AN ABSTRACT OF THE THESIS OF

Yong Woo Lee for the degree of Master of Science in Fisheries Science presented on August 29, 1997. Title: USING OREGON TRAWL LOGBOOKS TO STUDY SPATIAL AND TEMPORAL CHARACTERISTICS OF COMMERCIAL GROUNDFISH SPECIES ASSOCIATIONS.

Redacted for Privacy

Abstract approved: ______________________________

David B. Sampson

Species associations of fifteen major commercial groundfish species in the northeastern Pacific ocean and their spatial and temporal characteristics were studied using Oregon bottom trawl logbook data, 1987 to 1993. Screening procedures were used to remove questionable data from the original logbook files, which resulted in the exclusion of information from 46% of the total available tows. Two multivariate methods, detrended correspondence analysis (DCA) and Ward's method of hierarchical cluster analysis were used to derive the association patterns of species and species groups. A general linear model that was developed for the primary DCA axis suggested that the species associations are strongly correlated with depth, but minimally correlated with the other environmental variables that were examined (latitude, season, and year). The weak correlations between DCA axis 1 and the temporal variables indicate that species associations in the study region are fairly persistent over time. The same multivariate techniques were used to examine possible sampling effects due to changes in the

participating trawl vessels that contributed logbook information. Depth and latitudinal distributions of species occurrence in the logbook were similar to distributions derived from National Marine Fishery Service triennial bottom trawl survey. However, the analysis also showed that the depth coverage by the survey is not broad enough to accurately characterize associations among species that are currently subject to commercial fishing activity.

Using Oregon Trawl Logbooks to Study Spatial and Temporal Characteristics of Commercial Groundfish Species Associations

by

Yong Woo Lee

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed August 29, 1997
Commencement June 1998

Master of Science thesis of Yong Woo Lee on August 29, 1997

APPROVED:

Redacted for Privacy

Major Professor, representing Fisheries Science

Redacted for Privacy

Head of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release my thesis to any reader upon request.

Redacted for Privacy

Yong Woo Lee, Author

ACKNOWLEDGMENTS

The completion of this thesis would not have been possible without the support, encouragement, advice, and inspiration of teachers, colleagues, friends, and families. I am especially indebted to my major professor, Dr. David B. Sampson, who initiated me into the program and continually guided me towards the completion of this work with kindness, understanding, and encouragement. Dr. Sampson's patience with my many questions and his guidance have armed me with academic knowledge and skills, and inspired me with the joy of learning.

I also would like to extend my thanks to my committee members, Dr. Stan Gregory and Dr. Virginia Lesser, for their lectures and kind advice. I especially appreciate Dr. Gregory's letting me serve as Teaching Assistant for his limnology class in the spring of 1997.

There were agencies and groups of people who made this work possible by providing data, financial support, and facilities. The Oregon Department of Fish and Wildlife provided logbook data files. The Oregon Trawl Commission provided initial financing for this project. The Northwest Fishery Science Center of the National Marine Fisheries Service (NMFS) also provided essential funding. Dr. Chad Jay kindly provided results from his work on the NMFS survey data that enabled me to compare the survey data with my results from the logbook data. I am also very grateful to the fishers who work in a harsh environment and collect the raw logbook data. The Hatfield Marine Science Center of Oregon State University (OSU) in Newport, OR. provided research facilities and housing, and I thank all the staff including the housing manager, Maureen Collson, and librarians, Janet Webster and Susan Gilmont.

Dr. Bruce McCune in the OSU Botany department broadened my understanding of multivariate statistics in ecological studies and provided helpful comments on the analytical techniques applied in my thesis. Discussions on the multivariate analysis with my friend, Dr. Gary Allison in the OSU Zoology department, were also very helpful, and I am very thankful for his friendship and encouragement.

I thank my teachers in the Dept. of Oceanography at Inha University, Dr. Young Chul Lee, Dr. Joong Ki Choi and Dr. Jae Sang Hong, for their warm advice and getting me interested in fishery science and biological oceanography during my undergraduate program. I also thank Dr. Suam Kim in the Korea Ocean Research & Development Institute (KORDI) for his advice and for stressing to me the importance of this field.

Uncle Song Nai Rhee and Aunt Sue always welcomed me with love and hospitality at their home, and helped me to escape from depression and homesickness. I am grateful for their loving care. Without them, life here would not have been so pleasant.

I am thankful to my friends in Korea, Seong Wook Ko, Kyoung Ho Park, Seong Hoon Park, Dae Joong Yun, Woong Kyo Suh, for their friendship and for being there for me at all times.

Finally, I would like to devote this thesis to my family who make my life meaningful. Thank you all.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

DEDICATION

To my parents, Hak Nae Lee and Jeong Sook Shin, who have never lost their faith in me, even through the most trying times.

USING OREGON TRAWL LOGBOOKS TO STUDY SPATIAL AND TEMPORAL CHARACTERISTICS OF COMMERCIAL GROUNDFISH SPECIES ASSOCIATIONS

INTRODUCTION

Because of the nonselective characteristics of trawl gear, and because various fish species occur together, the demersal trawl fisheries along the west coast of the United States are multispecies fisheries. The fishery management scheme in this region, however, is based on single-species stock assessments that do not account for the complex multispecies characteristics of the demersal fish community (Gabriel 1982; Pimm and Hyman 1987). The nonselective characteristics of trawl gear lead the commercial fishers to discard the economically valueless fish species that are caught along with the target species. From a biological point of view, these incidental catches, which often go unreported, can represent a serious depletion of the noncommercial fish stocks (Pikitch 1988; Pikitch et. al. 1988). For fishery management, the ultimate goal would be to maintain the production level of commercially targeted species, while protecting other non-commercial species and maintaining the health of the surrounding environment. In order to achieve this goal, it is desirable to identify the units of species assemblages and their spatial and temporal characteristics. In this regard it is important to understand the conditions under which fish species are consistently caught together, regardless of whether the species are economically valuable or not.

To gain the required knowledge and understanding about fish communities, fishery managers and scientists collect and analyze data from representative samples taken from the complex system. Samples of fish collected by trawl can be categorized as coming from research surveys or from the commercial fishery. In theory, data from research surveys have the merits of being unbiased and coming from random sampling. They also have the limitations of coming from a fixed sampling season and consisting of small sample numbers. In contrast, data from the commercial fishery have the merits of year-round sampling and enormous numbers of samples, but the limitations of non-random sampling. A third category of information is sometimes available from so-called observer programs, in which trained observers are placed aboard commercial fishing vessels to estimate and record the catch of fish species (Rogers and Pikitch 1992). Data from observer programs are generally more accurate and detailed than the data collected from the commercial fishery, but the tow locations, trawl gear, and timing of the samples are not controlled as in a research survey.

The National Marine Fisheries Service (NMFS) since 1977 on a triennial basis has conducted standardized bottom trawl surveys along US west coast over the continental shelf and upper slope off California, Oregon, and Washington. These surveys provide sound sampling data for estimating the abundance and describing the spatial distribution of fish stocks (Gunderson and Sample 1980). Several studies have used data derived from the NMFS surveys to define demersal fish assemblages off northeastern Pacific ocean (Gabriel and Tyler 1980, Gabriel 1982, Weinberg 1994, Jay 1996a). However, even though survey data are collected randomly using a consistent gear type, vessel size, and towing duration and speed, because of budget limitations the survey is conducted on a triennial basis and only during the summer months. Thus, analyses for highly mobile organisms such as fishes can be quite variable. Also, seasonal variation in the spatial pattern of species composition cannot be investigated. Furthermore, the spatial scale in these surveys is limited because the survey is only conducted in the depths ranging from 30 to 200 fathoms (55-366 meters). If fishing substantially occurs in shallower or deeper than the survey depth range, the survey data would not accurately reflect the actual fish community that is under fishing pressure and subject to disturbance. Survey data nevertheless provide the least biased view of bottom fish abundance and distribution for fishery ecologists and resource managers seeking to examine biological and management issues.

Logbook data obtained from commercial trawl vessels do not suffer the same limitations as survey data. The trawl logbooks contain year-round sampling records and replicate observations covering a large geographic area. The Oregon trawl logbook data mostly cover the area off Washington and Oregon (latitude 41°- 48°), over depths ranging from a few fathoms up to 560 fathoms (Figure 1). Fishermen are legally required to record in the logbooks their estimates of the total weight of the retained catch (called "hails") for each species or group of species from each tow, along with other information such as fishing location, gear type used, and tow duration. However, problems can arise when

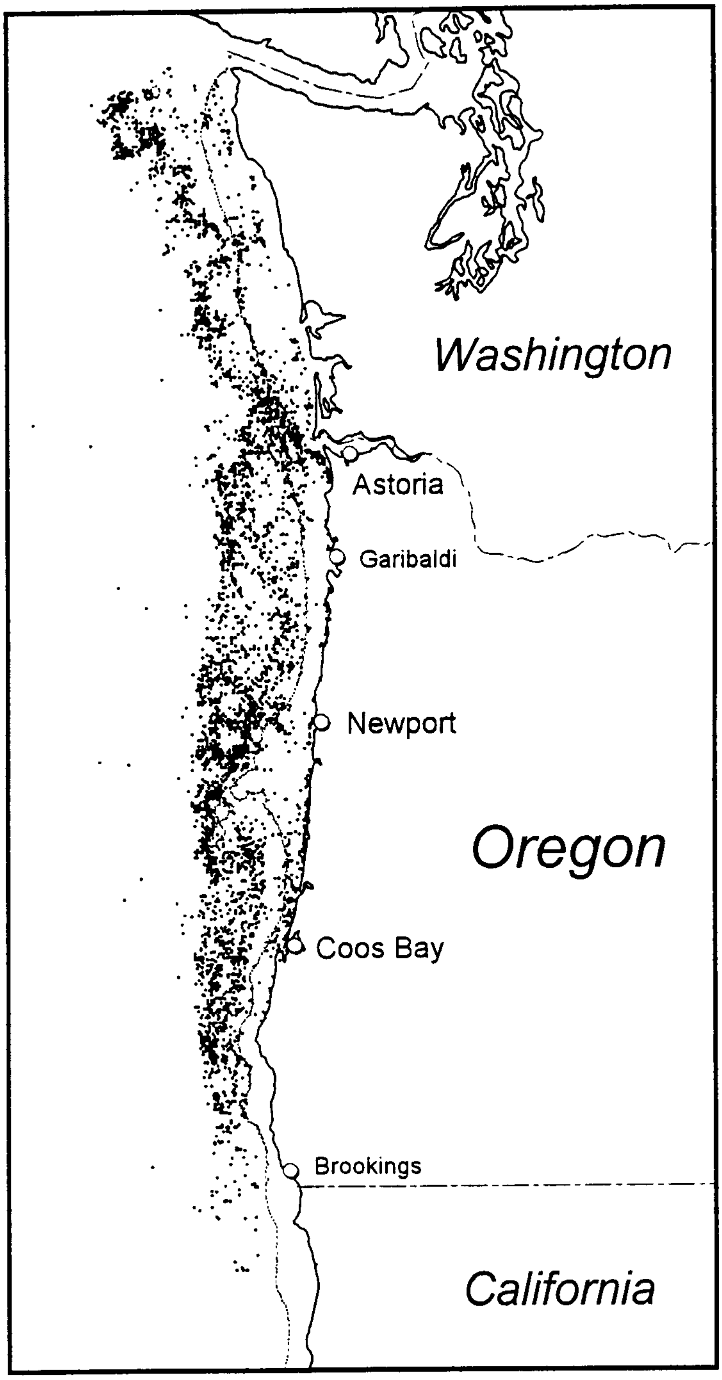


Figure 1. Map of the study area with tow locations from a 10% sample of 1991 logbooks.

using logbook data. Because these data are collected from the commercial fisheries, they do not represent random sampling in space and time. Also, the total weight and species composition of the catches are visually estimated by the skippers and therefore may not be accurate or consistent. Furthermore, while the research survey adopts a standardized sampling strategy with one gear type, the commercial fishery uses numerous gear types and fishing strategies that are possibly different from tow to tow or from trip to trip (Sampson et. al. 1997). Tow speed and duration are different between the survey and logbook data. The NMFS bottom trawl survey samples fishing locations using a consistent tow speed and duration, 3 nautical miles per hour (5.6 Km/hour) for 0.5 hour duration, thus the distance sampled (the sampling unit) can be easily calculated; 5.6 km/hr tow rate × 0.5 hr tow duration = 2.8 km sampling distance (Gunderson and Sample 1980). Commercial fishing vessels, however, do not maintain consistent tow speed or conduct tows of uniform duration. Long tows, which might last more than 12 hours and cover a path of 20-30 nautical miles (37-55.6 km), can result in the integration of several species or assemblage patches. Thus, commercial catch data may be too crude to evaluate biological or physical processes associated with fine-scale spatial distribution. Limited species resolution is another deficiency associated with using logbook data. Fish representing 53 families and 180 species, including more than 33 rockfish species (*Sebastes* spp.), were caught within the study area during the bottom trawl surveys, but only about 30 species or species group (market categories) are routinely recorded in the logbooks (Table 1).

Table 1. Species and species groups recorded in Oregon groundfish trawl logbook.

Common name	Scientific name
<u>Flatfish</u>	
Arrowtooth flounder*	*Atheresthes stomias*
Butter sole	*Iopsetta isolepis*
Curlfin turbot sole	*Pleuronichthys decurrens*
Dover sole*	*Microstomus pacificus*
English sole*	*Pleuronectis vetulus*
Petrale sole*	*Eopsetta jordani*
Rex sole*	*Glyptocephalus zachirus*
Rock sole	*Lepidopsetta bilineta*
Sand sole	*Psettichthys melnopstictus*
Sanddab*	*Citharichthys spp.*
Starry flounder	*Platichthys stellatus*
Miscellaneous flatfish	Not identified to species
<u>Rockfish</u>	
Miscellaneous rockfish*#	
Canary	*Sebastes pinniger*
Bocaccio	*Sebastes paucispinus*
Darkblotched	*Sebastes crameri*
Shortraker	*Sebastes borealis*
Yellowmouth	*Sebastes reedi*
Pacific ocean perch*	*Sebastes alutus*
Small rockfish*#	
Yellowmouth	*Sebastes reedi*
Darkblotched	*Sebastes crameri*
Redstripe	*Sebastes proriger*
Sharpchin	*Sebastes zacentrus*
Greenstriped	*Sebastes elongatus*
Thornyhead rockfish*	
Shortspine thornyhead	*Sebastolobus alascanus*
Longspine thornyhead	*Sebastolobus altivalis*
Widow rockfish*	*Sebastes entomelas*
Yellowtail rockfish*	*Sebastes flavidus*
<u>Others</u>	
Whiting	*Merluccius productus*
Pacific cod*	*Gadus macrocephalus*
Lingcod*	*Ophiodon elongatus*
Sable fish*	*Anoplopoma fimbria*

Table 1. *Continued.*

Common name	Scientific name
Shark	
Spiny dogfish	*Squalus acanthias*
Sturgeon	*Asipenser spp.*
Squid	Not identified to species
Octopus	Not identified to species
Miscellaneous	Not identified to species

* denotes15 species that were selected in this study.
# denotes species groups which are not identified into species level in the logbooks. Top 5 possible species, according to maximum percent contribution to total landing weights in the species groups, are referred here in descending order (Crone 1995).

Although many problems exist in the logbook data, there are potentially some major benefits that could be achieved by examining these data. One important advantage from using the logbook data is that all months of the year are well represented, and data are available for many years. Seasonal or year-to-year variation cannot be investigated with the available triennial survey data, but can be investigated with the logbook data. The massive number of data points, which include replicate observations for many locations, provide another benefit from using logbook data. During six surveys, spanning the period 1977-1992, data from a total of 2,565 multispecies hauls were collected, but in the 1991 logbook data alone, for example, information from more than 20,000 tows were recorded. From a statistical view, the bigger sample size associated with the logbook data should provide a less variable view of the population as compared to the survey data. A summary comparing the characteristics of logbook and survey data are presented in table 2.

Regardless of the problems, there are some studies that show possible uses of commercial fishery data to derive ecological information (Hewitt 1980; Tyler et. al. 1984; Stanley 1992; Rogers and Pikitch 1992; Fox and Starr 1996). In the Hewitt (1980) study, spatial distributions of English sole were derived from logbooks and successfully used to study spawning migration. Also, Stanley (1992) found that while factors such as catchability and vessel horsepower can be statistically significant and affect CPUE trends, they typically account for only a small portion (5-10%) of the overall variance. Weinberg (1994) used survey data to define and characterize rockfish assemblages and found them to be similar to the assemblages reported in Rogers and Pikitch (1992), which used commercial fishery data collected by observers. A recent study by Fox and Starr (1996),

Table 2. Comparisons of characteristics between survey and logbook data.

Characteristics	Logbook	Survey
Sampling Frequency	Annual	Triennial
Sampling Season	Year round	Summer only
Sampling Depth	> 400 fathoms	30 ~ 200 fathoms
Sampling Boat & Gear	Various	Standardized
Tow Duration	Various	Fixed at 0.5 hr.
Management Impact	Trip limits	No impact

which compared catch rates of five species (Dover sole, English sole, sablefish, yellowtail rockfish, and thornyheads) between Oregon trawl logbook data and survey data, found that the logbook data produced a similar pattern of catch rates as the survey data.

Even though these studies show the potential value of using logbook data, it appears that none of them made extensive use of validation tools to screen out inconsistent or implausible logbook data. The logbook data collected in Oregon can be validated by comparing the skippers' estimates of catch with the actual weight and composition of what was landed and sold to fish processors. Additional screening methods, such as checking for consistency between recorded depth and location, can be used to identify and eliminate questionable data.

The objectives of this study are to investigate species associations for 15 major commercial species and their spatial and temporal variability using Oregon trawl logbooks. Temporal as well as spatial scales are important in defining assemblage structure. Research trawl surveys were designed to describe abundance patterns, not to elucidate the underlying biological relationships, in which temporal elements may be crucial. Logbook data, which cover every month for an extended number of years, provide a basis for assessing interannual and intraannual changes in species assemblages. Knowing how the variability in assemblage distributions is related to environmental factors should increase our understanding of changes in fish abundance and community structure.

MATERIALS and METHODS

Description of logbook and ticket data

Seven years of Oregon trawl logbooks from 1987 to 1993 and their corresponding fish tickets (landing receipts), collected by the Oregon Department of Fish and Wildlife (ODFW), were used for this study. Logbooks contain the fishers' visually estimated information on retained catch on a tow-by-tow basis, and fish tickets contain actual poundage of official reported landings of each species on a trip basis. One trip may consist of several tows. Ticket data were mainly used for validating logbook catch records. It is a complex problem for an ecological study to use a series of data sets that are collected in non-standardized sampling manner, in which numerous different vessel types, gear types, collectors (fishers), and tow durations (fishing efforts) were involved. One cannot use all of the raw data directly from the logbooks because of their complicated nature and the non-standard manner of data collection. For the purposes of this study valid data were selected by using various screening criteria. Thus, it is important to know detailed information about the logbook data sets prior to setting up any screening criteria.

Fishing gear

There are basic 4 types of trawl gear recorded in the Oregon groundfish logbooks: generic bottom trawl, bottom trawl with rollers, bottom sole trawl, and mid-water trawl. Although the fishing gears on a vessel would have different characteristics and performance relative to each other, even within the same gear category, the logbook data files only report the four types gears described above. Total numbers of tows made by each gear type, as well as the number of active fishing vessels varied year to year (Table 3). Some fishing vessels are able to switch gear types during a fishing trip at sea. The gear type, "sole trawl" was selected for this study because the greatest relative number of tows were made by this gear type. Also, the flatfish species are more likely to be caught with this gear type and missed by the other bottom gear types (Sampson 1996). Midwater trawls rarely catch species other than whiting, widow rockfish, and yellowtail rockfish. In general, the commercial trawl gear types differ in size and construction from standard Nor'Eastern otter trawl used on the NMFS triennial bottom trawl survey. The NMFS deploys trawl gear equipped with rollers and a 3.2 cm mesh cod-end liner. The gear and the survey are designed primarily for sampling rockfish (Gunderson and Sample 1980; Weinberg 1994).

Tow duration

Tow duration and speed are fixed at 0.5 hr and 5.6 km/h for the standardized NMFS bottom trawl survey. Thus, there are few concerns about variation between tows due to differences in tow duration. However, tow duration can be problematic in using logbook data, because tow durations vary considerably in the trawl fishery. Duration can range from less than half an hour to more than 12 hrs depending upon fishing location (shallow or deep water), weather condition, season, and target species. Cumulative distributions of trawl durations by year show that at least 85% of sole trawls are of 8 hrs tow duration or less (Figure 2). Tows of more than 8 hrs duration were excluded from the

Table 3. Number of active boats and number of tows by gear type, 1987 to 1993.
Only sole trawls were selected for this study.

