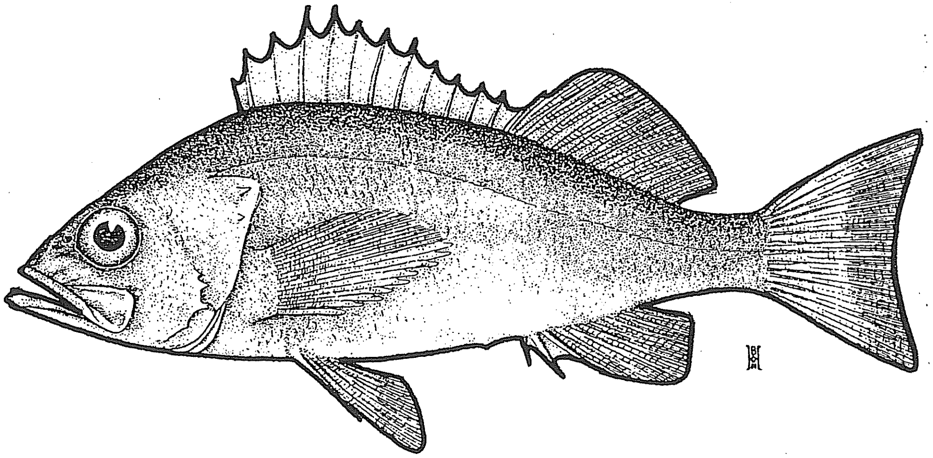
OCS STUDY
MMS 91-0052

FISH ASSEMBLAGES OF ROCKY BANKS OF THE PACIFIC NORTHWEST

Final Report

1991



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Pacific OCS Region

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OCS STUDY
MMS 91-0052

FISH ASSEMBLAGES OF ROCKY BANKS OF THE PACIFIC NORTHWEST

Final Report

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Pacific OCS Region
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Camarillo, California 93010

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KEY WORDS: Pacific northwest; Oregon OCS; Heceta Bank; Coquille Bank; Daisy Bank; submersible transects; community description; between-year comparisons; between-bank comparisons; fish assemblages; invertebrates; bottom types; multivariate analyses.

BACKGROUND: In anticipation of proposed leasing of Outer Continental Shelf (OCS) lands off Oregon and Washington (Sale 132), the Minerals Management Service (MMS) required data on fish assemblages of rocky banks in this region. These data would allow the MMS and the affected states to make environmental assessments about potential impacts that may result from oil and gas exploration and development. Informed decision-making requires detailed information on coastal marine resources so that potential environmental risks associated with minerals development may be evaluated.

OBJECTIVES: The general objective was to obtain information on the fish resources of OCS rocky banks of the Pacific northwest. The specific goal was to produce a database of fish densities and fish-habitat associations among years and banks for assessing the impacts of future offshore drilling and other mining activities.

The limits of that value would depend upon the temporal and spatial scales over which the database was relevant and representative. Therefore, beyond describing the fish assemblages and fish-habitat associations at each bank, the study focused on two major questions: (1) ***What was the extent of natural interannual variability in the distribution and abundance of demersal fishes at the largest OCS bank of the Pacific Northwest, Heceta Bank?*** The null hypothesis was that there was no temporal variation over the three-year period of the study. (2) ***How similar were the demersal fish assemblages at Heceta Bank to those at two other OCS rocky banks off Oregon, Coquille and Daisy Banks?*** The null hypothesis was that there was no difference among the banks in 1990, the year all three banks were sampled. Also of interest to the MMS was the pattern of movement of individual large rockfish on rocky banks of the OCS. Therefore, a secondary goal was to describe the diel movements of and homing by yellowtail rockfish at Heceta Bank.

DESCRIPTION: Each September from 1988 to 1990, the manned submersible *Delta* ran visual belt transects at fixed predetermined stations (6 at Heceta Bank, 8 at Coquille Bank, and 3 at Daisy Bank). Heceta Bank was sampled all three years, whereas the other two banks were sampled only in 1990. Two or three replicate one-hour transects were run at each station (except 4 exploratory stations at Coquille Bank), during which fish densities (by species and size class), macroinvertebrate densities, and bottom type were quantified. These data were analyzed by multivariate and univariate techniques both to describe associations of bottom type, invertebrates, and fishes at each bank, and to test our null hypotheses concerning between-year constancy at Heceta Bank from 1988 to 1990 and between-bank similarity in 1990. Ultrasonic telemetry and fish translocation experiments were used to determine the movements of yellowtail rockfish at Heceta Bank.

SIGNIFICANT CONCLUSIONS: Both null hypotheses were rejected. (1) Despite overall constancy in bottom types and invertebrate assemblages sampled at Heceta Bank from 1988 to 1990, the densities of eight abundant fish taxa (pygmy, sharpchin, rosethorn, yellowtail, and juvenile rockfishes, lingcod, shortspine thornyhead, and sablefish) varied substantially between years. These data provided an estimate of natural interannual variation in the densities of these fishes. (2) Differences in fish assemblages among the three banks in 1990 was even more substantial than interannual variation at Heceta Bank. Two common species were not found at all banks: yellowtail rockfish (observed only at Heceta Bank, but reported by fishermen to occur during the winter at Coquille Bank), and sablefish (not observed at Daisy Bank, probably because little mud was encountered there). Most other dominant species varied among banks in both abundance and body length. These results indicate that each of these banks comprises a unique system that should be managed as a separate entity.

The shallow, rocky portions of all three banks were nursery habitats for juvenile rockfishes, which may be crucial for replenishing these commercially valuable species. Yellowtail rockfish at Heceta Bank demonstrated strong site fidelity and homing.

STUDY RESULTS: During 42 transects at Heceta Bank from 1988 to 1990, 69 taxa of fishes (24 families) and 90 taxa of invertebrates (9 phyla) were observed. In general, Heceta Bank is characterized by three major habitats: (1) *Shallow Ridge-Boulder Habitat* (<100 m [330 ft] depth): The dominant invertebrates are vase-sponges and basketstars, and the dominant fishes are yellowtail rockfishes, lingcod, and juvenile rockfishes (0-1 dm [0-4 in] total length size class). (2) *Mid-Depth Boulder-Cobble Habitat*: The dominant invertebrates are demosponges and brittlestars, and the dominant fishes are sharpchin, pygmy, greenstripe, and rosethorn rockfishes, as well as sculpins. (3) *Deep Mud Habitat* (>150 m [495 ft] depth): The dominant invertebrates are urchins and sea cucumbers, and the dominant fishes are various flatfishes, poachers, eelpouts, shortspine thornyhead, and sablefish.

During 8 transects at Coquille Bank in 1990, 55 taxa of fishes and 64 taxa of invertebrates were observed. Coquille Bank lacked the shallow rock-ridge habitat, but the other two habitats were dominated by the same fishes as at Heceta Bank. In general, soft-bottom species were more abundant at Coquille than at the other two banks, perhaps because most of the bottom at Coquille was covered by a thin layer of silt, probably as a result of its proximity to coastal runoff.

During 6 transects at Daisy Bank in 1990, 40 taxa of fishes and 25 taxa of invertebrates were observed. Daisy Bank comprised mostly boulder-cobble habitat, which was dominated by the same species as at Heceta Bank, in addition to the species found on rock ridges at Heceta (except yellowtail rockfish). Rosethorn rockfish, juvenile rockfish, and lingcod reached their highest densities among banks in this habitat. Little mud occurred at the depths sampled at Daisy Bank, so the abundance of mud-bottom fishes was low.

STUDY PRODUCTS:

Pearcy, W.G., D.L. Stein, M.A. Hixon, E.K. Pikitch, W.H. Barss, and R.M. Starr. 1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. *U.S. Fishery Bulletin* 87: 955-965.

Hixon, M.A., B.N. Tissot and W.G. Pearcy. 1991. Fish Assemblages of Rocky Banks of the Pacific Northwest. A final report by the Department of Zoology and College of Oceanography of Oregon State University for the U.S. Department of the Interior, Minerals Management Service Pacific OCS Office, Camarillo, CA. Contract No. 14-12-0001-30445.

ACCESS NUMBER: **30445**

Stein, D.L., B.N. Tissot, M.A. Hixon, and W. Barss. In press. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. *U.S. Fishery Bulletin*.

Note: The three major chapters of the final report will each be submitted for publication, and several additional manuscripts are in preparation.

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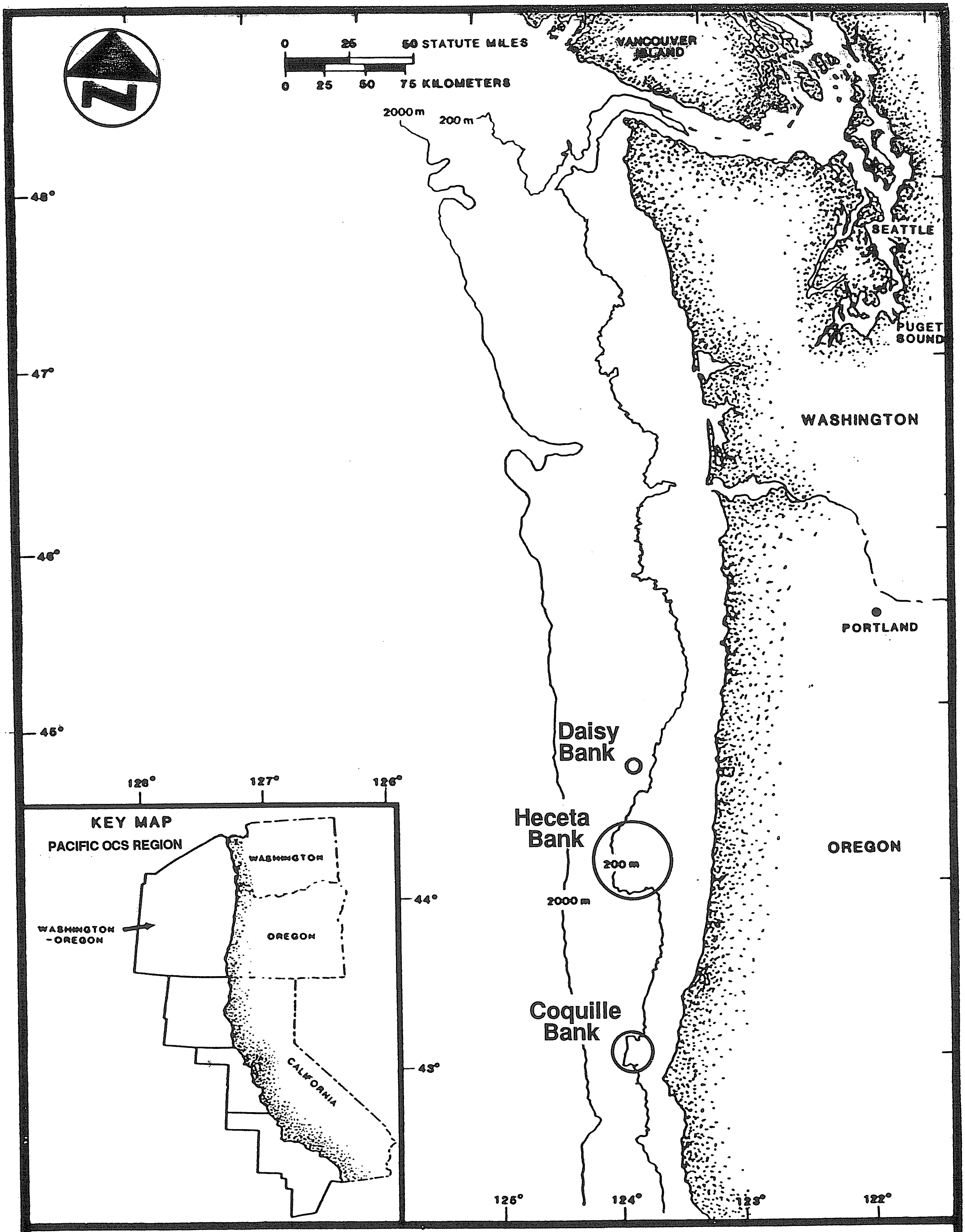
* P.I.'s affiliation may be different than listed for the Project Managers.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VANCOUVER ISLAND
2000 m
200 m
SEATTLE
PUGET SOUND
WASHINGTON
PORTLAND
OREGON
48°
47°
46°
45°
44°
43°
Daisy Bank
Heceta Bank
200 m
2000 m
Coquille Bank
125°
124°
123°
122°
128°
127°
126°
KEY MAP
PACIFIC OCS REGION
WASHINGTON
OREGON
WASHINGTON -OREGON
CALIFORNIA

FISH ASSEMBLAGES OF ROCKY BANKS OF THE PACIFIC NORTHWEST

Final Report

MMS
U.S. Department of the Interior
Minerals Management Service
Pacific OCS Region

PREFACE

This preface outlines the format of this final report, section by section, and lists our acknowledgments.

Chapter 1 has three parts. First, we briefly characterize the ichthyofauna of rocky banks of the Pacific Northwest. Second, we provide a background summarizing previous studies of the ecology of demersal fishes inhabiting rocky banks of the Oregon outer continental shelf. Third, we present the specific goals and hypotheses of our study.

Chapter 2 describes our general methods for Chapters 3 and 4. We describe our study sites, submersible transects, and data analyses. We provide a brief introduction to canonical correlation analysis, a powerful multivariate technique we used to extract patterns from our database.

Chapter 3 describes the associations of bottom types, visually dominant invertebrates, and demersal fishes at Heceta Bank. We examine the extent of interannual variation in these assemblages from 1988 to 1990.

Chapter 4 describes the associations of bottom types, invertebrates, and demersal fishes at Heceta, Coquille, and Daisy Banks in 1990. We examine similarities and differences in these assemblages among banks.

Chapter 5 describes our study of diel movements and homing in yellowtail rockfish at Heceta Bank, using acoustical tags.

The appendices provide detailed summaries of our data, above and beyond our separately bound raw data report. Appendix I, in particular, lists the common and scientific names of all fish and invertebrate taxa discussed in this report.

Acknowledgments

We thank NOAA's National Undersea Research Program for providing the submersible and support ship over the three years of this study. We are grateful to the 1988-1990 crews of the *R/V McGaw*, who were always very helpful and hospitable, and to the personnel from Delta Oceanographics, who maintained and piloted the *DSV Delta*. We thank J. P. Fisher, R. Albright, and the Captain of the *F/V Corsair*, W. Dixon, and his crew for conducting the yellowtail tracking at sea, and J. P. Fisher for his help with analyses of the yellowtail data. We are grateful to J. P. Fisher and A. Schoener for reviewing Chapter 5, and W. H. Barss for reviewing the entire report. A. Ebeling kindly provided the microgasometer to determine the composition of gas escaping from decompressed yellowtail rockfish. Sue Benech was a cooperative and efficient subcontractor for our invertebrate analyses, and Malin Masreliez provided accurate data entry and able assistance. Greg White produced excellent maps (Figs. II-1 and II-2), and Rich Gorecki drew superb illustrations of things he never saw (Fig. II-3). Ultimately, we thank the personnel at the MMS Pacific OCS Office, especially Gary Brewer, Marty Golden, and Frank Manago, for their excellent assistance and support throughout this contract. (The fish illustrated on the front cover is a yellowtail rockfish [*Sebastes flavidus*] drawn by D. R. Harriott for: Hart, J. L. 1973. *Pacific Fishes of Canada*. Fisheries Research Board of Canada, Bulletin 180.)

TABLE OF CONTENTS

LIST OF TABLES

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

LIST OF FIGURES

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 5:

Chapter 1

INTRODUCTION

The goals of this chapter are threefold. First, we briefly characterize the ichthyofauna of rocky banks of the Pacific Northwest. Second, we provide a background summarizing previous studies of the ecology of demersal fishes inhabiting rocky banks of the Oregon outer continental shelf (OCS). Third, we present the specific goals and hypotheses of our study.

Ichthyofauna of Pacific Northwest Rocky Banks

The OCS banks of the Pacific northwest of the United States lie within the cold-temperate Oregon Faunal Province of Briggs (1974). The marine ichthyofauna inhabiting these rocky habitats are dominated by the Order Scorpaeniformes (scorpionfishes and relatives). The most speciose and numerically dominant family is the commercially valuable Scorpaenidae, which includes some 60 species of rockfishes, genus *Sebastes* (Hubbs et al. 1979). Other scorpaeniform families with important food fishes are the Hexagrammidae (greenlings), including the lingcod, and the Anoplopomatidae (sablefishes). The second most speciose family in this order is the Cottidae (sculpins), yet these fishes are small, cryptic, and commercially unimportant. Also speciose yet unimportant as food fishes are the Agonidae (poachers) and the Liparididae (snailfishes).

The second most speciose order inhabiting OCS banks in this region, especially over soft bottoms, are the Pleuronectiformes (flatfishes). This commercially valuable group is dominated by the mostly right-eyed Family Pleuronectidae (including soles, turbots, and halibuts) and the left-eyed Family Bothidae (including sanddabs and soles).

Other commercially valuable fishes occur off the bottom over rocky banks, including the pelagic anadromous salmon (Order Salmoniformes, Family Salmonidae) and midwater Pacific hake (Order Gadiformes, Family Merlucciidae).

Dominance of this region by two largely cold-temperate orders (Scorpaeniformes and Pleuronectiformes) stands in contrast to the ichthyofauna of southern California. Inhabiting the warm-temperate region south of Point Conception, the southern California ichthyofauna shows greater representation of perciform fishes, especially in shallower areas (Hubbs 1948; Horn and Allen 1978).

Previous Studies

Outer Continental Shelf: Prominent offshore banks of exposed bedrock, formed by subduction of oceanic plates, occur along the continental shelf of Oregon (Kulm and Fowler 1974). The largest of these reefs, Heceta and Coquille Banks, are major commercial fishery areas, comprising part of the "California Current large marine ecosystem" (Sherman 1988). There is: (1) a demersal trawl fishery for many species of flatfishes, rockfishes, and sablefish; (2) a midwater trawl fishery for rockfishes and Pacific hake; (3) a long-line fishery for rockfishes, sablefish, and Pacific halibut; (4) a vertical long-line fishery for rockfishes; and (5) during upwelling, a troll fishery for salmon.

Before our study, very little was known about the distribution and abundance of fishes inhabiting these rocky banks. Although soft-bottom areas in the region were relatively well-sampled (reviews by Alton 1972; Gabriel and Tyler 1980), surface based sampling gear was ineffective in high-relief habitats. Previous surface-based sampling at Heceta Bank relied on bottom trawls equipped with roller gear, which were limited to relatively low-relief areas (Gunderson and Sample 1980; Barss et al. 1982; Dark et al. 1983; Broeder and Pearcy 1984; Weinberg et al. 1984). For example, after using echograms to categorize bottom topography as either "rough" or "smooth," Barss et al. (1982) separately analyzed trawl catches on both bottom types. The densest concentrations of both yellowtail and canary rockfish were obtained over rough bottom. The "rough" terrain in that study was still trawlable, and thus the range of terrain types sampled did not include high-relief rocky areas. Note that trawls with roller gear are also widely employed by fishing vessels that operate within the region, these trawlers also avoiding areas of high relief.

Not until our first submersible dives in 1987 were the fish assemblages of Heceta Bank adequately characterized (Pearcy et al. 1989). Funded by NOAA's National Undersea Research Program, and using the submersible *Mermaid II*, we conducted 16 dives on 23-31 August at depths ranging from 64 to 305 m (210 to 1000 ft). We encountered a wide variety of bottom types, ranging from soft mud to cobble to boulders to solid rock walls and pinnacles.

During our 1987 dives, we observed 42 taxa of fish, 31 of which we identified to species. Rockfishes (12 species) were by far the most speciose and abundant group. We observed dense schools of juvenile rockfishes and large yellowtail rockfish mostly over high-relief areas near the top of the bank, and the highest densities of small benthic rockfishes (up to 5-10/m^2) on the flanks of the bank. These observations suggested that shallow, rocky portions of Heceta Bank are nursery areas for juvenile rockfishes.

Two species groups of nonschooling fishes were identified based on transects over the diverse seafloor habitats around the bank: one comprised primarily of rockfishes in shallow water on rock and cobble, and the other comprised of flatfishes, poachers, sablefish, and some rockfishes in deep water over mud and cobble. Species composition of fishes observed from the submersible differed from the species composition of fishes taken from trawl catches in the same general areas.

Inner Continental Shelf: Nearshore reef areas in the Pacific Northwest are the focus of an intense recreational fishery. From 1980 through 1986, an estimated 900,000 angler trips, primarily for rockfish, annually occurred in Oregon (Butler 1990). About 30,000 of those angler trips per year were targeted on nearshore reefs. From 1984-1989, bottom fish angler trips in Washington steadily increased, averaging over 30,000 angler trips during the period (Washington Department of Fisheries 1990). As salmon stocks have declined, salmonid fishing seasons have been shortened, and more emphasis has been placed on the recreational harvest of rockfish (Barss and Demory 1989).

Because of the greater fishery activity closer to shore, more extensive surface-based studies of fish assemblages have been conducted inshore than on the outer continental shelf.

Barker (1974) tested the relative efficiency of troll, jig, gill net, and longline gear, and his catches provided some of the first estimates of species and size composition of Oregon's nearshore reef fishes. In a longer term study, Steiner (1978), Coombs (1979), McClure (1982), and DeMott (1982) fished with hook and line in an effort to evaluate how a recreational fishery affected species and size composition of inshore reef fishes. They found rockfishes in general, and black rockfish in particular, to be the most abundant fishes caught.

Such attempts to characterize reef-fish assemblages were somewhat successful, but Coombs (1979) noted different species composition between research catches and the recreational fishery. She attributed the differences in catches to differences in the selectivity of the gear used. Charter fishing vessels used live bait, while researchers used jigs. Gear selectivity always influences species composition determined from catch data, and this fact was one of our major justifications for using direct observations from a submersible.

Boettner and Burton (1990) recently completed an extensive acoustic study of shallow water areas in Washington in an attempt to estimate the abundance of schooling rockfish. They chose side-scan sonar to map the distribution of rock pinnacles in nearshore Washington waters, then used echointegration techniques to estimate schooling fish biomass in the water column near reefs. To date, however, they have not had *in situ* target strength measurements to use for calibrating the echointegrator output, so they do not know the acoustic signature of insonified targets. They planned to collect dual beam target strength data, and selected appropriate hardware, but had equipment problems. Without the *in situ* target strength measurements or extensive biological sampling, they cannot determine what proportion of the targets insonified are actually rockfish. Boettner and Burton (1990) also reported mixed success using a mid-water trawl net to verify that the acoustic targets were indeed rockfish.

Tagging studies conducted off Oregon have been designed to look at broad scale movements, and provide little information about how fish use specific reef habitats. The fish tagged by Steiner (1978), Coombs (1979), McClure (1982), and DeMott (1982) provided the first information about broad scale fish movements to and from reefs. The few tags recovered showed that most fish stayed near where they were tagged. Demott (1982) noted that the relatively low percentage of tag returns prevented them from obtaining relative abundance estimates. He cited poor tag retention as a reason for an unexpectedly low percentage of tag returns.

