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LONG-TERM TRENDS IN PUGET SOUND MARINE FISHES: SELECTED DATA SETS

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FINAL REPORT

for

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U.S. ENVIRONMENTAL PROTECTION AGENCY,
PUGET SOUND ESTUARY PROGRAM
EPA INTERAGENCY AGREEMENT
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Approved

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Director

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Long-term, trends, Puget Sound, marine fishes.

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EXECUTIVE SUMMARY

INTRODUCTION

The primary objective of this project was to analyze long-term trends in Puget Sound marine fishes based on a synthesis of the available data. A secondary objective was to establish baselines against which future fish monitoring efforts could be compared and evaluated. An additional benefit of the project was the identification of the collection methods used over the years, which can be used to help define standardized methods so that future investigations can be conducted in a compatible fashion.

METHODS

Three data sets were chosen for trend analysis: Geographical distribution data, University of Washington research beach seine data, and University of Washington research trawl data.

The geographical distribution data consisted of frequency-of-occurrence (presence or absence) data that was analyzed for all of Puget Sound and for central Puget Sound in terms of (1) the occurrence of rare (exotic) marine fish species that entered Puget Sound from ocean waters on occasion or historically had rarely been observed, and (2) the occurrence of marine fish species that were commonly caught in research trawls in Puget Sound.

From 1950-1972, a series of similar beach seine collections made at Golden Gardens, Seattle, was analyzed for trends in species richness, species diversity, and English sole catch-per-unit-effort (CPUE).

Finally, a series of research trawl data from 1965-1987 in Port Gardner (Everett) bay was analyzed for trends in species richness, species diversity and CPUE.

RESULTS

<u>Entire Puget Sound Long-term Demersal Marine Fish Trends</u>

Peak occurrences of rare species occurred during unusually cold (1918-1919, 1971-1975) or warm (1963-1965, 1983-1984) years, except for the peak in 1932-1935, which was a transition period from warm to cold temperatures. We think that routine monitoring of rare and unusual Puget Sound fish species yields important data, which to the best of our knowledge has not been collected since 1976. Although we do not claim that keeping current records of unusual occurrences of rare and exotic fishes is the most important Puget Sound monitoring tool, we think such monitoring can provide an early warning of environmental changes to Puget Sound.

In general, the analysis of marine fish trends in Puget Sound based on relative frequency-of-occurrence data (a form of CPUE) indicated that while research data did seem to measure real changes in abundances of some Puget Sound marine fishes, there was no indication of a serious change in the relative occurrence of marine fishes in Puget Sound. We noted that, by itself, data on commercial species is often not very useful for looking at long-term trends in fishes other than trends in the fishery itself, which may be impossible to separate from trends due to natural environmental changes (e.g., El Niño) and unnatural perturbations to the environment such as habitat destruction and toxic pollutants. We believe that a strong case can be made for monitoring as many non-economically important fishes in Puget Sound as possible; ideally, assemblages of fishes occupying the major habitats in Puget Sound should be monitored.

Long-term Trends at Specific Sites

Species richness at Golden Gardens beach in Seattle declined significantly from 1950-1972. A suggested reason for this decline was the habitat disturbance and change which occurred with the construction of the Shilshole breakwater in 1957-59. At Port Gardner in Everett, fish community measures (species richness and species diversity) were stable, but the CPUE of three common flatfish showed a decline from 1965-1987. Although we do not have a specific suggestion as to why this decline may have occurred, Port Gardner is well known to be located in an urban environment that has undergone continual alterations induced by humans.

We think these site-specific results further indicate the value of long-term monitoring using both community indices and individual species (both commercial and non-commercial "index" species) abundance measures of marine fishes in Puget Sound.

RECOMMENDATIONS

We think that monitoring of rare and unusual fishes in Puget Sound would provide useful baseline data; it can be done relatively easily and accurately, although it should be done formally instead of informally, as is now the case. Conversely, while recording the frequency-of-occurrence of reports for Puget Sound fish species (and then standardizing the data to English sole for a surrogate CPUE) was useful in generally showing that major changes in the frequency-of-occurrence do not appear to have taken place to date, such an approach is too qualitative for monitoring purposes. Instead, we think the use of standardized trawling and beach seining catches for long-term community measures and CPUE data, such as analyzed in this report at Golden Gardens and Port Gardner, is the approach to take in monitoring the long-term ecological health of Puget Sound marine fishes. Other long-term data sets from standardized sampling exist and should be compiled and analyzed as was done for this project, although our experience indicates that much of the data will have to be extracted by hand from logbooks, which is time-consuming. However, assuming that monitoring of Puget Sound marine fishes will be part of the Puget Sound Ambient Monitoring Program, which will follow the recommended Puget Sound Estuary Program protocols for trawling and beach-seining, the compilation and analysis of other long-term data sets should be done both for general Puget Sound regions (e.g., central Puget Sound, northern Puget Sound), and for site-specific areas (e.g., Port Orchard in central Puget Sound and Deadman Bay in the San Juan Islands), where sampling was done in the same manner as the standardized protocol. This data needs to be compiled into a usable database to ensure that it does not become lost or unusable as researchers come and go over the years.

New data that are collected in a standardized fashion should be added to the database at regular intervals to ensure that (1) the database remains current, and (2) data do not become lost through lack of proper documentation. The task of developing and maintaining the database should be the responsibility of one entity, but the data sources could be from a number of research efforts. It would be the responsibility of the central entity to evaluate new data to determine if it is suitable and appropriate for inclusion in the database.

LONG-TERM TRENDS IN PUGET SOUND MARINE FISHES: SELECTED DATA SETS

INTRODUCTION

Fish fauna changes have long been recognized as good indicators of ecological health of aquatic habitats, although the best record keeping seems to have taken place primarily in freshwater systems and where scientists and resource managers are funded to keep track of long-term changes in species diversity, distribution, and abundances of fishes. In a recent American Institute of Fishery Research Biologists newsletter (AIFRB 1990), an article summarized the findings of an American Fisheries Society's report that detailed the continuing decline of the health of our continent's rivers, lakes, and spring systems, as reflected in the decline of the continent's freshwater fish fauna. For example, the number of fish species warranting special protection because of their rarity rose 45% from 1979 to 1989 (251 to 364, respectively). Even more alarming are the findings that 40 species have become extinct because of expanding human pressures on our aquatic resources, and that during the past decade, for every fish species whose status improved, 25 fish species declined significantly in distribution range and abundance. These findings led to the recommendation that agencies put more funding into habitat protection programs (and into the more expensive habitat recovery programs), with a new strategy for protection of overall biodiversity, including protection of aquatic communities and ecosystems before their species reach the critical endangered stage.

The primary objective of this project was to analyze for long-term trends in Puget Sound marine fish distribution and abundance based on a synthesis of the available data. A secondary objective was to establish baselines of marine fish species presence and abundance against which future fish monitoring efforts could be compared and evaluated. An additional benefit of the project was the identification of the collection methods used over the years, which can be used to help define standardized methods so that future investigations can be conducted in a compatible fashion.

One focus of the Puget Sound Estuary Program is to characterize the study region through a system-wide synthesis and analysis of existing data on water and sediment quality and living resources. The objectives of this synthesis and analysis are to identify spatial and temporal changes in the estuarine system and evaluate probable causes for these changes.

Analysis of fish distributional differences in Puget Sound have been conducted and notable patterns exist (Wingert and Miller 1979); however, those analyses did not incorporate time into the evaluation. In a recent evaluation of historical data sets on Puget Sound marine fishes (Moulton and Miller 1987), information on location, date, gear used, number of sets made, depths sampled, and types of data recorded were reviewed to determine if these data were available in sufficient temporal and spatial coverage and were of sufficient quality to evaluate trends in selected species or assemblages, and at selected locations, over time. The conclusion was that there is data available for looking at trends over long periods of time.

To select a data set for further evaluation and possible inclusion in the characterization, we identified the following main criteria:

the data set was collected over 3 or more years using consistent methods;

the data set supplements similar information or extends the period of record from other sources; or

the data set appeared to have the detail needed to reveal changes over time in species composition, abundance, or size structure of marine fish in a specific area.

The results of this prior data evaluation have indicated that salmonids are the only species to initially be excluded, and that the University of Washington Puget Sound research on fish distribution, beach seining, and trawling should be analyzed.

MATERIALS AND METHODS

NAMES OF FISHES

Both common and scientific names of fishes are given the first time a fish species is mentioned in this report, after which only the common name is used. However, a list of the scientific and common names of all fishes referred to in this report is given in the Appendix Table.

DATA

The data we chose for the initial evaluation and trend analysis were as follows.

Geographical Distribution Data

The frequency-of-occurrence (presence or absence) data were examined for selected species fish in four Puget Sound geographical areas (Puget Sound total, north Puget Sound, central Pu Sound, and southern Puget Sound); the data were taken from primary literature, technical repo log books, etc., from the mid-1800s to the early 1970s (over 200 data sources; see Miller and Borton, 1980). Fish species were selected for analysis if they fell into one of two categories rare species of marine fishes that entered Puget Sound from ocean waters on occasion or historically had rarely been observed, and (2) marine fish species that were commonly caugh research trawls in Puget Sound.

University of Washington Research Beach Seine Data

An excellent series of similar beach seine collections were made at the Golden Gardens (Seattle) beach between 1950 and 1967, with some periodic sampling after that. These data were transferred from the original logbooks to data entry forms and then entered into the computer for analysis.

University of Washington (UW) Research Trawl Data

These data were considered excellent for the objectives of this project because they presented a good opportunity to evaluate site-specific, long-term trends in Puget Sound marine fish abundance and distribution, and would complement similar trawl data from the EPA Puget Sound Ambient Monitoring Program. The data were collected primarily under the direction of three UW researchers (Drs. Thomas S. English and Allan C. DeLacy, deceased; Dr. Bruce S. Miller) using standardized collection techniques. In the preliminary survey of available data, the areas that showed the greatest potential for evaluating marine fish trends were Port Orchard, Port Gardner, Bellingham Bay, Port Madison, and Case Inlet. Since the most promising data sets (for our trend analysis) appeared to be from Port Gardner, and owing to the general difficulty encountered in formatting the data from all locations, only trawl data from Port Gardner were analyzed for this project.

ANALYSIS METHODS

The Puget Sound marine fish data were analyzed for trends over time. When evaluating historical data that were originally collected without the objective of long-term trend analysis, it is necessary to do a "retrospective analysis" (Champ et al. 1987), which relies on the reconstruction of long-term records from existing data. With this approach, the analysis techniques are dictated by the quality and quantity of the long-term data available. Both qualitative and quantitative analyses of long-term data are useful because the emphasis of such studies are on trends and correlations; causality, unfortunately, cannot be determined.

Data Set: Rare Species Presence or Absence, 1863-1987

This data set was compiled from the available geographical distribution data and was supplemented by additional information from Dr. Alan Mearns (NOAA, Seattle), Wayne Palsson (Washington Department of Fisheries) and Dr. David Fluharty (UW School of Marine Affairs). Only rare (unusual, exotic) species records that had been verified by an expert were included in the analysis. The rare species data are qualitative in the sense that only presence or absence data were available, and we we know of no way to indicate, or even estimate, the annual effort expended at noting rare species.

Information was entered into a spreadsheet program Microsoft EXCEL) using a Macintosh PC, and calculations and plots of species presence were made.

Data Sets: Common Demersal Species Frequency-of-occurrence, 1932-1972

These data sets were also compiled from available geographical distribution data, in this case on the frequency-of-occurrence of Puget Sound demersal fishes, where a single net-haul catch (whether one specimen or many) of a species equals one frequency-of-occurrence record. In addition to looking at Puget Sound in total, we divided Puget Sound into four geographical areas for separate consideration (north Puget Sound, central Puget Sound, south Puget Sound and Hood Canal, Fig. 1.) On the basis of preliminary analysis, we decided to only evaluate common demersal (or near-demersal) fishes caught in demersal nets since this was the only large data set and because we felt it was the most reliable (species identification, likelihood of species being recorded).

However, a major difficulty in evaluating this long-term data set arose from the lack of sampling effort data, and clearly frequency-of-occurrence is a function of sampling effort. In order to make the data at least qualitatively useful, we chose English sole (*Parophrys vetulus*)—the most ubiquitous, abundant, and commonly identified species of Puget Sound demersal fishes (i.e., most likely to occur in a trawl)—to represent sampling effort and to allow relative quantitative comparisons to the other species. Specifically, the sampling effort for 1 year was considered equal to the number of reports of English sole for that year, and a "catch-per-unit-effort" (CPUE) was calculated for the other species by dividing their frequency-of-occurrence by that of English sole for each year. Justification for this unusual effort measurement was based on a preliminary survey of research trawling data that we had for several trawl types, trawl speeds, trawl depths, trawl locations and by seasons and time of day; in 96% of the individual trawls examined, English sole were present. Also, the fact that the "English sole" CPUE calculated in this report for individual species (see Results section) rarely exceeded 1.0 further indicates that English sole presence (frequency-of-occurrence) was a good indicator of effort.

To determine trends measured by this "English sole" CPUE for common Puget Sound demersal fishes, we made calculations and plots of CPUE using a spreadsheet program (Microsoft EXCEL) on a Macintosh PC.

Data Set: Central Puget Sound (Golden Gardens Beach) Species Diversity, 1950-1972

The Golden Gardens beach (Fig. 1) data set came from the original entries into the University of Washington's School of Fisheries log books from 1950-1967, and from scattered records from 1967 to 1973. Data were hand copied to computer format forms, entered onto computer disks, and then analyzed on a Macintosh PC.