	Year						
	1987	1988	1989	1990	1991	1992	1993
No. of boats	122	121	127	132	139	143	143
Total no. of tows	16107	19582	25303	21344	30092	25948	29427
Midwater trawl	694	542	621	622	962	2169	1568
Generic bottom trawl	31	495	596	1269	3218	2754	2553
Bottom with roller	3235	5596	7168	7451	9156	7921	10204
Sole trawl	12147	12949	16918	12002	16756	13104	15102
Sole./Total. Percent	75%	66%	67%	56%	56%	51%	51%

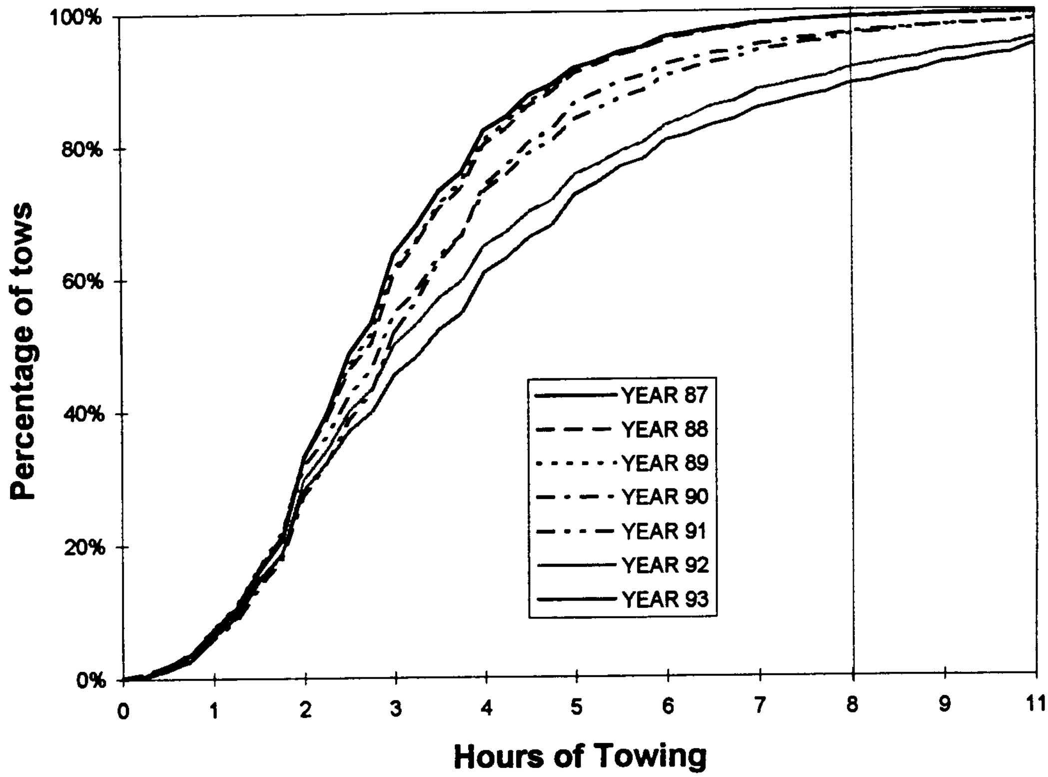


Figure 2. Cumulative distribution of tow durations with sole trawls recorded in the logbooks from 1987 to 1993. Tows with more than 8 hrs duration were excluded from the analyses.

analyses because they would have too broad a geographic coverage. Tows of 8 hrs duration or less sample strips of bottom that are no more than about 12 to 24 nautical miles (22.4 to 44.4 km) in length. Tow speed, which is not recorded in the logbooks, also would not be constant from tow to tow. Because of the variable tow duration and speed, individual tows were assigned to geographic blocks (described below) rather than treating each haul as a sampling unit. In their analyses of trawl survey data, Jay (1996a, 1996b) and Bianchi (1991) treated each tow as a sampling unit and used the 'swept-area' method to calculate standardized measure of catch biomass (Gunderson 1993). Gabriel (1982) used a similar approach but combined three adjacent tows.

Trip limits

The Pacific Fishery Management Council (PFMC) uses 'trip limits' as a management tool for regulating the US west coast groundfish fishing with the objectives of preventing the overharvest of individual species while maintaining a year-round fishery (PFMC 1993). Not all of the groundfish species are regulated by trip limits, however. There were five species or species groups regulated by trip limits in 1987; widow rockfish, yellowtail rockfish, Pacific ocean perch, sablefish, and the Sebastes complex (all rockfish except widow and Pacific ocean perch). The deep water species complex (Dover sole, sablefish, and thornyheads), bocaccio rockfish, and thornyhead rockfish (separately from the deep water complex) were added in later years. Details of the trip limits regulations (1987-1993) are summarized in Appendix 1.

Because different levels of trip limit apply to individual species or groups and because of the imperfectly selective characteristics of bottom trawl gears, fishers sometimes catch more than allowed by the trip limits and subsequently discard the excess catch at sea. Other factors that can result in discarding include unmarketable sizes of fish, low prices, and no market demand (Pikitch et. al. 1988). As a fishing season progresses and the cumulative landings of a species approaches the annual quota, levels of trip limits are also subject to change, possibly to the early closure of the fishery for a certain species. In this case, fishers are not allowed to land the particular species and catches of this species would be discarded at sea and recorded in the logbooks as zeros, despite actual catches occurring. The fishery for sablefish, for example, was closed in October 22, 1987, and there are no logbook records of sablefish catches later in the year. Here is another possible scenario to illustrate how trip limits could contaminate the data reported in the logbooks. If a fisher had already caught his or her trip limit for a given species, subsequent catches of that species would be discarded and recorded in the logbooks as zeros. Those zero catch records should not be treated as real zero catches. Logbook records may be greatly influenced by trip limits. Fishing trips that were influenced by trip limits may give a biased view of the catch rates and the spatial distribution of the fish.

Description of data screening procedures

Oregon trawl logbook data and fish ticket data were obtained from the Oregon Department of Fish and Wildlife (ODFW) in the form of computer database files. The files were processed and screened using database management programs (example in Appendix

2) developed under the system known as Foxpro for Windows, version 2.6. It was necessary to screen out questionable data from logbooks because the reported catch weights were visually estimated by the fishermen, and because catches of some species were regulated by trip limits.

There were a number of basic steps to screen the initial tow data and prepare them for the subsequent analyses (Figure 3). In step (1) the estimated retained catches from the logbooks were matched with the official weights of landed catch from the fish tickets for each species, based on boat and return date of a trip. In step (2) the ratio (R) of the sum of the hailed weight over the landed weight for each species was calculated on a trip basis ($R = \Sigma$ hailed weight / landed weight, where the summation is for all tows in a trip). In step (3) logbook data for a trip were accepted for further analysis if the ratio R fell into the acceptable range ($R = 0.6 \sim 1.1$). Ideally the ratio R would be 1 if the estimate of the retained catch for a given species was perfectly accurate. In step (4) trips were identified that reported catching more than 90% of the trip limits for a given species. These trips were excluded from the subsequent analyses. In step (5) data matrices containing species occurrence information were calculated from the screened data sets. In step (6) the data matrices were analyzed using two multivariate statistical methods to examine patterns of species associations.

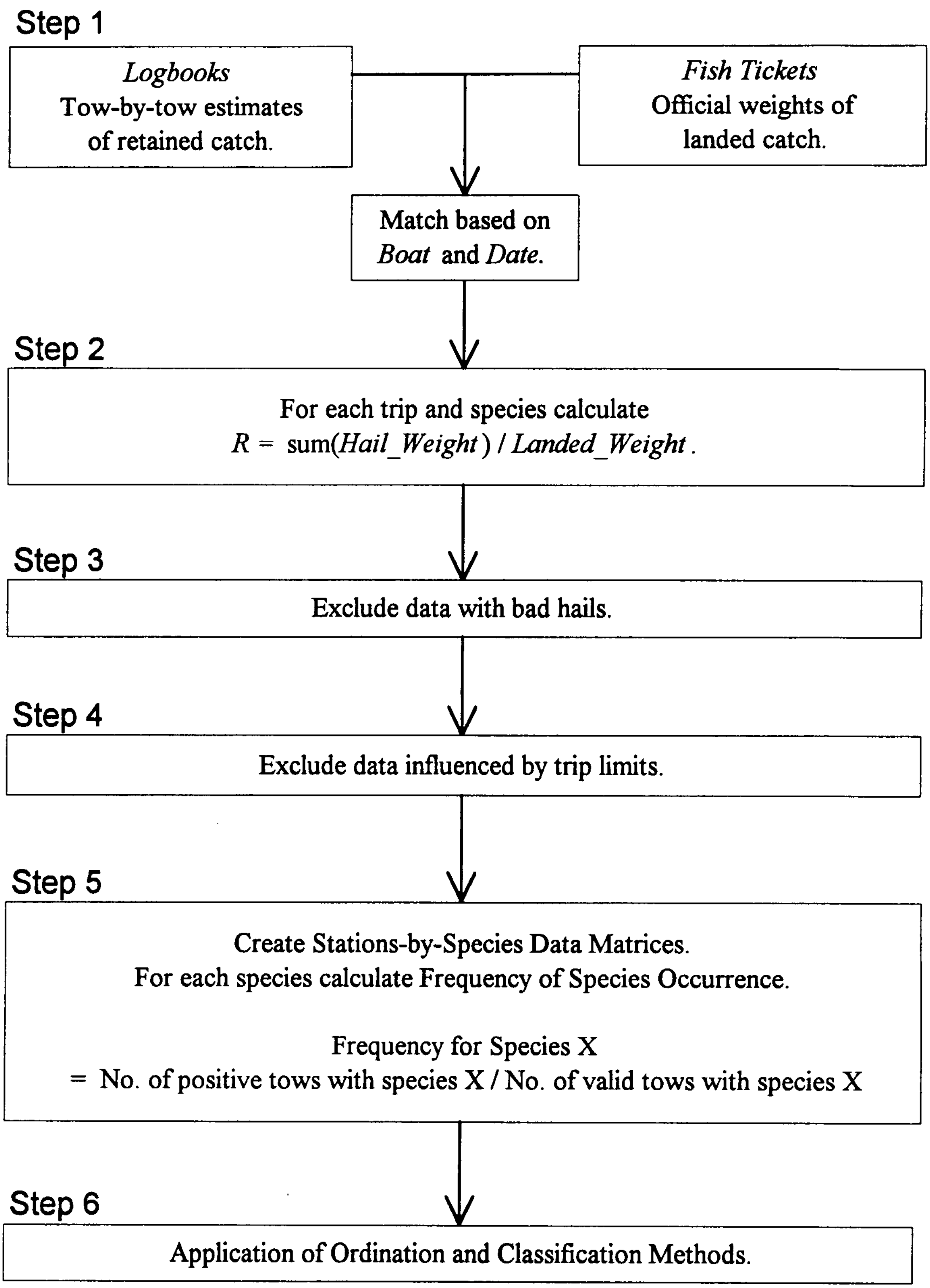


Figure 3. Overview of data screening and analysis.

Description of data matrices

Three different types of data matrices were prepared: (1) stations-by-species data matrices by individual years for the major analysis of species associations and their relationship with environmental characteristics; (2) a boats-by-species data matrix (across all years) for checking possible boat effects; and (3) species occurrence percentiles for mapping the geographic distribution over depths and latitudes, and compare with estimates from a study of survey data. In developing the data matrices (step 5 in Fig. 3), I used another screening procedure that excluded: boats that made less than 20 tows per year; tows that were more than 8 hours duration; tows that were not made using sole trawls, stations that contained less than 20 tows; and stations that contained less than 5 valid tows for any given species.

Fifteen major commercial species or species groups were selected from the available logbook data, based upon their commercial importance and the completeness of the logbook information (Table 4). The following were examined: 1. English sole (**ENG**), 2. petrale sole (**PET**), 3. Dover sole (**DOV**), 4. rex sole (**REX**), 5. sanddab (**DAB**), 6. arrowtooth flounder (**ARR**), 7. Pacific ocean perch (**POP**), 8. widow rockfish (**WID**), 9. yellowtail rockfish (**YEL**), 10. thornyhead rockfish (**THO**), 11. small rockfish group (**SMR**), 12. miscellaneous rockfish group (**MSR**), 13. Pacific cod (**COD**), 14. lingcod (**LIN**), and 15. sablefish (**SBL**). The three-letter acronyms in parentheses are used in figures and tables to denote the corresponding species.

Table 4. Retained catches (1000s of pounds) of the major commercial species reported in Oregon trawl logbooks from 1987 to 1993.

	Year						
	1987	1988	1989	1990	1991	1992	1993
Flat fish							
Arrowtooth flounder*	843.8	712.4	1418.8	3038.7	3571.0	3070.6	2900.1
Butter sole	7.9	0.9	0.7		1.2	0.1	0.2
Curlfin sole	3.9	3.9	3.1	0.1	0.8	0.1	0.7
Dover sole*	8798.1	12518.1	14991.0	13063.6	15340.8	9916.5	11687.3
English sole*	874.8	813.3	1096.1	794.2	1454.2	960.3	1194.3
Miscellaneous flatfish	1.6	11.7	2.5	20.8	12.7	16.5	6.1
Petrale sole*	1287.7	1308.5	1401.1	1232.2	1503.1	1194.8	1389.5
Rex sole*	396.2	415.2	398.2	319.5	705.4	510.9	381.7
Rock sole	1.6	5.5	4.2	3.7	2.5	0.5	2.1
Sand sole	422.8	292.1	391.0	397.3	531.8	308.4	392.9
Sanddab*	341.4	112.5	143.2	284.4	433.6	423.8	403.2
Starry flounder	149.0	251.7	363.3	139.5	593.8	127.6	134.0
Rockfish							
Miscellaneous rockfish*	4272.4	5522.7	6535.1	3919.2	4982.9	3706.3	4301.3
Pacific ocean perch*	696.8	1002.7	1237.8	847.0	1346.6	948.9	1193.0
Small rockfish*	1064.4	1785.1	1802.9	1911.4	1975.7	1216.0	3172.8
Thornyhead rockfish*	736.2	1323.9	3542.6	6674.7	5455.8	6643.0	7708.5
Widow rockfish*	10721.0	8247.2	10800.4	8541.4	5713.3	5226.6	8220.2
Yellowtail rockfish*	2796430	3484238	2683167	2581585	2681696	4793107	3746890
Others							
Lingcod*	737.8	1287.0	1493.0	1119.1	2284.9	734.2	1234.1
Pacific cod*	780.6	1456.8	1246.6	328.9	904.8	710.1	784.0
Sablefish*	3176.1	3031.0	3670.3	3676.0	3834.8	3658.4	4117.9
Shark	7.1	0.6	1.4	3.5	1.4	21.1	58.8
Skate	10.1		2.6	0.2		0.5	0.8
Whiting (Pacific hake)	284.6	310.9	126.4	3777.0	25515.3	98522.8	76199.3

* denotes 15 species that were selected in this study. From Sampson (1997).

Stations-by-species matrices

Based on findings from previous studies in the general study area (Gabriel 1982; Jay 1996b) that showed relatively strong associations between species distribution and depth, I assigned tow specific data to sampling stations based on 40 fathom (73.2 m) depth increments (e.g., 0-40, 40-80, etc.) and 1 degree latitude increments (e.g., 41°-42°, 42°-43°, etc.), and using a bimonthly temporal scale (Jan.-Feb., Mar.-Apr., etc.) for each year. Thus, each sampling station is associated with the abiotic factors depth, latitude, bimonth, and year. The spatial and temporal scale of the stations were selected on an arbitrary basis, but several other scales were also attempted. Initially I tried to make the spatial scale as fine as possible, but because there were tows with long towing times, which presumably covered long distances, and because I needed a reasonable number of tows at each station to measure frequency of occurrence, I decided to use the above scale. For each station, I calculated frequency of species occurrence to two decimal points by the ratio of the number of valid tows reporting a positive catch of the given species over the total number of valid tows made at that station. Valid tows are tows that were not excluded by the data screening processes. The number of valid tows at a given station can vary from species to species because the data from a trip could be valid for some species but invalid (and screened out) for others.

Boats-by-species matrix

Even though I screened out data by excluding tows made by boats that operated infrequently (less than 20 tows/year), there was still concern that boat-to-boat differences might adversely influence the pattern of species association. Because there were tows produced by 121 different boats included in the 7 years of stations-by-species data, changes in the boats from one year to the next might distort the species associations over time. During the 7 years of the study period there were boats appearing in the logbooks for only one or two years as well as boats appearing for all 7 years. Furthermore, the spatial distribution of boat operations are not random and do not usually extend over the entire study area because the fishers have different fishing strategies and preferences for target species. In order to check for possible artificial sampling effects due to changing boats I created a data matrix with combinations of boats and areas, where areas were defined by 40 fathom depth and 1° latitude increments. I selected the boats that operated extensively in more than 25 areas across all seasons and years, and calculated frequency of species occurrence for each boat and area combination in the same manner as described above. Six boats operating in more than 25 areas were selected, and the frequency of species occurrence was calculated for 172 boat and area combinations, where each combination had depth, latitude, and boat identification as extrinsic environmental factors. The boats-by-species matrix ignores possible differences across the seasons and years; the stations-by-species matrices ignore possible differences among boats.

Species occurrence percentiles

For descriptive purposes and for comparing the geographic ranges of the species, I estimated the 25th, 50th, and 75th percentiles of species occurrence across both depth and latitude from all the years combined. For comparison with similar information derived from the NMFS trawl survey data (Jay 1996b), I also calculated the 25th, 50th, and 75th percentiles for tows within the depth range of 30 to 200 fathoms. The species occurrence percentiles were estimated by tabulating frequency of occurrence; by 10 fathom depth increments across all latitudes, seasons, years, and boats; and by 1 degree latitude increments across all depths, seasons, years, and boats.

Description of analyses

Because of their multidimensionality, species patterns in a community are normally too complicated to identify and describe using univariate techniques. Instead, multivariate methods are needed to study species patterns and community structure (Pielou 1977). I employed two different types of multivariate techniques to analyze the stations-by-species data matrices, Detrended Correspondence Analysis (DCA) to develop ordinations (ranked orderings) and hierarchical agglomerative cluster analysis to develop classifications. I used the multivariate statistical software called PC-ORD, DOS version 2.0.

The DCA technique was originally developed as an improvement to another correspondence analysis technique known as reciprocal averaging. The notion was to correct for the two main faults of reciprocal averaging; the so-called "arch effect" and the stretching or compression of ecological distances in ordination space (Hill 1973; Gauch et. al. 1977; Hill and Gauch 1980; Gauch 1982). Although there continue to be arguments about the effectiveness of the DCA technique, it has been used successfully in studies of community ecology of aquatic vertebrates and benthic organisms (e.g., Leland et. al. 1986; Wartenberg et. al. 1987; Peet et. al. 1988; Bianchi 1991; Bianchi 1992). Correspondence analysis techniques are unusual because they ordinate samples (sampling stations) and species simultaneously, by calculating the species ordination scores from the averages of the sample ordination scores, and vice versa. Thus, correlations between influential environmental factors and the main axes of the DCA for the sampling stations can be related directly to the DCA species ordination.

In this study I used DCA to derive measures of species association in a low dimensional ordination space, and relate the patterns of association to extrinsic environmental factors in an interpretable manner. To establish which environmental factors are most responsible for explaining variation in the species associations, I calculated Pearson product-moment correlation coefficients for each environmental factor with the station scores for the first two main DCA axes. I also examined scatterplots of the DCA scores against the environmental variables, depth, latitude, bimonth, and year, to determine whether there were significant non-linear relationships between the ordination scores and the individual environmental variables, because the correlation coefficients only measure linear relationships. For a more thorough analysis of the relationships between patterns of station scores and environmental factors, I applied the Generalized Linear

Model (GLM) procedure (SAS 1988) to the scores of the first DCA axis obtained from the analysis of the data matrix of all years combined and constructed a statistical model for the effects of environmental factors such as season and year, and their possible interactions. GLM was also applied to the matrix of boats-by-species. GLM is well suited for analyzing unbalanced data, such as the data used in this study (SAS 1988). In the GLM analysis the environmental variables were treated as class variables, whereas in the correlation analysis they were treated as continuous variables.

One of the important assumptions of DCA ordination techniques is that the abundance of each species is distributed continuously along environmental gradients in a unimodal, Gaussian manner. This assumption makes it difficult to objectively assign similar species to groups based on an ordination of species pattern, unless there are distinct boundaries between the species groups. In contrast, numerical classification techniques objectively assign similar entities to groups or classes based on mathematical calculations of the similarity or dissimilarity of their attributes. In addition to DCA, I used an inverse numerical classification method, hierarchical agglomerative cluster analysis with Ward's minimum variance fusion strategy and the Euclidean distance measure, as a complementary tool to define the groupings of similar species (Ward 1963; Gauch and Whittaker 1981). Ward's method of cluster analysis performs well with respect to the chaining problem in which there is successive merging of single entities with a previously formed cluster. Chaining can severely distort the results of a cluster analysis and make it difficult to identify separate groups of clusters, and the groups may not effectively represent hierarchical characteristics of a community (Romesburg 1984; Sneath and Sokal

1973). I applied this technique to the same data matrices that were used for DCA analysis; stations-by-species data for individual years and for all years combined, and boats-by-species data. Cluster analysis produces a tree-like hierarchical structure (a dendogram) based on indices of similarity. As a result, groups of similar species can be objectively delineated. None of the different multivariate techniques are likely to provide perfectly correct patterns of species distribution and cooccurrence in any given community (Jongman et. al. 1987). However, they have different strengths and weaknesses that may tend to compensate for each other, especially when applied together in the analysis of a complex community system (Boesch 1977).

Prior to running the multivariate analyses I applied the monotonic arcsin transformation "$(2/\pi)\cdot\arcsin(X^{1/2})$" to each estimated proportion in the individual data matrices. This transformation, also known as the angular transformation, is often considered to be appropriate for proportions or percentage data (Sokal and Rohlf 1975). Such transformations can improve the validity of assumptions of normality, linearity, and homogeneity of variance as well as reduce the effects of having very common or very rare species in species composition data (Noy-Meir et. al. 1975; Jensen 1978).

Outliers can strongly influence the results of multivariate analyses (Tabachnick and Fidell 1989). In an attempt to reduce the effect of possible outliers, I first deleted the stations containing fewer than 3 non-zero species values. Then I used two separate steps to detect potential outliers. First, I identified stations with relatively high standard deviations (cut off point of 2.0) as calculated by the Euclidean distance measure (McCune and Mefford 1995). Next, I visually examined the DCA scatterplots of the station scores to identify stations that were relatively far from the main cluster of scores. If both methods identified particular stations as being outliers, I ran the DCA analyses with and without those potential outliers. If the outliers seemed to have a substantial influence on the ordination results, I removed them from the data matrices. To maintain consistency between the results of DCA and cluster analysis I applied the cluster analysis only to those transformed data matrices from which identified outliers had been removed.