In 1977 and 1978, the Oregon Department of Fish and Wildlife (ODFW) tagged lingcod on Stonewall Bank and at a nearshore reef to determine if lingcod migrate between inshore and offshore reef areas (Barss and Demory 1989). The study was designed to document movements, but not relative abundance. More recently, the ODFW and the Washington Department of Fisheries (WDF) have tagged rockfish to collect information for black rockfish stock assessments. These studies are providing more information about rockfish populations on reefs. In 1985 and 1988, ODFW tagged black rockfish off Newport and Tillamook (Butler 1990). Angler creel surveys in both areas have provided information on species composition of the catch by major reef complex. However, the tagging studies have not been able to estimate fish densities on any specific reef. WDF has had a similar ongoing tagging project for black rockfish (Washington Department of Fisheries 1990). The ODFW and WDF work to date has indicated that some rockfish in Oregon and Washington have "home" reefs. These data are consistent with the observed territoriality (e.g., Larson 1980a) and limited movements (e.g., Love 1980) of rockfishes off California.

Goals and Hypotheses

Given our statement of work and the general lack of previous information on the demersal fish assemblages inhabiting rocky banks of the outer continental shelf of the Pacific Northwest, ours was a descriptive study of fish distribution and abundance. Our contracted goal was to produce a database that would be valuable for before-and-after comparisons determining the impacts of offshore drilling and other mining activities (MMS 1986). The limits of that value would depend upon the temporal and spatial scales over which our data were relevant and representative. Therefore, beyond describing the fish assemblages at each bank, our study focused on three questions:

(1) ***What is the extent of natural interannual variability in the distribution and abundance of demersal fishes at the largest OCS bank of the Pacific Northwest, Heceta Bank?*** Our null hypothesis was that there was no temporal variation over the three-year period of our study. The more constant the fish assemblages were through time (i.e., the less we were able to falsify this null

hypothesis), the greater the confidence one would have in attributing cause and effect to future changes in these assemblages following human activities. If, on the other hand, fish distributions and abundances naturally varied substantially and erratically from year to year, then it would be difficult to attribute any future changes to human impacts. The critical untestable assumption here is that the period of 1988-1990 was representative of all subsequent years in terms of natural variation within a bank.

(2) ***How similar are the demersal fish assemblages at Heceta Bank to those at two other OCS rocky banks off Oregon, Coquille and Daisy Banks?*** Our null hypothesis was that there was no difference among the banks in 1990, the year we sampled all three banks. The more uniform the fish assemblages were through space (i.e., the less we were able to falsify this null hypothesis), the greater the probability would be that our database was an adequate description all rocky banks in the region. If, on the other hand, fish distributions and abundances varied substantially from bank to bank, then it would be difficult to extrapolate our findings between banks. The critical untestable assumption here is that 1990 was representative of all subsequent years in terms of variation among banks.

(3) ***What is the pattern of movement of individual large rockfish on rocky banks of the OCS?*** Using acoustic tags, we studied the diel movements and homing by yellowtail rockfish (*Sebastes flavidus*) at Heceta Bank.

Chapter 2

GENERAL METHODS

Our basic approach was to use manned submersibles to run replicated visual belt transects at fixed predetermined stations, simultaneously quantifying densities of demersal fishes by species and size class, macroinvertebrate densities, and bottom type. These data were analyzed by multivariate and univariate techniques both to describe the fish communities at the three banks and to test our null hypotheses concerning between-year constancy at Heceta Bank from 1988 to 1990 (Chapter 3) and between-bank similarity in 1990 (Chapter 4).

Study Period

All submersible dives were restricted to September of each year (1988-1990, Table II-1, Appendix 2), which precluded seasonal comparisons. This restriction was due to a variety of constraints, the most important of which was weather. Except on rare occasions, manned submersible operations off Oregon are possible only during the late summer. We also faced the usual constraints of funding and submersible/ship scheduling.

Study Areas

Our study sites were the three major rocky banks on the outer continental shelf of the Pacific Northwest: Daisy, Heceta, and Coquille Banks (Fig. II-1). Other large rocky features in this region include Stonewall Bank, situated at the center of the continental shelf (Fig. II-1), and Rogue River Reef, located about 19 km (10 n mi) off Gold Beach, Oregon, and extending

Table II-1. Sampling effort among the three banks, 1988-1990.

Bank	Sampling stations	Year	Dives per station
Heceta Bank	6	1988	3
	6	1989	2
	6	1990	2
Coquille Bank	4*	1990	2
Daisy Bank	3	1990	2

* Stations 5-8 (Stations 1-4 were exploratory: 1 dive each).

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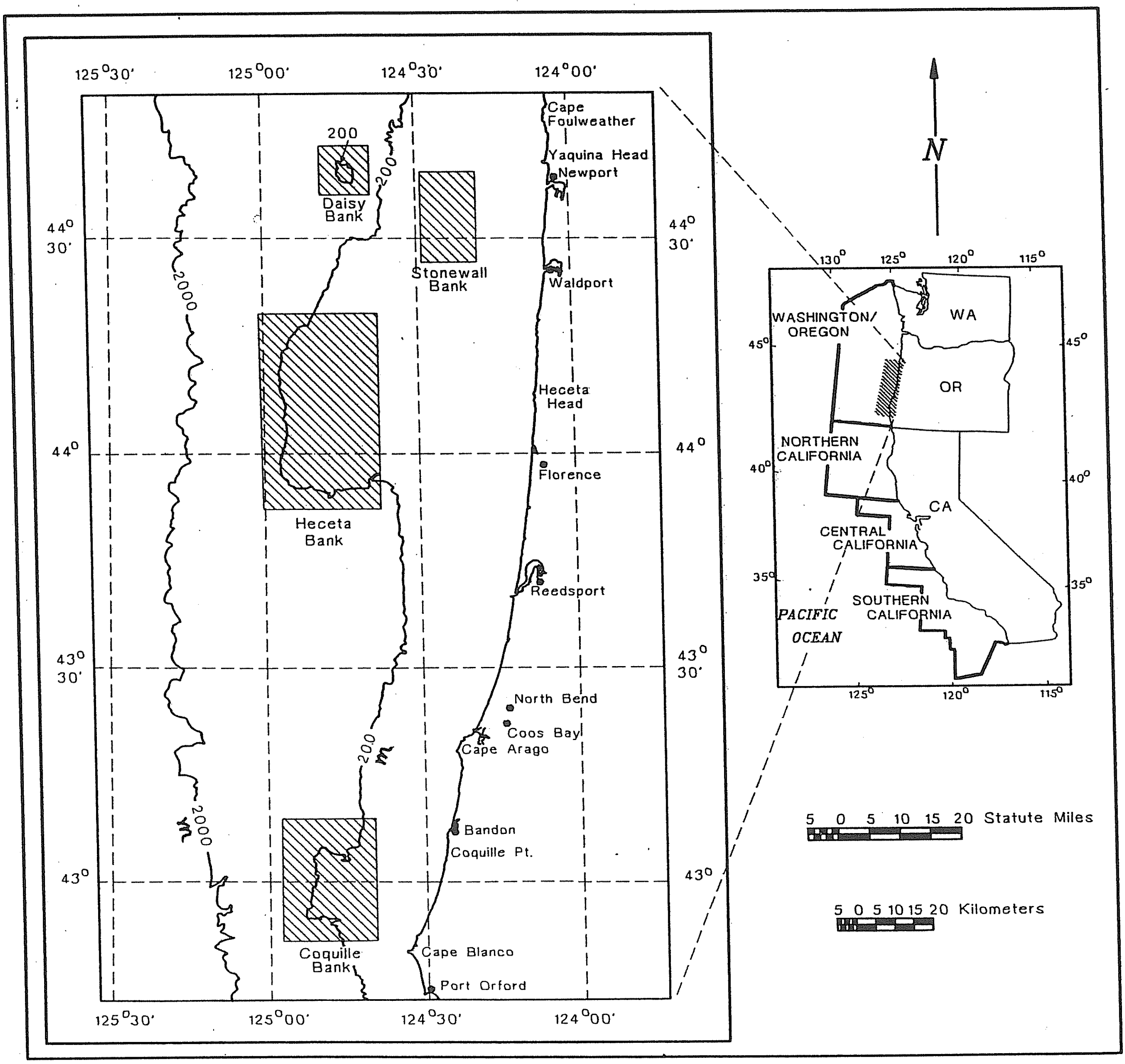
Figure II-1. Locations of the study banks off the Oregon coast in relation to the MMS Pacific OCS Planning Areas. See Figure II-2 for detailed maps of each bank within each hatched area.


125°30'
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124°30'
124°00'
44° 30'
44°
43° 30'
43°
200
2000
Daisy Bank
Stonewall Bank
Heceta Bank
Coquille Bank
Cape Foulweather
Yaquina Head
Newport
Waldport
Heceta Head
Florence
Reedsport
North Bend
Coos Bay
Cape Arago
Bandon
Coquille Pt.
Cape Blanco
Port Orford
N
130°
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WA
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within about 100 m (330 ft) of the surface. We will sample Stonewall Bank during the Fall of 1991 on a no-cost extension of this contract. Nehalem Bank and other "banks" in the region are largely comprised of mud.

Daisy, Heceta, and Coquille Banks are all sufficiently deep that they support very few algae--the benthos is dominated by various macroinvertebrates.

Daisy Bank is a cone-shaped, inactive, submarine volcano lying beyond the 200-meter (660-foot) continental-margin depth contour (Fig. II-2). Its steep flanks are dominated by boulders fading into cobble and mud (Fig. II-3). The flattened caldera, projecting within about 125 m (410 ft) of the surface, is comprised mostly of various-sized boulders overlying smooth lava flows.

Our 1990 transects at Daisy Bank were from 3 stations: one across the caldera, one up the northwest slope, and one up the southwest slope (Fig. II-2).

Heceta Bank is the largest rocky reef of the Pacific Northwest, comprising the southwest corner of a region of outcrops extending toward Stonewall Bank (Fig. II-2). Heceta is a large basaltic outcrop characterized by a tremendous variety of bottom types (Fig. II-3). In a typical transect from the shallowest parts of the bank (about 50 m [165 ft] deep) seaward (westward), we encountered diagonally stacked ridges separated by sand, pebble, and cobble-filled depressions, a narrow band of precipitous pinnacles on the edge of the bank, and large boulders on the seaward slope, which gradually faded to cobble and finally mud.

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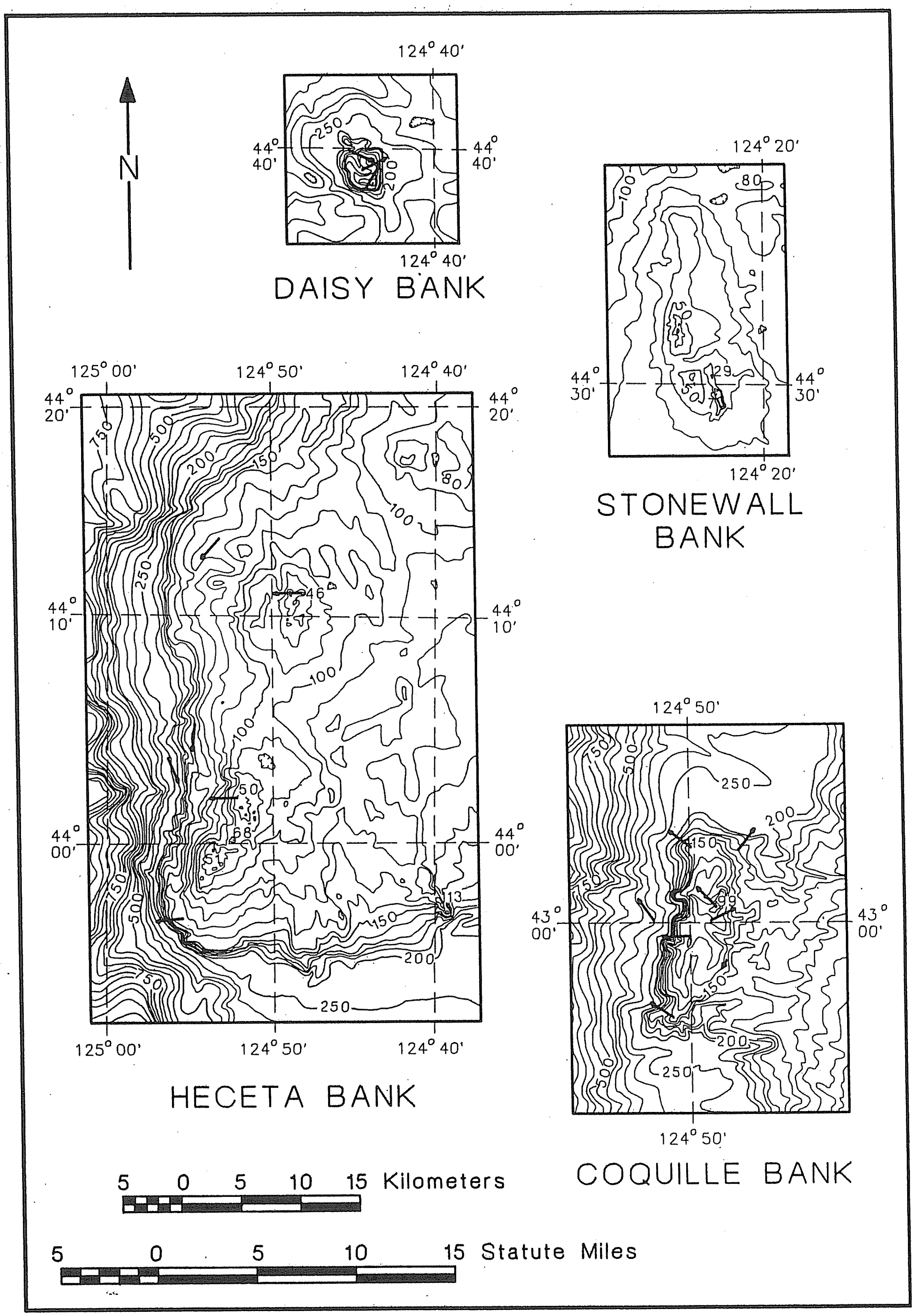
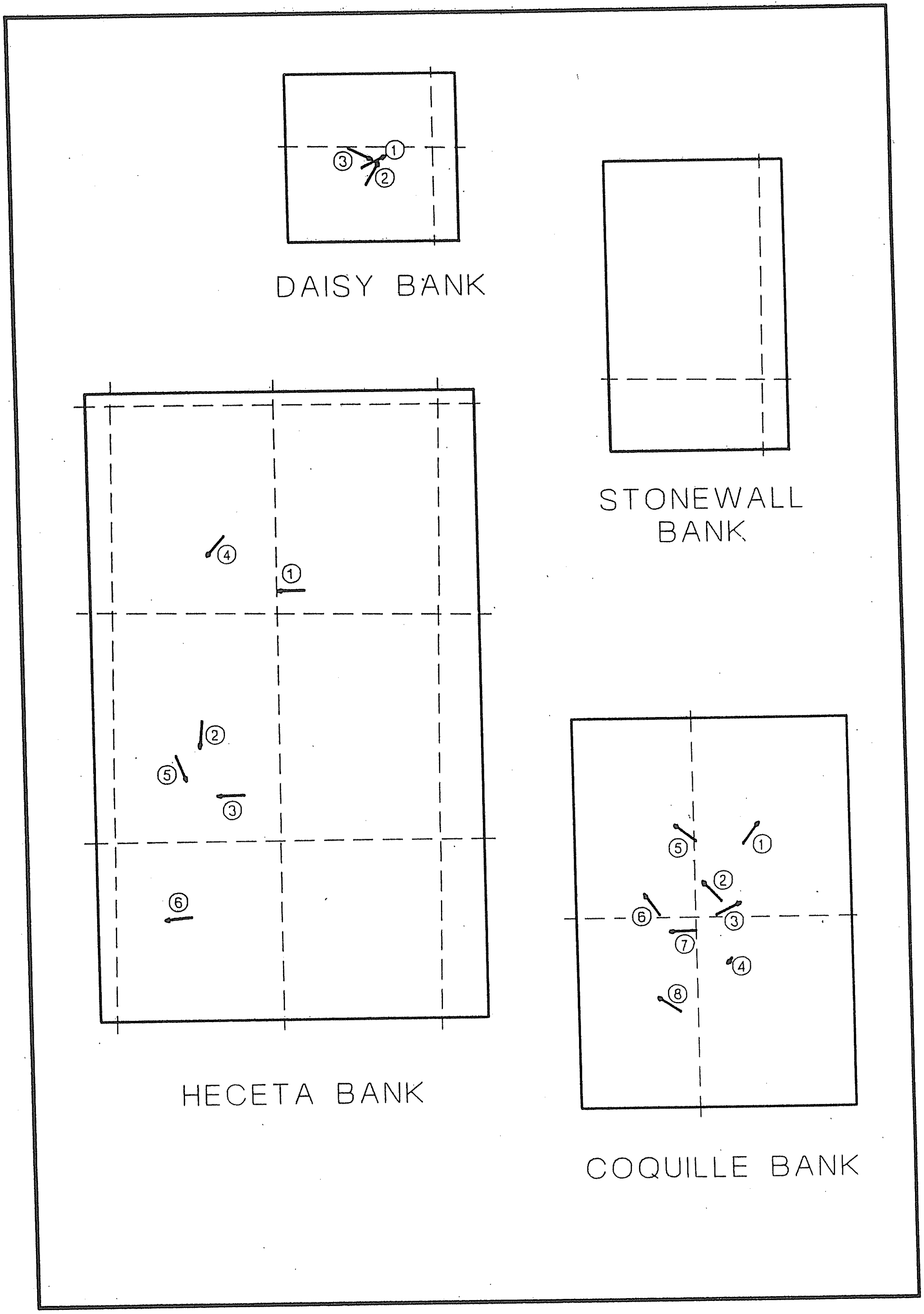
Figure II-2. Bathymetric charts of the study banks in relation to the average transect paths at submersible sampling stations (see Appendix 4), which are identified by numbers on the accompanying template. Stonewall Bank will be sampled in 1991. Contours in meters. Redrawn from charts NL 10-10 and C&GS 130N-17.


N
124° 40'
44° 40'
250
200
124° 40'
DAISY BANK
124° 20'
80
100
29
50
44° 30'
124° 20'
STONEWALL BANK
125° 00'
124° 50'
124° 40'
44° 20'
750
500
200
150
80
100
250
46
44° 10'
100
50
68
51
44° 00'
13
150
500
750
200
250
125° 00'
124° 50'
124° 40'
HECETA BANK
124° 50'
150
500
250
200
150
50
99
43° 00'
150
200
500
250
124° 50'
COQUILLE BANK
5 0 5 10 15 Kilometers
5 0 5 10 15 Statute Miles



DAISY BANK
①
②
③
STONEWALL BANK
HECETA BANK
①
②
③
④
⑤
⑥
COQUILLE BANK
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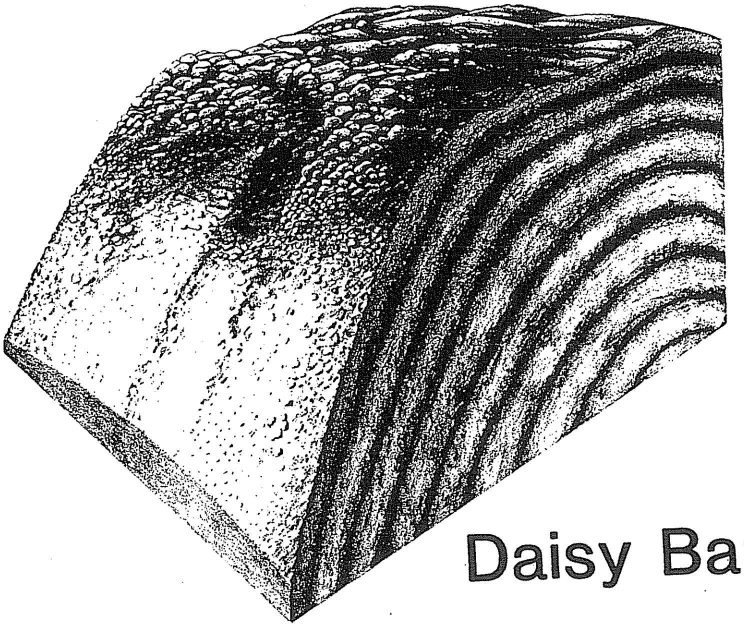
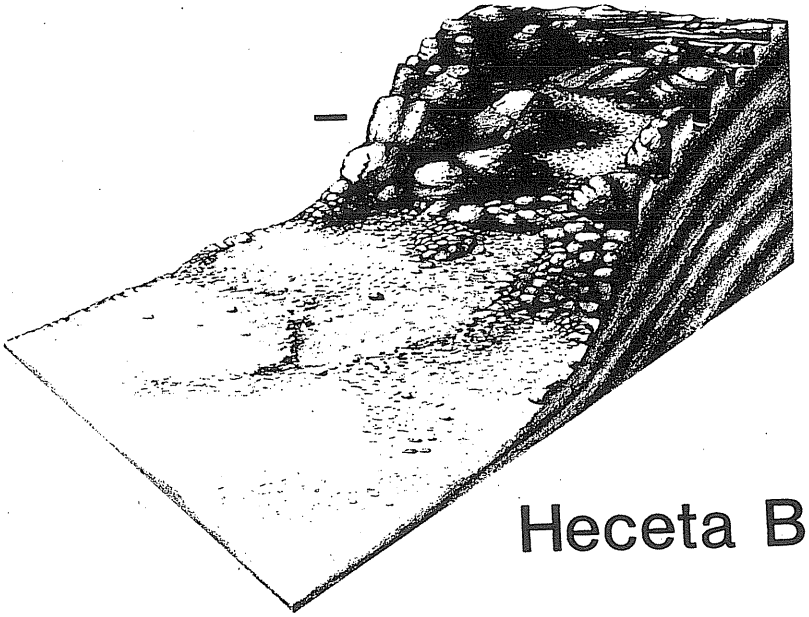
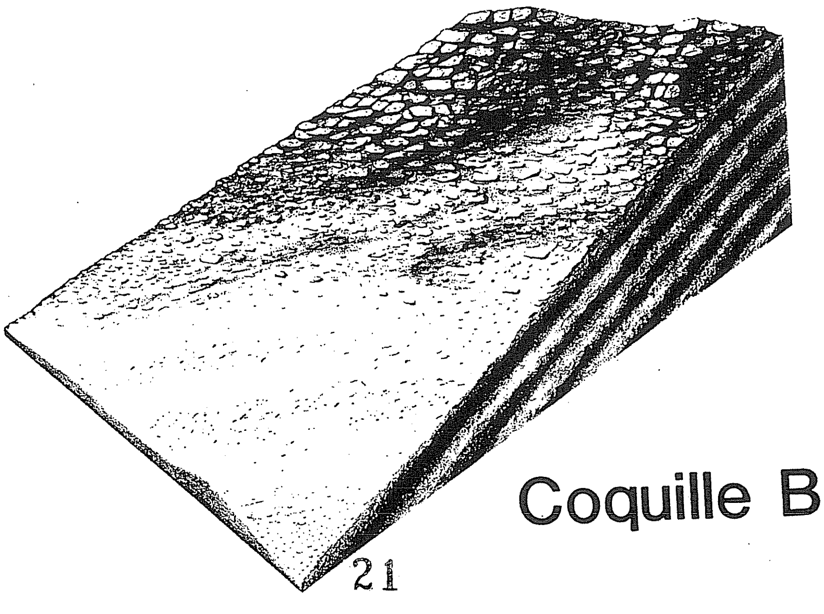
Figure II-3. Artist's conception of offshore slope profiles at Daisy, Heceta, and Coquille Banks, as viewed from the southwest. Each illustration is a composite summary of the range of bottom types observed at each bank. Scale bars equal roughly 5 meters (16 feet), the length of the submersible.