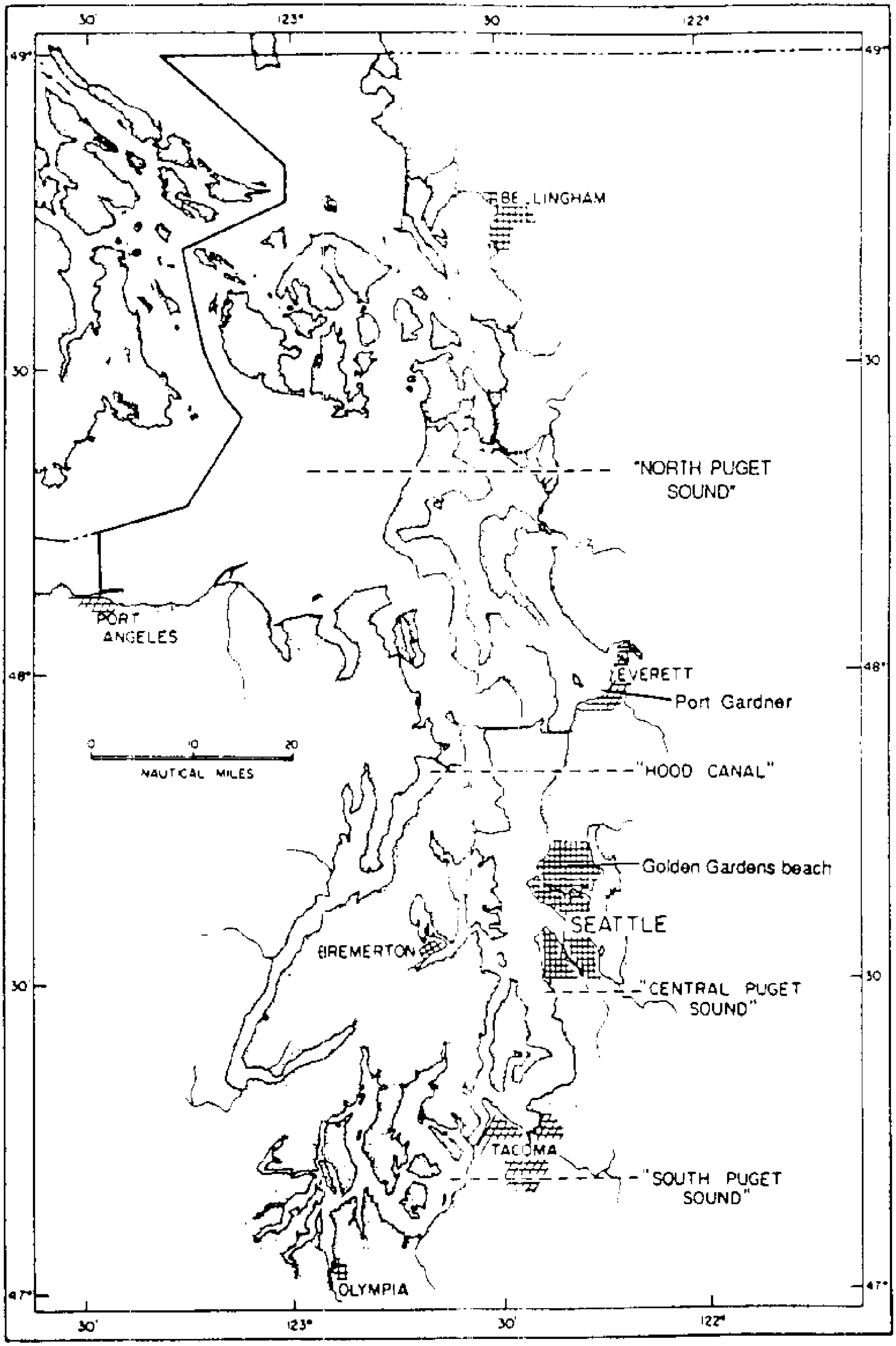


Figure 1. The four sampling areas (in quotes) used to group reports of fish occurrence in Puget Sound, and other place names.

The data from 1950-1972 consisted of location, year, day, time, gear type, species caught, and the total number of specimens of each species caught. Species richness (SR), defined as the total number of species caught, was calculated for the Golden Gardens data; although a simple calculation, Pielou (1975) considers species richness as a useful tool in ecological studies of aquatic communities. Species diversity (H') was also calculated for the Golden Gardens data: species diversity combines the number of fish species and their relative abundances. Species diversity (H') was calculated after Pielou (1978):

$$H' = -\sum_{i=1}^{n} p_i \ln p_i,$$

where p_i is the proportion of the community that belonged to the i^{th} species, and n is the number of species.

Data Set: Central Puget Sound (Golden Gardens Beach) English Sole CPUE, 1950-1972

This data set also came from the original entries into the University of Washington's School of Fisheries log books from 1950-1967, and from scattered records from 1967 to 1973. Data were hand copied to computer format forms, entered onto computer disks and then loaded onto the VAX mainframe computer at the University of Washington, and on to a Macintosh PC; programs used for analyzing for yearly trends in the data (regression analysis) were SPSSX and SYSTAT.

Preliminary examination of the Golden Gardens Beach data set revealed that English sole was the only species at Golden Gardens with sufficient count data for long-term analysis. Differences in the season of the year, time of the day, and gear type were accounted for in the analysis by appropriately grouping the data based on statistical comparisons.

Data Set: Central Puget Sound (Port Gardner Bay) Species Changes, 1965-1987

The Port Gardner Bay (Fig. 1) data set consisted of three subsets: 1966-1967, 1973-1978, 1986-1987. Various parts of this data set were in original log books, on 80-column computer cards, or on magnetic tapes. Data was hand copied or translated for data entry onto computer disks, and then loaded onto the VAX mainframe at the UW, and on to a Macintosh PC; programs used for analyzing the data were SPSSX, SYSTAT, and EXCEL. The data in the 1960s and 1970s were restricted by the original investigator (Dr. Tom English) to the 14 most common species caught during those periods, so we also evaluated the 1986-1987 data for those same species in regard to species richness (SR14), species diversity (H'14), and CPUE of species (number of a species caught-per-5-min-tow); species richness and diversity are abbreviated "SR14" and "H'14" to indicate that only data for the 14 most common species were used in analysis.

Data Set: Central Puget Sound (Port Gardner Bay), Common Species CPUE, 1965-1987

The Port Gardner Bay data set of 14 species allowed us to analyze the CPUE (number of fish caught-per-5-minute-tow) trend for 6 species of fish that were caught regularly, and in adequate abundance, from 1965-1987. SPSSX and SYSTAT were the statistical programs used for summarizing and displaying the data on a yearly basis, and for regression analysis. Differences in the seasons of the year, time of day, and gear type were accounted for by appropriately grouping the data based on statistical comparisons.

RESULTS

RARE SPECIES PRESENCE OR ABSENCE, 1863-1987

Fish distribution records archived at the University of Washington through 1976 were compiled and examined for the occurrence of 27 species deemed to be rare (Table 1), and the number of rare species seen in any 1 year from 1863 to 1976 was plotted (Fig. 2a). These records were then reanalyzed using a more restricted list of rare species that is monitored by Dr. Alan Mearns at NOAA (Table 1), but which extends the data set from 1863 to 1987 (Fig. 2b, Table 1). Finally, data on a small group of rare species (Table 1) recorded by the Washington Department of Fisheries from 1977 to 1987 were also compiled and plotted (Fig. 2c).

The data indicate that peak occurrences of rare/uncommon species appear to have occurred during the early 1870s, the early 1880s, 1918, the mid-1960s, 1972, and 1983 (Fig. 2).

COMMON DEMERSAL SPECIES CPUE, 1932-1972, FOR THE ENTIRE PUGET SOUND (INCLUDING WDF COMMERCIAL/RECREATIONAL DATA TO 1987) AND FOR CENTRAL PUGET SOUND

The use of English sole frequency-of-occurrence to represent sampling effort resulted in sample sizes adequate for examining Puget Sound as a whole, and for central Puget Sound (Fig. 1), but not for south Puget Sound, north Puget Sound or Hood Canal. The data set extended from 1932 to 1972. In addition, for the entire Puget Sound we have included WDF commercial/recreational fish data (Schmitt 1990), which extend the data set for some economically important species to 1987.

Entire Puget Sound

Commercial and recreationally important fishes. English sole (*Parophrys vetulus*) frequency-of-occurrence reports ("catch") in research samples showed a general increase into the 1960s, as did English sole commercial catches and CPUE (Fig. 3); but since the later 1960s, the commercial CPUE has shown an overall moderate decrease, and quite a bit of variability. No English sole

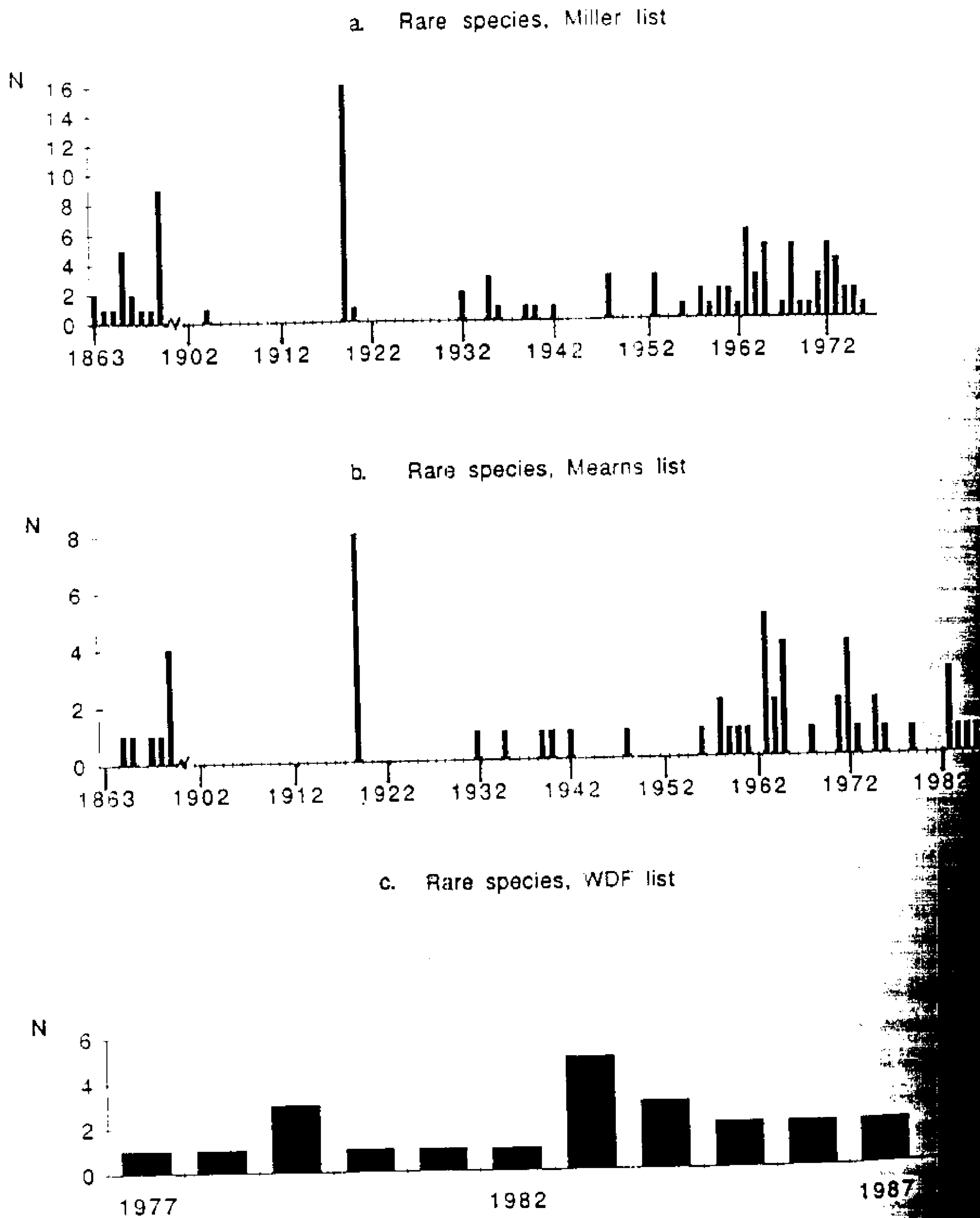


Figure 2. Number of rare species (N) in Puget Sound reported by year.

Table 1. Lists of rare species from Puget Sound, 1863-1987.

Common name	Scientific name	Miller list*	Mearns list*	WDF list*
Sixgill shark	*Hexanchus griseus*			X
Sevengill shark	*Notorynchus maculatus*	X		
Thresher shark	*Alopias vulpinus*	X	X	
Basking shark	*Cetorhinus maximus*	X	X	
Blue shark	*Prionace glauca*	X		
Pacific sleeper shark	*Somniosus pacificus*	X		
Pacific angel shark	*Squatina californica*	X		
Pacific electric ray	*Torpedo californica*	X	X	
Slender snipe eel	*Nemichthys scolopaceus*	X		
Pacific sardine	*Sardinops sagax*	X	X	
Northern anchovy	*Engraulis mordax*	X		X
Whitebait smelt	*Allosmerus elongatus*	X		X
Capelin	*Mallotus villosus*	X		
California lizardfish	*Synodus lucioceps*	X	X	X
Ribbon barracudina	*Notolepis coruscans*	X		
Longnose lancetfish	*Alepisaurus ferox*	X		
California headlightfish	*Diaphus theta*	X		
Northern lampfish	*Stenobrachius leucopsarus*	X		
Blue lanternfish	*Tarletonbeania crenularis*	X		
Striped bass	*Morone saxatilis*	X		
Pacific pomfret	*Brama japonica*	X	X	
White seabass	*Cynoscion nobilis*	X	X	
White croaker	*Genyonemus lineatus*	X		
Pacific barracuda	*Sphyraena argentea*	X	X	
Pacific bonito	*Sarda chiliensis*	X		
Chub mackerel	*Scomber japonicus*	X	X	X
Pacific pompano	*Peprilus simillimus*	X	X	
Ocean sunfish	*Mola mola*	X	X	

*See text for explanation of sources.

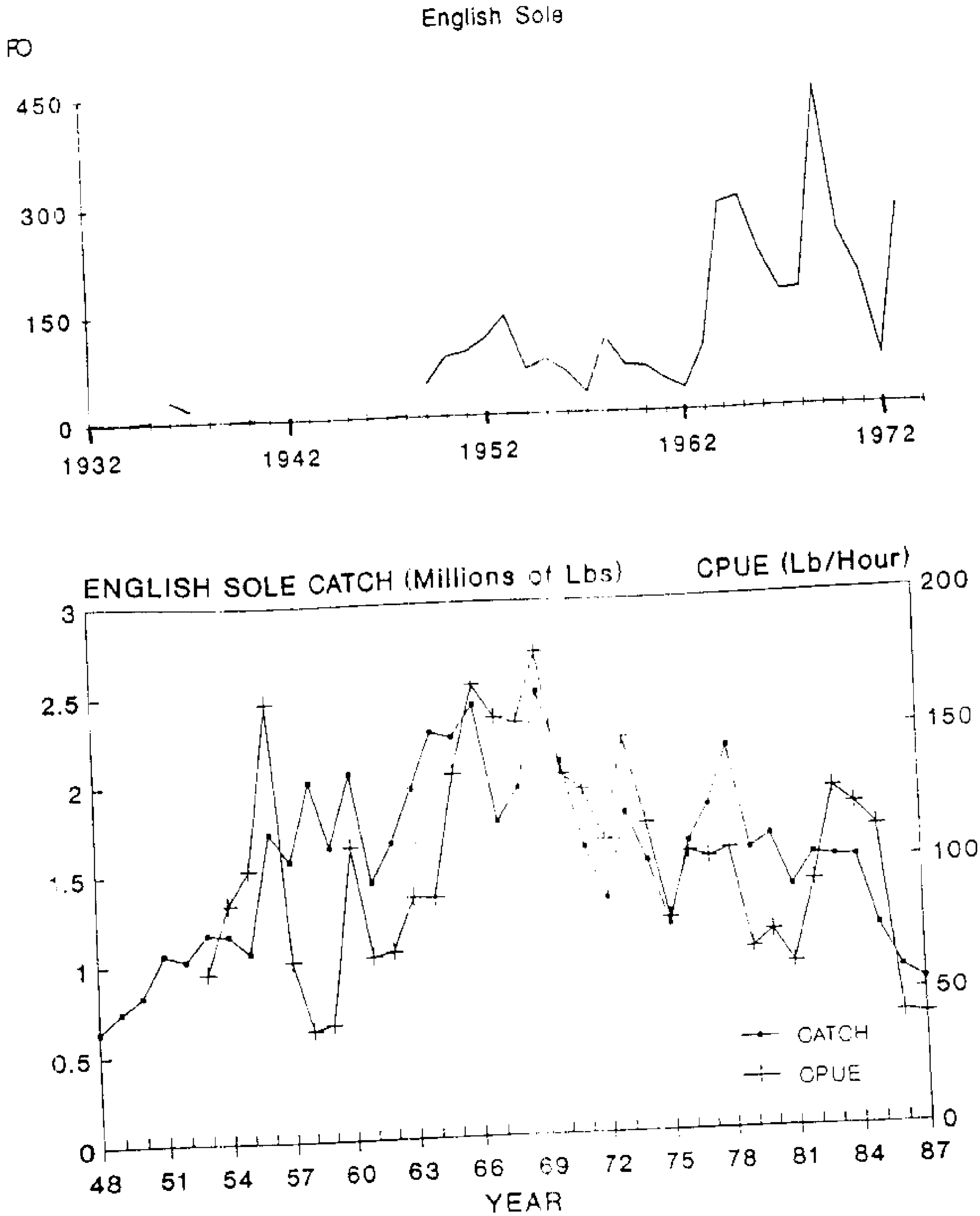


Figure 3. Plot of yearly English sole frequency-of-occurrence (FO), which was used to standardize other research sampling (see text), and the catch (millions of pounds) and CPUE (lb/hr) of English sole from commercial fishing.

research CPUE can be calculated because the frequency-of-occurrence for English sole is a direct reflection of sampling effort and is therefore used as the effort data in calculating research trawl CPUE for all other species caught in research trawls.

