1986 were 1.28, 1.11, and 1.78 times larger, respectively, than in 1977. These population increases may have increased competition for food, which resulted in a decreased growth rate for all age groups. Another factor is the 1982–83 El Niño, which possibly created an adverse environment for good growth. Francis[5] observed smaller mean weight at age in 1983 and 1984 in an analysis based on fishery samples and suggested that the El Niño played an important role in retarding growth. More recently, Canadian and U.S. scientists have observed continuing reductions in mean length at age throughout the commercial range of Pacific hake; these reductions cannot be readily explained by intensive exploitation or the factors cited above (Hollowed et al., 1988).

Table 6

Pacific hake, *Merluccius productus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91-183	23.4	4,949	21-9,877		37.2	29,130	18,623-39,637	
	184-366	9.5	841	512-1,171		8.1	2,418	717-4,120	
	91-366	19.3	5,791	848-10,734	42.4	29.2	31,549	20,998-42,099	20.0
1980	55-183	42.9	11,293	1,687-20,899		16.3	18,999	11,908-26,091	
	184-366	5.3	477	190-765		2.9	859	438-1,280	
	55-366	33.4	11,770	2,160-21,380	46.8	13.6	19,858	12,756-26,961	21.4
1983	55-183	28.0	7,381	0-15,647		44.7	52,042	36,920-67,165	
	184-366	7.7	687	213-1,162		15.3	4,623	3,104-6,141	
	55-366	22.9	8,068	0-16,347	57.9	38.7	56,665	41,474-71,856	16.0
1986	55-183	65.1	18,068	8,155-27,982		62.9	77,147	50,585-103,710	
	184-366	15.1	1,335	750-1,919		5.1	1,421	957-1,885	
	55-366	53.1	19,403	9,559-29,247	28.2	52.3	78,568	52,002-105,134	19.9

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91-183	53.1	9,508	978-18,038		43.6	15,875	6,855-24,895		38.6	59,463	43,062-75,864	
	184-366	8.0	645	370-921		25.1	2,616	0-7,250		11.4	6,520	1,530-11,510	
	91-366	39.1	10,153	1,619-18,688	48.5	39.4	18,491	9,105-27,877	29.6	31.2	65,983	49,344-82,622	15.2
1980	55-183	52.2	10,536	694-20,379		218.0	138,575	70,787-206,363		79.2	179,403	110,139-248,667	
	184-366	10.0	802	0-1,827		19.6	2,373	1,112-3,634		7.6	4,511	2,893-6,129	
	55-366	40.2	11,338	1,451-21,226	49.9	186.3	140,948	73,176-208,720	28.7	64.4	183,915	114,634-253,196	22.5
1983	55-183	138.0	41,998	17,247-66,748		27.4	17,438	10,567-24,310		50.2	118,859	88,628-149,090	
	184-366	19.5	1,561	933-2,189		14.3	1,727	844-2,609		14.5	8,598	6,723-10,472	
	55-366	113.3	43,559	18,800-68,317	32.7	25.3	19,165	12,243-26,087	21.6	43.1	127,457	97,167-157,747	14.1
1986	55-183	132.2	42,321	29,682-54,959		138.0	91,128	63,619-118,637		92.1	228,666	179,217-278,115	
	184-366	34.5	2,903	550-5,256		38.2	4,829	828-8,830		18.1	10,487	4,140-16,834	
	55-366	111.9	45,224	32,416-58,032	16.8	122.0	95,957	68,218-123,696	17.1	78.2	239,153	189,367-288,940	12.5

Yellowtail rockfish — Yellowtail rockfish is among the most important rockfish species off the west coast, and in recent years landings have been second only to widow rockfish, *S. entomelas*. Landings from 1980 to 1987 ranged from 3,214 to 8,718 t and averaged about 13% of the total rockfish landings (PacFIN[3]). Because of the species' historical commercial importance and concern about the status of the resource, it was designated as a target species for the triennial assessment surveys.

Many rockfishes display a strong tendency to school, which results in contagious or "clumped" distributions. This seriously degrades the precision of area-swept abundance estimates and places high demands on the sampling design. In spite of intensive sampling in important rockfish areas, abundance estimates are often accompanied by relatively large variances. Also, biases associated with trawl sampling of rockfish probably result in conservative estimates of abundance. The precision and accuracy of rockfish abundance estimates will be more fully discussed later in this paper.

In all survey years yellowtail rockfish densities were greatest off Washington and central Oregon (Table 8, Fig. 8). Density tended to decrease from north to south. Mean CPUE over all the surveys was 32.2 kg/km in the U.S.-Vancouver area, 5.7 kg/km in the Columbia area,

Table 7

Values used to test the significance of observed differences between pairs of biomass estimates for 1977, 1980, 1983, and 1986. Asterisks denote significance at P = 0.02[1]. See text for scientific names.

		Pacific hake			Canary rockfish			Yellowtail rockfish			Bocaccio			Chilipepper			Pacific ocean perch		
		1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986
U.S.-Vancouver	1977	0.992	0.431	2.267	0.880	0.778	0.845	0.870	0.866	1.037	1.011	0.891	1.036	—	—	—	0.859	0.743	1.291
	1980		0.513	0.983		0.684	0.293		0.058	0.643		0.933	0.314		—	—		0.299	1.099
	1983			1.573			0.556			0.457			1.276			—			1.716
Columbia	1977	1.534	2.268	2.785*	1.517	0.050	0.211	1.130	0.959	1.208	0.994	0.861	0.646	1.537	1.251	0.986	1.738	1.883	2.726
	1980		3.667*	3.619*		1.364	0.906		0.412	0.063		0.176	0.168		1.011	0.800		0.226	1.086
	1983			1.210			0.239			0.491			0.050			0.199			0.807
Eureka	1977	0.158	2.219	3.878*	1.054	3.262*	2.140	0.263	0.021	0.657	2.593*	2.027	1.315	0.800	0.846	3.163*	0.701	0.736	0.698
	1980		2.104	3.579*		0.765	0.379		0.320	0.951		1.318	0.869		0.967	2.355		0.246	1.334
	1983			0.103			1.165			0.679			1.127			3.269*			1.116
Monterey	1977	2.998*	0.098	4.472*	0.983	1.392	0.855	1.156	0.567	1.077	0.602	0.299	0.012	0.132	0.068	0.455	1.272	0.822	1.522
	1980		2.993*	1.030		1.476	1.463		1.087	1.610		0.627	0.336		0.059	0.394		0.000	1.488
	1983			4.532*			1.234			0.408			0.227			0.364			1.487
Total	1977	2.765*	2.985*	5.503*	0.998	0.387	0.791	1.454	1.158	1.490	0.892	0.019	0.087	0.231	0.055	0.444	1.386	1.340	2.136
	1980		1.249	1.081		1.856	0.937		0.406	0.126		0.574	0.502		0.152	0.081		0.114	1.505
	1983			3.206*			1.185			0.459			0.063			0.275			1.717

		Sablefish			Lingcod			English sole			Dover sole			Rex sole			Arrowtooth flounder		
		1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986	1980	1983	1986
U.S.-Vancouver	1977	0.052	0.985	0.075	0.572	0.304	0.840	1.494	3.209*	7.772*	0.454	0.498	1.146	0.762	0.052	0.794	0.911	1.393	0.822
	1980		1.230	0.165		0.635	0.528		0.248	1.290		0.801	1.272		0.802	0.490		0.696	0.375
	1983			1.760			1.990			1.650			0.566			1.030			3.185*
Columbia	1977	1.803	1.761	1.416	0.299	0.751	0.942	1.392	4.951*	5.484*	3.651*	0.662	1.530	0.144	6.549*	9.053*	2.768*	3.185*	1.703
	1980		0.893	1.050		0.726	1.069		3.116*	3.862*		3.919*	4.846*		6.438*	8.799*		0.607	2.527
	1983			1.439			2.507*			1.123			0.795			0.917			4.579*
Eureka	1977	0.996	2.324	1.883	0.583	1.033	0.413	2.582	4.698*	8.796*	0.344	2.783*	4.986*	0.134	4.150*	7.007*	1.330	0.707	1.096
	1980		0.778	0.452		0.252	0.362		3.965*	7.647*		3.597*	5.897*		4.187*	7.084*		1.151	0.594
	1983			1.072			0.786			1.702			2.388*			2.500*			0.722
Monterey	1977	1.210	1.501	1.828	1.440	0.056	1.611	1.010	4.035*	4.151*	1.408	2.309	4.530*	0.153	3.406*	5.572*	2.430*	1.776	0.000
	1980		1.008	0.422		1.137	0.244		4.612*	5.472*		3.075*	5.040*		3.388*	5.538*		0.868	2.009
	1983			1.298			1.269			1.599			2.487*			2.456*			1.490
Total	1977	1.964	2.031	2.134	0.416	0.767	1.112	1.498	7.376*	9.128*	3.141*	2.539*	4.588*	0.370	8.113*	10.182*	1.905	2.541*	1.442
	1980		0.621	0.804		0.520	1.139		5.672*	6.776*		5.145*	6.458*		7.217*	9.372*		0.818	1.258
	1983			0.218			3.320*			0.156			2.474*			2.727*			4.950*

[1] In fact P < 0.12 due to multiple testing of pairs (Bonferroni's inequality).

2.3 kg/km in the Eureka area, and 1.5 kg/km in the Monterey area. Density in the waters off Washington was relatively higher and more uniform in 1977 than in later years. In that year and area, yellowtail rockfish densities were also higher on the upper continental slope between 184 and 366 m (Table 8). Conversely, in 1986 the species was almost completely confined to the continental shelf (depths <184 m), which is more characteristic of its typical distribution.

Biomass estimates for the entire area ranged from 10,978 t in 1980 to 24,725 t in 1977 (Table 8). Almost all of the estimated biomass occurred on the continental shelf in waters less than 183 m. Only 1–5% of the total biomass occurred in deeper waters. Biomass consistently decreased in the U.S.-Vancouver area between 1977 and 1986 (Fig. 9); the 1986 biomass estimate was only about 24% of the 1977 estimate. Biomass estimates in the Columbia area decreased by 55% (from 11,801

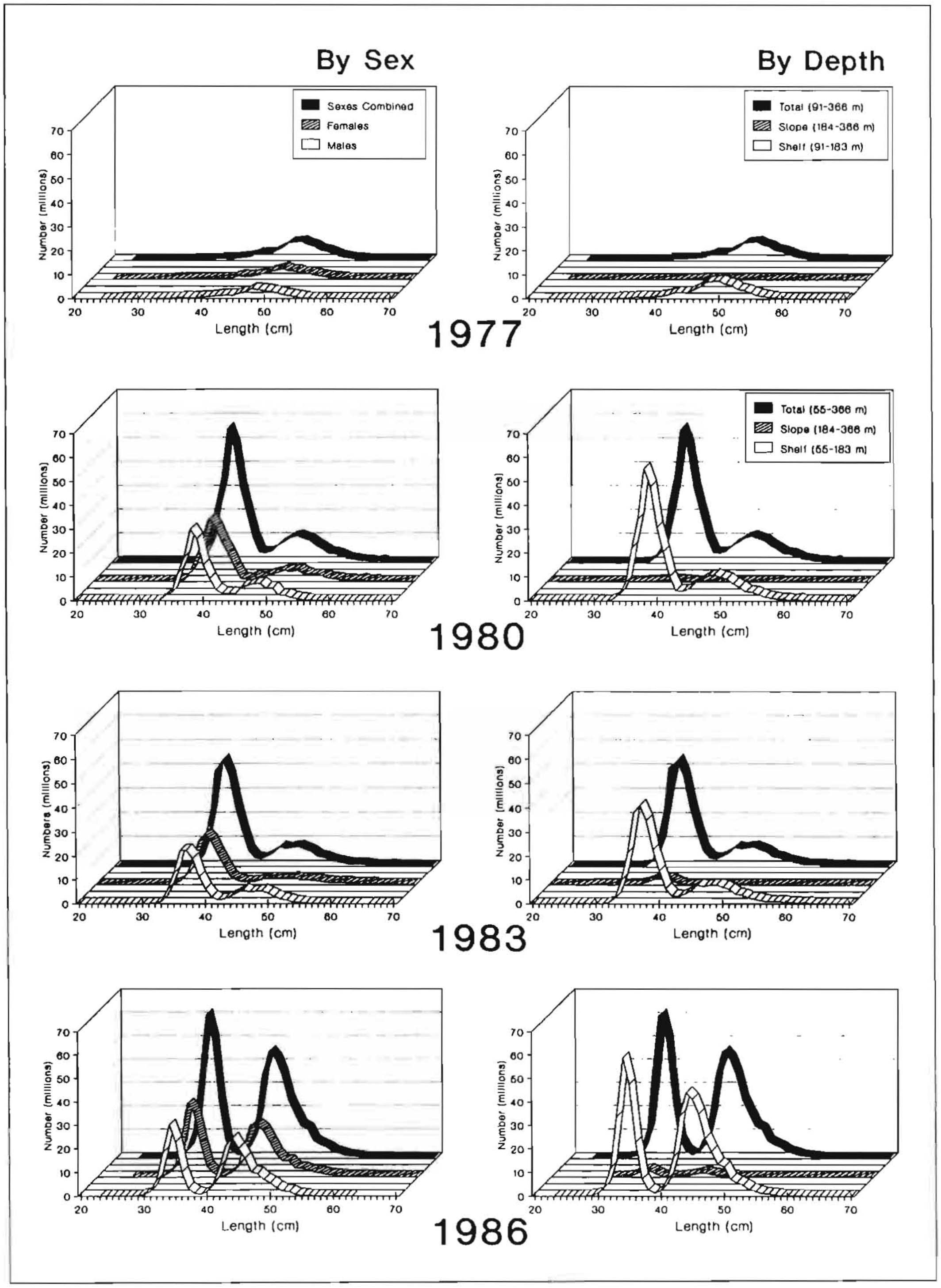

Figure 5
Pacific hake, *Merluccius productus*, length compositions by year, depth, and sex.

to 5,276 t) between 1977 and 1980 but have remained rather constant since. The estimated biomass in the Eureka and Monterey areas was very low, but there is an indication of recent increases in both areas. As typical for most rockfishes, sampling variability was large. Coefficients of variation for total biomass estimates ranged from about 24 to 48%, but were as high as 90% in some INPFC areas (Table 8). Confidence intervals for total biomass estimates are relatively large and overlap in all years even though estimates often differed by more than a factor of two (Fig. 9). Biomass estimates did not differ significantly among years (Table 7).

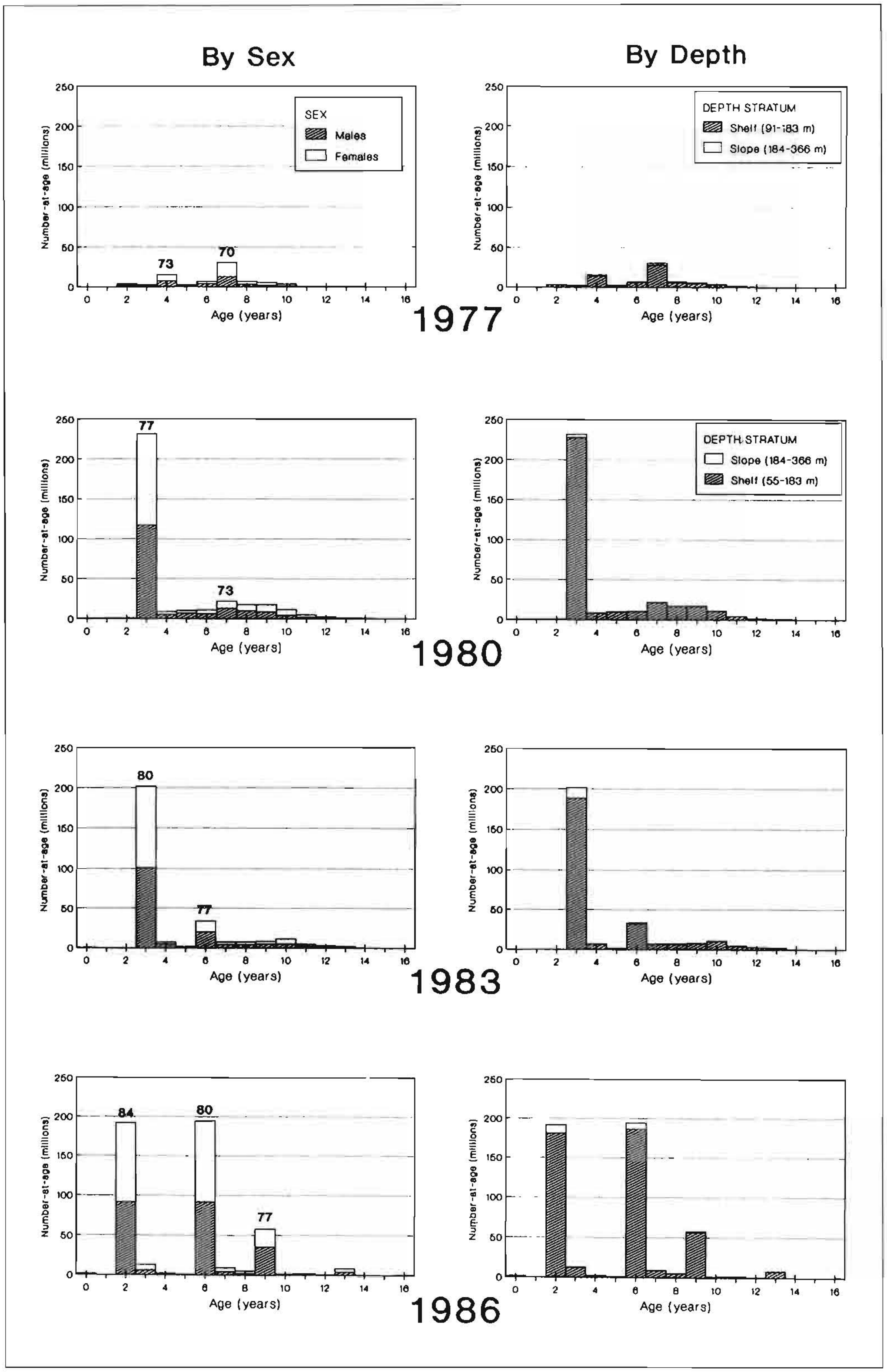

Figure 6

Pacific hake, *Merluccius productus*, age compositions by year, depth, and sex. Numerals at top of bars identify prominent year classes.

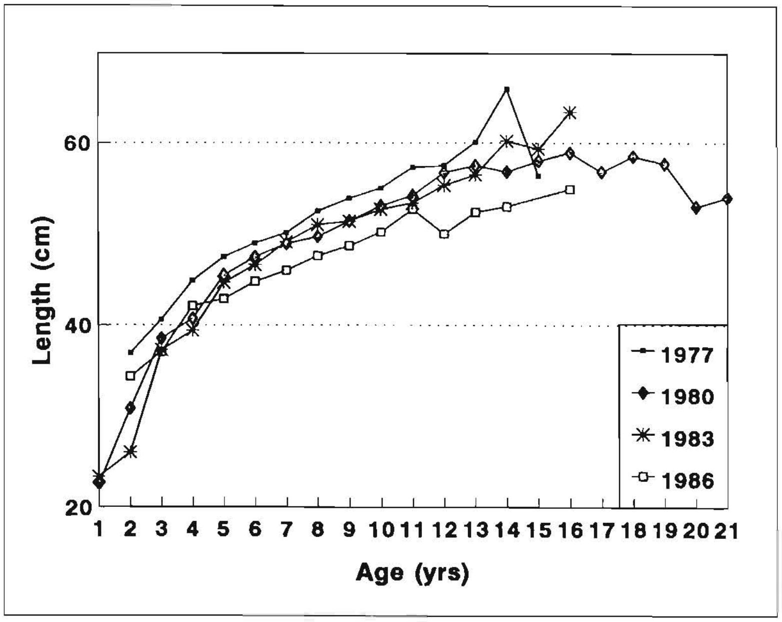

Figure 7
Pacific hake, *Merluccius productus*, mean length-at-age by year.

Length compositions for 1977 and 1980 were similarly unimodal; most lengths ranged between 40 and 54 cm (Fig. 10). The 1983 distribution was also unimodal but the numbers of fish smaller than 40 cm increased, suggesting improved recruitment. The length distribution in 1986 was clearly bimodal with modes at about 33 and 43 cm. This provides further evidence of good recruitment in recent years. Few fish less than about 40 cm were found to inhabit the deep zone.

Yellowtail rockfish ages were available only for 1977 and 1980 (Fig. 11). Ages were determined from reading otolith surfaces in both years, but evidence that sectioned otoliths yield older ages may have influenced readers to assign older ages to some 1980 samples.[6] This may explain why there appeared to be relatively more fish older than about age 17 in 1980. The variability in year-class strength in 1977 was not so extreme in 1980, when only ages 4–15 are compared. The proportion of females aged 10 or older decreased steadily, with very few remaining in the population by age 15; this is contrary to the usual situation where females dominate the older age groups because of their greater longevity. In all years males predominated in catches by as much as 6:1, especially in the northern part of the survey area (i.e. Columbia and Vancouver areas). A similar disproportionate abundance of males has been observed in commercial landings in Washington (Tagart[7]). As yet there is no sound explanation for this, but it could be a matter of differential availability to trawls or a higher rate of natural mortality for females.

Canary rockfish — Canary rockfish is also one of the more commercially important rockfish species in the survey area. Between 1980 and 1987, landings varied from 1,819 to 4,297 t. In 1987 total landings of 2,493 t ranked the species third among rockfish, behind widow and yellowtail rockfish. Most of the catch was made in the U.S.-Vancouver and Columbia areas. In 1987 the two areas accounted for 89% of the total landings (PacFIN, 1988[3]).

Canary rockfish densities showed a latitudinal cline similar to that of yellowtail rockfish (Fig. 12, Table 9). The mean CPUE of canary rockfish was usually greatest in the U.S.-Vancouver area (7.3–66.0 kg/km) and decreased southward to the Monterey area (0.3–9.9 kg/km). However, there was some interannual variability in canary rockfish distribution. In 1977 densities were higher (>50 kg/km) in the northern Columbia area in both the 91–183 m and 184–366 m depth zones than throughout the remainder of the survey area (mostly <12 kg/km; Table 9). In 1980 canary rockfish were concentrated more in the southern Columbia area. An exception to the usual pattern of distribution occurred in 1983 when high densities were found between Point Arena and Cape Mendocino, California, as well as the

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[6] Tagart, J. V., Washington Department of Fisheries, Natural Resources Building, Olympia, WA 98504. Personal commun., June 1988.

[7] Tagart, J. V. 1988. Status of the yellowtail rockfish stocks in the International North Pacific Fishery Commission Vancouver and Columbia areas. *In* Pacific Fisheries Management Council, Status of the Pacific coast groundfish fishery through 1988 and recommended acceptable biological catches for 1989, 112 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

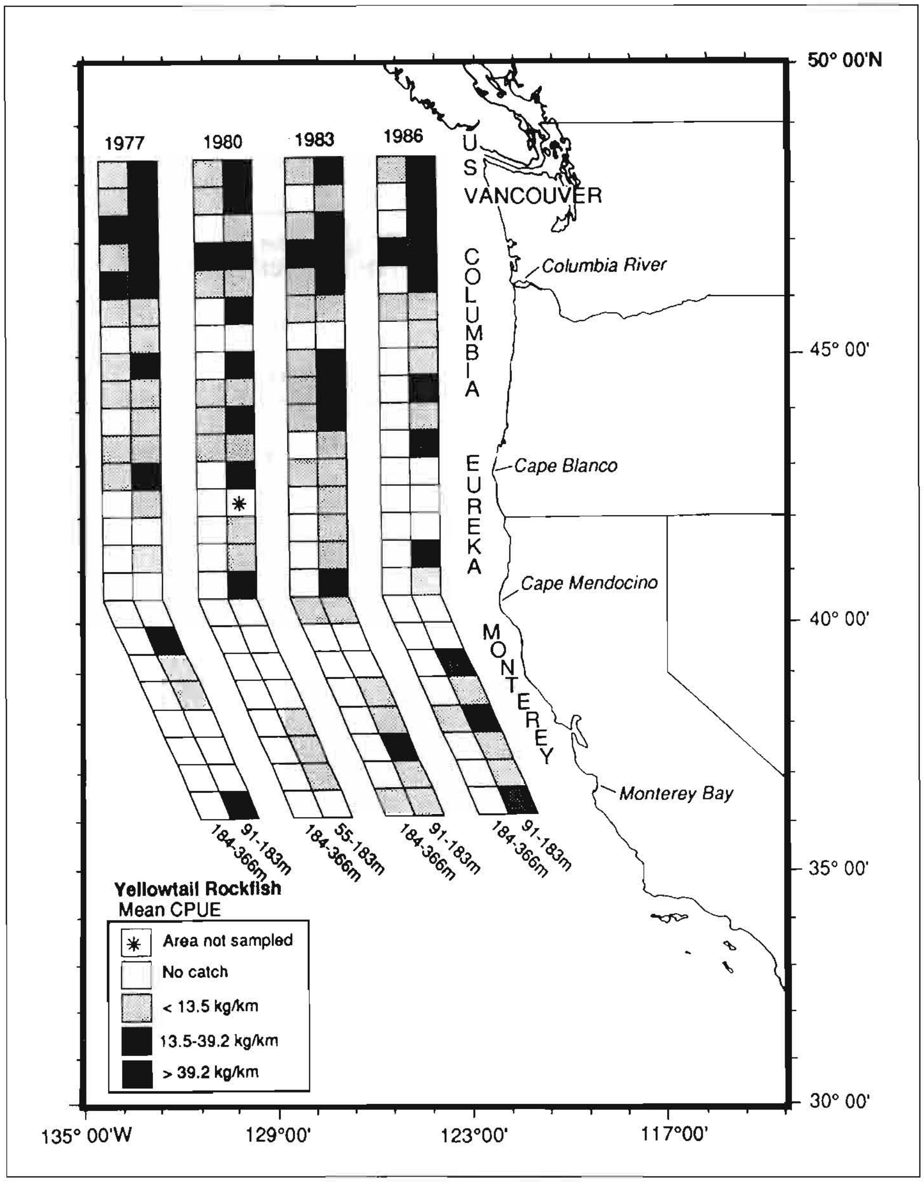

Figure 8
Distribution of yellowtail rockfish, *Sebastes flavidus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

area north of lat. 45°30'N. Finally, higher mean densities were found on Heceta Bank, off southern Oregon, in 1986 than in previous surveys.

Estimates of canary rockfish biomass varied widely from 26,732 t in 1977, 6,965 t in 1980, 18,821 t in 1983, down to 10,998 t in 1986 (Table 9, Fig. 13). Generally lower, variable population levels have been observed since 1977. In every year most of the biomass occurred in the U.S.-Vancouver and Columbia areas. Almost all the estimated biomass was in the 55–183 m depth interval. The single exception was in the U.S.-Vancouver area in 1983, when about one-third of the biomass was present in the 184–219 m depth interval. However, only 5% of the total biomass over all areas and years was found on the continental slope (i.e. deeper than 183 m). As in yellowtail rockfish, abundance estimates of canary rockfish were also highly variable. Because this species schools, overall CV's ranged from about 30 to 73%; values for individual strata reached as high as 98% (Table 9). Confidence intervals were large and overlapped extensively (Fig. 13). Only the relatively small biomass estimates in the Eureka area in 1977 and 1983 were significantly different (Table 7); estimates were higher in 1983 than in 1977.

Canary rockfish length distributions in 1977 and 1980 were generally unimodal, with modes at about 50 cm, but in 1983 a second mode of smaller fish appeared at about 30 cm (Fig. 14). The latter group was composed

Table 8

Yellowtail rockfish, *Sebastes flavidus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	53.4	11,277	0–22,585		14.5	11,325	2,793–19,858	
	184–274	2.9	172	0–359		2.7	465	217–713	
	275–366	2.0	1	0–3		4.6	10	0–22	
	91–366	38.2	11,450	140–22,759	57.8	10.9	11,801	3,265–20,337	41.9
1980	55–183	18.9	4,965	0–10,927		4.5	5,177	151–10,203	
	184–219	0.3	11	0–37		0.7	58	0–118	
	220–366	0.0	0	—		0.2	42	0–108	
	55–366	14.1	4,976	0–10,914	68.4	3.6	5,276	250–10,303	56.5
1983	55–183	17.6	4,640	0–11,700		5.6	6,559	3,457–9,661	
	184–219	0.8	25	0–50		0.7	64	17–112	
	220–366	0.0	0	—		5.0	102	2–201	
	55–366	13.2	4,665	0–11,725	89.7	4.6	6,725	3,622–9,829	27.8
1986	55–183	9.7	2,689	1,079–4,299		4.3	5,312	2,478–8,146	
	184–219	0.4	12	0–34		1.9	178	0–1,280	
	220–366	0.0	0	—		0.0	0	—	
	55–366	7.4	2,701	1,091–4,311	36.0	3.6	5,490	2,643–8,337	30.6

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	3.6	649	0–1,407		1.0	813	0–1,762		15.5	24,064	10,123–38,006	
	184–274	0.3	12	0–34		0.0	0	—		1.9	649	345–954	
	275–366	0.0	0	—		0.0	0	—		1.2	11	0–23	
	91–366	2.6	661	0–1,419	66.1	0.7	813	0–1,762	62.8	11.6	24,725	10,780–38,670	33.5
1980	55–183	2.6	522	9–1,035		0.3	205	0–416		4.8	10,868	3,234–18,502	
	184–219	0.0	0	—		0.0	0	—		0.4	69	7–131	
	220–366	0.0	0	—		0.0	0	—		0.1	42	0–108	
	55–366	2.0	522	9–1,035	57.1	0.3	205	0–416	61.5	3.9	10,978	3,344–18,613	41.3
1983	55–183	2.2	671	38–1,304		2.5	1,579	0–3,700		5.7	13,450	5,482–21,418	
	184–219	0.1	2	(one sample)		0.0	0	—		0.5	92	39–144	
	220–366	0.0	0	—		0.1	7	0–16		0.2	109	7–209	
	55–366	1.8	673	42–1,306	54.3	2.1	1,587	0–3,706	79.7	4.6	13,650	5,682–21,619	34.9
1986	55–183	3.5	1,128	178–2,077		3.5	2,326	121–4,531		4.6	11,455	6,718–16,192	
	184–219	0.0	0	—		0.0	0	—		1.0	190	0–1,299	
	220–366	0.1	3	0–10		0.1	6	0–17		0.7	9	0–27	
	55–366	2.8	1,131	182–2,081	50.1	3.0	2,332	127–4,537	56.4	3.8	11,655	6,909–16,400	24.5

mainly of 4- and 5-year-olds of the 1978 and 1979 year classes (Fig. 15). In 1986 the length distribution was again unimodal but flattened as the 1978 and 1979 year classes grew into the 35–45 cm length interval. New recruitment was not evident in the 1986 samples. Females predominated at lengths greater than 55 cm. Although sample sizes from the deep zone were small, individuals in those samples were generally larger on average than those from the shallow zone.

