DEEPWATER HABITAT AND FISH RESOURCES ASSOCIATED WITH THE BIG CREEK MARINE ECOLOGICAL RESERVE

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ABSTRACT

Big Creek Marine Ecological Reserve (BCER), located off the central California coast, has been closed to fishing since January 1994. We used side scan sonar and an occupied submersible to collect baseline information on species-habitat relationships, density, and species and size composition of fish inside and outside BCER. Forty-three dives were made in the fall of 1997 and 1998, at depths of 20–250 m. From 142 video transects, we identified over 70,000 fish from 82 taxa, including 36 species of rockfish. About 93% of the 25,159 fish inside BCER were rockfishes representing at least 20 species. Young-of-the-year rockfishes dominated rock outcrops in 20–90 m depth inside and outside BCER. Four distinct fish assemblages were associated with (1) fine, smooth sediment in deep water; (2) bedrock with uneven surface in deep water; (3) sand waves and shell hash in shallow water; and (4) boulders and organic habitats on rock in shallow water. There were no significant differences in fish density among locations (inside and outside BCER) and depths or between years. Density was significantly higher in high-relief rock habitat than in low-relief soft and mixed sediments, regardless of location. There were no consistent patterns of larger fish inside compared to outside the protected area. We recommend development of a monitoring program to continue these surveys after increased time of protection and with increased assessment effort in the appropriate habitats of economically valuable species. In addition, extending the boundaries of BCER seaward would protect habitats and fish in water depths greater than 100 m.

INTRODUCTION

Marine reserves (also known as no-take areas, marine protected areas [MPAs], and harvest refugia) are being considered as a supplement to traditional resource management practices on the West Coast, as well as throughout the world (Rowley 1994; Yoklavich 1998; Murray et al. 1999; Parrish et al. 2000). Reserves serve as undisturbed areas for research on natural populations and as fishery exclusion zones where fish have refuge from exploitation. Marine reserves have demonstrably enhanced fish populations within their borders by (1) increasing fish abundance, size, and reproductive output; (2) protecting critical spawning stocks and habitats; and (3) providing multispecies protection (Dugan and Davis 1993; Halpern in press; Murawski et al. 2000). In addition, fisheries have been identified as a critical threat to biodiversity (Boehlert 1996; Bohnsack and Ault 1996) and to the structure and function of coastal marine ecosystems (Jackson et al. 2001); marine reserves may help to conserve and restore these systems. Unharvested areas also could provide the means to separate the effects of fishing and other human activities on fish populations from the effects of natural changes in the environment. While not as well documented, it also has been suggested that reserves could serve as sources of replenishment to fisheries in unprotected areas.

The Big Creek Marine Ecological Reserve (BCER), located on the central California coast, has been closed to fishing since January 1994. This has afforded researchers the opportunity to collect baseline information on fish species composition, densities, and size, and to initiate an evaluation of potential benefits of BCER to its resources.

Many benthic fish species have affinities for specific seafloor substrata, the type and extent of which can help determine species distribution, abundance, and richness (Richards 1986; Pearcy et al. 1989; Stein et al. 1992; Yoklavich et al. 2000). Studies of marine fish assemblages and their habitats are limited by available technology. Most studies on fish-habitat specificity have been conducted using scuba in shallow (<30 m depth) subtidal environments (e.g., Larson 1980; Carr 1991); surveys in deep water have been logistically more difficult. In recent years a foundation for a systematic approach to characterizing marine habitats and fish assemblages has been developed in deep water using in situ submersible observations and remote geophysical mapping techniques (Yoklavich et al. 1997; Greene et al. 1999; Yoklavich et al. 2000).

Characterizing and quantifying elements of habitat, such as substratum type and water depth, and the association of fish assemblages with habitat are critical in evaluating the effectiveness of BCER in maintaining local fish resources. The overall goal of our research was to inventory and describe fishes and habitats in deep water (i.e., >20 m depth) of BCER. This baseline information will be useful when evaluating future changes to BCER populations of benthic fishes, and particularly to the assessment of nearshore species, as required by the California Department of Fish and Game's new nearshore management plan.

Our objectives during this study were (1) to verify and revise our interpretations of seafloor substrata made from side scan sonar images collected during a previous geophysical survey; (2) to estimate relative abundance and distribution of seafloor habitats; (3) to quantify fish density (number of fish per habitat-specific area), size structure, and species composition and diversity, relative to depth and substrata; (4) to compare these variables between 2 years of continued protection; (5) to test the null hypothesis that there is no difference in fish assemblages (numbers and sizes) between BCER and adjacent unprotected areas to the north and south of BCER.

METHODS

Study Site

BCER is about 8 km^2 in area, located within the Monterey Bay National Marine Sanctuary and about 90 km south of Monterey (fig. 1). It is contiguous with the University of California Landels-Hill Big Creek Reserve, which protects about 16 km^2 of coastal terrestrial habitats. The boundary of BCER extends for 4.5 km along the coast from 36°05.31'N and 121°37'W to 36°03.65'N and 121°35.6'W, and due west offshore to about 100 m water depth.

Our study site was situated on a relatively narrow part of the continental shelf, which leads into several steep submarine canyons along the continental slope. Surveys were conducted during 29 September–4 October 1997 and 20–25 September 1998 inside BCER at water depths of 20–100 m, as well as in areas adjacent to BCER at similar depths; these areas comprised 4.8 km^2 inside the reserve, 7.6 km^2 to the north, and 7.4 km^2 to the south. We also surveyed fishes and habitats in about 4.8 km^2 seaward of these three areas at water depths of 100–250 m.

Distribution and Abundance of Seafloor Substrata

A map of seafloor substratum types was produced from a side scan sonar survey conducted in our study site in June 1996 (Yoklavich et al. 1997). During our recent research we verified and revised our interpretations of this map by direct observations made from the *Delta* submersible. Submersible dive tracks were positioned precisely using acoustic track-point navigation and a differential global positioning system (dGPS). We used this map to quantify the amount of various types of substrata and to locate dive sites for fish and habitat surveys.

Fish and Habitat Surveys

Methodologies to assess benthic fishes and associated habitats in the BCER study site were similar to those used previously during surveys of deepwater fishes and habitats in submarine canyons (Yoklavich et al. 2000). Dives of 1–2 h duration were made in the *Delta* submersible during daylight to avoid bias due to diel activity patterns of some species. Dives were documented continuously with a high-8-mm video camera externally mounted on the starboard side of the submersible. We conducted 1–4 10-min strip transects during each dive, 1–2 m off the seafloor at 0.5–1.0 knots. Transects were verbally annotated by the scientific observer, who identified, counted, and estimated size of all fish within a 2-m strip of the viewing field.

Two parallel lasers were installed on either side of the video camera at 20 cm apart. The laser spots were projected onto the seafloor and were visible to the observer and on the videotape. We made measurements by comparing the size of a fish or habitat feature to the known spacing of the two bright laser spots when the object was perpendicular to the camera and lasers (Tusting and Davis 1993; Yoklavich et al. 2000). We estimated the length of each transect, independent of submersible speed and bottom currents, by counting the number of laser spot intervals as they moved along the seafloor in the video transect.

The type of substratum associated with each fish in the transect was characterized from the videotapes; these included boulder, rock outcrop, vertical rock pinnacle, cobble, sand, hash, organic (e.g., understory algae), and

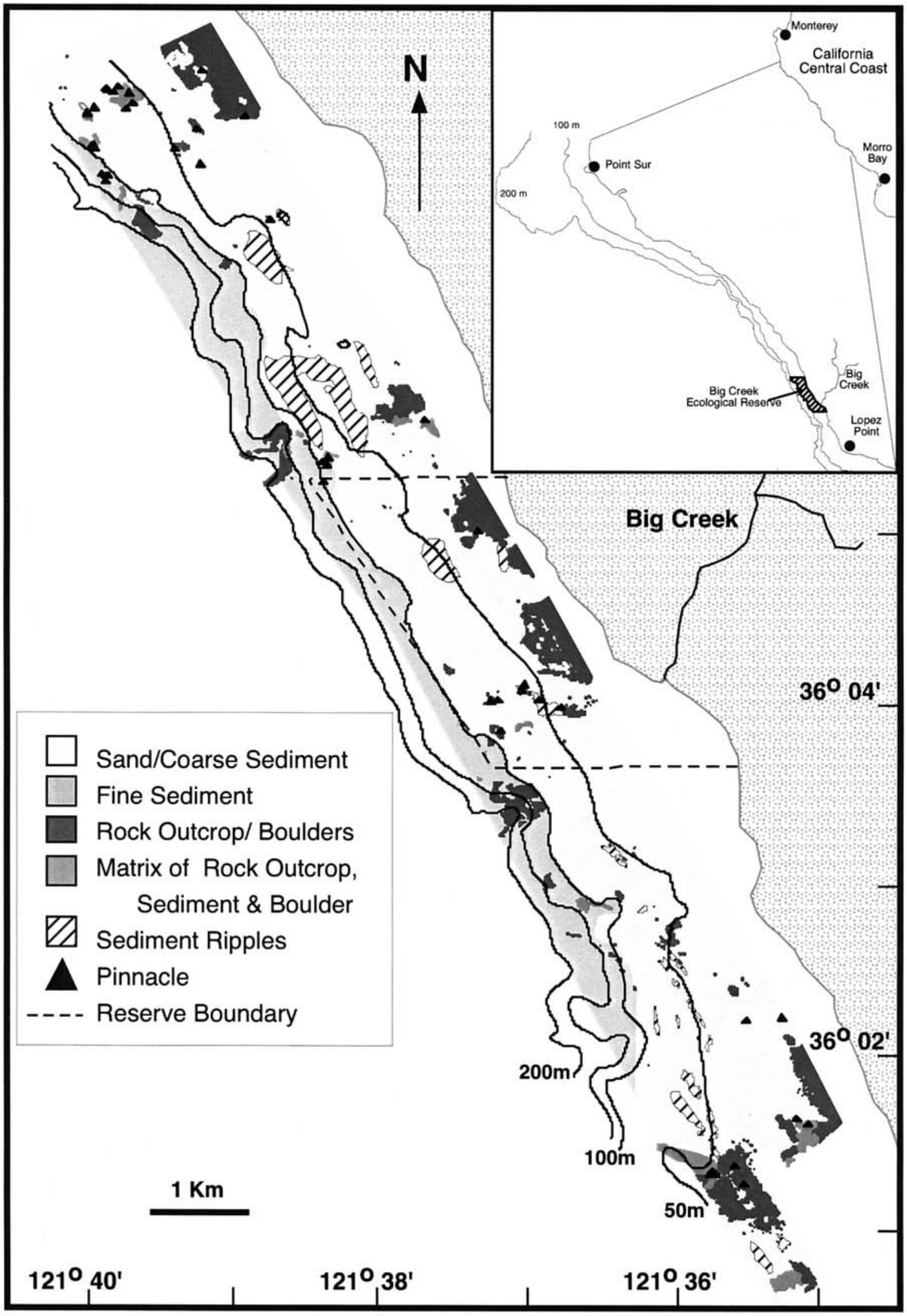

Figure 1. BCER study site off central California (inset modified from Pomeroy 1999). Seafloor substratum types identified from side scan sonar and observations from *Delta* submersible.

fine sediment, as described in Greene et al. (1999). Secondarily, surface morphology also was described as either smooth, uneven (i.e., sediment, rock, or organic substratum with holes, depressions, caves, crevices, ledges, and other rugosities), and sediment waves and ripples.