RESULTS

Data screening and preparation

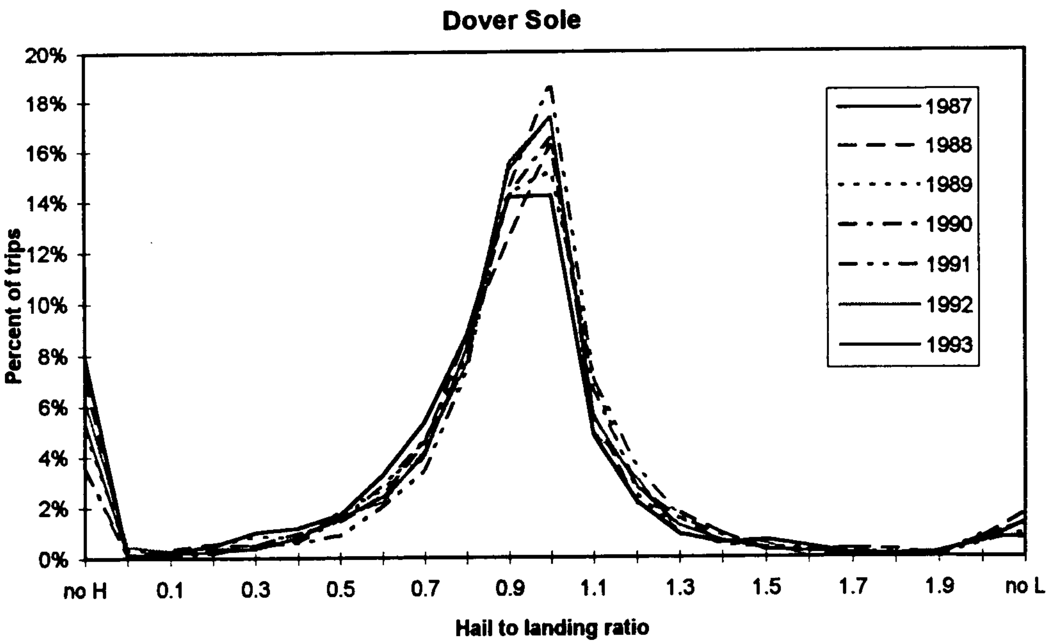
Logbook data were reduced by a number of screening procedures and data preparation criteria. In step (1) logbook data were matched with corresponding ticket data on a trip basis. There were about 20,000 trips reported in returned logbook files for the study period, 1987-1993 (Table 5). There were no logbook data without corresponding ticket information, but about 21% on average of the ticket data could not be matched with logbook data. This corresponds to a logbook submission rate by the fishers of about 79 % of all the trips landing groundfish that were reported in the ticket data files.

In step (3) the acceptable range for the hail to landing ratio ($R = 0.6 \sim 1.1$) was selected on an arbitrary basis after examining the distributions of ratios of each species. Distributions of hail to landing ratios showed a consistent pattern from species to species; the fishers tend to slightly underestimate their retained catches (Figure 4). Also, there were numerous trips for which there were hails with no corresponding landing information (R calculated as infinity) and landings without hails (R calculated as zero). Data that fell outside of the acceptable range of ratios were excluded from the data matrices for the analyses. On average this screening step excluded about 43% of the trips that had positive catch records (Table 6). In step (4) trips influenced by trip limits were identified and excluded. The percent of trips that were not influenced by trip limits was variable from year to year and from species to species (Table 7). For any given species only those trips that were not influenced by trip limits were included in the various data matrices.

Table 5. Logbook and ticket data match result during the study period of 1987-1993.

	Year							
	1987	1988	1989	1990	1991	1992	1993	Total
Logbook Trips	2107	2404	2641	2454	3287	3581	3565	20039
Fish Ticket Deliveries	3138	3561	3797	3639	4610	4835	4707	28287
Log Trips w Tickets	2107	2395	2633	2451	3285	3580	3565	20016
Logs without Tickets	0%	0%	0%	0%	0%	0%	0%	0%
Tickets without Logs	23%	24%	23%	23%	21%	21%	17%	21%

From Sampson (1997).



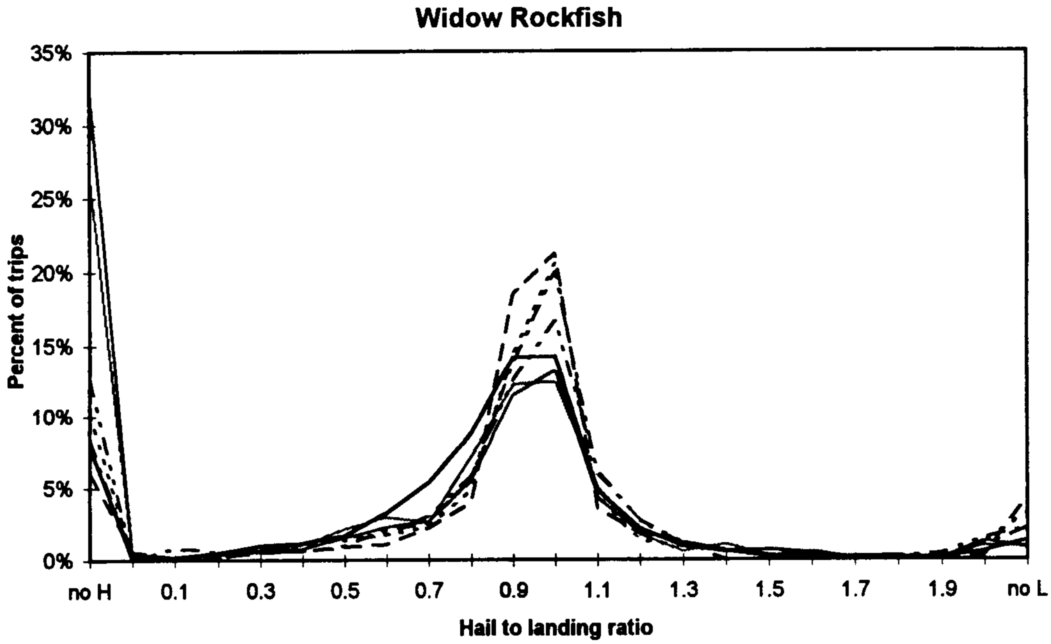


Figure 4. Distribution of hail to landing ratio for two species. "no H" and "no L" indicate hails without landings and landings without hails, respectively.

Table 6. Summary of hail to landing ratios.

	Year							
	1987	1988	1989	1990	1991	1992	1993	Total
	A. No. of Trips with Hail / Landing Ratio in (0.6 - 1.1).							
Arrowtooth Flounder	251	285	412	546	700	533	561	3288
Dover Sole	1078	1333	1497	1463	1901	1533	1883	10688
English Sole	661	696	752	645	1023	789	1055	5621
Lingcod	462	625	787	784	997	742	947	5344
Misc. Rockfish	634	822	906	756	1002	792	1017	5929
Pac. Ocean Perch	179	263	350	326	486	401	527	2532
Pacific Cod	409	562	501	389	686	528	629	3704
Petrale Sole	676	749	828	786	1035	814	1006	5894
Rex Sole	419	432	476	418	631	440	606	3422
Sablefish	667	990	1049	1135	1442	1290	1643	8216
Sand Dab	251	163	171	229	340	221	200	1575
Small Rockfish	220	303	381	458	567	379	768	3076
Thornyheads	269	537	791	1064	1331	1133	1464	6589
Widow Rockfish	454	505	617	665	681	641	860	4423
Yellowtail Rockfish	298	446	462	534	740	707	855	4042
	B. Total Number of Trips (with Hails or Landings).							
Arrowtooth Flounder	589	765	949	977	1330	1078	1315	7003
Dover Sole	1528	1900	2112	1981	2530	2073	2509	14633
English Sole	1239	1481	1564	1257	1821	1587	2056	11005
Lingcod	1242	1568	1807	1562	1992	1614	2085	11870
Misc. Rockfish	1374	1767	1963	1567	2127	2041	2458	13297
Pac. Ocean Perch	344	533	629	588	877	726	971	4668
Pacific Cod	1029	1361	1153	784	1292	1103	1362	8084
Petrale Sole	1351	1621	1814	1494	1968	1589	2075	11912
Rex Sole	930	1024	1129	896	1239	1037	1501	7756
Sablefish	1203	1746	1886	1802	2241	2170	2705	13753
Sand Dab	413	290	321	344	489	340	314	2511
Small Rockfish	585	775	897	969	1161	904	1592	6883
Thornyheads	750	1181	1481	1571	1968	1671	2130	10752
Widow Rockfish	594	712	889	938	1095	1190	1718	7136
Yellowtail Rockfish	459	704	815	796	1140	1307	1814	7035

From Sampson (1997).

Table 7. Summary of trips that were not influenced by trip limits.

	Year							
	1987	1988	1989	1990	1991	1992	1993	Total
Total no. trips with Logbooks and Tickets	2107	2395	2633	2451	3285	3580	3565	20016
	No. trips by species, with landings greater than zero							
Widow Rockfish	574	684	869	925	1077	1192	1727	7048
Sebastes Complex	1668	2044	2209	1950	2572	2533	3072	16048
Yellowtail Rockfish	452	675	795	791	1141	1312	1850	7016
Sablefish	1191	1735	1869	1797	2234	2177	2713	13716
Pac. Ocean Perch	306	457	551	552	845	704	944	4359
Deepwater Complex	1599	2005	2180	2066	2590	2388	2885	15713
Thornyheads	681	1108	1420	1559	1951	1664	2126	10509
	Percent of trips uninfluenced by trip limits							
Widow Rockfish	50%	69%	57%	60%	69%	82%	84%	71%
Sebastes Complex	91%	89%	91%	92%	95%	98%	99%	94%
Yellowtail Rockfish	63%	67%	66%	67%	46%	68%	76%	66%
Sablefish	93%	85%	78%	73%	68%	72%	75%	76%
Pac. Ocean Perch	79%	79%	60%	76%	71%	78%	79%	75%
Deepwater Complex	100%	100%	92%	92%	83%	97%	93%	93%
Thornyheads	100%	100%	100%	100%	82%	95%	95%	95%

From Sampson (1997).

After removing questionable data, the data for the analyses were selected by a number of criteria (described in the Methods section). To remove potential outliers, stations with fewer than 3 non-zero species values were also deleted from the staions-by-species and boats-by-species data matrices; 2 stations in 1988 and 2 stations in 1993. Based on additional outlier detection procedures (described in the Methods section), I removed 2 more stations from the matrix for 1993 and 1 station from the boats-by-species matrix. Even though 2 outliers were identified in the 1993 data matrix, those stations were not regarded as outliers in the analysis of the matrix with all years combined. The data from the 6th bimonthly period of 1987 were not included in the analyses because the fishery for sablefish was closed on October, 22. This resulted in the exclusion of 13 stations from the data matrix for 1987. The number of stations and number of tows that were included in the stations-by-species data matrices for individual years and for all years combined, and the boats-by-species data matrix are presented in the Table 8. The number of stations as well as the number of tows in each data matrix varied from year to year. All the screening procedures and data preparation criteria resulted in the inclusion of 54% (61,207 tows) of the total tows made by sole trawls during the study period.

I also mapped out in the form of a table the stations that were included in the analyses and the corresponding number of tows (Appendix 3). The tables show that the data are highly unbalanced and that there is a strong seasonal pattern to the fishing locations (sampling locations). Boats tend to operate in deeper water during the winter period (bimonth periods of 1st, 2nd, and 6th), and move into shallower water during

Table 8. Summary of number of stations and maximum number of valid tows in stations that were included in each data matrix: stations-by-species for individual years (1987-1993) and all years combined, and boats-by-species.

	Logbooks	Data matrix		
Year	Sole trawl tows	No. Stations	Tows in stations	Percent
1987	12147	90	7115	59%
1988	12949	123	7835	61%
1989	16918	171	11697	59%
1990	12002	135	7647	64%
1991	16756	161	10818	65%
1992	13104	134	7060	54%
1993	15102	140	9035	60%
All years combined	98978	956	61207	54%
Boats-by-Species	17945	171	11165	60%

summer period (bimonth periods of 3rd, 4th, and 5th). This feature of sampling coverage could influence the appearance of seasonality in the species associations.

Ordinations and classifications of data matrices

Results from both ordination and classification analyses of the stations-by-species matrices revealed strikingly similar species patterns and environmental correlations among the individual years and the analysis with all years combined, despite the different numbers of stations and the varying sampling coverage. First I applied DCA to extract the DCA scores of stations for the first two main DCA axes and plotted the stations based on their scores on the DCA space. I was able to check the potential outliers by plotting those stations (Figure 5). The relationship between the depth variable and DCA axis 1 and between the latitude variable and DCA axis 2 from the data matrix for all years combined are shown in Figure 6. Even though there was a slight curvilinear relationship between DCA axis 1 and depth, the degree of curvature was so small that a linear correlation was considered to be sufficient to explain the relationship (Figure 6, upper panel). For all of the data matrices there was a strong relationship between the DCA axis 1 scores and the depth variable (Table 9), with the correlation coefficients ranging from a minimum of -.947 to a maximum of -.884. The negative coefficients indicate that the depth component in DCA axis 1 is oriented with shallower depths in the positive direction and deeper depths in the negative direction. Depth is negatively correlated with the DCA axis 1 for all the data matrices. Other environmental variables such as latitude, bimonth, and year are not strongly correlated with DCA axis 1 scores. Latitude is the variable most responsible for

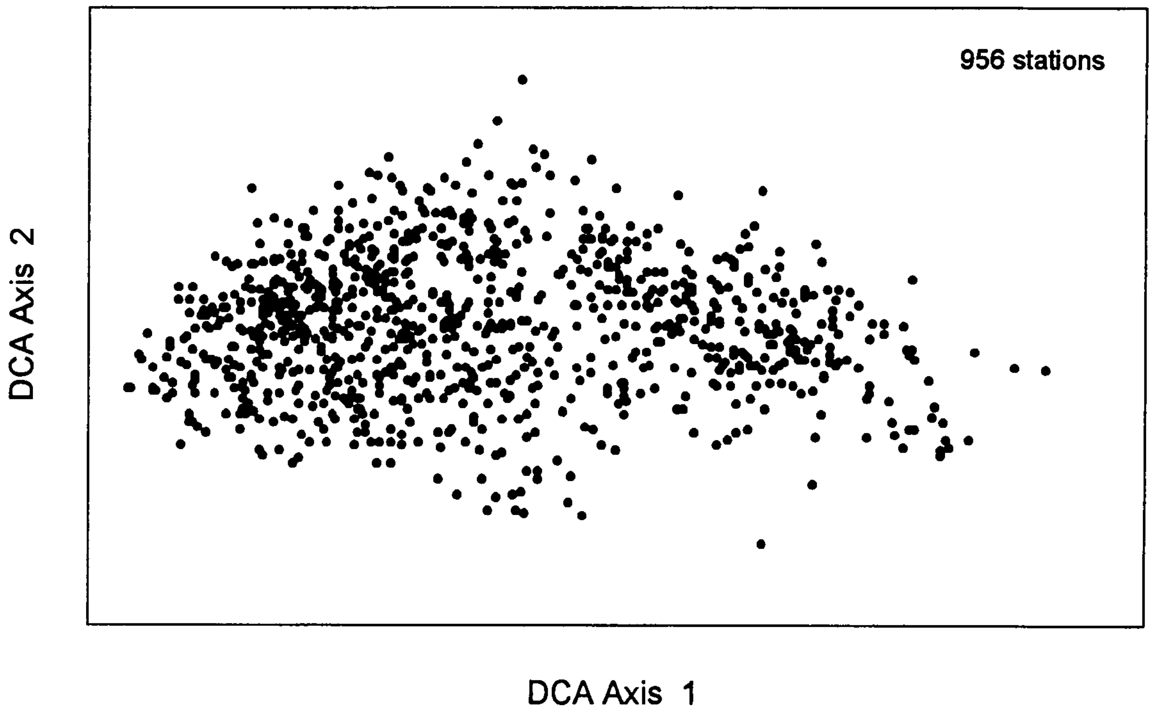


Figure 5. DCA plot of station scores for the stations-by-species data matrix with all years combined. Each dot represents one station. No outliers were excluded from this DCA.

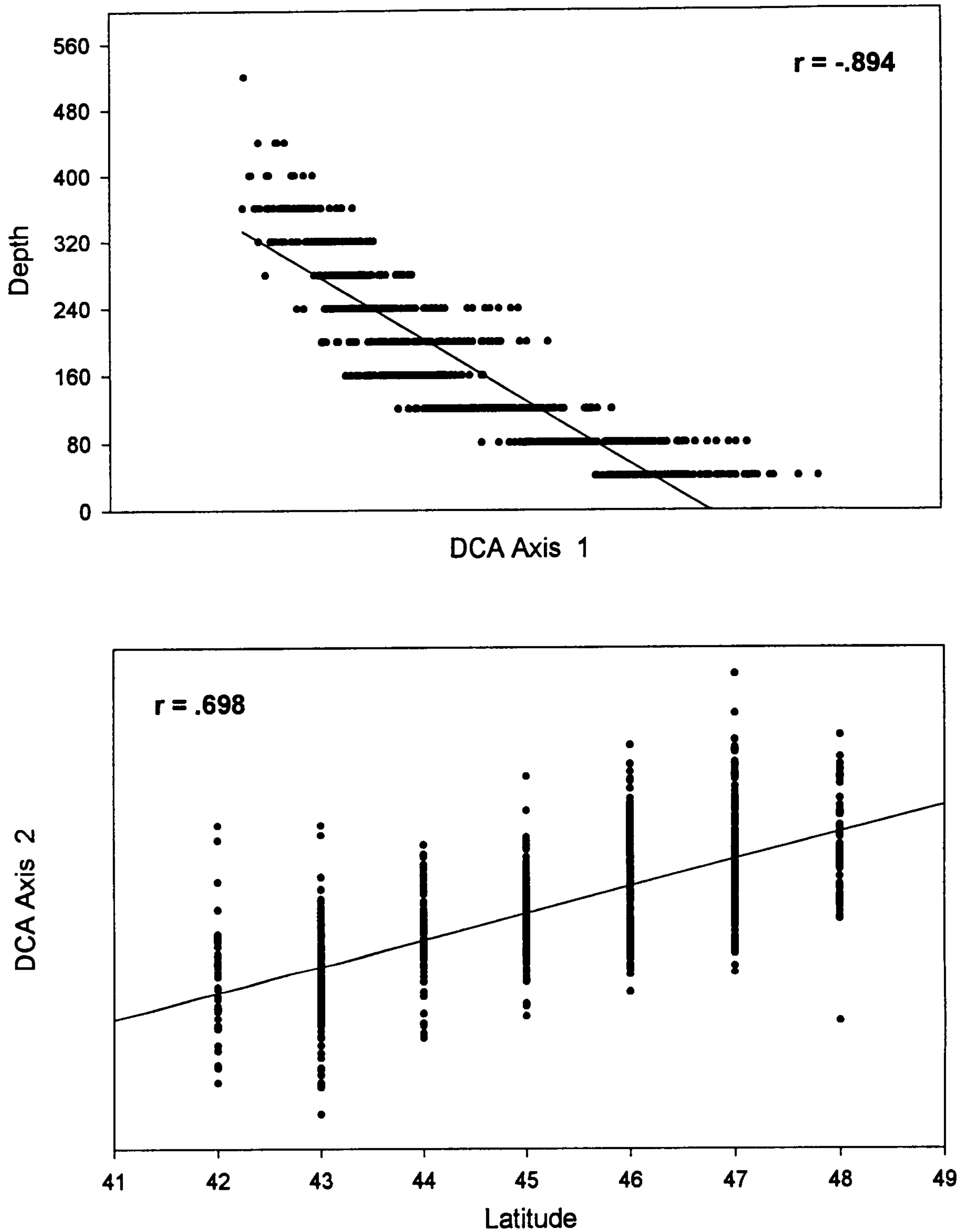


Figure 6. Plot of DCA stations axis 1 against depth (upper panel), and plot of DCA stations axis 2 against latitude (lower panel). DCA axes were derived from the stations-by-species data matrix for all years combined.

Table 9. Summary for all data matrices of the Pearson product-moment correlation coefficients between the environemntal variables and the main DCA scores for the stations and environmental variables for all the data matrices. The coefficient of determination (r^2) of each axis is noted in parentheses.