Canary rockfish age compositions for 1977, 1980, and 1983 are presented in Figure 15. Ages were determined from reading otolith surfaces in 1977 and 1980.

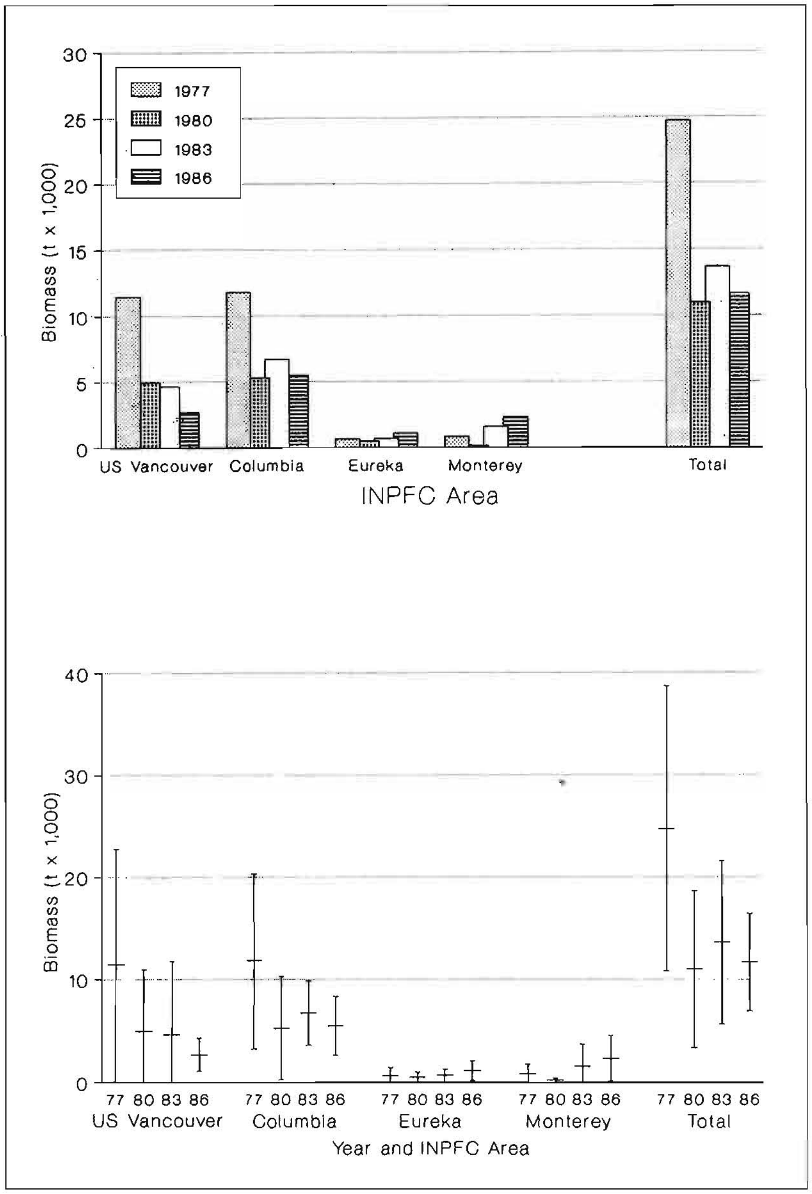

Figure 9

Estimates of yellowtail rockfish, *Sebastes flavidus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

Adoption of sectioning and break-and-burn techniques with the 1983 samples resulted in the detection of older fish. Whereas 20- to 25-year-olds were the oldest aged in 1977 and 1980, maximum ages read in 1983 were about twice as old. Discrepancies between canary rockfish ages read from whole and sectioned otoliths appear to arise at about ages 10 to 12 years, or at the age of maturity (Gunderson et al., 1980; Wyllie Echeverria, 1987), and increase linearly with age (Boehlert and Yoklavich, 1984). However, some observations and comparisons can be made, assuming that differences between the ageing techniques resulted in minor differences in age composition for ages less than 15 years old. Canary rockfish ages ranged from 2 to 40 years; samples were typically dominated by specimens of age 7–15 years. Younger fish took on special prominence in 1983 when large numbers of age 4 and 5 fish of the 1978 and 1979 year classes appeared. Golden[8] reported a similar trend in samples from commercial landings in the Co-

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[8] Golden, J. T. 1987. Progress report on the status of canary rockfish (*Sebastes pinniger*) in the INPFC Columbia area and recommended ABC for 1988. Unpubl. manuscr., 25 p. Oregon Department of Fish and Wildlife, Hatfield Marine Science Center, Newport, OR 97365.

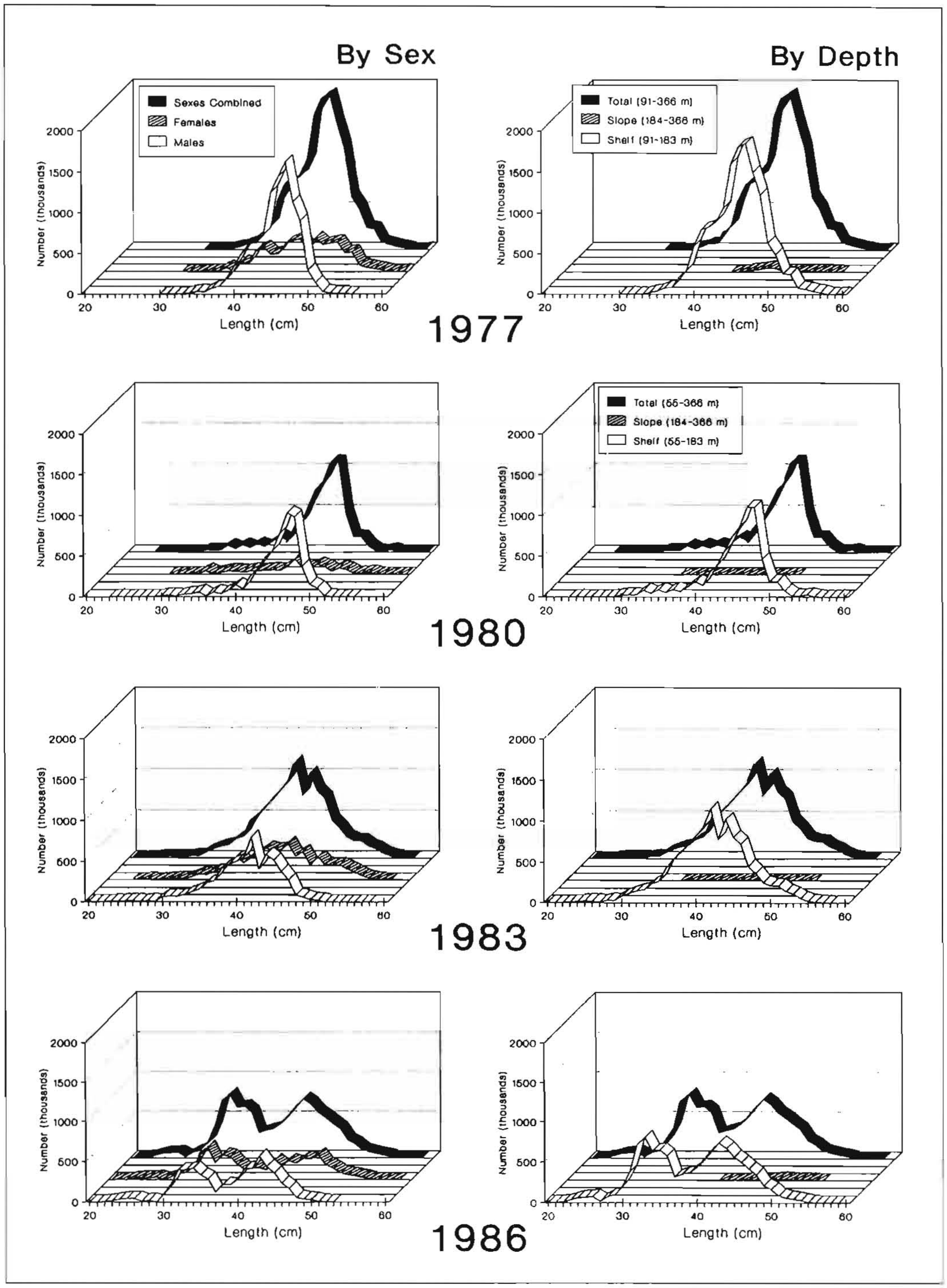

Figure 10
Yellowtail rockfish, *Sebastes flavidus*, length compositions by year, depth, and sex.

lumbia area. He found that fish less than 13 years of age accounted for 26.8% of the 1980–82 population, but the same age groups composed 51.3% of the 1983–86 population. The 1968 year class appeared large in both 1977 and 1980 survey samples, but the prominent 1961–64 year classes observed in 1977 were much smaller by 1980. The 1965 and 1966 year classes seemed relatively weak. The 1976–79 year classes, which first appeared in significant numbers as age 4–7 fish in 1983, were unusually large when compared with the numbers of age 4–7 fish in 1977 and 1980.

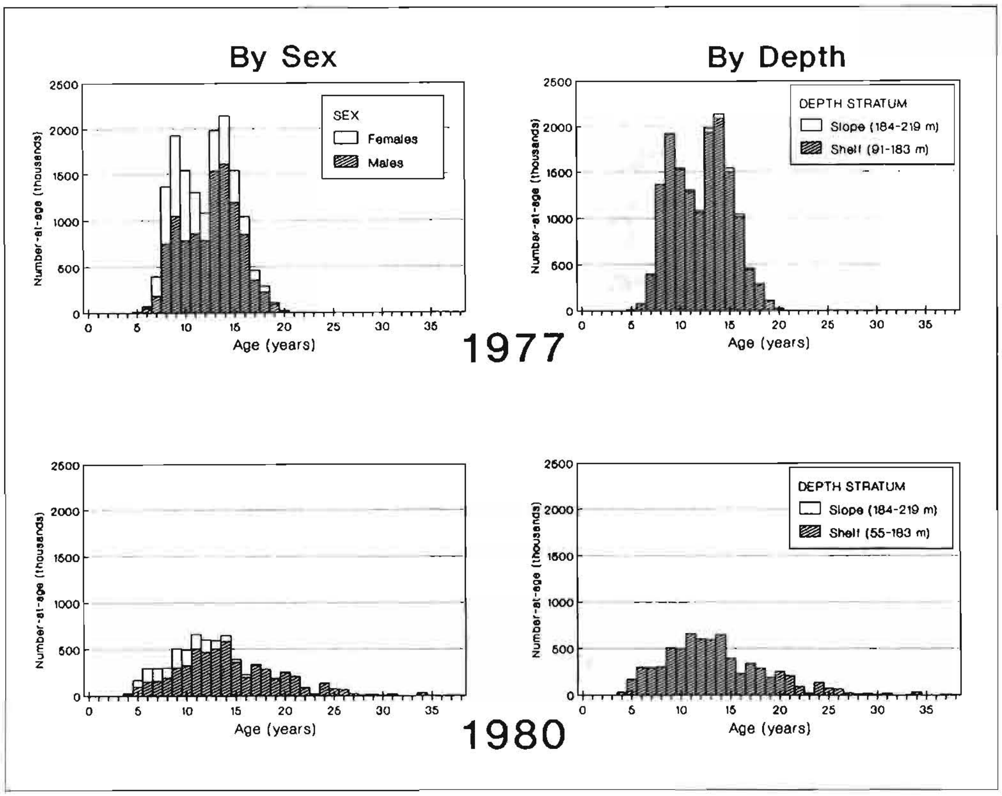

Figure 11
Yellowtail rockfish, *Sebastes flavidus*, age compositions by year, depth, and sex.

Bocaccio — This rockfish species is a common component of commercial and recreational groundfish catches throughout the survey area, but it is most important in California fisheries, particularly those in the Monterey area. The 1987 coastwide catch was 1,218 t and 57% of that was landed in the Monterey area. The 1980–87 landings ranged from 669 to 4,237 t.

Survey data showed bocaccio was distributed over a broader bathymetric range than the rockfish previously discussed (Fig. 16). The CPUE in the deep stratum (184–366 m) often equaled or exceeded the CPUE in the shallow stratum (55–183 m) (Table 10). Highest densities were in the southern portion of the survey region in the Monterey and Eureka areas. Some annual changes in distribution were observed (Fig. 16). Bocaccio rarely occurred in samples taken from about Cape Mendocino, California, to Cape Blanco, Oregon, (lat. 41°00'-42°30'N) in 1977 and 1986. Although the species did occur in that region during the 1980 and 1983 surveys, densities were never high. In 1980 and 1983 the general distribution of bocaccio throughout the survey area was similar. The distribution in 1986 was discontinuous and patchy, but the estimated biomass was relatively large. Such widely scattered but dense aggregations were not as prevalent during previous surveys. In general, densities off California were much lower in 1986.

Total biomass estimates varied little during the study period (7,620–8,162 t), with the exception of 1980 when the estimate dropped to 5,186 t (Table 10, Fig. 17). Biomass was by far the highest in the Monterey area where, on average, 71% of the total occurred. There is an indication that stock reductions have occurred in the U.S.-Vancouver and Columbia areas since 1977. The greatest reduction occurred in the U.S.-Vancouver area, where a decline of 92% was estimated. An apparent population increase was noted in the Monterey area in 1983, which may have resulted from recruitment of a large 1977 year class (Thomas[9]). Abundance was most variable in the Eureka area, where the precision of bocaccio biomass estimates was among the worst in the study. The 90% confidence intervals were plus or minus 54, 42, 94, and 119% of the 1977, 1980, 1983, and 1986 total biomass estimates, respectively. Coefficients of variation were 32, 53, 55, and 71% for the same years. This large variability affected the sensitivity of the surveys and our ability to detect changes in

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[9] Thomas, D. H. 1985. Status of California's bocaccio stock. *In* Pacific Fisheries Management Council, Status of the Pacific coast groundfish fishery through 1985 and recommended acceptable biological catches for 1986, 9 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

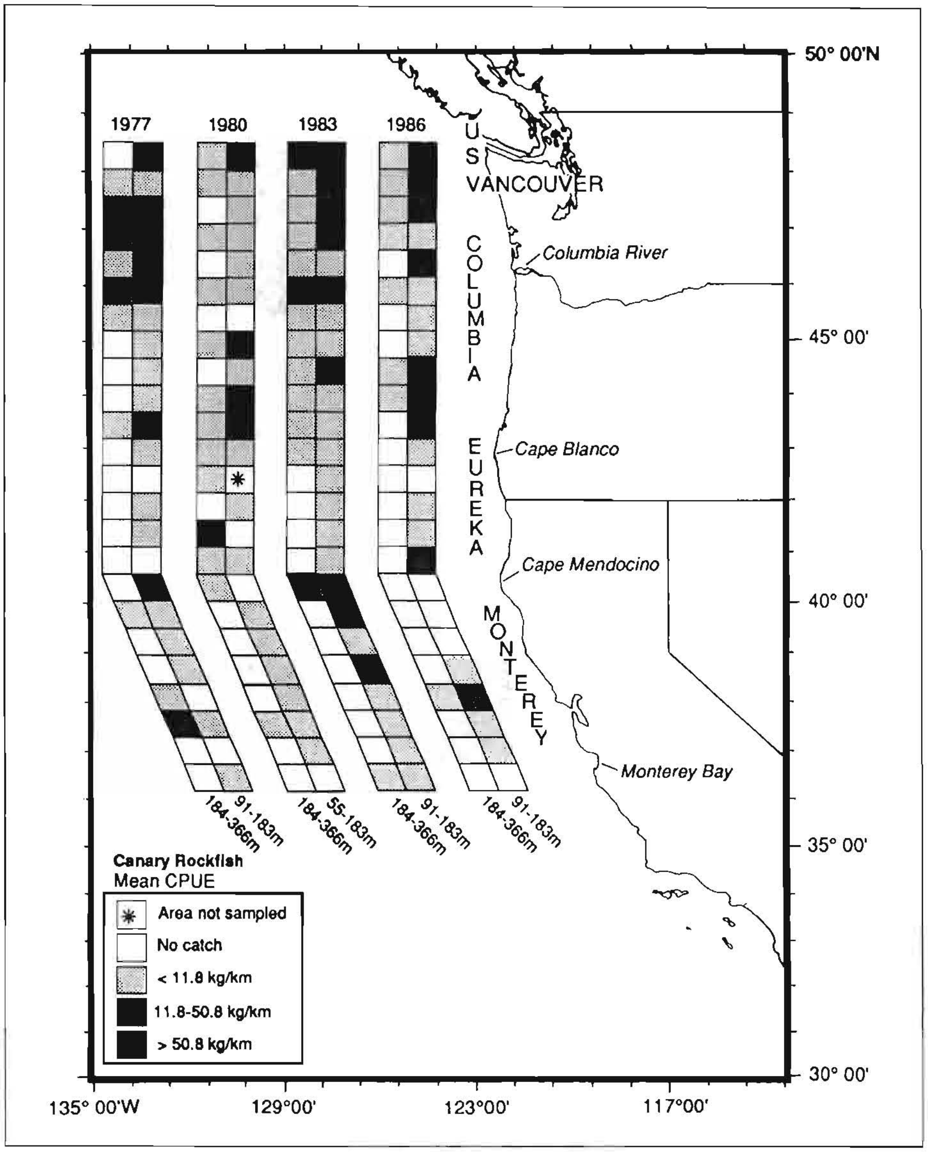

Figure 12
Distribution of canary rockfish, *Sebastes pinniger*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

population size. Only the 1977 and 1980 biomass estimates in the Eureka area were found to be significantly different (Table 7), even though in some areas interannual differences in estimated abundance were relatively large.

Most of the length data was collected from the Monterey area in 1977, 1980, and 1983, but sampling was more evenly distributed among INPFC areas in 1986. Samples were relatively small in all years. Lengths in the samples ranged from about 23 to 79 cm (Fig. 18). Two prominent modes noted in 1977 and 1986 reflected the presence of substantial numbers of relatively new recruits (32–45 cm) and much older fish (50–65 cm). The 1980 length composition is distinct because the population was so strongly dominated by fish in the 37–47 cm interval; few fish were longer than 47 cm. This group was observed in the 1983 length composition (46–54 cm), but probably because of under-sampling it was not as abundant as we would have expected given its abundance in 1980. Contrary to observations in other survey years, no fish were less than 33 cm in 1983 samples.

Age data were available only for 1977 and only for the Monterey area (Fig. 19). Ages based on otolith surface readings ranged from 2 to 13 years but ages from 4 to 9 years prevailed. Males dominated most age groups. As bocaccio became older they were less abundant on the shelf and were more likely to occur above the upper continental slope.

Table 9

Canary rockfish, *Sebastes pinniger* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	94.1	19,804	0–53,217		7.3	5,687	2,558–8,817	
	184–274	0.1	5	(one sample)		2.9	495	0–993	
	275–366	0.0	0	—		1.7	10	0–33	
	91–366	66.0	19,809	0–53,222	98.1	5.7	6,193	3,040–9,345	30.5
1980	55–183	9.8	2,579	0–6,667		2.4	2,835	1,101–4,570	
	184–219	0.2	7	0–28		0.8	71	0–164	
	220–366	0.0	0	—		0.1	13	0–31	
	55–366	7.3	2,586	0–6,658	90.2	2.0	2,920	1,184–4,655	35.7
1983	55–183	11.8	3,093	1,208–4,977		5.1	5,893	2,092–9,694	
	184–219	46.9	1,544	0–4,293		4.5	406	0–828	
	220–366	0.0	0	—		0.2	43	11–75	
	55–366	13.2	4,636	1,401–7,872	40.6	4.3	6,342	2,528–10,155	36.0
1986	55–183	12.1	3,356	1,218–5,495		4.4	5,432	992–9,873	
	184–219	0.3	11	2–20		0.4	40	0–91	
	220–366	0.0	0	—		0.2	32	0–73	
	55–366	9.2	3,367	1,229–5,506	38.3	3.7	5,504	1,064–9,945	48.3

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.2	38	7–69		1.4	525	0–2,879		17.2	26,134	0–59,627	
	184–274	0.0	0	—		1.4	88	0–264		1.8	587	88–1,087	
	275–366	0.0	0	—		0.0	0	—		1.1	10	0–33	
	91–366	0.2	38	7–69	47.2	1.3	612	0–3,024	62.4	12.8	26,732	0–60,227	73.4
1980	55–183	6.11	1,235	0–3,237		0.3	200	0–430		3.0	6,850	2,098–11,602	
	184–219	0.2	6	(one sample)		0.4	12	0–29		0.5	97	1–192	
	220–366	0.1	5	0–12		0.0	0	—		<0.1	18	0–36	
	55–366	4.8	1,246	0–3,247	92.0	0.3	213	0–443	64.5	2.4	6,965	2,212–11,717	40.2
1983	55–183	1.2	365	196–533		11.7	7,432	0–15,674		7.1	16,782	7,560–26,003	
	184–219	0.0	0	—		0.0	0	—		9.6	1,949	0–4,718	
	220–366	<0.1	2	0–5		0.5	45	0–117		0.2	90	12–168	
	55–366	1.0	366	198–535	27.0	9.9	7,476	0–15,716	65.8	6.4	18,821	9,265–28,376	30.5
1986	55–183	2.4	784	197–1,371		2.0	1,326	62–2,591		4.4	10,899	5,477–16,322	
	184–219	0.2	6	0–16		0.2	9	0–29		0.4	65	17–114	
	220–366	2.3	2	0–4		0.0	0	—		0.1	33	0–77	
	55–366	2.0	792	204–1,379	44.4	1.7	1,335	70–2,599	56.5	3.6	10,998	5,575–16,421	29.7

Chilipepper — Chilipepper is of minor importance to rockfish communities in the U.S.-Vancouver, Columbia, and Eureka areas but is a predominant species in commercial and recreational catches from the Monterey and Conception areas off California (Henry[10]). Between 1980 and 1987 landings tended to decrease, averaging

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[10] Henry, F. D. 1985. A progress report on the status of chilipepper (*Sebastes goodei*) off California. *In* Pacific Fisheries Management Council, Status of the Pacific coast groundfish fishery through 1985 and recommended acceptable biological catches for 1986, 16 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

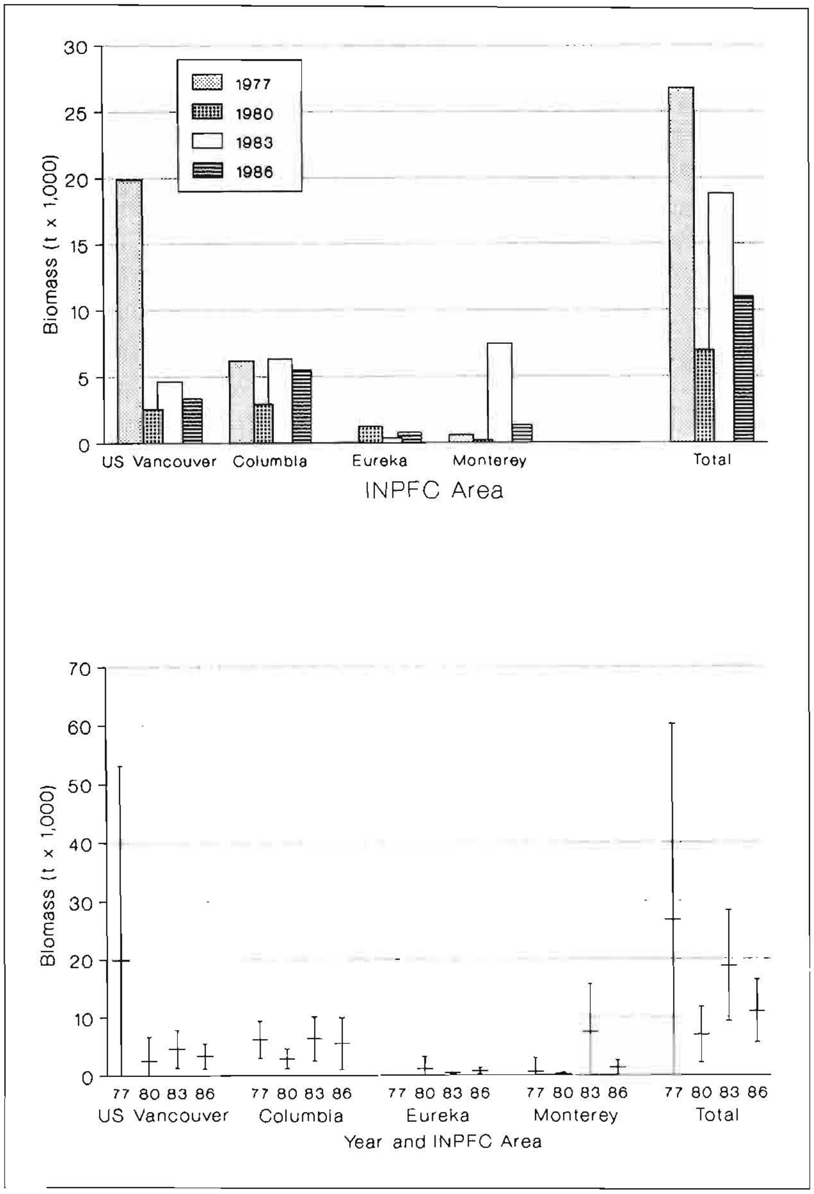

Figure 13

Estimates of canary rockfish, *Sebastes pinniger*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

about 1,493 t and ranging from 669 to 2,427 t (PacFIN, 1980–87[3]).

The distribution and relative abundance of chilipepper during the survey years showed no significant concentrations north of lat. 41°00'N and relatively high CPUE values in the Monterey area (Fig. 20). High or moderate densities occurred in both depth zones, except in 1986 when chilipepper were either absent or scarce in waters deeper than 183 m. In some years densities on the upper continental slope substantially exceeded those on the shelf. Distributions differed little annually until 1986, when the deep zone contained a smaller proportion of the population.