Various combinations of substrata were categorized according to primary (at least 50% of the area viewed) and secondary (>20% of the area viewed) microhabitat, following the protocol of Stein et al. (1992) and Yoklavich et al. (2000). Areas of uniform substratum composition were quantified along each transect and were used as the sample unit. Species-specific abundance was standardized per area of uniform substratum.

Data Analyses

Canonical correlation analysis (CCA) was used to identify patterns in associations among fishes and characteristics of their habitat. This analysis uses a matrix of species by habitat variables to describe assemblages of fishes. Species were included in analyses if they were nonschooling (i.e., nonpolarized aggregations or solitary individuals) benthic fishes that occurred in at least 5% of all possible habitat patches. Unidentified young-of-the-year rockfishes were not included in these analyses. "Year" (i.e., 1997 and 1998) was included as a covariate; its effect was removed by using a partial CCA to best describe the fish-habitat associations.

We used Analysis of Variance (ANOVA), with balanced design and log transformation of data where appropriate, to compare fish density among location (inside, north, and south of BCER), habitat type, water depth (<35 m, 35–100 m), and year (1997 and 1998). We did not include those species that were particularly mobile and difficult to accurately count (i.e., tubesnout, Pacific saury, Pacific hake, Pacific argentine, young-of-the-year rockfishes, and shortbelly rockfish). Based on the results of the CCA, we defined three groups of habitat types (1) low-relief soft sediments of primarily shell hash and sand; (2) low-relief mixed sediments of cobbles, organic understory, sand, shell hash, and flat rock; and (3) high-relief rock substratum primarily composed of boulders and rock outcrop. We used Tukey post-hoc multiple comparisons of cell means with Kramer's modification to identify specific locations, habitat types, depth, or year that contributed to significant factors in the models.

Overall richness (number of species), Shannon-Wiener diversity index, and evenness (Krebs 1999) were calculated for species assemblages at 15 discrete areas, as identified by depth and substrata on the habitat map.

We used a Kolmogorov-Smirnov goodness-of-fit test to compare size frequency distributions of economically valuable species that occurred at 20–100 m depths inside and outside BCER in each year. Because there was a statistical difference in the size of blue rockfish from <35 m and 35–100 m water depths, we analyzed size distributions from these two depth strata separately.

RESULTS

We completed 142 10-min video transect surveys of fishes and associated habitats during 43 dives (tab. 1). Thirty-nine transects were conducted inside BCER; the rest were located to the north (68 transects) and south (35 transects) of BCER.

Distribution and Abundance of Seafloor Substrata

From submersible observations, we verified our interpretation of 24.6 km^2 of seafloor and modified pre-existing maps to accurately reflect substratum types in 20–250 m water depth (fig. 1). Sand (grain size = 0.06–2 mm diameter) substratum of low relief was located almost entirely on the shelf in water depths <100 m; sand represented 64% of the seafloor types within the reserve (tab. 2). We could not distinguish fine and coarse sediments (grain size <0.06 mm) from the side scan sonar images; however, our observations from the submersible revealed that fine sediment typically occurred at water depths >100 m, and coarse sediments were found at depths <100 m. Sediment was distinct from sand substratum in both the side scan sonar and video images. Ninety percent of the seafloor in water depth > 100 m was identified as fine sediment (tab. 2).

TABLE 1
Distribution of Submersible Dives and Strip Transects Conducted Inside and Adjacent to BCER, 1997 and 1998

			Adjacent to BCER					
	Inside BCER		North		South		Total	
	1997	1998	1997	1998	1997	1998	1997	1998
No. of dives	5	5	8	13	7	5	20	23
No. of transects								
depth <35 m	6	5	4	7	2	0	12	12
depth 35–100 m	11	17	10	21	9	7	30	45
depth >100 m	0	0	12	14	10	7	22	21
Total	17	22	26	42	21	14	64	78

TABLE 2
Occurrence of Each Substratum Type as Determined by Surveys Using Side Scan Sonar and Observations from a Submersible

	Within BCER		Adjacent to BCER, depth >100 m		North of BCER, depth <100 m		South of BCER, depth <100 m	
Substratum type	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
Fine sediment	0.02	0.5	4.37	90.4	0.07	1.0	0.10	1.4
Sand	3.08	63.6	0.01	0.1	1.49	19.7	2.70	36.6
Coarse sediment	0.99	20.5	0.14	3.0	4.68	61.6	3.60	48.9
Boulders	0.01	0.2	0.00	0.1	0.03	0.3	0.08	1.1
Rock outcrop	0.55	11.5	0.29	5.9	0.56	7.3	0.49	6.7
Rock/sediment	0.05	1.1	0.02	0.4	0.10	1.3	0.18	2.5
Sediment ripples	0.13	2.7	—	—	0.67	8.8	0.21	2.8
Total area	4.84		4.83		7.60		7.37	

TABLE 3
Total Number (*n*), Relative Abundance (%), and Rank Abundance of Fish Taxa Observed from the *Delta* Submersible, Fall 1997 and 1998 (data ordered by total number from 1997)

a. Inside BCER

		1997			1998		
Scientific name	**Common name**	*n*	%	Rank	*n*	%	Rank
Sebastes spp. (YOY)[a]	unidentified rockfishes	8,235	64.6	**1**	2,044	16.5	**3**
Sebastes semicinctus (YOY)	halfbanded rockfish	2,236	17.5	**2**	667	5.4	**5**
Sebastes mystinus	blue rockfish	918	7.2	**3**	755	6.1	**4**
Citharichthys stigmaeus	speckled sanddab	359	2.8	**4**	65	0.5	12
Sebastes wilsoni	pygmy rockfish	200	1.6	**5**	118	1.0	**9**
Aulorhynchus flavidus	tubesnout	153	1.2	**6**	—		
Rhinogobiops nicholsii	blackeye goby	146	1.1	**7**	127	1.0	**8**
Oxylebius pictus	painted greenling	115	0.9	**8**	73	0.6	11
Citharichthys sordidus	Pacific sanddab	91	0.7	**9**	52	0.4	16
Sebastes serranoides	olive rockfish	73	0.6	**10**	89	0.7	**10**
Pleuronectiformes	unidentified flatfishes	37	0.3	11	21	0.2	20
Sebastes carnatus	gopher rockfish	23	0.2	12	33	0.3	18
Sebastes spp.	unidentified rockfishes	18	0.1	13	343	2.8	**6**
Pisces	unidentified fishes	18	0.1	13	248	2.0	**7**
Sebastomus spp.[b]	*Sebastomus* rockfishes	16	0.1	15	55	0.4	15
Embiotoca lateralis	striped surfperch	15	0.1	16	5	<0.1	32
Ophiodon elongatus	lingcod	13	0.1	17	25	0.2	19
Sebastes semicinctus	halfbanded rockfish	12	0.1	18	3,938	31.8	**1**
Damalichthys vacca	pile surfperch	9	0.1	19	4	<0.1	37
Embiotocidae	unidentified surfperches	9	0.1	19	3	<0.1	38
Cottidae	unidentified sculpins	9	0.1	19	—		
Hexagrammos decagrammus	kelp greenling	8	0.1	22	5	<0.1	32
Sebastes caurinus	copper rockfish	6	0.1	23	59	0.5	13
Sebastes atrovirens	kelp rockfish	6	0.1	23	6	0.1	31
Sebastes rosaceus	rosy rockfish	4	<0.1	25	58	0.5	14
Citharichthys spp.	unidentified sanddabs	4	<0.1	25	17	0.1	23
Semicossyphus pulcher	California sheephead	4	<0.1	25	7	0.1	27
Sebastes miniatus	vermilion rockfish	3	<0.1	28	13	0.1	24
Enophrys taurina	bull sculpin	2	<0.1	29	5	<0.1	32
Zalembius rosaceus	pink surfperch	2	<0.1	29	5	<0.1	32
Sebastes pinniger	canary rockfish	2	<0.1	29	1	<0.1	47
Lepidopsetta bilineata	rock sole	2	<0.1	29	—		
Oxyjulis californica	señorita	2	<0.1	29	—		
Phanerodon atripes	sharpnose surfperch	1	<0.1	34	7	0.1	27
Embiotoca jacksoni	black surfperch	1	<0.1	34	1	<0.1	47
Pleuronichthys spp.	turbots	1	<0.1	34	1	<0.1	47
Hypsopsetta guttulata	diamond turbot	1	<0.1	34	—		
Parophrys vetulus	English sole	1	<0.1	34	—		
Sebastes melanops	black rockfish	1	<0.1	34	—		
Sebastes jordani[c]	shortbelly rockfish	—			3,416	27.5	**2**

Note: Boldface indicates a ranking in the top ten.
[a] Young of the year.
[b] The seven species of rockfish within the *Sebastomus* complex that occur off central California are difficult to discern without close examination.
[c] Likely *S. jordani*, but some could be juvenile *S. goodei*.