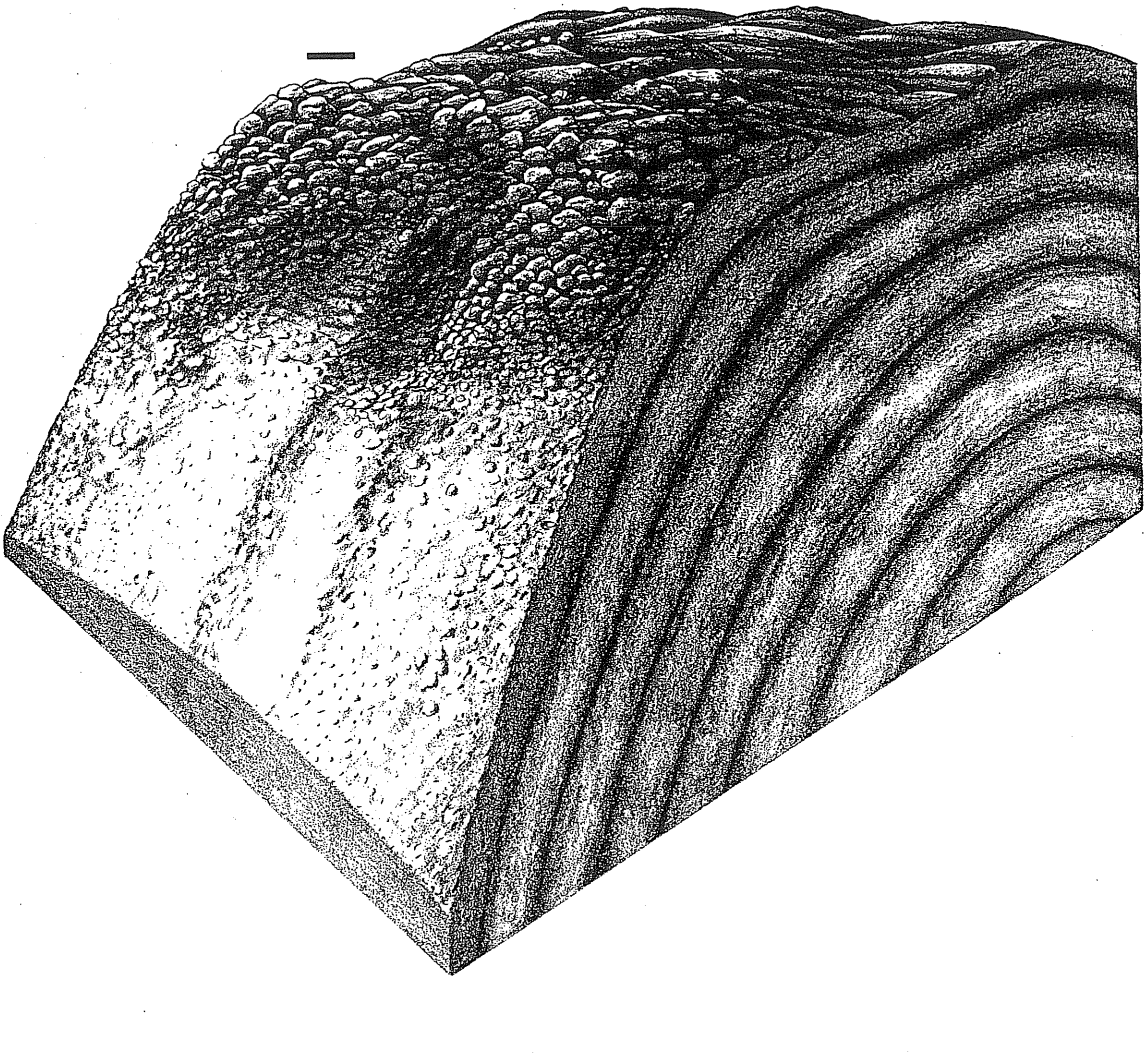
Daisy Bank



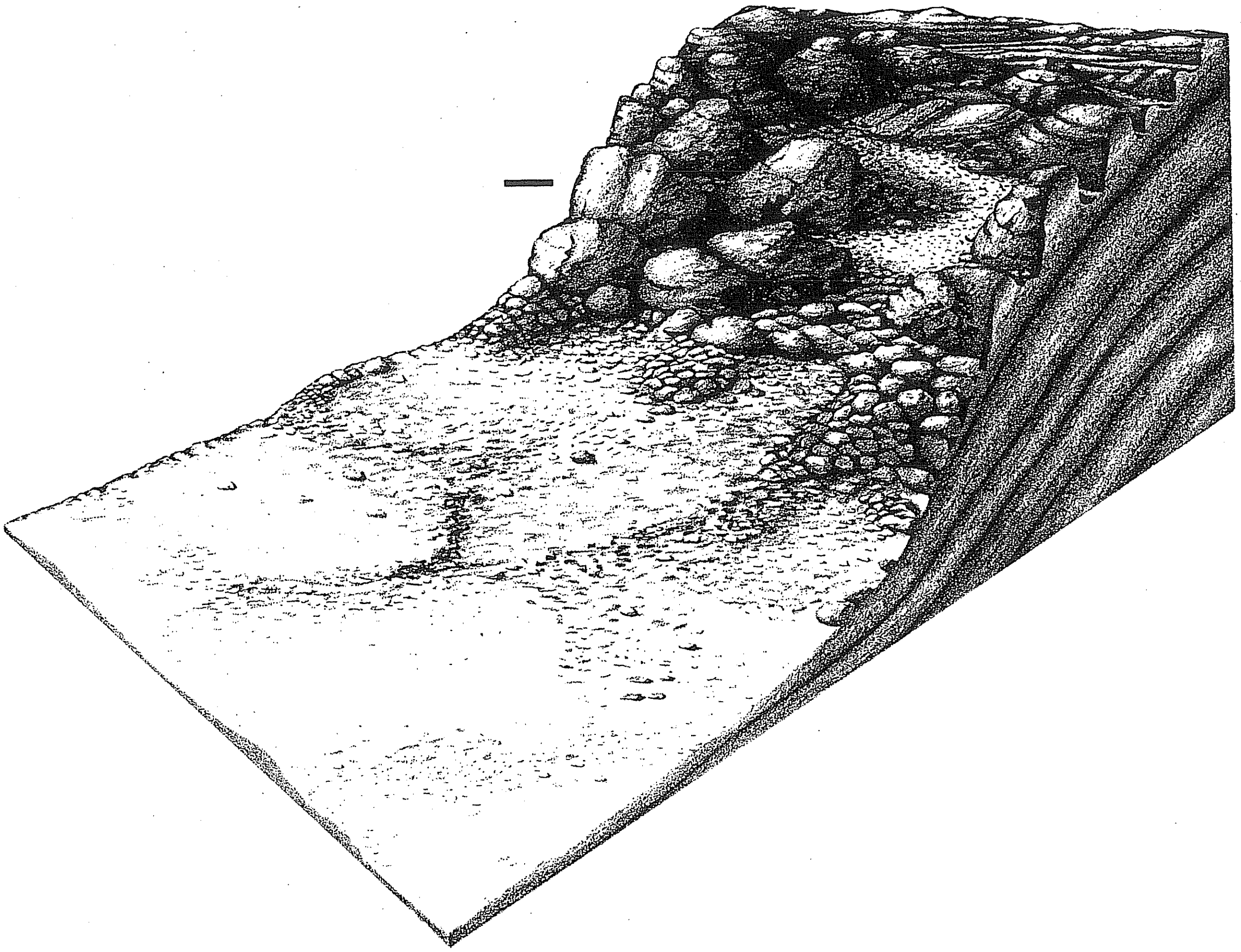
Heceta Bank



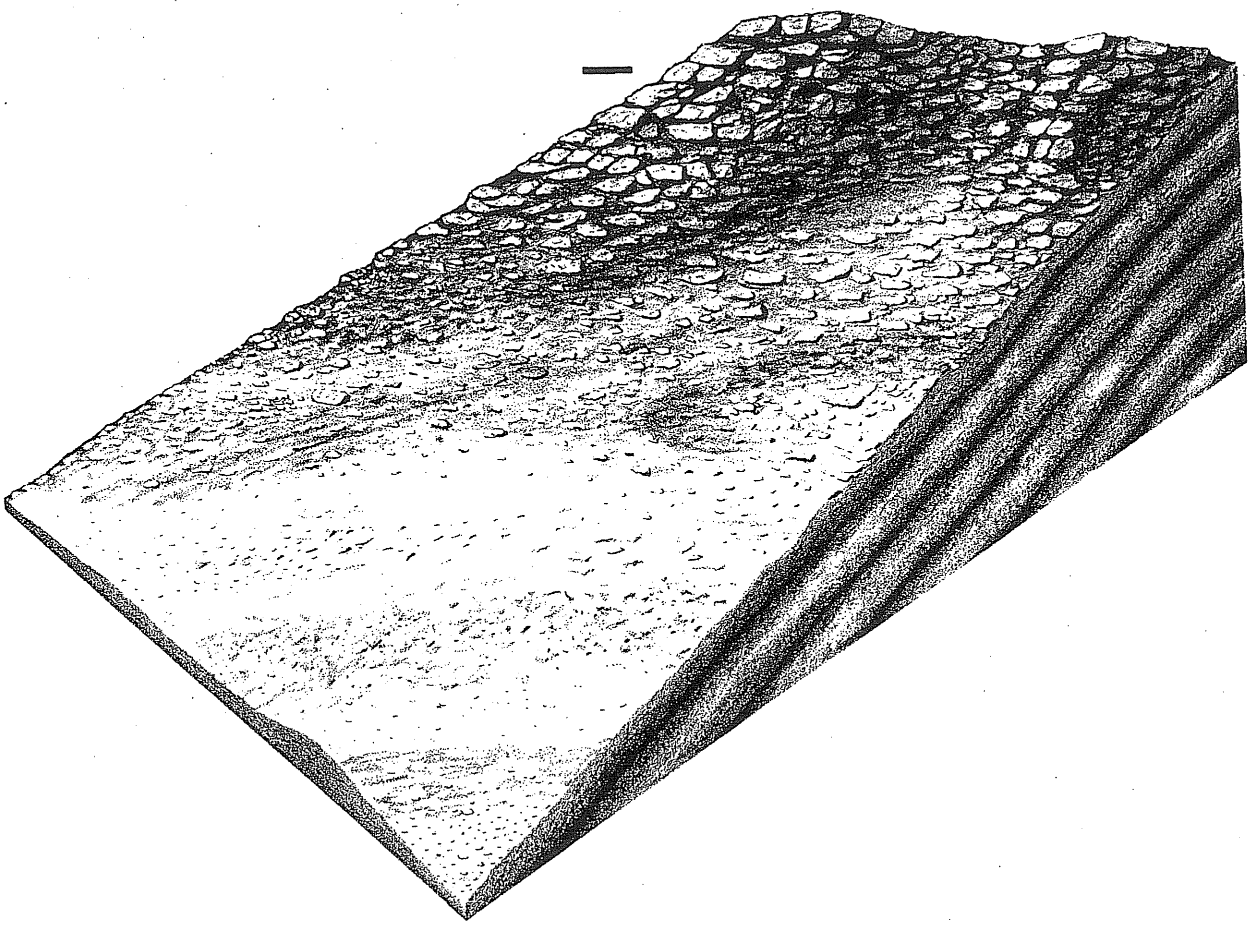
Coquille Bank



Daisy Bank



Heceta Bank



Coquille Bank

We selected our transect sites at Heceta Bank based on our exploratory dives during 1987 (Pearcy et al. 1989). We chose 6 of our original 18 stations, three distributed in a north-south cross-section on the top of the bank and three similarly aligned along the edge of the offshore slope (Fig. II-2). We considered these stations to be representative sites in terms of the fauna and bottom types we encountered in 1987.

<u>Coquille Bank</u> covers about a quarter the area of Heceta Bank and is only half the distance offshore (Fig. II-2). Coquille appeared to be comprised largely of siltstone and mudstone, characterized by eroded, exfoliating, slab-like boulders, mostly covered by a layer of silt (Fig. II-3). From shallowest depths of about 100 m (330 ft), the offshore slope of this bank gradually fades into mud, much like Heceta Bank.

At Coquille Bank, we used the same criteria as at Heceta Bank to select 4 sampling stations (numbers 5-8) for replicated transects from our original 8 exploratory transects in 1990 (Fig. II-2).

Submersible Transects

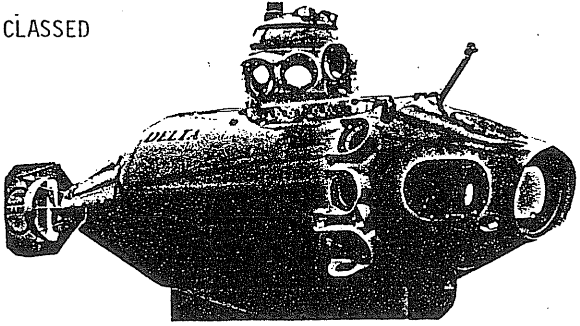
<u>Submersible</u>: We used the *DSV Delta* from the support vessel *R/V McGaw*. The *Delta* is a two-man submersible (pilot and observer) with a cruising speed of about 2.8 kph (1.5 knots) and maximum operating depth of about 350 m or 1150 ft (Fig. II-4). The sub is designed such that, when the observer looks forward and downward, he views the bottom simultaneously through two bow ports, actually looking through the fore ballast tank. This view provides a field width of 2.3 m (7.5 ft) when the sub is 2 m (6.6

Figure II-4. Description of the submersible *Delta* used during surveys between 1988 and 1990 on Oregon OCS banks.

DELTA

TWO-MAN RESEARCH SUBMERSIBLE

ABS CLASSED

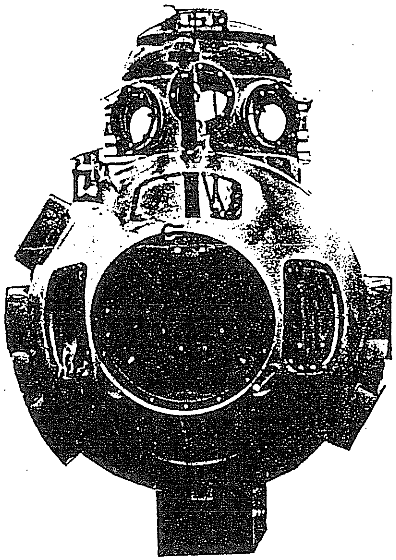


SPECIFICATIONS

Length Overall - 15'6"
Height Overall - 6'
Hull Diameter - 3'6"
Operating Depth- 1150' (ABS)
Tested Depth - 1700'
Weight - 5000 lbs.
Viewports - 19
Top Speed - 3.5 knts.
Cruising Speed - 1.5 knts.
Life Support - 144 man-hours

EQUIPMENT

Manipulator - Mechanical Arm
Sampling Devices - Slurp Gun
    - Corers - Grabs
    - Water Samplers
Navigation - Magnetic Compass
    - Directional Gyro Compass
    - Fathometer
    - Depth Gauges
    - Sonar
    - O.R.E. Trackpoint II
    - Transponders - Pingers
Communication - VHF Marine Radio
    - Underwater Telephone
Photographic - External Bulk Loaded 35mm Camera
    - Internal Hand-held 35mm Camera
    - (2) External Strobes
    - Color Video w/ Internal Monitor



DELTA is the newest subersible designed and built by MARFAB's Doug Privitt, who has designed and built ten similiar type submersibles since 1959. Mr. Privitt's subs have completed thousands of dives for clients including most major oil companies, government agencies and universities. DELTA incorporates many significant improvements over Mr. Privitt's earlier submersibles including better visibility for the observer more comfort and better instrumentation. DELTA has (1983-87) already made over 1000 successful dives off California, New England, Florida and in the South Pacific and Caribbean. DELTA's pilots include Doug Privitt and Rich Slater. Dr. Slater has logged over 1250 deep submersible dives as a pilot and/or scientific observer in 12 different submersibles.

ft) off the bottom, which we used as the width of our belt transects for calculating densities of demersal and benthic animals. The *Delta*'s 5-cm (2-in) diameter slurp gun was useful for collecting small invertebrates. However, the mechanical arm was ineffective at the depths we were operating, which prevented us from dispensing anesthetic for capturing fishes.

Transect Design: Our visual belt transects were adapted from methods long used for SCUBA surveys (Brock 1954, 1982; Ebeling 1982; Sale and Sharp 1983). During each dive, we ran a single one-hour transect, separated into two 30-minute segments by a "quiet period" to determine the effect of the sub on fish behavior (see below). Overall, each dive lasted about 2 hours, including transit time between the surface and bottom.

If there was no current, a transect would measure approximately 2800 m (1.5 n mi) by 2.3 m (7.5 ft). However, most dives encountered currents, and because the pilot could effectively steer the sub only by heading into the current, the currents defined our specific headings from the fixed starting point of each station, and ultimately, the lengths of the transects (see Appendix 4). For mapping transect paths, we used a Trackpoint II system to position the vessel directly above the sub every 10-15 minutes, then noted our latitude and longitude using Loran. Using these fixes, we calculated the approximate length of each one-hour transect, which averaged 2030 m (1.1 n mi) with a standard error of 66 m (216 ft, n=51).

Fish Counts: During each transect, the pilot attempted to maintain a 2 m (6.6 ft) altitude above the bottom, noted any peripheral observations, and radioed depth, temperature, and habitat information to the support vessel. The scientist observer verbally tape-recorded data on the species, size class (to the nearest dm TL), abundance, and behavior (e.g., schooling vs nonschooling) of all visible demersal fishes, and occasionally, dominant macrobenthos and bottom types along the transect path. To accurately estimate fish lengths and to provide an external scale for our photography, we suspended by a chain into the transect path a 0.3 m (1 ft) fiberglass rod marked in decimeter intervals.

The transecting process was analogous to counting objects on a moving conveyor belt while wearing blinders. Thus, error was introduced when the sub passed through a particularly dense aggregation of fishes. In such cases, the observer simply estimated aggregation sizes because counting each individual was impossible. Therefore, we ran separate analyses of "schooling" vs "nonschooling" fishes to factor-out this source of error.

A visual record of the transect path was provided by both standard VHS videotape (with timed datalogger and audio track) and 35-mm Photosea still photos taken every 30 seconds. The videotapes and photos were not useful for estimating fish densities because, first, the resolution was insufficient to distinguish similar species, second, the field of view was too small to use as a standard, and third, the photographic equipment provided with the sub was not always reliable.

We attempted to determine the extent to which fishes were differentially repelled by or attracted to the submersible by comparing their behavior just before and after "quiet periods." Midway through and at the end of each transect, we would rest the sub on the bottom and turn-off all lights and motors for 10-15 minutes. Turning-on the lights at the end of these periods invariably showed that the local distribution and abundance of fishes had not changed appreciably, suggesting that the presence of the submersible *per se* caused little sampling bias due to attraction or avoidance by fishes. At the very least, whatever bias existed was consistent between dives, stations, banks, and years.

Back aboard the support vessel, the scientist observer immediately transcribed the detailed data on fishes, as well as incidental data on benthos and bottom-type, from the tape recorders into a computerized database (dBase III). The data were then integrated, collated, backed-up on disk, and printed, so the observer could immediately review the data for transcription errors. We also reviewed the transect videotape for verification of some species identifications and other supplemental observations, such as bottom-type descriptions and unusual fish behaviors.

<u>Bottom-Type Description</u>: Because the submersible observers needed to concentrate on identifying and counting fishes, we extracted detailed data on bottom types from our videotape records of each transect. We used 8 different categories of substratum, using standard geological definitions. In order of

increasing particle size or relief, these substrata were: mud (code *M*), sand (*S*), pebble (*P*), cobble (*C*), boulder (*B*), continuous flat rock (*F*), diagonal rock ridge (*R*), and vertical rock-pinnacle "top" (*T*, which we encountered only in 1989 at Heceta Bank).

We defined ***bottom type*** as a two-letter code representing the approximate percent cover of the two most prevalent substrata in a particular uniform patch, as follows: The first character represented the substratum that accounted for at least 50% of the patch, and the second represented the second most prevalent substratum accounting for at least 20% of the patch (e.g., *"BC"* for at least 50% cover by boulders with at least 20% cover by cobble). If the field of view was purely a single substratum, or the second most abundant substratum covered less than 20% of the field, then the observer would enter a single code twice (e.g., *"BB"* for >80% cover by boulders). We encountered a total of 36 two-way combinations of the 8 substratum codes, defining 36 bottom types.

To standardize any inherent bias in this method, one of us (Tissot) reviewed all the videotapes for all dives, recording a two-character code each time he noted a distinct change in bottom type. We defined each transect segment of uniform bottom type as a ***habitat patch***, which was the sample unit of our multivariate analyses (see below).

Although the submersible's video system occasionally failed, we were able to extract bottom-type data for 97.7% of the 166,508 fishes we counted. The percentage of each videotape that was usable for each transect is given in Appendix 3.

<u>Invertebrate Counts</u>: Because the transect observers were ichthyologists, we subcontracted an invertebrate expert (Suzanne Benech, Benech Biological and Associates) to provide data on the macroinvertebrates encountered during our dives. Two kinds of data were compiled. First, in all years, the transect videotapes and still photos were used to compile a species list for each and every transect (listed in Appendix 3). These species lists were supplemented in 1990 by invertebrate collection dives at Stations 3, 4, and 6 at Heceta Bank, Stations 5, 7, and 8 at Coquille Bank, and Stations 1 and 2 at Daisy Bank (Fig. II-2). Second, in all years, for one or two representative transects at Heceta Bank, the transect videotapes were used to quantify the densities of dominant macroinvertebrates in the same way we counted fishes (see Appendix 3). This second analysis was necessary for detailed statistical analyses. However, extracting these data from the videotapes was extremely time-consuming, which precluded such analysis of every single transect.

<u>Sample Sizes</u>: Within the constraints of the time allocated for our cruises and the sea state, we ran replicate transects at each of 6 stations at Heceta Bank (1988 to 1990), 4 stations at Coquille Bank (1990, plus 4 other exploratory stations), and 3 stations at Daisy Bank (1990) (Table II-1). Overall, we logged 83 dives, including 61 transect dives, 6 dives tracking yellowtail rockfish (chapter 5), 9 dives collecting invertebrates, and 4 initial exploratory dives at Coquille Bank (Appendix 2).

Observer Bias: Because there were three transect observers (Hixon, Stein, and Barss), who rotated dives, we wished to determine relative observer bias in terms of fish counts. In 1988 only, we were able to run three transects at each station at Heceta Bank, such that every observer sampled every station. We examined differences in fish abundances among stations (factor 1) and observers (factor 2) using 2-way analysis of variance. This analysis indicated significant differences among stations (as expected), but not among observers (Stein et al., in press). Therefore, we concluded that among-observer differences in sampling bias were sufficiently low to treat dives by different observers at the same station as legitimate replicates.

Overall, our methods provided a database integrating spatially and temporally replicated transect data on demersal fishes, benthic macroinvertebrates, and bottom types, allowing us to characterize the fish communities of rocky banks of the Pacific Northwest.