Biomass estimates derived from the trawl surveys indicate that this resource was largely confined to the Monterey area (Fig. 21). The species was absent in the U.S.-Vancouver area. Low densities of chilipepper were found in the Columbia area, and only in 1986 did significant densities occur in the Eureka area. The Monterey area CPUE averaged about 13.3 kg/km over the four years, which was 266 and 5 times greater than mean CPUE's in the Columbia and Eureka areas, re-

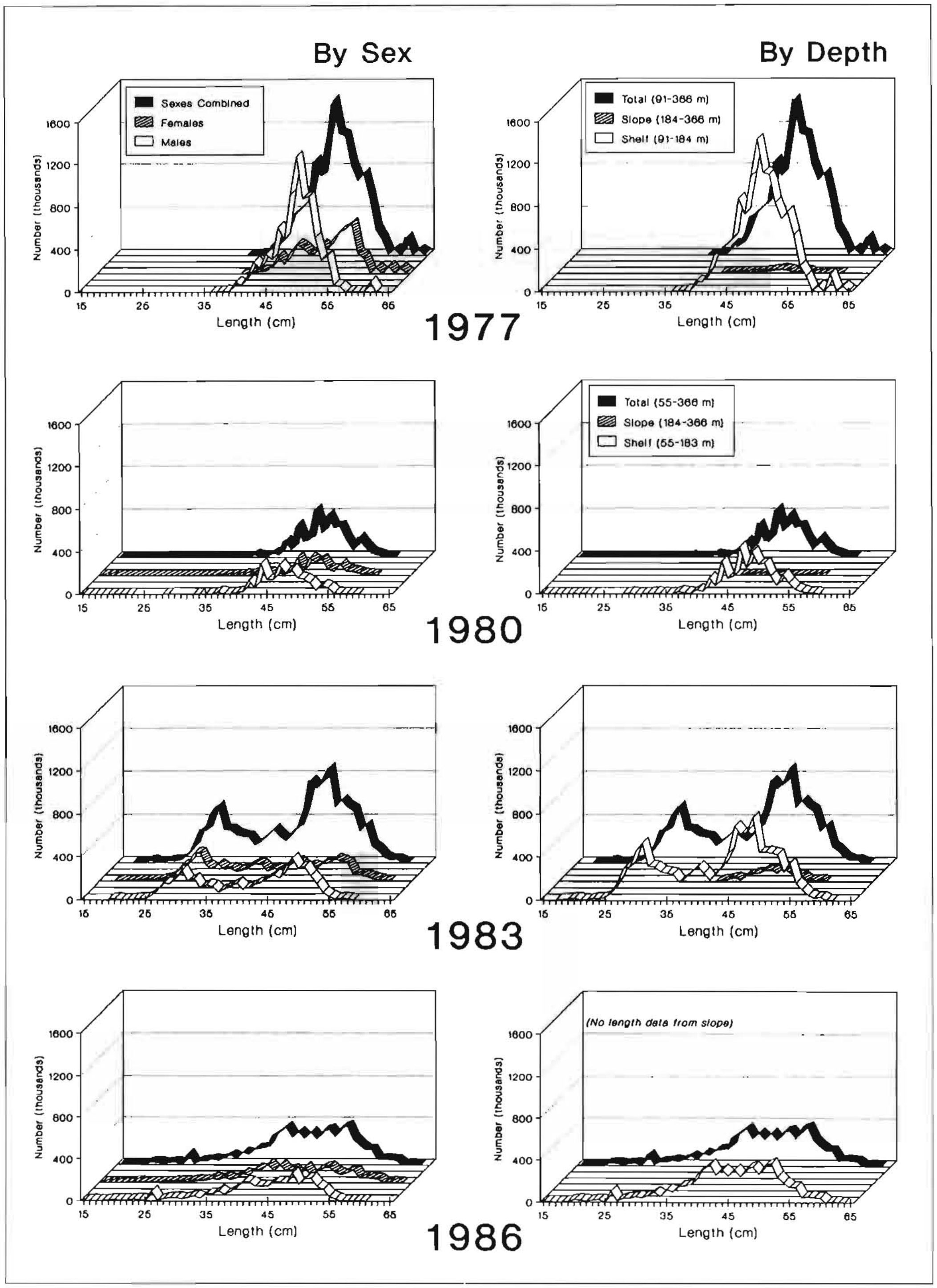

Figure 14
Canary rockfish, *Sebastes pinniger*, length compositions by year, depth, and sex.

spectively. Biomass estimates in the Monterey area and over all areas were remarkably consistent for the 4 years; values ranged from 7,567 to 9,799 t in the Monterey area and from 9,152 to 10,945 t in all other areas, suggesting that population sizes were relatively stable. Most of the biomass in the Monterey area was found on the continental shelf, but from 6% (1986) to 47% (1977) occurred in waters 184–366 m over the upper continental slope (Table 11). The precision of biomass estimates for this species was also relatively poor. Ninety percent confidence intervals ranged from 42 to 82% of the total estimates and CV's overall were

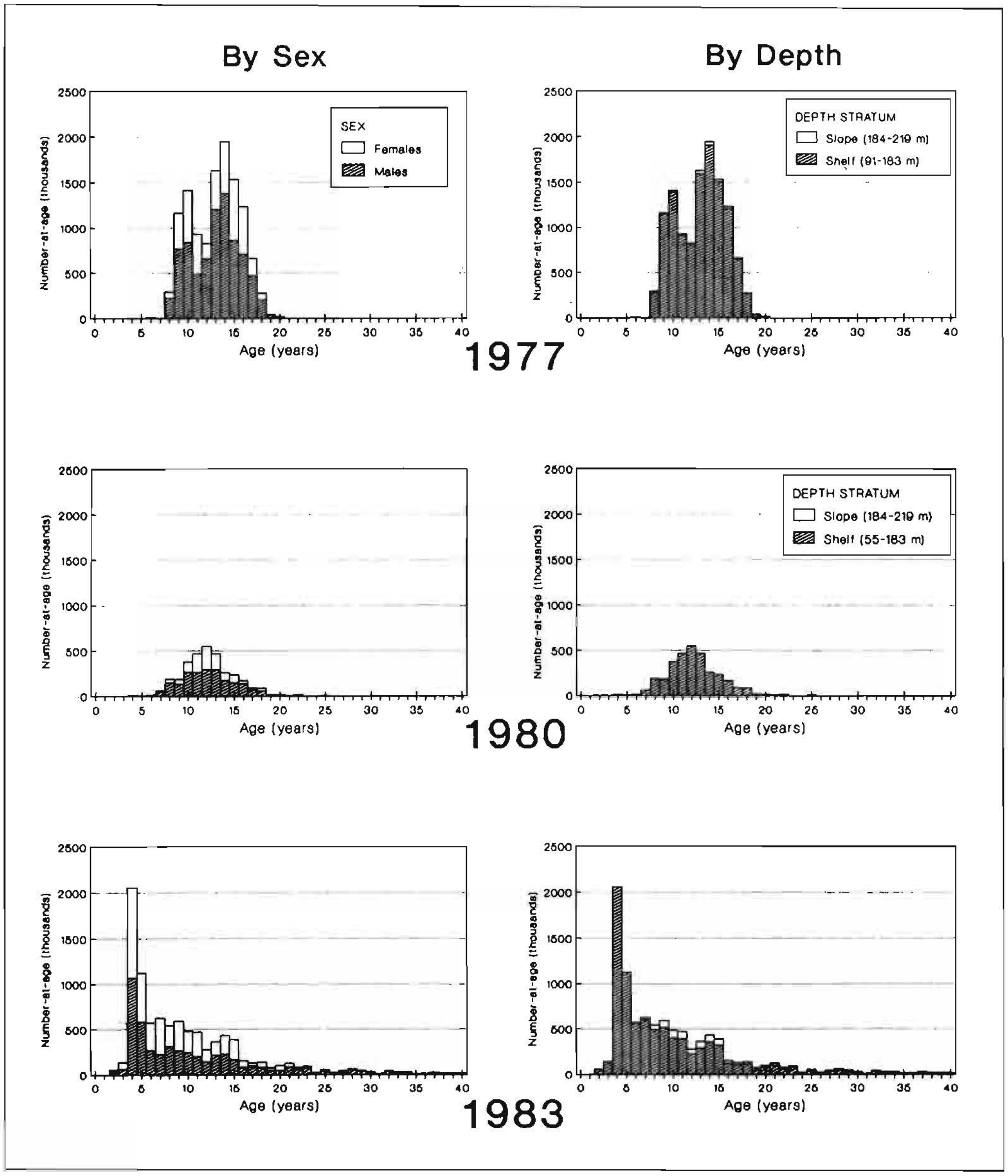

Figure 15
Canary rockfish, *Sebastes pinniger*, age compositions by year, depth, and sex.

from 25 to 49%. However, in some INPFC areas and years CV's approached or exceeded 100%, reflecting the extremely contagious distribution of the species. Significant differences in biomass were only detected between 1977 and 1986 and between 1983 and 1986 in the Eureka area (Table 7).

Chilipepper length compositions consisted of several distinct length modes and demonstrated considerable interannual variability (Fig. 22). The smallest size group (20–28 cm) was present in 1977 and prominent in 1986. The 28–38 cm category was present in all survey years. A third group, ranging from 38 to 53 cm, also occurred in all years to a greater or lesser extent. Length distributions revealed some aspects of male and female growth and survival histories. The right-hand mode consisted almost entirely of large females. Males seldom reach lengths greater than 40 cm, whereas females commonly attain lengths of 50 cm or greater (Wilkins, 1980). Approximately equal numbers of males and females were present in the group of smallest fish. Fish in the lower portion (28–33 cm) of the middle group were mostly males, while those in the upper portion of the group were mostly females. This is probably a result of the differential growth rates between the sexes of this species noted by Wilkins (1980). The persistent low incidence of females in that length interval, however,

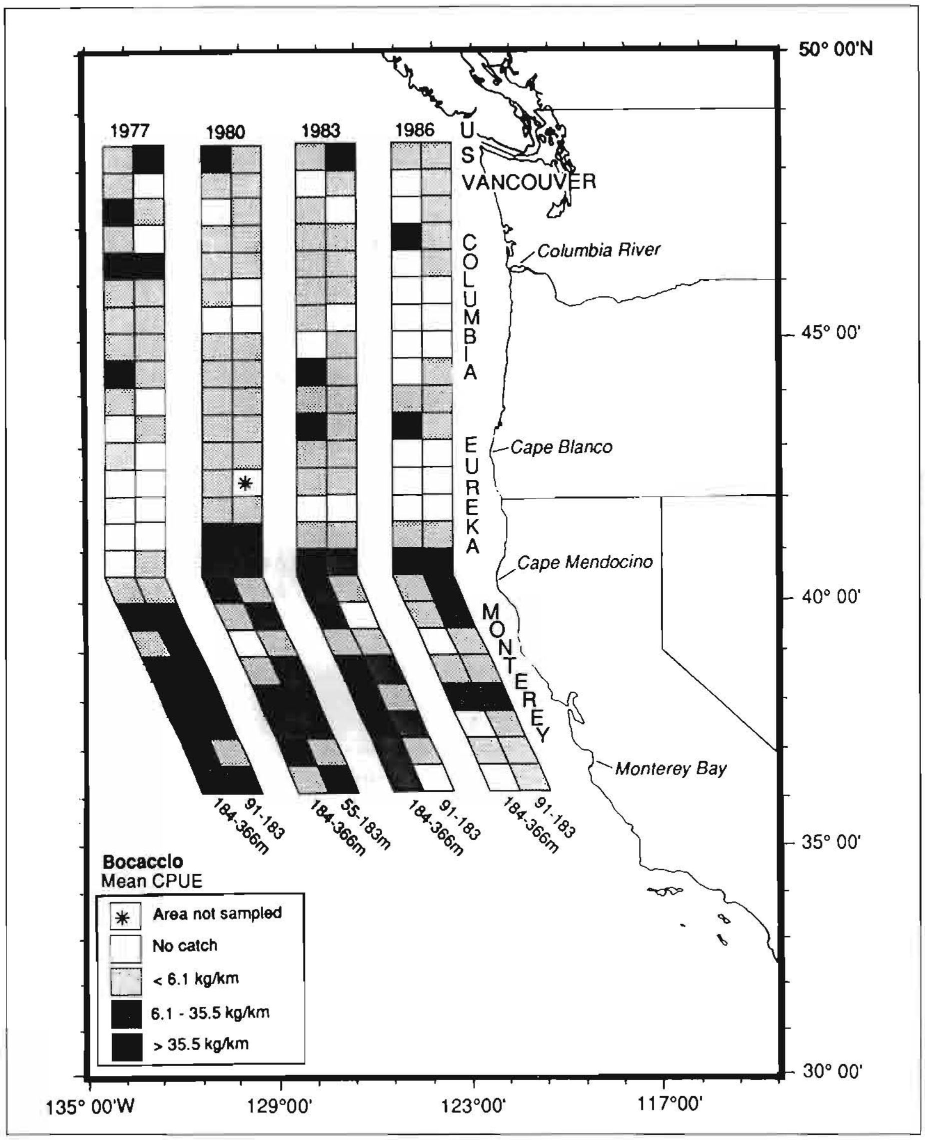

Figure 16
Distribution of bocaccio, *Sebastes paucispinis,* during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

could also imply less availability to the trawl during certain life history stages. In all years except 1977 most fish were found on the continental shelf. Small fish less than about 30 cm were prevalent in the shallow zone and seldom seen in samples from the upper continental slope. This observation is similar to that noted in length compositions for other rockfish species and provides evidence that young rockfish generally first recruit to fishable populations in shallow water and migrate into deeper waters only after attaining larger sizes (Moser, 1967; Carlson and Haight, 1976; Boehlert, 1977 and 1980; Lenarz, 1980; Wilkins, 1980). Samples from the continental slope mainly contained fish larger than 30 cm.

In 1977 and 1980, chilipepper ranged from 2 to 22 years old (based on otolith surface readings), but few specimens older than 13 years were present (Fig. 23). Age compositions were similar for the two years except that 2- and 3-year-old fish, observed in 1977, were not seen in 1980. Following the pattern observed previously in the depth distribution of fish smaller than 30 cm, the age 2–3 fish present in 1977 occurred almost exclusively in the shallow (91–183 m) zone. In each year, age-5 fish were dominant and apparently fully recruited to the sampling trawl. The shape of the age compositions indicates that variation in year-class strength has not been extreme, although the 1977 and 1978 year classes

Table 10

Bocaccio, *Sebastes paucispinis* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	7.4	1,569	0–4,019		0.7	566	55–1,078	
	184–366	0.8	49	3–95		1.1	340	166–515	
	91–366	5.4	1,618	0–4,068	88.7	0.8	907	369–1,444	35.6
1980	55–183	0.5	130	0–291		0.4	475	197–754	
	184–366	0.4	34	0–98		0.2	68	0–137	
	55–366	0.5	164	0–333	59.6	0.4	544	259–829	31.5
1983	55–183	1.2	313	59–567		0.4	462	165–760	
	184–366	0.2	19	1–37		0.4	126	70–181	
	55–366	0.9	332	77–587	45.6	0.4	588	286–891	31.0
1986	55–183	0.4	121	45–198		0.2	240	64–416	
	184–366	0.1	9	0–24		1.3	367	0–1,113	
	55–366	0.4	130	52–208	36.0	0.4	607	0–1,393	55.1

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.1	13	0–34		5.6	2,159	385–3,933		2.7	4,306	1,316–7,297	
	184–366	0.2	10	0–27		28.2	2,914	0–6,344		5.8	3,313	65–6,561	
	91–366	0.1	22	0–49	72.1	10.7	5,073	1,600–8,547	37.4	3.5	7,620	3,482–11,758	31.5
1980	55–183	3.3	668	171–1,166		4.6	2,956	966–4,946		1.9	4,230	2,164–6,296	
	184–366	1.3	105	12–197		6.2	749	52–1,445		1.6	956	253–1,659	
	55–366	2.7	773	270–1,277	37.4	4.9	3,705	1,610–5,799	33.9	1.8	5,186	3,014–7,358	25.1
1983	55–183	0.5	142	31–253		1.4	892	400–1,383		0.8	1,809	1,178–2,440	
	184–366	2.5	198	0–468		46.0	5,558	0–12,786		9.3	5,901	0–13,134	
	55–366	0.9	340	57–623	45.9	8.5	6,450	0–13,696	65.0	3.3	7,710	447–14,972	54.5
1986	55–183	6.4	2,049	0–4,944		7.2	4,756	0–11,517		2.9	7,166	0–16,825	
	184–366	3.0	250	8–492		2.9	371	0–780		1.7	995	80–1,910	
	55–366	5.7	2,299	0–5,202	75.3	6.5	5,127	0–11,898	78.8	2.7	8,162	0–17,856	70.9

seem to be very much underrepresented in 1980 and may be unusually weak or unavailable.

Pacific ocean perch — Pacific ocean perch was once an important rockfish in Washington and Oregon trawl landings. Landings increased slowly until the early 1960's when U.S. and Canadian landings from the Vancouver and Columbia areas peaked at about 8,500 t. Intensive foreign fishing during the late 1960's seriously depleted stocks, and U.S. and Canadian landings from these areas plummeted to about 400 t in 1974 (Gunderson et al. 1977). Since 1978 the U.S. Pacific ocean perch fishery has been managed under a program to rebuild stock size using annual catch quotas and trip limits to discourage targeting by the fishery. Optimum yields and landings for the U.S.-Vancouver and Columbia areas combined have been about 1,300 t since 1987.

From 1977 to 1986, population densities were greatest in the northern portion of the survey area and generally decreased from north to south, with very low densities south of Cape Mendocino (Fig. 24). Average CPUE in the U.S.-Vancouver area (12.0 kg/km) was considerably larger than in the Columbia area (3.0 kg/km), the Eureka area (1.0 kg/km), and the Monterey area (<0.1 kg/km). Relatively high densities occurred

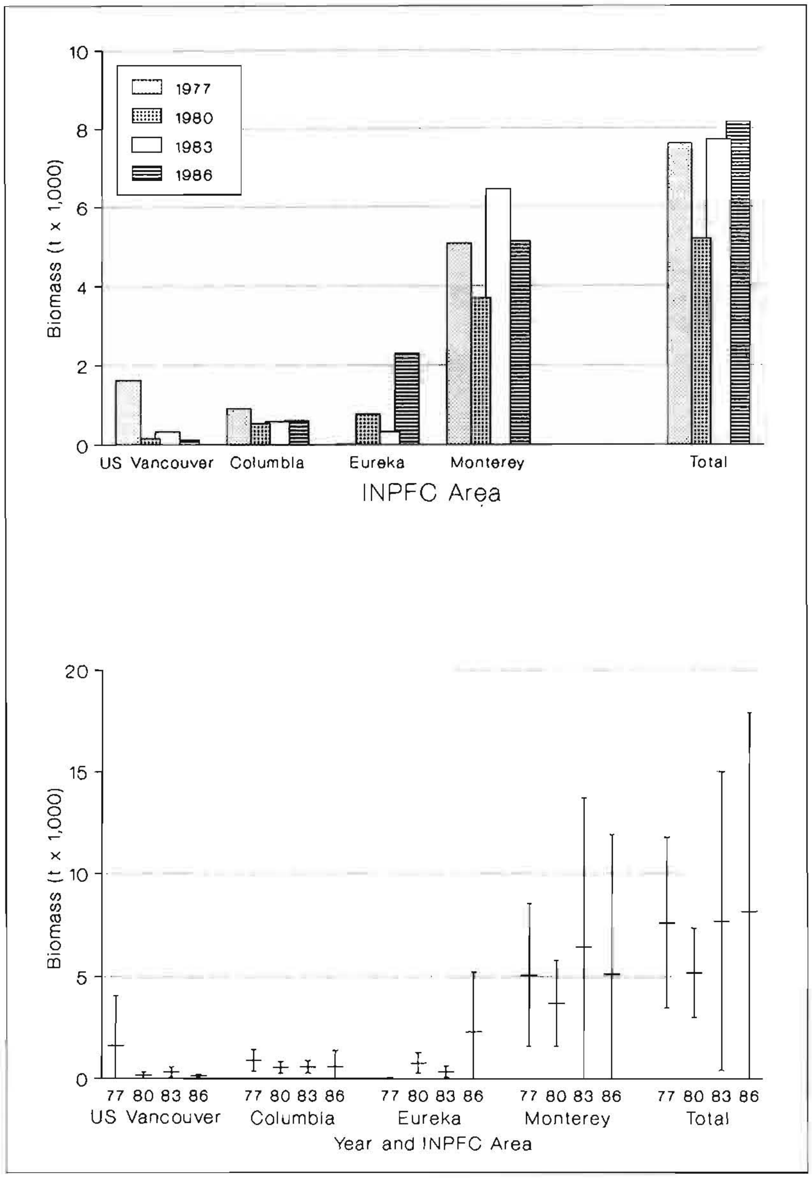

Figure 17
Estimates of bocaccio, *Sebastes paucispinis*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

in the deep zone throughout the area off Washington and Oregon in 1977, but in 1980 densities off Oregon decreased. There was little change in 1983, but by 1986 densities were relatively low everywhere except off Washington. Densities were consistently low in the shallow depth zone.

Our biomass estimates were based on samples from waters less than 366 m deep, which did not cover the full bathymetric range of this species. However, in 1977 sampling did occur deeper than 366 m, and results showed that the average CPUE in the 366–475 m zone was about 6% of the Pacific ocean perch CPUE in waters less than 366 m deep (Gunderson and Sample, 1980). So, although our biomass estimates are certain to be conservative, the failure to sample deeper waters should not seriously distort our estimates. Almost all of the estimated biomass occurred in the Vancouver and Columbia areas, with only small amounts appearing in the Eureka and Monterey areas (Table 12, Fig. 25). Biomass was approximately equally divided between the U.S.-Vancouver area and the Columbia area, even though the U.S.-Vancouver area is only about 25% as large as the Columbia area. Major reductions in stock size apparently occurred in both the U.S.-Vancouver

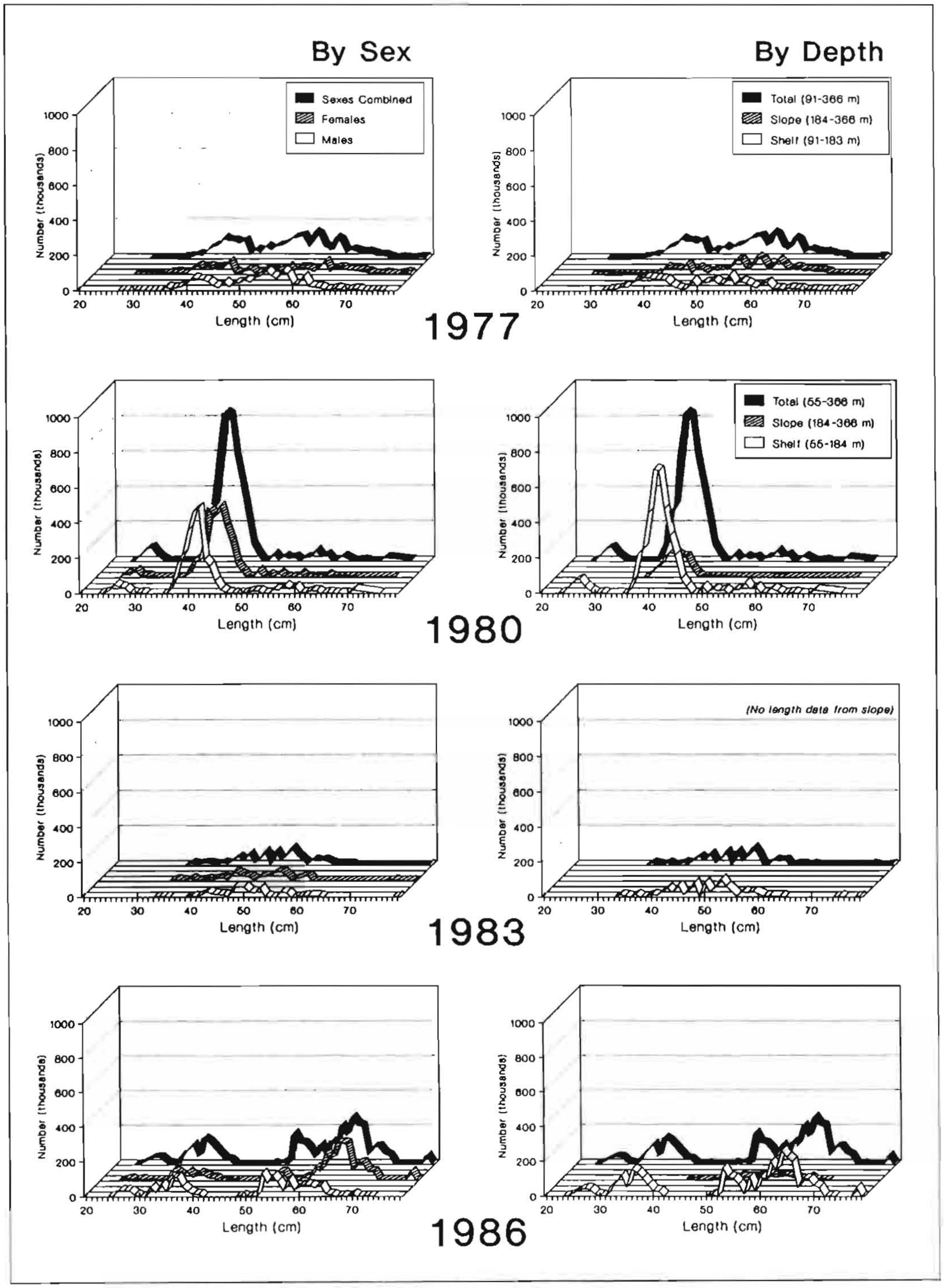

Figure 18
Bocaccio, *Sebastes paucispinis*, length compositions by year, depth, and sex.

and Columbia areas between 1977 and 1980. Little change was observed between 1980 and 1983; the total estimated biomass in these years was approximately 48% of that in 1977. Another notable reduction in biomass (a 54% decrease) followed in 1986. Pacific ocean perch primarily inhabit waters of the upper continental slope; over the four surveys, an average of 91% of the estimated biomass was found there. The precision of Pacific ocean perch biomass estimates varied considerably among strata, as was observed in other

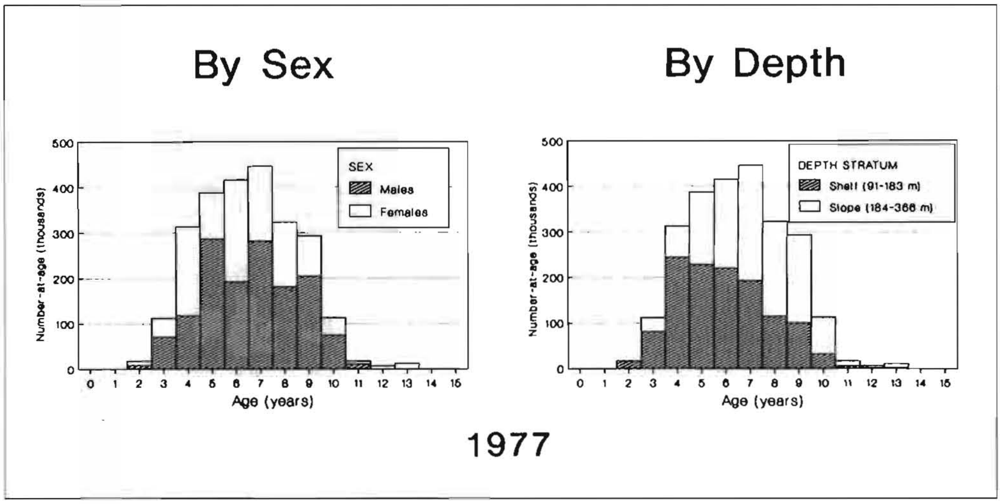

Figure 19
Bocaccio, *Sebastes paucispinis*, age compositions by year, depth, and sex.

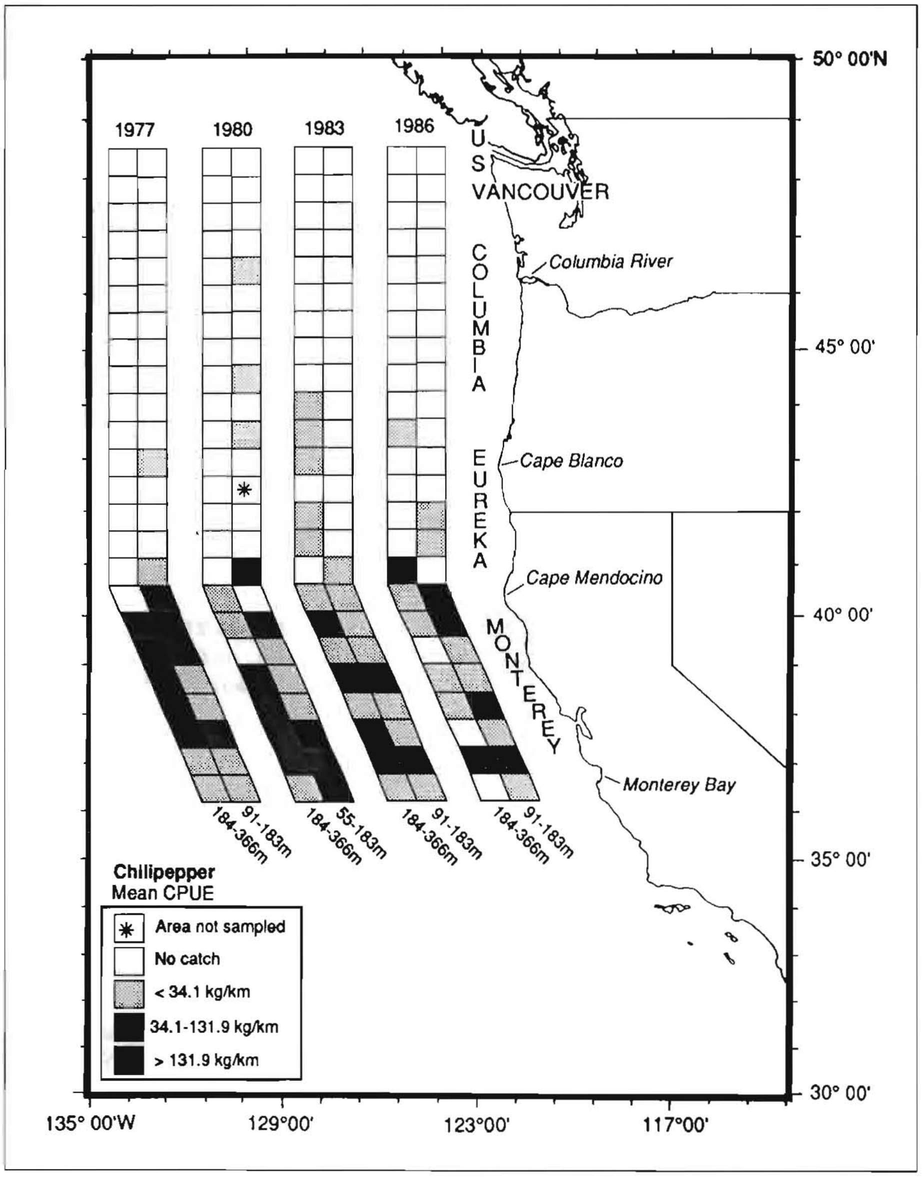

Figure 20
Distribution of chilipepper, *Sebastes goodei*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

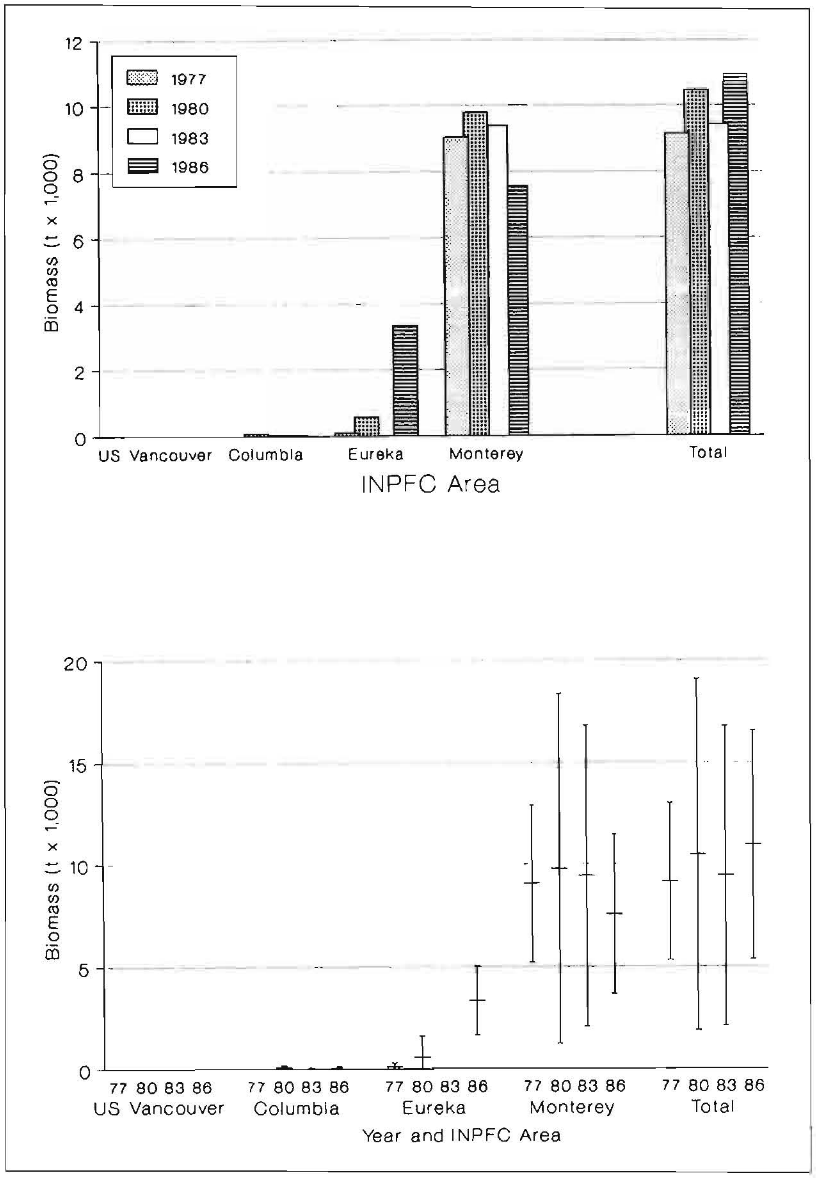

Figure 21
Estimates of chilipepper, *Sebastes goodei*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

rockfishes, but precision was relatively high in most instances. Confidence limits for total biomass ranged from 46 to 252% of the point estimates. Coefficients of variation for total estimates ranged from 27 to 40%. No significantly different biomass estimates were found for this species (Table 7).