TABLE 3 (*continued*)

a. Inside BCER

		1997			1998		
Scientific name	Common name	*n*	%	Rank	*n*	%	Rank
Sebastes paucispinis	bocaccio	—			38	0.3	17
Zaniolepis spp.	unidentified combfishes	—			20	0.2	21
Zaniolepis latipinnis	longspine combfish	—			18	0.2	22
Agonidae	unidentified poachers	—			8	0.1	25
Sebastes crameri (YOY)	darkblotched rockfish	—			8	0.1	25
Sebastes crameri	darkblotched rockfish	—			7	0.1	27
Sebastes hopkinsi	squarespot rockfish	—			7	0.1	27
Sebastes carnatus/caurinus[d]	gopher/copper complex	—			5	<0.1	32
Argentina sialis	Pacific argentine	—			3	<0.1	38
Lyopsetta exilis	slender sole	—			3	<0.1	38
Phanerodon furcatus	white surfperch	—			3	<0.1	38
Sebastes ruberrimus	yelloweye rockfish	—			3	<0.1	38
Hydrolagus colliei	spotted ratfish	—			2	<0.1	43
Sebastes flavidus	yellowtail rockfish	—			2	<0.1	43
Sebastes saxicola	stripetail rockfish	—			2	<0.1	43
Zaniolepis frenata	shortspine combfish	—			2	<0.1	43
Micrometrus minimus	dwarf surfperch	—			1	<0.1	47
Raja spp.	unidentifed skates	—			1	<0.1	47
Rathbunella alleni	stripefin ronquil	—			1	<0.1	47
Scorpaenichthys marmoratus	cabezon	—			1	<0.1	47
Sebastes chlorostictus	greenspotted rockfish	—			1	<0.1	47
Sebastes ensifer	swordspine rockfish	—			1	<0.1	47
Total no. of fish		12,756			12,403		
Total no. of rockfish		11,753	(92%)		11,669	(94%)	
Minimum no. of taxa		30			44		
Minimum no. of rockfish species		11			19		

[d] These two similar-looking species are sometimes difficult to discern under water.

Sediment waves and ripples, clearly identified in images from side scan sonar and video, represented 3% of the seafloor inside BCER.

Complex substratum types of relatively high-relief (e.g., boulders [>0.25 m diameter], pinnacles, rock outcrop, and a matrix of rock outcrop, boulder, cobble, and sediment) comprised about 12.8% of the 4.8 km^2 of seafloor that was surveyed inside BCER (tab. 2). Similar proportions of complex rock bottom types were represented in our study areas to the north (8.9%) and south (10.3%) of the reserve at the same water depth. Complex rock outcrop and boulders comprised about 6.4% of the seafloor in water depths >100 m and were found exclusively in the heads of submarine canyons outside BCER.

Fish and Habitat Associations

We identified 70,094 individual fish representing 82 taxa from all video transects (tab. 3). These included at least 36 species of rockfish (genus *Sebastes*). About 93% of the 25,159 fish (representing 49 taxa) counted inside BCER were rockfish comprising at least 20 species (tab. 3a). From those transects conducted at similar water depths (i.e., <100 m), in general there was a greater number of fish and rockfish species inside and to the north of BCER compared to the assemblage surveyed to the south of the reserve (tab. 3b). From 30% to 82% of the fish surveyed in water depths <100 m, both inside and outside BCER, were young-of-the-year rockfishes. We were unable to identify most of these young-of-the-year to species. Young-of-the-year rockfishes represented only 0.7–1.9% of the total number of fish counted in water depths >100 m (tab. 3c).

The most abundant rockfish species (>0.1% of total number of fish) inside BCER in both years included halfbanded, blue, pygmy, olive, and gopher rockfishes. Bocaccio and shortbelly, copper, and rosy rockfishes were relatively abundant (>0.1% of total number of fish) only in 1998. Relatively abundant non-rockfish species inside BCER included speckled and Pacific sanddabs, blackeye goby, and painted greenling. Similar species were relatively abundant outside the reserve to the north at depths <100 m (i.e., halfbanded, blue, pygmy, olive, gopher, copper, and rosy rockfishes), as well as widow, squarespot, and vermilion rockfishes. While far fewer fish and species were surveyed to the south of the reserve at similar depths, species composition was similar.

TABLE 3 (*continued*)

b. North and South of BCER, depth <100 m		North of BCER						South of BCER					
		1997			1998			1997			1998		
Scientific name	Common name	*n*	%	Rank	*n*	%	Rank	*n*	%	Rank	*n*	%	Rank
Sebastes spp. (YOY)[a]	unidentified rockfishes	7,223	64.4	**1**	11,846	74.9	**1**	8,001	80.9	**1**	551	45.8	**1**
Sebastes semicinctus (YOY)	halfbanded rockfish	1,052	9.4	**2**	154	1.0	**8**	20	0.2	11	11	0.9	14
Sebastes mystinus	blue rockfish	474	4.2	**3**	311	2.0	**5**	1,255	12.7	**2**	26	2.2	**8**
Sebastes hopkinsi	squarespot rockfish	459	4.1	**4**	383	2.4	**4**	—			12	1.0	11
Sebastes spp.	unidentified rockfishes	439	3.9	**5**	991	6.3	**2**	12	0.1	18	186	15.4	**2**
Citharichthys spp.	unidentified sanddabs	285	2.5	**6**	45	0.3	14	26	0.3	**9**	—		
Sebastes semicinctus	halfbanded rockfish	214	1.9	**7**	195	1.2	**7**	30	0.3	**8**	175	14.5	**3**
Cololabis saira	Pacific saury	200	1.8	**8**	—			—			—		
Sebastes wilsoni	pygmy rockfish	134	1.2	**9**	747	4.7	**3**						
Phanerodon atripes	sharpnose surfperch	100	0.9	**10**	—			32	0.3	**7**	—		
Sebastes entomelas	widow rockfish	81	0.7	11	298	1.9	**6**	2	<0.01	25	—		
Sebastes serranoides	olive rockfish	59	0.5	12	46	0.3	13	141	1.4	**3**	44	3.7	**5**
Citharichthys stigmaeus	speckled sanddab	58	0.5	13	137	0.9	**10**	23	0.2	**10**	1	0.1	19
Sebastes rosaceus	rosy rockfish	51	0.5	14	62	0.4	11	15	0.2	16	20	1.7	**9**
Zaniolepis spp.	unidentified combfishes	41	0.4	15	—			—			—		
Citharichthys sordidus	Pacific sanddab	40	0.4	16	57	0.4	12	—			—		
Zalembius rosaceus	pink surfperch	37	0.3	17	11	0.1	24	—			—		
Pleuronectiformes	unidentified flatfishes	36	0.3	18	40	0.3	15	6	0.1	19	1	0.1	19
Ophiodon elongatus	lingcod	34	0.3	19	35	0.2	19	20	0.2	11	5	0.4	15
Oxylebius pictus	painted greenling	21	0.2	20	39	0.2	16	108	1.1	**4**	29	2.4	**7**
Pisces	unidentified fishes	19	0.2	21	35	0.2	19	15	0.2	16	12	1.0	11
Sebastes jordani[b]	shortbelly rockfish	17	0.2	22	2	<0.01	39	—			—		
Damalichthys vacca	pile surfperch	16	0.1	23	3	<0.01	36	5	0.1	20	1	0.1	19
Sebastomus spp.[c]	*Sebastomus* rockfishes	15	0.1	24	38	0.2	17	16	0.2	14	4	0.3	16
Sebastes miniatus	vermilion rockfish	14	0.1	25	37	0.2	18	17	0.2	13	13	1.1	**10**
Sebastes caurinus	copper rockfish	14	0.1	25	35	0.2	19	5	0.1	20	4	0.3	16
Rhinogobiops nicholsii	blackeye goby	12	0.1	27	147	0.9	**9**	40	0.4	**6**	53	4.4	**4**
Cottidae	sculpins	9	0.1	28	3	<0.01	36	3	<0.01	24	1	0.1	19
Sebastes carnatus	gopher rockfish	8	0.1	29	23	0.2	22	16	0.2	14	12	1.0	11
Semicossyphus pulcher	California sheephead	6	0.1	30	—			5	0.1	20	—		
Sebastes saxicola	stripetail rockfish	6	0.1	30	—			—			—		
Embiotoca jacksoni	black surfperch	5	<0.01	32	1	<0.01	45	2	<0.01	25	—		
Enophrys taurina	bull sculpin	4	<0.01	33	11	0.1	24	—			—		
Sebastes paucispinis	bocaccio	4	<0.01	33	3	<0.01	36	—			—		
Sebastes pinniger	canary rockfish	3	<0.01	35	6	<0.01	28	1	<0.01	28	3	0.3	18

Note: Boldface indicates a ranking in the top ten.

[a] Young of the year.

[b] Likely *S. jordani*, but some 1998 could be juvenile *S. goodei*.

[c] The seven species of rockfish within the *Sebastomus* complex that occur off central California are difficult to discern without close examination.

TABLE 3 (*continued*)

b. North and South of BCER, depth <100 m		North of BCER						South of BCER					
		1997			1998			1997			1998		
Scientific name	Common name	*n*	%	Rank	*n*	%	Rank	*n*	%	Rank	*n*	%	Rank
Embiotocidae	surfperches	3	<0.01	35	1	<0.01	45	4	<0.01	23			
Oxyjulis californica	señorita	3	<0.01	35	—			64	0.7	5	36	3.0	6
Argentina sialis	Pacific argentine	2	<0.01	38	16	0.1	23	—			—		
Hexagrammos decagrammus	kelp greenling	2	<0.01	38	4	<0.01	32	2	<0.01	25	1	0.1	19
Icelinus filamentosus	threadfin sculpin	2	<0.01	38	1	<0.01	45	—			—		
Zaniolepis latipinnis	longspine combfish	1	<0.01	41	7	<0.01	27	—			—		
Agonidae	unidentified poachers	1	<0.01	41	6	<0.01	28	1	<0.01	28	—		
Pleuronichthys spp.	unidentified turbots	1	<0.01	41	5	<0.01	31	1	<0.01	28	—		
Sebastes ruberrimus	yelloweye rockfish	1	<0.01	41	4	<0.01	32	—			—		
Embiotoca lateralis	striped surfperch	1	<0.01	41	1	<0.01	45	1	<0.01	28	1	0.1	19
Rathbunella alleni	stripefin ronquil	1	<0.01	41	1	<0.01	45	—			—		
Parophrys vetulus	English sole	1	<0.01	41	—			—			—		
Sebastes elongatus	greenstriped rockfish	1	<0.01	41	—			—			—		
Psettichthys melanostictus	sand sole	—			9	0.1	26	—			—		
Sebastes flavidus	yellowtail rockfish	—			6	<0.01	28	—			—		
Lyopsetta exilis	slender sole	—			4	<0.01	32	—			—		
Synodus lucioceps	California lizardfish	—			4	<0.01	32	—			—		
Anarrichthys ocellatus	wolf-eel	—			2	<0.01	39	—			—		
Glyptocephalus zachirus	rex sole	—			2	<0.01	39	—			—		
Microstomus pacificus	Dover sole	—			2	<0.01	39	—			—		
Sebastes helvomaculatus	rosethorn rockfish	—			2	<0.01	39	—			—		
Sebastes rufus	bank rockfish	—			2	<0.01	39	—			—		
Icelinus tenuis	spotfin sculpin	—			1	<0.01	45	—			—		
Sebastes chlorostictus	greenspotted rockfish	—			1	<0.01	45	—			—		
Sebastes constellatus	starry rockfish	—			1	<0.01	45	—			—		
Sebastes serriceps	treefish	—			1	<0.01	45	—			—		
Symphurus atricaudia	California tonguefish	—			1	<0.01	45	—			—		
Torpedo californica	Pacific electric ray	—			1	<0.01	45	—			—		
Sebastes miniatus/pinniger[d]	vermilion/canary complex	—			—			1	<0.01	28	—		
Sebastes nebulosus	China rockfish	—			—			1	<0.01	28	—		
Hydrolagus colliei	spotted ratfish	—			—			—			1	0.1	19
Sebastes carnatus/caurinus[d]	gopher/copper complex	—			—			—			1	0.1	19
Total no. of fish			11,210			15,826			9,891			1,204	
Total no. of rockfish			10,269 (92%)			15,194 (96%)			9,533 (96%)			1,062 (98%)	
Total no. of taxa			38			46			24			19	
Minimum no. of rockfish species			16			20			10			9	