Research data indicated little change in the relative abundance of dogfish (*Squalus acanthias*) from the late 1940s through the early 1970s, while the commercial catch data reflected almost no catch in the early 70s, a high catch in the late 70s, and then a decline to a mid-level catch in the 80s (Fig. 4). Both research and commercial data for Pacific cod (*Gadus macrocephalus*; Fig. 5) indicated an increase in abundance from the 1940s to the mid-1970s, when CPUE peaked, and then a CPUE decline until the 1980s, when it appears to have stabilized. Shiner surfperch (*Cymatogaster aggregata*) caught in research sampling showed an increase in CPUE from the late 1940s to the early 1970s, although a noticeable drop occurred in the late 1960s before increasing again in the early 1970s (Fig. 6a); commercially caught surfperch (striped seaperch, *Embiotoca lateralis* , and pile perch, *Rhacochilus vacca*) CPUE declined during the 1970s and stabilized during the 1980s, but there was some indication of an increase in the late 1980s (Fig. 6b). Copper rockfish (*Sebastes caurinus*) were infrequently caught in research samples from 1950 through 1970 (Fig 7a), while the total commercial catch of rockfish (*Sebastes* spp.) increased during the 1970s and stabilized during the 1980s (Fig 7b). Lingcod (*Ophiodon elongatus*) occurrence in research samples was infrequent and showed little change except for a 1-year increase in the early 1960s, and a marked increase in the early 1970s; total catch data in the lingcod fisheries indicated a moderate decline in the 1970s, a pronounced increase in the early 1980s, and a fairly stable catch through 1987 (Fig. 8).

Starry flounder (*Platichthys stellatus*), rock sole (*Lepidopsetta bilineata*), and sand sole (*Psettichthys melanostictus*) are shallow-water flatfish that overlap in many habitats with English sole; unfortunately only research trawling data is available on an individual species basis for these commercially important species. Starry flounder and rock sole showed a general increase in relative abundance in the 1960s, while sand sole showed little overall change (Fig. 9). Flathead sole (*Hippoglossoides elassodon*) and Dover sole (*Microstomus pacificus*), which generally overlap with English sole only in deeper water habitat, both seemed to show decreases in their relative abundances in research sampling from the 1930s to the early 1970s (Fig. 10).

Non-commercial/recreational fishes. Long-term data were available for five species of fish not considered to be commercially or recreationally important, but which are potentially affected by other factors (such as environmental) influencing population regulation: ratfish (*Hydrolagus colliei*), tomcod (*Microgadus proximus*), staghorn sculpin (*Leptocottus armatus*), roughback sculpin (*Chitonotus pugetensis*), and the snake prickleback (*Lumpenus sagitta*). None of these species caught in research samples, except ratfish, showed clear upward or downward trends in relative abundance (Fig. 11). In general, ratfish showed a declining trend in the early 1950s and

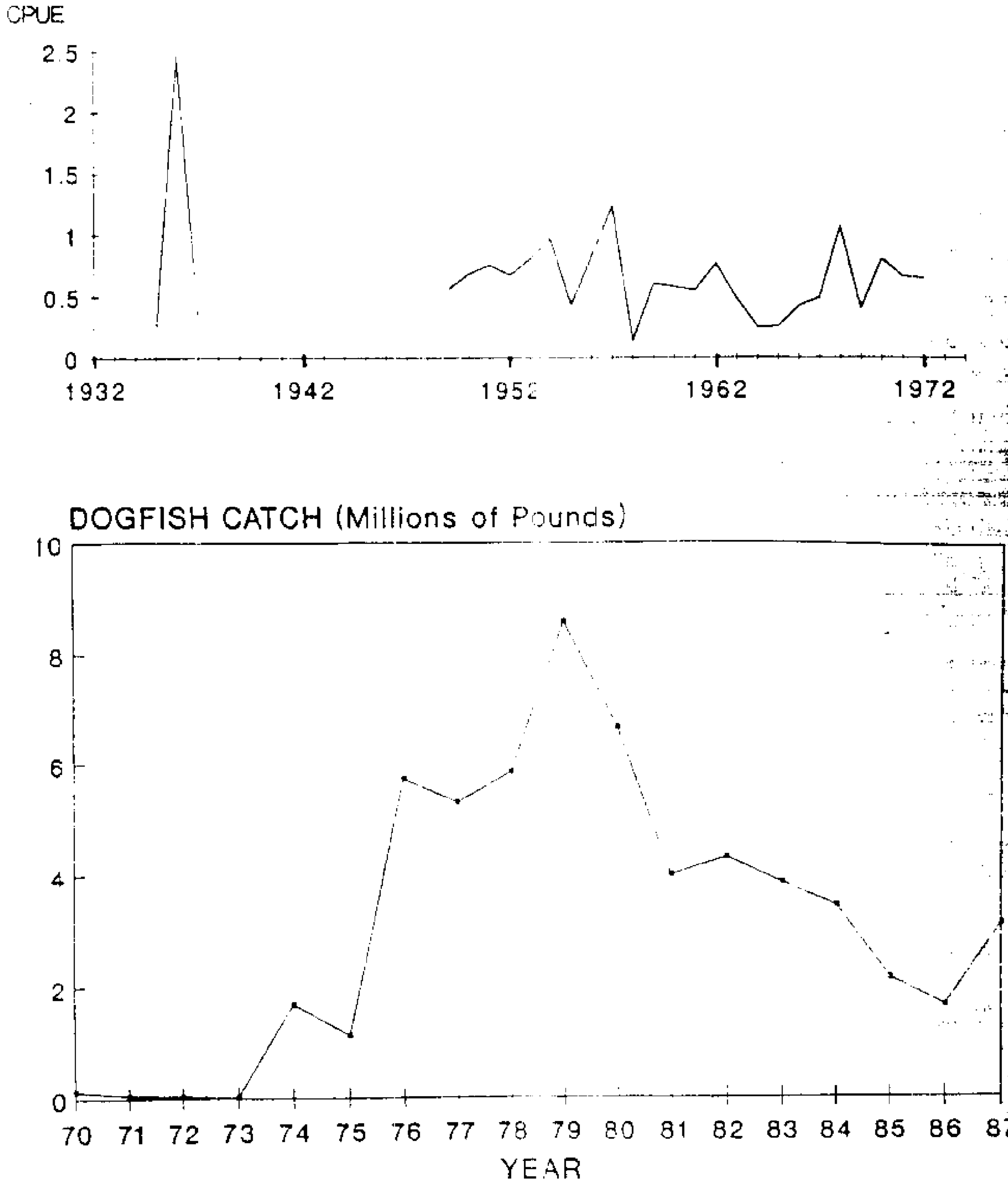


Figure 4. Puget Sound yearly spiny dogfish CPUE (number of occurrences/number of occurrences of English sole) in research sampling, and catch (millions of pounds) from commercial fishing.

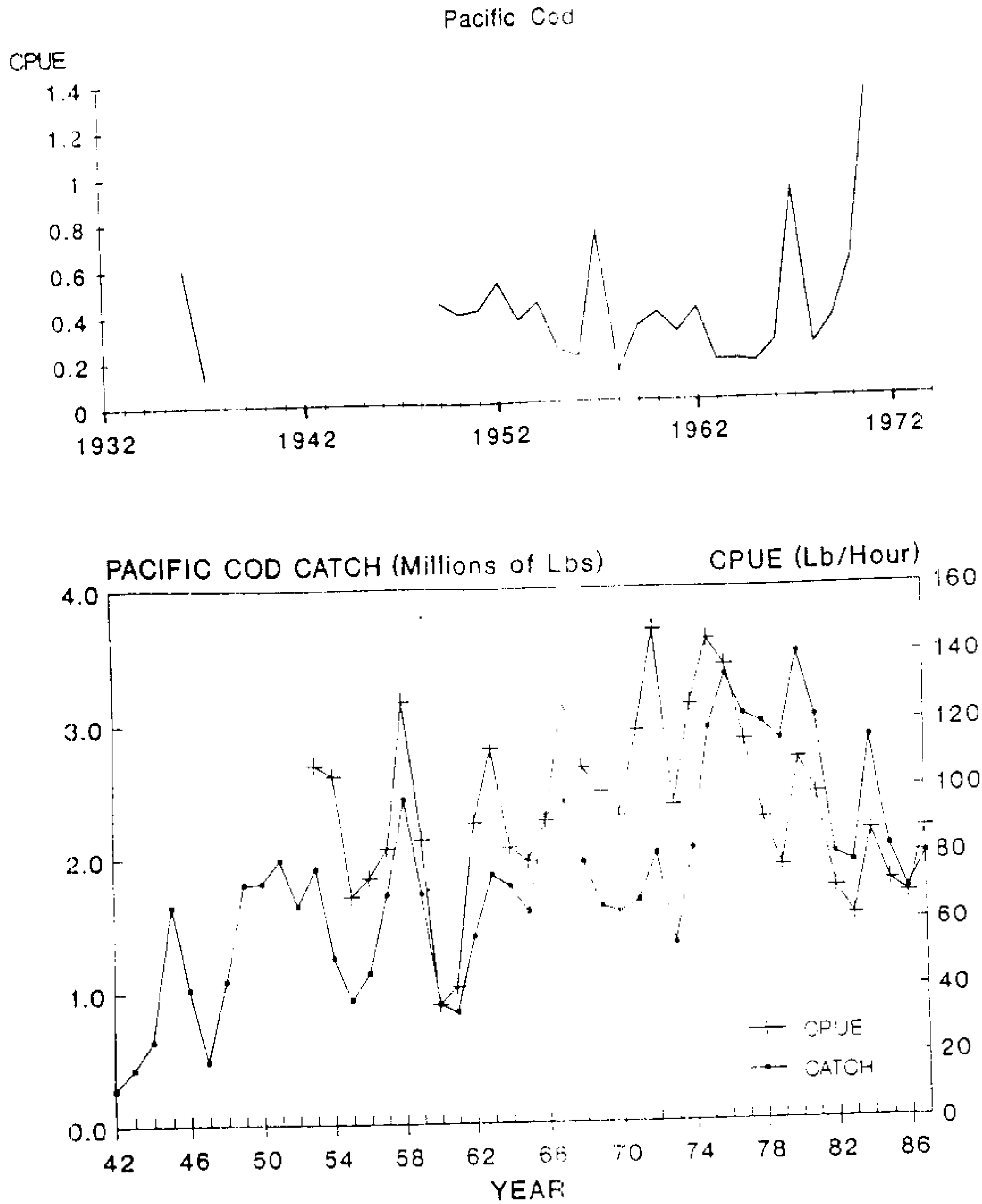
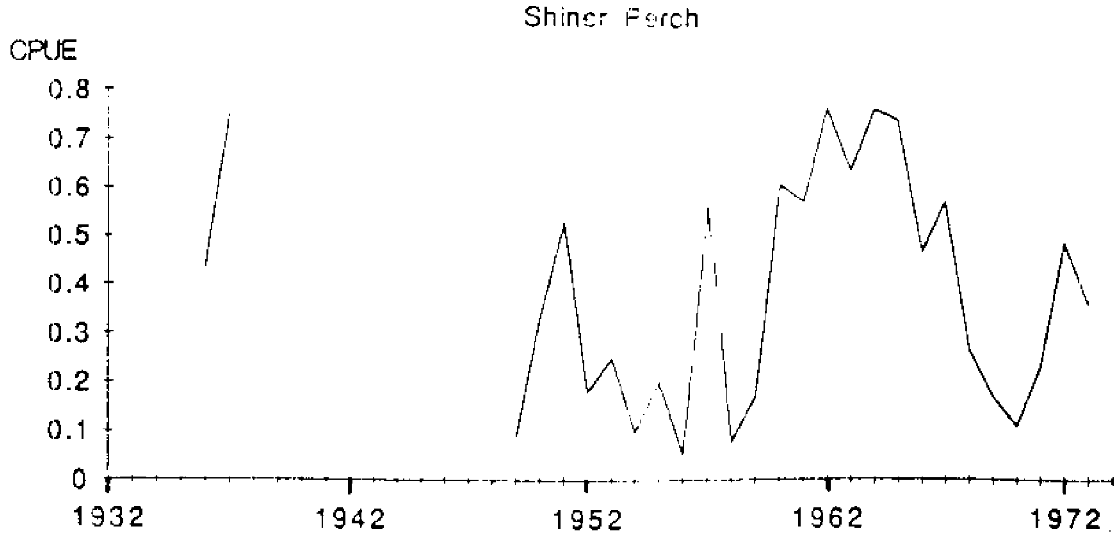


Figure 5. Puget Sound yearly Pacific cod CPUE (number of occurrences/number of occurrences of English sole) in research sampling, and from commercial fishing (lb/hr).

a.



b.