Pacific ocean perch ranged in length from 11 to 50 cm, but most were between 30 and 48 cm (Fig. 26). As noted in other species discussed in this study, females were generally longer than males. Few males were longer than 45 cm, while fish of 42–49 cm were often the most abundant female length group sampled. Several modes were often present due to sexual dimorphism and variable year-class strength. In 1977, 1980, and 1986, a mode occurred at about 32 cm marking the entry of substantial numbers of young fish. That was not the case in 1983 when the population was dominated by relatively old fish greater than 34 cm and there was little in the way of new recruitment. This could at least partly explain the much reduced estimate of biomass in 1986. Only a very small portion of the resource occurred in the shallow zone and our samples showed no particular trend in size with depth. The use of more depth strata across the slope would likely have revealed

Table 11

Chilipepper, *Sebastes goodei* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.0	0	—		0.0	0	—	
	184–366	0.0	0	—		0.0	0	—	
	91–366	0.0	0	—	—	0.0	0	—	—
1980	55–183	0.0	0	—		0.1	87	0–181	
	184–366	0.0	0	—		0.0	0	—	
	55–366	0.0	0	—	—	0.1	87	0–181	65.1
1983	55–183	0.0	0	—		0.0	0	—	
	184–366	0.0	0	—		0.1	26	0–62	
	55–366	0.0	0	—	—	0.0	26	0–62	79.9
1986	55–183	0.0	0	—		0.0	0	—	
	184–366	0.0	0	—		0.1	34	0–135	
	55–366	0.0	0	—	—	<0.1	34	0–135	101.4

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.6	109	0–293		13.4	4,854	1,828–7,879		3.1	4,962	1,932–7,993	
	184–366	0.0	0	—		40.6	4,189	1,581–6,797		7.3	4,189	1,581–6,797	
	91–366	0.4	109	0–293	96.9	19.6	9,043	5,217–12,868	25.0	4.3	9,152	5,322–12,981	24.7
1980	55–183	2.9	583	0–1,601		13.1	8,316	0–16,805		4.0	8,986	447–17,525	
	184–366	0.0	0	—		12.1	1,463	423–2,504		2.5	1,463	422–2,504	
	55–366	2.1	583	0–1,601	100.0	12.9	9,779	1,238–18,321	52.2	3.7	10,449	1,854–19,044	49.2
1983	55–183	0.1	9	0–26		10.8	6,849	0–13,921		2.9	6,858	0–13,928	
	184–366	0.1	9	0–23		20.9	2,531	378–4,684		4.3	2,566	413–4,719	
	55–366	0.1	19	0–39	62.5	12.4	9,380	2,030–16,729	46.9	3.2	9,424	2,075–16,774	46.7
1986	55–183	9.6	3,083	1,408–4,758		10.8	7,126	3,262–10,990		4.1	10,209	4,671–15,748	
	184–366	3.1	261	0–580		3.5	441	0–989		1.3	736	0–1,605	
	55–366	8.3	3,344	1,647–5,041	30.4	8.3	7,567	3,675–11,459	30.8	3.6	10,945	5,358–16,533	30.6

a positive relationship between size and depth (Wilkins and Golden, 1983; Wilkins and Weinberg, 1987).

Ages of Pacific ocean perch were based on otolith surface readings. Age composition data were available only for 1977 and 1980 (Fig. 27), from which two features should be noted. In 1977, the 1970 year class (7-year-olds) was extremely strong. The unusual strength of that year class was also reported by Wilkins and Golden (1983) based on a 1979 Pacific ocean perch survey. They also observed that the 1970 year class was particularly strong in the Columbia area. Surprisingly, the 1970 year class was insignificant in the 1980 age composition. The reason for this discontinuity is unexplained, but sampling error, age determination error, and heavy commercial exploitation of that specific year class[11] are possible causes. In 1980 more fish younger than 7 years and fewer fish older than 18 years were present. Age 4–6 fish occurred in greater numbers in 1980 than in 1977, suggesting improved recruitment since 1977.

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[11] Demory, R. L., Oregon Department of Fish and Wildlife, Hatfield Marine Science Center, Newport, OR 97365. Personal commun., September 1988.

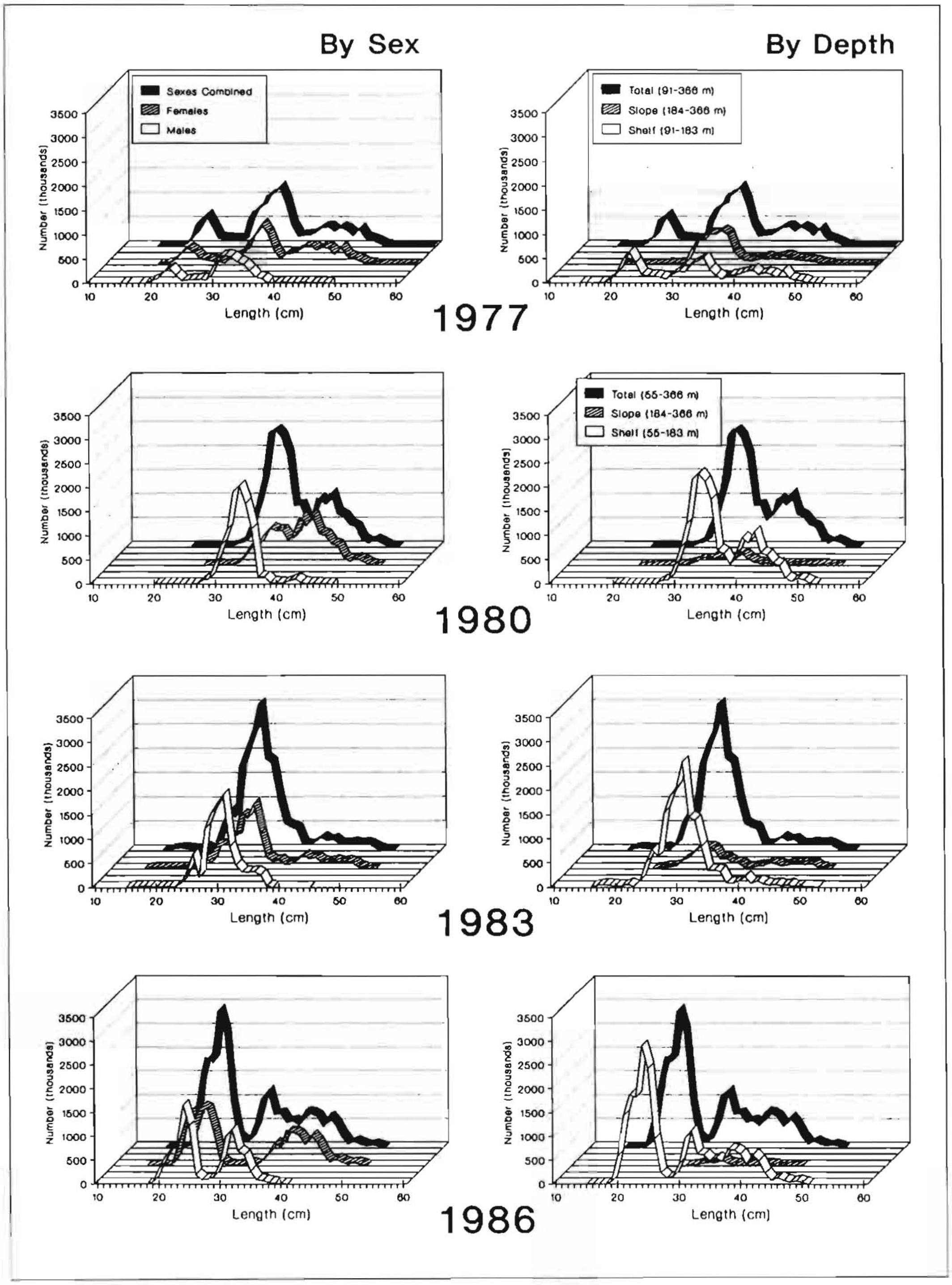

Figure 22
Chilipepper, *Sebastes goodei*, length compositions by year, depth, and sex.

Sablefish — Sablefish has a long history as an important species for the west coast groundfish industry. Annual landings were less than 6,000 t until the late 1970's when a peak catch of about 24,000 t was recorded (Francis[12]). Sablefish commands a higher price than

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[12] Francis, R. C. 1985. Status of the sablefish resource of the west coast and recommendations for management in 1986. Unpubl. manuscr., 30 p. Northwest and Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

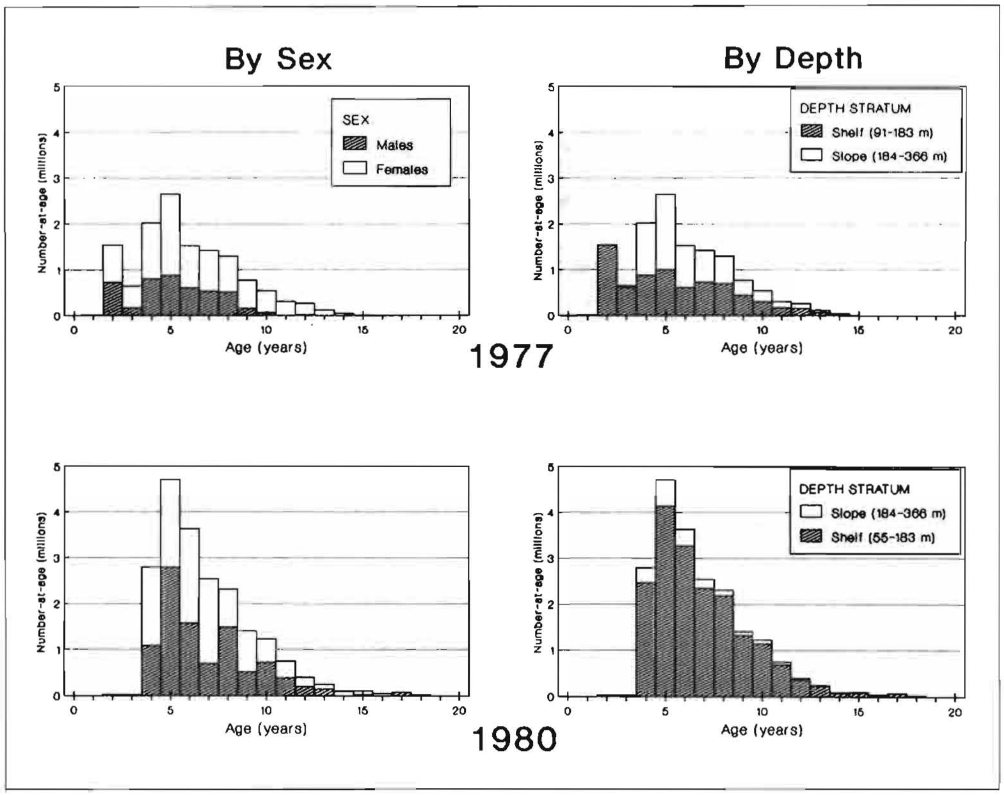

Figure 23
Chilipepper, *Sebastes goodei*, age compositions by year, depth, and sex.

most other groundfish species, which enhances its value to the industry. Volatile markets and prices have resulted in variable landings more recently, but landings have averaged about 13,123 t during 1980–87 (PacFIN 1980–1987[3]). Landings since 1986 have been limited by the optimum yield levels set by the Pacific Fishery Management Council.

Sablefish densities were greatest north of Cape Mendocino, California, in all survey years (Fig. 28). Densities tended to be greater in the deep zone, but occasionally high densities were found in small areas within the shallow stratum. There were annual, small-scale variations in density distributions, but major changes over large areas were not noted.

Biomass estimates are probably minimal because significant quantities of sablefish occur in depths greater than those surveyed (Low et al.[13]). A trawl survey of the upper continental slope off Oregon in late summer of 1984 showed that only about 50% of the sablefish biomass in the 110–914 m zone occurred between 110 and 366 m (Raymore and Weinberg, 1990). This would suggest that the 1977, 1980, and 1983 surveys accounted for, at most, only about half of the total biomass. Another factor that would contribute to underestimated biomass is the relatively low vulnerability of at least some population components to capture by trawl. Large sablefish may have a lower vulnerability to trawls than small sablefish (Parks, 1973). Therefore, survey biomass estimates presented herein may be used as indices of population size (especially for the younger component of the population); however, we caution against interpreting them as estimates of total population abundance. Sablefish population trends varied among INPFC areas (Table 13, Fig. 29). Biomass levels remained rather constant in the U.S-Vancouver area. However, in the Columbia area, biomass increased markedly between 1977 and 1983, only to fall by 57% in 1986. The biomass peak that occurred in the Columbia area in 1983 was not observed in other INPFC areas. Instead, 1983 abundance estimates were lower in those areas than in either 1980 or 1986. Trends in the Eureka and Monterey area were nearly identical. Over all areas, biomass estimates increased markedly between 1977 and 1980 only to decline thereafter. However, because of the imprecision of the total biomass estimates, the reality of this decline

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[13] Low, L. L., G. K. Tanonaka, and H. H. Shippen. 1976. Sablefish of the northeastern Pacific Ocean and Bering Sea. Northwest and Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115. NWAFC Processed Rep., 115 p.

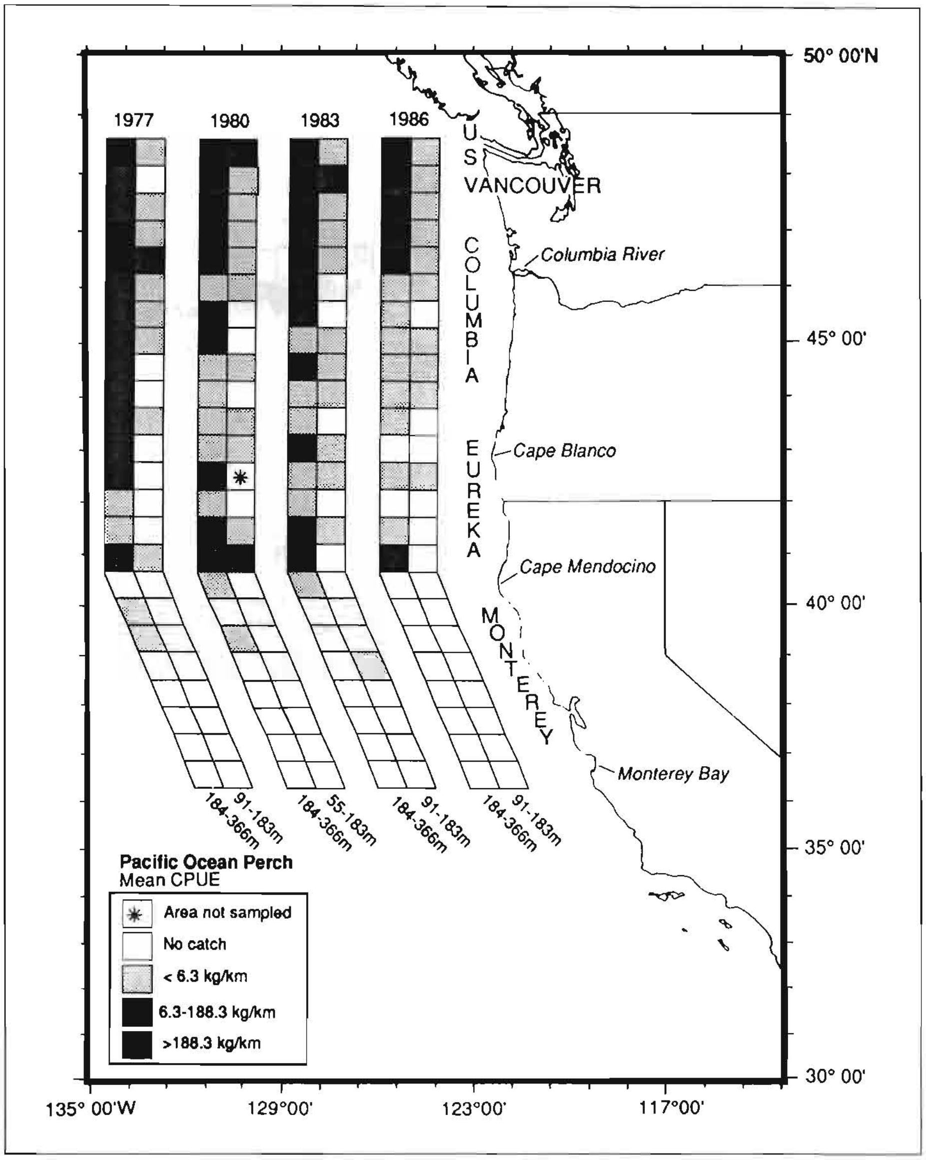

Figure 24

Distribution of Pacific ocean perch, *Sebastes alutus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

remains in question. Biomass estimates did not differ significantly between any years in any area (Table 7).

Sablefish caught in trawl samples ranged in length from 22 to 70 cm; most were between 35 and 55 cm long (Fig. 30). Because of size selection by the trawl and the absence of samples from the deeper portions of this species' bathymetric range, actual mean population lengths were probably greater than sample mean lengths. Parks (1973), for instance, found that trawls failed to sample sablefish longer than 68 cm in the same proportion as did traps. The use of small mesh (32 mm) liners in codends probably resulted in the trawls sampling small sablefish in proportion to their true abundance. Klein[14] found that the minimum retention length for 32-mm mesh was 25 cm. Very few sablefish less than 27 cm occurred in our surveys. Most sablefish in survey trawl samples are less than 52 cm, which until recently was considered an unmarketable size by the industry. Except in 1986, length compositions were bimodal in all years, with modes at about 38 and 46 cm; in 1986, only the mode at 38 cm was noted.

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[14] Klein, S. J. 1986. Selectivity of trawl, trap, longline and set-net gears to sablefish, *Anoplopoma fimbria*. Northwest and Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115. NWAFC Processed Rep. 86-06, 84 p.

Table 12

Pacific ocean perch, *Sebastes alutus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.8	165	0–446		1.0	802	42–1,562	
	184–366	84.1	7,424	0–16,037		19.7	5,854	3,081–8,627	
	91–366	25.3	7,589	0–16,207	64.8	6.2	6,656	3,870–9,442	22.5
1980	55–183	2.0	525	0–1,294		0.1	96	13–178	
	184–366	29.1	2,602	0–5,673		10.8	3,245	1,167–5,322	
	55–366	8.9	3,128	50–6,205	53.7	2.3	3,340	1,260–5,420	35.4
1983	55–183	4.2	1,093	0–3,183		0.0	58	1–114	
	184–366	30.1	2,693	980–4,407		9.6	2,889	594–5,184	
	55–366	10.7	3,786	1,262–6,310	37.6	2.0	2,947	651–5,243	43.4
1986	55–183	0.3	73	30–117		<0.1	24	10–37	
	184–366	12.9	1,141	314–1,968		5.6	1,559	0–8,534	
	55–366	3.3	1,214	386–2,043	38.3	1.0	1,583	0–8,558	69.8

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.1	10	0–26		0.0	0	—		0.6	977	170–1,783	
	184–366	2.7	220	64–375		<0.1	1	0–2		23.7	13,499	4,595–22,402	
	91–366	0.9	229	73–385	39.3	<0.1	1	0–2	50.3	6.9	14,475	5,532–23,419	35.5
1980	55–183	0.4	90	0–232		0.0	0	—		0.3	710	0–1,492	
	184–366	3.0	238	101–375		<0.1	6	0–12		10.3	6,090	2,587–9,593	
	55–366	1.2	328	140–515	33.2	<0.1	6	0–12	65.0	2.4	6,801	3,225–10,377	30.2
1983	55–183	0.1	28	0–67		<0.1	6	0–16		0.5	1,184	0–3,276	
	184–366	4.4	354	4–704		0.0	0	—		10.0	5,937	3,193–8,680	
	55–366	1.0	381	29–734	48.8	<0.1	6	0–17	101.0	2.4	7,121	3,835–10,406	27.0
1986	55–183	<0.1	<1	0–1		<0.1	<1	0–1		<0.1	98	52–144	
	184–366	1.7	141	0–297		1.8	230	0–497		5.3	3,072	0–11,058	
	55–366	0.4	141	0–298	62.6	0.3	230	0–497	65.4	1.0	3,169	0–11,149	39.9

Data from other studies (Chilton and Beamish, 1982; Parks and Shaw, 1987; Methot and Hightower[15]) indicate that fish in the 38 cm mode were primarily age-1 fish and most of those in the 46 cm mode were probably age 2–4 fish. In all years, few fish less than 45 cm were found in the deep stratum, but those of 45–55 cm were somewhat more equally distributed between the two zones. These data and the results of other studies (McFarlane and Beamish, 1983; Sasaki, 1985) provide good evidence that sablefish first occur in bays, inlets, and on the continental shelf at age 1, move off the shelf and onto the upper slope as they grow older, and move deeper with increasing age.

Lingcod — Lingcod has always been an important component of west coast trawl landings, but landings have recently been less than those of commercially important rockfish and flatfish species. Landings in-

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[15] Methot, R., and J. Hightower. 1988. The status of the Washington-Oregon-California sablefish stock in 1988. *In* Pacific Fisheries Management Council, Status of the Pacific Coast groundfish fishery through 1988 and recommended acceptable biological catches for 1989. Appendix B. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR, 97201.

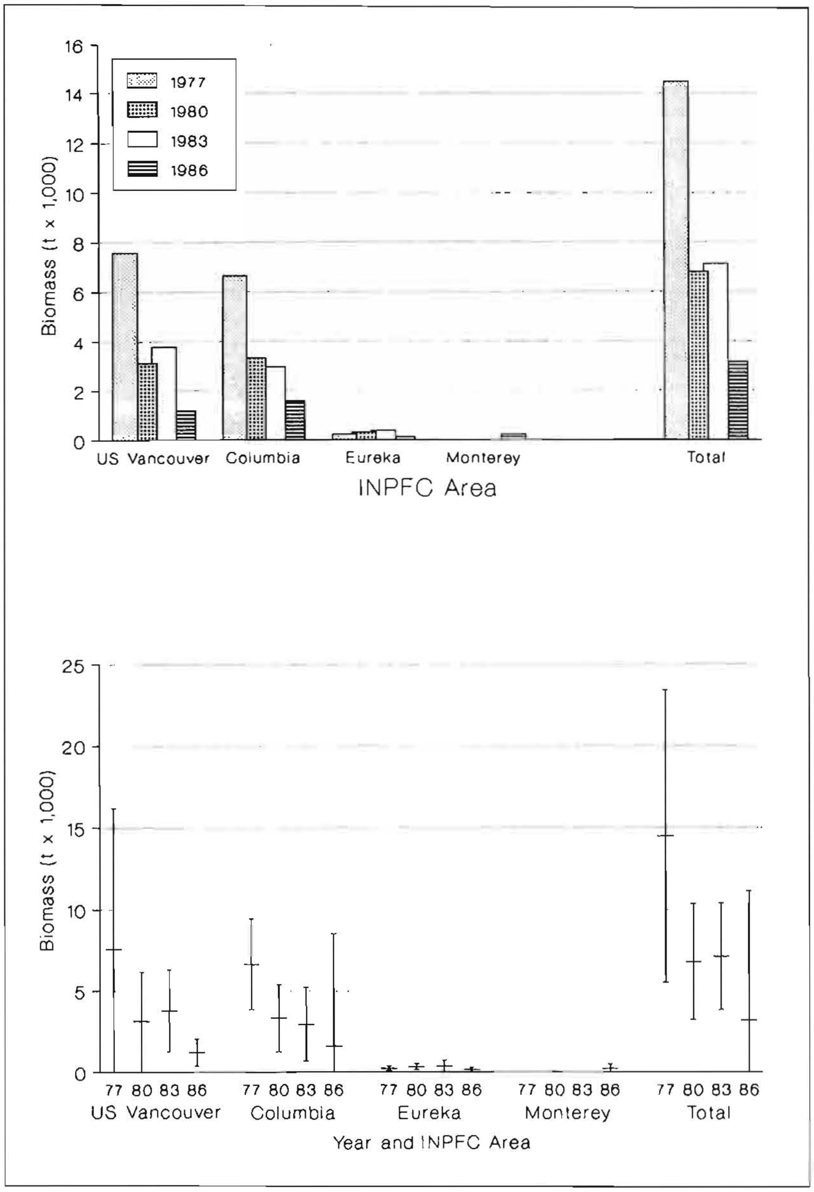

Figure 25

Estimates of Pacific ocean perch, *Sebastes alutus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

creased constantly from 806 t in 1963 to 4,146 t in 1983, but decreased to 2,561 t in 1987 (Pacific Fishery Management Council[16]; PacFIN, 1983 and 1988[3]). The species is sought by recreational as well as commercial fishermen.

Based on survey CPUE observations, lingcod densities were always relatively high in the U.S.-Vancouver and northern Columbia areas (Fig. 31). Elsewhere, high densities occurred sporadically with little consistency among years, but abundance dropped notably south of the Columbia area. Average CPUE for the four surveys combined was 4.8 kg/km in the U.S.-Vancouver area, 5.4 kg/km in the Columbia area, 1.2 kg/km in the Eureka area, and 1.7 kg/km in the Monterey area. Densities were noticeably higher in the shallow zone, although in some areas, particularly in the U.S.-Van-

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[16] Pacific Fishery Management Council. 1982. Fishery management plan and supplemental environmental impact statement for the Washington, Oregon, and California groundfish fishery. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201. 320 p.

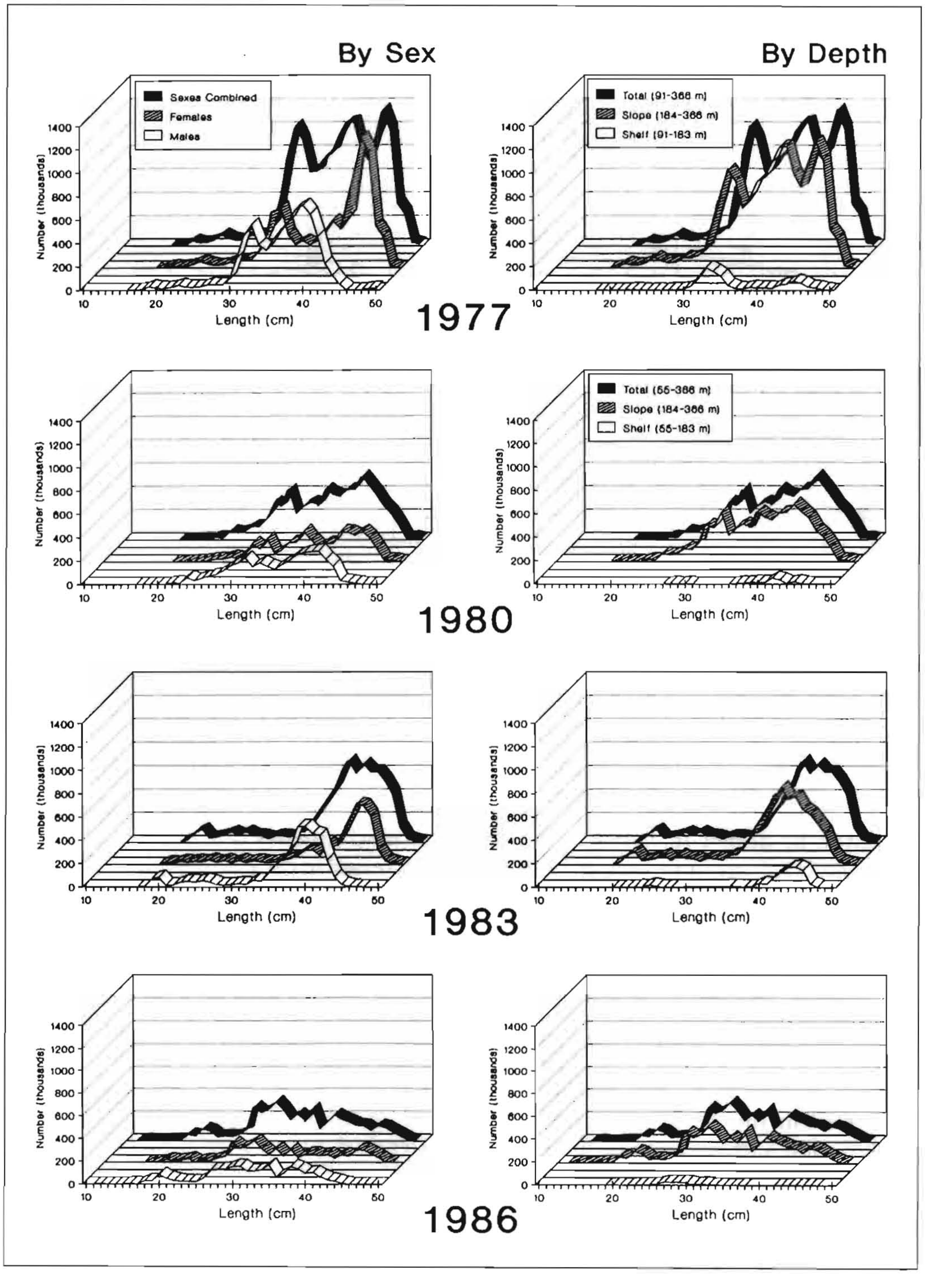

Figure 26
Pacific ocean perch, *Sebastes alutus*, length compositions by year, depth, and sex.

couver area in 1980 and 1983, lingcod were also quite abundant in the deep zone. The distribution of biomass in 1986 was clearly more patchy than in earlier survey years, particularly in the deep zone.

