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Assemblage Structure of Fish at Offshore Petroleum Platforms on the San Pedro Shelf of Southern California

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Abstract.—Offshore petroleum platforms in California's Santa Barbara Channel have been shown to be of ecological importance for local fish populations; however, before our investigation, no data existed on the fish assemblages associated with the platforms on the San Pedro Shelf further south. Our surveys of these platforms in 2006 and 2007 indicate that there is a core group of warm-temperate nearshore reef species in the midwater depth (<30 m), including California sheephead *Semicossyphus pulcher*, blacksmith *Chromis punctipinnis*, garibaldi *Hypsypops rubicundus*, opaleye *Girella nigricans*, and kelp bass *Paralabrax clathratus*. Platforms located further from shore (i.e., offshore platforms [>14 km]) had a strong seasonal presence of pelagic fishes (primarily jack mackerel *Trachurus symmetricus*) and recruit blacksmiths. At platforms closer to shore (i.e., inshore platforms [<4.8 km]), sea basses (Serranidae) and surfperches (Embiotocidae) were predominant; only slight seasonal variations were observed, which were attributed to prespawning aggregations of barred sand bass *Paralabrax nebulifer*. At the offshore platforms total fish density had a negative relationship with depth but a positive relationship with water temperature; conversely, total fish biomass exhibited a positive relationship with depth but a negative relationship with temperature. In contrast, at the inshore platforms both total fish density and biomass increased with increasing water temperature. With the exception of blacksmiths, nearshore reef fishes showed significantly greater densities of adults than juveniles. Furthermore, some species were observed spawning at these structures. Therefore, the San Pedro Shelf platforms may provide suitable habitat for several species of nearshore reef fish. Removing the upper levels and superstructure of the offshore platforms to a depth of 25 m (the partial removal decommissioning option) would eliminate critical habitat for several fish species and result in a potential loss of 95% of the total fish density and 77% of the total fish biomass, thus reducing the productivity advantages of some of these structures.

The complex and unique structure of offshore petroleum platforms in California, along with access restrictions and the isolated locations, allow platforms to act as de facto marine reserves, protecting fish communities from harvest and degradation (Love et al. 2003; Fabi et al. 2004). This protection has contributed to greater fish species richness, diversity, biomass, and density observed at petroleum platforms compared with adjacent natural habitat throughout the world including the Gulf of Mexico (Stanley and Wilson 1996; Wilson et al. 2003), the North Sea (Løkkeborg et al. 2002, Soldal et al. 2002), the Adriatic Sea (Fabi et al. 2002, 2004), the Red Sea (Rilov and Benayahu 2000), and California's Santa Barbara Channel (Love et al. 1994, 2003). These benefits have led some resource managers to advocate the retention of obsolete platform structures as fisheries conservation and enhancement tools (Reggio 1987).

Platform retention (rigs-to-reefs) programs use one

of four decommissioning alternatives including: No removal (leaving in place); topping (removing structure at the waterline); partial removal (removing to a depth of 25 m to comply with navigational safety); or toppling (falling the structure on its side) (Schroeder and Love 2004). In the Gulf of Mexico, these decommissioning strategies have been well received because of economic benefits arising from recreational and commercial activity (McGinnis et al. 2001; Hiett and Milon 2002), as well as funding provided for fisheries conservation programs (Kasprzak 1998; Kaiser and Pulsipher 2005). In California, however, previous attempts to establish a rigs-to-reefs program have failed because of a lack of scientific data pertaining to ecological and economic benefits (Helvey 2002).

Research conducted at platforms in the Santa Barbara Channel (Love et al. 2003, 2006) have indicated that some of these platforms function as important habitat for rockfishes (*Sebastes* species). However, the seven platforms further south on the San Pedro Shelf have remained largely unstudied (Figure 1). The complex transition between the cold-temperate Oregonian and warm-temperate San Diegan biogeographic provinces in the Southern California Bight