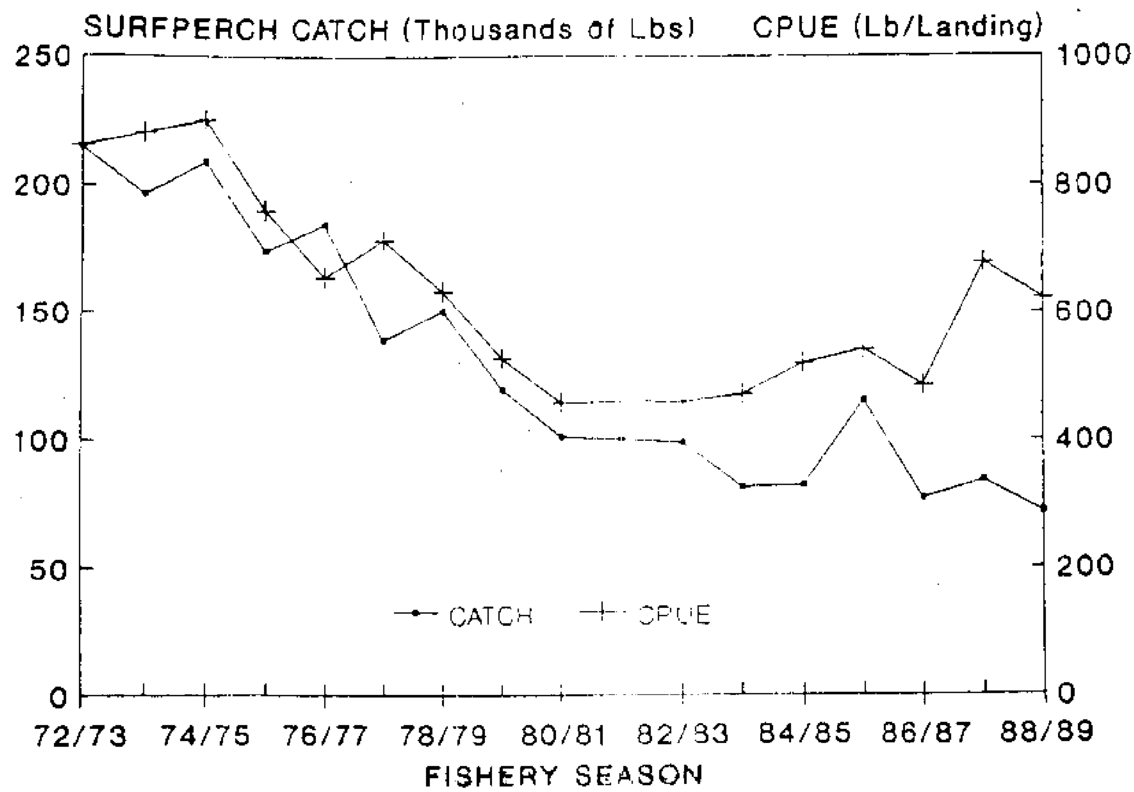
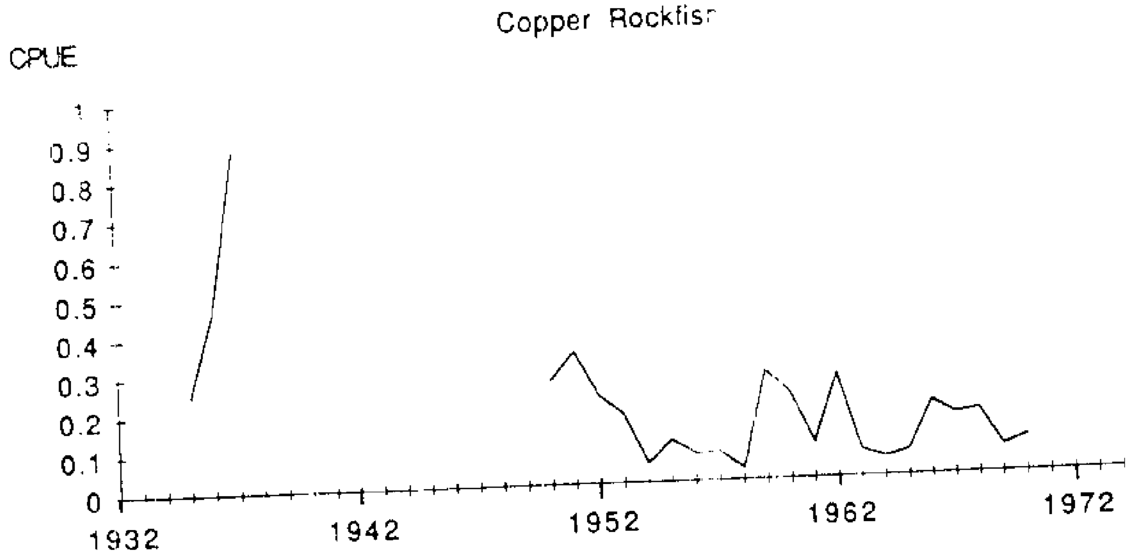


Figure 6. (a) Puget Sound yearly shiner surfperch CPUE (number of occurrences/number of occurrences of English sole) in research sampling; (b) CPUE (lb/landing) of surfperch mixed species from commercial fishing.

a.



b.

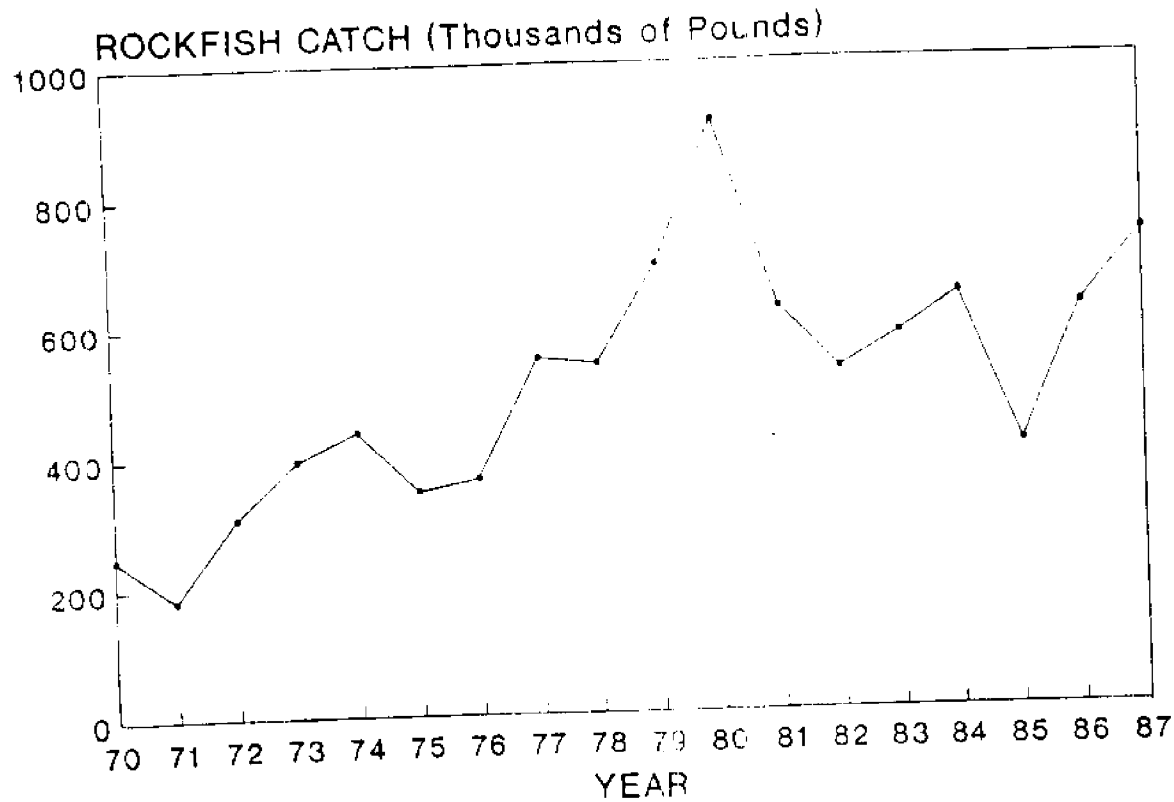
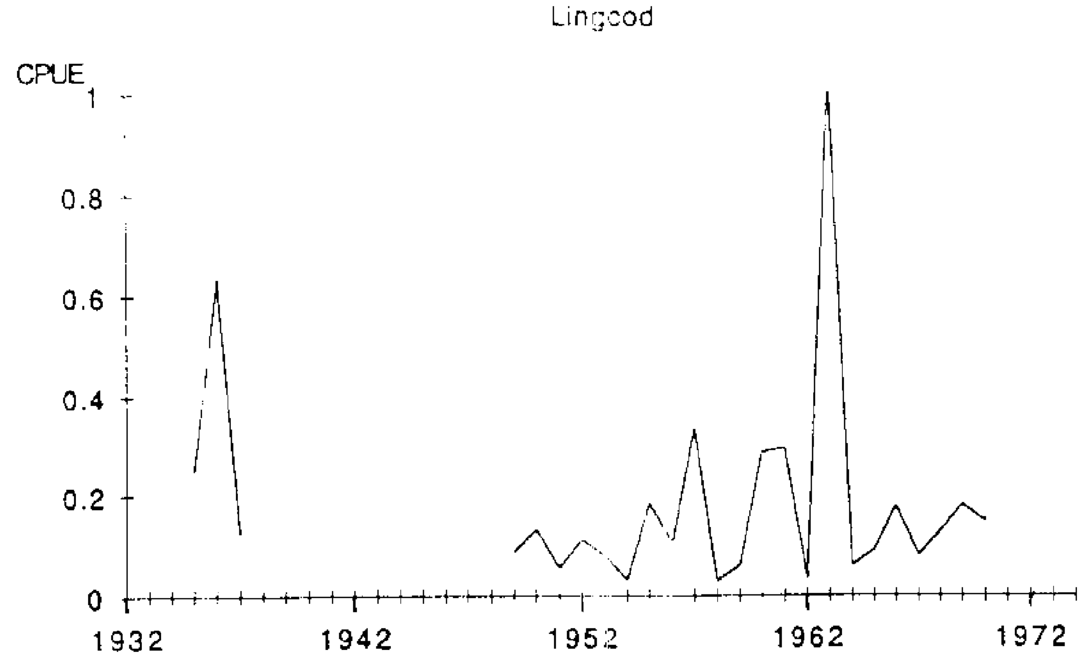


Figure 7. (a) Puget Sound yearly copper rockfish CPUE (number of occurrences/number of occurrences of English sole) in research sampling; (b) mixed species rockfish catch (thousands of pounds) from commercial fishing.



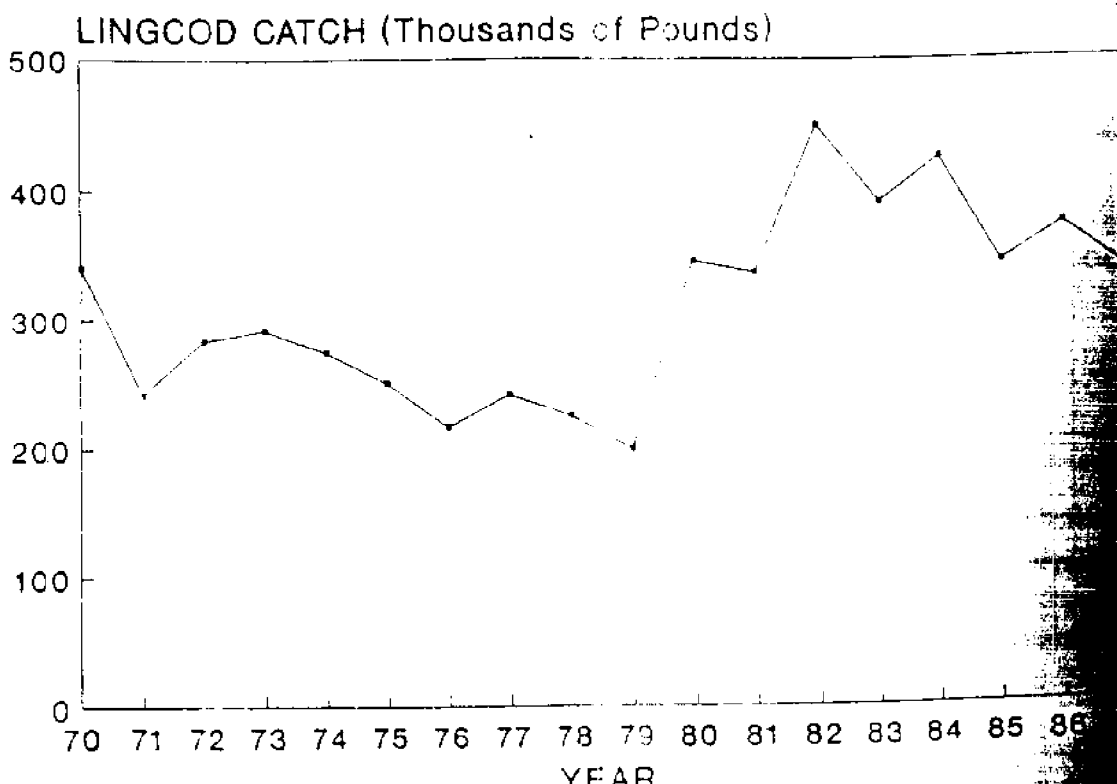


Figure 8. Puget Sound yearly lingcod CPUE (number of occurrences/number of occ English sole) in research sampling, and catch (thousands of pounds) from commercial fishing.

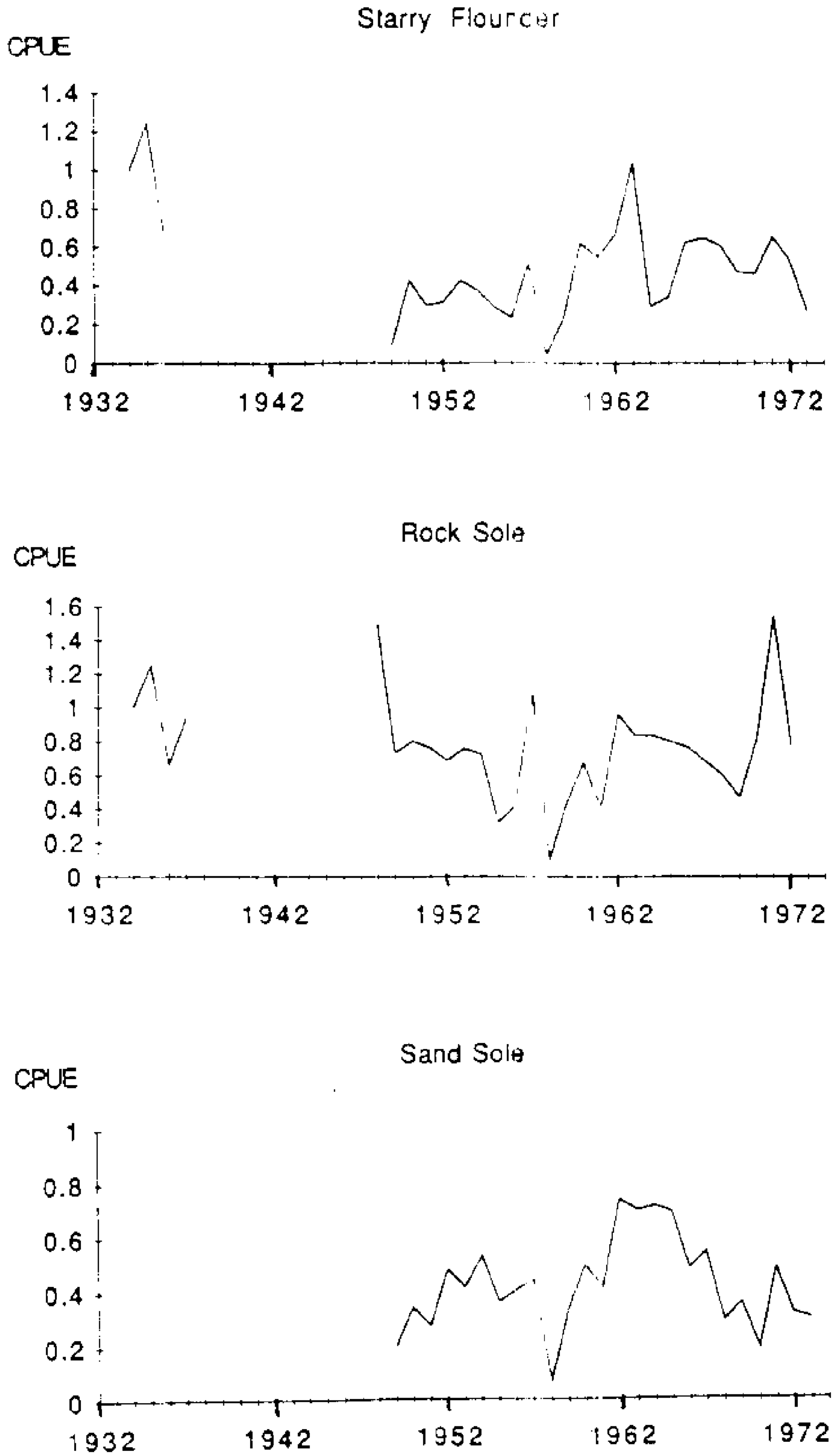


Figure 9. Puget Sound yearly starry flounder, rock sole, and sand sole CPUE (number of occurrences/number of occurrences of English sole) from research sampling.