Data Analyses

Multivariate vs Univariate Approaches: Ecological communities are, by definition, multivariate systems (Gauch 1982, Digby and Kempton 1987). Therefore, to adequately characterize a community, as well as to test for both interannual variation within a community and differences between communities, multivariate statistical methods are essential.

The basic goal of our analyses was to integrate our data on fish abundances, invertebrate abundances, and bottom types to characterize distinct assemblages within and between rocky banks of the Pacific Northwest. By simply running a series of univariate analyses comparing transects, we could not meet this goal. There are at least two major problems with univariate analysis at the station level. First, it is the combination and association of species and bottom types and their relative abundances that characterize these communities. It is impossible to examine the variation in each and every variable in isolation and come to a meaningful conclusion concerning the community.

Second, each transect in our study necessarily followed a different and arbitrary path, representing a unique combination of bottom types and associated fauna. The object of our study was not to examine variation among transects per se, but to document the habitat-species associations sampled by those transects. By examining our data at the level of bottom-type patches independent of transect location, we were able to run a truly community-level analysis. For those who nonetheless prefer univariate analyses, we also included standard analyses of variance at the level of sampling stations.

<u>Multivariate Analyses</u>: We examined multivariate associations among fish abundances, invertebrate abundances, and bottom types using canonical correlation analysis (CCA). CCA is a multivariate technique designed to extract a series of intercorrelations between two related data sets (Pimentel 1979). In this case, we examined the relationships between fish abundance (data set 1) and habitat (data set 2, which was a combination of bottom types and invertebrate abundances). Our

primary goal was to extract meaningful, natural associations between fishes and habitat factors potentially influencing their distribution and abundance. However, once extracted these associations serve an additional purpose: they measure the abundance of fish within a particular habitat type. Thus, in addition to describing basic fish-habitat associations, the analysis provides a measure of habitat-specific fish abundances. In effect, CCA allowed us to control for the effects of sampling across a range of different habitats, and thus increased our ability to detect meaningful spatial and temporal variation in fish abundances.

For this community-level multivariate analysis, the sample unit was not an entire transect, but a patch of uniform bottom type (see above for our definitions of "habitat patch" and "bottom type"). This approach freed us from the arbitrary nature of station locations and the vagaries of individual transect paths, and allowed us to examine patterns across all stations simultaneously. It also allowed us to integrate our invertebrate data with our bottom-type data, providing a more realistic resolution of "habitat" that incorporated both biotic and abiotic variables. Each observation in the analysis represented the density of fish and macroinvertebrates enumerated along a transect within the same bottom type. When the bottom type changed along a transect, a new patch observation was initiated. Thus, the data collected for an individual dive consisted of the sum of the different bottom type changes occurring along the transect, each observation representing an sample of fish and invertebrate abundances within a particular bottom type. Because

CCA neither assumes nor requires independence of samples, there was no problem posed by the patches along a transect being contiguous.

We used CCA to extract a series of patterns (or axes) from the collection of habitat patches which represent contrasting intercorrelations between fish, invertebrates, and bottom types. A major asset of CCA is that each axis depicts an orthogonal, or statistically independent, description of the association between data sets. Because axes are independent, each pattern represents a unique association common to both data sets. For example, if the first CCA axis described particular fishes associated with mud-dwelling invertebrates, the second axis would depict an additional pattern that occurs independently of the mud association. Perhaps the best way to conceptualize the derivation of CCA axes is to imagine the successive extraction of independent fish-habitat associations that eventually describes all of the variation in fish abundance.

Each derived axis can be characterized by four different measures. First, the ***canonical correlation coefficient*** measures the extent of overall association between fish abundance and bottom-type/invertebrate abundance on each axis. Like univariate correlation, the canonical correlation can vary between 0 (no association between data sets) and 1 (perfect association). Second, the ***redundancy coefficient*** measures the actual extent of overlap between the two data sets, and varies between 0 (no overlap) to 1 (perfect correspondence). In principle, the redundancy coefficient describes a significantly different aspect of the CCA than the canonical correlation coefficient. While the canonical correlation coefficient describes the goodness-of-fit of the two data sets, which can be influenced by a single high correlation between one variable in each data set, the redundancy coefficient measures the overall fit, or overlap in variation, between all variables in both sets. In our CCA of fish-invertebrate-bottom data, we typically encountered high canonical correlations and low redundancy. These results are consistent with what we observed from habitat-specific fish distributions: on each CCA axis some species were abundant within a particular bottom type while others were not. This pattern results in a high goodness-of-fit but low overlap among data sets.

The third and most informative metric in CCA is the ***loading*** of each variable on each axis. Variable loadings indicate which fish are abundant within a particular bottom type-invertebrate assemblage. On each axis, three types of loadings can occur: (1) high positive loadings, which indicate that a variable was positively correlated with the pattern depicted on that axis; (2) high negative loadings, which indicate that a variable was negatively correlated with that pattern; and (3) low positive or negative loadings, which indicate no strong correlation. Variable loadings represent contrasting associations among fishes, invertebrates, and bottom types. For example, if muddy bottoms display high positive loadings on an axis and rocky bottoms display high negative loadings, then fish with high positive loadings are abundant on mud, while those with high negative loadings are common on rock.

The fourth and final CCA metric, the ***canonical variate score***, measures the loading of each patch on each axis. These loadings are derived from a combination of the raw data (i.e., the abundance of fish within a habitat patch) and the variable loadings. Hence, canonical variate scores measure the extent to which each habitat patch is correlated with the fish-habitat pattern depicted on each axis. Further, due to the partitioning of data sets in CCA, canonical variate scores are derived independently of each data set. For each axis there are canonical scores for fishes, which measure fish abundance in a particular habitat patch, and canonical scores for invertebrates and bottom types, which measure combined invertebrate abundance and bottom type in each patch. Canonical variate scores thus provide a community-level metric of both fish and invertebrate abundances relative to the areal extent of individual habitat patches.

When used for descriptive purposes, CCA requires no underlying assumptions about the statistical distributions of the data (Dillon and Goldstein 1984). In this respect CCA is limited only to the extent that correlations between variables measure truly causal associations in nature.

Univariate Analyses: We tested various predictions from our general hypotheses by analysis of variance (ANOVA). Prior to all ANOVAs, we examined homogeneity of variances by Bartlett's tests. Although ANOVA is robust with respect to departures from this assumption and the assumption of normality (Scheffe 1959), when the data were strongly heteroscedastic or nonnormal, we substituted nonparametric analogs (Kruskal-Wallis tests in lieu of 1-way ANOVA, and Friedman's tests in lieu of 2-way ANOVA).

Our ANOVAs comparing transects necessarily involved small sample sizes (2-3 replicates per station). In cases where we found no significant differences among treatments, thus accepting the null hypothesis of no change through time or no differences between sites, we ran the risk of committing what is known in statistics as a "type II error": accepting a false null hypothesis. We examined this source of error by calculating the "power" of each ANOVA, which is the probability that one has not committed a type II error (Tiku 1967; Winer 1971; Toft and Shea 1983; Cohen 1988; Peterman 1990). Unfortunately, the power of our tests averaged about 0.5, which meant that about half the time our tests were unable to detect real differences. This was a major constraint of examining patterns at the level of stations, further justifying our examination of habitat patches.

An important assumption for any inferential statistical test is "independence" of samples. In our tests, samples were either entire transects or individual habitat patches (defined above). By assuming independence, we asserted that each transect or patch represented a sample of the bottom types, invertebrates, and fishes that did not overlap with other samples. We do not believe that our samples strongly violated this assumption, for the reasons given below. However, to be conservative, we followed our significant ANOVAs and nonparametric analogs only by visually comparing means and distributions (as advocated by Hurlbert 1984), rather than by employing multiple comparisons with their restrictive assumptions (Day and Quinn 1989).

First, consider transects as independent sample units. Because our transect paths were dictated by prevailing currents (see above), no two transects covered the same path. Rather, transects at each station tended to either roughly parallel each other, or cross each other (Appendix 4). Whereas the cross points certainly represented some overlap between samples, we assumed that the extent of overlap was greatly exceeded by the amount the transects did not overlap. Clearly, our samples of bottom types and invertebrates were virtually independent, especially given that most of the invertebrates we observed were sessile. Of course, even demersal fish can be highly mobile, conceivably swimming from one transect path to another, and thereby being counted twice. Between sampling stations, this problem was almost certainly unimportant. Shortest distances between adjacent stations with replicate transects ranged from about 2 km (1 n mi) to 11 km (6 n mi) at Heceta Bank, and about 2 km (1 n mi) to 6 km (3 n mi) at Coquille Bank (Fig. II-2). However, stations at the relatively small Daisy Bank were necessarily separated by less than 1 km (0.5 n mi). If fish were counted twice, it almost certainly occurred within stations. However, rockfishes (genus *Sebastes*) were the most abundant species in our samples (Chapters 3 and 4). Benthic rockfishes exhibit highly restricted home ranges (Larson 1980a; Matthews 1990), and more open water species exhibit both high site fidelity and homing (Love 1980; Carlson and Haight 1972; Chapter 5). Thus, over the short time intervals of our annual sets of dives, it seems likely that our transects comprised reasonably independent samples.

At a finer scale of resolution, we also statistically examined the scores of our canonical correlation analyses, which were based on the sample units being habitat patches. Clearly, no patch is a strict isolate, especially considering immediately adjacent patches. However, three facts convinced us that this truism did not strongly violate the assumption of independence overall. First, patches at different stations were almost certainly independent, as explained in the previous paragraph. Second, given that each transect was about 2 km (1 n mi) long, patches far apart on the same transect were also arguably independent. Third, patches of one bottom type could be adjacent to patches of many different bottom types. This interdispersion of patch types would tend to average and cancel the effects of neighboring patches, such that any pattern that remained could be safely attributed to the particular bottom type being examined. Therefore, we believe that there was sufficient independence among all patches sampled to swamp any dependence between immediately adjacent patches.

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Chapter 3

INTERANNUAL VARIATION IN FISH ASSEMBLAGES OF HECETA BANK, OREGON

The goals of this chapter are twofold: (1) to describe the associations of bottom types, visually dominant invertebrates, and demersal fishes at Heceta Bank; and (2) to examine the extent of interannual variation in these assemblages from 1988 to 1990. We conclude that, although the basic species composition of these assemblages was constant between years, the abundances of 8 of 15 common and/or commercially important fish taxa varied substantially over this three-year period.

General Patterns

During our 42 transect dives at Heceta Bank, we observed 69 taxa of fishes (50 of which we identified to species) representing 24 families. We also observed or collected 84 taxa of invertebrates representing 9 phyla, along with several taxa of algae and a bacterial mat. Appendix 1 provides a master list of the scientific and common names of all taxa sampled, as well as an overview of the relative abundance or presence/absence of each taxon among sampling stations and years. Appendix 2 provides a master list of all our dives, and Appendix 3 provides a data summary from each transect dive, including the abundance or presence/absence of each fish/invertebrate taxon and bottom type encountered.

Habitat Characterization

Our six sampling stations (Chapter 2: Fig. II-2), selected from our 18 exploratory stations in 1987 (Pearcy et al. 1989), comprised a broad representation of all the bottom types we had encountered. Distributed among our submersible transects at these stations from 1988-1990 were 36 different bottom types (Table III-1).

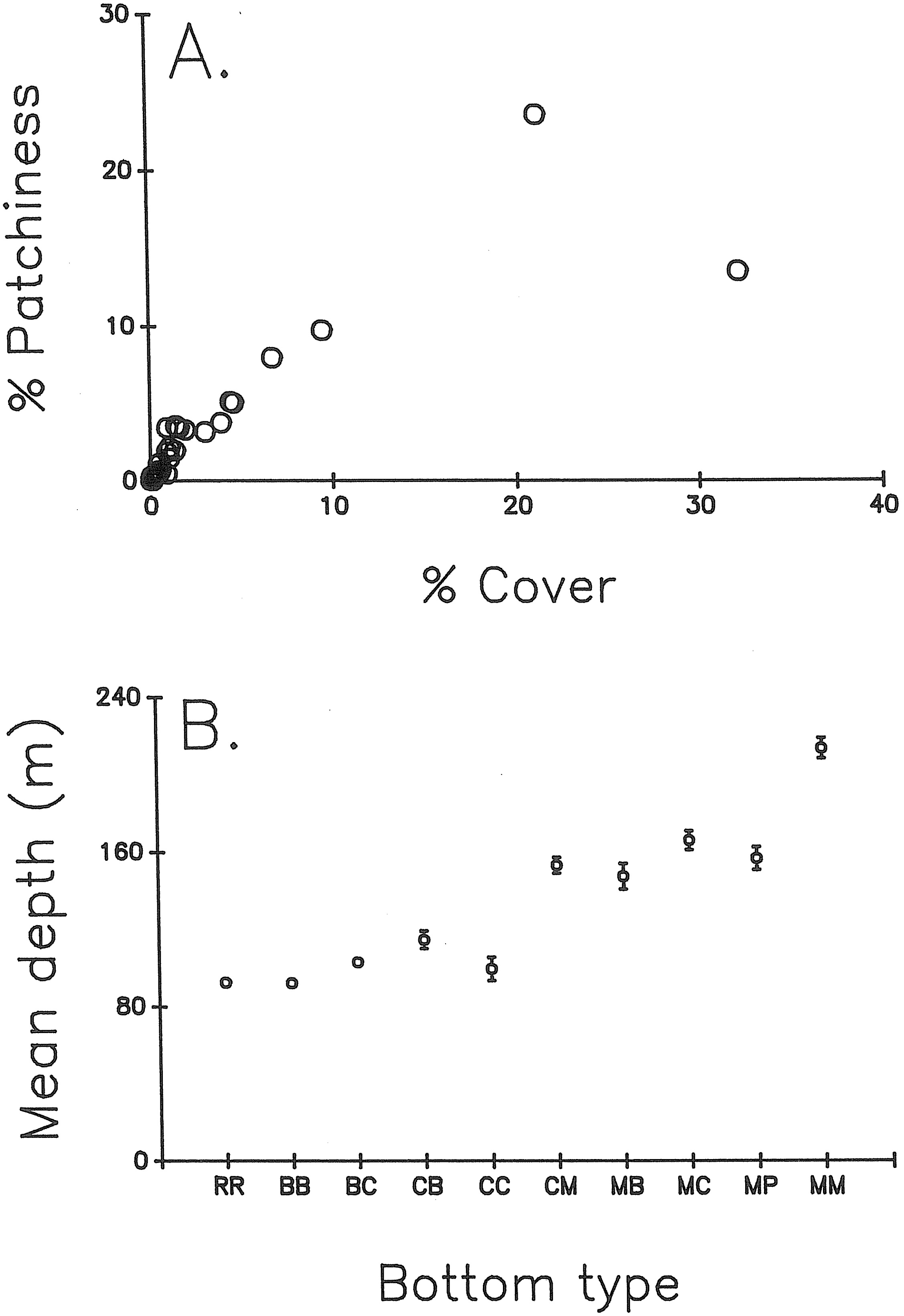
Cover vs Patchiness: We examined the distribution of bottom types by two measures: (1) ***cover***, which was the percent of the transect area covered by each bottom type; and (2) ***patchiness***, defined here as the percent of all patches counted on the transect representing each bottom type (a ***habitat patch*** being a segment of uniform bottom type along a transect). In theory, these measures are independent. For example, suppose a transect consisted of two bottom types (*A* and *B*) that comprised 10 small patches of *A* interspersed with 10 large patches *B*. Bottom type *A* would thus have lower cover than bottom type *B*, despite the fact that *A* and *B* had equal patchiness.

In fact, the cover and patchiness of bottom types were highly correlated (Fig. III-1A, Spearman rank correlation, $P<<0.001$, $r=0.96$, $n=36$), indicating that patch sizes tended to be equal among bottom types (see Appendix 3 for transect-by-transect distributions of cover and patchiness). This correlation allowed us to use only cover (and not patchiness) in our analyses of bottom-type distributions.

Table III-1. Percent cover of all bottom types observed at Heceta Bank from 1988 to 1990, pooled by station and year and ranked by total cover over all samples ("Total"). Substratum codes are (in order of increasing particle size or relief): M=mud, S=sand, P=pebble, C=cobble, B=boulder, F=flat rock, R=diagonal ridge, T=vertical pinnacle top. The first and second letters of each bottom type is the substratum accounting for at least 50% and 20% of a patch, respectively (see Chapter 2: General Methods).

		By station						By Year		
Bottom type	Total	1	2	3	4	5	6	'88	'89	'90
MM	32.20	--	46.09	2.36	5.82	95.63	33.45	34.91	23.74	35.07
RR	21.21	56.11	2.16	39.87	35.39	--	--	18.13	23.15	23.89
MC	9.47	0.31	28.87	4.22	8.07	1.95	11.89	6.59	7.68	14.79
BC	6.72	8.64	0.49	5.55	11.73	--	15.91	8.75	7.98	2.95
CB	4.56	3.74	0.22	2.38	9.78	--	12.47	3.80	9.20	1.99
MP	4.39	--	4.31	6.97	4.37	0.43	10.06	3.81	3.83	5.62
CM	3.86	0.24	8.47	1.14	5.01	1.22	6.86	2.91	5.99	3.52
MB	2.98	--	8.08	2.14	6.17	0.78	--	1.19	6.85	2.43
CC	1.89	3.87	--	1.36	0.64	--	6.41	0.72	3.24	2.42
BB	1.55	2.78	0.16	5.90	0.37	--	0.10	2.24	0.94	1.08
SC	1.39	5.69	--	3.30	0.07	--	--	2.10	0.77	0.90
BS	1.33	3.85	--	4.43	--	--	--	2.74	0.03	0.41
BM	1.04	2.20	1.15	1.13	1.98	--	--	1.23	0.97	0.84
CP	1.02	1.96	--	3.10	0.93	--	0.22	1.18	1.78	0.20
SS	0.92	2.29	--	3.37	--	--	--	0.35	1.18	1.51
CS	0.88	2.83	--	2.73	--	--	--	1.23	0.31	0.86
RC	0.86	0.35	--	--	4.90	--	--	1.99	--	--
RB	0.53	1.76	--	--	1.69	--	--	1.21	--	--
SB	0.49	0.67	--	2.20	--	--	--	0.95	0.16	0.11
BR	0.46	0.65	--	0.29	1.92	--	--	1.06	--	--
PS	0.46	0.32	--	2.29	--	--	--	0.78	0.29	0.14
SP	0.42	0.31	--	2.09	--	--	--	0.46	0.42	0.36
PM	0.29	--	--	1.03	0.02	--	0.66	0.13	0.57	0.30
TT	0.22	--	--	0.46	0.83	--	--	--	0.90	--
MF	0.13	--	--	--	--	--	0.85	0.31	--	--
BP	0.12	--	--	0.69	--	--	--	0.28	--	--
FF	0.11	0.82	--	--	--	--	--	0.26	--	--
SM	0.11	--	--	0.60	--	--	--	0.25	--	--
FM	0.10	--	--	--	--	--	0.66	--	--	0.32
CN	0.07	--	--	--	--	--	0.46	0.16	--	--
PC	0.06	0.46	--	--	--	--	--	--	--	0.20
FC	0.06	0.06	--	--	0.30	--	--	0.13	--	--
CR	0.04	--	--	0.22	--	--	--	0.09	--	--
PB	0.02	--	--	0.12	--	--	--	0.05	--	--
PP	0.02	--	--	0.09	--	--	--	--	0.01	0.04
SR	0.01	0.07	--	--	--	--	--	--	--	0.03

Figure III-1. **A.** Percent patchiness as a function of percent cover of the 36 bottom types encountered at Heceta Bank. See text for definitions. **B.** Depths (mean ± 1 SE) of the ten dominant bottom types sampled by habitat patch on Heceta Bank, 1988-1990. Bottom types are listed by decreasing relief and particle size, where the first letter is the dominant substratum and the second letter is the second most prevalent substratum: R=rock ridge; B=boulder; C=cobble; P=pebble; M=mud. Sample sizes (number of patches per bottom type) are: RR, 145; BB, 16; BC, 34; CB, 17; CC, 29; CM, 19; MB, 17; MC, 79; MP, 42; MM, 98.


A.
% Patchiness
30
20
10
0
0
10
20
30
40
% Cover
B.
Mean depth (m)
240
160
80
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Bottom type

Depth vs Bottom Type: Another strong correlation occurred between depth and bottom type ranked by degree of relief (Fig. III-1B, Spearman rank correlation, P<0.001, r=0.93, n=10). Examining all patches of the ten most abundant bottom types (which accounted for nearly 90% of the total cover, Table III-1), the shallower parts of the bank were strongly dominated by rock ridges (code RR in Fig. III-1) and pure boulders (BB), intermediate depths by combinations of boulders and cobble (BC, CB, and CC), and deeper areas by mostly mud (MM, MP, MC, MB, and CM). This correlation was simply a consequence of Heceta Bank being a rock outcrop projecting upward from a mud bottom, with boulders and cobble around its base (Chapter 2: Fig. II-3). This correlation allowed us to use only bottom-type (and not depth) in our multivariate analyses.

Station-Level Habitats: Bottom Types: To characterize habitat types at the level of sampling station, we examined the relative cover of the ten most abundant bottom types among stations (Fig. III-2). This analysis suggested four basic habitat types: (1) clearly rock-ridge dominated (Stations 1 and 3), (2) heterogeneous but mostly rock-ridge dominated (Station 4), (3) heterogeneous but mostly mud-dominated (Stations 2 and 6), and (4) clearly mud-dominated (Station 5). Obviously, these were arbitrary distinctions, emphasizing the importance of our multivariate approach. This conclusion is especially true given that most transects tended to run from shallow rocky to deep muddy habitats, precluding exclusive distinctions at the station level.