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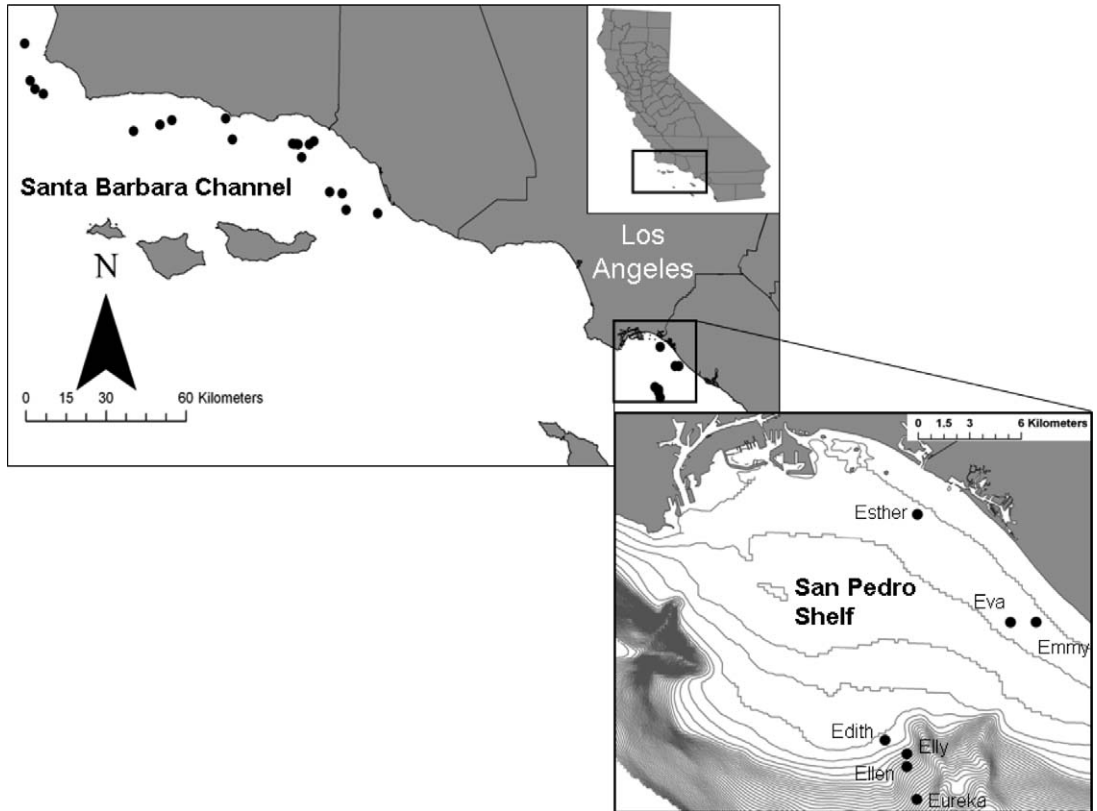


FIGURE 1.—Locations of the 27 offshore petroleum platforms in California. The inset shows the locations the 7 platforms on the San Pedro Shelf, along with the 10-m isobath lines.

(Horn et al. 2006) adds greater uncertainty to this knowledge gap. Because different water masses exist in these two regions (Lynn and Simpson 1987), differences in species assemblage characteristics can be anticipated (Blanchette et al. 2008).

To date, only two cursory fish surveys have been conducted at the San Pedro Shelf platforms (Carlisle et al. 1964; Love et al. 2003). Both data sets reported fish assemblages predominated by blacksmith *Chromis punctipinnis* and California sheephead *Semicossyphus pulcher*; however, neither study was designed to quantify spatial and temporal variability. Fish assemblages in the Southern California Bight are known to exhibit large fluctuations in species abundance and composition over seasonal (Stephens and Zerba 1981), annual, and decadal time scales (Holbrook et al. 1997). Therefore, a systematic sampling design over multiple years is necessary to thoroughly characterize platform-associated fish communities. The goal of our research was to characterize, to a depth of 30 m, the fish assemblages associated with the San Pedro Shelf

petroleum platforms and assess the temporal and spatial variations in community structure.

Methods

Study site.—Fish assemblages were surveyed at six of the seven platforms on the San Pedro Shelf every 2 months between October 2006 and September 2008. The surveyed platforms included Esther (water depth, 9 m), Eva (17 m), Edith (49 m), Elly (80 m), Ellen (81 m), and Eureka (212 m) (Table 1; Figure 1). Platform Emmy (14 m) was not surveyed because of access restrictions. An additional sampling session was conducted in August 2007, for a total of 17 survey sessions per platform. At Platform Esther, sampling had to be omitted in March 2007 because of high swells and again in May 2007 because of a prolonged red tide.