Most of the lingcod biomass occurred in the Columbia area (Fig. 32, Table 14). The major proportion of the biomass was found in the 55–183 m depth interval in all areas. Overall, slightly more than 8% of the bio-

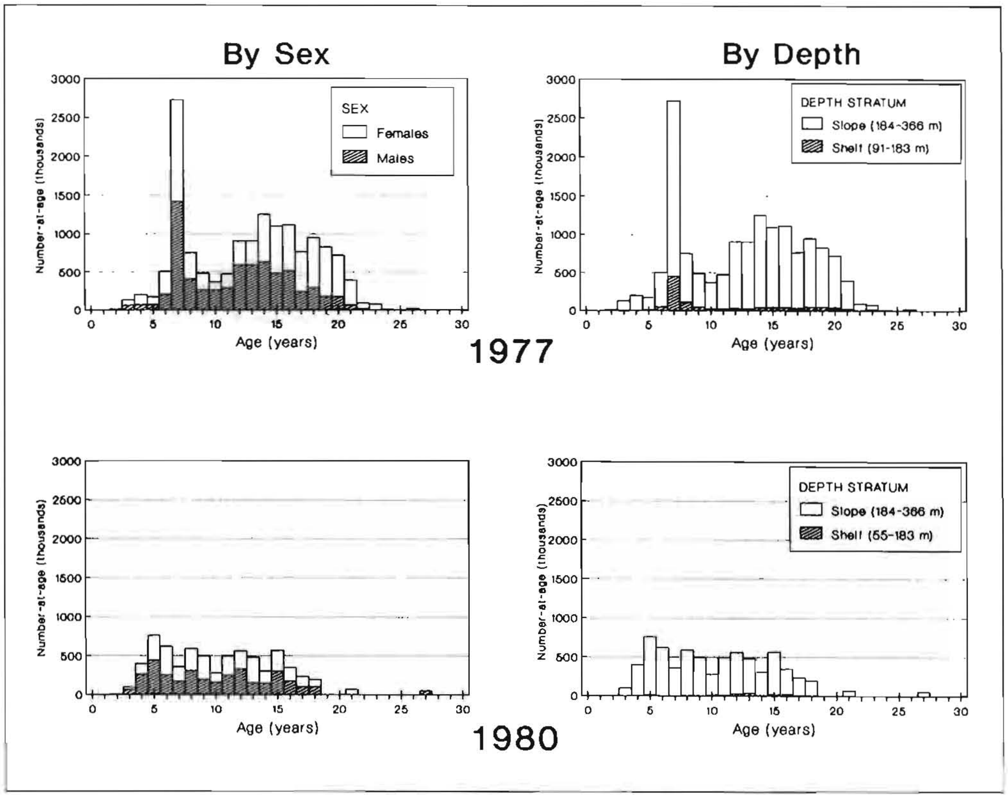

Figure 27
Pacific ocean perch, *Sebastes alutus*, age compositions by year, depth, and sex.

mass was estimated to be deeper than 183 m, but in certain areas (e.g. the U.S.-Vancouver area in 1983) as much as 62% occurred in the deep zone. A declining trend in biomass over time was observed in the U.S.-Vancouver area, but the most dramatic reduction occurred in the Columbia area, where estimates fell from 12,650 t in 1977 to 1,849 t in 1986. Biomass estimates in the Eureka and Monterey areas were relatively small and variable, without a discernable temporal trend. The dominating influence of the trend in the Columbia area was reflected in the estimates of coastwide biomass, which also show a steady and precipitous decline of 77% since 1977. However, because of the relatively large confidence intervals around some of the point estimates, this trend may not be valid. For instance, in 1977 the 90% confidence interval for the total biomass was ±126% of the point estimate. The CV in that year was about 70%, but it then decreased steadily from 47% in 1980 to 12% in 1986. Lingcod densities in 1986 were lower than in other years throughout the survey area (Fig. 31), suggesting a declining population. The total biomass and Columbia area estimates for 1986 were significantly smaller than the corresponding 1983 estimates, but *Z* values for all other paired comparisons were not significant (Table 7).

English sole — English sole has long been a mainstay in trawl fisheries of the west coast, but landings have decreased in the past eight years from 3,242 t in 1980 to 2,474 t in 1987 (PacFIN, 1981 and 1988[3]). Even so, English sole usually ranked second among flatfish only to Dover sole in tonnage landed (Jow and Geibel[17]).

English sole were distributed more evenly throughout the survey area than many other species. Somewhat higher densities of English sole were often found off California, south of Cape Mendocino (Fig. 33). The CPUE averaged over the four surveys ranged from 1.3 (Eureka) to 2.4 (Monterey) kg/km trawled (Table 15). Densities were lower throughout the survey area in 1977 and 1980, with only scattered pockets of high densities. In contrast, higher overall abundance in 1983 and 1986 resulted in more uniform distributions; densities were moderate to high over much of the continental shelf. The species was much less densely distributed in depths greater than 183 m.

Estimates of English sole biomass steadily increased between 1977 and 1986 in all areas except Monterey,

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[17] Jow, T., and J. J. Geibel. 1985. Progress report on the status of English sole in California Conception, Monterey, and Eureka areas. *In* Pacific Fisheries Management Council, Status of the Pacific Coast groundfish fishery through 1985 and recommended acceptable biological catches for 1986, 7 p. Pacific Fisheries Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, OR 97201.

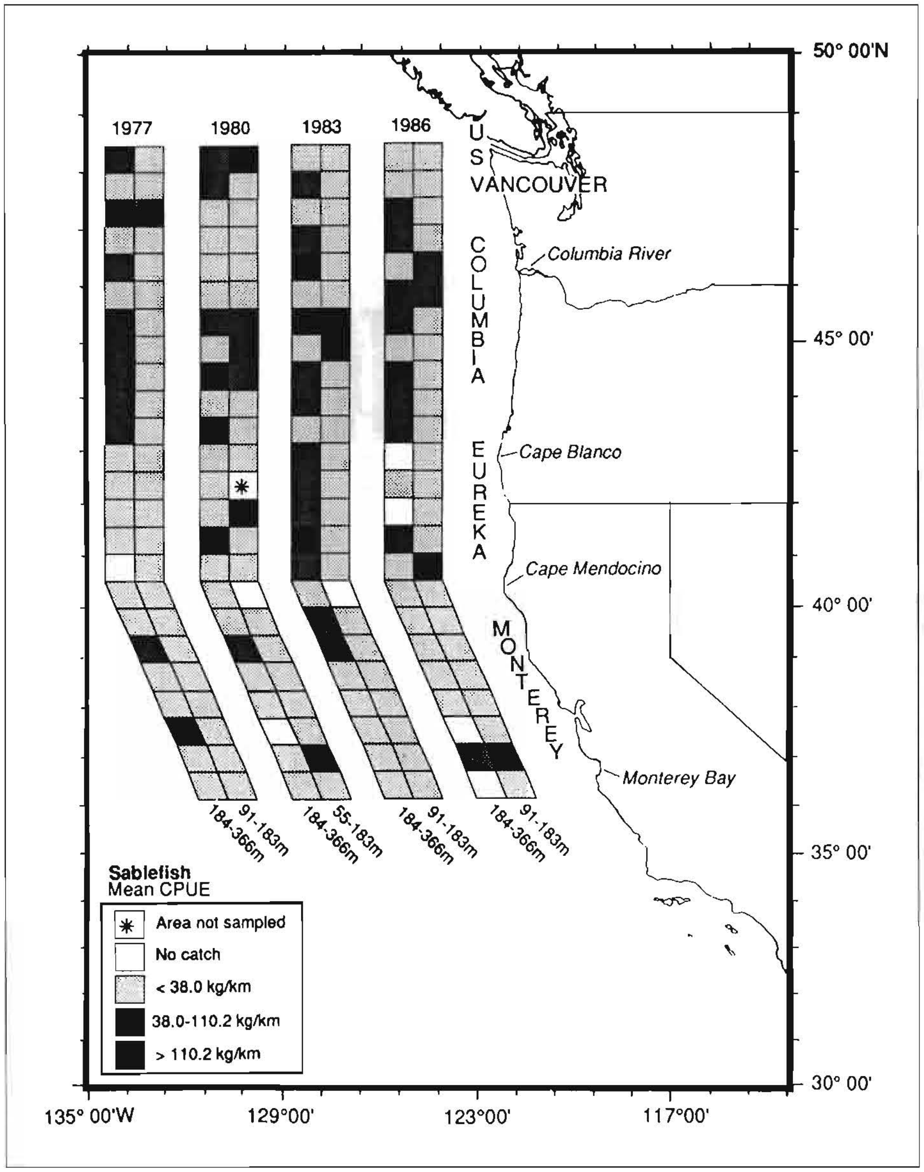

Figure 28
Distribution of sablefish, *Anoplopoma fimbria*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

where biomass decreased 31% between 1983 and 1986 (Table 15, Fig. 34). Estimates derived for the entire survey area showed continuous increases (1,785 in 1977, 2,598 in 1980, 7,180 in 1983, and 7,313 t in 1986). Only 5% of the estimated biomass occurred in the deep stratum. English sole, and flatfishes in general, are much more uniformly distributed than non-flatfishes. Consequently, the precision of flatfish biomass estimates tends to be much higher. Therefore, trawl surveys are capable of detecting smaller changes in population sizes. Confidence intervals of biomass estimates were clearly compressed (Fig. 34), and CV's for the total biomass estimates were less than 20% (Table 15). More than half of the biomass estimate pairs that were compared by Z-tests were significantly different (Table 7). Significant changes in abundance took place in all INPFC areas and the survey area as a whole, giving more validity to the observed trends. Total biomass estimates for 1983 and 1986 were significantly greater than estimates for 1977 and 1980, lending support to the conclusion that a major increase in abundance has occurred since 1980. English sole biomass estimates were low, given the magnitude of commercial landings. Relatively low vulnerability to the sampling gear and the absence of

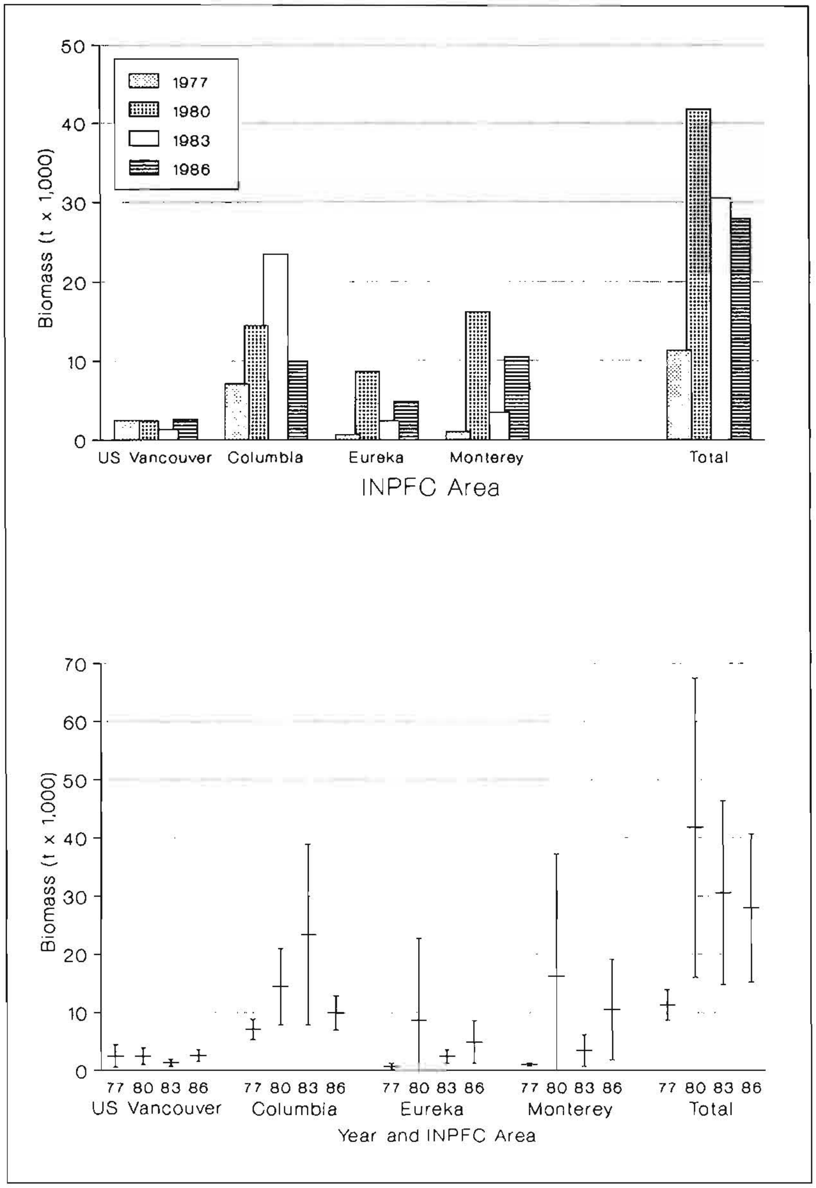

Figure 29

Estimates of sablefish, *Anoplopoma fimbria*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

sampling throughout the species' bathymetric range were probably major factors leading to underestimation. The trawl equipment employed in our groundfish surveys was selected to sample rockfish and Pacific hake, and the roller gear on the footrope may have caused it to be less efficient for capturing flatfish. Flatfish biomass estimates were derived for the purpose of identifying population changes and should be viewed as minimal estimates of abundance.

Lengths of English sole collected in the 1980, 1983, and 1986 surveys ranged from about 14 to 50 cm with females predominating at lengths longer than about 29 cm (Fig. 35). Almost all individuals larger than 40 cm were females. The vast majority of the resource was located in waters over the continental shelf, so few observations were available from the deep zone. However, a small sample obtained in 1986 was composed of fish larger than 32 cm. Little interannual variation in the length distribution occurred during the three years of record. The most abundant length classes in 1986 were more broadly distributed than in previous years, possibly because of the presence of several strong

Table 13

Sablefish, *Anoplopoma fimbria* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	4.0	848	283–1,413		4.5	3,513	1,955–5,072	
	184–366	18.9	1,667	0–3,587		12.1	3,605	2,720–4,490	
	91–366	8.4	2,515	531–4,499	45.2	6.6	7,119	5,385–8,852	14.3
1980	55–183	6.5	1,711	384–3,039		8.1	9,470	3,759–15,182	
	184–366	8.2	731	136–1,325		16.7	4,988	1,556–8,420	
	55–366	6.9	2,442	1,023–3,860	33.7	9.9	14,458	7,894–21,022	27.3
1983	55–183	1.6	431	0–938		14.3	16,647	1,375–31,920	
	184–366	10.2	914	488–1,341		22.3	6,723	3,696–9,751	
	55–366	3.8	1,345	734–1,956	25.6	16.0	23,371	7,862–38,879	39.3
1986	55–183	6.3	1,740	934–2,547		5.1	6,269	3,529–9,009	
	184–366	9.9	873	87–1,658		13.3	3,675	2,478–4,873	
	55–366	7.2	2,613	1,542–3,684	24.2	6.6	9,944	7,009–12,879	17.2

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	3.1	548	16–1,079		1.1	389	203–575		3.5	5,298	3,580–7,016	
	184–366	1.5	117	48–187		5.8	623	400–845		10.5	6,012	3,948–8,076	
	91–366	2.6	665	131–1,199	46.3	2.2	1,012	728–1,295	16.6	5.4	11,310	8,676–13,944	13.8
1980	55–183	41.2	8,324	0–2,234		24.9	15,815	0–36,808		15.6	35,321	9,824–60,818	
	184–366	4.3	347	0–708		3.0	366	128–604		10.9	6,431	2,946–9,916	
	55–366	30.7	8,671	0–22,694	92.6	21.4	16,181	0–37,167	77.5	14.6	41,752	16,047–67,457	36.9
1983	55–183	2.7	832	0–1,669		2.3	1,475	455–2,496		8.2	19,385	4,062–34,708	
	184–366	19.6	1,571	669–2,472		16.2	1,963	0–4,535		18.9	11,171	7,230–15,113	
	55–366	6.2	2,403	1,233–3,573	28.4	4.5	3,438	693–6,183	46.7	10.3	30,557	14,783–46,330	30.6
1986	55–183	13.2	4,211	507–7,916		14.4	9,515	899–18,132		8.8	21,736	9,124–34,348	
	184–366	8.2	693	140–1,246		7.5	948	7–1,890		10.8	6,189	4,317–8,061	
	55–366	12.1	4,904	1,178–8,631	45.5	13.3	10,464	1,819–19,108	49.4	9.1	27,925	15,190–40,660	27.3

year classes; however, no age data were available to confirm this.

Dover sole — Dover sole is another species that always has been a key component of trawl landings. In recent years, Dover sole and arrowtooth flounder, *Atheresthes stomias*, were the only two flatfishes that have contributed to major increases in landings. From 1963 to 1968, Dover sole landings averaged about 6,400 t, but in 1969 landings rose to 8,643 t and continued to increase, reaching 20,719 t in 1983 before declining to 18,391 t in 1987 (Pacific Fishery Management Council[16]; PacFIN, 1984 and 1988[3]). Much of this increase was due to the expansion of the Dover sole fishery to new grounds in deep waters, especially off northern California. Presently, Dover sole landings are exceeded only by Pacific hake landings.

Most of the Dover sole resource occurred on the upper continental slope in the deeper portions of the survey area (Fig. 36). There were notable interannual variations in distribution and density. Higher densities were found in the deep stratum throughout much of the survey area in 1977 but densities at all depths were uniformly low in 1980. By 1983 densities were higher and even more uniform than in 1977. Overall density

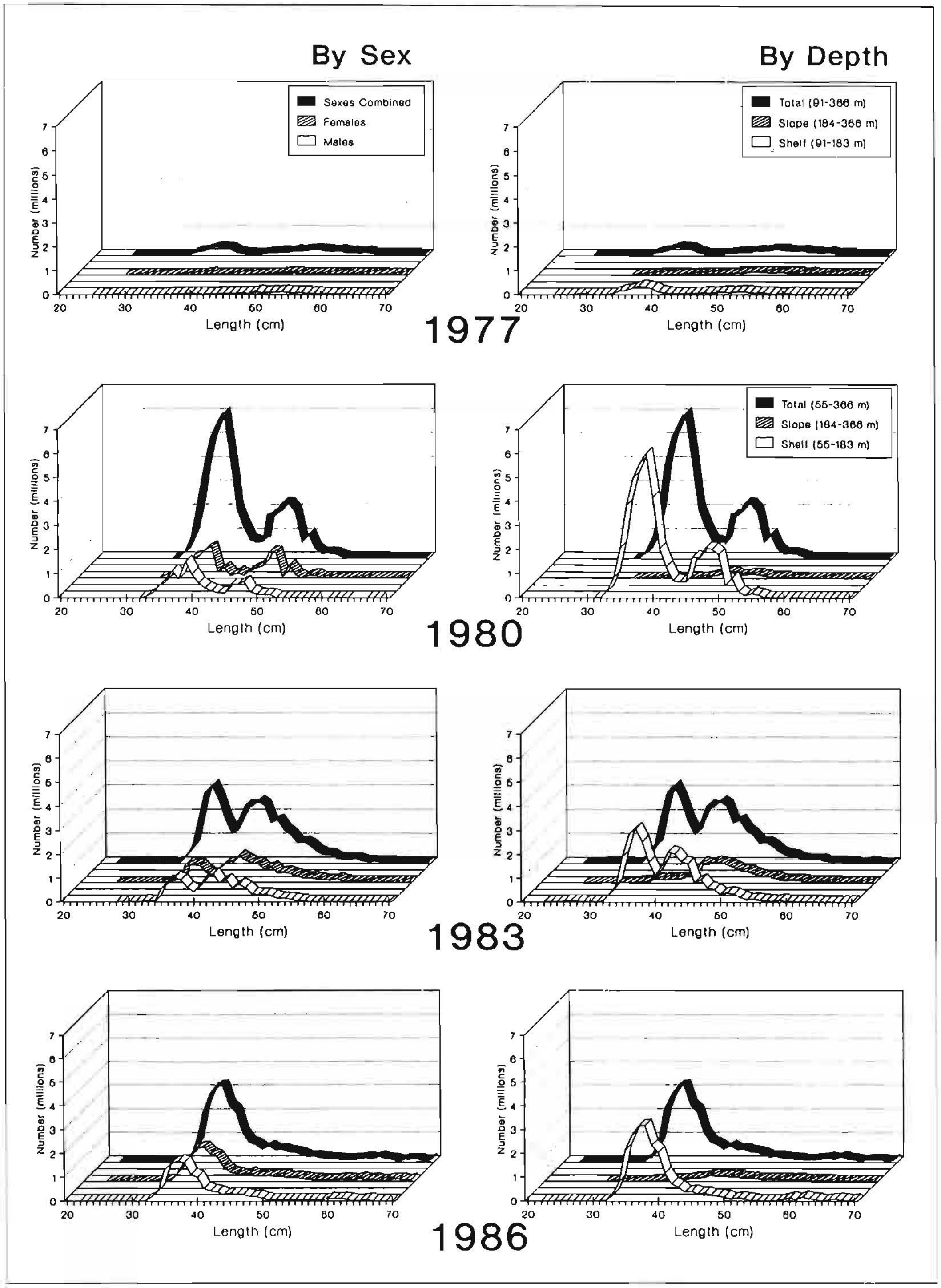

Figure 30
Sablefish, *Anoplopoma fimbria*, length compositions by year, depth, and sex.

rose again in 1986, with much of the increase occurring south of Washington. In all years, higher densities were observed in the Monterey area.

These values should be considered minimal estimates as for English sole. A bottom trawl survey of the upper continental slope conducted in the Columbia area in 1984 between 110 and 914 m (Raymore and Weinberg, 1990) indicated that 51% of the estimated Dover sole biomass occurred between 366 and 914 m, a depth interval not sampled by the coastwide triennial surveys.

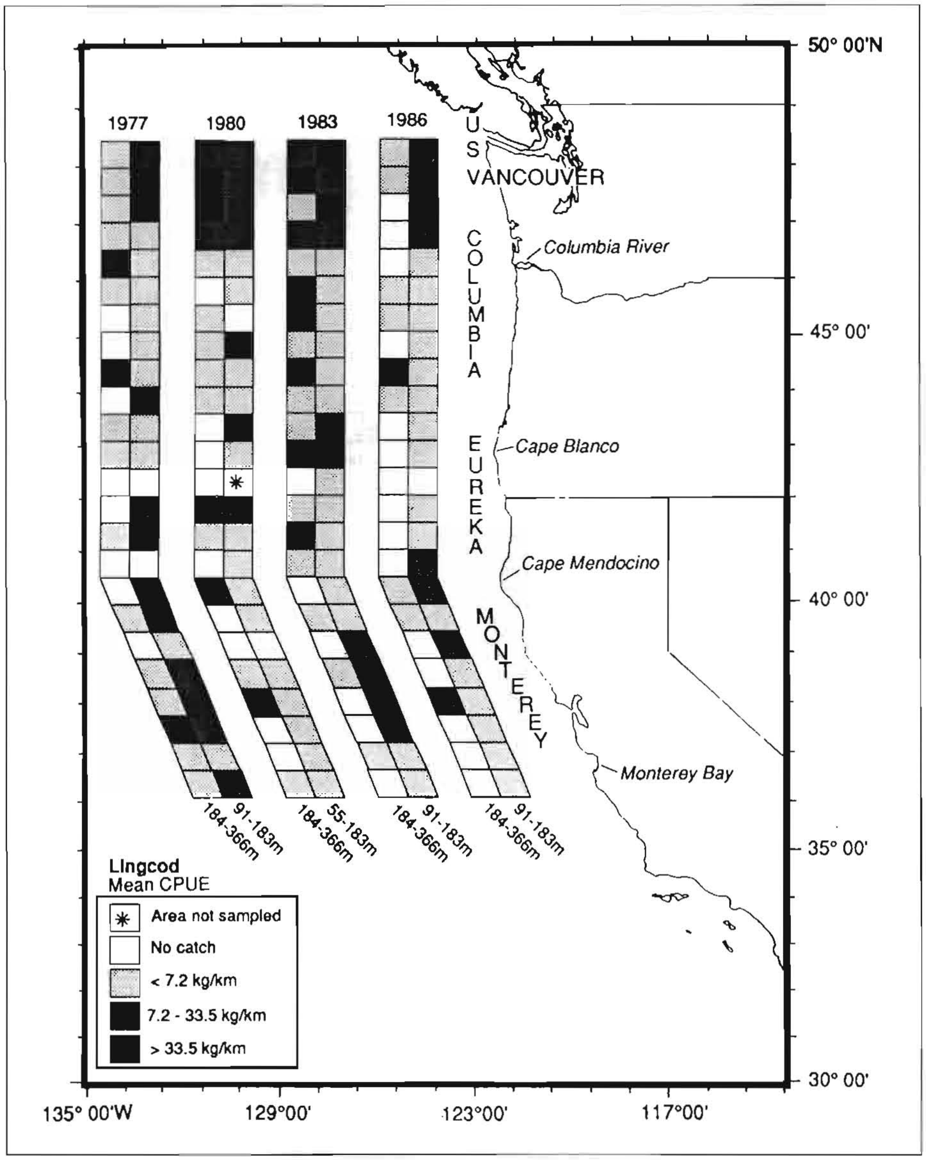

Figure 31

Distribution of lingcod, *Ophiodon elongatus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

This suggests that our biomass estimates are only about half the level they would be had sampling occurred as deep as 914 m. In all years most of the biomass was in the Columbia area (Table 16, Fig. 37), more because of the area's size than higher fish density. As with English sole, the population size of Dover sole increased during the survey period in all areas except the U.S.-Vancouver area. The 29% decrease in estimated biomass (from 15,054 to 10,698 t) observed between 1977 and 1980 was reversed in 1983 and 1986 when total biomass estimates increased to 19,241 and 25,121 t, respectively. Thus, estimated total stock size increased between 1980 and 1986. The relatively uniform distribution of Dover sole led to low estimates of variance (overall CV's were less than 10%) and narrow confidence limits (15% or less of the total biomass estimates). Biomass estimates for this species were the most precise in this study. The total biomass estimates for all years were significantly different from one another, giving credibility to the major biomass increases observed since 1980 (Table 7). Many significant interannual differences in biomass were observed in all INPFC areas except the U.S.-Vancouver area. Thus, the increasing trend in biomass was nearly coastwide during the study period.

Dover sole ranged in length from 15 to 64 cm, with most fish between 25 and 45 cm (Fig. 38). Females were

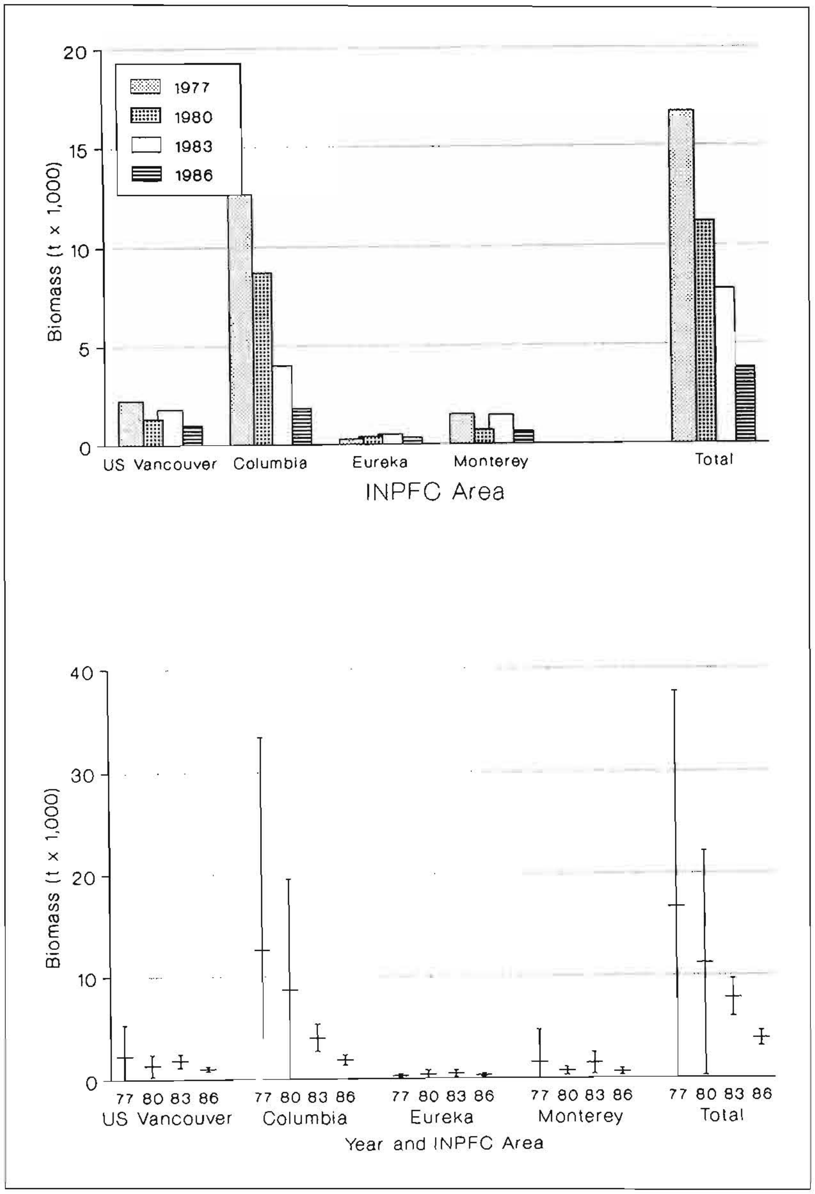

Figure 32
Estimates of lingcod, *Ophiodon elongatus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

larger than males on average, and they predominated at lengths greater than about 38 cm. Males tended to predominate in the 25–35 cm length range, which may be a result of differential growth rates or perhaps unequal vulnerability to the sampling gear. The length distribution shifted somewhat toward larger sizes when samples from the deep zone were isolated, displaying a tendency for length to increase with depth. The population was composed of a greater proportion of small fish (<28 cm) in 1983 and 1986 than in 1980, but otherwise few interannual differences in size composition were observed.

Rex sole — Landings of rex sole, *Errex zachirus*, have varied between 1,200 and 1,745 t from 1981 to 1987 (PacFIN, 1982–1988[3]). Although the species is common in mixed species trawl catches, it usually ranks only fourth or fifth among flatfish landings. This remained true in 1987, when the ex-vessel price was about $0.38 per pound, which was higher than that paid for Dover sole or arrowtooth flounder—the two most abundant species in the landings (PacFIN, 1988[3]).