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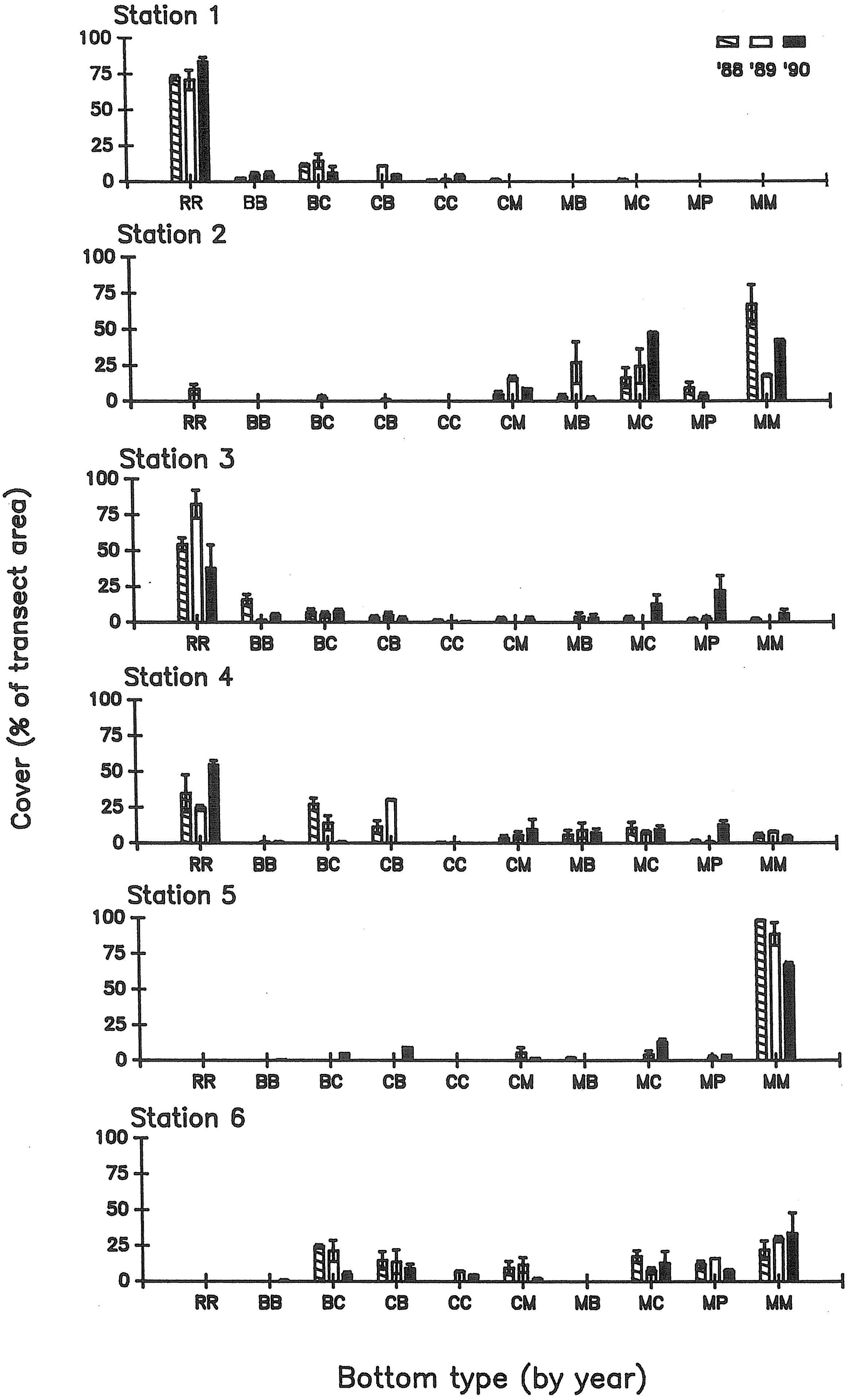
Figure III-2. Percent cover (mean ± 1 SE) of the ten dominant bottom types sampled by habitat patch on Heceta Bank by station and year. Bottom types are listed by decreasing relief and particle size, where the first letter is the dominant substratum and the second letter is the second most prevalent substratum: R=rock ridge; B=boulder; C=cobble; P=pebble; M=mud. Sample sizes (number of patches per bottom type by year) are:

Bottom type	1988	1989	1990
RR	93	100	106
BB	22	5	13
BC	41	37	21
CB	20	31	10
CC	12	3	4
CM	17	17	16
MB	11	18	10
MC	33	26	61
MP	19	10	32
MM	40	53	79

(total number of patches = 1198)


Station 1
Station 2
Station 3
Station 4
Station 5
Station 6
100
75
50
25
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
'88 '89 '90
Cover (% of transect area)
Bottom type (by year)

Patch-Level Habitats: Bottom Types and Invertebrates: For our community-level multivariate analysis, the sample unit was not an entire transect, but a patch of uniform bottom type. This approach freed us from the arbitrary nature of station locations and the vagaries of individual transect paths, and allowed us to examine patterns across all stations simultaneously. It also allowed us to integrate our invertebrate data with our bottom-type data, providing a more realistic resolution of "habitat" that incorporated both biotic and abiotic variables.

The first and second axes of the canonical correlation analysis (CCA) provided ecologically meaningful contrasts. Bottom-type and invertebrate loadings on these axes defined three basic habitat types (Fig. III-3). The first axis provided a primary contrast between a strongly mud-dominated habitat (mostly deeper than 150 m or 490 ft) and various rock-dominated habitats (mostly shallower than 150 m), which were subdivided by the second axis.

The "mud" habitat (positive loadings on axis 1 in Fig. III-3) supported mostly *Allocentrotus* urchins, which occurred in isolated patches, and occasional seastars (such as *Pycnopodia* and *Luidia*) and sea cucumbers (*Parastichopus*). The canonical variate scores for bottom type and invertebrates on axis 1 (Fig. III-4) showed that this mud/urchin habitat comprised mostly portions of stations 2, 5, and 6.

Orthogonal to the first axis, the second CCA axis subdivided rocky bottoms into those dominated by rock ridges interspersed with sand and flat rock (positive loadings in Fig. III-3), and

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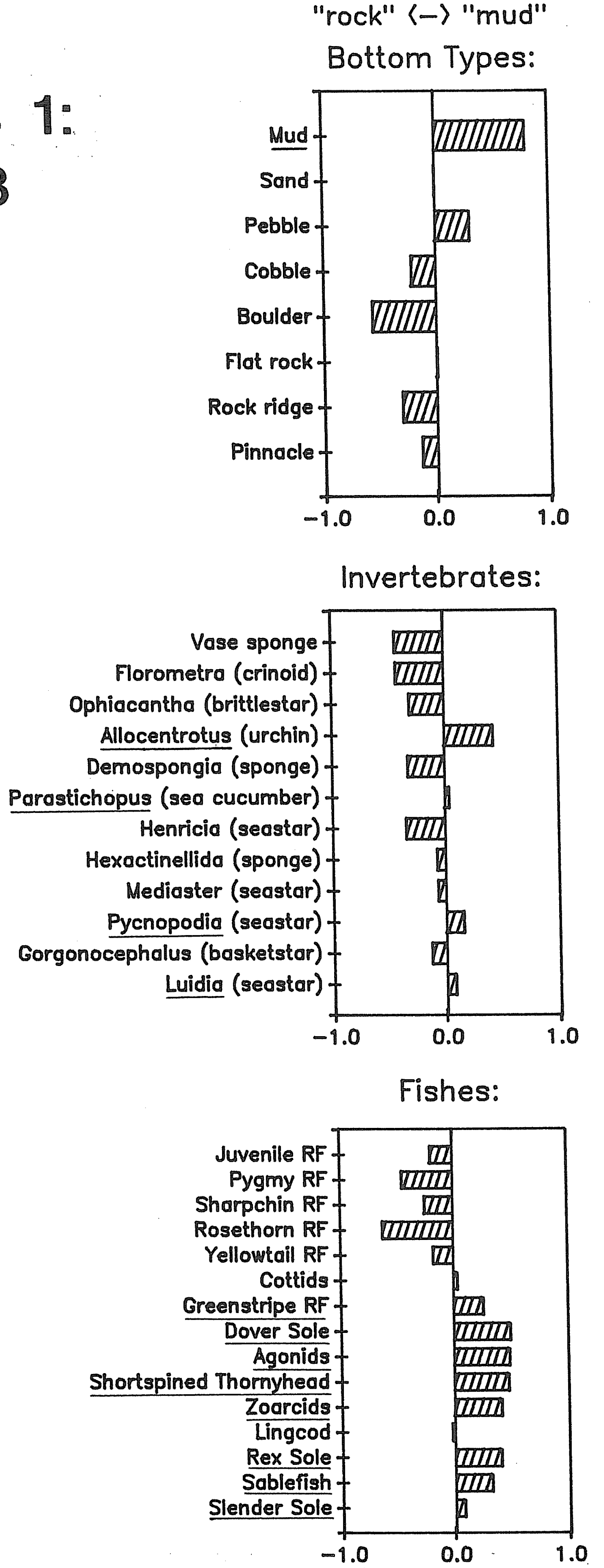
Figure III-3. Variable loadings of bottom types, invertebrates, and fishes on the two axes of the canonical correlation analysis. The canonical correlation coefficient (r) measures the overall association between bottom-type/invertebrate abundance and fish abundance. High positive loadings on axis 1 define a mud habitat with associated invertebrates and fishes (underlined). High negative loadings on axis 1 define a general rock habitat, subdivided on axis 2. High positive loadings on axis 2 define a rock-ridge habitat with associated species (underlined). High negative loadings on axis 2 define a boulder-cobble habitat with associated species. Data for analysis were derived from discrete habitat patches for which all variables could be measured (n = 1198, see table in caption to Fig. III-2).

CCA Axis 1:
r = 0.63



Variable loadings

CCA Axis 2:
r = 0.44

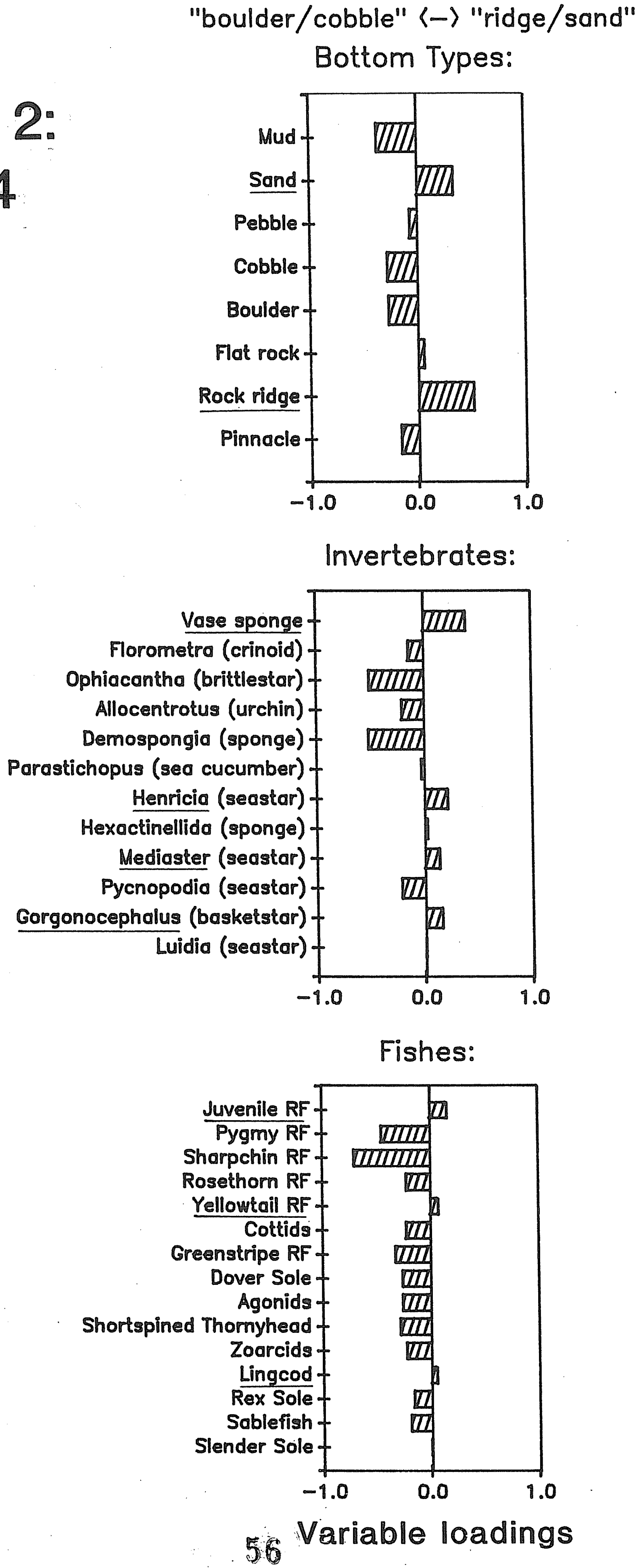


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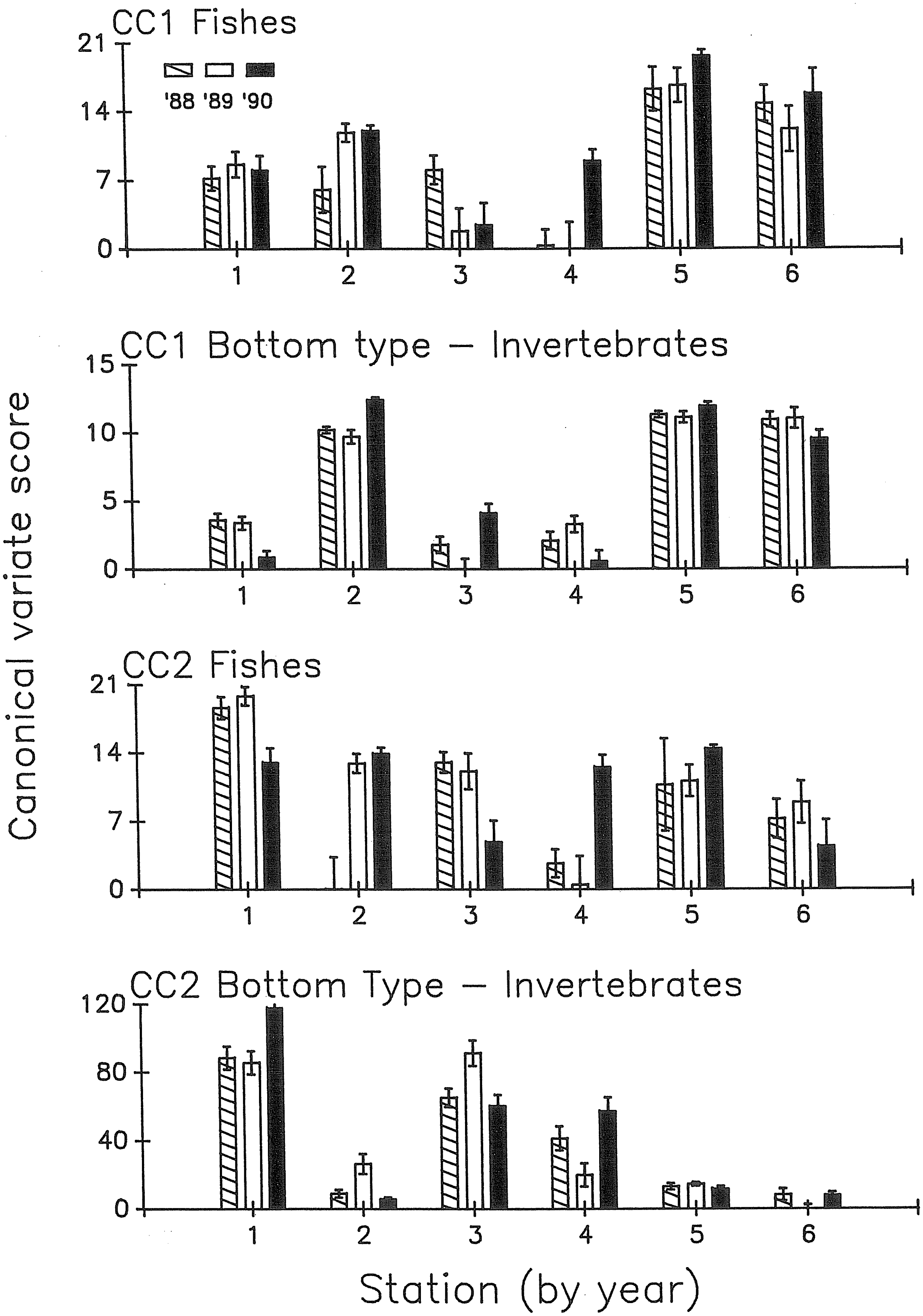
Figure III-4. CCA variate scores (mean ± 1 SE) among sampling stations and years at Heceta Bank for fishes and habitat (bottom type and invertebrates). Stations with high scores on axis 1 (CC1) are associated with mud/urchin habitats, while stations with low scores are associated with rock habitats. Stations with high scores on axis 2 (CC2) are associated with ridge-boulder/vase-sponge/basketstar habitats, while stations with low scores are associated with boulder-cobble/demosponge/brittlestar habitats. Sample sizes (number of patches per station by year) are:

Station	1988	1989	1990
1	81	87	99
2	33	67	69
3	135	92	93
4	107	74	81
5	15	17	19
6	43	34	52

(total number of patches = 1198)


CC1 Fishes
'88 '89 '90
21
14
7
0
1 2 3 4 5 6
CC1 Bottom type — Invertebrates
15
10
5
0
1 2 3 4 5 6
CC2 Fishes
21
14
7
0
1 2 3 4 5 6
CC2 Bottom Type — Invertebrates
120
80
40
0
1 2 3 4 5 6
Canonical variate score
Station (by year)

those dominated mostly by a mixture of boulders and cobble dispersed over mud bottoms (negative loadings).

The rock ridges were interspersed at the same depths with pure-boulder bottoms (codes RR and BB in Fig. III-1), which were important areas for some fishes (see below). However, because pure-boulder bottoms (as opposed to bottoms of boulders mixed with other substrata) were relatively rare (Fig. III-2), they failed to load heavily on the CCA. Therefore, we called the mixed habitat defined by positive loadings on CCA axis 2 the "ridge-boulder" habitat. This habitat supported mostly vase sponges (*Scypha* and *Iophon*), basketstars (*Gorgonocephalus*), and the seastars *Henricia* and *Mediaster* (positive loadings on axis 2 in Fig. III-3). The sponges showed a strikingly even distribution on the rock ridges and large boulders, the basketstars occurred only on ridge tops, and seastars occurred occasionally throughout. The canonical variate scores for bottom type and invertebrates on axis 2 (Fig. III-4) showed that this ridge-boulder/vase-sponge/basketstar habitat comprised mostly stations 1 and 3.

The "boulder-cobble" habitat supported mostly demosponges and brittlestars (*Ophiacantha*), but also included crinoids (*Florometra*)(negative loadings on axis 2 in Fig. III-3). The demosponges tended to be evenly distributed over the surfaces of boulder-cobbles, the brittlestars occurred mostly in crevices near the bases of the boulder-cobbles, and the crinoids occurred on the tops of boulder-cobbles. The canonical variate scores for bottom type and invertebrates on axis 2 (Fig. III-4) showed that this boulder-cobble/demosponge/brittlestar habitat (negative loadings and low scores) comprised mostly portions of stations 2, 5, and 6. Therefore, these three stations comprised a gradient from shallower boulder-cobble habitats (defined by axis 2) to deeper mud habitats (defined by axis 1).

Station 4 was relatively heterogeneous, showing low canonical variate scores on axis 1 and intermediate scores on axis 2 (Fig. III-4). Thus, this station comprised mostly a mixture of ridge-boulder and boulder-cobble habitats.

Fish Community Characterization

Our canonical correlation analysis considered 15 fish taxa selected by three criteria (Table III-2): first, all taxa with more than 300 individuals observed among all years (12 taxa, including 6 rockfishes); second, two commercially important and fairly common species excluded by the first criterion (rex sole and sablefish); and third, the largest predatory sportfish we observed, lingcod. These taxa accounted for over 97% of all fish we observed at Heceta Bank from 1988 to 1990. We had to pool species in four of these taxa (juvenile rockfishes, cottids, agonids, and zoarcids) because, first, these fish were usually too small to identify to species from the submersible, videotapes, or photographs, and second, the submersible provided no means of capturing fish.

Considering these key species, the three major habitats defined above were correlated with distinct fish assemblages (Fig. III-3). In order of generally increasing depth, these were:

Table III-2. Fish taxa used in canonical correlation analysis and subsequent analyses, ranked by total number of individuals observed at Heceta Bank over all years. See text for criteria by which these taxa were selected. Note that not every individual fish listed here was used in the canonical correlation analysis, only those for which we had corresponding bottom-type and invertebrate data (97.7% of these fish).

	Total number of fish observed			
Taxon	All Years	1988	1989	1990
Pygmy rockfish (*Sebastes wilsoni*)	33382	12212	8069	13101
Juvenile rockfish (*Sebastes* spp.)	30891	12347	17715	829
Sharpchin rockfish (*Sebastes zacentrus*)	7109	2322	1301	3486
Rosethorn rockfish (*Sebastes helvomaculatus*)	2421	945	754	722
Yellowtail rockfish (*Sebastes flavidus*)	2410	718	1440	252
Sculpins (Cottidae)	1233	428	386	419
Dover sole (*Microstomus pacificus*)	857	458	198	201
Greenstriped rockfish (*Sebastes elongatus*)	703	297	114	292
Eelpouts (Zoarcidae)	628	327	166	135
Shortspine thornyhead (*Sebastolobus alascanus*)	562	310	103	149
Poachers (Agonidae)	613	254	176	183
Slender sole (*Lyopsetta exilis*)	416	242	102	72
Rex sole (*Glyptocephalus zachirus*)	280	132	63	85
Sablefish (*Anoplopoma fimbria*)	136	33	77	26
Lingcod (*Ophiodon elongatus*)	63	20	32	11

(1) Ridge-Boulder/Vase-sponge/Basketstar Habitat: This bank-top habitat on the shallowest parts of the bank (less than 100 m or 330 ft deep) supported mostly (in order of decreasing loadings on CCA axis 2): juvenile rockfishes, yellowtail rockfish, and lingcod. Note that most of the juvenile rockfish and lingcod in this habitat occurred over pure boulder bottoms (see below). Also present but less abundant in this habitat were all species in the boulder-cobble habitat, especially rosethorn rockfish (see below).

When encountered by the submersible, juvenile rockfishes usually schooled within 2 m (7 ft) of the bottom, yellowtail rockfish either schooled within 3 m (10 ft) of the bottom (and sometimes well off the bottom above the sub) or sat on the bottom, and lingcod usually sat on the bottom. The rockfish schools were spectacular, comprising hundreds (if not thousands) of individuals, whereas the lingcod occurred as infrequent individuals. (We had to lump all juvenile rockfishes into a single category because, first, at <10 cm [4 in] TL, they were usually too small to identify to species from the submersible, videotapes, or photographs, and second, the submersible provided no means of capturing fish.)

(2) Boulder-Cobble/Demosponge/Brittlestar Habitat: This bank-slope habitat at intermediate depths supported mostly (in order of decreasingly negative loadings on CCA axis 2): sharpchin rockfish, pygmy rockfish, greenstripe rockfish, rosethorn rockfish, and cottids (sculpins). The moderate loadings of mud-bottom species in this habitat (compare axis 1 positive loadings

with axis 2 negative loadings in Fig. III-3) was due to the interspersion of mud between patches of boulders and cobble.

Sharpchin and pygmy rockfishes attained virtually uncountable densities in this habitat, occurring in dense patches on and within 2 m (7 ft) of the bottom, often in mixed-species aggregations. Greenstripe rockfish were perhaps the most specialized of the rockfishes in terms of habitat, almost invariably occurring as one to several individuals sitting on the bottom near small, isolated rock patches surrounded by mud. In contrast, rosethorn rockfish were rock-habitat generalists, being the most ubiquitous and evenly distributed of all fish species. Because rosethorns and cottids occurred over all rocky bottoms, and thus provided little contrast between habitat types, their CCA loadings were usually low.

<u>(3) Mud/Urchin Habitat</u>: This deep habitat (mostly deeper than 150 m or 490 ft) supported (in order of decreasing loadings on CCA axis 1): Dover sole, agonids (poachers), shortspine thornyhead, zoarcids (eelpouts), rex sole, sablefish, greenstripe rockfish, and slender sole. When encountered by the submersible, fish of all of these species were sitting on the mud bottom, except sablefish, which actively swam within a few meters of the bottom. All these species tended to be evenly and sparsely distributed over mud bottoms, except greenstripe rockfish, which were invariably associated with small patches of rock surrounded by mud, and sablefish, which occurred in schools.

Also present yet relatively uncommon over mud were hagfish, ratfish, and skates. Ratfish usually hovered within a meter of the bottom, whereas skates usually lay on the bottom. We observed hagfish in burrows with their heads extended, or curled on the bottom, or occasionally actively swimming (in several instances consuming dead fish).