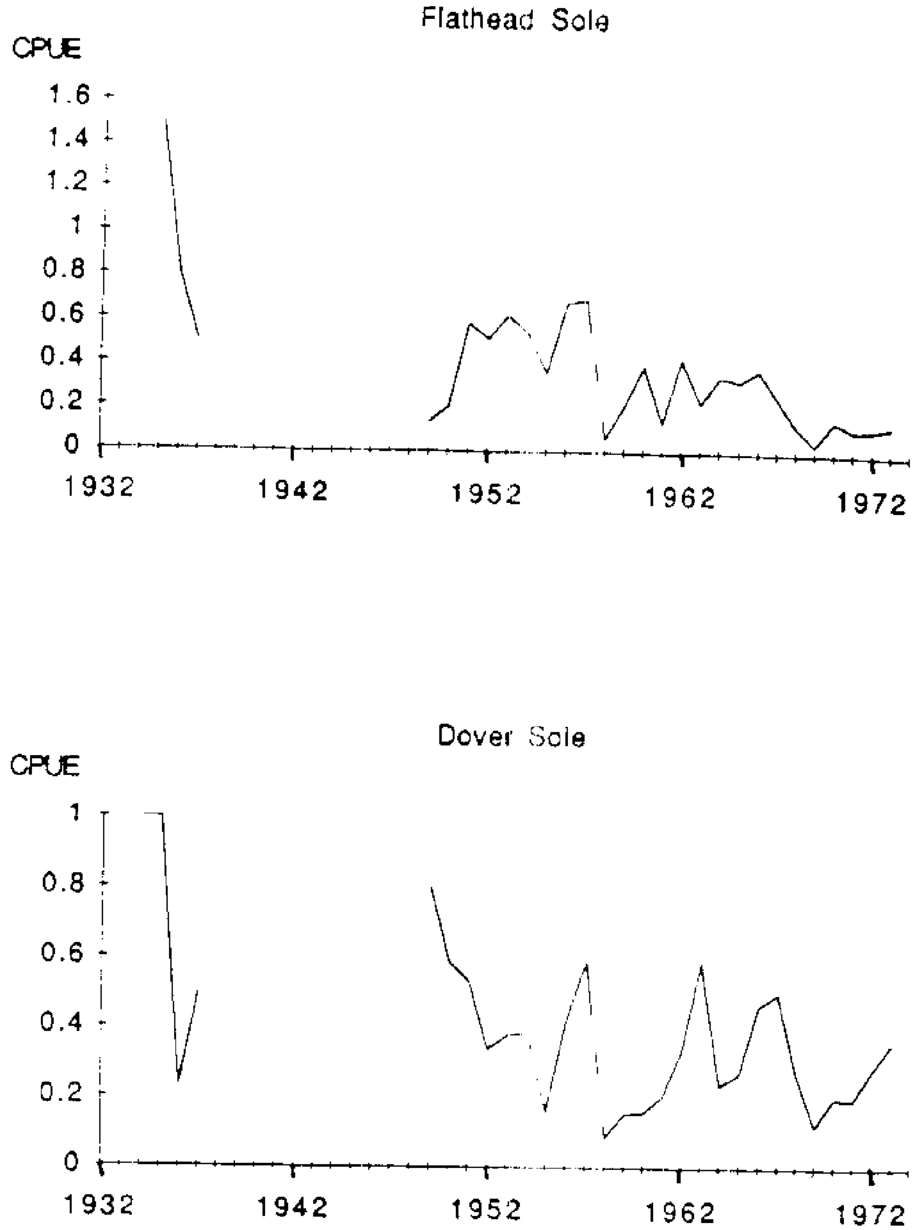


Figure 10. Puget Sound yearly flathead sole and Dover sole CPUE (number of occurrences/ number of occurrences of English sole) from research sampling.

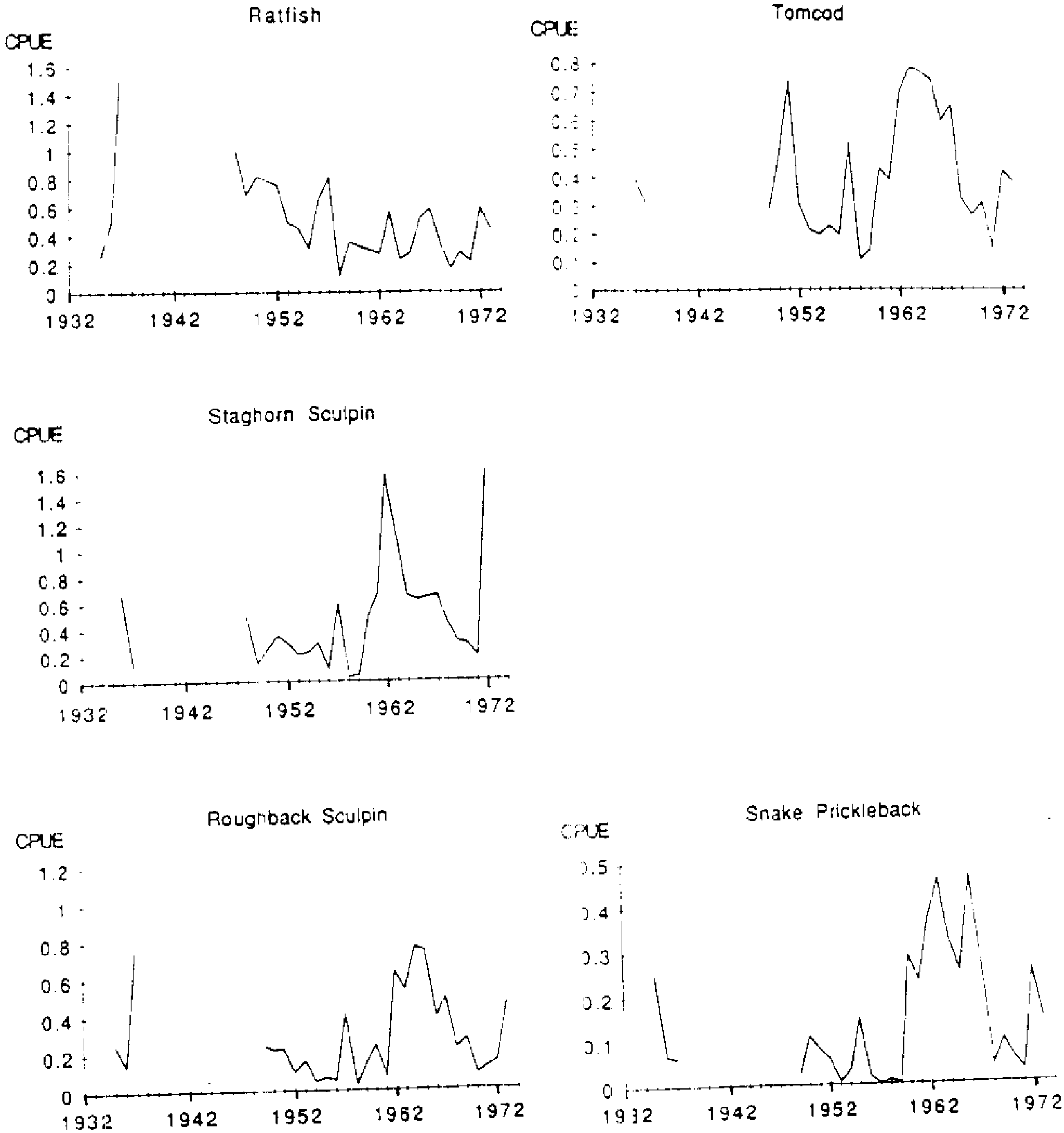


Figure 11. Puget Sound yearly CPUE (number of occurrences/number of occurrences of English sole) from research sampling for ratfish, tomcod, staghorn sculpin, roughback sculpin and snake prickleback.

then stabilized; tomcod data gave an indication of a possible 10-year cycle with a period of peak abundance in the 1960s (but a longer time series is needed to cover another 10-year period); and roughback sculpin, staghorn sculpin and snake prickleback may also be showing the same cycle as tomcod.

Central Puget Sound

Commercial and recreationally important fishes. The central Puget Sound relative abundance or CPUE data from research sampling, which was again standardized to the English sole effort data (Fig. 3), were similar to the entire Puget Sound data from the late 1940s to the early 1970s (Figs. 12 and 13). Pacific cod, shiner perch, copper rockfish, lingcod, starry flounder, and rock sole showed general increases in CPUE; Dover sole and flathead sole showed decreases; and dogfish and sand sole showed little change in CPUE.

Non-commercial/recreational fishes. Five species of non-economically important fish—ratfish, tomcod, staghorn sculpin, roughback sculpin and snake prickleback—did not show general trends toward increasing or decreasing CPUE over time (Fig. 14), although some possible shorter-term abundance cycles may be present. However, it appears that unexploited (non-economically important) Puget Sound fishes have not exhibited long-term changes in their relative abundance from the late 1940s to the early 1970s.

Central Puget Sound (Golden Gardens) Beach Seine Data, 1950-1972

In order to avoid bias of seasonal changes in species assemblages and species abundance, the Golden Gardens beach seine data was partitioned by season for analysis; this partitioning revealed that only the spring season (April and May) had been sampled frequently enough for examining long-term trends in the data.

A plot of the spring season species richness (number of species present) at Golden Gardens beach from 1950 to 1972 (Fig. 15), evaluated by regression analysis (weighted by the number of hauls made), revealed a significant ($p < 0.05$) decline in the number of species from 40-50 in the early 1950s to 15-20 in the early 1970s. A histogram of the spring season species diversity index, H' (Fig. 16), also indicated an overall decline in this index, but the decline was not statistically significant as a long-term trend regression line ($p > 0.05$).

Because of its ubiquitous abundance and frequency, English sole was the one species with enough samples for CPUE to be calculated. A plot (Fig. 17) of the mean of the natural log transformation of the catch of English sole did not reveal a statistically significant ($p > 0.05$) change over time in the CPUE of this species. These data were also partitioned by capture time (day vs. night) and analyzed, but no statistically significant trends were observed.

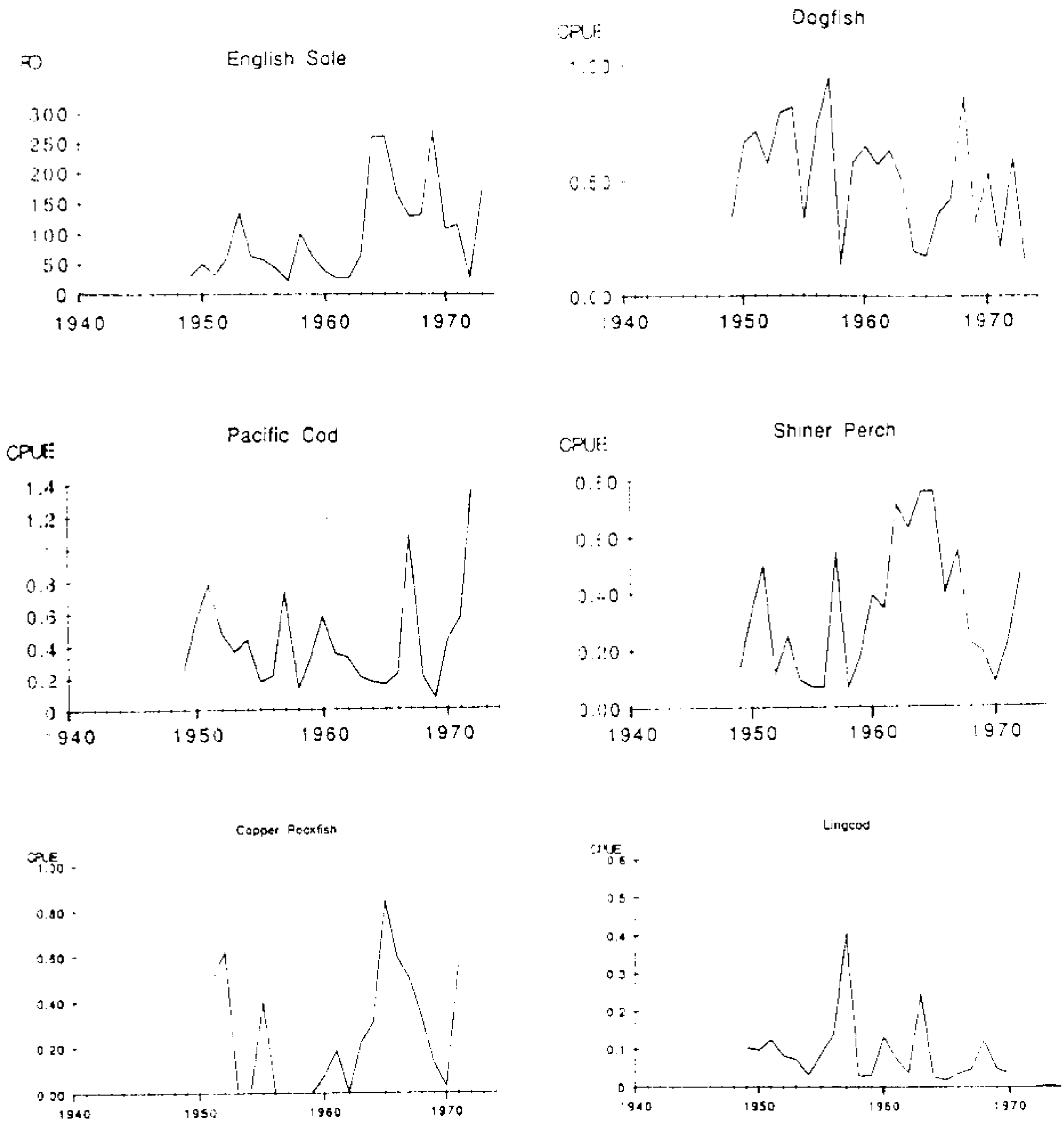


Figure 12. Plot of yearly central Puget Sound English sole frequency-of-occurrence (FO), which was used to standardize other research sampling (see text), and CPUE (number of occurrences/number of occurrences of English sole) from research sampling for dogfish, Pacific cod, shiner perch, copper rockfish, and lingcod.