Rex sole densities displayed notable interannual variability (Fig. 39). Densities in 1977 and 1980 were lower in all INPFC areas than in subsequent years. However,

Table 14

Lingcod, *Ophiodon elongatus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.7	2,260	0–5,298		15.8	12,343	0–33,121	
	184–366	0.2	17	0–38		1.0	307	85–529	
	91–366	7.6	2,277	0–5,315	66.2	11.7	12,650	0–33,429	90.7
1980	55–183	3.6	951	47–1,854		7.4	8,548	0–19,450	
	184–366	4.4	393	0–1,059		0.6	167	41–292	
	55–366	3.8	1,343	274–2,413	46.5	6.0	8,715	0–19,617	73.6
1983	55–183	4.4	1,152	689–1,615		2.9	3,419	2,096–4,741	
	184–366	7.3	652	194–1,110		2.0	597	333–862	
	55–366	5.1	1,805	1,172–2,438	20.8	2.7	4,016	2,669–5,363	20.2
1986	55–183	3.5	974	735–1,213		1.4	1,698	1,227–2,169	
	184–366	0.4	31	0–64		0.5	151	0–334	
	55–366	2.8	1,005	764–1,246	14.5	1.2	1,849	1,355–2,343	16.0

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	1.4	242	63–420		3.3	1,234	0–4,203		10.5	16,080	0–37,055	
	184–366	0.4	32	0–71		2.7	279	0–675		1.1	635	214–1,055	
	91–366	1.1	274	93–455	38.3	3.2	1,513	0–4,705	33.4	8.0	16,714	0–37,693	69.3
1980	55–183	1.8	356	0–752		0.8	504	176–832		4.6	10,359	0–21,308	
	184–366	0.8	67	0–168		1.7	210	7–413		1.4	836	151–1,521	
	55–366	1.5	423	19–827	55.1	0.9	714	332–1,095	32.0	3.9	11,195	227–22,163	57.7
1983	55–183	1.3	391	47–735		2.3	1,442	399–2,485		2.7	6,404	4,639–8,169	
	184–366	1.4	108	18–197		0.2	26	0–62		2.3	1,384	862–1,905	
	55–366	1.3	499	149–848	38.2	1.9	1,468	425–2,511	42.4	2.6	7,788	5,953–9,622	14.2
1986	55–183	0.8	253	136–371		0.8	516	245–787		1.4	3,441	2,772–4,110	
	184–366	0.9	79	0–210		1.0	124	0–349		0.7	385	10–761	
	55–366	0.8	332	170–494	28.1	0.8	641	313–968	30.2	1.2	3,826	3,083–4,569	11.7

in all years the Monterey area was the most important region for rex sole. In contrast, the U.S.-Vancouver area always contained lower densities. As overall biomass increased in 1983 and 1986 (Fig. 40), densities in the Monterey, Eureka, and Columbia areas increased markedly. Increases in biomass resulted in the same types of distributional changes that have been noted for other flatfishes; the distribution became more homogeneous and young fish were more abundant in the 55–183 m depth zone.

Rex sole biomass followed the pattern observed in other flatfish species, with major increases occurring in 1983 and 1986 (Fig. 40, Table 17). Little change was observed in the U.S.-Vancouver area, but significant increases in abundance occurred in all areas to the south (Table 7). The greatest percentage change took place in the Eureka area, where the 1986 biomass was about ten times greater than the 1977 and 1980 estimates. The overall rex sole biomass estimate increased by 254% between 1980 and 1986. Variances were relatively small; CV's for total biomass estimates were less than 12%.

Rex sole ranged in length from 10 to 48 cm; most occurred in a single mode between 20 and 33 cm (Fig.

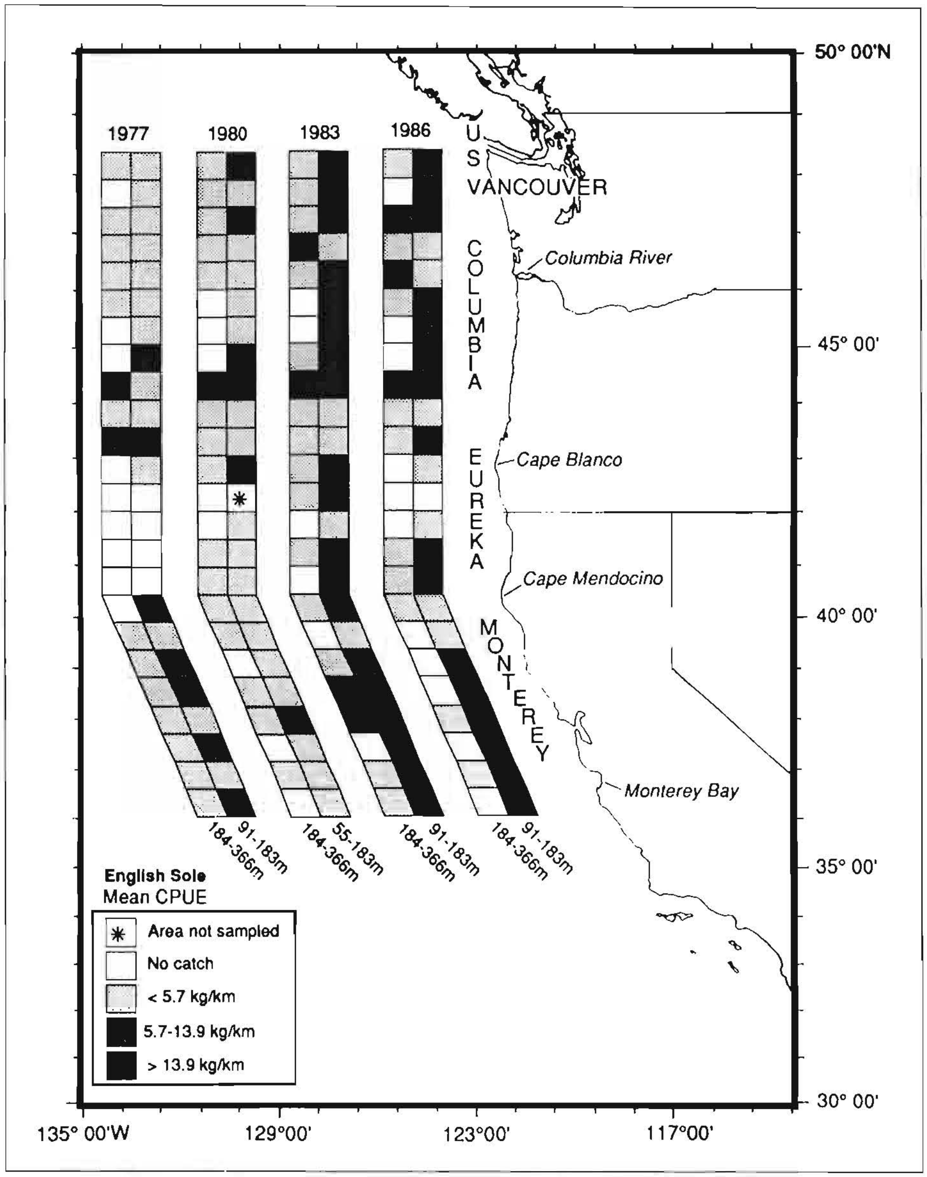

Figure 33

Distribution of English sole, *Pleuronectes vetulus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

41). Differential growth between sexes was similar to that found in other flatfishes; females were generally larger than males and dominated at sizes greater than 28 cm. Again, little interannual variation in length composition was apparent.

Arrowtooth Flounder — Historically, arrowtooth flounder has been considered a low value species and typically was used in the reduction industry. Landings have been small, amounting to only a few hundred tons annually. However, landings began to increase in the early 1980s and in 1987 they were more than triple historical levels at 2,831 t (PacFIN, 1988[3]; Coleman and Raymore[18]). Although that was still a relatively low utilization rate, an expanding market would lead one to anticipate continued increases in landings.

Arrowtooth flounder occurs mainly in the Gulf of Alaska. The area covered by these surveys is at the southern extreme of its range. A distinct latitudinal cline in arrowtooth flounder density was observed off the west coast from 1977 to 1986 (Fig. 42). On average,

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[18] Coleman, B. A., and P. A. Raymore Jr. 1990. An investigation of the history and population trends for the Pacific west coast arrowtooth flounder (*Atheresthes stomias*) resource from 1975–1986. Unpubl. manuscr., 72 p. Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115.

Table 15

English sole, *Pleuronectes vetulus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.3	63	26–99		0.8	612	300–924	
	184–366	0.1	8	1–14		0.8	238	75–400	
	91–366	0.2	71	34–108	30.5	0.8	849	501–1,198	24.4
1980	55–183	2.1	556	0–1,149		1.1	1,262	777–1,747	
	184–366	0.2	23	0–51		0.2	53	0–112	
	55–366	1.6	578	0–1,170	58.6	0.9	1,315	826–1,804	20.0
1983	55–183	2.4	634	322–945		2.0	2,271	1,882–2,660	
	184–366	0.5	41	0–114		0.5	158	39–278	
	55–366	1.9	674	360–988	27.7	1.7	2,430	2,025–2,834	10.0
1986	55–183	3.7	1,022	808–1,235		2.2	2,733	2,235–3,232	
	184–366	0.2	21	3–39		0.5	134	33–235	
	55–366	2.8	1,043	828–1,257	11.8	1.9	2,867	2,360–3,374	10.6

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	<0.1	3	0–8		2.0	829	378–1,280		0.9	1,507	1,005–2,008	
	184–366	0.0	0	—		0.3	33	0–73		0.5	278	113–443	
	91–366	<0.1	3	0–8	96.2	1.6	862	409–1,314	24.6	0.8	1,785	1,261–2,308	16.7
1980	55–183	0.5	98	27–169		0.9	558	320–796		1.1	2,474	1,708–3,240	
	184–366	0.1	5	0–9		0.4	45	5–85		0.2	125	52–198	
	55–366	0.4	102	31–174	37.5	0.8	603	362–844	23.9	0.9	2,598	1,827–3,369	17.5
1983	55–183	2.4	739	469–1,008		5.0	3,168	2,224–4,111		2.9	6,811	5,718–7,903	
	184–366	0.2	13	1–26		1.3	156	0–331		0.6	369	158–579	
	55–366	2.0	752	482–1,022	21.2	4.4	3,324	2,366–4,281	17.2	2.4	7,180	6,069–8,291	9.3
1986	55–183	3.4	1,078	871–1,285		3.5	2,285	1,824–2,746		2.9	7,118	6,250–7,987	
	184–366	0.2	18	6–29		0.2	23	3–42		0.3	195	87–303	
	55–366	2.7	1,096	888–1,303	11.3	2.9	2,308	1,846–2,769	12.0	2.4	7,313	6,439–8,188	7.2

densities in the U.S.-Vancouver area (14.5 kg/km) were much greater than in the Columbia (3.5 kg/km), Eureka (0.5 kg/km), or Monterey (0.1 kg/km) areas. Highest densities were found north of the Columbia River in all years, and low densities occurred south of Cape Blanco, Oregon; the species was absent in survey samples from south of San Francisco Bay (lat. 37°30'N). We concluded that both depth zones provided important habitat because densities in the shallow zone were usually commensurate with densities in adjacent sections of the deep zone. Densities and distributions were similar throughout the study period.

The biomass estimates (Fig. 43, Table 18) of this study are conservative. The aforementioned survey of the continental slope in 1984 (Raymore and Weinberg, 1990) indicates that over one third of the arrowtooth flounder biomass could occur between 366 and 549 m, a depth interval not covered in this study. Almost all of the estimated arrowtooth flounder biomass occurred in the U.S.-Vancouver and northern Columbia areas (Fig. 43). In all four years, biomass estimates were similar in the U.S.-Vancouver area and the Columbia area.

Declines in biomass occurred in these two areas between 1977 and 1983; the 1983 biomass estimates were

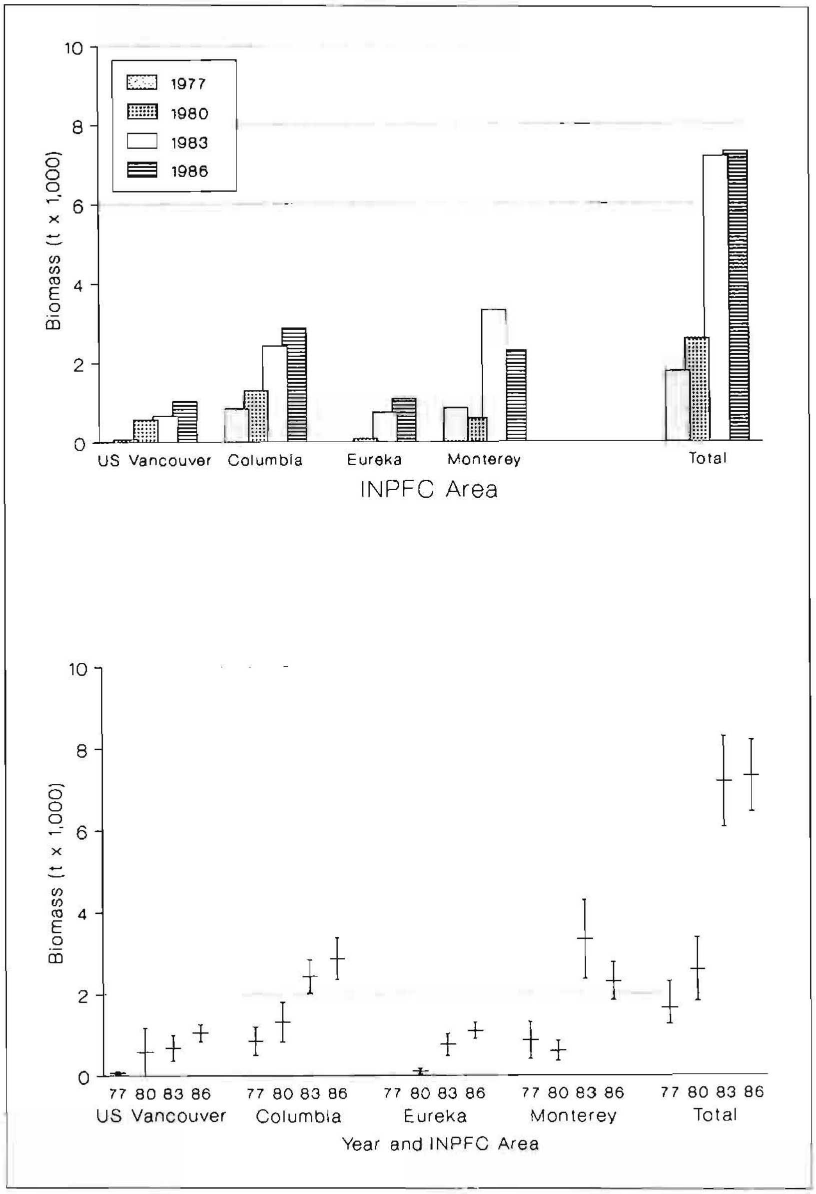

Figure 34
Estimates of English sole, *Pleuronectes vetulus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

less than 30% of the 1977 estimates. That trend was contrary to what was observed for other flatfishes. Increased fishing mortality may have played a role in reducing population size, or the conditions which favored high production in English, Dover, and rex soles during those years may not have benefitted arrowtooth flounder populations in this region. Another possibility is that the apparent reduction in stock size in 1983 was, instead, a northward displacement of this more northerly distributed species brought on by the unusually warm water temperatures of that year. The latter hypothesis appears weak based on the analysis of flatfish distribution and water temperatures discussed in the following section.

The total biomass estimate rose in 1986 to 9,812 t, representing an 86% increase from the 1983 level, but that was still only 62% of the 1977 estimated abundance. Variances associated with the total biomass estimates tended to be larger than for the other flatfishes, with CV's ranging from about 7 to 30%. Confidence intervals also were generally wider and fewer pairs of biomass estimates generated significant Zvalues (Table

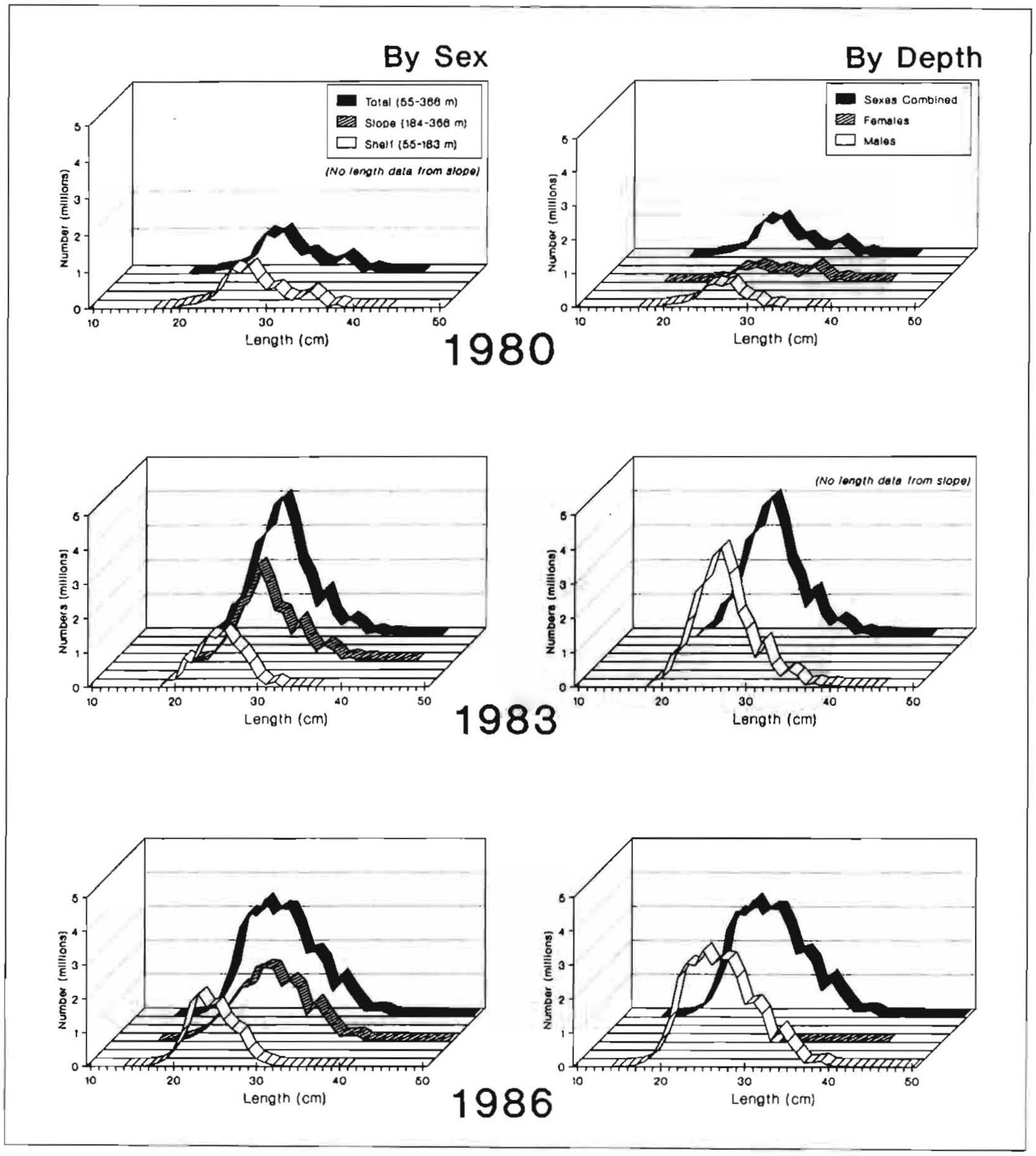

Figure 35
English sole, *Pleuronectes vetulus*, length compositions by year, depth, and sex.

7). The total biomass estimate for 1983 was significantly smaller than both the 1977 and 1986 estimates. Thus, the indicated major decline in total abundance between 1977 and 1983 and subsequent recovery in 1986 can be accepted.

Length data, available only for 1980 and 1986, showed considerable variability because of small sample sizes (Fig. 44). Arrowtooth flounder ranged in length from 11 to 80 cm, but most were between 15 and 60 cm. Several length modes were present in both years. Small arrowtooth flounder of 18–22 cm, which were absent in 1980, were abundant in 1986 and probably represent the recruitment of a relatively strong year class. Strong modes between 28 and 55 cm suggest that highly variable recruitment is common. Almost all specimens greater than 50 cm were females. As with most other groundfish species, length and bottom depth are strongly associated. Virtually all specimens less than 25 cm and most less than 40 cm were found on the continental shelf. Although some of the largest specimens were captured in the shallow stratum, most of the larger fish inhabited the upper continental slope.

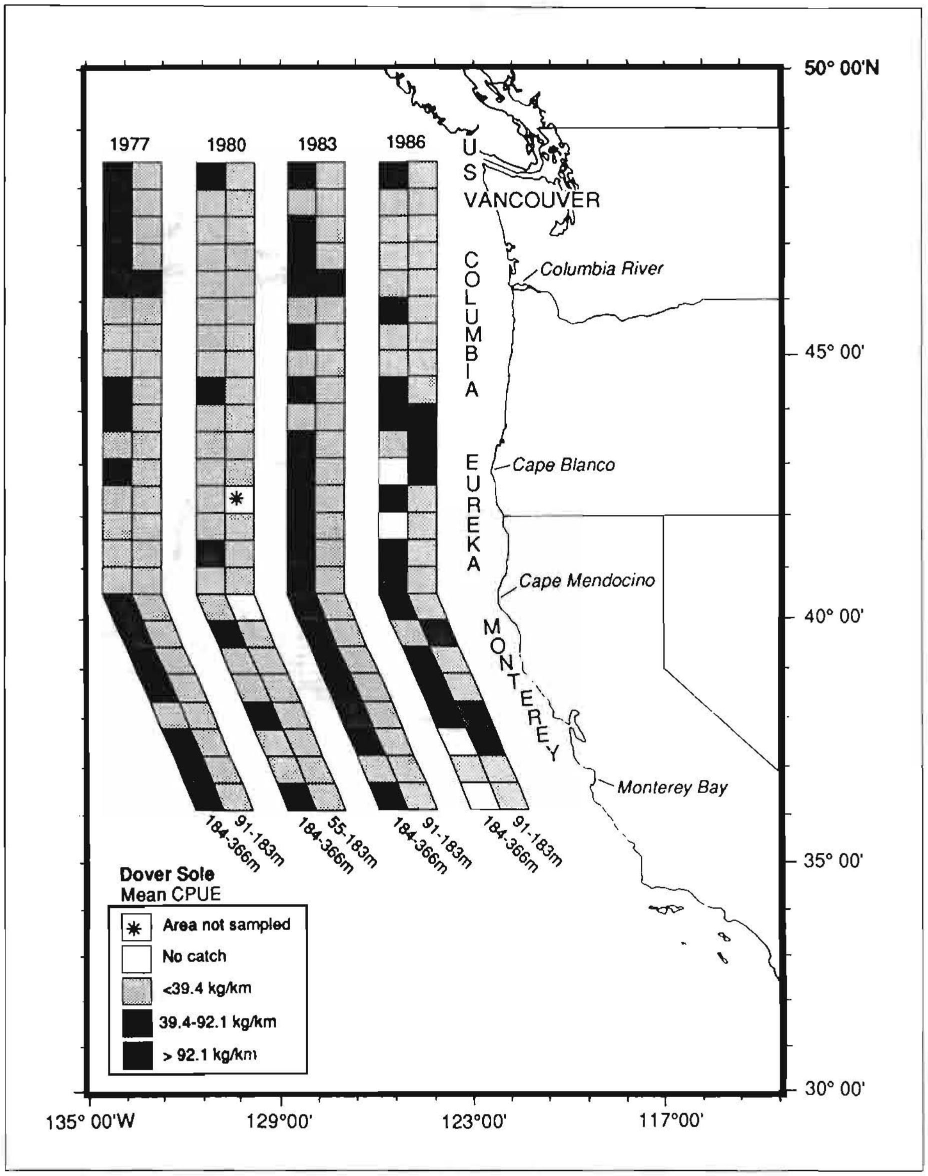

Figure 36
Distribution of Dover sole, *Microstomus pacificus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

Sea Temperatures and Groundfish Distribution

We examined the relationship between bottom temperature and fish distribution as a factor that might explain some of the observed interannual variability in distribution. The period spanned by this study was of particular interest because a strong El Niño phenomenon occurred in 1983, resulting in an environmental anomaly that could have stimulated observable changes in distribution.

Unfortunately, bottom temperature data are sparse and were not always collected in a way that adequately represented the full range of latitudes and depths surveyed. As previously mentioned, bottom temperature data collected during the 1977 survey were excluded from this analysis. Bottom temperatures were collected from 62 of 586 hauls (11%) in 1980, 92 of 596 hauls (15%) in 1983, and 202 of 569 hauls (36%) in 1986.

Temperatures were averaged by 0.5° latitudinal intervals for each year (Fig. 45). Surface temperatures generally decreased from lat. 37°00' to 39°30'N, remained relatively constant from lat. 39°30'N to 44°00'N, and increased northward before they decreased again at the northern limit of the survey area. The area off Califor-

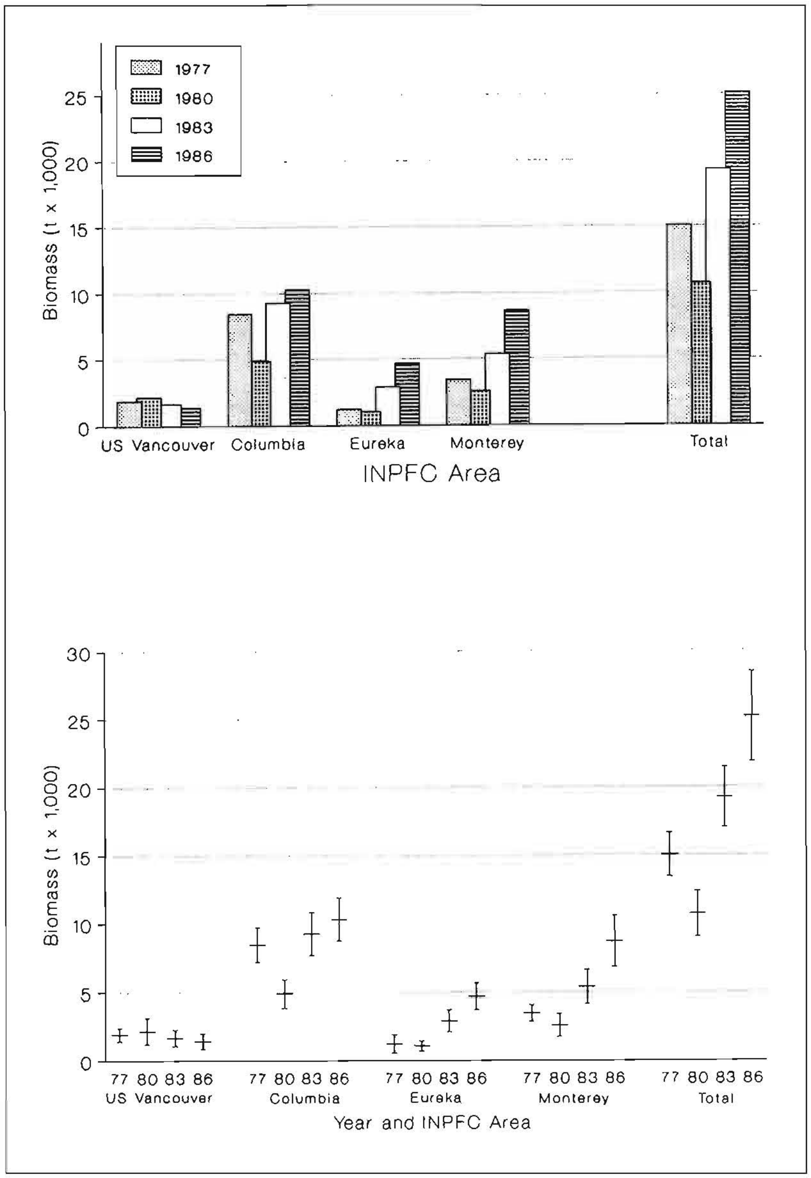

Figure 37

Estimates of Dover sole, *Microstomus pacificus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

nia is known for strong upwelling during the summer, which depresses surface temperatures (Ingraham and Love, 1978). Upwelling weakens off northern Oregon and Washington. Reduced temperatures in the extreme northern portion of the survey area may have resulted from mixing from strong tidal flows in the vicinity of the Strait of Juan de Fuca. Bottom temperatures, on the other hand, usually decreased steadily with increasing latitude. Both surface and bottom temperatures were generally warmer coastwide in 1983 than in the other survey years, as a result of the El Niño event. Surface temperatures off Oregon and Washington were unusually warm in 1983; means ranged from 2 to 6°C higher than those observed in previous surveys.

The temperature regime preferred by each species was examined by plotting CPUE against bottom temperatures. During 1980, 1983, and 1986, bottom temperatures usually ranged from 5.5 to 11.0°C. The flatfishes were most dense where temperatures were mid-range, with highest CPUE observations occurring between 6.5° and 8.0°C in the "normal" years of 1980 and 1986 (Fig. 46). However, in 1983 all flatfish species were most densely distributed at about 9.0°C, suggesting that those species did not avoid unusually warm

Table 16

Dover sole, *Microstomus pacificus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	2.7	576	220–933		6.2	4,895	3,878–5,911	
	184–366	15.1	1,330	982–1,678		12.1	3,592	2,824–4,359	
	91–366	6.4	1,907	1,419–2,395	15.2	7.9	8,486	7,221–9,752	9.0
1980	55–183	2.3	595	108–1,082		2.9	3,326	2,613–4,038	
	184–366	17.6	1,574	713–2,436		5.2	1,565	748–2,381	
	55–366	6.2	2,170	1,213–3,126	23.1	3.3	4,890	3,839–5,942	12.7
1983	55–183	2.7	715	225–1,206		4.2	4,911	3,817–6,006	
	184–366	10.8	967	594–1,340		14.5	4,372	3,218–5,525	
	55–366	4.8	1,682	1,088–2,276	20.6	6.3	9,283	7,722–10,843	10.0
1986	55–183	2.3	650	509–791		6.2	7,616	6,347–8,885	
	184–366	8.7	768	227–1,308		9.8	2,716	1,753–3,679	
	55–366	3.9	1,418	864–1,971	22.0	6.9	10,332	8,772–11,892	9.0

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	1.9	336	78–594		3.5	1,238	947–1,528		4.6	7,045	5,909–8,180	
	184–366	10.9	875	260–1,489		18.8	2,213	1,677–2,750		13.6	8,010	6,866–9,154	
	91–366	4.7	1,211	554–1,868	32.0	7.0	3,451	2,849–4,052	10.3	7.1	15,054	13,445–16,664	6.4
1980	55–183	2.1	430	171–689		2.2	1,375	797–1,952		2.5	5,725	4,672–6,778	
	184–366	7.9	630	364–897		10.0	1,203	557–1,850		8.4	4,973	3,684–6,262	
	55–366	3.8	1,060	705–1,416	19.5	3.4	2,578	1,725–3,431	19.7	3.7	10,698	9,047–12,349	9.3
1983	55–183	3.0	911	503–1,320		3.4	2,155	1,251–3,059		3.7	8,692	7,157–10,228	
	184–366	24.9	1,991	1,277–2,704		26.6	3,220	2,309–4,130		17.8	10,549	8,938–12,160	
	55–366	7.6	2,902	2,098–3,706	16.1	7.1	5,375	4,113–6,636	14.0	6.5	19,241	17,032–21,451	6.9
1986	55–183	7.6	2,433	1,896–2,970		7.7	5,504	3.812–6,295		6.3	15,752	13,536–17,968	
	184–366	26.6	2,244	1,383–3,106		28.8	3,641	2,178–5,104		16.3	9,370	6,855–11,886	
	55–366	11.6	4,677	3,687–5,667	12.3	11.0	8,695	6,829–10,560	12.7	8.2	25,121	21,824–28,418	7.8

temperatures by migrating to deeper or more northern waters. Water temperatures in 1983, though higher, may still have been within the comfort range for flatfishes and thus failed to trigger major avoidance movements.