[d] These two similar-looking species are sometimes difficult to discern under water.

TABLE 3 (*continued*)

c. Outside BCER, depths >100 m

		1997			1998		
Scientific name	**Common name**	*n*	%	**Rank**	*n*	%	**Rank**
Merluccius productus	Pacific hake	1,098	23.8	**1**	6	0.3	34
Sebastes jordani[a]	shortbelly rockfish	1,007	21.8	**2**	201	9.2	**3**
Sebastes spp.	unidentified rockfishes	297	6.4	**3**	224	10.3	**2**
Sebastes semicinctus	halfbanded rockfish	232	5.0	**4**	114	5.2	**7**
Sebastes wilsoni	pygmy rockfish	207	4.5	**5**	356	16.3	**1**
Pleuronectiformes	unidentified flatfishes	206	4.5	**6**	141	6.5	**4**
Sebastomus spp.[b]	*Sebastomus* rockfishes	173	3.7	**7**	127	5.8	**5**
Sebastes miniatus/pinniger[c]	vermilion/canary complex	155	3.4	**8**	—		
Sebastes saxicola	stripetail rockfish	118	2.6	**9**	20	0.9	20
Agonidae	unidentified poachers	97	2.1	**10**	93	4.3	**8**
Sebastes crameri	darkblotched rockfish	92	2.0	11	28	1.3	17
Sebastes spp. (YOY)[d]	unidentified rockfishes	88	1.9	12	15	0.7	25
Argentina sialis	Pacific argentine	83	1.8	13	42	1.9	16
Sebastes helvomaculatus	rosethorn rockfish	77	1.7	14	68	3.1	**9**
Sebastes elongatus	greenstriped rockfish	71	1.5	15	47	2.2	15
Sebastes chlorostictus	greenspotted rockfish	67	1.5	16	67	3.1	11
Sebastes entomelas	widow rockfish	64	1.4	17	2	0.1	42
Microstomus pacificus	Dover sole	54	1.2	18	61	2.8	13
Zoarcidae	unidentified eelpouts	44	1.0	19	24	1.1	18
Citharichthys spp.	unidentified sanddabs	44	1.0	19	—		
Lyopsetta exilis	slender sole	38	0.8	21	15	0.7	25
Sebastes paucispinis	bocaccio	35	0.8	22	8	0.4	31
Pisces	unidentified fishes	34	0.7	23	125	5.7	**6**
Citharichthys sordidus	Pacific sanddab	31	0.7	24	5	0.2	36
Hydrolagus colliei	spotted ratfish	23	0.5	25	12	0.5	29
Sebastes hopkinsi	squarespot rockfish	22	0.5	26	24	1.1	18
Zalembius rosaceus	pink surfperch	20	0.4	27	18	0.8	21
Sebastes rufus	bank rockfish	18	0.4	28	58	2.7	14
Zaniolepis spp.	unidentified combfishes	17	0.4	29	14	0.6	27
Glyptocephalus zachirus	rex sole	16	0.3	30	65	3.0	12
Sebastolobus spp.	unidentified thornyheads	10	0.2	31	—		
Ophiodon elongatus	lingcod	9	0.2	32	14	0.6	27
Sebastes rosenblatti	greenblotched rockfish	9	0.2	32	8	0.4	31
Lycodes cortezianus	bigfin eelpout	9	0.2	32	7	0.3	33
Sebastes pinniger	canary rockfish	8	0.2	35	1	0.0	49
Sebastes ruberrimus	yelloweye rockfish	7	0.2	36	11	0.5	30
Zaniolepis latipinnis	longspine combfish	6	0.1	37	16	0.7	23
Sebastes zacentrus	sharpchin rockfish	5	0.1	38	68	3.1	**9**
Rajiformes-egg cases	skate egg cases	5	0.1	38	—		
Cottidae	unidentified sculpins	4	0.1	40	18	0.8	21
Eptatretus stoutii	Pacific hagfish	4	0.1	40	4	0.2	38
Chilara taylori	spotted cusk-eel	3	0.1	42	2	0.1	42
Sebastes ovalis	speckled rockfish	2	<0.1	43	1	0.1	49
Stichaeidae	unidentified pricklebacks	2	<0.1	43	1	0.1	49
Enophrys taurina	bull sculpin	1	<0.1	45	6	0.3	34
Sebastes constellatus	starry rockfish	1	<0.1	45	4	0.2	38
Sebastes levis	cowcod	1	<0.1	45	2	0.1	42
Sebastolobus alascanus	shortspine thornyhead	1	<0.1	45	2	0.1	42
Porichthys notatus	plainfin midshipman	1	<0.1	45	1	0.1	49
Raja spp.	unidentified skates	1	<0.1	45	1	0.1	49
Pleuronichthys spp.	unidentified turbots	1	<0.1	45	—		
Raja inornata	California skate	1	<0.1	45	—		
Sebastes ensifer	swordspine rockfish	—			16	0.7	23
Sebastes diploproa	splitnosed rockfish	—			5	0.2	36
Zaniolepis frenata	shortspine combfish	—			4	0.2	38
Sebastes miniatus	vermilion rockfish	—			3	0.1	41
Anoplopoma fimbria	sablefish	—			2	0.1	42
Sebastes nigrocinctus	tiger rockfish	—			2	0.1	42

Note: Boldface indicates a ranking in the top ten.

[a] Likely *S. jordani*, but some in 1998 could be juvenile *S. goodei*.

[b] The seven species of rockfish within the *Sebastomus* complex that occur off central California are difficult to discern without close examination.

[c] These two similar-looking species are sometimes difficult to discern under water.

[d] Young of the year.

TABLE 3 (*continued*)

c. Outside BCER, depths >100 m

		1997			1998		
Scientific name	Common name	*n*	%	Rank	*n*	%	Rank
Synodus lucioceps	California lizardfish	—			2	0.1	42
Icelinus filamentosus	threadfin sculpin	—			1	0.1	49
Parophrys vetulus	English sole	—			1	0.1	49
Sebastes babcocki	redbanded rockfish	—			1	0.1	49
Sebastes gilli	bronzespotted rockfish	—			1	0.1	49
Total no. of fishes			4,619			2,185	
Total no. of rockfishes			2,756 (60%)			1,482 (68%)	
Minimum no. of taxa			39			49	
Minimum no. of rockfish species			19			25	

The CCA of fish density constrained by habitat data revealed a primary separation of species by depth (fig. 2; axis 1 accounted for 62% of the total variance) and a secondary separation of species based on combinations of substrata, seafloor morphology, and degree of slope (axis 2 accounted for 16% of the variance). All species to the right of the vertical line (fig. 2a) occurred in relatively deep water; the depth gradient increased from the center point to the right in Figure 2b. There were two deepwater groups (the two quadrants on the ordination) within the deepwater assemblage: (1) Dover, rex, and slender soles, poachers, and Pacific hake were found on deep, smooth, fine sediment; unidentified flatfishes also were found on smooth, fine sediments of various depths; and (2) the rockfishes (rosethorn, greenspotted, bank, yelloweye, squarespot, and darkblotched) occurred in relatively deep, sloping habitats primarily comprising bedrock and some cobble with uneven surface morphology. In addition, pygmy rockfish stood out as an idiosyncratic species that also was related to deep rock habitats with uneven surfaces. Stripetail, sharpchin, and greenstriped rockfishes occurred in the deepwater assemblage but were not strictly associated with either rock or fine sediments.

Within the relatively shallow fauna, there also were two groups: (1) speckled and Pacific sanddabs and unidentified sculpins were found on sand waves and ripples and shell hash; and (2) the rockfishes (olive, blue, gopher, rosy, copper, vermilion, and halfbanded), painted greenling, blackeye goby, sharpnose surfperch, and señorita were associated with boulders and organic habitats (such as kelp and understory algae) that overlay rock outcrop.

From these primary (depth) and secondary (substratum type) habitat characteristics, the seafloor along each transect was categorized into three general types of habitats: high-relief rock; low-relief mixed sediments; and low-relief soft sediment. Relative percentage of each of these habitat types varied by depth and location (tab. 4).