Platforms Eva and Esther are in water shallow enough for divers to survey the seafloor and are located within state waters, 4.8 km from shore (we refer to these as “inshore platforms”). Platforms Edith, Ellen, Elly, and Eureka are all more than 14 km offshore (i.e.,

TABLE 1.—Global Positioning System coordinates and survey depths at study platforms on the San Pedro Shelf. The surveyed area is the total transect surface area surveyed during each sampling session.

Platform	Latitude (N)	Longitude (W)	Depth (m)				Surveyed area (m ²)
			Sea floor	Level 1	Level 2	Level 3	
Esther	33°43.07'	118°06.88'	9	4	8		1,204
Eva	33°39.70'	118°03.66'	18	4	12	18	1,440
Edith	33°35.75'	118°08.45'	49	5	12	30	2,424
Elly	33°34.93'	118°07.65'	80	5	15		1,360
Ellen	33°34.93'	118°07.65'	81	5	12	31	1,756
Eureka	33°33.83'	118°07.00'	212	5	16		1,532

under federal jurisdiction) and in water deeper than 49 m, preventing divers from safely surveying the seafloor habitat (we refer to these as “offshore platforms”). Because of changing oceanographic conditions with distance from shore (Conversi and McGowan 1994; Nezlin et al. 2004), inshore and offshore communities were considered separately.

Survey methods.—Fish survey methods followed those described by Love et al. (2003), sampling species composition at three major depth levels for inshore (level 1 = 4 m, level 2 = 9–12 m, and level 3 = 18 m) and three for offshore (level 1 = 5–10 m, level 2 = 12–20 m, and level 3 = 26–31 m). These survey levels were selected based on the location of horizontal supports of the offshore platforms, which varied in depth considerably among platforms. Because of the shallow depth of the inshore platforms, the last level was conducted along the seafloor, underneath the structure; at Esther the water was too shallow to conduct surveys at all three depth levels, so only two levels were surveyed (Table 1). At two offshore platforms, Eureka (40 m) and Elly (35 m), the third level of horizontal supports were too deep to safely and logistically survey using scuba, so the third-level transect was omitted at these two platforms.

One diver tallied and identified all fishes to the lowest possible taxonomic level (Table 2) and estimated fish total lengths into 5-cm intervals. A second diver followed while operating an underwater digital video camera. Video footage was used to calibrate fish identification and assess interobserver variability. After the completion of each survey, a YSI model 6600 Sonde was deployed from the surface to 31 m. Water temperature, photosynthetically active radiation (PAR), dissolved oxygen (DO), salinity, chlorophyll, and pH were recorded.

Data analysis.—Data were standardized to density (number of fish/100 m²) and biomass (kg/100 m²) with the methods of Love et al. (2003). Biomass estimates were calculated using established length–weight equations that were available for most species observed. Although rare, when fish such as rockfish were not

identified to the species level, biomass calculations were based on the most abundant and closest related species. The fish count data were also used to calculate community-structure metrics, including Shannon–Weiner diversity (H'), species richness (S), and species evenness (J').

For each platform and sampling session, community-structure metrics were calculated for each depth level and were tested for normality (Ryan–Joiner test) and equal variances (Bartlett’s test). Whenever needed, data were transformed as $\log_{10}(x + 1)$ to meet the assumptions for analysis of variance (ANOVA). Due to the occurrence of unequal sample sizes, ANOVA procedures were conducted using a general linear model (GLM). Because of the replication of set survey circuits, a repeated-measures design was used to avoid the effects of pseudoreplication. Post hoc pairwise comparisons were conducted following each GLM analysis via Tukey’s honestly significant difference (HSD) test. If data were unable to achieve a normal distribution or equal variances, a nonparametric Kruskal–Wallis test was used with Mann–Whitney U -test comparisons.

The effects of environmental variables were tested using the best-fitting GLM as determined by the Akaike information criterion with a second-order correction for small sample sizes (AIC_c), in our case a relatively small ratio of sample size to the number of variables (Burnham and Anderson 2002). This Information Theoretic Approach provides a measure of model fit whereby the smallest AIC_c value indicates the model that loses the least amount of information. The best fit model was used for interpretation.