Stations-by-species: 1987 (90 stations)

	Axis 1 (70%)		Axis 2 (4.3%)	
	r	r^2	r	r^2
Depth	-.925	.856	.119	.014
Latitude	-.368	.135	.414	.171
Bimonth	.089	.008	-.163	.027

Stations-by-species: 1988 (123 stations)

	Axis 1 (67%)		Axis 2 (4.7%)	
	r	r^2	r	r^2
Depth	-.915	.838	-.128	.016
Latitude	.038	.001	.788	.620
Bimonth	.067	.004	.041	.002

Stations-by-species: 1989 (171 stations)

	Axis 1 (76%)		Axis 2 (3.1%)	
	r	r^2	r	r^2
Depth	-.909	.826	.194	.037
Latitude	-.069	.005	.668	.447
Bimonth	.030	.001	-.140	.020

Table 9. *Continued.*

Stations-by-species: 1990 (135 stations)

	Axis 1 (78%)		Axis 2 (3.6%)	
	r	r^2	r	r^2
Depth	-.882	.777	.218	.048
Latitude	-.204	.042	.668	.473
Bimonth	.078	.006	.024	.001

Stations-by-species: 1991 (161 stations)

	Axis 1 (74%)		Axis 2 (5.8%)	
	r	r^2	r	r^2
Depth	-.874	.765	.040	.002
Latitude	-.200	.040	.754	.562
Bimonth	.043	.002	.030	.001

Stations-by-species: 1992 (134 stations)

	Axis 1 (64%)		Axis 2 (9%)	
	r	r^2	r	r^2
Depth	-.884	.781	.183	.033
Latitude	-.273	.075	-.672	.451
Bimonth	.194	.038	.038	.001

Table 9. *Continued.*

Stations-by-species: 1993 (140 stations)

	Axis 1 (71%)		Axis 2 (4.8%)	
	r	r^2	r	r^2
Depth	-.895	.802	.045	.002
Latitude	-.186	.035	.782	.612
Bimonth	.185	.034	-.257	.066

Stations-by-species: all years combined (956 stations)

	Axis 1 (70%)		Axis 2 (5%)	
	r	r^2	r	r^2
Depth	-.894	.800	-.099	.010
Latitude	-.138	.019	.698	.487
Year	-.025	.001	.064	.004
Bimonth	.081	.007	-.015	.000

Boats-by-species (171 combinations)

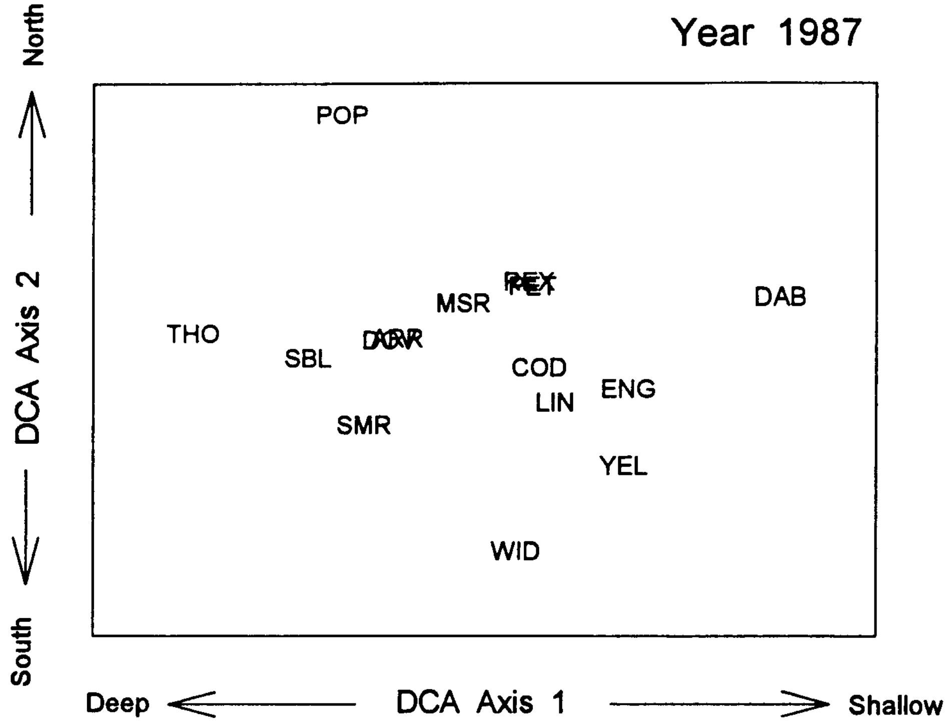
	Axis 1 (72%)		Axis 2 (5.2%)	
	r	r^2	r	r^2
Depth	-.947	.897	.074	.006
Latitude	.168	.028	-.177	.031
Boat	-.051	.003	.009	.000

explaining the variation in the DCA axis 2 scores for all the data matrices, except the one for 1987 ($r = .414$) and the boats-by-species ($r = -.177$). The correlation coefficients for other years range from -.672 to .788. Positive correlations indicate that axis 2 is oriented south to north. There are no strong correlations between DCA axis 2 and the other environmental variables.

When comparing results for the different data matrices, the relationship between the DCA axes and environmental variables should be interpreted with a caution because from one matrix to the next each axis has a different ability to explain the variability in the original data. The degree of explanatory power can be gauged by the coefficient of determination (r^2). In principle components analysis and correspondence analysis the eigenvalue of each axis is used to determine the performance of the axis in ordination space. However, interpreting the eigenvalue for a DCA axis is problematic because the DCA methods involves detrending and rescaling. I used the Euclidean distance measure for calculating the value of r^2 to evaluate how well distances in ordination space represent distances in the original high dimensional space. Values of r^2 for the first two DCA axes demonstrated that about 70% of the total variance is explained by axis 1, whereas only about 5 % is explained by axis 2. Therefore, the environmental variable represented by axis 1 is the principal variable related to variability of the species associations. Even though the DCA procedure derives a series of ordination axes, the third axis and subsequent axes were not used to examine the species patterns because those axes have very minimal explanatory power.

The DCA plots of species scores show remarkable similarity among all the data matrices (Figure 7). The relationships between the DCA scores for sampling stations and the environmental variables provide an interpretation of the DCA axis in terms of environmental gradients. The DCA axis 1 is linearly correlated with depth ($r^2 > .765$) for all of the data matrices and DCA axis 2 is linearly correlated with latitude ($r^2 > .447$) for seven of nine matrices. Species are fairly evenly distributed in ordination space, especially along axis 1, and the locations of species in the DCA plots are consistent from year to year. For example, the DCA scores for thornyheads (THO), sablefish (SBL), and Dover sole (DOV) are lined up in the middle left portion of each DCA plot, indicating that these species occur across all latitudes but in deeper waters, with Dover sole at shallower depths, thornyheads at deeper depths, and sablefish in between. The relative positions of some species such as widow rockfish (WID), yellowtail rockfish (YEL), and Pacific cod (COD) change along DCA axis 2 from plot to plot. Pacific Ocean perch (POP) and small rockfish (SMR) are consistently at opposite sides of axis 2. Change in the positions of species over time could be due to changes in the distribution of sampling to some extent. In general the DCA results indicate that species associations are determined primarily by depth and secondarily by latitude.

The DCA species plot for the data with all years combined shows a pattern of species distribution that is similar to the plots of individual years. The DCA species plot of the boats-by-species analysis has a similar pattern as the plots derived from the data collected from hundreds of boats, but the spread of species scores along DCA axis 2 is reduced and the position of sanddab (DAB) is unusual relative to the other plots.



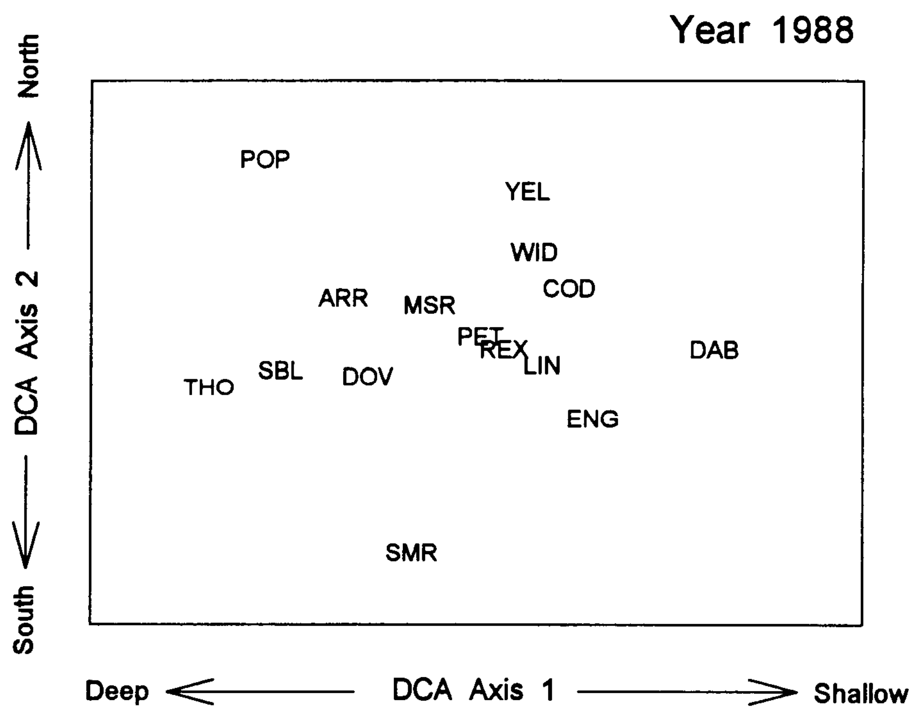


Figure 7. DCA species plots for individual years (1987-1993), all years combined, and area by boat. Orientation of environmental variables is indicated for each axis if a strong linear correlation exists ($r^2 > .447$).

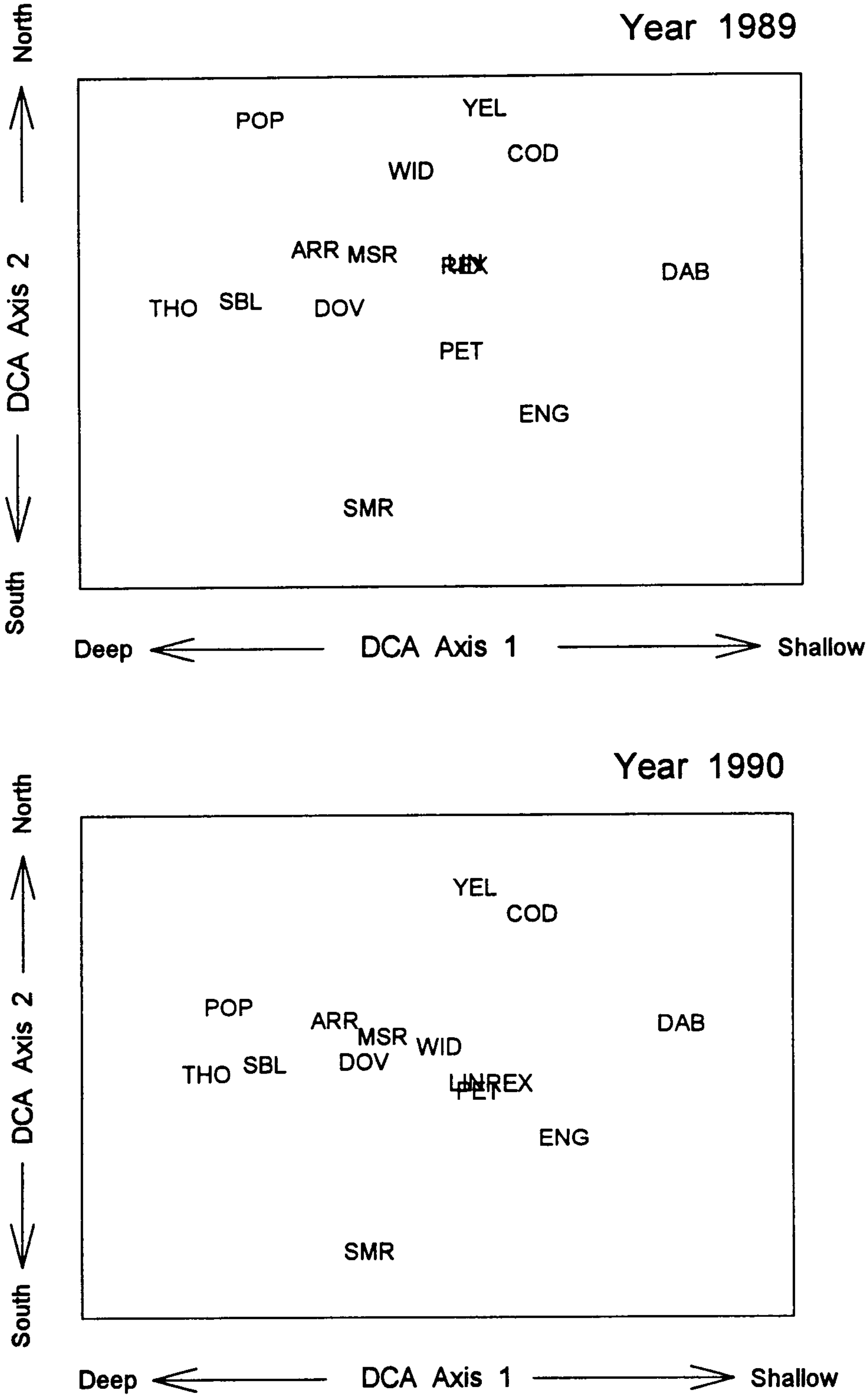


Figure 7. *Continued.*

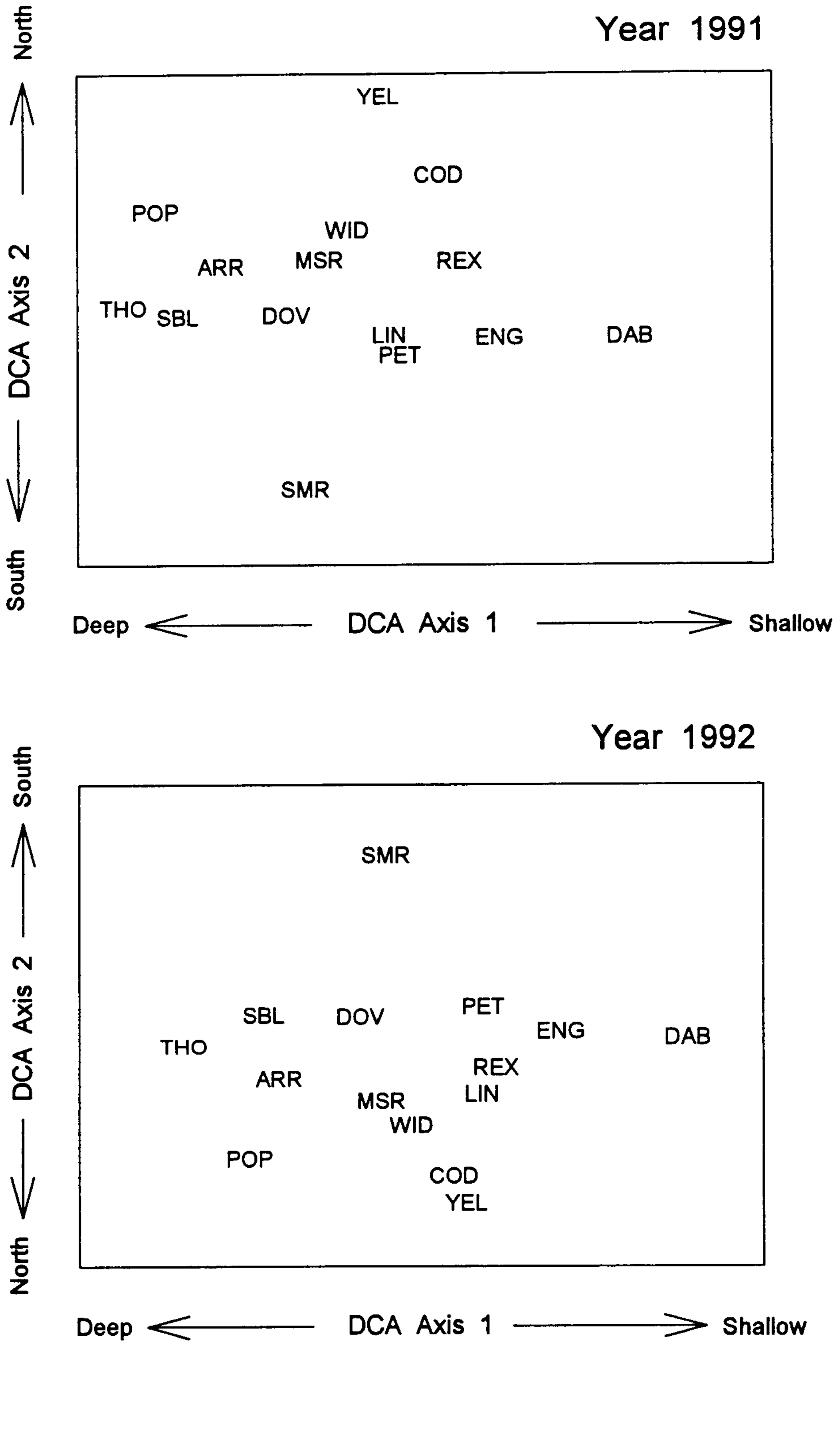
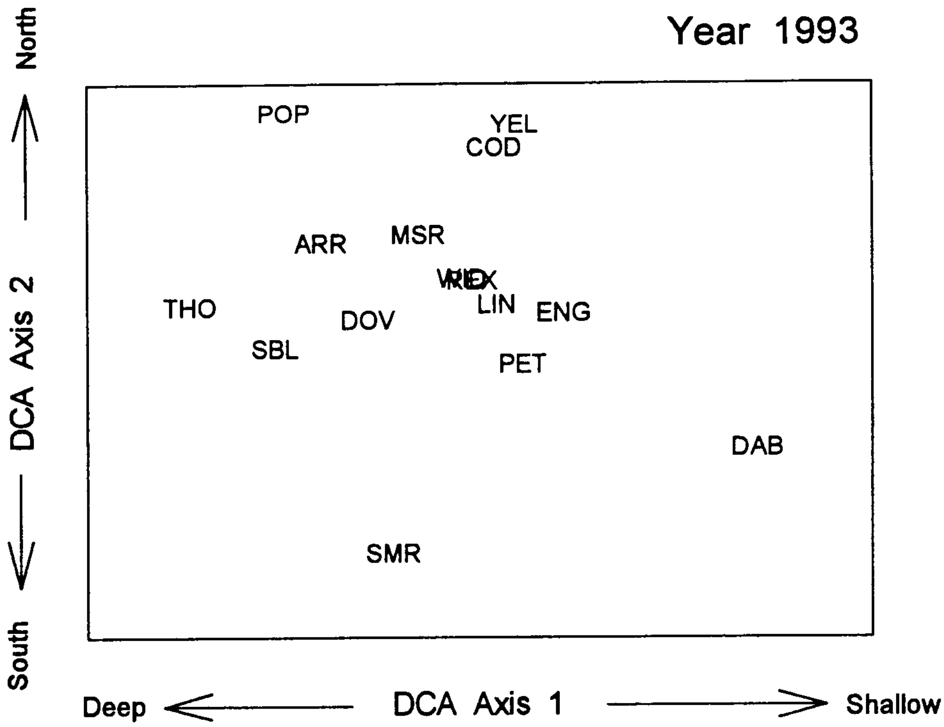


Figure 7. *Continued.*



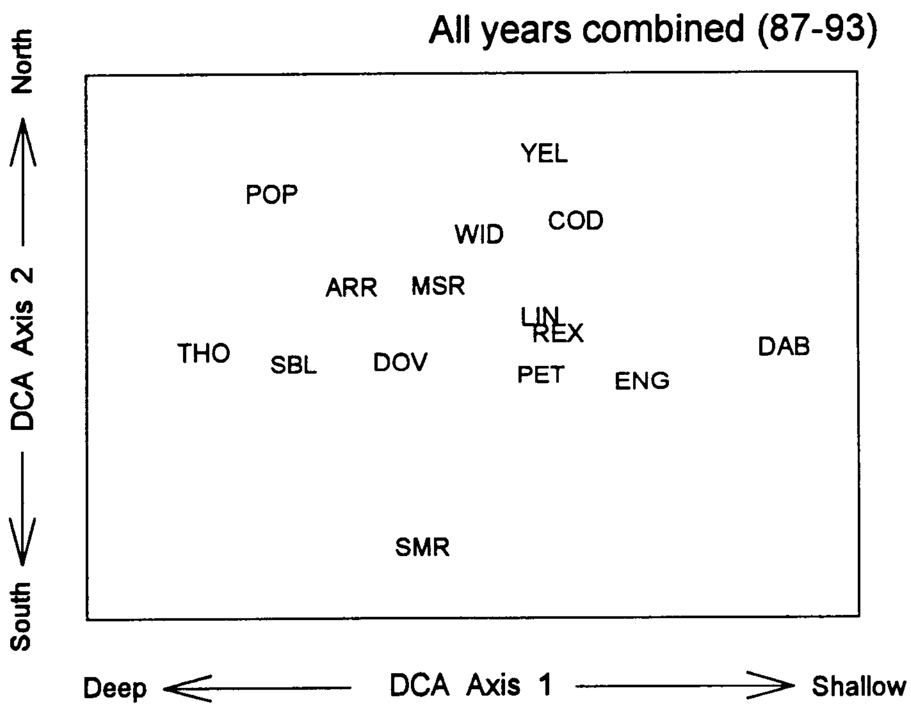


Figure 7. *Continued.*

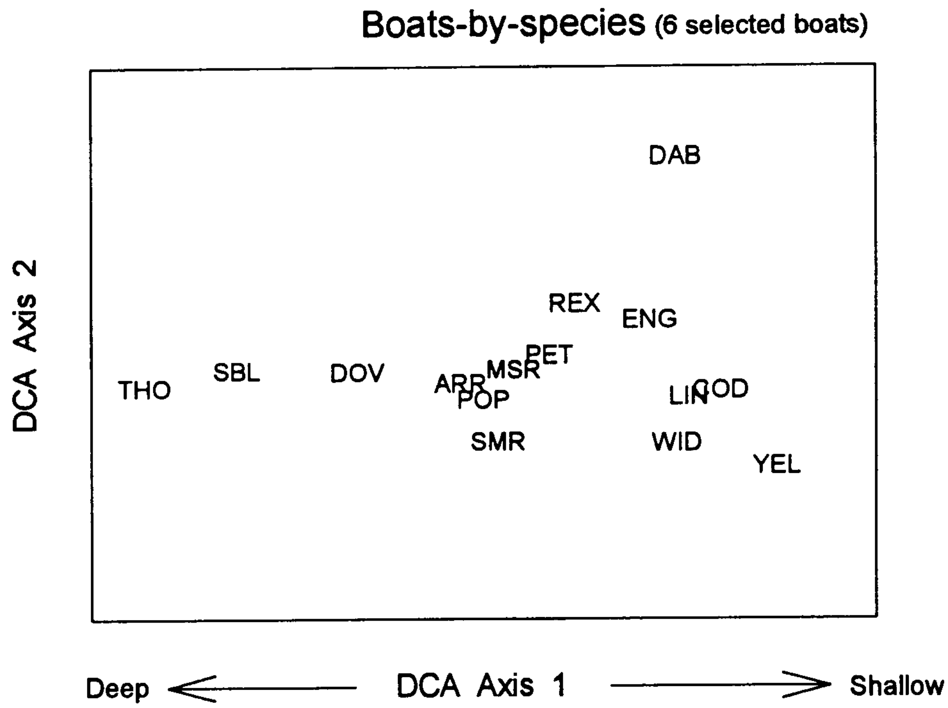


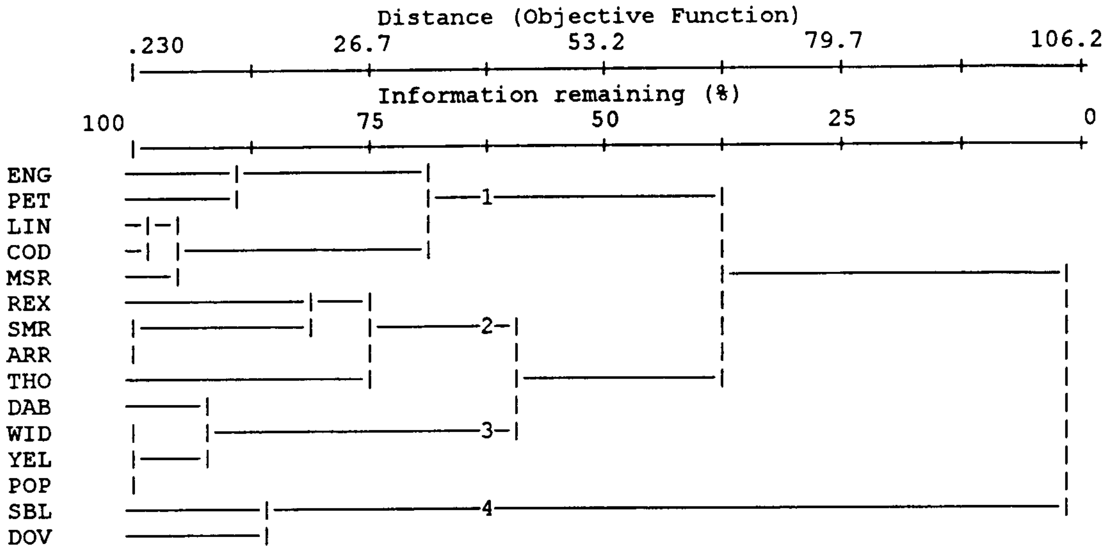
Figure 7. *Continued.*

However, axis 2 in the boats-by-species analysis should be interpreted cautiously because axis 2 is weakly correlated with the environmental factors.