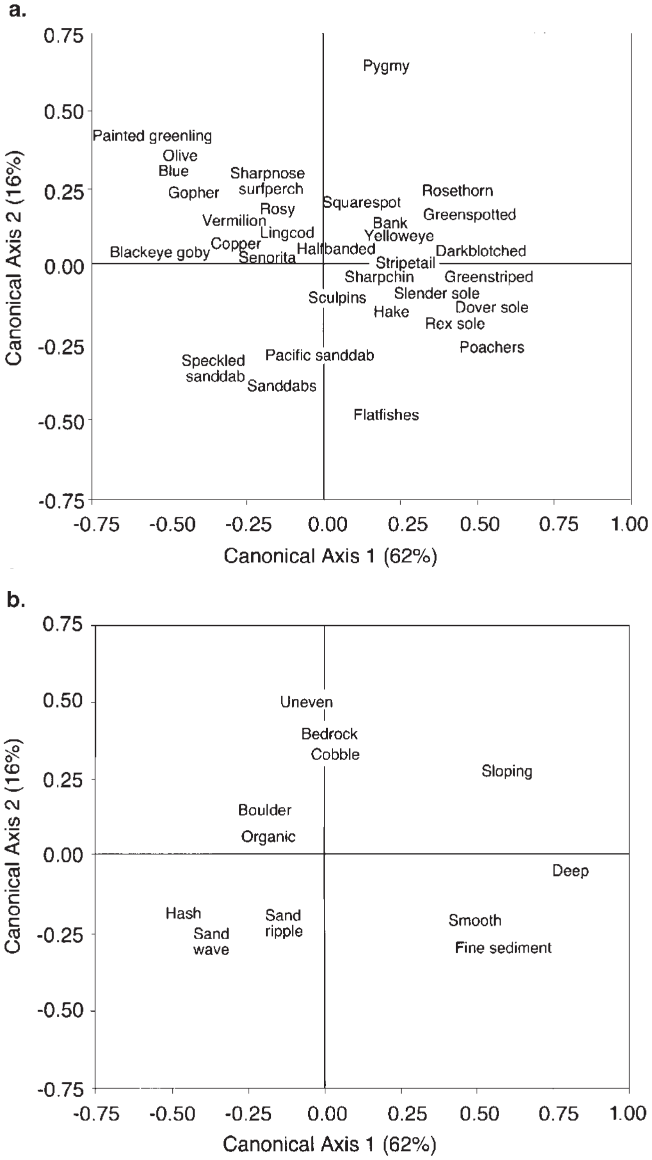

Figure 2. Results of canonical correlation analysis of fish-habitat data. (*a*) Coefficients (scores) for species; (*b*) coefficients for habitat variables.

TABLE 4
Total Area (m^2) Surveyed During Quantitative Transects Inside and Adjacent to BCER, by depth and habitat type

		Inside BCER			North of BCER			South of BCER			
Year	Depth (m)	Rock	Mixed	Soft	Rock	Mixed	Soft	Rock	Mixed	Soft	Total
1997	<35	1,287	52	693	618	283	748	183	68	599	4,529
	35–100	1,019	654	2,530	835	1,011	1,980	1,411	1,262	1,339	12,040
	>100	—	—	—	1,624	549	2,470	1,167	621	2,379	8,810
1998	<35	1,244	192	779	579	390	1,332	—	—	—	4,517
	35–100	1,488	377	3,587	1,313	128	6,156	973	625	959	15,606
	>100	—	—	—	2,188	182	3,710	562	148	1,890	8,680
Total		5,038	1,274	7,589	7,157	2,544	16,395	4,295	2,723	7,166	54,182

TABLE 5
Results of Analysis of Variance (ANOVA) and Tukey Post Hoc Multiple Comparison (with Kramer's Modification) of Fish Density (no. fish/m^2) in 1997

Location: North, inside, south of BCER
Substrata: High-relief rock, low-relief mixed rock, low-relief soft sediment
Depth: 1 = <35 m, 2 = 35–100 m

	ANOVA				
Source	Sum-of-squares	df	Mean-square	*F*-ratio	*p* value
Location	0.024	2	0.012	0.546	0.580
Substrata	0.553	2	0.276	12.825	**0.000**
Depth	0.011	1	0.011	0.516	0.474
Location*Substrata	0.041	4	0.010	0.474	0.755
Location*Depth	0.022	2	0.011	0.507	0.603
Substrata*Depth	0.008	2	0.004	0.187	0.829
Depth*Substrata*Location	0.001	4	0.000	0.017	0.999
Error	3.622	68	0.022		

Note: Boldfacing indicates statistical significance.

Tukey Post Hoc Multiple Comparison (with Kramer's Modification) to Test Fish Density Among Substrata Categories

	High-relief rock	Low-relief mixed rock	Low-relief soft sediment
Adj. least squares mean	0.205	0.084	0.042
SE	0.023	0.027	0.024
N	69	54	63

Overall we visually surveyed 13,901 m^2 of seafloor inside BCER during 1997 and 1998, and 15,373 and 7,410 m^2 to the north and south in similar water depths (20–100 m) as BCER, respectively. While the relative percent of low-relief soft sediment generally was high in these surveys, we focused effort in the complex habitats with high species density and diversity. Low-relief mixed sediment habitat occurred to a lesser amount in the study area and consequently was surveyed to a lesser extent than the other two categories. In deep water outside the reserve, we surveyed mostly high-relief rock habitat and low-relief soft sediment.

Fifteen discrete areas were identified by depth and various substratum types (rock outcrop, sand, pinnacle, etc.) on the habitat map of the entire study site (fig. 3). Overall fish density (excluding young-of-the-year rockfishes) was higher over rock substrata than over sand and fine sediment. The shallow-water assemblages in general were more diverse over rock outcrops than over sand. Some of the shallow-water assemblages were dominated by one or two species (e.g., blue rockfish on shallow pinnacles or outcrops and sanddabs over shallow sand areas), which resulted in low evenness indexes. In general, diversity was higher in deepwater assemblages than in shallow water.

Young-of-the-year rockfishes dominated the fish assemblages on rock outcrops and pinnacles at 20–90 m depth, especially at sites 1, 2, 9, 11, 12, and 15, both inside and outside BCER (fig. 4). Density of young-of-the-year at these sites ranged from 27 to 857 fish per 100 m^2 and represented 38–93% of all fish on the outcrops. Low-relief fields of coarse sand and sea pens in about 70 m of water (site 12) appeared to be a nursery ground for stripetail rockfish in particular (one of the few species of rockfish that was identified from young-of-the-year).

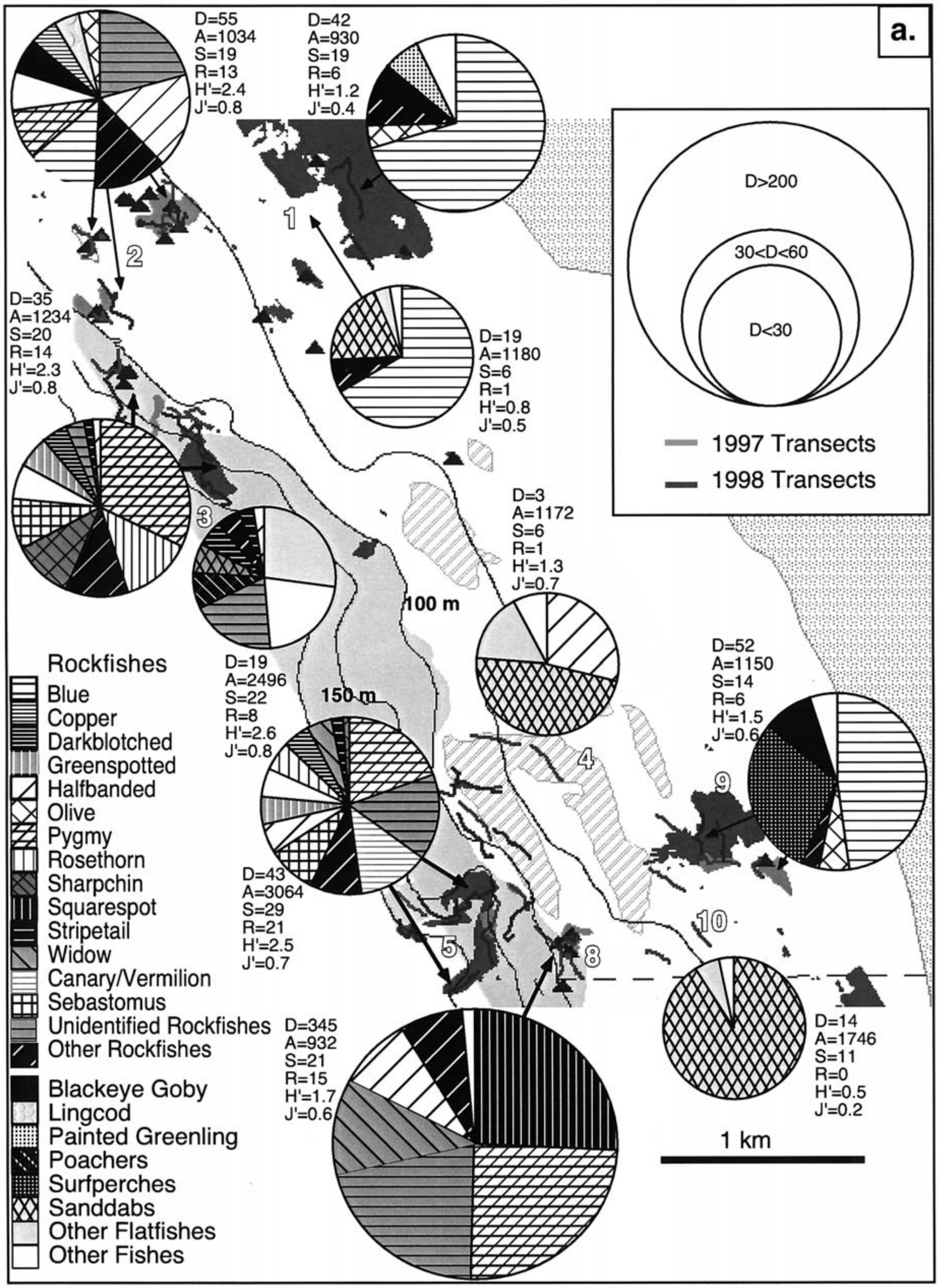

Figure 3. Average density and diversity of benthic fishes at 15 sites in BCER study area. Size of pie diagrams is scaled by density (D = number of fish/100 m^2); A = amount (m^2) of area surveyed; S = minimum number of fish species; R = minimum number of rockfish species; H' = species diversity index; and J' = species evenness index. (a) Sites north of BCER; (b) sites inside and seaward of BCER; and (c) sites south of BCER. (See fig. 1 for seafloor substratum types.)