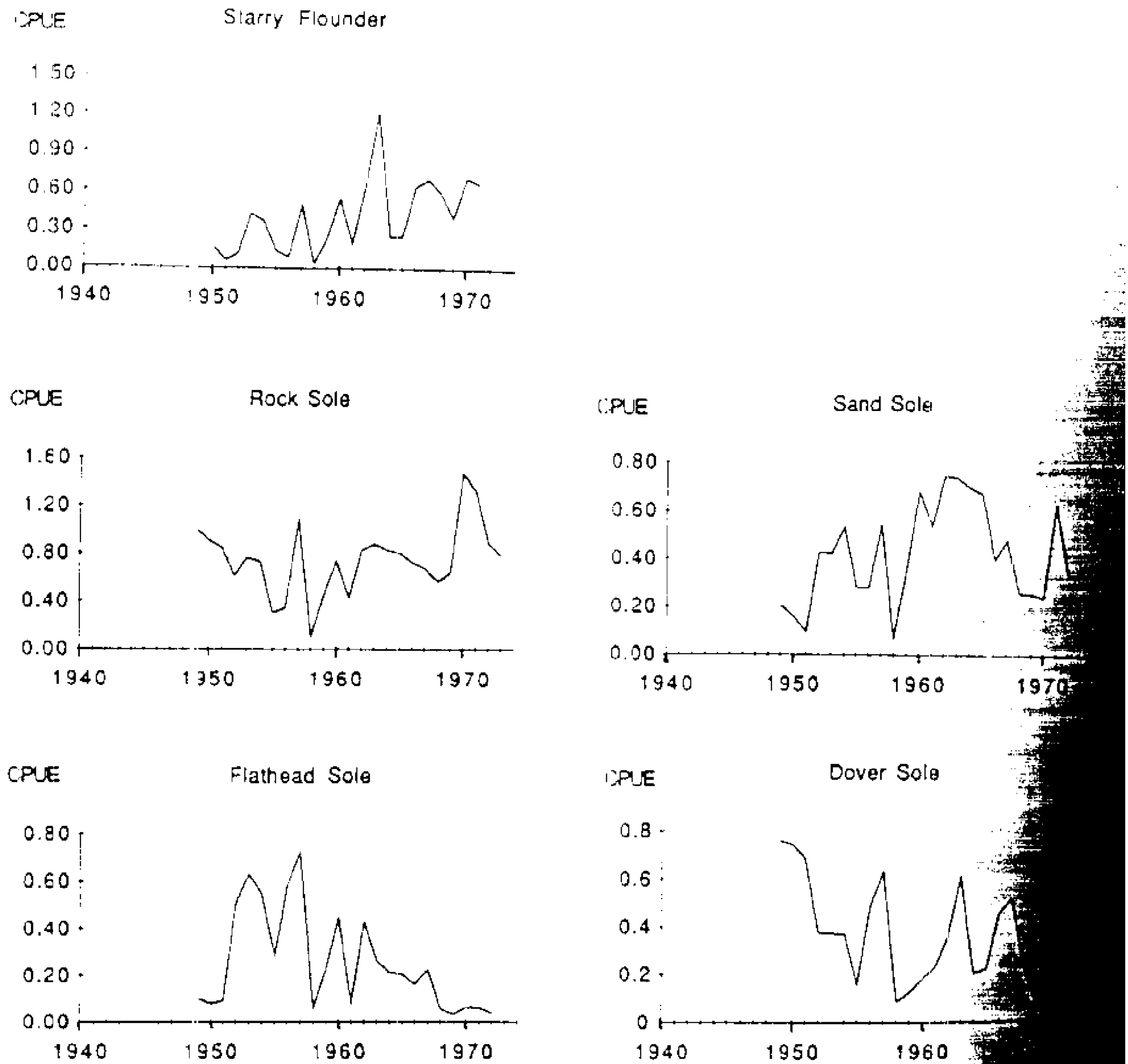


Figure 13. **Central Puget Sound yearly CPUE** (n**umber of occurrences/number of occurre**
English sole) from research sampling **for** s**tarry flounder, rock sole, sand sol**
flathead sole, and Dover sole.

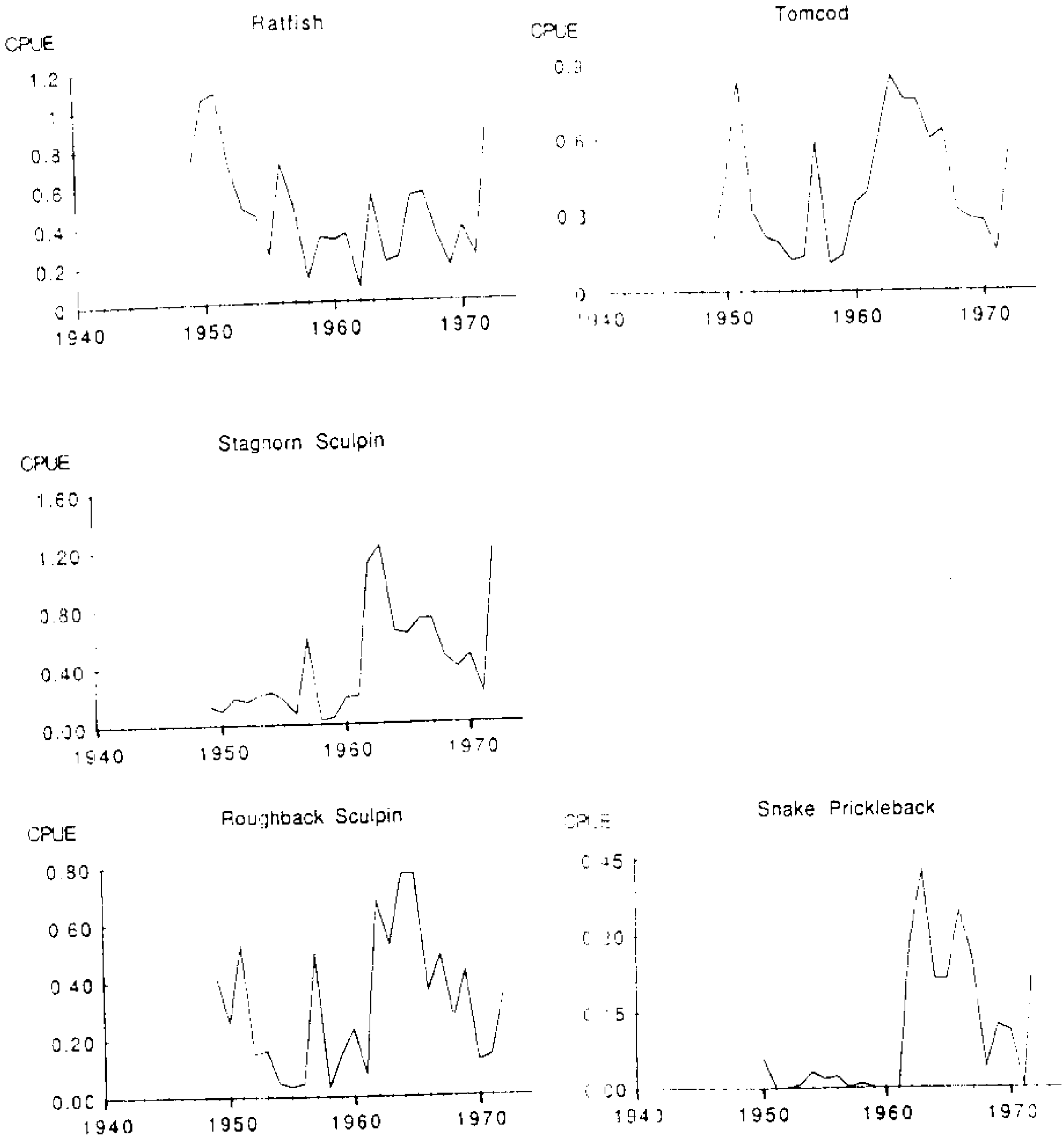


Figure 14. Central Puget Sound yearly CPUE (number of occurrences/number of occurrences of English sole) from research sampling for ratfish, tomcod, staghorn sculpin, roughback sculpin, and snake prickleback.

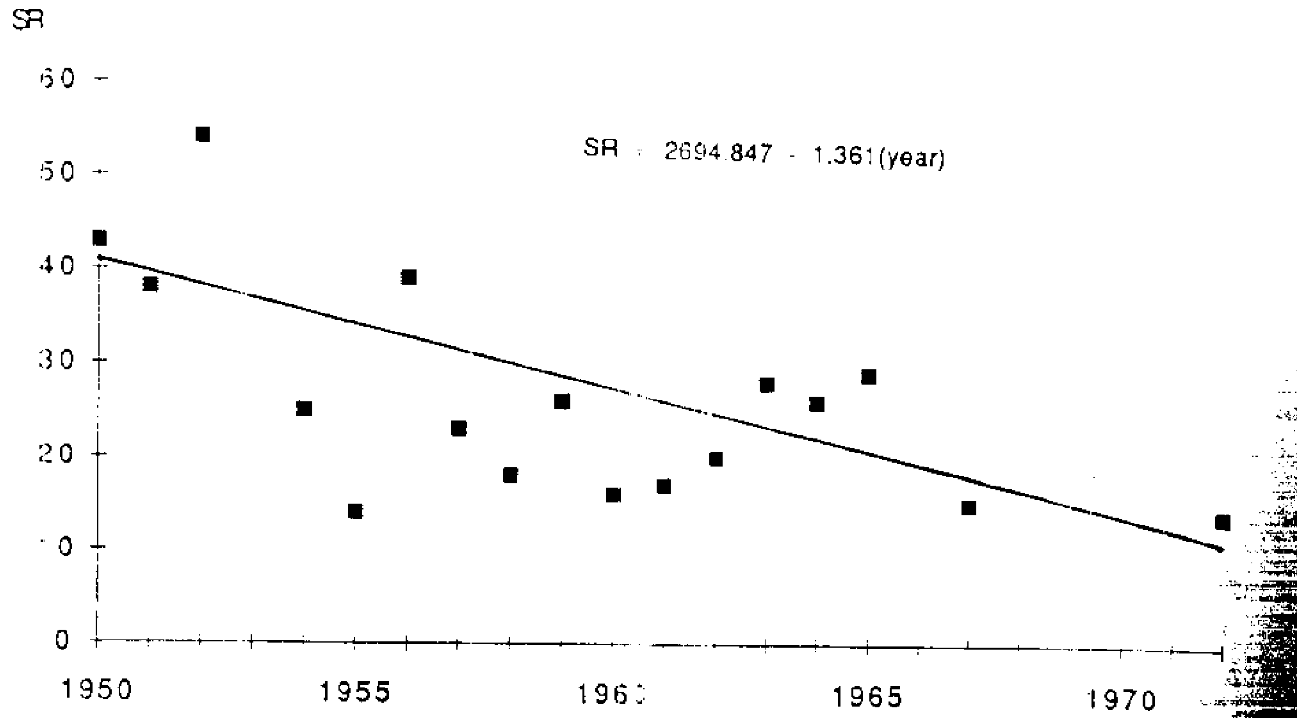


Figure 15. Species richness (SR) during spring at Golden Gardens beach from 1950-1972.

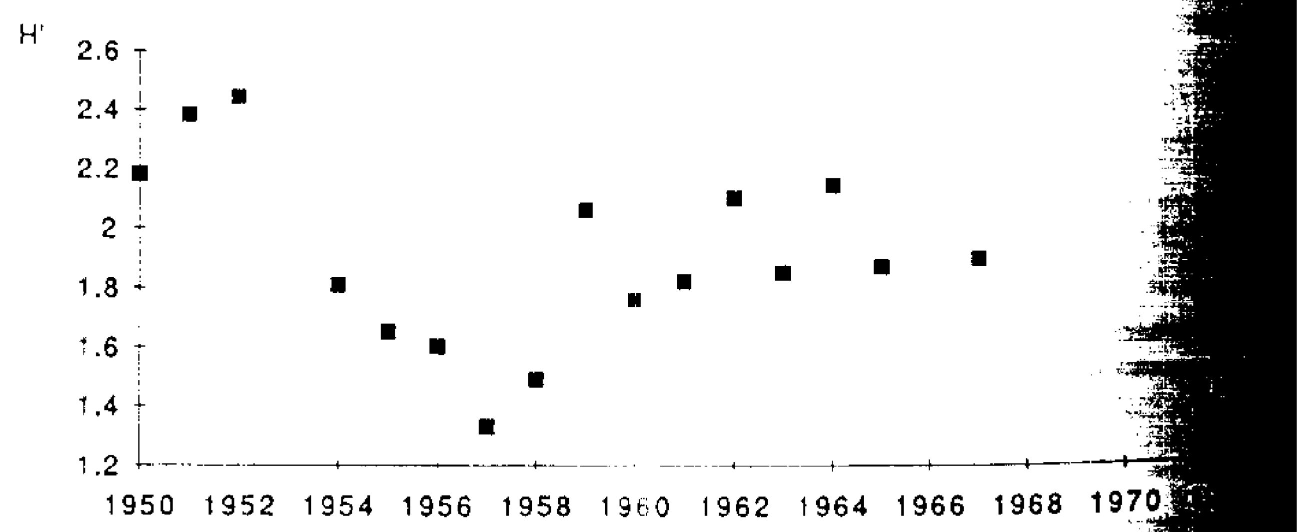


Figure 16. Species diversity (H') during spring at Golden Gardens beach from 1950-1972.