Cluster analysis was used to group the species in an objective manner. Results for all the matrices show that the analyses were not badly affected by the chaining problem (less than 20%), and that the species can be clustered into 4 groups while retaining about 65% or more of the information in the original data (Figure 8). In the dendograms, similar species are merged into groups in a sequential manner due to the characteristics of the hierarchical cluster analysis. Comparisons between the results from DCA and cluster analysis show that they share many common features. It appears that species are fused into groups by the cluster analysis based mainly on depth gradients rather than latitude effects. For example, the cluster analysis does not always differentiate between Pacific ocean perch (POP) and small rockfish (SMR), whereas the DCA scores for these species tend to be at opposite ends of DCA axis 2. Although the constituent species in a given group tend to change from year to year, the deeper water species thornyheads (THO), sablefish (SBL), and Dover sole (DOV) were grouped together in eight of the nine analyses. If species are divided into 2 groups at about the 45% information level, these deep water species become one group and the rest of species become the other group.

One of the apparent discrepancies between the results of the ordination versus the cluster analyses is the location of sanddab (DAB), which is one of the most shallow occurring species. In the early stage of clustering sanddab tend to be fused into a group with species such as widow rockfish (WID) and yellowtail rockfish (YEL), which occur in

Year: 1987
Percent chaining = 15.00



Year: 1988
Percent chaining = 10.00

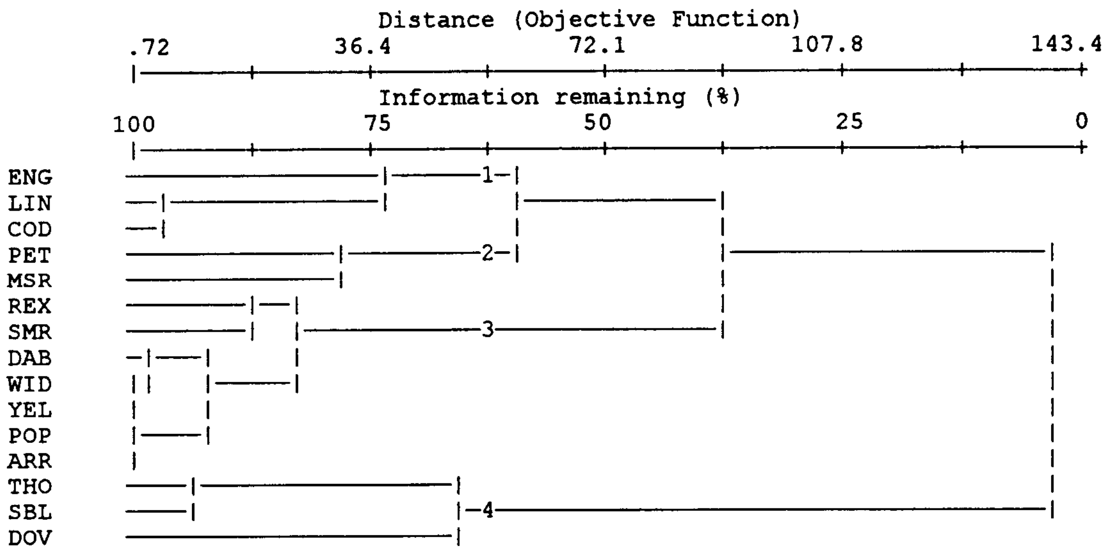
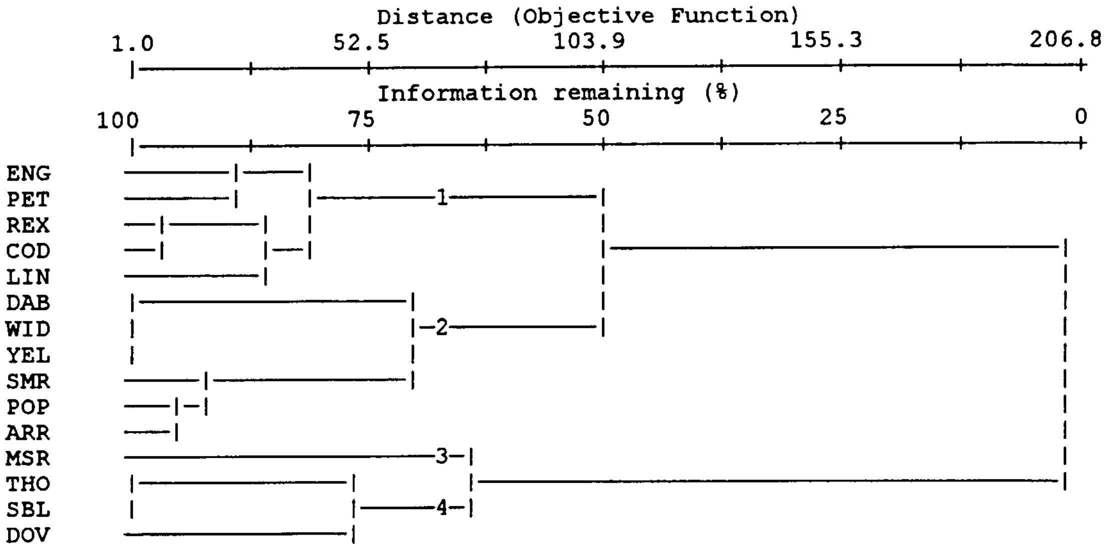


Figure 8. Dendograms from cluster analyses for individual years (1987-1993), all years combined, and boats-by-species data matrices.

Year: 1989
Percent chaining = 6.67



Year: 1990
Percent chaining = 15.00

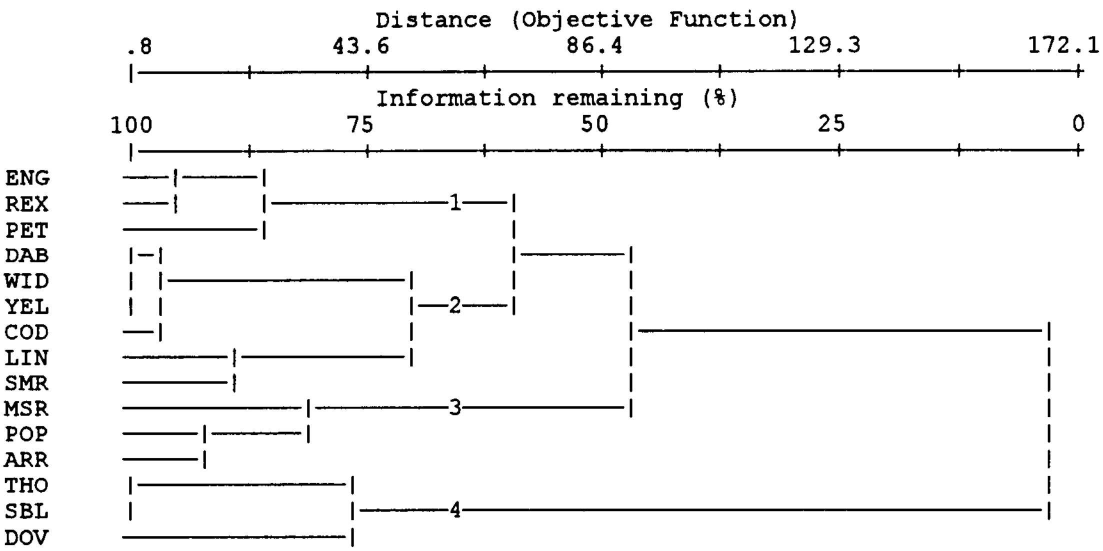
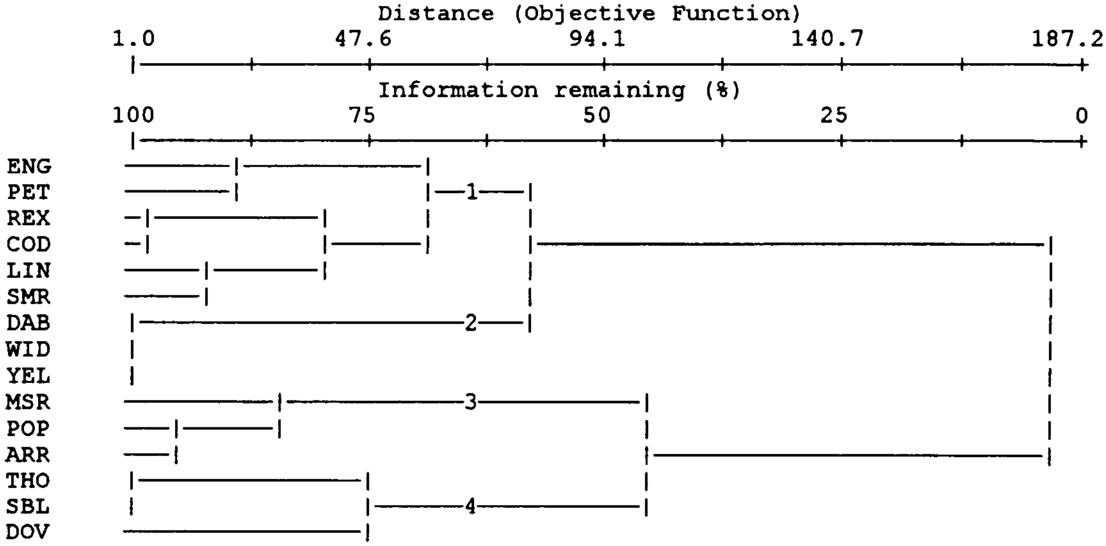


Figure 8. *Continued.*

Year: 1991
Percent chaining = 3.33



Year: 1992
Percent chaining = 18.33

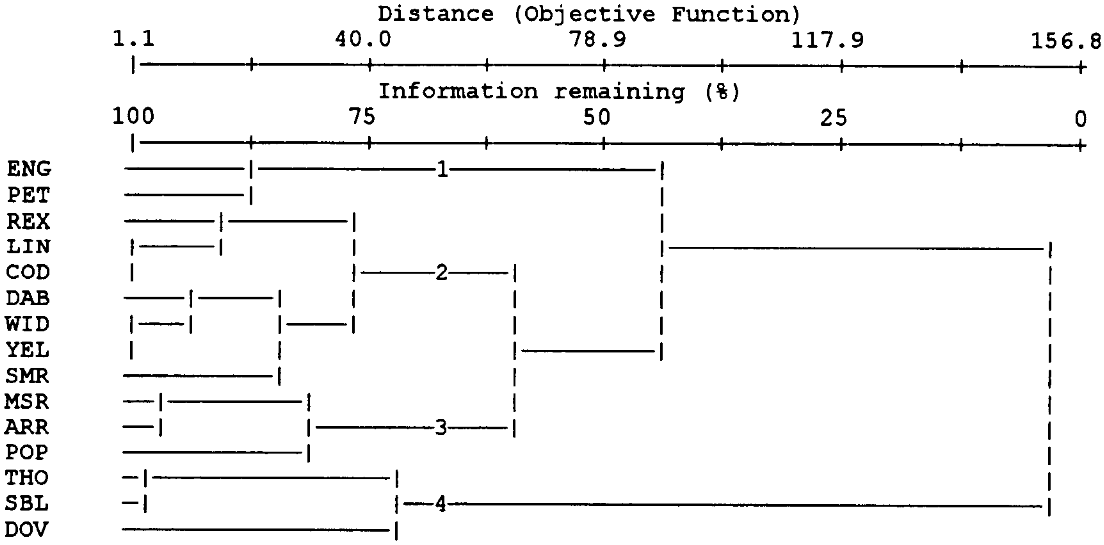
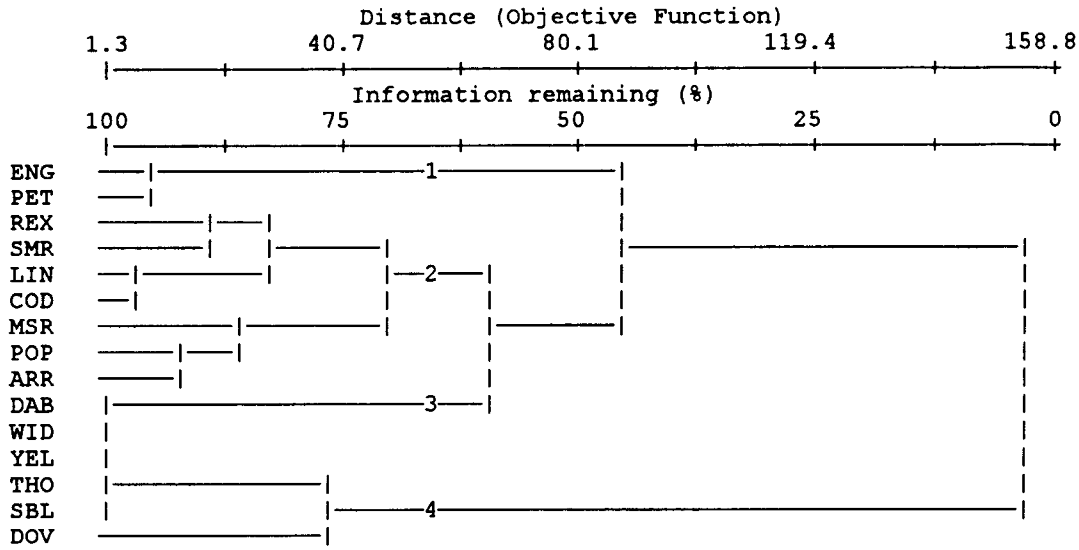


Figure 8. *Continued.*

Year: 1993
Percent chaining = 16.67



All years combined: 1987~93
Percent chaining = 10.00

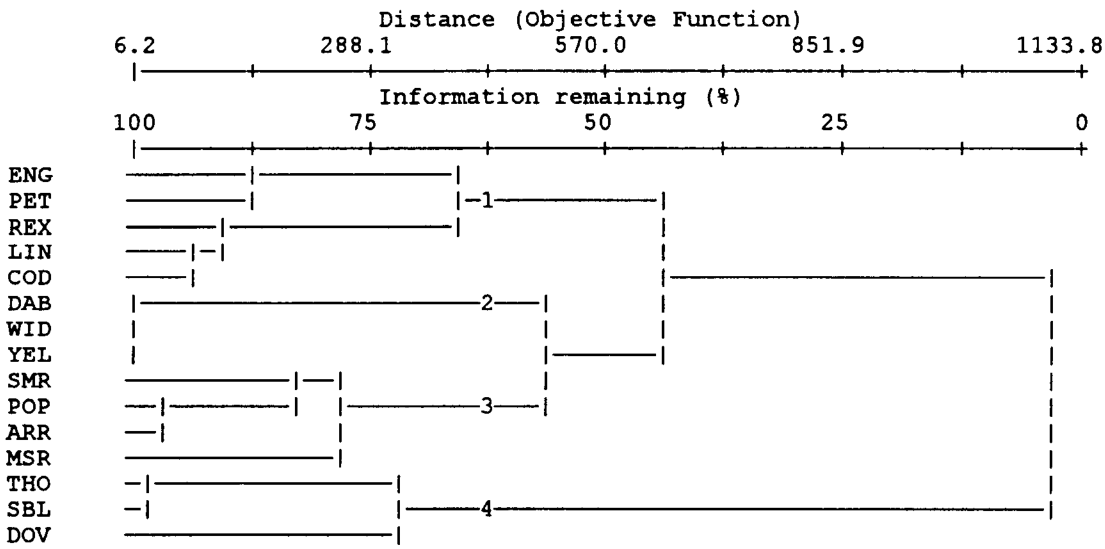


Figure 8. *Continued*.

Boats-by-species
Percent chaining = 5.00

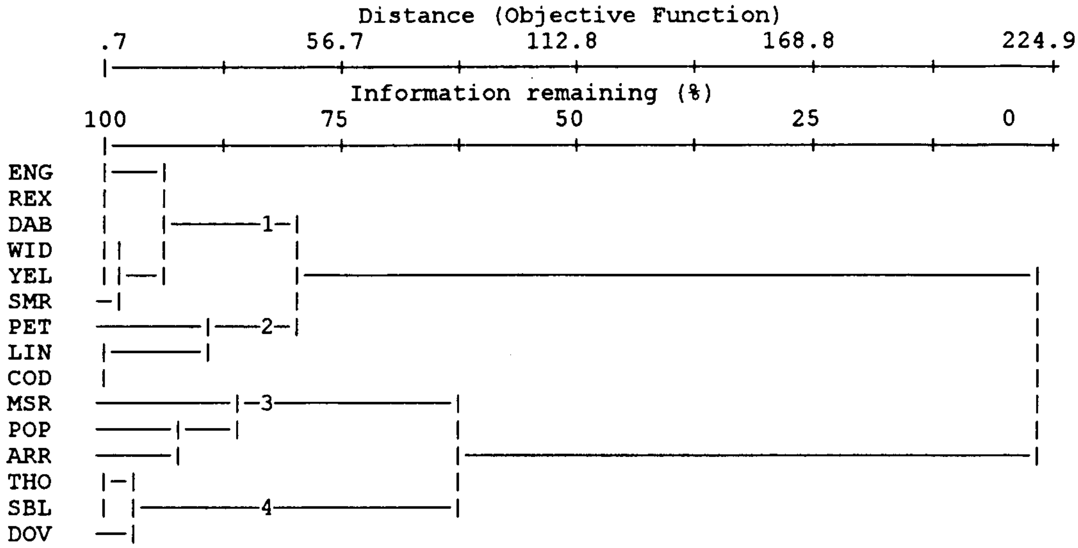


Figure 8. *Continued.*

ordination space as the second most shallow water species group. According to the results of the ordinations, it would seem reasonable that sanddab should be grouped with species such as English sole (ENG) or petrale sole (PET), which tend to occur in the most shallow water.

GLM analysis

Even though I detected no strong correlations between species associations and the temporal variables bimonth and year, these results could have been artifacts of the highly unbalanced sampling coverage over time. Also, I wanted to explore the possible influence of interactions between the environmental variables. I applied GLM analysis techniques to the DCA axis 1 scores obtained from the stations-by-species data matrix with all years combined. This allowed me to examine in detail relationships between the species associations and the environmental factors including possible interactions, while accounting for the effect of the unbalanced data. I constructed a model starting with all main environmental factors (depth, latitude, month, and year) and all possible two way-interactions of the main effects. I sequentially removed insignificant terms until only statistically significant ones remained (two-sided p-value < .05). As a result, a model with the environmental variables was created that explains the most of variability in the species associations (DCA axis 1). The model can be represented by an equation of the form, DCA axis 1 = Depth + Latitude + Month + Year +

Depth·Latitude + Depth·Month + Depth·Year + Latitude·Month

The model is highly significant (two-sided *p*-value = .0001), and it accounts for 99.1% (adjusted R^2) of the variation in species association expressed by DCA axis 1. The main variables and interaction terms that were included in the model are all statistically significant ($p < .05$) (Table 10). In the process of building the model, two interaction terms (Latitude·Year and Month·Year) were removed from the model.