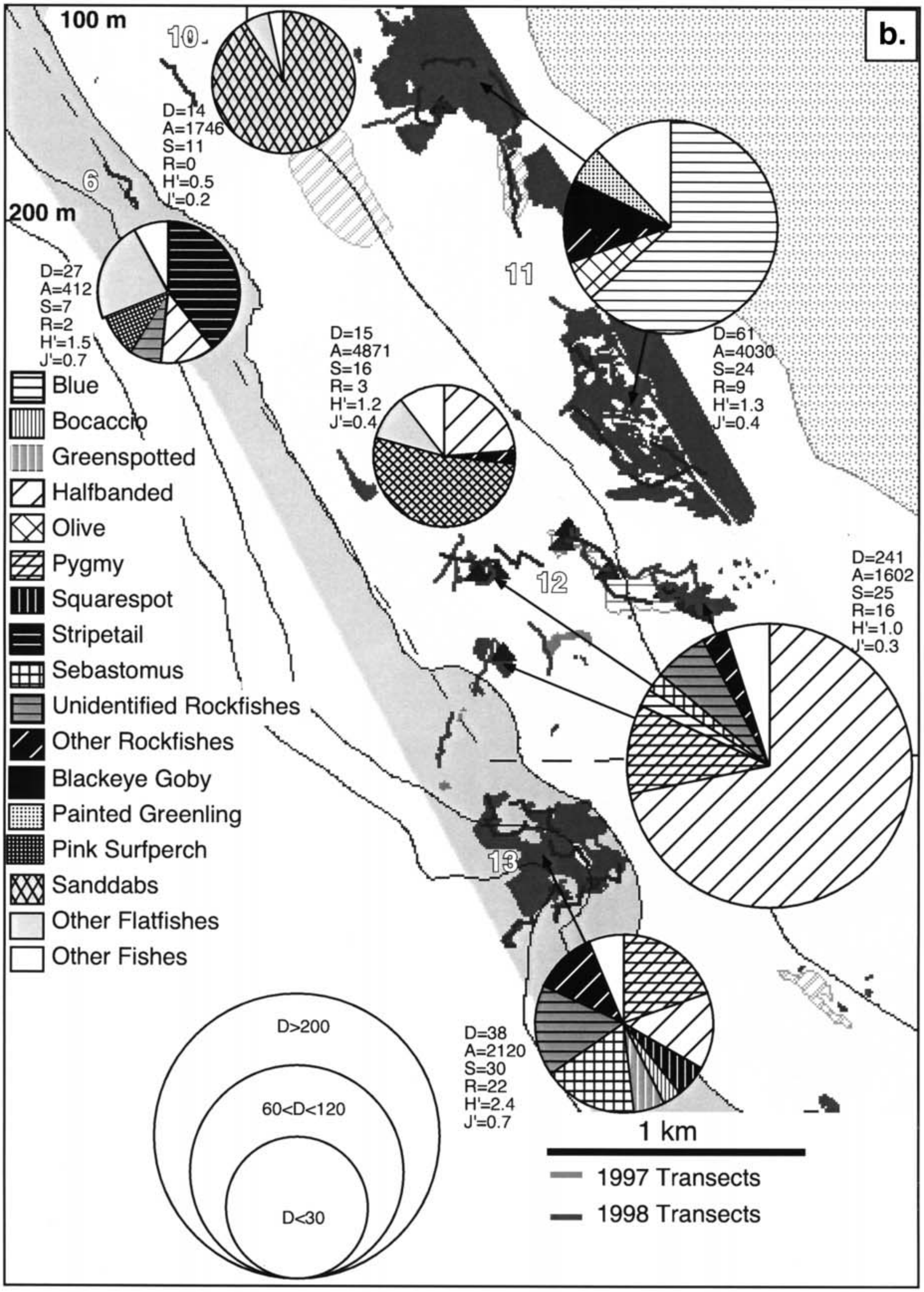

Figure 3. (*continued*)

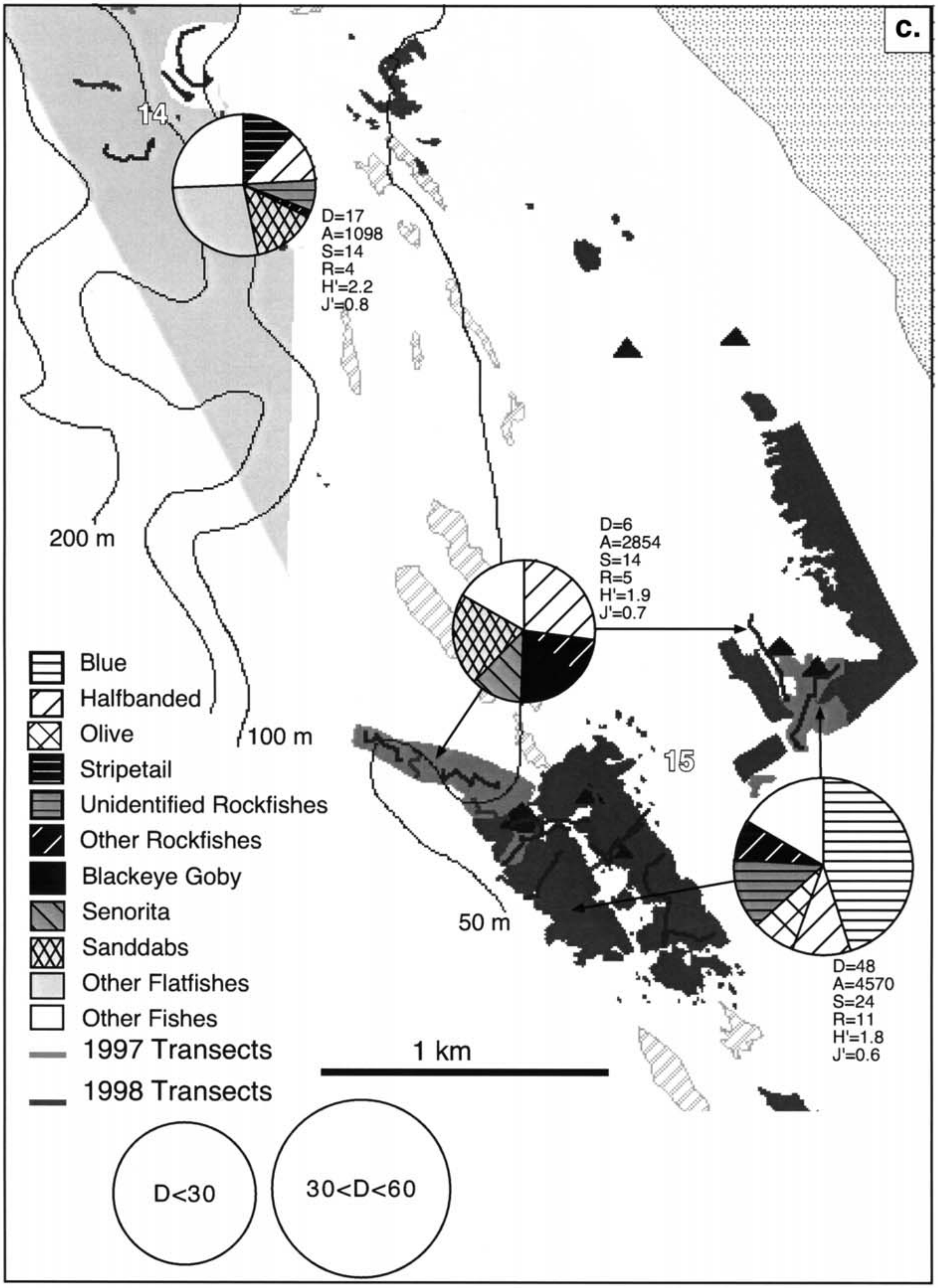

Figure 3. (*continued*)

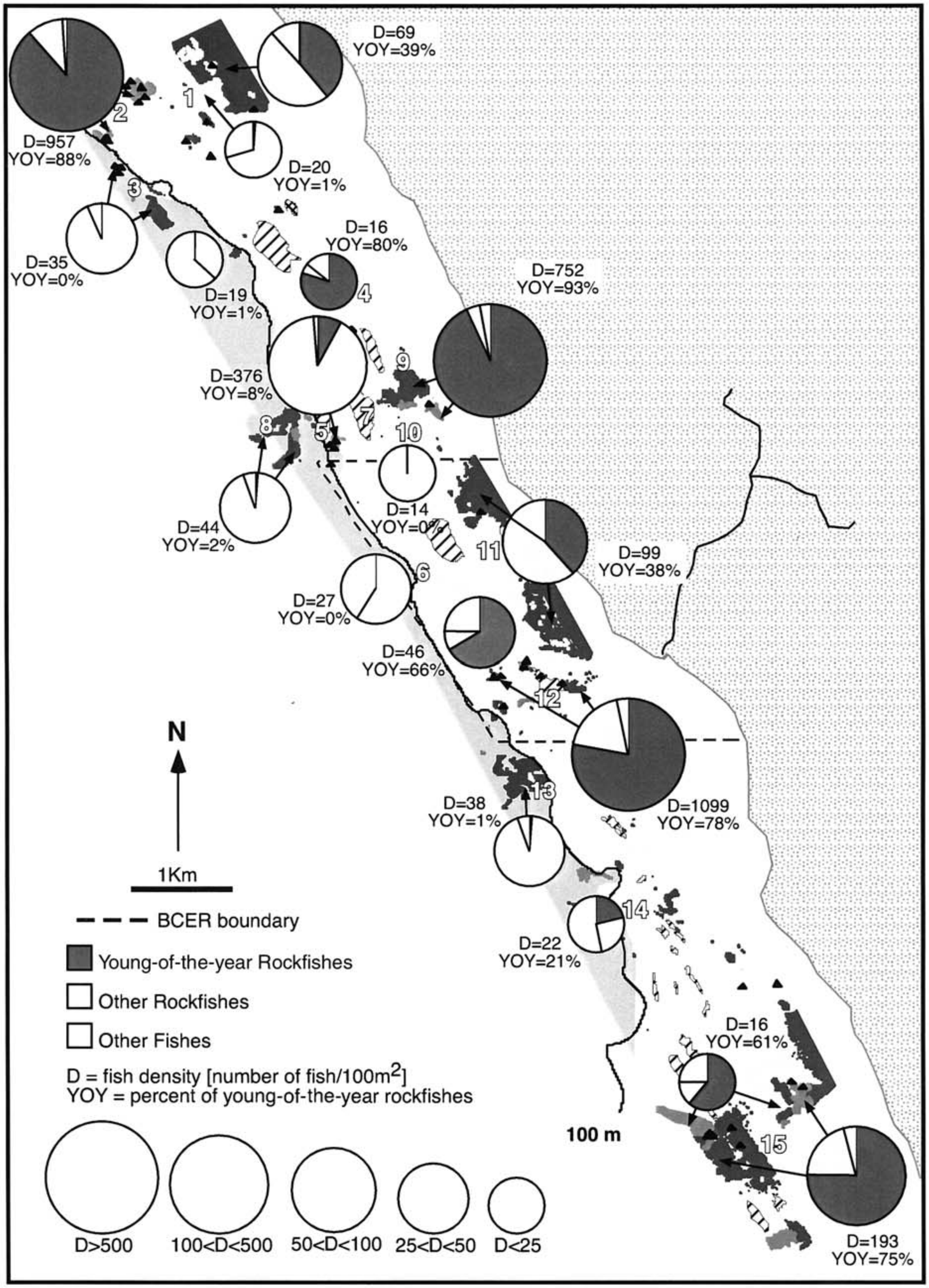

Figure 4. Distribution and average density of young-of-the-year rockfishes, all adult rockfishes, and all other adult fishes at 15 sites in the BCER study area. Pie diagrams are scaled by fish density (D).