Sablefish seemed to demonstrate stronger temperature preferences than flatfishes during the three years. While some sablefish clearly inhabited waters warmer than 9°C in 1983, highest densities generally occurred in waters colder than 8.0°C, which was consistent with the other two years (Fig. 47). In 1983, 37% of the estimated biomass occurred in the 184–366 m depth zone compared to only 15% in 1980 and 22% in 1986 (Table 13). This information suggests that sablefish responded to the El Niño conditions in 1983 by moving down the continental slope to cooler habitats. Because only a portion of the sablefish population was sampled by the triennial surveys, it is uncertain how the population as a whole reacted to the warmer conditions.

The greatest densities of lingcod were found at slightly different temperatures each year (Fig. 47). Highest CPUE values were observed between 7° and 8° in 1980, 8° and 10° in 1983, and 6.5° and 7.5°C in 1986. The depth and latitudinal distribution of lingcod was similar in all years, suggesting that it also did not seek different habitat in response to warming in 1983. Ling-

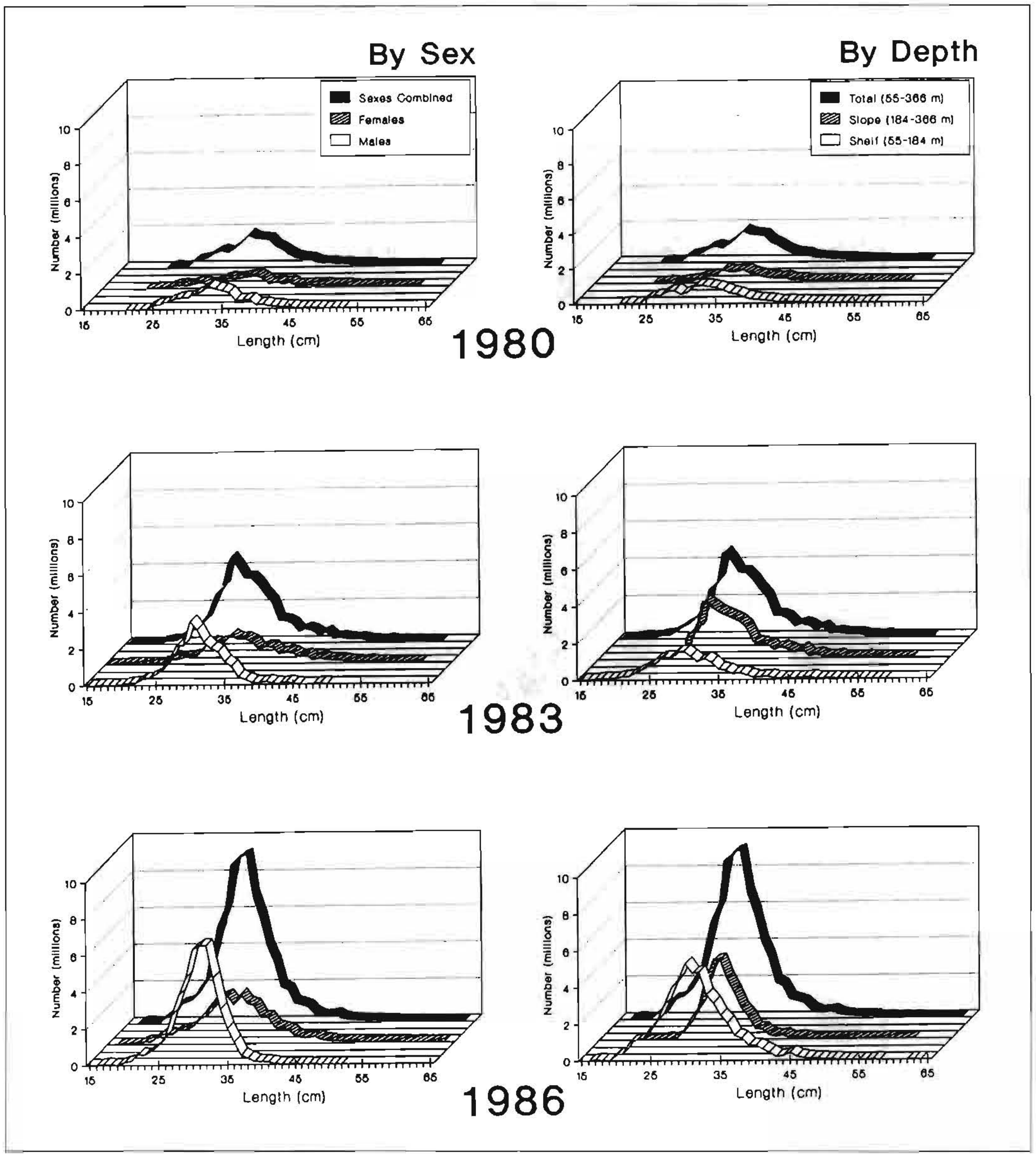

Figure 38
Dover sole, *Microstomus pacificus*, length compositions by year, depth, and sex.

cod are relatively sedentary and, like flatfishes, are closely associated with a particular substrate (generally hard bottom). A strong substrate preference could have inhibited movement in response to the range of temperatures observed during the study period.

We could not clearly demonstrate that Pacific hake avoided the warmer temperatures of 1983. This species occurred over a broad temperature range in 1983, and its highest densities that year were found in water warmer than in 1980 and 1986 (Fig. 47). Latitudinal shifts in densities or biomass are, to a large extent, related to population age composition, which would tend to confound any attempt to relate distribution and temperatures. While we noted that three-year-old hake, which are not normally found in the northern portion of the survey area, were clearly more prominent there in 1983, an explanation is elusive. The temperature regime could have played a role, as could have the unusually large size of the 1980 year class. We have observed that large year classes often occupy a greater latitudinal range than do less abundant ones.

The five rockfish species examined also failed to show any pronounced changes in density that might be considered a response to changes in the temperature regime. The 1983 distributions of each of the five rockfishes were spread over a broader range of tempera-

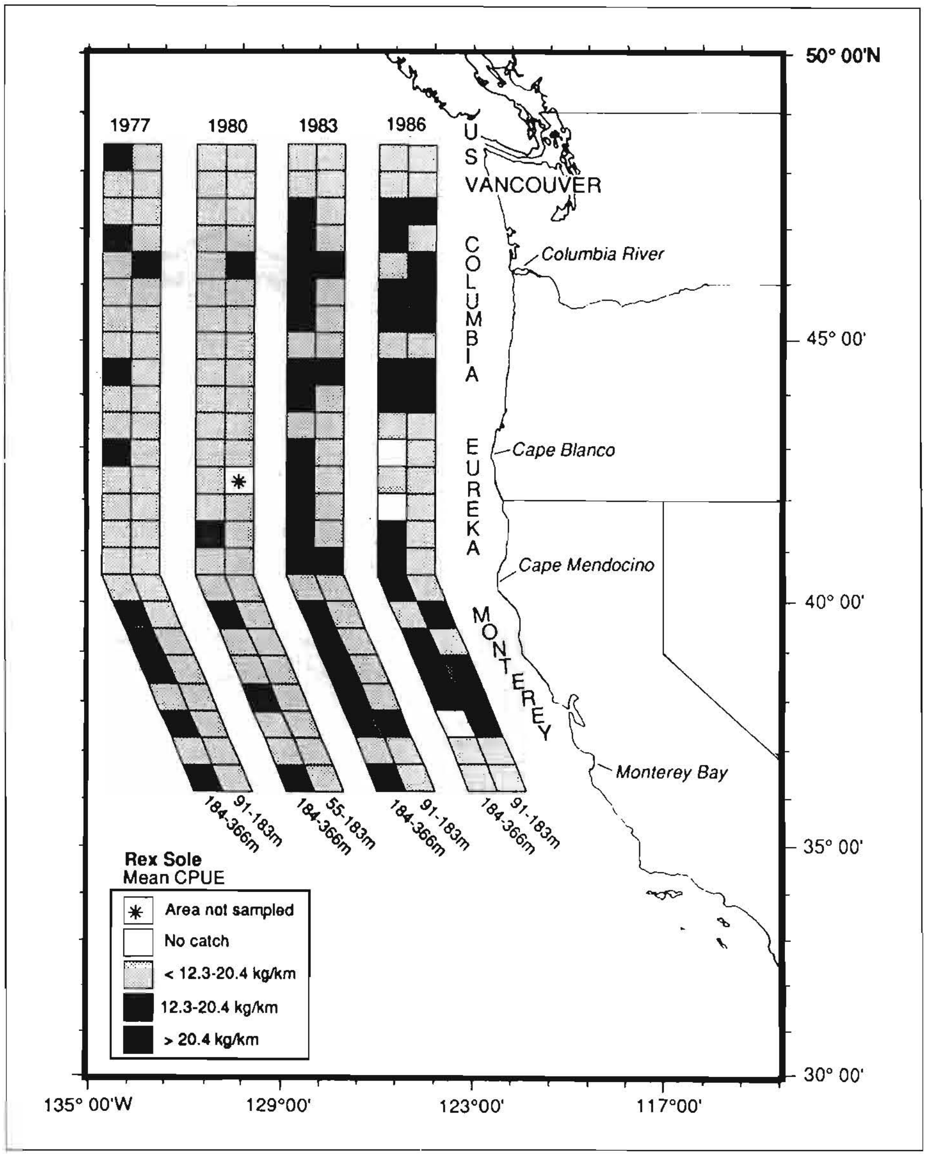

Figure 39
Distribution of rex sole, *Errex zachirus*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

tures, and highest CPUE tended to be associated with slightly warmer water than was observed in the other two years (Fig. 48). Coupled with the lack of any indication of depth or latitudinal shifts in their distribution, this would indicate that these rockfishes remained on their usual grounds in 1983 and endured the influx of warmer water.

From this examination, only sablefish exhibited a clear response to warmer conditions brought on by the 1982–83 El Niño. Sablefish is a relatively mobile species that commonly undergoes seasonal bathymetric migrations (Heyamoto and Alton, 1965; Alton, 1972; Tuponogov and Kodolov, 1983) and moves considerably within the water column. Although its sensitivity to temperature may prevail over its responses to other habitat parameters, the species is known to tolerate a wide temperature range. Pacific hake shares many behavioral characteristics with sablefish, and there is some evidence that the large 1980 year class might have sought cooler temperatures through a general northward movement. Pacific hake data will have to be reviewed by age group to interpret the effects of temperature on distribution. We were not able to detect an aversion to the warm conditions present in 1983 in true demersal species (flatfishes, lingcod, and rockfishes). We surmise that other features of their habitat exerted stronger

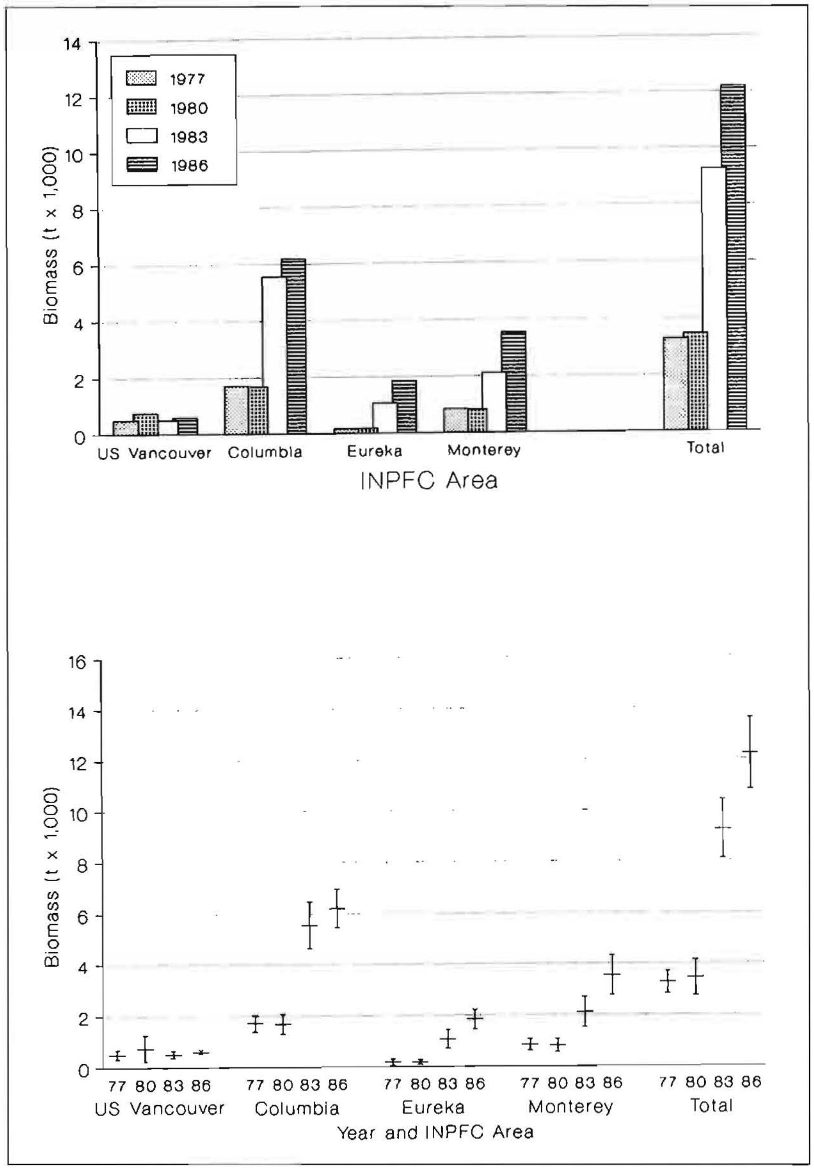

Figure 40

Estimates of rex sole, *Errex zachirus*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

influences over their behavior than did the differences in temperature range.

Discussion

In summary, data collected in bottom trawl surveys during the summers of 1977, 1980, 1983, and 1986 off Washington, Oregon, and California were compared to examine trends in groundfish population sizes. The sampling effort was designed to provide the most precise and comprehensive information on a few key species, but CPUE and estimates of biomass were derived for a variety of commercially important species. Canary and yellowtail rockfish and Pacific hake were most frequently designated as "target" species, but we also focused on bocaccio and chilipepper during the 1977 survey.

The estimated abundance of Pacific hake tended to increase, canary and yellowtail rockfish abundance estimates decreased, and bocaccio and chilipepper abundance estimates held relatively stable over the study period. Among the secondary study species, English sole, rex sole, and Dover sole abundance estimates

Table 17

Rex sole, *Errex zachirus* — Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.9	185	66–305		1.5	1,153	863–1,443	
	184–366	3.7	323	190–456		1.9	573	419–728	
	91–366	1.7	508	332–684	20.7	1.6	1,726	1,400–2,052	11.3
1980	55–183	1.7	449	0–921		1.2	1,347	997–1,696	
	184–366	3.3	297	57–536		1.2	345	149–541	
	55–366	2.1	746	234–1,258	39.4	1.2	1,691	1,295–2,088	14.1
1983	55–183	1.1	293	185–401		3.7	4,264	3,419–5,109	
	184–366	2.3	208	115–300		4.5	1,286	930–1,642	
	55–366	1.4	501	362–640	16.5	3.8	5,550	4,638–6,462	9.9
1986	55–183	1.8	486	423–548		4.1	5,064	4,369–5,760	
	184–366	1.3	114	58–170		4.1	1,140	821–1,459	
	55–366	1.6	600	518–682	8.2	4.1	6,204	5,448–6,960	7.3

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91–183	0.1	21	6–36		1.1	401	201–600		1.2	1,759	1,394–2,124	
	184–366	1.9	153	41–266		3.9	454	353–554		2.6	1,503	1,256–1,750	
	91–366	0.7	174	61–288	38.0	1.8	854	634–1,074	15.0	1.5	3,263	2,823–3,702	8.1
1980	55–183	0.4	73	34–111		0.8	527	334–719		1.1	2,395	1,789–3,001	
	184–366	1.4	112	30–195		2.5	297	111–482		1.8	1,050	703–1,397	
	55–366	0.7	185	97–273	26.5	1.1	823	561–1,086	19.1	1.2	3,445	2,752–4,138	12.1
1983	55–183	1.4	420	239–600		2.5	1,559	1,019–2,099		2.8	6,536	5,516–7,556	
	184–366	8.2	658	325–991		4.6	555	333–778		4.6	2,707	2,189–3,224	
	55–366	2.8	1,078	714–1,442	19.3	2.8	2,114	1,534–2,693	16.4	3.1	9,242	8,102–10,382	7.4
1986	55–183	7.6	1,144	858–1,429		3.6	2,385	1,745–3,024		3.7	9,078	7,915–10,241	
	184–366	8.4	710	433–986		9.1	1,154	683–1,624		5.4	3,117	2,318–3,915	
	55–366	4.6	1,853	1,466–2,240	12.4	4.5	3,538	2,763–4,314	13.1	4.0	12,195	10,807–13,584	6.9

increased. Estimates of sablefish abundance increased between 1977 and 1980 and then decreased steadily. Pacific ocean perch, lingcod, and, to a lesser extent, arrowtooth flounder abundance estimates showed rather precipitous decreases. However, none of the interannual differences in estimated abundance for sablefish or any of the rockfishes were statistically significant.

Population trends within INPFC areas tended to parallel the overall coastwide trend for each species, but frequent exceptions did occur. For instance, almost all of the decline in canary rockfish abundance took place in the U.S.-Vancouver area. Likewise, yellowtail rockfish abundance estimates decreased in the U.S.-Vancouver and Columbia areas but were stable or increased elsewhere. Changes in flatfish abundance seemed to be more uniform among INPFC areas. This may be due to dissimilarities between non-flatfish and flatfish responses to small-scale environmental changes and to their distinctly different recruitment mechanisms, or it may be an artifact of sampling variability (i.e. because flatfish distributions are generally more uniform, estimates of their biomass are usually less variable).

Precision has long been a concern to researchers estimating population abundance. Fishery research lit-

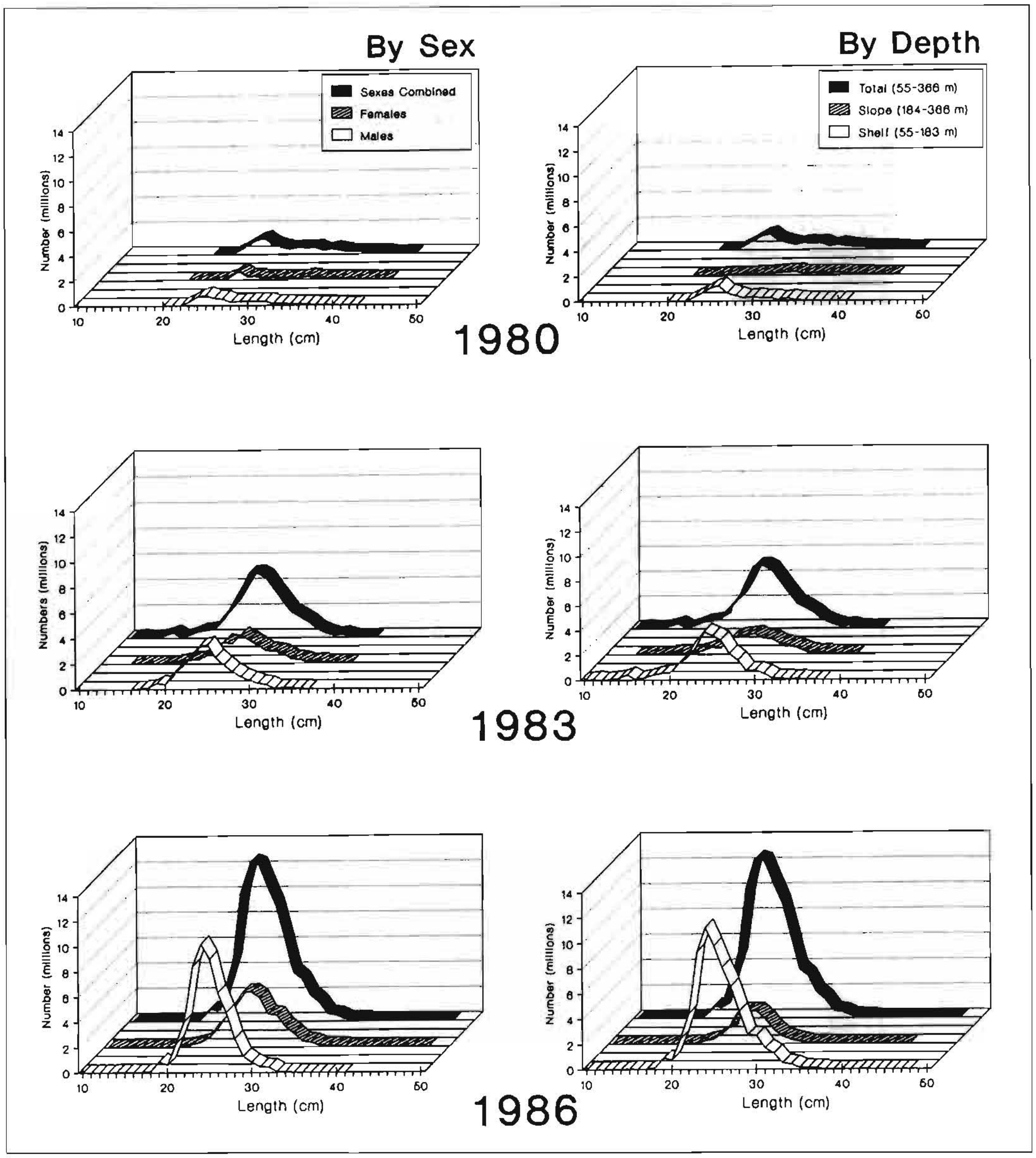

Figure 41
Rex sole, *Errex zachirus*, length compositions by year, depth, and sex.

erature contains a multitude of studies directed at controlling the variance of abundance estimates using a variety of survey designs and data manipulations (Byrne et al., 1981; Pennington and Brown, 1981; Wilkins and Golden, 1983; Smith and Gavaris, 1993). Trawl sampling is time consuming and costly; thus survey designs that seek to increase precision are often compromised by operational and fiscal realities. Hydroacoustic surveys, to a large extent, can overcome the problem with their inherent capability of sampling at very high rates.

Our study utilized sampling designs that were molded by the need to obtain relatively precise abundance estimates for the target species without sacrificing the important multispecies aspects of the triennial surveys. The first priority was to preserve the multispecies time series by providing a minimum level of sampling throughout the survey area; the second priority was to allocate all remaining samples to areas where target species were expected to be most abundant and sampling variability the highest. Much of the sampling effort was therefore assigned to important rockfish areas because it is well known that most rockfish species exhibit extremely contagious distributions, requiring intensive sampling or effective stratification to gain control of variance.

Coefficients of variation can give some insight into species' schooling or aggregating behavior. As expected,

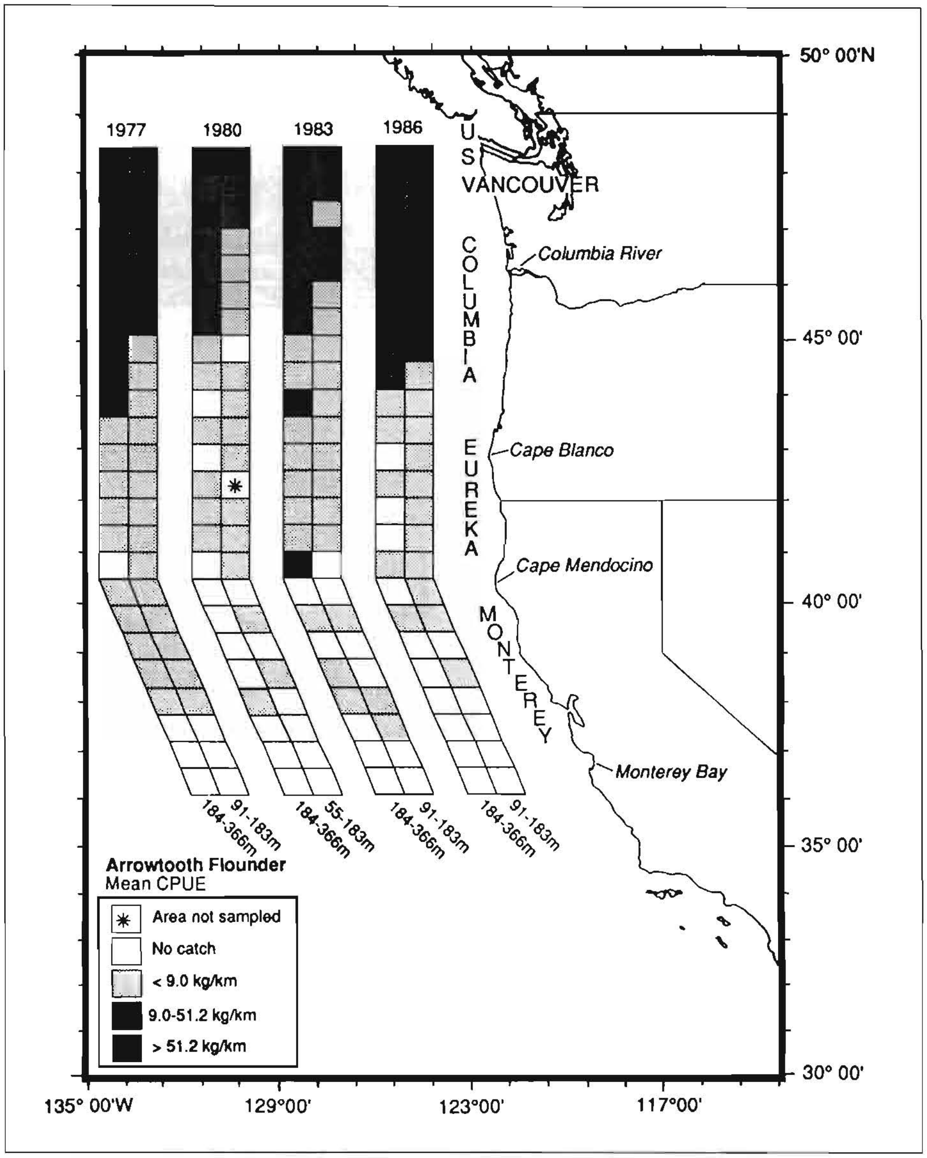

Figure 42
Distribution of arrowtooth flounder, *Atheresthes stomias*, during 1977, 1980, 1983, and 1986 National Marine Fisheries Service bottom trawl surveys.

the magnitude of the CV's varied markedly among species. Mean CV's were calculated using total biomass estimates and variance of the biomass for the four surveys. Average CV's were highest for bocaccio, canary rockfish, lingcod, chilipepper, yellowtail rockfish, Pacific ocean perch, and sablefish, averaging 46, 43, 38, 38, 34, 33, and 27%, respectively. This would suggest that these species have the most nonuniform or contagious distributions. Arrowtooth flounder and Pacific hake biomass estimates displayed intermediate variability with CV's averaging 18 and 16%, respectively. Smallest CV's were indicative of the most uniformly distributed species and belonged to the flatfish group comprised of Dover, rex, and English soles. Those three species had CV's of 8, 9, and 13%, respectively.