The scatterplot of predicted values against residuals was used to verify the absence of any pattern or shape that might indicate violation of the model assumptions (e.g., homogenous variability). Nothing unusual was observed. I also tested for possible three-way interactions by sequentially adding to the model three-way combinations of the two-way interactions. Although 2 three-way interactions, Depth·Latitude·Month and Depth·Latitude·Year, were statistically significant, the model with those terms was much more complex and reduced the adjusted R^2 to 98.2%. Thus, it was more plausible to fit the simpler model that had only two-way interactions.

Even though all terms in the model are significant, the predictive power of each term differs from factor to factor. Depth is the most influential main effect (mean square = 7590.5) and Month is the second most influential (MS = 237.7), but the level of contribution of Month to the model is much less than that of Depth.

Table 10. Result of GLM analysis on the DCA axis 1 extracted from the data matrix of all years combined.

Class	Levels	Values
Depth	12	40 80 120 160 200 240 280 320 360 400 440 520
Latitude	7	42 43 44 45 46 47 48
Month	6	1 2 3 4 5 6
Year	7	87 88 89 90 91 92 93

Source	df	Sum of Squares	Mean Square	F Value	Pr > F
Model	198	394463.72	1992.24	109.68	0.0001
Error	757	13750.40	18.16		
Corrected Total	955	408214.12			

$R^2 = .966$
Adj. $R^2 = .991$

Source	df	Type III SS	Mean Square	F Value	Pr > F
Depth	11	83495.71	7590.52	417.88	0.0001
Latitude	6	480.33	80.05	4.41	0.0002
Month	5	1188.38	237.68	13.08	0.0001
Year	6	243.00	40.50	2.23	0.0386
Depth*Lat	48	6038.04	125.79	6.93	0.0001
Depth*Month	38	3440.11	90.53	4.98	0.0001
Depth*Year	54	1850.36	34.27	1.89	0.0002
Lat*Month	29	1374.63	47.40	2.61	0.0001

The Year factor is the weakest among the main effects (MS = 40.5) and contributes less than the interaction terms Depth·Latitude (MS = 125.8), Depth·Month (MS = 90.5), and Latitude·Month (MS = 47.4).

Checking for potential boat effect

The same ordination and cluster analyses that were applied to the stations-by-species matrices for individual years and all years combined were also applied to the boats-by-species matrix. The results from both analyses of the boats-by-species matrix are similar to the results from stations-by-species matrices. Among all the data sets the correlation between DCA axis 1 and depth was the highest ($r = -.947$) and the correlation between DCA axis 2 and latitude was the lowest ($r = -.177$). This is probably an artifact of the sampling coverage because in the boats-by-species matrix there are few samples in the southern part of study area (41° - 44°), whereas samples for depths are well represented (see Appendix 3, boats-by-species matrix). The similar patterns of species distribution in the ordinations and groupings of species in the cluster analyses among all the data matrices imply that the species associations derived from the data sets with information from numerous different boats are not artificially created by a boat effect.

Geographical distribution of species

For both the logbook data and the NMFS bottom trawl survey data the estimates of the 25th, 50th, and 75th percentiles of species occurrence showed similar patterns of species distributions for the depth range of 30 to 200 fathoms (Figure 9 and Figure 10). The estimates from the logbook data, however, indicate that the species tend to occur in deeper water and occupy more extensive depth ranges. Percentile estimates for the species arrowtooth flounder (ARR) and the miscellaneous and small rockfish groups (MSR, SMR) were unavailable for the trawl survey. Separation of the species in terms of depth gradients is gradual, with many species overlapping each other. Differentiating the species by depth habitat in the plots estimated from the limited depth range (30-200 fathoms) is more difficult than in the plots derived from the complete logbook data sets, which covered the full depth range to 560 fathoms (Figure 11). However in whichever species occurrence plot, it is evident that English sole (ENG) and sanddab (DAB) are relatively shallow water species, whereas sablefish (SBL), Dover sole (DOV), and thornyheads (THO) are relatively deep water species.

Each of the fifteen species has a range of occurrence over depth, with species like English sole, lincod (LIN), and yellowtail (YEL) having narrower ranges and others like Dover sole, sablefish, thornyheads, rex sole (REX), and petrale sole (PET) having wider ranges. Comparison between survey and logbook data for ranges of species occurrence over latitude was not attempted because of the different scales of the study areas. The NMFS survey covers a wider range of latitudes (36°48'N to the Washington-Canada border) than the Oregon trawl fishery (41° - 48°N). In the logbook data most species share similar latitudinal ranges, but Pacific ocean perch (POP), arrowtooth flounder (ARR), and Pacific cod (COD) tend to occur more in the northern area, and widow

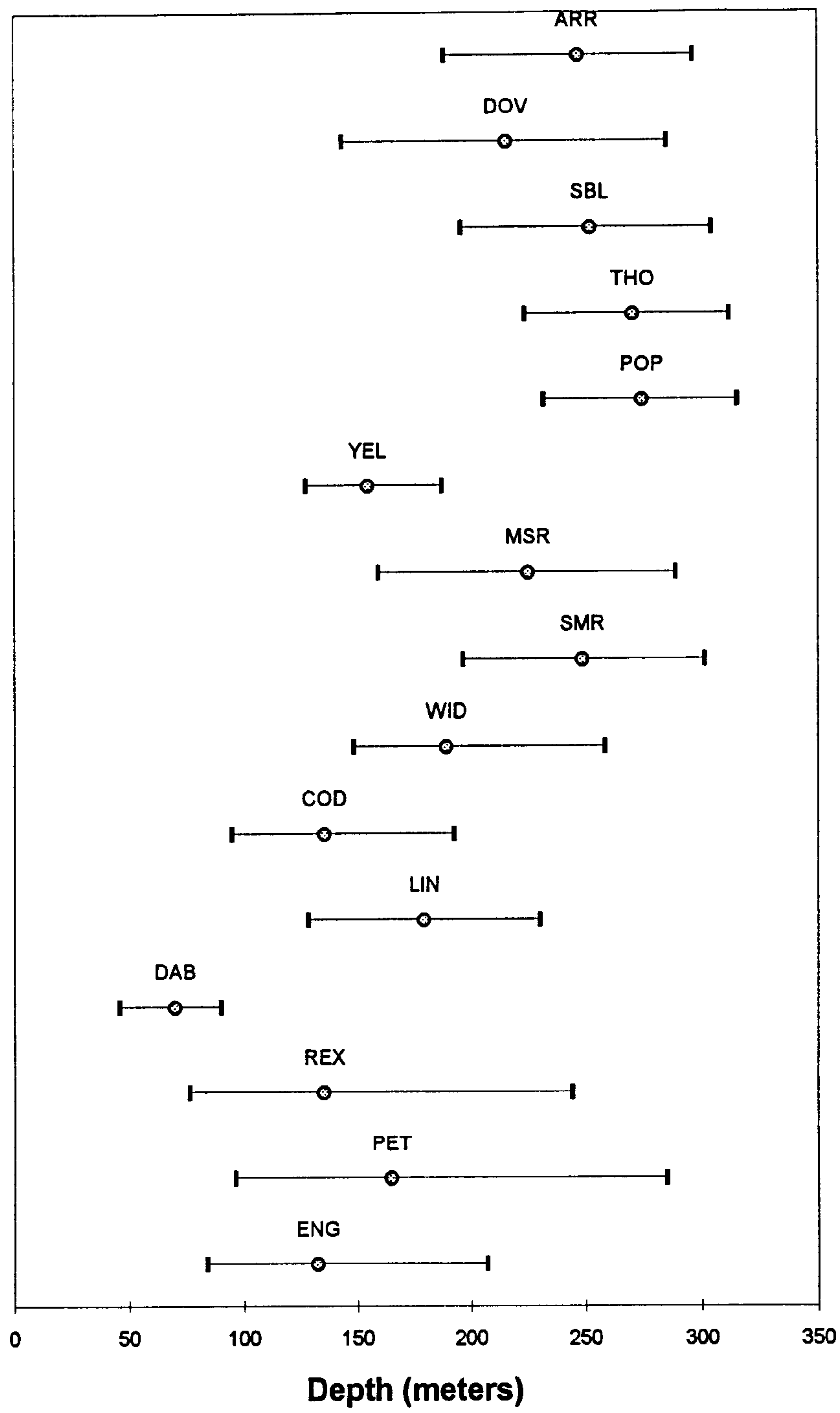


Figure 9. Estimates from logbook data (1987-1993) of the 25th, 50th, and 75th percentiles of species occurrence over the depth range 30 to 200 fathoms.

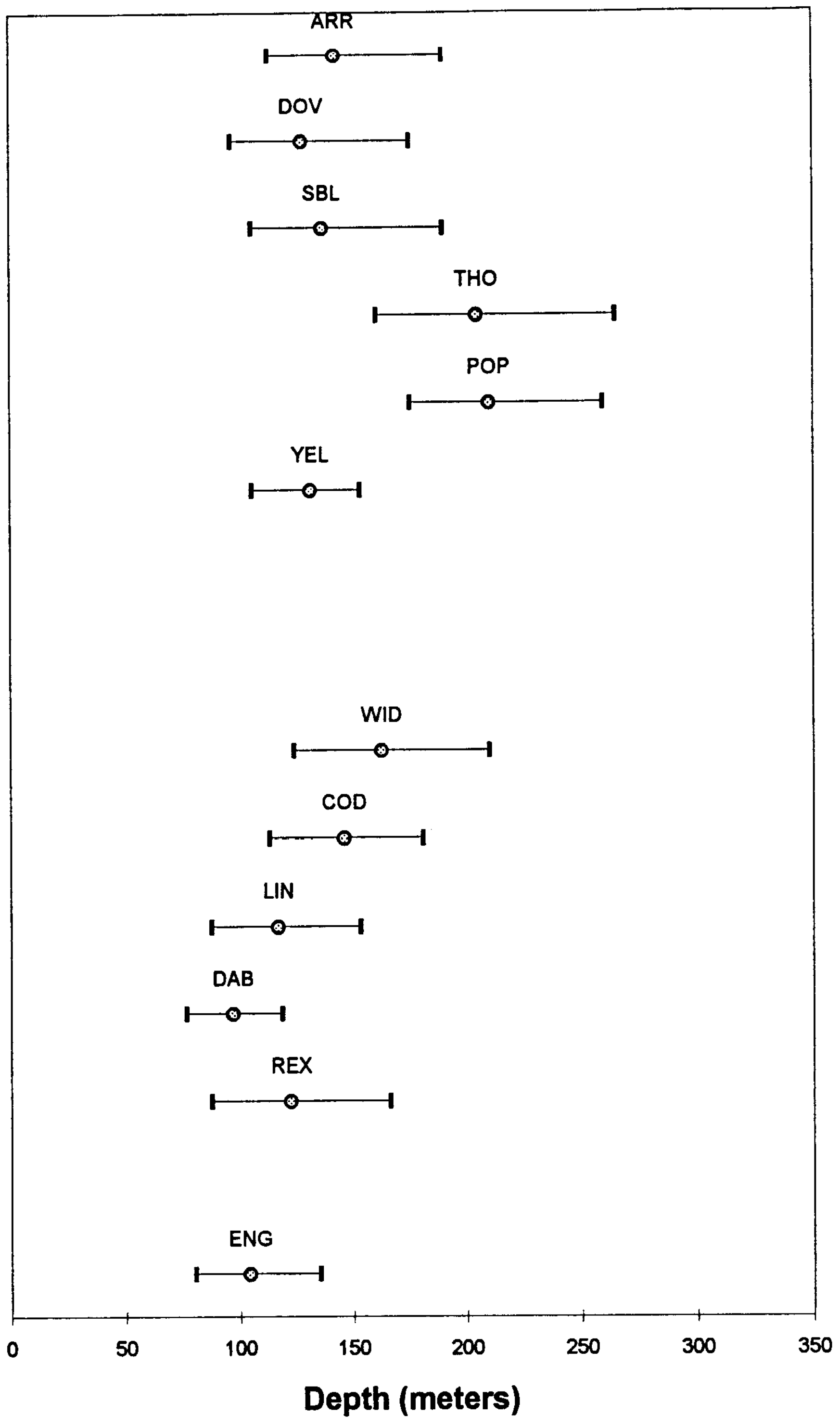


Figure 10. Estimates from five triennial trawl surveys (1980-1993) of the 25th, 50th, and 75th percentiles of species occurrence over the depth range 30 to 200 fathoms.

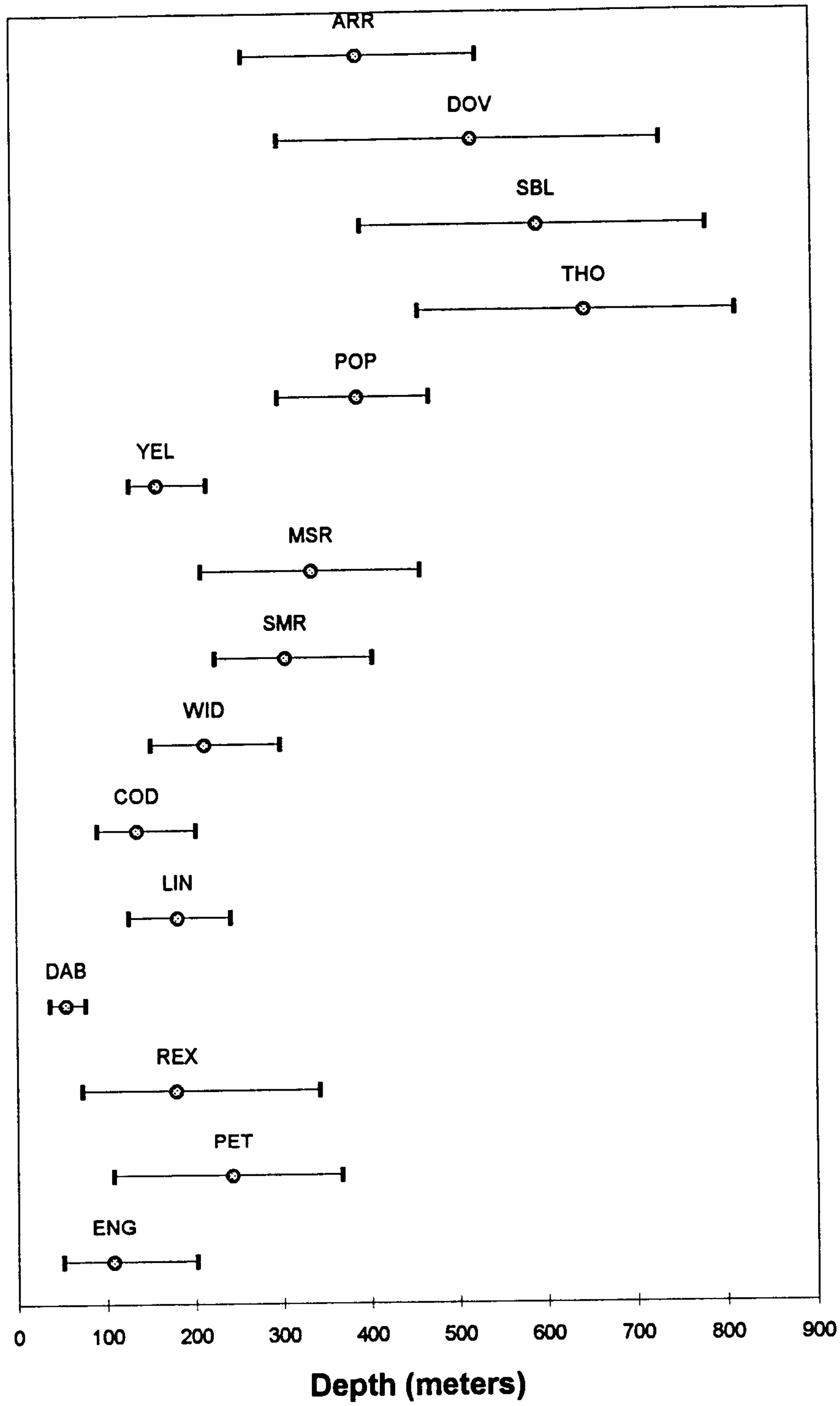


Figure 11. Estimates from logbook data (1987-1993) of the 25th, 50th, and 75th percentiles of species occurrence over the depth range 1 to 560 fathoms.

rockfish (WID) and small rockfish (SMR) tend to occur in the southern area (Figure 12). Pacific ocean perch seems to have narrow and sharp boundaries of occurrence over latitude. The patterns of species geographical distribution estimated by depth and latitude gradients are consistent with the patterns found in the ordination analyses.

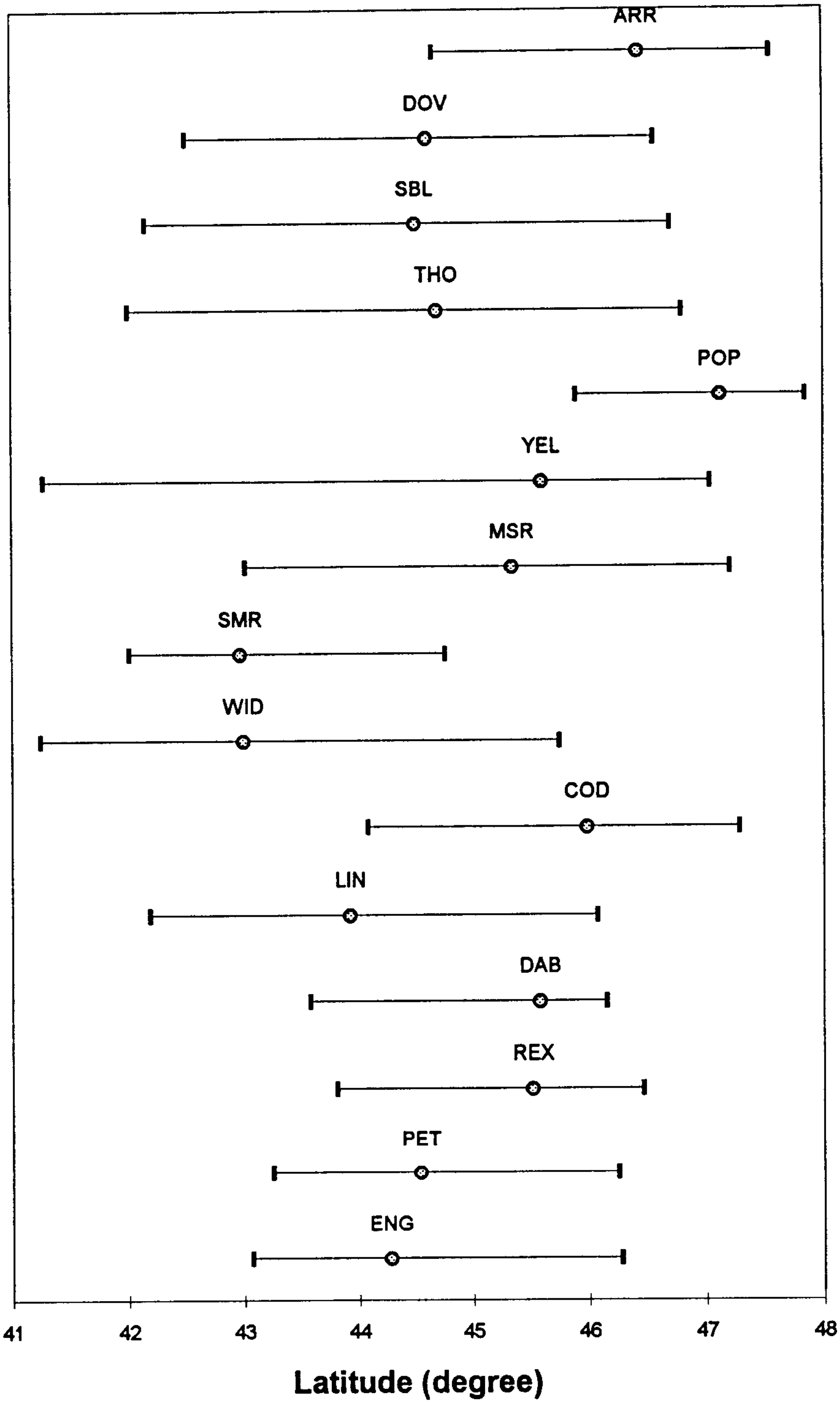


Figure 12. Estimates from logbook data (1987-1993) of the 25th, 50th, and 75th percentiles of species occurrence over the latitude range 41° to 48°.

DISCUSSION AND CONCLUSIONS

This study provides a general picture of species associations among 15 species that are harvested by the commercial trawl fishery. In the ordination and cluster analyses a very consistent pattern of species associations was observed from year to year. A general linear model of the variability in the species associations also indicates that they are fairly persistent relative to temporal variables such as season and year. The model indicates that the variability in species associations can be primarily represented by depth gradients.

Given the apparent stability of species associations over the years, it is therefore practical to use the results obtained from the stations-by-species data matrix with all 7 years combined to determine general features of the commercial species associations off the US Pacific northwest. From ordination and cluster analyses of the data, species that are closely associated each other can be classified into three groups along the depth gradients: (1) a shelf species group that includes English sole, sanddab, petrale sole, and lincod; (2) an upper slope species group that includes widow rockfish, yellowtail rockfish, small rockfish, Pacific ocean perch, arrowtooth flounder, and miscellaneous rockfish; and (3) a deep slope species group that includes thornyheads rockfish, sablefish, and Dover sole.

The dendograms generated from the cluster analysis show the early fusion into a cluster of the species sanddab, widow rockfish, and yellowtail rockfish. This result is inconsistent with the results of the DCA. A possible explanation for this discrepancy is that cluster analysis may be more sensitive to variable or erratic species. Both widow rockfish and yellowtail rockfish are known to be target species in the mid-water trawl fishery, and they are caught incidentally in the ground trawl fishery. Sanddab is also highly variable probably due to fluctuations in market demand and market conditions. Therefore, the cluster analysis may have classified theses species together because of their erratic traits compared to the other species.