Interannual Variation

Variation in Habitats Sampled: In order to examine interannual variation in the distribution and abundance of fishes, we needed to determine whether our transects sampled the same relative abundance of bottom types between years. This preliminary analysis was necessary because the exact path of each transect at each station was different from all others both within and between years (Appendix 4). If there were significant differences in the distribution of bottom types between years, then between-habitat and between-year differences would be confounded, complicating our analysis.

In fact, at both the station and patch level, there was little interannual variation in the bottom types we sampled. At the station level, there was surprisingly little difference in the distribution of bottom types within stations between years (Fig. III-2, Table III-1). Of all 18 possible pairwise comparisons between years (6 stations x 3 years) using all 36 bottom types, the only significant difference appeared at Station 4 between 1989 and 1990 ($P<0.05$, Kolmogorov-Smirnov two-sample test). In 1990, we sampled more rock ridge (code RR) and less boulder and cobble bottoms (codes BC and CB) at this station than in 1989 (Fig. III-2, Table III-1). In any case, given that 1/18 is close to 5% (the percent of tests in a series commonly allowed to falsely reject the null hypothesis of no difference), it appears that we sampled virtually the same distribution of bottom types each year at each station.

At the patch level, we combined all habitat patches from all transects within each year (Fig. III-5, Table III-1). Analysis of these patterns revealed no significant differences between years in the relative abundances of all 36 bottom types ($P>0.05$, Kolmogorov-Smirnov two-sample tests). Therefore, any between-year differences in fish assemblages we detected could be safely attributed to interannual variation independent of habitat.

Community-Level Comparisons: Even at a coarse scale of resolution, the overall rank abundances of the 15 most abundant and/or commercially valuable species we examined (listed in Table III-2) were significantly different among years (Kendall's coefficient of rank concordance=0.271, $P=0.017$, df=2).

At a finer scale of resolution, the variate scores of our canonical correlation analysis are essentially composite variables that combine all habitat variables (bottom types and invertebrates) or all fish species by habitat patch. Therefore, examining among-year variation in the CCA scores provided a truly community-level test of interannual variation in the fish assemblages of Heceta Bank.

One-way analyses of variance (ANOVA) of the CCA variate scores for both habitats and fishes on the first and second axes (i.e., four analyses) detected significant differences among years only for fishes on axis 1 (Table III-3). The lack of significant interannual variation in the habitat scores on both

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Figure III-5. Overall percent cover of the ten dominant bottom types observed at Heceta Bank, pooled for each year. Bottom types are listed by decreasing relief and particle size, where the first letter is the dominant substratum and the second letter is the second most prevalent substratum: R=rock ridge; B=boulder; C=cobble; P=pebble; M=mud.

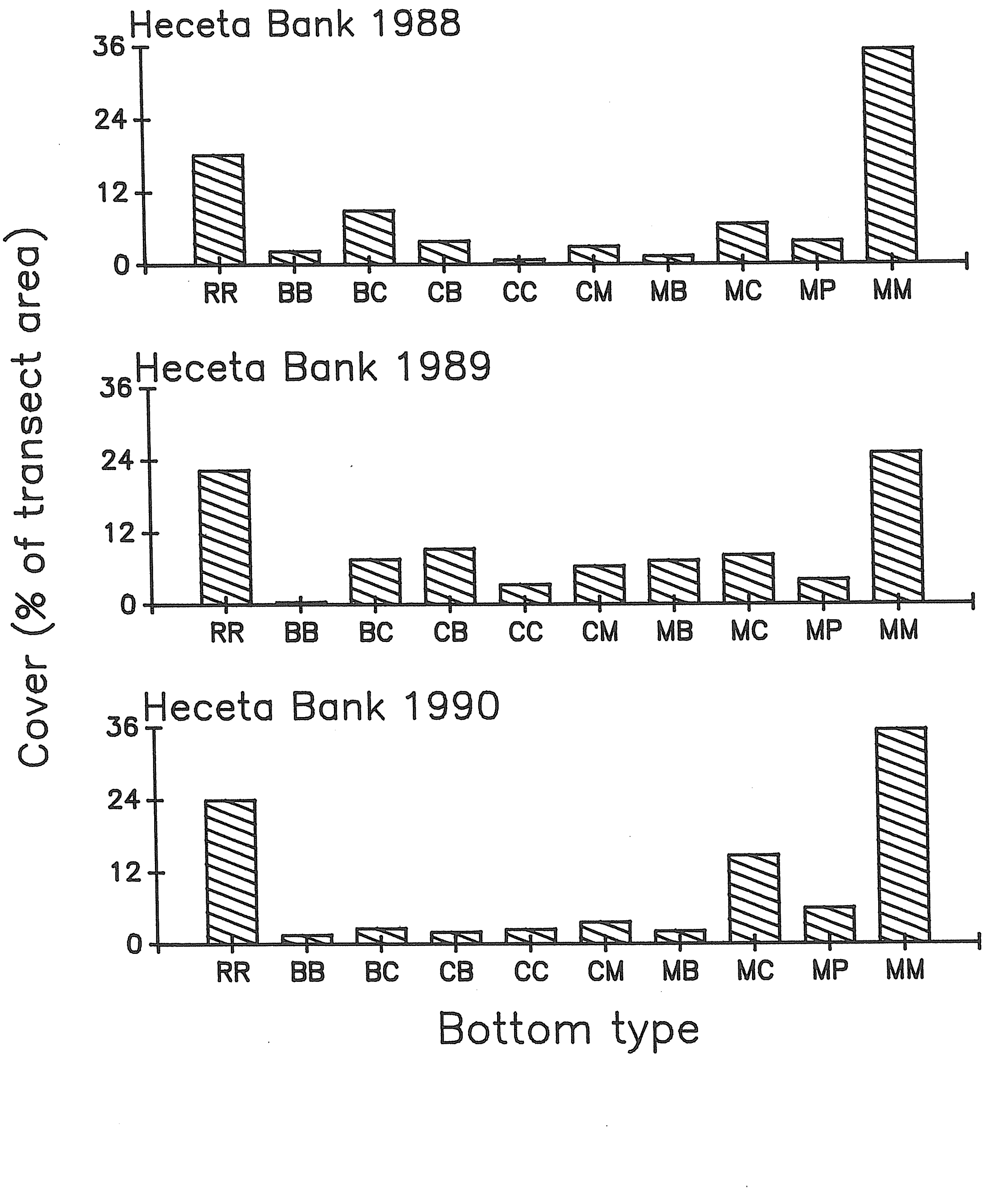

Heceta Bank 1988
Heceta Bank 1989
Heceta Bank 1990
Cover (% of transect area)
0
12
24
36
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Bottom type

Table III-3. One-way analyses of variance on CCA variate scores among years at Heceta Bank, 1988-1990. Canonical variate scores were derived from canonical correlation analysis of habitat patches (n = 1198, see table in caption to Fig. III-2).

Source	df	MS	Fs
A. Axis 1: Habitat			
Year	2	86.84	1.83 NS
Residual	1195	47.34	
B. Axis 1: Fish			
Year	2	862.8	3.18 *
Residual	1195	270.9	
C. Axis 2: Habitat			
Year	2	2150	0.47 NS
Residual	1195	4555	
D. Axis 2: Fish			
Year	2	292.3	1.18 NS
Residual	1195	247.6	

* P < .05
NS = Not significant (P > .05)

axes bolstered our previous conclusion that we had sampled largely the same suite of bottom types each year. Moreover, because the habitat scores included invertebrate abundances, these tests also inferred that we sampled largely the same invertebrate assemblages each year.

The significant interannual variation in canonical variate scores for fishes on axis 1 (Table III-3) occurred on boulder-dominated bottoms (codes BB and BC in Fig. III-6). By and large, the species involved were the most abundant occupants of these bottom types, namely: juvenile rockfish, pygmy rockfish, and sharpchin rockfish (Fig. III-7). Juvenile rockfish were most abundant in 1989, reaching densities of tens of thousands per hectare, but were nearly absent in 1990 (codes BB and BC in Fig. III-7). Juveniles occurred mostly over solid boulders (code BB), which appeared to provide numerous refuges. In contrast, pygmy rockfish were most abundant in 1990, occurring over both pure boulders and boulders with cobble (code BC). Among years, pygmies were more abundant over BB bottoms in 1988, more abundant over BC bottoms in 1989, and about equally abundant over both bottom types in 1990. Sharpchin rockfish were also more abundant in 1990 than the other two years, occurring that year over both BB and BC bottoms. Thus, overall, juvenile rockfish were most abundant in 1989, whereas pygmy and sharpchin rockfish were most abundant in 1990 (Fig. III-7).

<u>Station-Level Comparisons of CCA Scores</u>: Because any future comparative sampling at Heceta Bank will probably be at our six stations, it was desirable to relate our overall canonical

Figure III-6. CCA variate scores (mean ± 1 SE) for fishes and habitat (bottom type and invertebrates) at Heceta Bank, 1988-1990. Habitat patches with high scores on axis 1 (CC1) are associated with mud/urchin habitats, while patches with low scores are associated with rock habitats. Patches with high scores on axis 2 (CC2) are associated with ridge-boulder/vase-sponge/basketstar habitats, while patches with low scores are associated with boulder-cobble/demosponge/brittlestar habitats. Bottom types are listed by decreasing relief and particle size, where the first letter is the dominant substratum and the second letter is the second most prevalent substratum: R=rock ridge; B=boulder; C=cobble; P=pebble; M=mud. (n = 1198, see table in caption to Fig. III-2.)

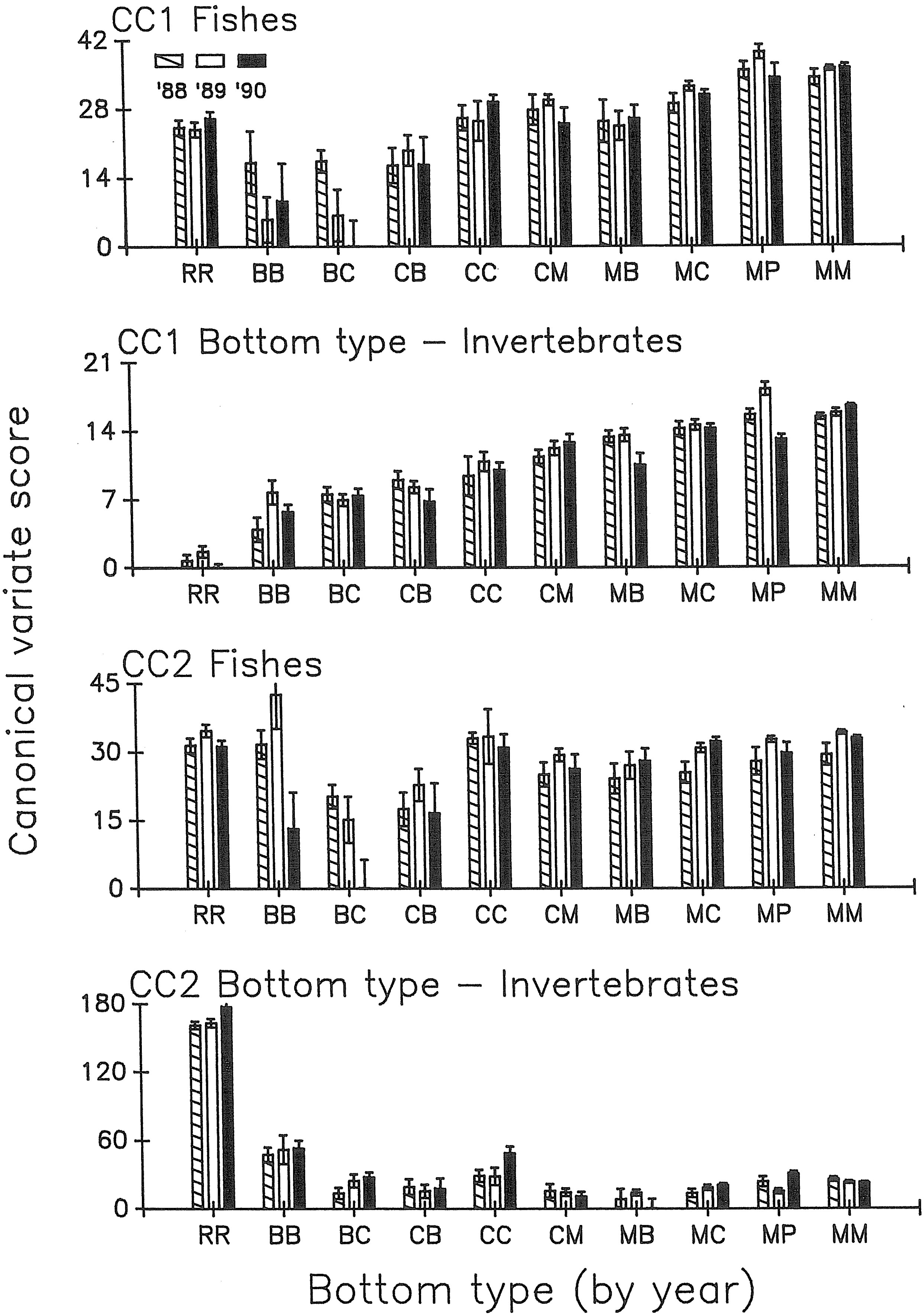
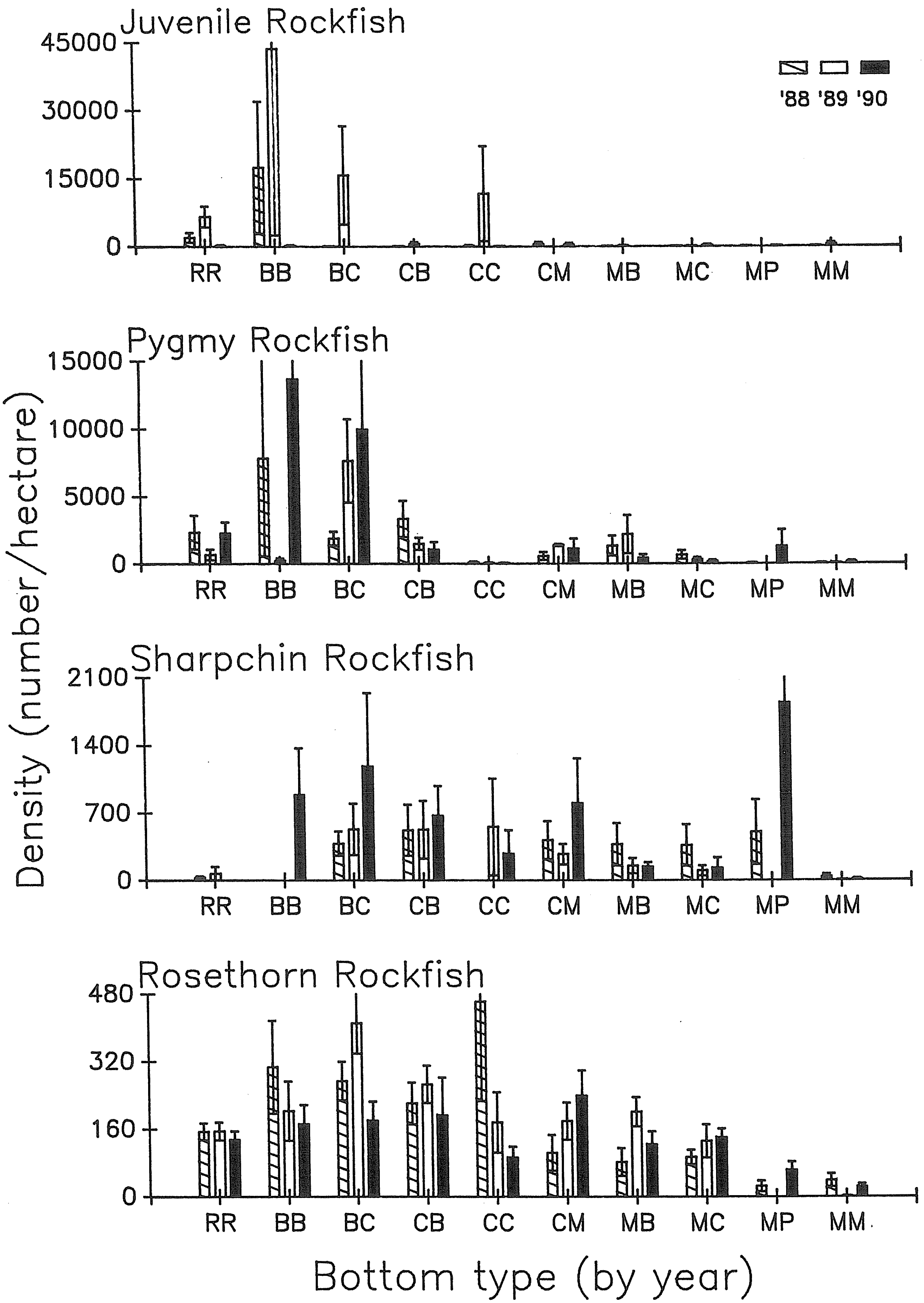
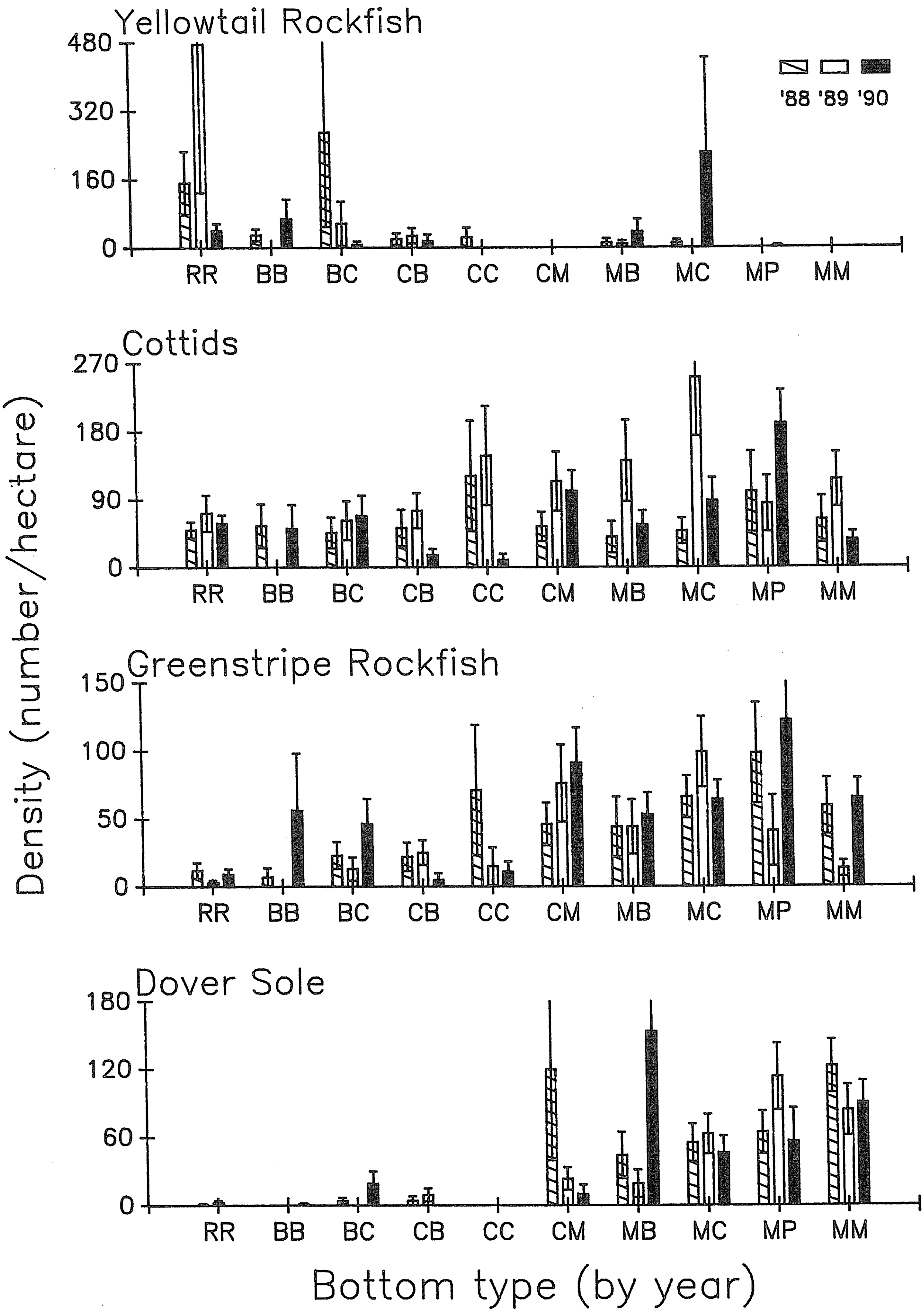
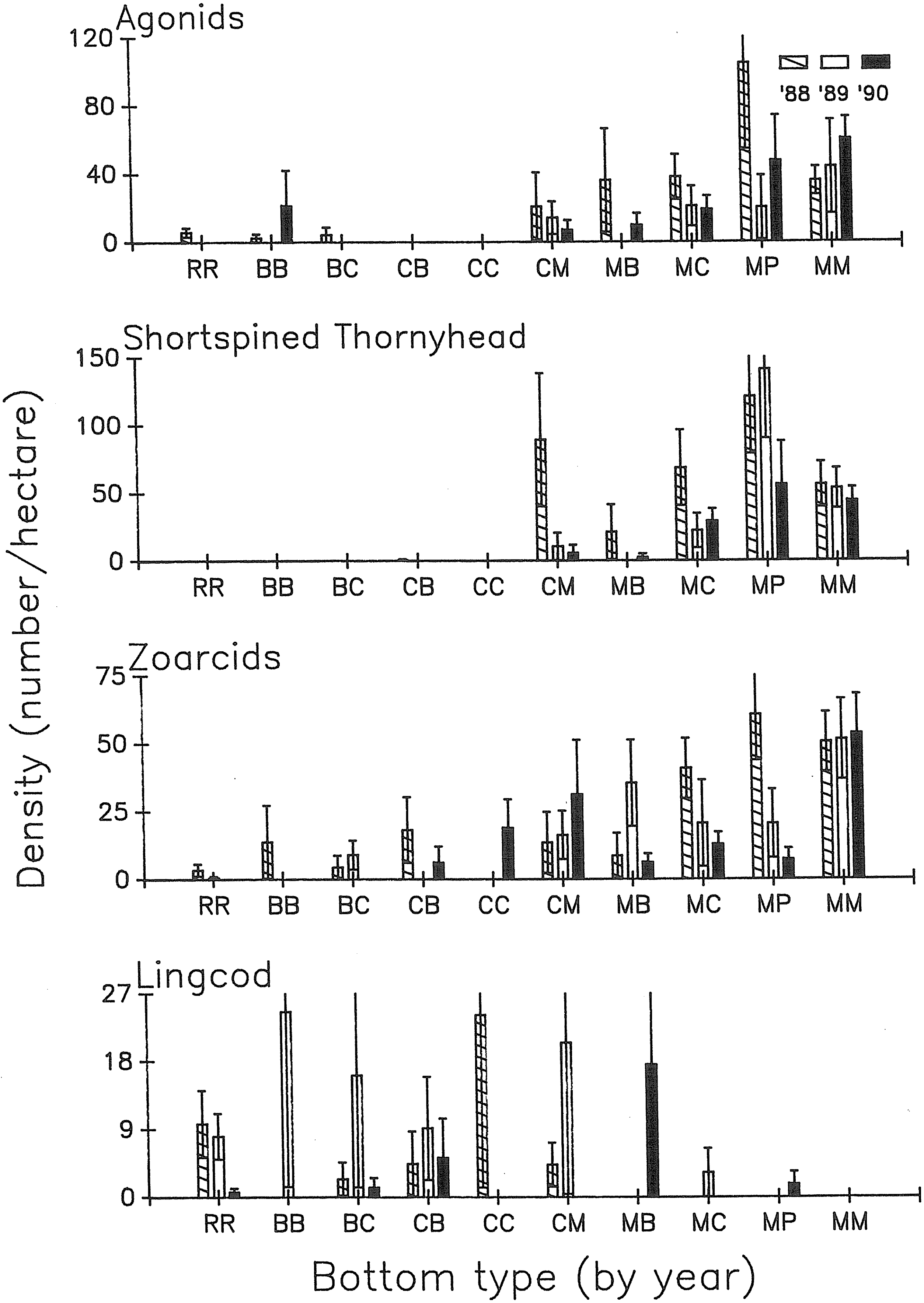