The variances associated with biomass estimates were determined largely by each species' distribution and characteristics of the experimental design. The extreme patchiness of rockfish distribution and the relatively uniform and ubiquitous flatfish distributions were influential in fixing the precision levels for the two groups. Canary and yellowtail rockfish were principal survey species that received special sampling considerations aimed at reducing variance. Even so, abundance esti-

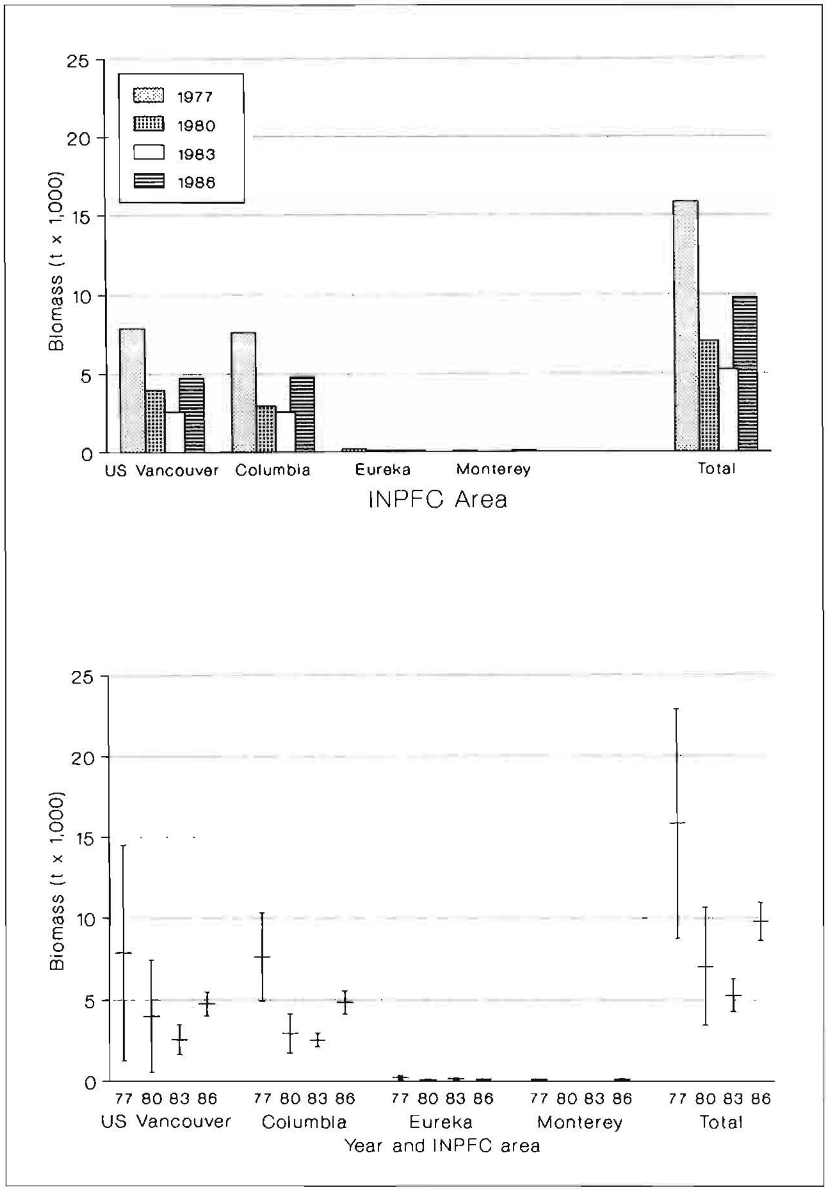

Figure 43
Estimates of arrowtooth flounder, *Atheresthes stomias*, biomass and associated 90% confidence intervals by International North Pacific Fisheries Commission (INPFC) area and year.

mates for those species were relatively imprecise. The survey design was modified in 1980 in an effort to improve precision, particularly in the Columbia area, through more accurate delineation of canary and yellowtail rockfish distribution (based on commercial fishery data) and reallocation of sampling effort. Although this resulted in more precise estimates in the Columbia area, no clear improvement in the precision of the total estimates was noted for either species. While the same design was employed in 1983 to provide information on the stability of variances, additional time at the completion of the survey was used to sample an additional 44 stations in the U.S-Vancouver area. The 1980 CV for canary rockfish in that area was reduced by more than half, but the yellowtail rockfish CV actually increased. Clearly, interannual variation in distribution or behavior can confound efforts to develop a sampling strategy based on historical data. This was further demonstrated in 1986 when the sampling design was based on a much more rigorous analysis of historical fishery and survey data. Results were mixed: precision improved in some strata but remained unchanged or deteriorated in other

Table 18

Arrowtooth flounder, *Atheresthes stomias*— Mean catch per unit of effort (CPUE) (kg/km trawled), biomass estimates (metric tons), 90% confidence intervals (CI), and coefficients of variation (CV in %) of biomass estimates by International North Pacific Fisheries Commission statistical area, depth stratum, and year.

		U.S.-Vancouver				Columbia			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91-183	12.2	2,575	846–4,304		6.2	4,818	2,456–7,181	
	184-366	60.2	5,319	0–11,743		9.4	2,806	1,376–4,236	
	91-366	26.4	7,894	1,283–14,505	48.0	7.1	7,624	4,928–10,321	20.7
1980	55-183	11.9	3,121	0–6,541		1.5	1,779	484–3,074	
	184-366	9.8	877	175–1,579		3.9	1,164	696–1,631	
	55-366	11.3	3,998	542–7,453	49.7	2.0	2,943	1,751–4,135	20.8
1983	55-183	3.9	1,026	357–1,695		1.3	1,482	1,161–1,803	
	184-366	17.2	1,540	867–2,214		3.5	1,058	767–1,350	
	55-366	7.3	2,567	1,658–3,475	20.7	1.7	2,540	2,115–2,966	10.0
1986	55-183	11.0	3,050	2,492–3,608		2.8	3,445	2,807–4,083	
	184-366	19.4	1,711	1,199–2,224		5.0	1,396	1,026–1,766	
	55-366	13.0	4,761	4,024–5,498	9.2	3.2	4,841	4,118–5,564	8.9

		Eureka				Monterey				Total			
Year	Depth stratum (m)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)	Mean CPUE	Biomass	CI	CV (%)
1977	91-183	0.8	151	28–274		0.2	51	8–94		5.0	7,595	4,734–10,456	
	184-366	0.6	46	0–94		0.5	48	14–81		14.4	8,219	1,662–14,776	
	91-366	0.8	197	68–327	38.3	0.2	98	48–148	29.6	7.6	15,814	8,754–22,873	25.9
1980	55-183	0.3	54	14–94		<0.1	7	0–15		2.2	4,960	1,444–8,476	
	184-366	0.4	36	6–66		0.1	14	0–37		3.5	2,092	1,293–2,891	
	55-366	0.3	90	42–138	31.0	<0.1	21	0–45	61.2	4.1	7,052	3,466–10,638	29.5
1983	55-183	0.2	45	16–74		<0.1	15	0–30		1.1	2,568	1,844–3,292	
	184-366	1.2	94	45–143		0.2	25	1–48		4.6	2,717	1,994–3,441	
	55-366	0.4	139	84–194	23.1	0.1	39	12–67	41.7	1.8	5,285	4,289–6,282	11.2
1986	55-183	0.2	80	48–112		0.1	88	29–148		2.7	6,663	5,652–7,675	
	184-366	0.4	31	12–49		0.1	10	0–21		5.5	3,148	2,536–3,760	
	55-366	0.3	111	74–147	19.5	0.1	98	38–159	36.8	3.2	9,812	8,645–10,978	7.1

areas where historical data failed to predict current distribution.

Another question contingent upon the precision of biomass estimates is whether the observed differences were statistically significant. Due to the large variances associated with biomass estimates of many of these species, most differences observed between years were not statistically significant. As expected, the surveys were most sensitive to population changes in species with relatively small CV's such as Pacific hake and flatfishes. In some INPFC areas, biomass estimates for canary and yellowtail rockfish differed by factors as great as 35 and 11, respectively, among years; however, these estimates were not found to be significantly different. Imprecision of such magnitude causes one to question the utility of trawl surveys for rockfish assessment. It certainly emphasizes the need to review all elements of the experimental design and perhaps consider other assessment strategies. We used the results of the 1977–86 triennial surveys to compare projected and realized precision levels of rockfish abundance estimates. We concluded that we could not reasonably expect future "area-swept" surveys to furnish adequate information to discern rockfish abundance trends and have deleted this objective from triennial bottom trawl surveys conducted since 1989.

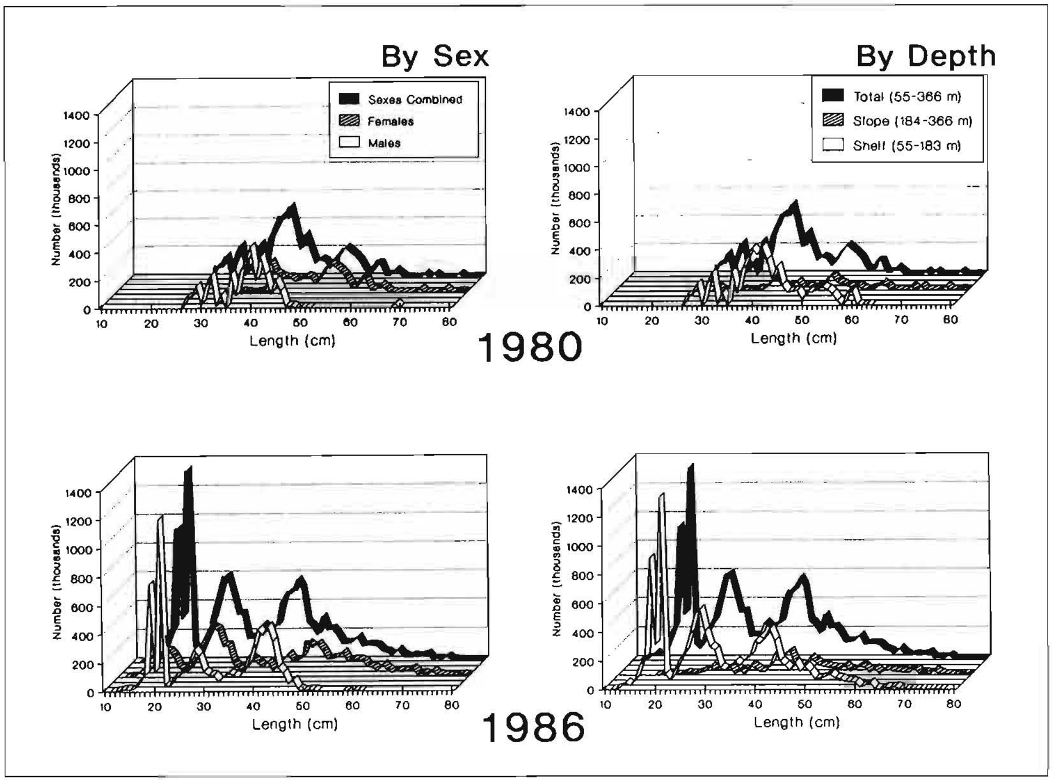

Figure 44

Arrowtooth flounder, *Atheresthes stomias*, length compositions by year, depth, and sex.

The accuracy of population estimates based on bottom trawl surveys is a continuing concern and is not as easily addressed as the question of precision. Typically, evaluations of accuracy rely on comparison of survey estimates with estimates derived independently. Resource assessments based on commercial catch-and-effort data have been unavailable for many west coast species until recently because of the lack of adequate fishery statistics and biological data. However, since implementation of the groundfish management plan in 1981, improvements have been made in the collection of commercial fisheries statistics and some new assessments have followed.

Independent assessments that provide for comparisons with the survey results are available only for canary rockfish, yellowtail rockfish, and sablefish (Fig. 49). A cohort analysis was conducted on yellowtail rockfish (Tagart[7]), which provides annual biomass estimates for the INPFC Columbia area from 1977 to 1985, and a dynamic pool model was used to project the biomass in 1986. The initial instantaneous rate of fishing mortality was unknown, so Tagart used a range of 0.05–0.30. The estimates (Fig. 49) are the averages of estimates derived using initial fishing mortalities of 0.10 and 0.15, which Tagart considered to be liberal and conservative estimates respectively. The survey and cohort analysis population trends were similar, both indicating a marked decline between 1977 and 1980 with a very slow decline or near-stability subsequently. Estimates of absolute abundance derived by cohort analysis are 3–5 times larger than those from the bottom trawl surveys and serve as an indication that the true catchability of the survey trawl is considerably less than the assumed value of 1.0.

Cohort analysis and catch-at-age analysis (CAGEAN) were used by Golden[8] in an assessment of canary rockfish in the INPFC Columbia area. He generated annual exploitable biomass estimates from 1980 to 1986 using instantaneous natural mortality rates (M) of 0.05 and 0.10. The values in Figure 49 were derived using M = 0.05. In this instance, the cohort analysis and CAGEAN produced quite different estimates of absolute abundance, but the trends were similar. Both analyses portrayed decreasing biomass from 1980 to 1984 and subsequent increases. Survey biomass estimates, in fact, followed the opposite trend. Canary rockfish presented a worst case example of patchy distribution and the greatest challenge in obtaining reasonable precision. It may be that sampling variability was responsible for the failure of survey data to correspond to the other indices or that the species was relatively unavailable during the time of the survey in the Columbia area. Once again, we

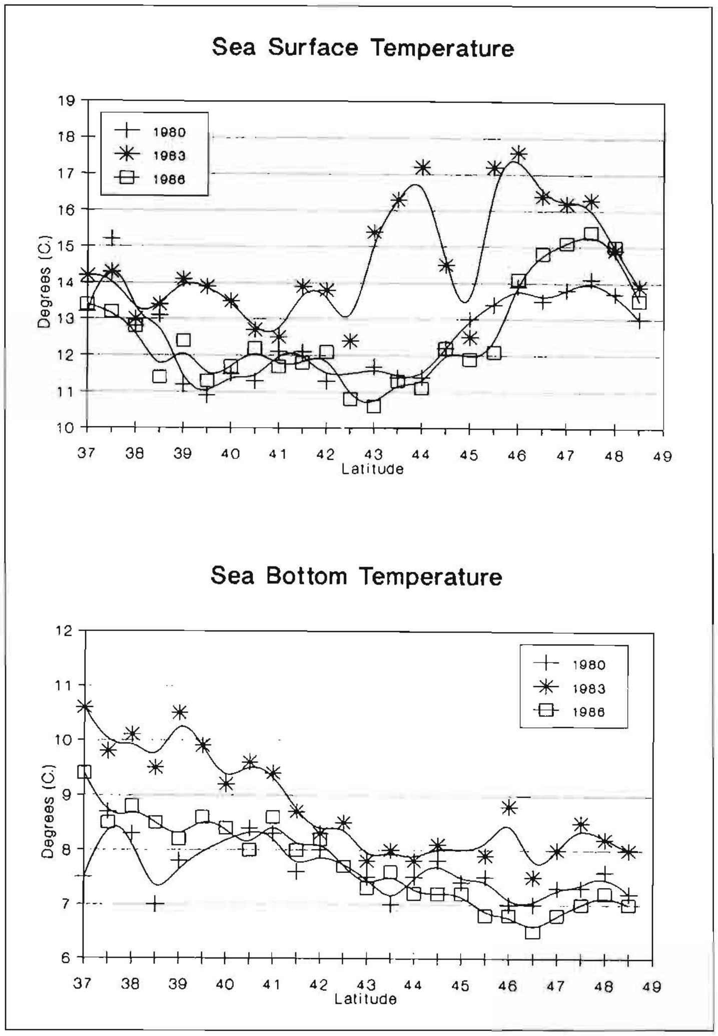

Figure 45

Sea surface and bottom (55–366 m) temperatures averaged by 30' latitudinal intervals by year.

believe that the biomass estimates from the bottom trawl survey were only a fraction of the estimates from analysis of fishery data because catchability was lower than assumed.

Sablefish biomass estimates from bottom trawl surveys in the Columbia and U.S.-Vancouver areas were compared with indices of changes in relative abundance of sablefish obtained from AFSC trap surveys (Parks and Shaw, 1988) in the same region (Fig. 49). The general trends in biomass were similar. Both studies showed increasing sablefish biomass during 1980–83 with ensuing decreases. Methot and Hightower[15] also found that the abundance of age-1 sablefish in the trawl surveys (left-hand size mode in Fig. 30) was consistent with the magnitude of the population inferred from commercial catch levels.

These limited comparisons are inconclusive but suggest that even though there may be considerable variability around survey estimates of abundance, long-term trends can compare favorably with trends derived by other methods. However, some species, such as canary rockfish, may never be tracked very accurately with any practical level of sampling effort. More conclusive evaluations of accuracy must await additional independent resource assessments and longer time series. It is notable that survey estimates are always considerably smaller than those based on catch data except for age-1 sablefish. This is largely due to the probable violation of catchability assumptions associated with the survey, resulting in an underestimation of biomass. The difference between estimates of absolute abundance from survey and fishery-based models could be considered a

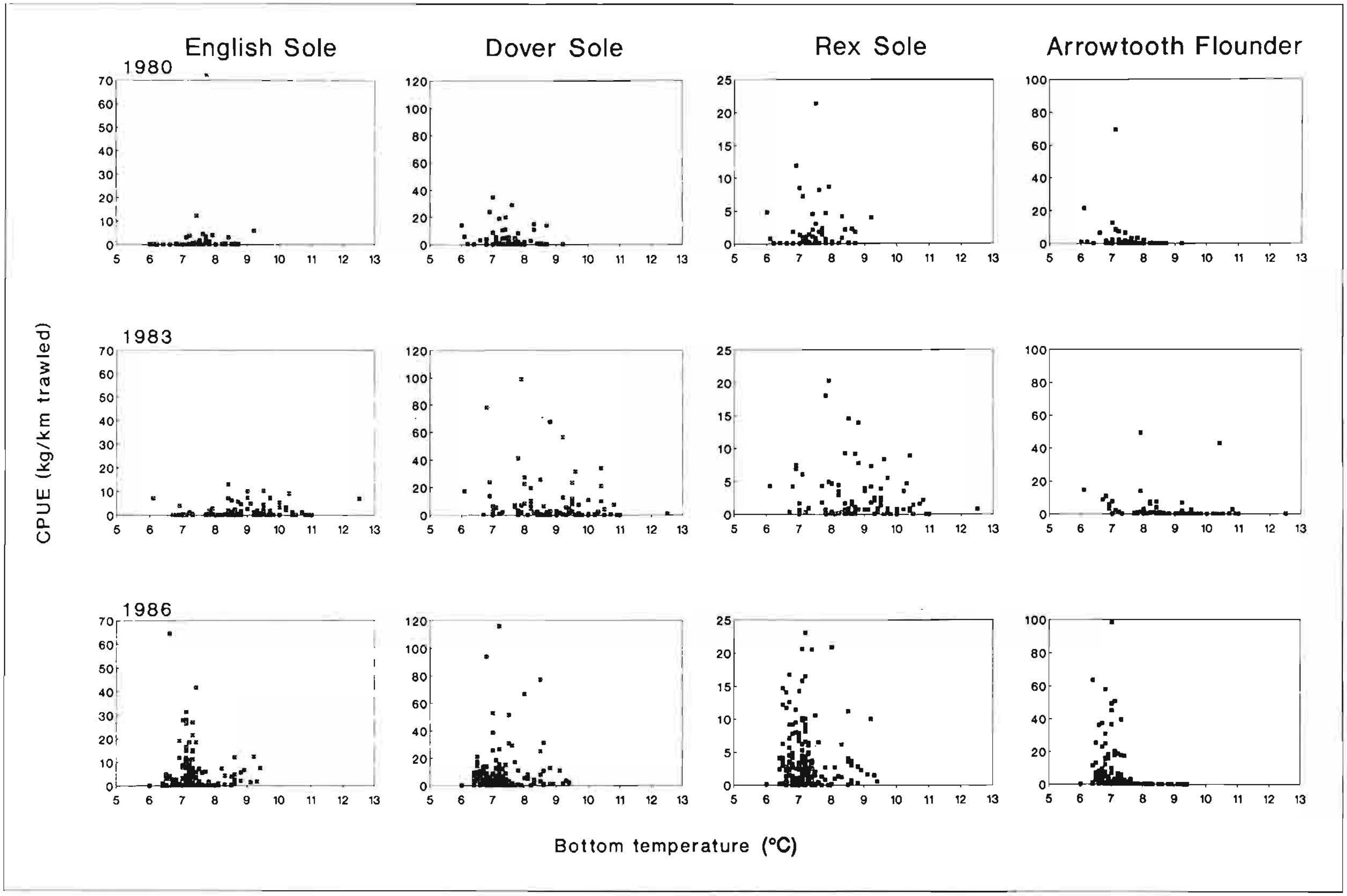

Figure 46
Relationship between flatfish catch per unit of effort (CPUE) and bottom temperature by year. See text for scientific names.

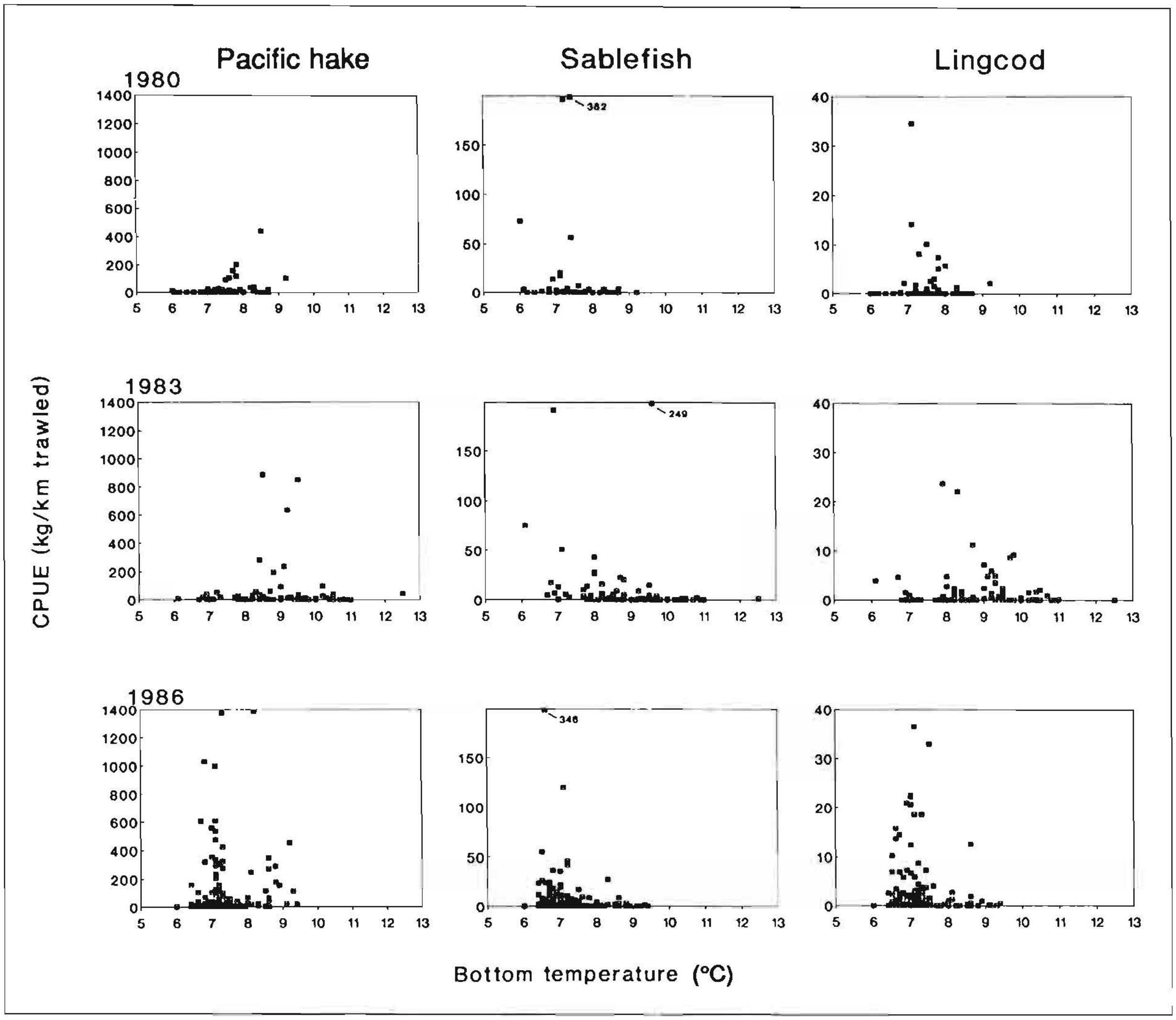

Figure 47

Relationship between Pacific hake, *Merluccius productus*, sablefish, *Anoplopoma fimbria*, and lingcod, *Ophiodon elongatus*, catch per unit of effort (CPUE) and bottom temperature by year.

gross indication of true catchability. More comparisons of this type, accompanied by dedicated studies of trawl performance and fish behavior, should begin to provide some insight to real catchability values and better estimates of absolute abundance.

Acknowledgments

The collection of survey data at sea for research on groundfish resources is demanding. Over the ten years of this study period, many dedicated biologists and technicians from the Alaska Fisheries Science Center, the Southwest Fisheries Science Center, state fishery agencies, and universities devoted weeks or months in that endeavor. Their sacrifices are deeply appreciated. Helpful statistical guidance provided by Doug Knechtel, Peter Munro, and Susan Picquelle enabled us to substantiate the inferences made from our analyses. Production and editorial assistance was provided by the Graphics and Publications Units at the AFSC. Finally, many reviewers provided encouragement and constructive advice during the long preparation of this manuscript. Although we received helpful suggestions from many colleagues, we especially thank Miles Alton, Rick Methot, and Bill Lenarz.

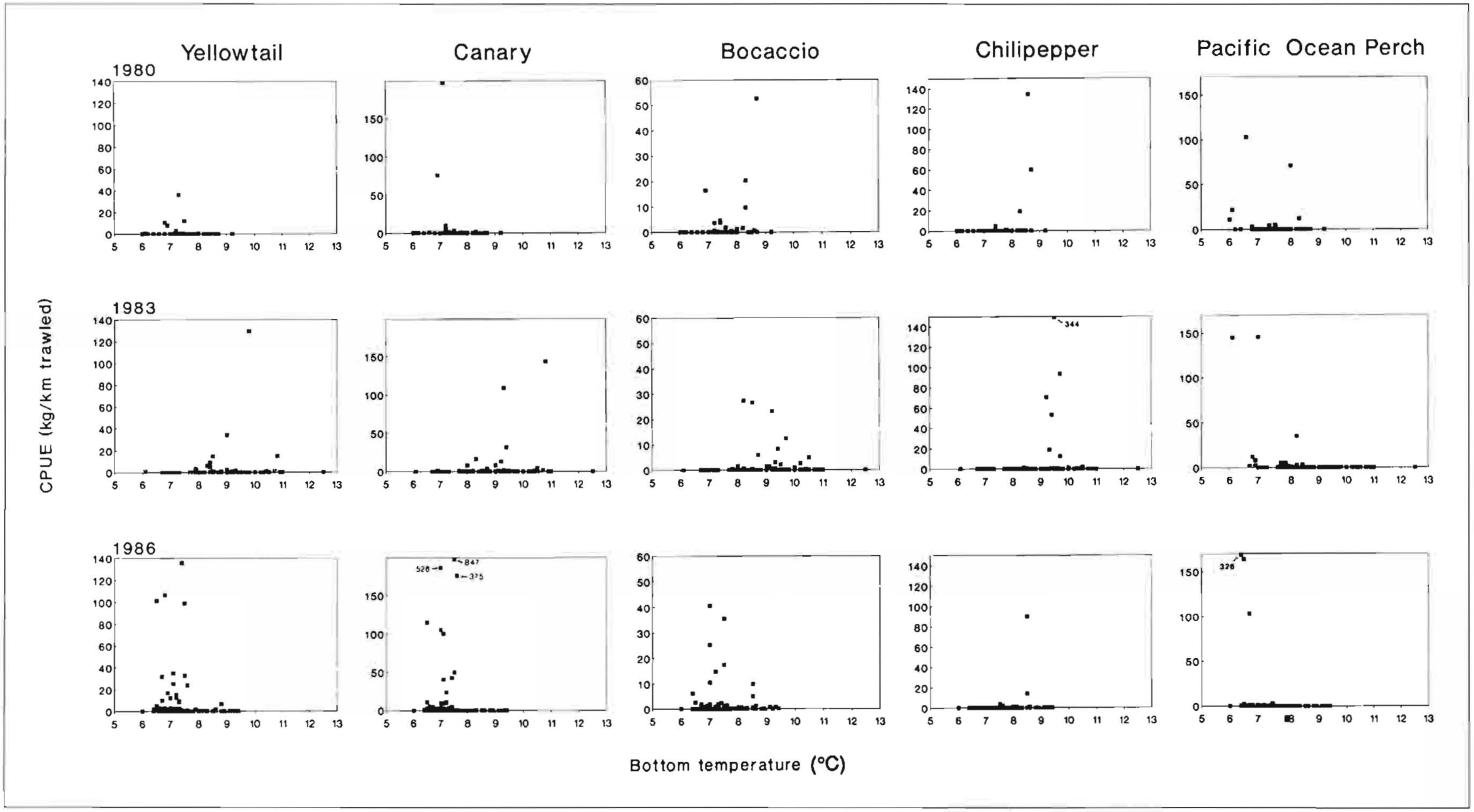

Figure 48

Relationship between rockfish catch per unit of effort (CPUE) and bottom temperature by year. See text for scientific names.

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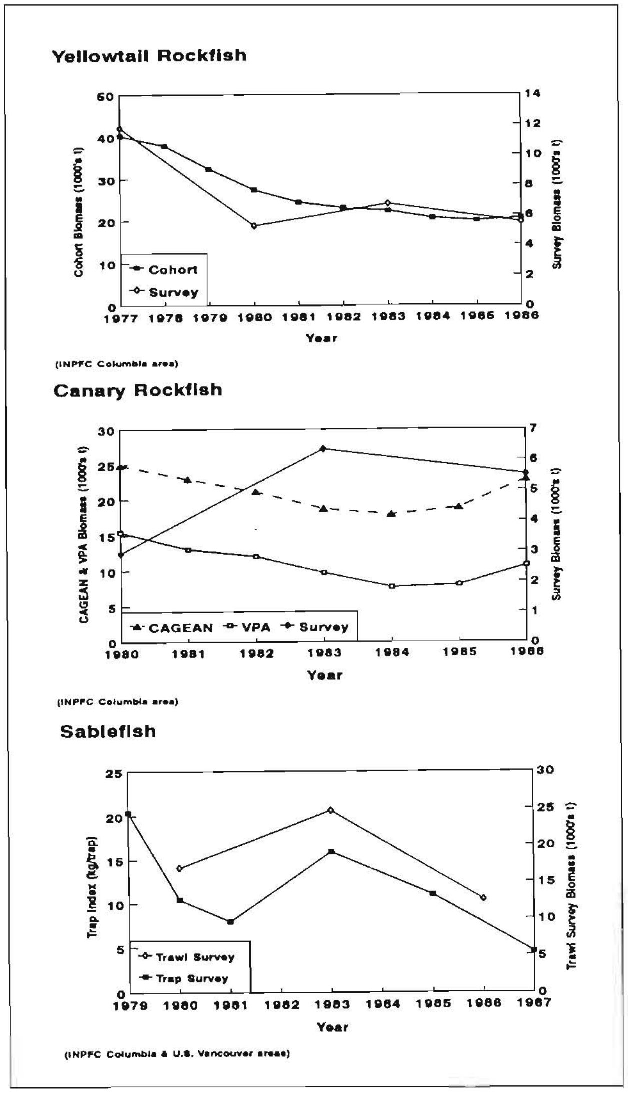

Figure 49

A comparison of abundance trends based on survey and commercial catch analyses. (Yellowtail rockfish, *Sebastes flavidus*, cohort analysis from Tagart, text footnote 9; canary rockfish, *S. pinniger*, catch-at-age analysis (CAGEAN) and cohort analysis from Golden, text footnote 8; sablefish, *Anoplopoma fimbria*, trap analysis from Parks and Shaw, 1988.) VPA = virtual population analysis; INPFC = International Pacific Fisheries Commission.

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