The similar pattern of species occurrence determined by comparing estimates from the logbook data with corresponding estimates from the NMFS shelf survey data partly verifies the validity of the logbook information, but in general the logbook data placed the species slightly deeper than the survey data. Possible reasons for differences in the species occurrence between the two data sources could be differences in the types of trawl and the tow duration. The surveys deployed a bottom trawl with roller gear and maintained standardized 0.5 hr tow durations, but the logbook data includes tows with sole trawls (no rollers) and tow durations of up to 8 hrs. Another reason could be due to differences in mesh size. The survey trawl is equipped with a cod-end liner with a relatively fine mesh size (3.2 cm), thus small fish are more vulnerable to the survey trawl than to the commercial trawls. Commercial sole trawls' legal minimum mesh size is 4.5 inches (11.43 cm) (PFMC 1996). Fox and Starr (1996) reported that the survey caught fish that were smaller than the estimated minimum market size. It is known that for some species younger fish occupy shallow water and move toward deeper water as they grow and become mature. It is therefore possible that the commercial fishery did not effectively catch the smaller sizes of fish in shallower water.

The pattern of species occurrence that was estimated from the logbook data over the full depth range (up to 560 fathoms) provides a different pattern of species distribution over depth, although the overall pattern for shallow and deep water species is still consistent with the pattern from the survey data. The species range estimated from the logbook data occur far deeper than the species estimated from the survey. Besides the shelf survey the NMFS conducts a slope survey with bottom trawl gear from 100 to 700 fathoms, but the trawl gear differs from that used in the shelf surveys and the slope surveys have been conducted infrequently (Amos et. al. 1995).

One of the major concerns in using logbook data was that there might be artificial sampling effects in the species associations because the data were collected by hundreds of different vessels. The comparisons between the DCA results for the stations-by-species data for individual years and the boats-by-species matrix constructed for 6 selected boats indicate that there is no serious artificial boat effect in the species association patterns derived from individual years. If there was a large boat effect, it seems very unlikely that the DCA species plots would be so consistent from year to year. This lack of a boat effect contradicts the results of Sampson (1997). He used the same logbook data sets that were used in this study, and found that the factor boat was the first or second most influential factor for 12 of 15 species in logistic regression models for presence-absence. Possible explanations for the different findings of the two studies could be that Sampson constructed models for each species one at a time, whereas I accounted for all the species simultaneously in the process of constructing the data matrices for the community pattern analyses. In other words, I treated species occurrence as a repeated and redundant measure that was collected by numerous different samplers. McCune et. al. (1997) experimented with the effect of having different levels of sampler groups (such as novice and expert) in large-scale lichen studies, and they concluded that community composition is effectively identified even if data on species richness contains substantial observer error. This result may also apply to the current study and account for the absence of a boat effect.

The screening criteria that were used in this study to exclude questionable data were chosen subjectively. Thus, it would be useful to conduct a comparative study of data matrices that were screened using different criteria in order to develop a more objective basis for screening logbook data.

Rogers and Pikitch (1992) identified six major assemblages of groundfish species off Washington and Oregon using commercial fishery data obtained from observer programs spanning 1985 to 1987. The main difference in the assemblages that were identified in my study versus their study was their finding of a midwater assemblage dominated by widow rockfish and a shrimp assemblage. This difference is due to fundamental differences in the underlying data. They used data sets collected by six fishing strategies, including ones that used midwater trawls and shrimp trawls. These gear types were not included in my study. Three assemblages were similar to the assemblages that were identified in my study, and the member species in each corresponding assemblage were also very similar. Having the benefit of better species resolution from observer data, they were able to identify a bottom rockfish assemblage which was unidentifiable in the logbook data. They could not, however, directly investigate the temporal variability of the assemblages because of the relatively short study period.

Based on NMFS bottom trawl survey data Jay (1996b) identified 23 species assemblages by using the 33 dominant species from the 6 surveys combined (1977-1992), and Gabriel (1982) identified 32 assemblages from the 1977 survey. Both studies showed that depth and latitude account for the variability in species assemblages, but neither study was able to straightforwardly relate temporal variables to the variability in species assemblages because of the limited temporal scale of the survey collections.

The Oregon coast has a relatively smooth and broad continental shelf with significant fresh water input to the north, and a relatively rough and narrow continental shelf with little fresh water input to the south. Oceanographic conditions on the Oregon-Washington shelf exhibit strong seasonal patterns, with winter and summer current regimes that are quite distinct. In winter there is little or no mean shear, the mean flow is northward at all depths, and the northward flow is strongest very near shore (Huyer et. al. 1979). In summer the mean surface current is southward, and there is a strong mean vertical shear such that deeper currents are always more northward than shallower currents. Surface and bottom temperature, salinity, upwelling, coastal sea level, and wind stress also show interannual variation over the continental shelf off Oregon (Huyer 1977). Therefore, it is natural to expect that temporal factors would influence the variability of species assemblages in the study area. However, in this study I found little evidence of seasonal or interannual variation in the species associations 15 commercial species. Some would argue that this result may be partly due to the type of data used in this study. If I had used data with more complete sets of species I would have obtained a better representation of the study area and the ecological interactions among the species. Also, if instead of using frequency of species occurrence, I had used CPUE or relative biomass as a species abundance estimator, which are commonly used for the assemblages studies based on survey data, the results might reveal strong temporal characteristics of species assemblages. However, several studies of demersal fish communities that used biomass or relative biomass estimated from trawl survey data also report persistence of species assemblages over time (Iglesias 1981; Overholtz and Tyler 1985; Wright 1989; Mahon and Smith 1989).

One of the drawbacks of using logbook data in a community study is the low level of species resolution and identification. Because logbooks contain only retained catches, it is inevitable that accurate catch information is only available for the valuable commercial species. For example, Pacific hake is one species that was not included in this study even though it is a major commercial species (PFMC 1996) and is widely distributed in the study area (Jay 1996b). This species is normally targeted by mid-water trawlers and forms a large catch in that fishery. In the bottom trawl fishery Pacific hake are considered a trash fish and are discarded at sea because of poor flesh quality. One of the conclusions from Jay (1996b) was that hake are a major player in the dynamics of groundfish communities off the US west coast and many of the assemblages defined in that study were dominated by this species. Other non-commercial species such as skate, spiny dogfish, and squid were also not included in this study. As there is no or small market demand for these species, it is unlikely that fishermen retain them or keep accurate records of their catches. Also, in the logbooks and fish tickets the diverse rockfish species were only categorized into two groups, small rockfish group and miscellaneous rockfish group. Thus, it was impossible to study interactions of the individual rockfish species and their role in defining assemblages.

In spite of the complicated nature of the logbook data, which were collected by the commercial fishery, this study shows encouraging results about investigating fish communities using logbook data. Logbooks are a very cost-effective way of obtaining information about fish populations that have been disturbed by human exploitation. Therefore, I recommend that the logbook program be continued, but with enhancements for collecting data about discarded as well as retained catches. Also, more detailed information about tow locations (e.g., ending position and depth) would allow researchers to investigate fish communities on a finer geographical scale so that even subtle environmental variations might be related to variations in the fish communities.

BIBLIOGRAPHY

Amos, D., Maguire, J., O'Boyle, R., Parma, A., Smith, A. (The west coast groundfish stock assessment review panel). 1995. The report of west coast groundfish assessment review to the Pacific fishery Management Council, Portland, OR.

Bianchi, G. 1991. Demersal assemblages of the continental shelf and slope edge between the gulf of Tehuantepec (Mexico) and the gulf of Papagayo (Costa Rica). Mar. Ecol. Prog. Ser. **73**: 121-140.

Bianchi 1992. Demersal assemblages of the continental shelf and upper slope of Angola. Mar. Ecol. Prog. Ser. **81**: 101-120.

Boesch, D.F. 1977. Application of Numerical Classification in Ecological Investigations of Water Pollution. Spec. scient. Rep. 77, U.S.E.P.A. Publ. 600/3-77033, 155 pp.

Clifford, H.T., and Stephenson, W.. 1975. An introduction to numerical classification. Academic Press, New York, NY. 229 pp.

Crone, P. R. 1995. Sampling design and statistical considerations for the commercial groundfish fishery of Oregon. Can. J. fish. Aquat. Sci. **52**: 716-732

Fox, D.S., and Starr, R.M. 1996. Comparison of commercial fishery and research catch data. Can. J. Fish. Aquat. Sci. **53**: 2681-2694.

Gabriel, W.L. 1982. Structure and dynamics of northeastern Pacific demersal fish assemblages. Ph.D. diss., Oregon State Univ., Corvallis, 298 pp.

Gabriel, W.L. and Tyler, A.V. 1980. Preliminary analysis of Pacific coast demersal fish assemblages. Mar. Fish. Rev. **42**(3-4): 83-88.

Gauch, H.G.Jr. 1982. Multivariate analysis in communmity ecology. Cambridge Univeristy Press, Cambridge. 298 pp.

Gauch, H.G.Jr., Whittaker, R.H., and Wentworth, T.R.. 1977. A comparative study of reciprocal averaging and other ordination techniques. J. Ecol. **65**: 157-174.

Gauch, H.G.Jr., and Whittaker, R.H. 1981. Hierarchical Classification of Community data. J. Ecol. **69**: 537-557.

Gunderson, D.R. 1993. Surveys of fisheries resources. John Wiley & Sons, Inc. 248 pp.

Gunderson, D.R., and T. M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. Mar. Fish. Rev **42**(3-4): 2-16.

Hewitt, G.R. 1980. Seasonal changes in English sole distribution: An analysis of the inshore trawl fishery off Oregon. M.S. Thesis. Oregon State University. 59 pp.

Hill, M.O. 1973. Reciprocal Averaging: an eigenvector methods of ordination. J. Ecol. **61**: 237-249.

Hill, M.O., and Gauch, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. Vegitatio **42**: 47-58.

Huyer, A. 1977. Seasonal variation in temperature, salinity, and density over the continental shelf off Oregon. Limnol. Oceanogr. **22**: 442-453.

Huyer, A., Sobey, J.C., and Smith R.L. 1979. The spring transition in currents over the Oregon continental shelf. J. Geophys. Res., **84**: 6995-7011

Inglesias, J. 1981. Spatial and temporal changes in the demersal fish community of the Ria de Arosa (NW spain). Mar. Biol. (Berl.) **65**:199-208.

Jay, C.V. 1996a. Spatial and temporal characteristics of bottom-trawl fish assemblages of the continental shelf and upper slope of the Pacific coast of the United States, 1977-1992. Ph.D. diss., Oregon State Univ., Corvallis, 168 pp.

Jay, C.V. 1996b. Distribution of bottom-trawl fish assemblages over the continental shelf and upper slope of the U.S. west coast, 1977-1992. Can. J. Fish. Aquat. Sci. **53**: 1203-1225.

Jensen, S. 1978. Influence of transformation of cover-abundance values on classification and ordination of lake vegetation. Vegetatio **48**:47-59.

Jongman, R.H.J., TerBraak, C.J.F., and Vantongeren, O.F.R.. 1987. Data analysis in community and landscape ecology.

Leland, H.V., Carter, J.L., and Fend, S.V. 1986. Use of detrended correspondence analysis to evaluate factors controlling spatial distribution of benthic insects. Hydrobiologia **132**: 113-126.

McCune, B., and Mefford, M.J. 1995. PC-ORD. Multivariate analysis of ecological data. MjM Software. Gleneden, Oregon.

McCune, B., Dey, J.P., Peck, J.E., Cassell, D., Heimen, K., Will-Wolf, S., and Neitlich, P.N. 1997. Repeatability of community data: speceis richness versus gradient scores in large-scale lichen studies. The Bryologist **100**(1): 40-46.

Muraski, S.A., and Finn, J.T. 1988. Biological bases for mixed-species fisheries: species co-distribution in relation to environmental and biotic variables. Can. J. Fish. Aquat. Sci. **45**: 1720-1735.

Noy-Meir, I., Walker, D., and Williams, W.T. 1975. Data transformations in ecological ordination. II. On the meaning of data standardization. J. Ecol. **63**:779-800.

Overholtz, W.J., and Tyler, A.V. 1985. Long-term responses of the demersal fish assemblages of Georges Bank. Fish. Bull. **83**: 507-520.

Pacific Fishery Management Council. 1993. Pacific coast groundfish plan: fishery management plan for the California, Oregon, and Washington groundfish fishery as amended through Amendment 7. Pacific Fishery Magement Council, Portland, Oregon.

Pacific Fishery Management Council. 1996. Status of the Pacific coast groundfish fishery through 1996 and recommended acceptable biological catches for 1997: stock assessment and fishery evaluation. Pacific Fishery Management Council, Portland, Oregon.

Peet, R.K., Knox, R.G., Case, J.S., and Allen, R.B.. 1988. Putting things in order: The advantages of DCA. Am. Naturalist, **131**: 924-934.

Pielou, E.C. 1977. Mathematical ecology, John Wiley & Sons, New york. 385 pp.

Pikitch, E.H. 1988. Objectives for biologically and technically interrelated fisheries. Chap. 5. Pages 107-136 *in* W. S. Wooster(ed.), Fisheries Science and Management: Objectives and Limitations. Springer-Verlag, New York.

Pikitch, E.K., Erickson, D.L., and Wallace, J.R. 1988. An evaluation of the effectiveness of trip limits as a management tool. U.S. Dept. Commerce, Natl. Mar. Fish. Serv., NWAFC Proc. Rep. 88-27. 33 pp.

Pimm, S.L., and Hyman, J.B. 1987. Ecological stability in the context of multispecies fisheries. Can. J. Fish. Aquat. Sci. **44**(S2): 84-94.

Rickey, M. H., and Lai, H-L. 1990. The deep water complex species mix in the Washington and Oregon trawl fishery. Wash. Dep. Fish. Tech. Rep. No. 111. 40 pp.

Rogers, J.B., and Pikitch, E.K. 1992. Numerical definition of groundfish assemblages caught off the coasts of Oregon and Washington using commercial fishing strategies. Can. J. Fish. Aquat. Sci. **49**: 2648-2656.

Romesburg, H.C. 1984. Cluster analysis for researchers. Life Time Learning Publications. 334 pp.

Sampson, D.B. 1996. Estimates of effective fishing effort for the US west coast groundfish trawl fishery. Final report to the National Oceanic and Atmospheric Administration, Saltonstall-Kennedy Program, Award No. NA46FD0397, 109 pp.

Sampson, D.B. 1997. Effective fishing effort in the Oregon groundfish trawl fishery. Final report to the Oregon Trawl Commission. 90 pp.

Sampson, D.B., Crone, P.R., and Saelens, M.R. 1997. Groundfish data collection in Oregon. p. 51-100. *In*: Sampson, D.B. and Crone, P.R. (ed.) Commercial fisheries data collection procedures for the U.S. Pacific coast groundfish. NOAA Tech. Memo. NMFS/NWFSC, 181 pp.

SAS Institute Inc. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute Inc., Cary, N.C. 1028 pp.

Sneath, P.H.A., and Sokal, R.R. 1973. Numerical taxonomy: the principles and practice of numerical classification. W. H. Freeman, Sanfransisco, Calif. 573 pp.

Sokal, R.R., and Rohlf, F.J. 1981. Biometry. W. H. Freeman & Co., New York. 859 pp.

Stanley R. D. 1992. Bootstrap calculation of catch-per-unit-effort variance from trawl logbooks: do fisheries generate enough observations for stock assessments? North American Journal of Fisheries Management **12**: 19-27.

Tabachnick, B.G., and Fidell, L.S. 1996. Using multivariate statistics (3rd edition). HarperCollins college publishers. 880 pp.

Tyler, A. V., Beals, E.L., and Smith, C.L. 1984. Analysis of logbooks for recurrent multi-species effort strategies. Int. North Pac. Fish. Comm. Bull. **42**: 39-46.

Tyler, A.V., Gabriel, W.L., and Overholtz, W.J. 1982. Adaptive management based on structure of northern continental shelves. *In* M. C. Mercer(editor), Multispecies approaches to fishery management advice, p. 149-156. Can. Spec. publ. Fish. Aquat. Sci. No 59, 169 pp.

Ward, J.H. 1963. Hierachical grouping to optimize an objective function. J. Amer. Stat. Assoc. **58**: 236-244.

Wartenberge,D., Ferson, S., and Rohlf, J.F. 1987. A crtique of DCA. Am. Naturalist, **129**: 434-448.

Weinberg, K.L. 1994. Rockfish assemblages of the middle shelf and upper slope off Oregon and Washington. Fish. Bull. **92**: 620-632.

Wright, J.M. 1989. Diel variation and seasonal consistency in the fish assemblage of the non-estuarine Sulaibikhat Bay, Kuwait. Marine Biology. **102**: 135-142.

APPENDICES

Appendix 1. Summary of trip limit regulations for each species from 1987 to 1993.

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish 1	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1987	1/1: 30000 lb / week. Only 1 landing per week of more than 3000 lb.	1/1: N of Coos Bay, 25000 lb / week, 50000 biweekly, or 12500 lb twice a week. Landings under 3000 lb unrestricted. S of Coos Bay, 40000 lb/trip	1/1: N of Coos Bay, 10000 lb / week, 20000 biweekly, or 5000 lb twice a week. Landings under 3000 lb unrestricted.	1/1: 5000 lb / trip of small fish.	1/1: Min of 5000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage.			
	5/3: Fishing week changed from Sunday through Saturday to Wednesday through Tuesday.	5/3: Fishing week changed from Sunday through Saturday to Wednesday through Tuesday.	5/3: Fishing week changed from Sunday through Saturday to Wednesday through Tuesday.	10/2: Max of 6000 lb or 20% of fish on board, including no more than 5000 lbs of small fish.				
	11/25: Fishery closed.		7/22: N of Coos Bay, 7500 lb/week, 15000 lb bi- weekly, or 3750 lb twice a week	10/22: Fishery closed.				

Appendix 1. *Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish 1	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1988	1/1: 30000 lb / week. Only 1 landing per week of more than 3000 lb. Landings under 3000 lb unrestricted.	1/1: N of Coos Bay, 25000 lb/week, 50000 bi-weekly, or 12500 lb twice a week. Landings under 3000 lb unrestricted. S of Coos Bay, 40000 lb/trip.	1/1: N of Coos Bay, 10000 lb / week, 20000 biweekly, or 5000 lb twice a week. Landings under 3000 lb unrestricted.	1/1: Max of 6000 lbs or 20% of fish on board. Only 2 landings / week over 1000 lb. Landings under 1000 lb unrestricted, regardless of percentage. Limit of 5000 lb/trip of small fish.	1/1: Min of 5000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage.			
	9/21: 3000 lb / trip		10/5: N of Coos Bay, 7500 lb / week. Bi- weekly and twice weekly options remain in effect (at reduced rates)	8/3: Only 1 landing / week, not to exceed 2000 lb, regardless of percentage.				
				10/5: Removed 1 landing / week restriction, but 2000 lb limit still in effect.				

Appendix1.*Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish 1	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1989	1/1: 30000 lb / week. Only 1 landing per week of more than 3000 lb. Landings under 3000 lb unrestricted.	1/1: N of Coos Bay, 25000 lb / week, 50000 biweekly, or 12500 lb twice a week. Landings under 3000 lb unrestricted. S of Coos Bay, 40000 lb/trip.	1/1: N of Coos Bay, 7500 lb / week, 15000 lb biweekly, or 3750 lb twice a week. Landings under 3000 lb unrestricted.	1/1: Max of 1000 lb/trip or 45% of deepwater complex. Limit of 5000 lb/trip of small fish.	1/1: Min of 5000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage.	4/26: defined as sablefish, Dover sole, arrowtooth flounder, and thornyheads. 1 landing/week over 4000 lb, not to exceed 30000 lb. Landings under 4000 lb unrestricted. Biweekly and twice weekly options available.		
	4/26: 10000 lb / week.		7/26: Max of 3000 lb/trip or 20% of Sebastes complex.	4/26: One landing per week with max of 1000 lb or 25% of deepwater complex. Limit of 5000 lb/landing of small fish. Biweekly and twice weekly options available.	7/26: Min of 2000 lb or 20% of fish on board. No restrictions on trip frequency. Landings under 1000 lb unrestricted, regardless of percentage.	10/4: Removed poundage and trip frequency limits.		
	10/11: 3000 lb/trip. No restriction on frequency of landings.			10/4: max of 1000 lb or 25% of deepwater complex.	12/13: Fishery closed in Columbia area.			

Appendix 1. *Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish [1]	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1990	1/1: 15000 lb / week, 25000 lb per two weeks. Landings under 3000 lb not restricted.	1/1: N of Coos Bay, 25000 lb / week, 50000 lb biweekly, or 12500 lb twice a week. Landings under 3000 lb unrestricted. S of Coos Bay, 40000 lb / trip.	1/1: N of Coos Bay, 7500 lb/week, 15000 lb biweekly, or 3750 lb twice a week. Landings under 3000 lb unrestricted.	1/1: One landing per week with max of 1000 lb or 25% of deepwater complex. Limit of 5000 lb/landing of small fish. Biweekly and twice weekly options available.	1/1: Min of 3000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage.	1/1: No restrictions.		
	12/12: Fishery closed.		7/25: N of Coos Bay, max of 3000 lb / week or 20% of Sebastes complex. Biweekly and twice weekly options remain in effect.	10/3: max of 1000 lb or 25% of deepwater complex.		10/3: 15000 lb/trip. Only 1 landing / week over 1000 lb. Biweekly and twice weekly options available.		