TABLE 6
Results of ANOVA and Tukey Post Hoc Multiple Comparison (with Kramer's Modification) of Fish Density (no. fish/m²) at Depths of 35–100 m

Location: North, inside, south of BCER
Substrata: High-relief rock, low-relief mixed rock, low-relief soft sediment
Year: 1997, 1998

	ANOVA				
Source	Sum-of-squares	df	Mean-square	*F*-ratio	*p* value
Location	0.089	2	0.044	1.587	0.207
Substrata	1.902	2	0.951	34.010	**0.000**
Year	0.080	1	0.080	2.848	0.093
Location*Substrata	0.415	4	0.104	3.707	**0.006**
Location*Year	0.048	2	0.024	0.851	0.428
Substrata*Year	0.177	2	0.088	3.156	**0.045**
Year*Substrata*Location	0.657	4	0.164	5.870	**0.000**
Error	6.040	216	0.028		

Note: Boldfacing indicates statistical significance.

Tukey Post Hoc Multiple Comparison (with Kramer's Modification) to Test Fish Density Among Substrata Categories

	High-relief rock	Low-relief mixed rock	Low-relief soft sediment
Adj. least squares mean	0.266	0.114	0.048
SE	0.020	0.028	0.018
N	85	52	97

Fish Densities in BCER and Unprotected Areas

In a first ANOVA, we compared total fish densities among locations, substratum types, and depths in 1997. Data from 1998 were not included because we did not have an orthogonal sample design; depth was not represented in all combinations of the other factors. There was a significant difference in densities among the three substratum types (tab. 5). Fish density was significantly higher in high-relief rock than in the low-relief soft sediments and mixed rock habitats; densities were not significantly different between the two low-relief habitats. These patterns applied to both depth categories and all three locations (fig. 5). Fish density was not significantly different among locations or between depths, and there were no significant interactions among the factors.

In a second ANOVA, we compared total fish densities at one depth range (35–100 m) between years and among substrata and locations. Both depth categories were not used in this comparison because the shallow depth category (<35 m) was not represented in all combinations of the other factors. Again, the only significant difference among main factors was that of substrata (tab. 6). High-relief rock harbored greater fish densities than low-relief mixed rock and soft sediments; density in low-relief mixed rock was greater than that in low-relief soft sediments (fig. 5). These differences in density with substratum varied with year and location (i.e., there was a significant interaction term in the ANOVA; tab. 6). This variation was due largely to the high densities of fish (notably halfbanded rockfish) in 1998 in high-relief rock inside and north of BCER. There were no significant differences in fish densities among locations and between years (tab. 6).

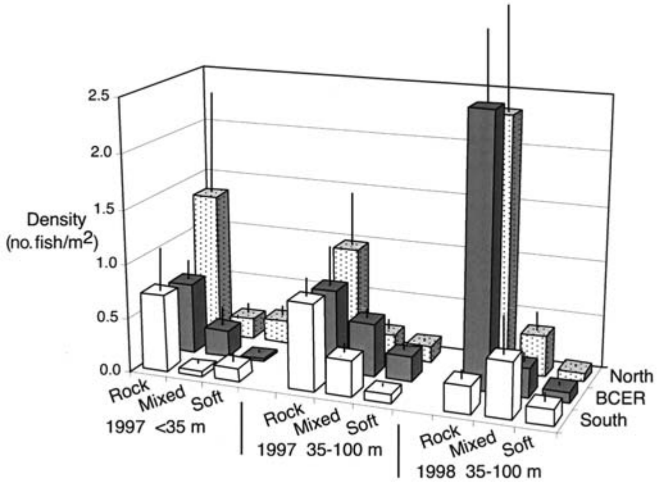

Figure 5. Mean density (no. fish/m²) of fishes on three types of substratum (high-relief rock [Rock], low-relief mixed rock [Mixed], and low-relief soft sediment [Soft]), at three locations (north of, south of, and inside BCER) in 1997 (at water depths of <35 m and 35–100 m) and 1998 (at water depths of 35–100 m). Error bar is 1 SEM.

In a third ANOVA, we compared densities of eight species of commercial and recreational economic value, including rockfishes (blue, olive, vermilion, canary, gopher copper, and yellowtail), and lingcod, that occurred on high-relief rock substrata among locations and between years. There were significant differences in fish

TABLE 7
Two-factor ANOVA Comparing Fish Density (no. fish/m^2) of Economically Valuable Species (i.e., blue, olive, vermilion, canary, gopher, copper, and yellowtail rockfish and lingcod) on High-Relief Rock Substrata Among Three Locations (north, south, and inside BCER) and Over Two Years (1997 and 1998)

	ANOVA				
Source	Sum-of-squares	df	Mean-square	*F*-ratio	*p* value
Location	0.006	2	0.003	0.163	0.850
Year	0.288	1	0.288	14.720	**0.000**
Location*Year	0.016	2	0.008	0.398	0.673
Error	2.211	113	0.020		

Note: Boldfacing indicates statistical significance.

density between years; adjusted least square mean density was higher in 1997 than in 1998 (tab. 7). Interestingly, the declines in mean densities from 1997 to 1998 were greatest in both areas outside the reserve; mean density of economic species in 1998 was greater inside BCER than outside (fig. 6). No differences in density were found among locations, and there were no significant interaction terms.

Fish Size in BCER and Unprotected Areas

The size distributions of blue rockfish were significantly different inside and outside BCER, during both years and at both depth strata (fig. 7a,b). However, only in deep water in 1998 (fig. 7b) were sizes skewed toward larger fish inside BCER (in 1998, 50% of 134 blue rockfish were 30 cm total length inside BCER compared to no fish of that size outside the reserve).

Size distribution of olive rockfish also differed significantly inside and outside the reserve in both years (fig. 7c). In 1997, the distribution outside BCER was skewed toward larger size classes (>30 cm) compared to inside. However, this pattern was reversed in 1998, and the largest size classes (>35 cm) were truncated in the size distribution of olive rockfish outside the reserve. There was no significant difference in size structure of gopher rockfish in and out of BCER in either 1997 or 1998 (fig. 7d).

Comparisons of size distributions could not be made for copper, vermilion, and rosy rockfishes in 1997 because of low sample sizes of estimated lengths inside BCER. Distributions of rosy and vermilion rockfishes in 1998 were not significantly different in and out of the reserve, and the largest vermilion rockfish occurred in the surveys outside the reserve. Size distributions of lingcod, a more vagile species than many of the rockfishes, were statistically similar inside and outside the reserve in both years.

DISCUSSION

In situ video methods for surveying from an occupied submersible were effective in characterizing benthic habitats of BCER and adjacent areas on a spatial scale (microscale of <1 m to macroscale of 1–10 m) relevant to associated fish species. Seafloor substratum types were not distributed uniformly within the reserve, nor were they equal in relative abundance. The shallow high-relief rock habitat, although limited in distribution and abundance, supported a diverse and abundant fish fauna, including many species of economic value to nearshore fisheries. This shallow rock habitat also harbored high numbers of young-of-the-year rockfishes and may serve as a nursery for these newly settled fish. To increase protection of these nearshore species associated with limited amounts of rock habitat, the boundaries of BCER could be extended both north and south.

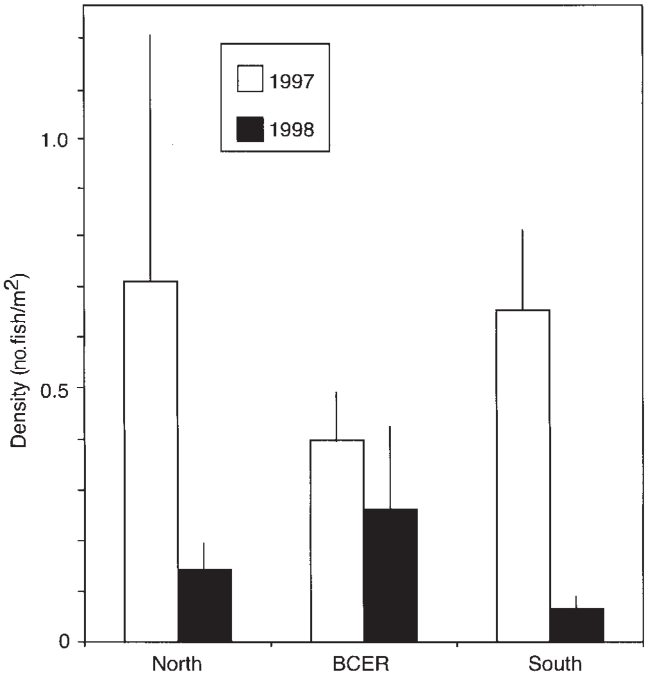

Figure 6. Mean density (no. fish/m^2) of economically valuable species (i.e., blue, olive, vermilion, canary, gopher, copper, and yellowtail rockfishes and lingcod) on high-relief rock substratum among three locations (north of, south of, and inside BCER) in 1997 and 1998. Standard error bar is included.