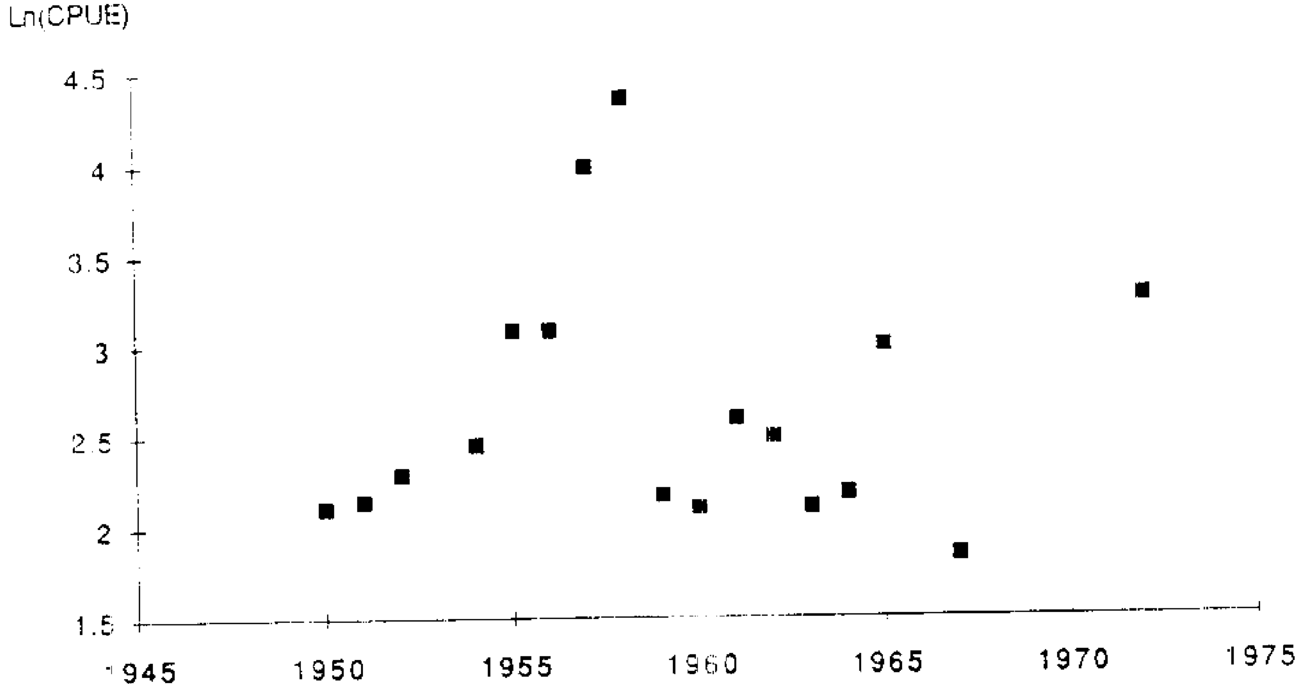


Figure 17. Ln CPUE (number of fish-per-beach-seine-set) of English sole at Golden Gardens beach from 1950-1972, spring season

Central Puget Sound (Port Gardner) Trawl Data, 1965-1987

Trawl collections made in Port Gardner from 1965-1987 were always made during daylight hours, were approximately equally spread over all four seasons, and were made from three depths (habitats) which have previously been shown to have significantly different fish assemblages associated with them in Puget Sound (Wingert and Miller 1979). Depths sampled were 10-30 m, 30-70 m, and >70 m. Unfortunately, only the 14 (Table 2) most commonly caught species (overall) were included in the database, which meant that true species richness or diversity indexes could not be calculated; species richness and diversity based only on the occurrence of these 14 species did not show any trends or statistically significant differences from 1965-1986, either on a seasonal basis or on a yearly basis with all seasons combined (Fig. 18). Analysis of CPUE trawl data by species indicated that the data needed to be partitioned by season of the year and by depth to look at long-term trends in CPUE. Six species (English sole, starry flounder, sand sole, rock sole, slender sole and staghorn sculpin) had sufficient data when separated out by seasons and depths to do this analysis.

English sole. Statistical analysis indicated that English sole data could be pooled for summer and fall seasons (July-December) and for the 10- to 30- m and 30- to 70-m depths. During summer and fall, English sole CPUE at a depth of 10-70 m (intermediate Puget Sound depth habitat)

Table 2. List of the 14 most common species in Port Gardner (grouped by families).

Common name	Scientific name
Ratfish	*Hydrolagus colliei*
Pacific hake	*Merluccius productus*
Tomcod	*Microgadus proximus*
Rockfish	*Sebastes sp.*
Staghorn sculpin	*Leptocottus armatus*
Pacific sanddab	*Citharichthys sordidus*
Speckled sanddab	*Citharichthys stigmaeus*
Butter sole	*Isopsetta isolepis*
Rock sole	*Lepidopsetta bilineata*
Slender sole	*Lyopsetta exilis*
Dover sole	*Microstomus pacificus*
English sole	*Parophrys vetulus*
Starry flounder	*Platichthys stellatus*
Sand sole	*Psettichthys melanostictus*

showed a negative trend (regression) from 1965-1987 (Fig. 19), which was statistically significant ($p < 0.05$). The English sole CPUE trend data is particularly useful for monitoring considerations because it is the largest data set and covers the longest span of time (1965-1987) in Port Gardner.

Starry flounder and sand sole. Both starry flounder and sand sole are primarily shallow water fishes and consequently were caught at the 5- to 10-m depth habitat. Sufficient starry flounder and sand sole CPUE data were available from 1965-1978, but not after that period because of the lack of shallow-water sampling in the 1980s.

Starry flounder CPUE data demonstrated a decline from 1965-1978 (summer season) in Port Gardner (Fig. 20), which was a statistically significant trend ($p < .05$). Statistical analysis indicated that the sand sole data for the fall, winter and spring could be combined, and a significant ($p < 0.05$) decline in CPUE for sand sole from 1965-1978 was also indicated (Fig. 21).

Rock sole, slender sole, and staghorn sculpin. The rock sole, slender sole and staghorn sculpin data did not show any trend in CPUE over time (years). The data was extremely variable and there was not a statistically significant ($p > 0.05$) trend correlation of CPUE with year from 1965-1987.

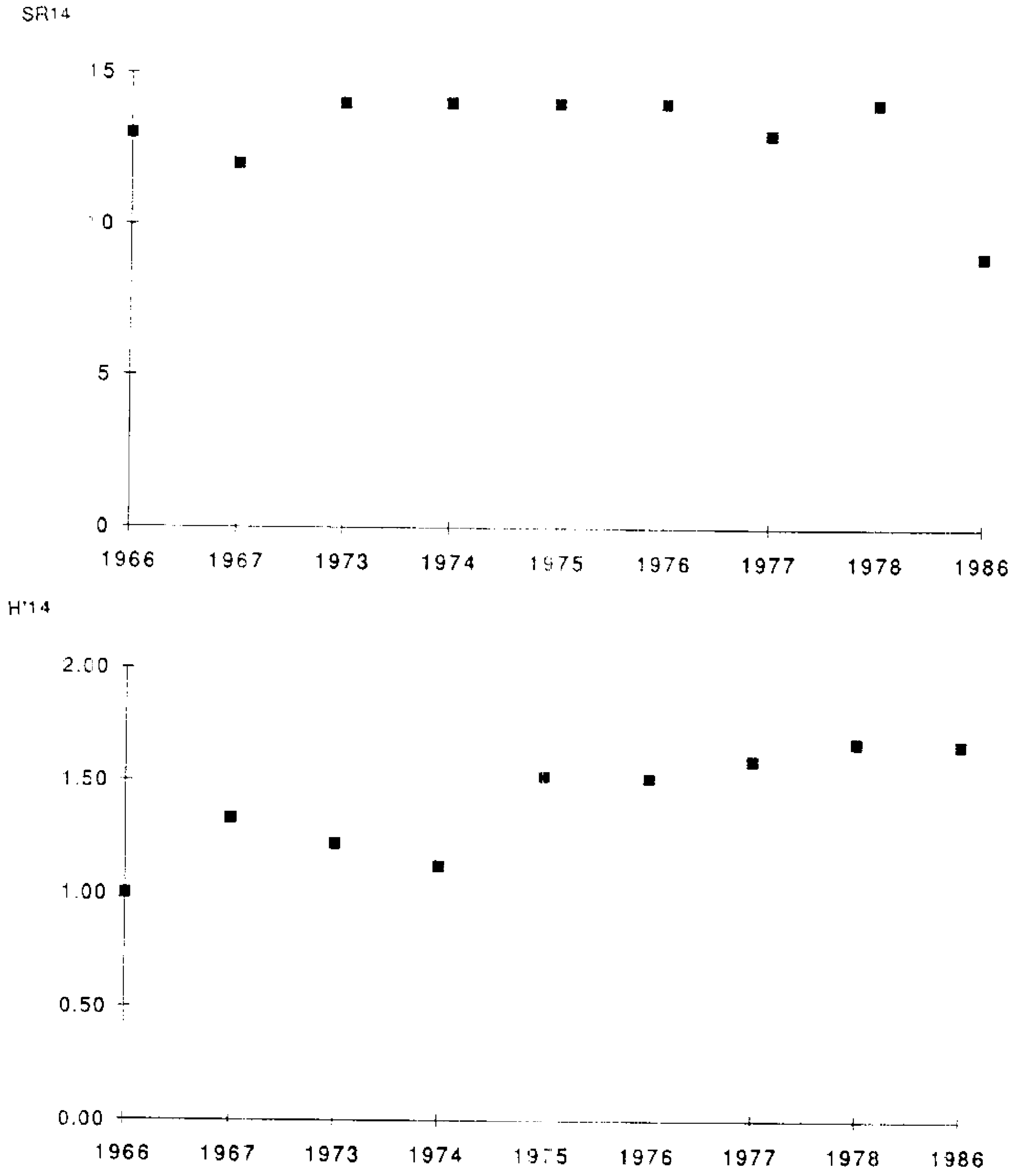


Figure 18. Species richness (SR14) and species diversity (H'14) at Port Gardner from 1965-1986 (based on a maximum of 14 species).

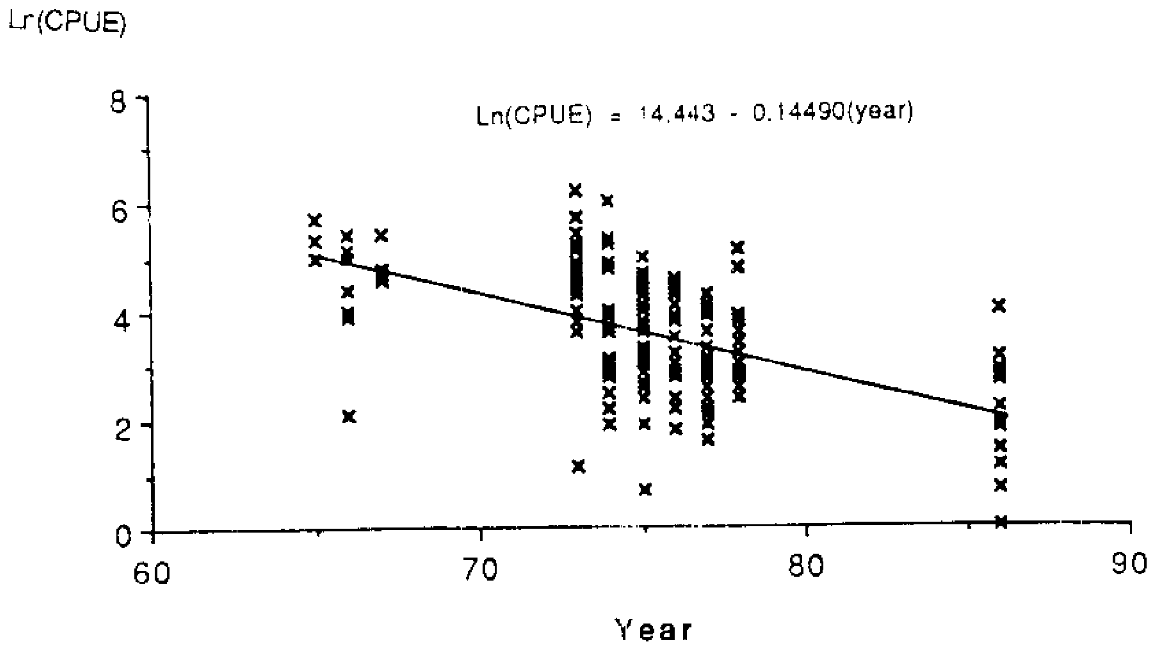


Figure 19. Ln CPUE (number of fish-per-5-min-trawl) of English sole at Port Gardner from 1965-1986, summer-fall season, 10- to 70-m depth.

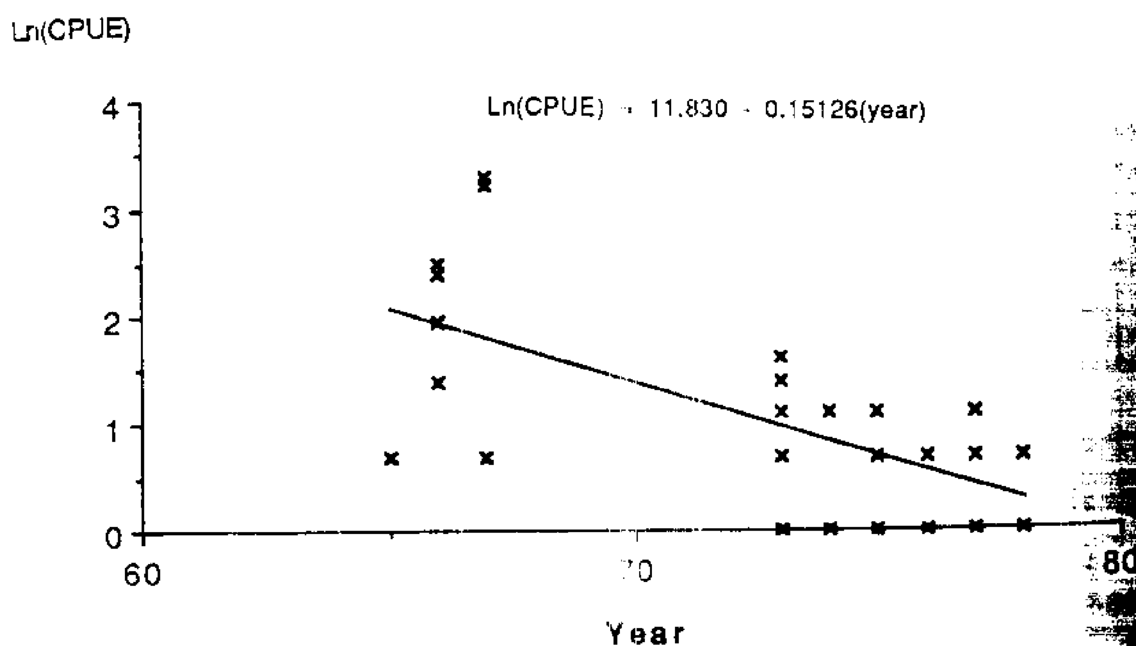


Figure 20. Ln CPUE (number of fish-per-5-min-trawl) of starry flounder at Port Gardner 1965-1978, summer season, 5- to 10-m depth.