Appendix 1. *Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish [1]	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1991	1/1: 10000 lb / week, only 1 landing / week over 3000 lb, or 20000 lb biweekly with 1 landing in that 2 week period over 3000 lb. Landings under 3000 lb unrestricted.	1/1: N of Coos Bay, 25000 lb / week, 50000 lb biweekly, or 12500 lb twice a week. Landings under 3000 lb unrestricted. S of Coos Bay, 25000 lb / trip.	1/1: N of Coos Bay, 5000 lb/week, 10000 lb biweekly, or 3000 lb twice a week. Landings under 3000 lb unrestricted.	1/1: One landing per week with max of 1000 lb or 25% of deepwater complex. Limit of 5000 lb/landing of small fish. Biweekly and twice weekly options available.	1/1: Min of 3000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage.	1/1: 27500 lb/week. Only 1 landing / week over 4000 lb. Biweekly and twice weekly options available. Landings under 4000 lb unrestricted.	1/1: S of Coos Bay, 5000 lb/trip. No trip frequency restriction.	1/1: 7500 lb/week. Biweekly and twice weekly options available. Landings under 4000 lb unrestricted.
	9/25: 3000 lb / trip. No restriction on landing frequency.		4/24: N of Coos Bay, 5000 lb once per 2 weeks.					7/31: 12500 lb/week. Biweekly and twice weekly options available.

Appendix 1. *Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish [1]	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1992	1/1: 30000 lb cumulative per 4 week period. 8/12: 3000 lb / trip. No restriction on frequency of landings. 12/2: 30000 lb cumulative per 4 week period.	1/1: 50000 lb cumulative per 2 week period.	1/1: N of C. Lookout, 8000 lb cumulative per 2 week period. 7/29: N of Coos Bay, 6000 lb cumulative per 2 week period.	1/1: Max of 25% of deepwater complex or 1000 lb per landing. Limit of 5000 lb/landing of small fish.	1/1: Min of 3000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage	1/1: 55000 lb cumulative per 2 week period. 10/7: 50000 lb cumulative per 2 week period.	1/1: S of C. Mendocino, 10000 lb cumulative per 2 week period.	1/1: 25000 lb cumulative per 2 week period. 7/29: 20000 lb cumulative per 2 week period. 10/7: 15000 lb cumulative per 2 week period.

Appendix 1. *Continued.*

Year	Widow Rk.	Sebastes	Yellowtail Rk.	Sablefish [1]	Pac. Oc. Perch	Deepwater	Bocaccio	Thornyheads
1993	1/1: 30000 lb cumulative per 4 week period.	1/1: 50000 lb cumulative per 2 week period.	1/1: N of Coos Bay, 8000 lb cumulative per 2 week period.	1/1: Max of 25% of deepwater complex or 1000 lb per landing. Limit of 5000 lb/landing of small fish.	1/1: Min of 3000 lb or 20% of fish on board. Landings under 1000 lb unrestricted, regardless of percentage	1/1: 45000 lb cumulative per 2 week period.	1/1: S of C. Mendocino, 10000 lb cumulative per 2 week period.	1/1: 20000 lb cumulative per 2 week period.
	12/1: 3000 lb / trip. No restriction on frequency of landings.		4/21: N of Coos Bay, 6000 lb cumulative per 2 week period.	9/8: Max of 1000 lb per landing or 25% of deepwater complex, not to exceed 3000 lb per landing.		4/21: 60000 lb cumulative per 4 week period.	10/6: S of C. Mendocino, 15000 lb cumulative per 2 week period.	4/21: 35000 lb cumulative per 4 week period.
				12/1: 1000 lb / trip. One landing / wk.		12/1: 5000 lb / trip. One landing / wk.		

From Sampson (1996).

Appendix 2. Examples of database management algorithms that were used for data screening and preparation procedures.

```
/* FREQ_SP.PRG: creating stations-by-species data matrices. */

close databases
for MYEAR = 87 to 93
      store str(MYEAR,2) to MYY

*Boat screening procedure
*Drop off boats with less than 20 tows per year,
*,or with 0 vaild tow(okhail tow) for any species
*create file tmp1 with selected boats after screening procedure.

      close databases

      if file('tmp1.DBF')
            delete file TMP1.DBF
      endif

      select BOAT;
            from N_BOAT&MYY;
            where TOW >= 20;
            and N_ENG > 0;
            and N_PET > 0;
            and N_REX > 0;
            and N_DAB > 0;
            and N_LIN > 0;
            and N_COD > 0;
            and N_WID > 0;
            and N_SMR > 0;
            and N_MSR > 0;
            and N_YEL > 0;
            and N_POP > 0;
            and N_THO > 0;
            and N_SBL > 0;
            and N_DOV > 0;
            and N_ARR > 0;
            into table TMP1

*create tmp2 from oklim.dbf with selected boats.
      if file('tmp2.DBF')
            delete file TMP2.DBF
      endif

      select *;
            from OKLIM&MYY O, TMP1;
            where O.BOAT=TMP1.BOAT;
            into table TMP2

*Modification from N_OKHAIL.PRG.
*create a table of counting number of valid tows for each species per
*plot(area+time).


      if file('X_HAIL&MYY..DBF')
            delete file X_HAIL&MYY..DBF
      endif
```

Appendix 2. *Continued.*

```
    select &MYY as year,;
    alltrim(str(int(LAT4))+'/'+str(DEPTH40,3)+'/'+ltrim(substr(BIMONTH
    ,1))) as PLOT,;
        int(LAT4) as LAT1, DEPTH40, count(*) as N_TOW, BIMONTH,;
        sum(iif(ENG_OKHAIL,1,0)) as N_ENG,;
        sum(iif(PET_OKHAIL,1,0)) as N_PET,;
        sum(iif(REX_OKHAIL,1,0)) as N_REX,;
        sum(iif(DAB_OKHAIL,1,0)) as N_DAB,;
        sum(iif(LIN_OKHAIL,1,0)) as N_LIN,;
        sum(iif(COD_OKHAIL,1,0)) as N_COD,;
        sum(iif(WID_OKHAIL,1,0)) as N_WID,;
        sum(iif(SMR_OKHAIL,1,0)) as N_SMR,;
        sum(iif(MSR_OKHAIL,1,0)) as N_MSR,;
        sum(iif(YEL_OKHAIL,1,0)) as N_YEL,;
        sum(iif(POP_OKHAIL,1,0)) as N_POP,;
        sum(iif(THO_OKHAIL,1,0)) as N_THO,;
        sum(iif(SBL_OKHAIL,1,0)) as N_SBL,;
        sum(iif(DOV_OKHAIL,1,0)) as N_DOV,;
        sum(iif(ARR_OKHAIL,1,0)) as N_ARR;
        from TMP2, OKTRIP&MYY T;
        where TMP2.BOAT_A= T.BOAT and TMP2.RDATE=T.RDATE;
        and NET="S" and TOW_HRS<=8;    && tows with sole trawls,
        having count(*)>=20;           && tow duration <= 8 hrs,
        group by 2;                    && stations with >= 20 tows,
        order by BIMONTH;
        into table X_HAIL&MYY

*cross-tabulation of X_HAIL by depth and latitude.
*counting maximum number of valid tow in each station.

    select X_HAIL&MYY..LAT1, X_HAIL&MYY..DEPTH40, X_HAIL&MYY..N_TOW;
        from X_HAIL&MYY;
        where alltrim(X_HAIL&MYY..BIMONTH) = "1";
        group by X_HAIL&MYY..LAT1, X_HAIL&MYY..DEPTH40;
        order by X_HAIL&MYY..LAT1, X_HAIL&MYY..DEPTH40;
        into table sys(2015)
    do (_genxtab) with 'XAT_1_&MYY'


*calculating species frequency.
*species frequency = sum(no. of positive tows)/sum(no. of valid tows).

    if file('XP_RAT&MYY..DBF')
        delete file XP_RAT&MYY..DBF
    endif
    if file('tmp3.DBF')
        delete file TMP3.DBF
    endif

    close databases
    rename 'oktrip&myy' to FILE1

    select year,;
    alltrim(str(int(LAT4))+'/'+str(DEPTH40,3)+'/'+ltrim(substr(BIMONTH
    ,1))) as PLOT,;
    count(*) as N_TOW,;
```

Appendix 2. *Continued.*

```
    sum(iif(ENG>0,1,0))/sum(iif(ENG_OKHAIL,1,0)) as P_ENG,;
    sum(iif(PET>0,1,0))/sum(iif(PET_OKHAIL,1,0)) as P_PET,;
    sum(iif(REX>0,1,0))/sum(iif(REX_OKHAIL,1,0)) as P_REX,;
    sum(iif(DAB>0,1,0))/sum(iif(DAB_OKHAIL,1,0)) as P_DAB,;
    sum(iif(LIN>0,1,0))/sum(iif(LIN_OKHAIL,1,0)) as P_LIN,;
    sum(iif(COD>0,1,0))/sum(iif(COD_OKHAIL,1,0)) as P_COD,;
    sum(iif(WID>0,1,0))/sum(iif(WID_OKHAIL,1,0)) as P_WID,;
    sum(iif(SMR>0,1,0))/sum(iif(SMR_OKHAIL,1,0)) as P_SMR,;
    sum(iif(MSR>0,1,0))/sum(iif(MSR_OKHAIL,1,0)) as P_MSR,;
    sum(iif(YEL>0,1,0))/sum(iif(YEL_OKHAIL,1,0)) as P_YEL,;
    sum(iif(pop>0,1,0))/sum(iif(POP_OKHAIL,1,0)) as P_POP,;
    sum(iif(THO>0,1,0))/sum(iif(THO_OKHAIL,1,0)) as P_THO,;
    sum(iif(SBL>0,1,0))/sum(iif(SBL_OKHAIL,1,0)) as P_SBL,;
    sum(iif(DOV>0,1,0))/sum(iif(DOV_OKHAIL,1,0)) as P_DOV,;
    sum(iif(ARR>0,1,0))/sum(iif(ARR_OKHAIL,1,0)) as P_ARR;
    from TMP2 O, FILE1 T;
    where O.BOAT_A= T.BOAT and O.RDATE=T.RDATE;
    and NET="S" and TOW_HRS<=8;          && tows with sole trawls,
    having count(*)>=20;                 && tow duration <= 8 hrs,
    group by 2;                          && stations with >= 20 tows,
    order by BIMONTH;
    into table TMP3

    close databases
    rename 'file1.dbf' to OKTRIP&MYY..DBF
    rename 'TMP3.DBF' to FREQ_SP&MYY..DBF

endfor
```

Appendix 3. Maximum number of valid tows made in each station for all data matrices: individual years, all years combined, and boats-by-species.

1987

Jan / Feb — **Depth** (fathoms)

Latitude	40	80	120	160	200	240	280	320	360	400
42					38	28	24	28		
43		26			82	83	78	88	43	30
44		23				28				
45					63	53				
46		78			26					
47										
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400
42						22				
43	25	42	54	34	29	45	68	50		
44		23								
45										
46	205	109								
47										
48										

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42		38	60							
43	112	110	181	62						
44	48	35	33							
45										
46	312	198	48							
47	50									
48										

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42		102	47							
43	144	177	142	44						
44	82	92	26	59						
45	33	32	26							
46	411	387	46							
47		32								
48		24								

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42		110	68	20	25	26	29	33		
43	23	116	331	69	55	30	33	29	22	
44	91	128	73	54	34	44				
45		56	73	25	34					
46	194	398	102							
47		28	44							
48										

Appendix 3. *Continued.*

1988

Jan / Feb — Depth (fathoms)

Latitude	40	80	120	160	200	240	280	320	360	400
42	27	36	27		63	29	44	66	36	
43		50	42		98	111	133	134	76	38
44		44								
45			44		56	64	39	26	28	
46		80	24	22	28	26	36	28		
47			27							
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400
42			32				20			
43		30	75	44	71	55	52	71	42	
44		136	29							
45					35	32				
46	220	199	27					22		
47		25	21			25	21	39	24	
48								27		

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43	42	38	73	39	38					
44	55	77	62	69						
45		44	42	49		27				
46	201	231	79	21						
47	31	20	49							
48			40							

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42		20	63							
43		109	143	28						
44	38	109	43	23						
45	20	84	84							
46	444	276	131							
47	80	97	114							
48			26							

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42			28							
43	29	45	130	87	50	30				
44		323								
45		59	101	33						
46	173	226	101	32	27					
47		88	58							
48										

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42					31					
43					48	29	26	43		
44					42	93	88	47		
45							33	25		
46										
47										
48										

Appendix 3. *Continued.*

1989

Jan / Feb — **Depth** (fathoms)

Latitude	40	80	120	160	200	240	280	320	360	400
42					20					
43		77			46	32	21	31	28	
44		60								
45		20	43	31	74	100	59	66	35	
46		65			31	26		26		
47		48			21	47	35	40	25	
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		26	23				22	32		
44		22								
45			22		42	99	127	85	52	33
46	56	211				40	60	46	21	
47		48				30	22		30	
48						27	28	23	21	

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		45	75							
44	230	75	38	20						
45		20	59	28	39	144	77	41		
46	232	226	106	26	30	50	30			
47	162	63	85	20		28	20	23	48	
48	97	81	50	32	21	29				

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42			25							
43	93	78	172	84						
44	66	530	80	30	20					
45	76	150	163	49	41	111	44			
46	361	397	187	29	31	36				
47	22	107	154	21						
48	24	36	58							

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		46	160	38	22					
44	22	217	79							
45	110	74	137	58	77	90	60			
46	132	454	198	52	41	51	36			
47	35	88	88			34	20	46		
48		39								

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42					30					
43		22			36	33	33	33		
44		25								
45		27			72	128	122	59	24	
46		58	26	37	43	66	69	47	35	
47			25		24	31	37	42	29	
48										

Appendix 3. *Continued.*

1989

Depth (fathoms)

Jan / Feb

Latitude	40	80	120	160	200	240	280	320	360	400
42					20					
43		77			46	32	21	31	28	
44		60								
45		20	43	31	74	100	59	66	35	
46		65			31	26		26		
47		48			21	47	35	40	25	
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		26	23				22	32		
44		22								
45			22		42	99	127	85	52	33
46	56	211				40	60	46	21	
47		48				30	22		30	
48						27	28	23	21	

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		45	75							
44	230	75	38	20						
45		20	59	28	39	144	77	41		
46	232	226	106	26	30	50	30			
47	162	63	85	20		28	20	23	48	
48	97	81	50	32	21	29				

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42			25							
43	93	78	172	84						
44	66	530	80	30	20					
45	76	150	163	49	41	111	44			
46	361	397	187	29	31	36				
47	22	107	154	21						
48	24	36	58							

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		46	160	38	22					
44	22	217	79							
45	110	74	137	58	77	90	60			
46	132	454	198	52	41	51	36			
47	35	88	88			34	20	46		
48		39								

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42					30					
43		22			36	33	33	33		
44		25								
45		27			72	128	122	59	24	
46		58	26	37	43	66	69	47	35	
47			25		24	31	37	42	29	
48										

Appendix 3. *Continued.*

1990

Depth (fathoms)

Jan / Feb

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43			23		22	35	26	43		
44										
45					51	85	39	25		
46		68		25	35	52	51	38	25	
47		32	20		23	28	21	27	34	
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43			26					28		
44		36								
45		45		20	31	56	43	39	45	28
46	75	190				45	67	84	72	26
47		39			24	40	52	65	61	41
48						21	37	31		

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42			24							
43	34	59	45	24						
44	125	62	20							
45	49	38								
46	236	208	47	25		23				
47	46	28	40	24		40	32	57	34	
48		28								

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42			35							
43	118	122	112	40						
44	134	442	107	27	22					
45	47	53	86	46						
46	342	225	124	44	21	21				
47	21		66	26						
48		37								

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42			21							
43	21	54	127	63	34					
44	87	147	78	62	38					
45			81	28	26	24				
46	90	124	62	26	34	25	23			
47			40	21		22				
48		32	21							

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43								23		
44	25									
45					59	79	73	26		
46						20	24			
47						26	20			
48										

Appendix 3. *Continued.*

1991

Depth (fathoms)

Jan / Feb

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		53	46		38	38				
44		40								
45					40	128	93	52	35	
46		69			38	92	47	55	22	
47		64	31	32	32	65	57	44	53	
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400	440
42			25								
43		20	96					37			
44		59	45								
45											
46	180	77			21	44	43	80	35		
47		30	26	36	37	77	83	138	72	23	25
48						20	26	21			

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42			76	21						
43	139	91	178	62	21					
44	110	45	50							
45	32	42	105	48						
46	293	408	106	43	33	48	35	21		
47	148	49	111	71	75	70	59	34		
48		59	20	25						

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42			48							
43	253	127	159	46						
44	70	111	64							
45	33	23	90	20						
46	350	337	109	42	21	21				
47	87	57	126	44	20	22				
48	70	76	33							

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42									20	
43	51	108	145	47	20					
44	195	51	29	21	29					
45		22	120	23	45	61	34			
46	219	255	74	49	30	51	37	20		
47	72	131	68	55	45	38	37	24		
48	39	27	27	25						

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43					64	38				
44										
45					47	93	71	27		
46	51	31	28		30	56	35	27		
47						20		29		
48										

Appendix 3. *Continued.*

1992

Depth (fathoms)

Jan / Feb

Latitude	40	80	120	160	200	240	280	320	360	400
42					21					
43			31		21			26		
44										
45					26	57	35			
46		100		21	35	37	21	22	27	
47		25			26	28	43	38	21	
48										

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400	440
42											
43		51	86					41	28		
44		21									
45			26			42	34	40			
46	84	80	28				23	58	35		20
47		42	22		23	46	56	97	63	47	25
48						24	35	36	23		

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42			26							
43	90	68	121	67	23					
44	20	53	63	35	29					
45	38	41	62							
46	354	247	55	22						
47	28	34	95	35	32	43	29			
48	28	30	50	45	25					

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42			28							
43	133	68	50	46						
44	49	80	39							
45	31	79	58							
46	170	269	59	28						
47	123	64	95	38						
48	25	48	85	24	26					

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43	43	122	79	38	27					
44	43	72	40							
45	45	36	61							
46	172	136	48	29				21		
47		30	35		25	27			24	
48										

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		25			27	22	20			
44										
45					41	57	48			
46	23					35	23	32		
47						27		27		
48										

Appendix 3. *Continued.*

1993

Jan / Feb — **Depth** (fathoms)

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43			50		28	29	32	30		
44										
45					45	77	36	30		
46		80			25	34	22	31	32	
47		35		23	64	57	39	41	33	
48								20		

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400	440
42											
43		22	49				20	47			
44		23	40								
45											
46	173					22		29			
47					26	44	38	38	29		22
48						33	34	28			

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		33	125	93	45					
44	94	78	71	48						
45		54	70	45		46	28			
46	236	315	97	26				22	22	
47	27	249	53	31	26	46	24	30		
48			27	27	27	20				

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43	119	59	146	67	42					
44	161	103	91	33						
45	30	98	184	85	50	38				
46	148	240	178							
47	27	287	113	33	24		27			
48		31	23							

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400	440	480	520
42			20		29								
43	92	60	202	107	85	42	29	25					
44	235	112	105	78	47								
45		22	63	62	60	71	54						
46	255	166	97	31				32	21				33
47	100	27	46	22			21						
48		57	39										

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400
42										
43		32			45	24				
44		26								
45					56	56				
46	42				25					
47										
48										

Appendix 3. *Continued.*

All years combined

Depth (fathoms)

Jan / Feb

Latitude	40	80	120	160	200	240	280	320	360	400	440
42	27	36	27		142	57	68	94	36		
43		250	189		333	328	288	350	147	68	
44		167				28					
45		20	87	31	355	564	299	197	97		
46	65	532	24	67	212	259	176	198	106		
47		196	76	55	165	225	193	187	166		
48								20			

Mar / Apr

Latitude	40	80	120	160	200	240	280	320	360	400	440
42			57			22	20				
43	25	191	409	78	98	99	161	306	70		
44		319	114								
45		45	48	20	108	229	204	164	97	61	
46	993	862	55	0	20	148	192	311	161	26	20
47		158	69	35	109	262	271	375	276	109	72
48						125	160	165	44		

May / Jun

Latitude	40	80	120	160	200	240	280	320	360	400	440
42		38	135	21							
43	417	442	798	347	127						
44	682	421	337	172	29						
45	119	235	337	167	39	217	105	41			
46	1864	1754	523	158	62	121	65	42	22		
47	491	411	426	180	133	225	164	143	82		
48	95	198	187	129	73	49					

Jul / Aug

Latitude	40	80	120	160	200	240	280	320	360	400	440
42		122	246								
43	860	734	919	354	42						
44	600	1464	447	172	42						
45	270	501	676	195	91	149	44				
46	2225	1998	827	142	73	78					
47	356	621	666	162	44	22	27				
48	119	224	202	24	26						

Sep / Oct

Latitude	40	80	120	160	200	240	280	320	360	400	440	480	520
42		110	137	20	54	26	29	33	20				
43	259	551	1172	449	293	102	62	54	22				
44	673	1040	404	213	146	44							
45	110	268	622	227	240	245	148						
46	1234	1655	657	216	128	126	92	73	21				33
47	207	389	378	97	70	119	78	46	24				
48	39	145	87	25									

Nov / Dec

Latitude	40	80	120	160	200	240	280	320	360	400	440
42					61						
43		79			220	146	79	99			
44	25	51									
45		27			317	499	393	156	24		
46	116	81	54	37	96	170	181	130	35		
47			25		24	102	57	97	29		
48											

Appendix 3. *Continued.*

Boats-by-species

Latitude	Depth (fathoms) 40	80	120	160	200	240	280	320	360	400	440	480
42					34							
43		20	42		26			22				
44												
45			58	93	368	1100	828	461	210	78		22
46		830	474	223	267	432	337	333	248	67	68	
47		83	593	281	349	488	407	500	396	214	45	
48		196	251	168	167	118	142	95	31			