CC1 Fishes
'88
'89
'90
42
28
14
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
CC1 Bottom type — Invertebrates
21
14
7
0
CC2 Fishes
45
30
15
0
CC2 Bottom type — Invertebrates
180
120
60
0
Canonical variate score
Bottom type (by year)

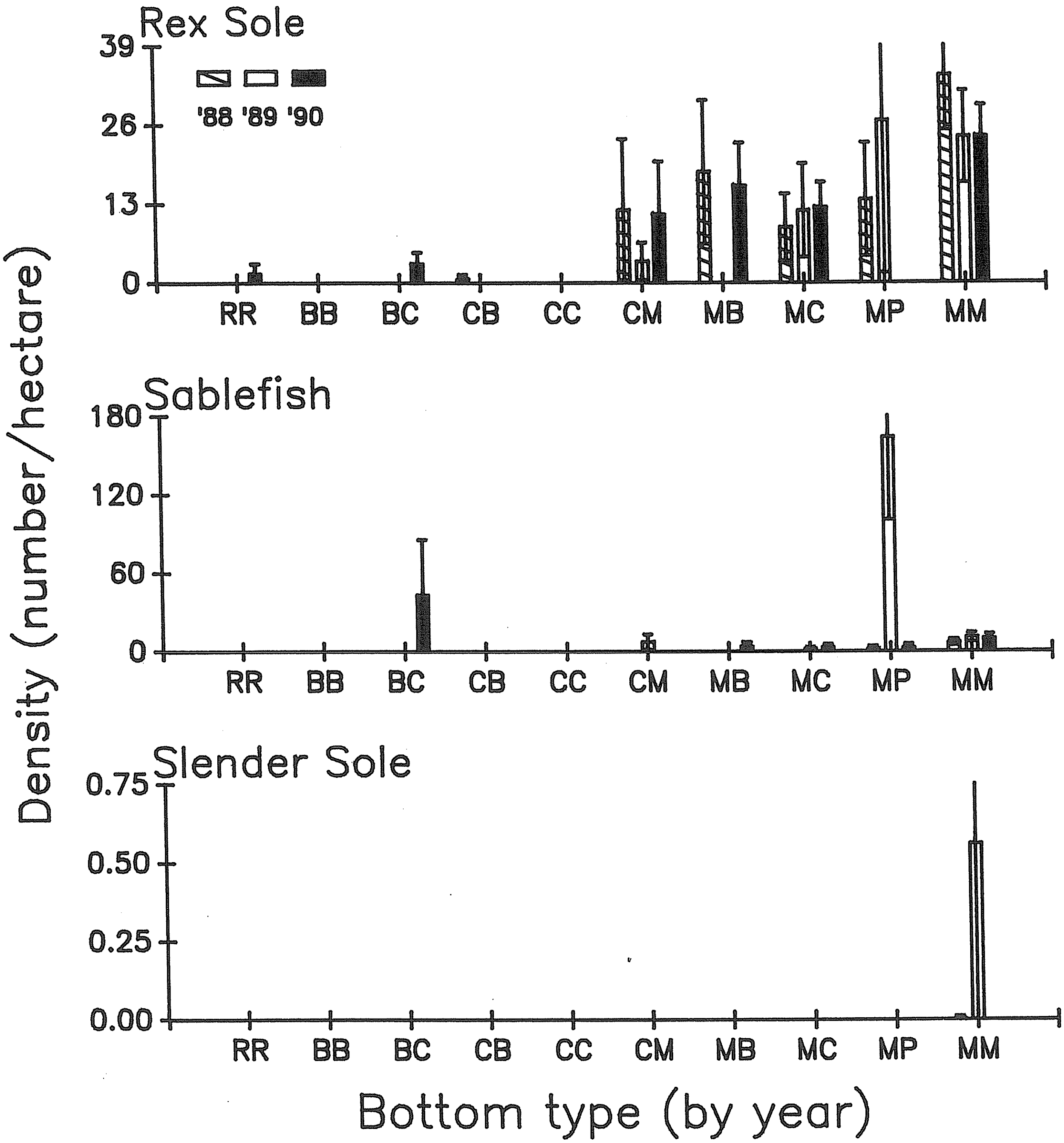
Figure III-7. Densities (mean number/hectare ± 1 SE) of 15 selected fish taxa among the ten dominant bottom types at Heceta Bank, 1988-1990. Note that the y-axis is scaled differently for each species, and that the species are ranked by overall abundance. Bottom types are listed by decreasing relief and particle size, where the first letter is the dominant substratum and the second letter is the second most prevalent substratum: R=rock ridge; B=boulder; C=cobble; P=pebble; M=mud. (n = 1198, see table in caption to Fig. III-2.)


Juvenile Rockfish
45000
30000
15000
0
'88 '89 '90
RR BB BC CB CC CM MB MC MP MM
Pygmy Rockfish
15000
10000
5000
0
RR BB BC CB CC CM MB MC MP MM
Sharpchin Rockfish
2100
1400
700
0
RR BB BC CB CC CM MB MC MP MM
Rosethorn Rockfish
480
320
160
0
RR BB BC CB CC CM MB MC MP MM
Density (number/hectare)
Bottom type (by year)



Yellowtail Rockfish
480
320
160
0
'88 '89 '90
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Cottids
270
180
90
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Greenstripe Rockfish
150
100
50
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Dover Sole
180
120
60
0
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Density (number/hectare)
Bottom type (by year)


Agonids
120
80
40
0
'88 '89 '90
RR
BB
BC
CB
CC
CM
MB
MC
MP
MM
Shortspined Thornyhead
150
100
50
0
Zoarcids
75
50
25
0
Lingcod
27
18
9
0
Density (number/hectare)
Bottom type (by year)



Rex Sole
'88 '89 '90
39
26
13
0
RR BB BC CB CC CM MB MC MP MM
Sablefish
180
120
60
0
RR BB BC CB CC CM MB MC MP MM
Slender Sole
0.75
0.50
0.25
0.00
RR BB BC CB CC CM MB MC MP MM
Density (number/hectare)
Bottom type (by year)

correlation analysis to each station. Recall that the CCA used habitat patches as samples *independent* of stations. Because we knew the stations from which each patch came, we could examine interannual variation in our CCA variate scores by station.

Two-way ANOVAs of the fish and habitat CCA variate scores for the first and second axes (i.e., four analyses) revealed every case that: first, there was no significant year effect (i.e., no significant interannual variation); second, there was a significant station effect; and third, there was a significant interaction between years and stations in all cases (Table III-4). The significant differences among stations was expected, and merely a byproduct of inherent station differences. The lack of significant interannual variation in habitat scores on both axes corroborated our earlier analyses indicating that the same habitats were sampled between years (see above).

The absence of significant interannual variation in fish scores on both CCA axes (Table III-4) suggested that comparisons at the community-level by sampling stations provided insufficient resolution to detect differences in composite fish variables among years. This outcome was most likely due to numerous variables being confounded at this level of analysis.

Station-Level Comparisons of Fish Densities: Independent of our canonical correlation analysis, we also ran a more traditional analysis of interannual variation: 2-way ANOVAs (year x station) of the densities of the 15 fish taxa we examined in the CCA. Four of the rockfish taxa occurred both in polarized schools and as individuals (juveniles, pygmies, sharpchins, and yellowtails).

Table III-4. Two-way analyses of variance on CCA variate scores among years and stations at Heceta Bank, 1988-1990 (n = 1198, see table in caption to Fig. III-2).

Source	df	MS	Fs
A. Axis 1: Habitat			
Year	2	3.34	0.11 NS
Station	5	3468.95	112.71 ***
Interaction	10	177.74	5.78 ***
Residual	1180	30.78	
B. Axis 1: Fish			
Year	2	593.06	2.37 NS
Station	5	4006.34	15.99 ***
Interaction	10	729.01	2.91 ***
Residual	1180	250.49	
C. Axis 2: Habitat			
Year	2	2496.39	0.75 NS
Station	5	255060.35	76.15 ***
Interaction	10	16797.81	5.02 ***
Residual	1180	3349.51	
D. Axis 2: Fish			
Year	2	346.02	1.59 NS
Station	5	4204.44	19.31 ***
Interaction	10	1829.34	8.40 ***
Residual	1180	217.78	

*** P < .001
NS = Not significant (P > .05)

Because our density estimates of schools were necessarily less accurate than those of nonschooling individuals, we ran separate analyses for these behavioral categories, as well as analyses of all fish pooled. Most of the ANOVAs detected significant station effects, which we expected given the habitat differences among stations. Significant year effects provided evidence for interannual variation in fish densities. In some cases, these were confounded by significant interaction terms, which meant that variation among years depended upon the particular station examined.

Of the 23 ANOVAs, only two species exhibited both a clearly significant year effect with a nonsignificant interaction term (Table III-5): rosethorn rockfish and lingcod. Both species were more abundant in 1989 than the other two years (Fig. III-8). Yellowtail rockfish (schooling and total) exhibited a marginally significant year effect ($P<0.08$) with a nonsignificant interaction term (Table III-5). This species was also most abundant in 1989 (Fig. III-8).

Clearly significant year effects confounded by significant interaction terms were detected for two taxa (Table III-5): both schooling and total juvenile rockfish, and shortspine thornyhead. Schooling and total juvenile rockfish were clearly most abundant in 1989 (at Station 1), whereas shortspine thornyhead were least abundant in 1989 (at Stations 5 and 6, Fig. III-8).

A marginally significant year effect confounded by a marginally significant interaction term was detected for sablefish (Table III-5). This species was most abundant in 1989 at the two stations (5 and 6) where it occurred (Fig. III-8).

Table III-5. Two-way analyses of variance of fish densities among years and stations at Heceta Bank, 1988-1990.

	Factors		
Species	Year	Station	Interaction
Pygmy rockfish			
Schooling	NS	**	NS
Non-schooling	NS	***	NS
Total	NS	**	NS
Juvenile rockfish			
Schooling	**	***	***
Non-schooling	NS	*	*
Total	**	***	***
Sharpchin rockfish			
Schooling	NS	NS	NS
Non-schooling	NS	*	NS
Total	NS	*	NS
Yellowtail rockfish			
Schooling	#	#	NS
Non-schooling	NS	**	NS
Total	#	*	NS
Rosethorn rockfish	*	***	NS
Greenstripe rockfish	NS	NS	NS
Shortspine thornyhead	**	***	**
Dover sole	NS	***	NS
Slender sole	NS	NS	NS
Rex sole	NS	***	***
Cottids	NS	**	NS
Zoarcids	NS	***	**
Agonids	NS	***	*
Sablefish	#	***	#
Lingcod	*	**	NS

*** P < .001
** P < .01
* P < .05
# P < 0.08
NS = Not significant (P > .05)

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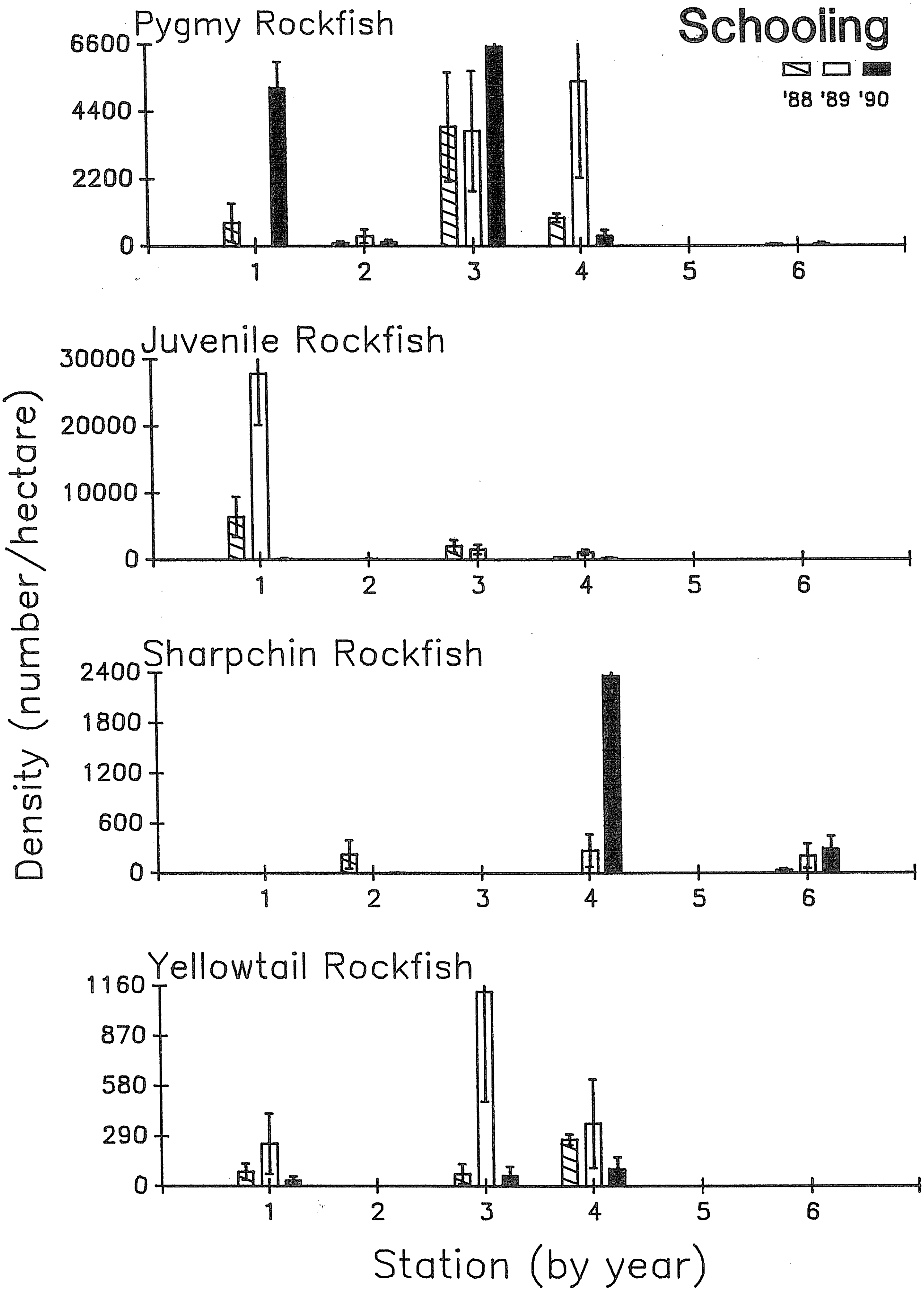
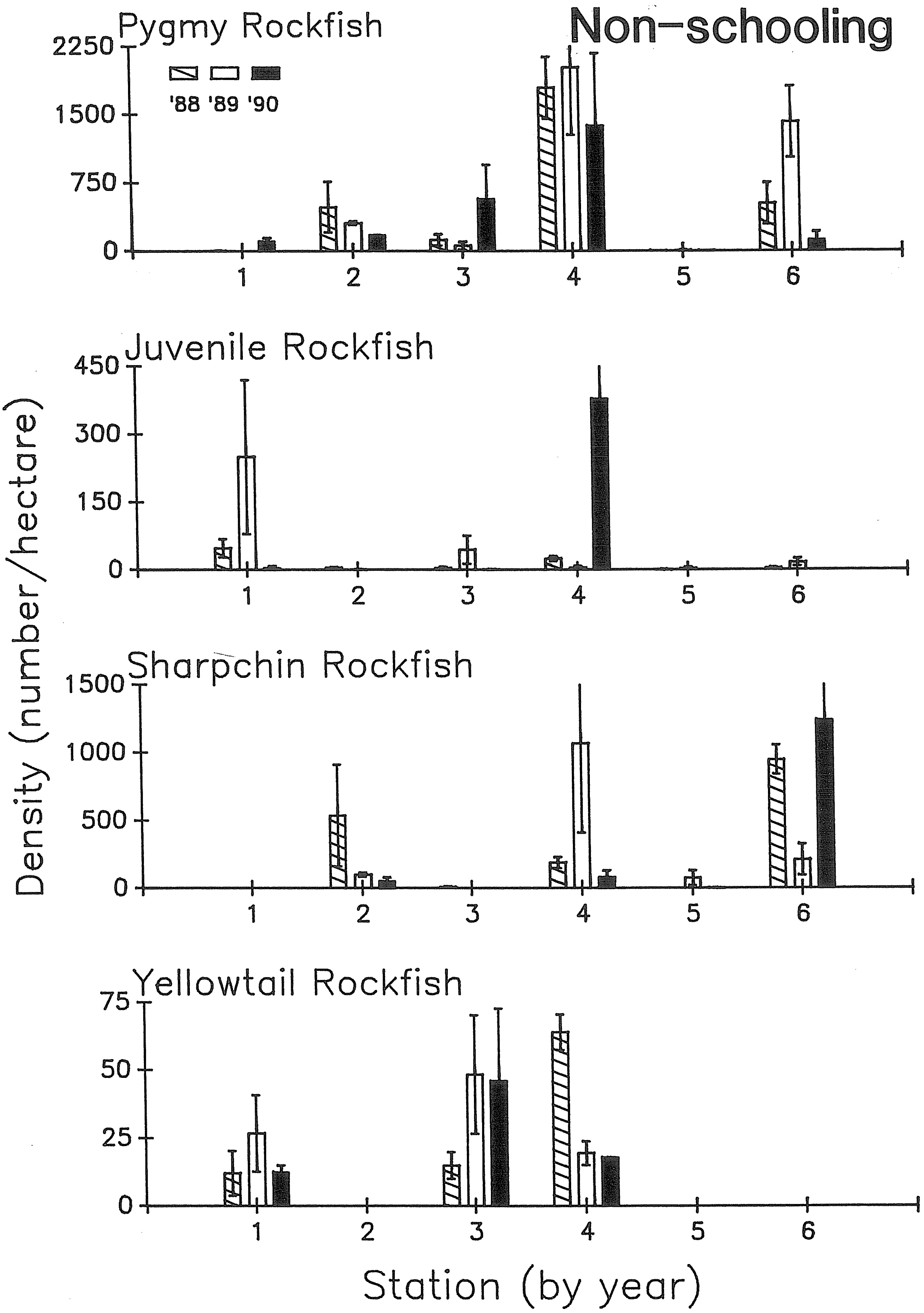
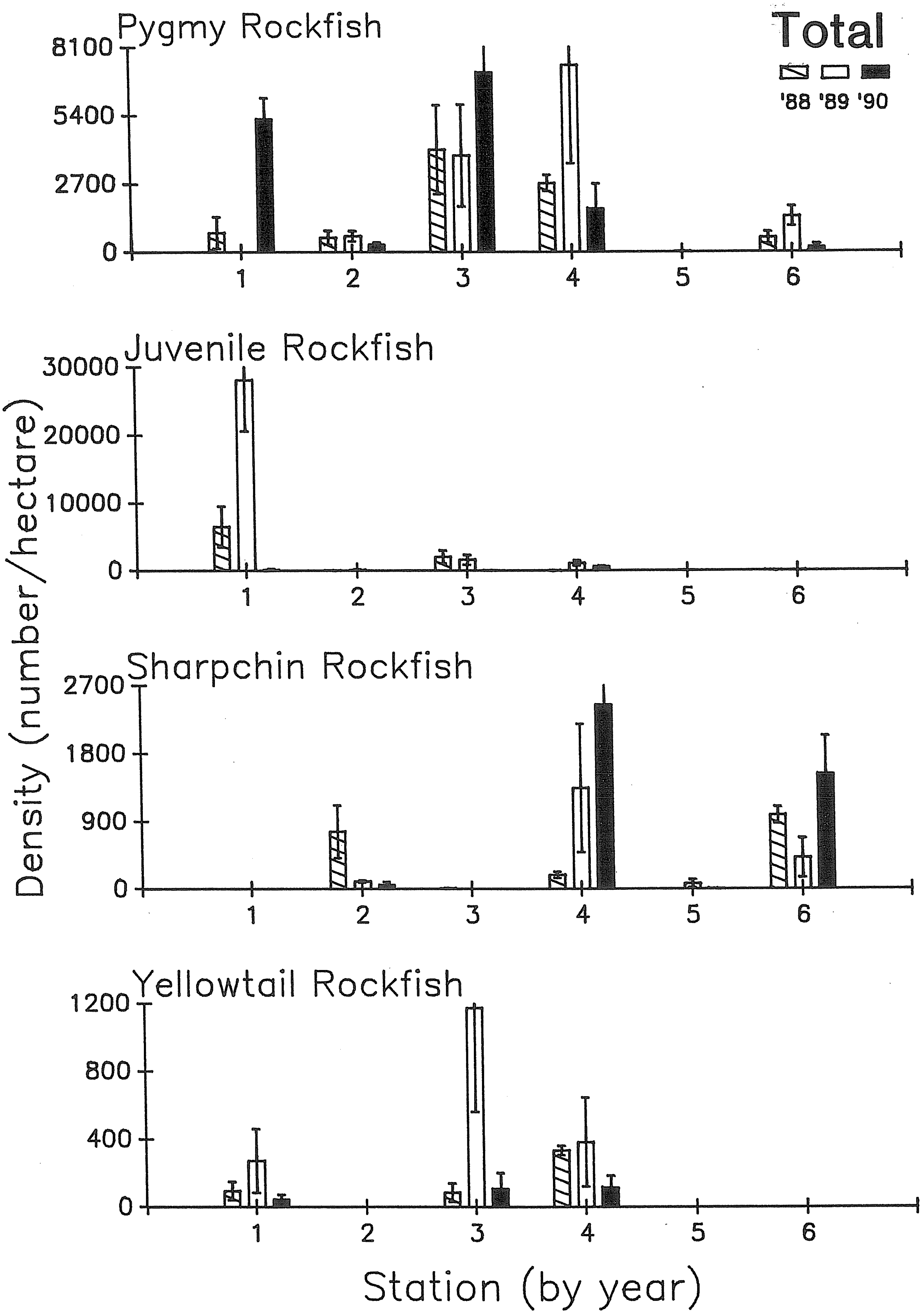
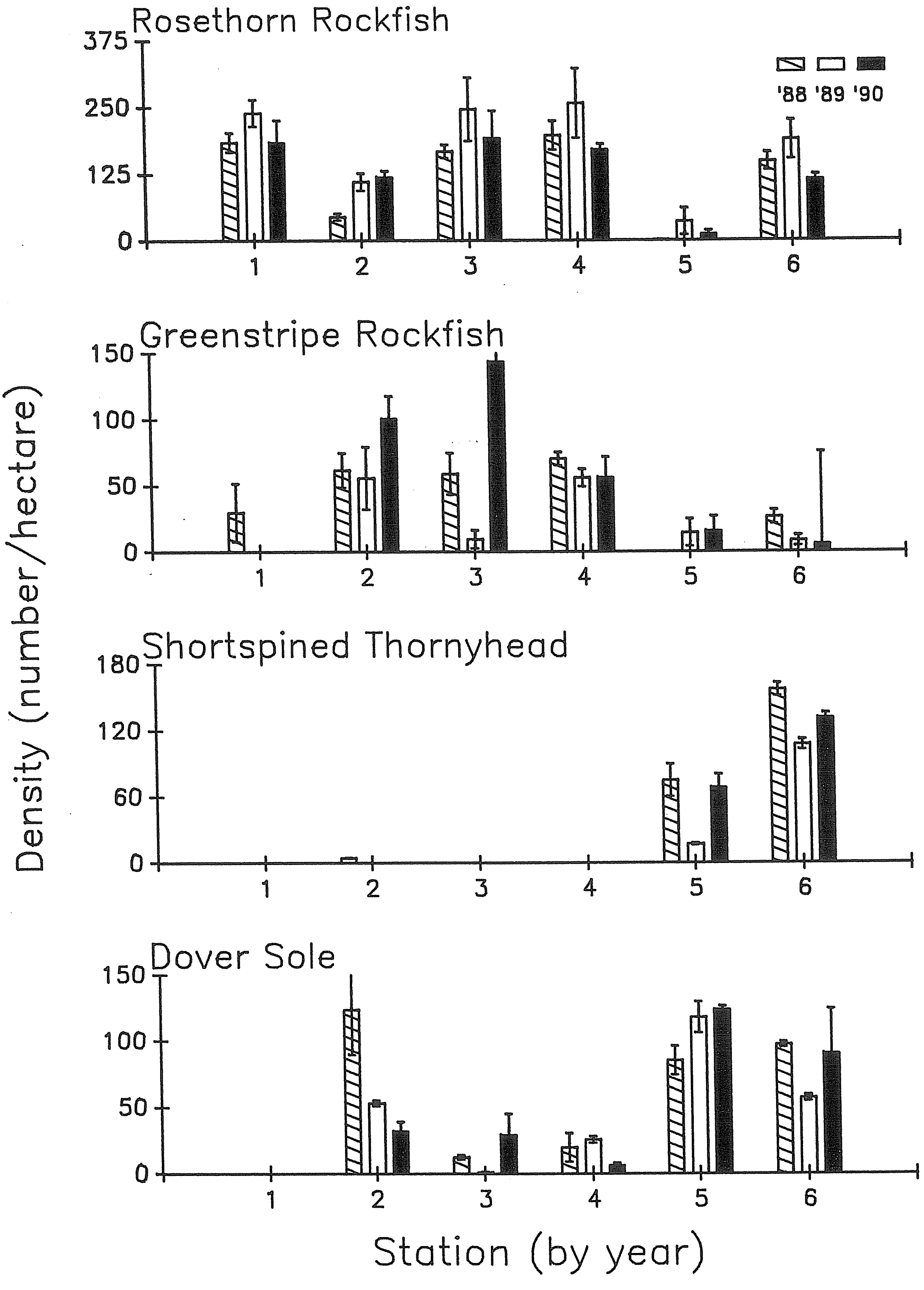
Figure III-8. Densities (mean number/hectare ± 1 SE) of 15 selected fish taxa among sampling stations at Heceta Bank, 1988-1990. Note that the y-axis is scaled differently for each species. Pygmy, juvenile, sharpchin, and yellowtail rockfishes are plotted for schooling, nonschooling, and total individuals. The remaining 11 taxa, which did not form schools, are plotted for total individuals, ranked by overall abundance. (n = 1198, see table in caption to Fig. III-4.)