Substantial amounts of high-relief rock outcrop habitat also are located just outside BCER in deepwater heads of submarine canyons. The boundaries of BCER could

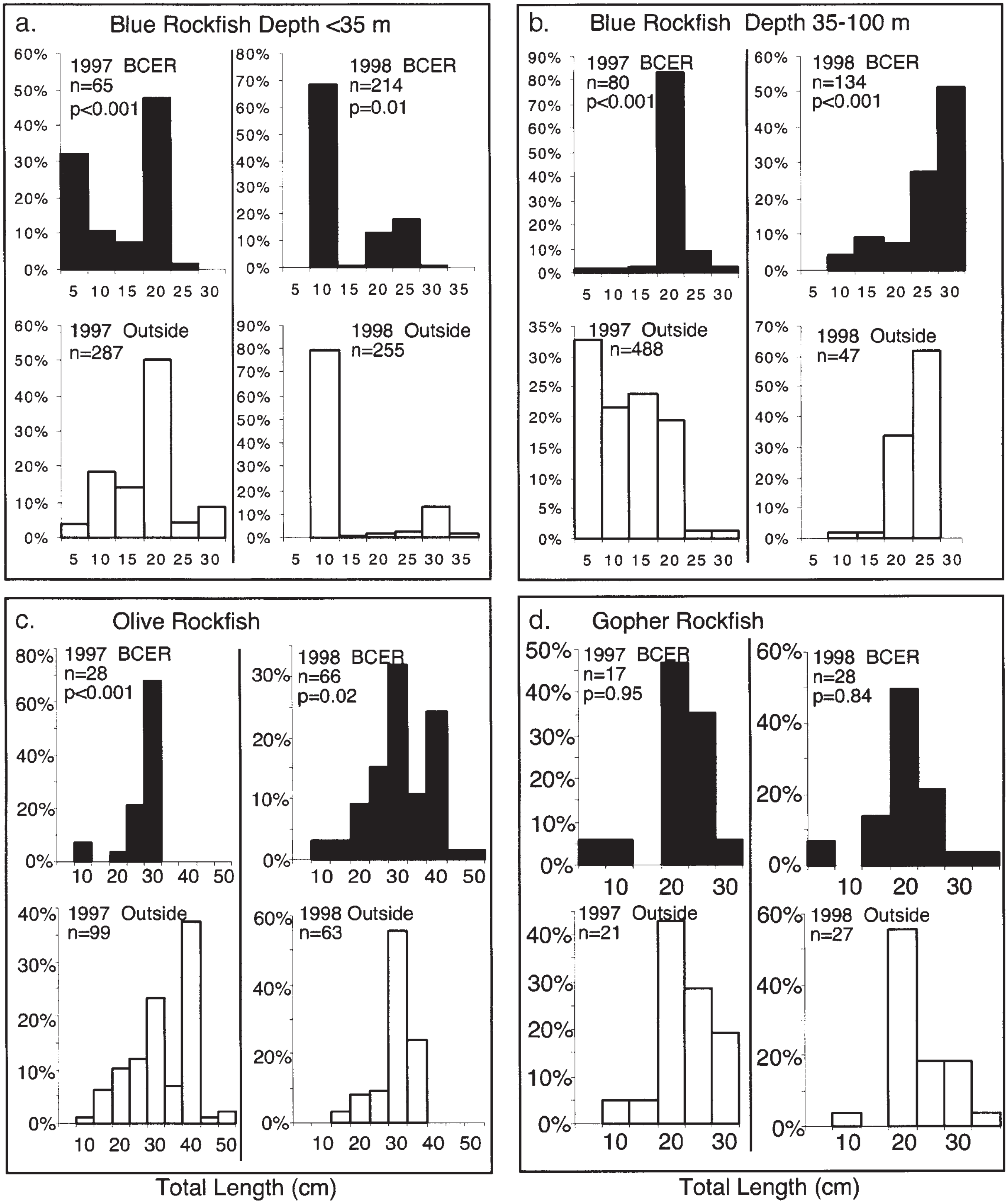

Figure 7. Frequency distributions (%) of total length of rockfishes inside (black) and outside (north and south; white) BCER in 1997 and 1998. (a) blue rockfish, <35 m water depth; (b) blue rockfish, 35–100 m water depth; (c) olive rockfish, 20–100 m water depth; and (d) gopher rockfish, 20–100 m water depth. *P* values are from Kolmogorov-Smirnov goodness-of-fit comparisons between sizes inside and outside the reserve. Sample size denoted as *n*.

be extended offshore to encompass the highly diverse deepwater canyon assemblages of fish associated with rock crevices and overhangs and those species most abundant over soft fine sediment on the canyon walls.

Presently there are no marine reserves that afford protection to those habitats and associated fauna at depths greater than 100 m off California (McArdle 1997; 1998) or off the entire West Coast. From results of our past research in Monterey Bay, rock outcrops on relatively steep canyon walls can offer natural refuge to some economically valuable species in deep water (Yoklavich et al. 2000). These deepwater assemblages include several species whose populations are in severe decline (i.e., bocaccio, cowcod, and canary and yelloweye rockfish; Ralston 1998; MacCall et al. 1999).

Fish densities and sizes were similar inside and outside BCER, and there are various explanations for this. First and most important, the recovery time (or time from the reserve's closure to fishing) could be inadequate to reflect significant effects. There is evidence elsewhere on the West Coast that some rockfish species and lingcod protected for much longer periods of time within a few existing no-take marine reserves have greater abundance or size, and consequently increased spawning biomass and reproductive potential, compared with those in adjacent fished areas.

For example, the reproductive potential of copper rockfish inside a 27-year-old marine reserve in shallow water in Puget Sound, Washington, was 55 times greater than that of copper rockfish subject to heavy fishing pressure outside the reserve (Palsson 1998). The enhanced reproductive potential resulted from greater densities and larger sizes of copper rockfish inside the reserve. Similarly, lingcod, especially large individuals, were more abundant inside a tiny 6-year-old no-take reserve in the San Juan Islands, Washington, compared to adjacent unprotected areas (Palsson and Pacunski 1995). Lingcod nests were denser inside the refuge than in the fished area. Copper rockfish were more abundant in the refuge than at the fished site, but large fish were no more common in any treatment. Positive benefits for lingcod also have been documented in small reserves off British Columbia (Martell et al. 2000).

Reproductive potential for black-and-yellow and kelp rockfishes was significantly greater inside both the Point Lobos State and Ecological Reserve (closed to fishing for more than 20 years prior to study) and Hopkins Marine Life Refuge (closed to fishing for 12 years prior to study) than in heavily fished areas immediately outside these reserves off central California (Paddack and Estes 2000). These researchers found no significant differences in the reproductive potential of these same species in shallow water (14 m) inside and outside BCER, which was closed to fishing for only 1–2 years prior to their surveys.

This suggests that the 3.5 years of protection prior to our surveys in deep water of BCER in 1997 and 1998 may not have been long enough to reflect differences in density, size, and subsequent reproductive potential. Length of time of protection is especially critical when evaluating effects of reserve protection on rockfish. Many rockfish species, particularly those in deep water, have maximum longevity of 50–205 years (Love et al. 2002). In general, rockfishes are slow growing, mature at older ages (6–12 years; Wyllie Echeverria 1987), and are relatively unproductive. The magnitude of recruitment of young rockfish varies greatly from year to year and is linked to environmental factors (Ralston and Howard 1995).

Because of these life history characteristics, the positive effects of areas protected from harvest could take years to accrue. For example, the expected median time to rebuild two of the most depleted populations of rockfishes to 40% of their original biomass in the absence of fishing is estimated to be 91 years for bocaccio[1] and 158 years for yelloweye rockfish.[2] Because BCER was closed to fishing for a relatively short period before we initiated our study, our inventory of habitats and associated fishes can be considered a valuable baseline from which to evaluate future changes to BCER populations of benthic fishes in deep water and the expectations of BCER to maintain species and habitat diversity.

Second, while we do not have estimates of fishing rates along the Big Sur coast, especially relative to BCER, this remote area with limited access likely receives relatively less fishing pressure than similar types of habitat closer to fishing ports. The expected positive effects of marine protected areas, such as increased abundance and sizes inside the protected area compared to adjacent unprotected areas, in large part depend on the contrast in fishing pressure between the two areas. This contrast might not have been great, particularly in deep water at the study site. It is especially important to continue to monitor this reserve and adjacent areas if fishing pressure is expected to increase along this coast.

Third, the size of BCER may not encompass the home range and movements of some benthic fish species and therefore may not adequately protect these fishes. We did not assess the movements of fishes within BCER, but many of the nearshore rockfish species are thought to be relatively sedentary (Stanley et al. 1994; Lea et al. 1999). Extent of movement depends on season for some species, temperature, food supplies, and developmental stage (young fish generally are more mobile than older

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[1] MacCall, A. D. 2002. Status of bocaccio off California in 2002. Unpublished report. National Marine Fisheries Service, 110 Shaffer Rd., Santa Cruz, Calif. 95060.

[2] Wallace, F. 2002. Rebuilding analysis for yelloweye rockfish. Unpublished report. Washington Department of Fish and Wildlife, 48 Devonshire Rd., Montesano, Wash. 98563.

stages). A recent tracking study of electronically tagged greenspotted rockfish and bocaccio in deep water of Monterey submarine canyon documented considerable short-term variation in movement (Starr et al. 2002). Even infrequent movements of fishes outside the boundaries of BCER could impede detection of reserve effect. Other small reserves did eventually demonstrate increased abundance and size of rockfishes (as noted above), but only after several years of protection. Increasing the size of BCER by extending the boundaries could reduce the percentage of time that fish move outside the boundaries and become vulnerable to fishing.

Finally, illegal fishing is known to occur within the boundaries of BCER (Paddack and Estes 2000; for a discussion on enforcement issues and marine reserves, see Proulx 1998). Although we have no good estimates of the extent of poaching in BCER, this activity could diminish fish densities and sizes inside the reserve and consequently conceal or negate any positive reserve effects. Conversely, the continued presence of an on-site reserve manager at BCER and the positive support of the local community likely serve to reduce the likelihood of poaching in this remote area. To further facilitate compliance with reserve regulations, the boundaries should be placed at more easily recognized points than is now the case. For example, the northern boundary could be made contiguous with the Landels-Hill Big Creek Reserve (a terrestrial protected area adjacent to BCER) and the southern boundary extended to Gamboa Point to make it clearly recognizable from sea.

The methodologies and results from this study will be valuable in the implementation of recent fishery management and marine reserve legislation in California (Marine Life Management Act and Marine Life Protection Act). Assessing habitat availability and species-specific habitat associations is paramount to locating marine reserves and evaluating their effectiveness. Results of our work can improve the effective design and monitoring of marine protected areas. For example, from our data we estimated that a minimum of 14 samples (independent estimates of abundance of the group of seven economically valuable species) from complex rock habitat in each of the three locations will be required to detect a two-fold (100%) difference in abundance inside and outside BCER; in contrast, to detect just a 50% change in abundance, 52 samples per location will be necessary. This information will be useful when developing monitoring plans for BCER and other similar reserves elsewhere off California.

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