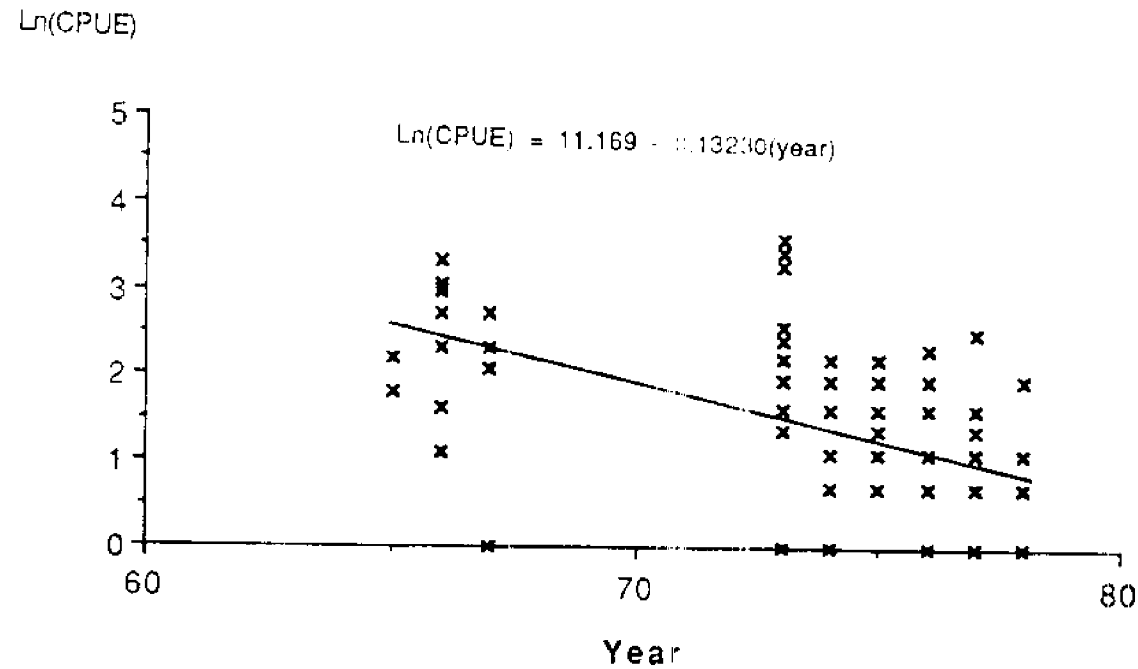


Figure 21. Ln CPUE (number of fish-per-5-min-trawl) of sand sole at Port Gardner from 1965-1978, winter-spring season, 5- to 10-m depth.

DISCUSSION

LONG-TERM TRENDS/CORRELATIONS

Entire Puget Sound Long-term Demersal Marine Fish Trends

Rare species presence or absence, 1863-1987. Dr. Alan Mearns (NOAA, Seattle) is a strong proponent of using "odd fishes" as indicators of changes that are occurring in the marine environment (Mearns 1988a, 1988b). By more than doubling the number of what we considered rare or unusual fishes in Puget Sound (compared to Mearns 1988b), we greatly expanded the database for analysis, although the trend/cycle results obtained were similar. Ebbesmeyer et al. (1988) have documented temperature changes in the Puget Sound area from 1916-1987, and there do appear to be reasonably good correlations of peak rare species occurrence and unusually cold (1918-1919, 1971-1975) and warm (1963-1965, 1983-1984) years, except for 1932-1935, which were transition years from warm to cold temperatures.

We think that routine monitoring of rare Puget Sound fish species yields important data, which to the best of our knowledge has not been done since 1976 (Miller and Borton 1980). Although we do not believe that keeping current records of unusual occurrences of rare and exotic fishes is the most important Puget Sound monitoring tool, we think the case is quite clear (Mearns 1988a, Schoener and Fluharty 1985, this study) that such monitoring can provide an early warning of changes to Puget Sound. One advantage is that rare species do not reflect fishing pressure changes (because of very low abundance, rare species are not fished in Puget Sound), and thus may be biological indicators of environmental changes to Puget Sound (temperature, salinity, etc.). Changes seen in rare species would be particularly useful in combination with other monitoring programs in that the "preponderance of evidence technique" can be used to monitor and evaluate the Puget Sound environment.

CPUE, 1932-1987. There is a period of increased research sampling catch rates (standardized to English sole occurrences) for several common Puget Sound marine fishes that are of little or no commercial importance: shiner perch, roughback sculpin, staghorn sculpin, tomcod, sand sole, and snake prickleback. The period of high abundance was approximately 1960-1968. After this period, the catch rates generally returned to the pre-1960 levels. Other species, such as the ratfish, dogfish, Pacific cod, copper rockfish, several flounder species, and lingcod, did not show a similar period of increased abundance.

It is interesting to speculate that the years (1960-1968) of peak abundances of several Puget Sound fishes might be correlated with warm-water years of approximately the same time period, especially when recognizing the probable unlikeliness of a direct correlation due to the divergent life history/ecological characteristics associated with the species showing increases. Unfortunately, Puget Sound fish research data for other warm-water years either is inadequate or (after 1972) simply has not yet been compiled. Commercial data are available for English sole, but English sole are the primary flatfish harvested in Puget Sound and after about 1972 the CPUE began a steady decline to rather low levels by the end of the 1980s, which was probably due in a large part to more restrictive fishing regulations imposed to reduce the catch of small flatfish (and thus reduce the overall catch of flatfish), but no doubt also was due to some overfishing (Schmitt 1990). The point is, data on commercial species are often not very useful for looking at long-term trends in fishes other than trends in the fishery itself, which may be impossible to separate from trends due to natural environmental changes (e.g., El Niño) and unnatural perturbations to the environment such as habitat destruction and toxic pollutants. We believe that a strong case should be made for monitoring as many non-economically important fishes in Puget Sound as possible; ideally, assemblages of fishes occupying the major habitats in Puget Sound (e.g., Wingert and Miller 1979) should be monitored.

Site-specific Long-term Trends

Golden Gardens, Seattle, 1950-1972. The data on species richness (SR) at Golden Gardens indicate a significant decrease in the number of species through the early 1950s. While the data presented support such a trend, the analysis is strongly influenced by high values during the first 3 years of sampling (1950-1952); after that period, the species richness appears reasonably stable. However, there were no species richness values greater than 30 after completion of the Shilshole breakwater in 1959, which was constructed during 1957 and 1958 (during which time there were low species richness values, possibly due to the construction activities and high water turbidity in the area—this was noted in the University of Washington School of Fisheries logbooks). Species diversity (H') at Golden Gardens was also highest in the first 3 years of sampling (1950-1952), declined through 1958, and then was quite stable from 1959-1960.

Although we have pointed out a major habitat disturbance (construction of the Shilshole breakwater) that occurred immediately adjacent to the Golden Gardens sampling site, which seems to offer a possible explanation for the species decline at Golden Gardens, we have only presented a correlation, not a causal relationship. However, we think that such fortuitous sampling of a site over a number of years during which a major human-caused perturbation occurred demonstrates the usefulness of monitoring fish assemblages in Puget Sound.

Port Gardner, Everett, 1965-1987. At Port Gardner, the 14 commonly caught species were quite stable in terms of the measurements of species richness and species diversity over the examined period (1965-1987), although an increase in species diversity was indicated. Conversely, CPUE of English sole, starry flounder, and sand sole decreased. The cause of CPUE (abundance) decrease of English sole, starry flounder and sand sole is unknown, but certainly Port Gardner is well known to be located in an urban environment that has undergone continual alterations induced by humans (e.g., see Brown 1988).

STANDARDIZED METHODS OF COLLECTING PUGET SOUND MARINE FISH DATA

As expected, this project emphasized the need for standardizing the collection of Puget Sound marine fish data, although much of the data collected since about 1970, and even the data collected by Dr. English in the 1960s and much of the data by Dr. DeLacy in the 1950s, has been reasonably well standardized. Fortunately, we have had the opportunity to provide major input into the writing of the EPA-sponsored trawling and beach-seining protocol for Puget Sound, and have emphasized the importance of continuing to employ for monitoring purposes the standardized collecting techniques begun in the 1970s, which were standardized as closely as possible to the pre-1970s sampling.

The biggest problem we faced was retrieving the data from the format it had been stored in. Although one might initially consider it an overstatement when Michener et al. (1987) conclude that long-term monitoring requires data backup on multiple media (paper, tape, mass storage, floppy disks), our experience supports this conclusion. The single most frustrating part of our project was the inability to electronically retrieve data from previous electronic storage systems, and instead having to go to the original handwritten data in the logbooks. If the data had been stored on multiple media it would have helped considerably, although it should also be emphasized that unambiguous documentation must be included with whatever media is used.

UTILITY OF EXAMINED DATA AS BASELINE FOR FUTURE MONITORING

Examining the historical data proved to be extremely time-consuming, and we had only begun to examine a portion of the available data. However, the analyses we conducted contained the portions of the data that were predicted to require less work to extract for analyses (which unfortunately did not turn out to be true), and which would be good for evaluating long-term trends in marine fish populations.

We think that monitoring of rare fishes in Puget Sound will generate useful baseline data and can be done relatively easily and accurately, although it should be done formally (i.e., the task should be specifically assigned to an institution or agency) instead of informally, as is now the case. On the other hand, while recording the frequency-of-occurrence of reports for Puget Sound fish species (and then attempting to standardize the data to English sole for CPUE) was useful in generally showing that major changes in Puget Sound fish species do not appear to have taken place to date, such an approach is too qualitative for monitoring purposes, which need to follow standardized sampling procedures. Instead, we think the use of standardized trawling and beach seining catches for long-term fish community measurements and CPUE data, such as analyzed in this report at Golden Gardens and Port Gardner, is the approach to take in monitoring the long-term ecological health of Puget Sound marine fishes. It should be understood that major changes to marine fish species abundance must take place before such changes will be recognized by monitoring programs, but that is far more desirable than performing post-mortem analysis of missing species or populations of fish. Miller et al. (1980) and Moulton (1977) found that seasonal sampling of Puget Sound marine fishes by beach seining or diving, as appropriate, would statistically recognize year-to-year changes when the populations had declined/increased 50-75%; these results could be improved further by more frequent sampling—we recommend (from experience) monthly sampling, which would considerably reduce the chance of a significant event (e.g., spawning migration/congregation) not being detected each year.

Other long-term data sets from standardized sampling exist (Moulton and Miller 1987) and should be compiled and analyzed as was done for this project, although our experience indicates that much of the data will have to be extracted by hand from logbooks, which is time-consuming. However, assuming that monitoring of Puget Sound marine fishes will be part of the Puget Sound Ambient Monitoring Program, which will follow the recommended EPA protocols for trawling and beach-seining (PTI et al. 1990), the compilation and analysis of other long-term data sets should be done both for general Puget Sound regions (e.g., central Puget Sound, northern Puget Sound), and for site-specific areas (e.g., Port Orchard in central Puget Sound and Deadman Bay in the San Juan Islands), where sampling was done in the same manner as recommended in the standardized protocol. Such data need to be compiled into a usable database to ensure that it does not become lost or unusable as researchers come and go over the years

New data that are collected in a standardized fashion should be added to the database at regular intervals to ensure that (1) the database remains current, and (2) data do not become lost through lack of proper documentation. The task of developing and maintaining the database should be the responsibility of one entity, but the data sources could be from a number of research efforts. It would be the responsibility of the central entity to evaluate new data to determine if it is suitable and appropriate for inclusion in the database.

One final recommendation: The Puget Sound Ambient Monitoring Program has sponsored a number of historical trends analyses similar to this one (e.g., water quality, sediment contaminants, benthic communities) that, when taken together, should yield much better evidence for certain trends and possible causes than any one of the studies alone. We certainly hope and recommend that the final project be a report that summarizes and synthesizes all of the individual project reports, and that identifies and evaluates the possible causes for the changes over time that have taken place in Puget Sound.

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APPENDIX

Appendix Table 1. Scientific and common names of species of fish referred to in this document; listed by families, and within a family alphabetized by scientific names (after American Fisheries Society, 1980).

Family Hexanchidae, Cow Sharks
- *Hexanchus griseus*, sixgill shark
- *Notorynchus maculatus*, seven gill shark

Family Alopiidae, Thresher Sharks
- *Alopias vulpinus*, thresher shark

Family Lamnidae, Mackerel Sharks
- *Cetorhinus maximus*, basking shark

Family Carcharhinidae, Requiem Sharks
- *Prionace glauca*, blue shark

Family Squalidae, Dogfish Sharks
- *Somniosus pacificus*, Pacific sleeper shark
- *Squalus acanthias*, spiny dogfish

Family Squatinidae, Angel Sharks
- *Squatina californica*, Pacific angel shark

Family Torpedinidae, Electric Rays
- *Torpedo californica*, Pacific electric ray

Family Chimaeridae, Chimaeras
- *Hydrolagus colliei*, ratfish

Family Nemichthyidae, Snipe Eels
- *Nemichthys avocetta*, threadfish

Family Clupeidae, Herrings
- *Sardinops sagax*, Pacific sardine

Family Engraulidae, Anchovies
- *Engraulis mordax*, northern anchovy

Family Osmeridae, Smelts
- *Allosmerus elongatus*, whitebait smelt
- *Mallotus villosus*, capelin

Family Paralepidae, Barracudinas
- *Notolepis coruscans*, ribbon barracudina

Family Alepisauridae, Lancetfishes
- *Alepisaurus ferox*, longnose lancetfish

Family Myctophidae, Lanternfishes
- *Diaphus theta*, California headlightfish
- *Stenobrachius leucopsarus*, northern lampfish
- *Tarletonbeania crenularis*, blue lanternfish

Family Gadidae, Codfishes
- *Gadus macrocephalus*, Pacific cod
- *Merluccius productus*, Pacific hake
- *Microgadus proximus*, Pacific tomcod

Family Percichthyidae, Temperate Basses
- *Morone saxatilis*, striped bass

Family Bramidae, Pomfrets
- *Brama japonica*, Pacific pomfret

Family Sciaenidae, Drums
- *Cynoscion nobilis*, white seabass

Family Embiotocidae, Surfperches
- *Cymatogaster aggregata*, shiner perch
- *Embiotoca lateralis*, striped seaperch
- *Rhacochilus vacca*, pile perch

Family Sphyraenidae, Barracudas
- *Sphyraena argentea*, Pacific barracuda

Family Stichaeidae, Pricklebacks
- *Lumpenus sagitta*, snake prickleback

Family Scombridae, Mackerels and Tunas
- *Sarda chiliensis*, Pacific bonito
- *Scomber japonicus*, chub mackerel

Family Stromateidae, Butterfishes
- *Peprilus simillimus*, Pacific pompano

Family Scorpaenidae, Rockfishes
- Sebastes *caurinus*, copper rockfish

Family Hexagrammidae, Greenlings

Ophiodon elongatus, lingcod

Family Cottidae, Sculpins

Chitonotus pugetensis, roughback sculpin

Leptocottus armatus, Pacific staghorn sculpin

Family Bothidae, Lefteye Flounders

Citharichthys sordidus, Pacific sanddab

Citharichthys stigmaeus, speckled sanddab

Family Pleuronectidae, Righteye Flounders

Hippoglossoides elassodon, flathead sole

Isopsetta isolepis, butter sole

Lepidopsetta bilineata, rock sole

Lyopsetta exilis, slender sole

Microstomus pacificus, Dover sole

Parophrys vetulus, English sole

Platichthys stellatus, starry flounder

Psettichthys melanostictus, sand sole

Family Molidae, Molas

Mola mola, ocean sunfish