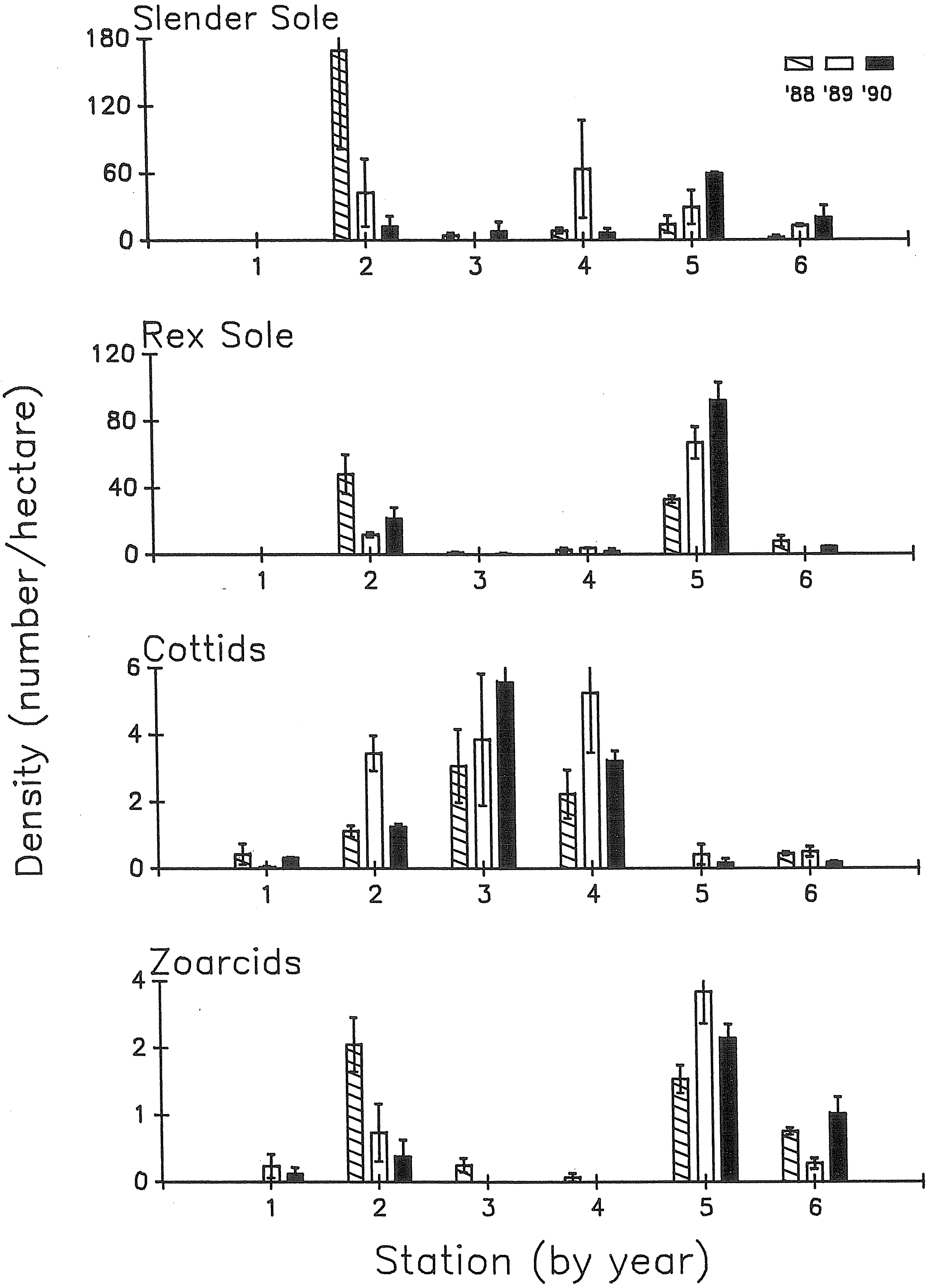

Schooling
▨ □ ■
'88 '89 '90
Pygmy Rockfish
6600
4400
2200
0
1
2
3
4
5
6
Juvenile Rockfish
30000
20000
10000
0
Sharpchin Rockfish
2400
1800
1200
600
Yellowtail Rockfish
1160
870
580
290
Density (number/hectare)
Station (by year)

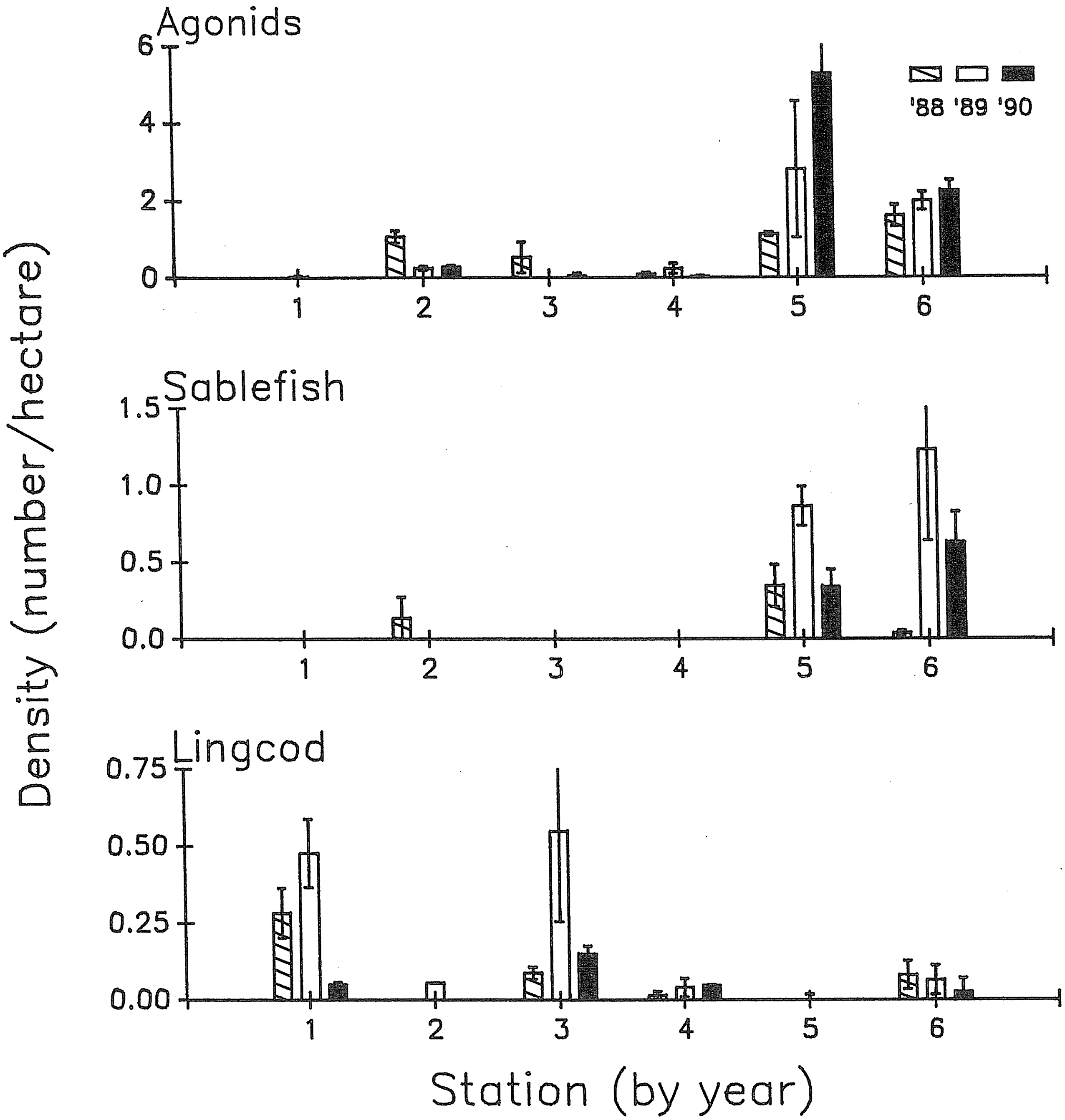


Non-schooling
Pygmy Rockfish
▨ □ ■
'88 '89 '90
2250
1500
750
0
1 2 3 4 5 6
Juvenile Rockfish
450
300
150
0
1 2 3 4 5 6
Sharpchin Rockfish
1500
1000
500
0
1 2 3 4 5 6
Yellowtail Rockfish
75
50
25
0
1 2 3 4 5 6
Density (number/hectare)
Station (by year)


Pygmy Rockfish
Total
'88 '89 '90
8100
5400
2700
0
1
2
3
4
5
6
Juvenile Rockfish
30000
20000
10000
0
1
2
3
4
5
6
Sharpchin Rockfish
2700
1800
900
0
1
2
3
4
5
6
Yellowtail Rockfish
1200
800
400
0
1
2
3
4
5
6
Density (number/hectare)
Station (by year)


Rosethorn Rockfish
375
250
125
0
'88 '89 '90
1
2
3
4
5
6
Greenstripe Rockfish
150
100
50
0
1
2
3
4
5
6
Shortspined Thornyhead
180
120
60
0
1
2
3
4
5
6
Dover Sole
150
100
50
0
1
2
3
4
5
6
Density (number/hectare)
Station (by year)


Slender Sole
180
120
60
0
'88 '89 '90
1
2
3
4
5
6
Rex Sole
120
80
40
0
Cottids
6
4
2
0
Zoarcids
4
2
1
0
Density (number/hectare)
Station (by year)


Agonids
6
4
2
0
1
2
3
4
5
6
▨ ☐ ■
'88 '89 '90
Sablefish
1.5
1.0
0.5
0.0
1
2
3
4
5
6
Lingcod
0.75
0.50
0.25
0.00
1
2
3
4
5
6
Density (number/hectare)
Station (by year)

In sum, the species-by-species station-level analyses detected substantial interannual variation in the abundances of 6 of the 15 most common and/or commercially important fish taxa. Five of these six species were more abundant in 1989 than 1988 and 1990, with abundances in the latter two years being similar.

Synthesis and Discussion

Fish Assemblages: There are three major habitats at Heceta Bank: (1) shallow rock ridges and boulders dominated by vase sponges and basketstars, (2) bank-slope boulder-cobble fields dominated by demosponges and brittlestars, and (3) deep mud flats dominated by *Allocentrotus* urchins. These habitats support at least 69 species of conspicuous fishes. Although several species, such as rosethorn rockfish and cottids (sculpins), are common over all rocky bottoms, most species form fairly distinct assemblages:

(1) Shallow Rock Ridges and Boulders: This habitat is characterized by supporting most of the juvenile rockfishes, yellowtail rockfish, and lingcod we encountered. Over all three years, this area supported an intermediate density of fish (grand average = 517 fish/hectare), yet the lowest species richness (about 28 fish species) of the three major habitats.

We hypothesize that rockfishes utilize shallow boulders as a juvenile nursery which provides: (1) the closest suitable habitat for larval settlement from the epipelagic plankton; (2) a source of small invertebrate food; and (3) numerous holes, crevices, and large sessile invertebrates for shelter, especially as refuges from predation (see Hixon 1991). This hypothesis is consistent with the observed ontogenetic shift of nearshore rockfishes from shallow to deep habitats as they grow (Love at al. 1991). Straty (1987) and Carlson and Straty (1981) also concluded that rocky pinnacles served as nursery habitat for rockfish off southeastern Alaska. Given the commercial importance of rockfishes, shallow rocky bank habitats may be crucially important "harvest refuges" for replenishing exploited stocks in the region.

Lingcod, a valued sportfish, may be attracted to shallow boulders because it feeds on the small rockfish. Yellowtail rockfish, a commercially important species, may utilize the bank-top habitat for shelter between foraging forays for midwater euphausiids (see Chapter 5).

(2) Boulder-Cobble Fields: This intermediate-depth habitat is characterized by supporting most of the sharpchin, pygmy, greenstripe, and rosethorn rockfish we encountered, as well as most of the cottids (sculpins). Over all three years, this habitat supported the greatest density of fish (grand average = 5133 fish/hectare), yet intermediate species richness (about 45 fish species) compared to the other two major habitats.

Pygmy and sharpchin rockfish occur in extremely high densities in this heterogeneous habitat, suggesting that this is a very productive area. Given that these abundant and morphologically similar congeners often occur together in aggregations, the mechanism of their coexistence is problematical. Rockfish species occupying shallower reefs typically segregate by depth (Hallacher and Roberts 1985), which has been demonstrated by field experiments to be a result of ongoing interspecific competition (Larson 1980b). We hypothesize that co-occurring pygmy and sharpchin rockfish consume different foods or that their prey may not be locally limiting. An alternative hypothesis is that each species may be most abundant on a different "source" bank (see Chapter 4).

Relative to other rockfishes at Heceta Bank, the greenstripe rockfish was a habitat specialist, occurring almost exclusively near small isolated patches of rock surrounded by mud. Richards (1986) observed a similar distribution for greenstripe rockfish in the Strait of Georgia, British Columbia. In contrast, the rosethorn rockfish was a habitat generalist, found commonly in all rocky areas. Trophic analyses of all these rockfishes will be necessary before the ecological interactions among the species inhabiting deep reefs can be hypothesized.

(3) Deep Mud: This habitat is characterized by supporting most of the shortspine thornyhead, flatfishes, sablefish, zoarcids (eelpouts), and agonids (poachers) we encountered. Also mostly exclusive to this habitat are hagfish, ratfish, and skates. This is the most distinct assemblage because of the obvious structural modifications of most of the resident species, apparent adaptations for exploiting soft bottoms. Over all three years, this habitat surprisingly supported the greatest species richness (about 54 fish species), yet the lowest density of fish (grand average = 41 fish/hectare) of the three major habitats.

<u>Interannual Variation</u>: In our samples from 1988 to 1990, we detected substantial interannual variation in the densities of 8 of 15 common and/or commercially valuable fish taxa at Heceta Bank, summarized in Table III-6. This variation occurred at two levels of resolution: community-level by habitat patches ("patch level" in Table III-6), species-level by sampling stations ("station level" in Table III-6). Not surprisingly, community-level comparisons by sampling stations were not significant, probably because so many variables were confounded.

At the community-level analysis of habitat patches, only three taxa (juvenile rockfish, pygmy rockfish, and sharpchin rockfish) varied significantly among years (Table III-6). This variation occurred over the boulder and cobble bottoms that these species dominate. There was no general pattern among these species in interannual variation; juvenile rockfish were most abundant in 1989, whereas pygmy and sharpchin rockfish were most abundant in 1990.

It is tempting to speculate that the abundant juveniles observed in 1989 grew into the abundant pygmies and sharpchins observed in 1990. However, given the patchy nature of schools of juvenile rockfishes, it is impossible to separate true interannual variation in these fish from the possible statistical artifact of sampling clumped items. This is problem is compounded by the fact that this "taxon" included more than one species. Nonetheless, it appeared that there was substantial interannual variation in the recruitment of rockfishes at Heceta Bank, as has been noted for inshore species (Love et al. 1991). The more ubiquitous and even distributions of pygmy and sharpchin

Table III-6. Summary of patterns of substantial interannual variation in fish densities at Heceta Bank, 1988-1990. Patch-level comparisons are derived from analyses of CCA variate scores (Table III-3, Figs. III-6 and III-7). Here, "habitats" are the bottom types over which each species was most abundant. Station-level comparisons are derived from analyses of fish densities (Table III-5, Fig. III-8). Here, "habitats" are the sampling stations at which each species was most abundant. For each comparison among years, the maximum density is underlined.

		Average density (number/hectare)		
Taxon	Habitat	1988	1989	1990
A. Patch-level comparisons:				
Pygmy rockfish	BB,BC	4,094	6,392	11,201
Sharpchin rockfish	BB,BC	240	441	1,082
Juvenile rockfish	BB,BC	6,487	20,321	45
B. Station-level comparisons:				
Lingcod	all stations	4	8	1
Rosethorn rockfish	all stations	148	154	104
Yellowtail rockfish	all stations	96	159	45
Juvenile rockfish	station 1	6,542	16,342	164
Shortspine thornyhead	stations 5 & 6	176	96	101
Sablefish	stations 5 & 6	4	46	33

rockfish suggest that the observed interannual variation in these species was real.

At the species-level analysis by sampling stations, the densities of six taxa (lingcod, rosethorn and yellowtail rockfish, juvenile rockfish, shortspine thornyhead, and sablefish) exhibited substantial interannual variation (Table III-6). All these fishes, except thornyheads, were more abundant in 1989 than the other two years, suggesting concordant variation. The high abundance of juvenile rockfish in 1989 could be attributed to a strong recruitment cohort, which was perhaps tracked by local immigration of piscivorous adults of the other species, especially lingcod. In any case, 1989 was not an unusual year in terms of general oceanographic conditions, so the ultimate cause of this concordant variation is unknown.

Finally, it appears that interannual variation was most prevalent in the shallower rock-dominated parts of Heceta Bank. Fish assemblages on deep mud seemed to be more constant among years. Eight of the 15 species we examined were from the deep-mud habitat, yet only two of these eight (shortspine thornyhead and sablefish) varied substantially in abundance between years.

Conclusions

In detecting cases of substantial interannual variation in 8 of the 15 most abundant and/or commercially important fish taxa sampled, we are inclined to reject our null hypothesis of between-year constancy in the fish assemblages at Heceta Bank. This conclusion is bolstered by our low sample sizes causing low power in our statistical tests (Chapter 2). That is, our tests conservatively tended to detect no differences between years when real differences existed.

Such interannual variation is typical of demersal fish populations on continental shelves worldwide, despite the fact that the causes of such variability still eludes general explanation (review by Postma and Zijlstra 1988). Nonetheless, the species composition of the fish assemblages at Heceta Bank did remain constant from year to year. The value of this data set is that it provides a measure of natural variation in the densities of the dominant fishes in these assemblages, thus presenting a useful basis of comparison for evaluating future human impacts.

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Chapter 4

COMPARISON OF FISH ASSEMBLAGES AT HECETA, COQUILLE, AND DAISY BANKS, OREGON

The goals of this chapter are twofold: (1) to describe the associations of bottom types, visually dominant invertebrates, and demersal fishes we sampled at Heceta, Coquille, and Daisy Banks in 1990; and (2) to examine similarities and differences in these assemblages among the banks. We conclude that, although these banks support similar suites of species, the relative abundances (and in some cases, sizes) of the fishes they support are substantially different.

General Patterns

Table IV-1 compares our sampling effort and number of fish and invertebrate taxa observed at the three banks in 1990. Appendix 1 provides a master list of the scientific and common names of all taxa sampled, as well as an overview of the relative abundance or presence/absence of each taxon among banks and sampling stations. Appendix 2 provides a master list of all our dives, and Appendix 3 provides a data summary from each transect dive, including the abundance or presence/absence of each fish/invertebrate taxon and bottom type encountered. Maps of all banks and transect paths are provided by Figures II-1 and II-2 (Chapter 2) and Appendix 4, respectively.

Habitat Characterization

Geologically, the three banks are strikingly different. As detailed in Chapter 2 (Fig. II-3), Daisy Bank is a submarine

Table IV-1. Sampling effort among the three banks in 1990.

Sampling stations	Dives per station	Depth range sampled	Taxa observed	
			Fishes	Invertebrates
Daisy Bank:				
3	2	127-203 m (417-666 ft)	40	25
Heceta Bank:				
6	2	67-360 m (220-1181 ft)	57	84
Coquille Bank:				
4*	2	97-355 m (318-1099 ft)	55	64

* Stations 5-8 (Stations 1-4 were exploratory: 1 dive each).