To compare species composition, a nonmetric multidimensional scaling analysis (MDS) was conducted using PRIMER-E version 6.1.7 (PRIMER-E, Plymouth, UK). Data were $\log(x + 1)$ transformed to reduce the influence of numerically abundant species and the Bray–Curtis index was calculated (Clarke et al. 2006). The analysis of similarity (ANOSIM) procedure was used to assess significant community differences among location, season, and depth factors. Significant

TABLE 2.—Mean \pm SE density (fish/100 m²) for all observed species. Group indicates the designated behavior related to site fidelity: P = pelagic (not associated with reef structure), T = transient (associated with benthic or reef habitat but with low site fidelity), and R = resident (species that were observed throughout our research). Age-0 fish were 10 cm or less in total length.

Species	Group	Inshore		Offshore			
		Esther	Eva	Edith	Elly	Ellen	Eureka
Baitfish, unidentified	P			0.73 \pm 0.73		32.8 \pm 32.8	0.22 \pm 0.22
Clupeiformes							
Barred sand bass	R	2.27 \pm 0.44	11.69 \pm 2.52				
<i>Paralabrax nebulifer</i>							
Barred surfperch	R	0.78 \pm 0.78					
<i>Amphistichus argenteus</i>							
Bat ray <i>Myliobatis californica</i>	T		0.004 \pm 0.004				
Black perch <i>Embiotoca jacksoni</i>	R	4.55 \pm 0.63	0.13 \pm 0.05				
Black-and-yellow rockfish <i>Sebastes chrysomelas</i>	R			0.002 \pm 0.002			0.009 \pm 0.006
Blackeye goby <i>Rhinogobiops nicholsii</i>	R			0.002 \pm 0.002			0.002 \pm 0.002
Blacksmith <i>Chromis punctipinnis</i>	R	30.32 \pm 6.71	11.99 \pm 3.73	64.9 \pm 12.40	39.9 \pm 12.70	51.09 \pm 9.90	100.80 \pm 15.70
Blenny, unidentified	R		0.004 \pm 0.004				
Blennidae							
Blue rockfish <i>Sebastes mystinus</i>	R					0.003 \pm 0.003	
Bocaccio <i>Sebastes paucispinis</i>	R						0.009 \pm 0.009
Cabezon <i>Scorpaenichthys marmoratus</i>	R	0.13 \pm 0.04	0.31 \pm 0.04	0.28 \pm 0.04	0.18 \pm 0.06	0.31 \pm 0.04	0.07 \pm 0.02
Pacific barracuda <i>Sphyræna argentea</i>	P	0.008 \pm 0.008	0.09 \pm 0.09				
California scorpionfish <i>Scorpaena guttata</i>	T	0.008 \pm 0.008	0.08 \pm 0.08				0.004 \pm 0.004
California sheephead <i>Semicossyphus pulcher</i>	R	3.25 \pm 0.41	1.43 \pm 0.14	2.49 \pm 0.12	1.61 \pm 0.16	0.93 \pm 0.11	2.18 \pm 0.14
Copper rockfish <i>Sebastes caurinus</i>	R			0.01 \pm 0.004		0.16 \pm 0.03	
Flag rockfish <i>Sebastes rubrivinctus</i>	R				0.01 \pm 0.009	0.01 \pm 0.007	
Garibaldi <i>Hypsypops rubicundus</i>	R	1.87 \pm 0.34	0.35 \pm 0.09	2.47 \pm 0.21	1.64 \pm 0.14	0.81 \pm 0.23	2.01 \pm 0.19
Giant kelpfish <i>Heterostichus rostratus</i>	R			0.002 \pm 0.002			
Gopher rockfish <i>Sebastes carnatus</i>	R			0.01 \pm 0.007	0.01 \pm 0.009	0.03 \pm 0.02	0.06 \pm 0.03
Grass rockfish <i>Sebastes rastrelliger</i>	R			0.03 \pm 0.02	0.009 \pm 0.006	0.12 \pm 0.04	0.21 \pm 0.05
Halfmoon <i>Medialuna californiensis</i>	T	1.38 \pm 0.31	1.59 \pm 0.28	1.22 \pm 0.46	1.25 \pm 0.56	1.81 \pm 0.72	2.55 \pm 0.81
Hornyhead turbot <i>Pleuronichthys verticalis</i>	T	0.008 \pm 0.008					
Jack mackerel <i>Trachurus symmetricus</i>	P		0.49 \pm 0.49	66.30 \pm 61.70	16.80 \pm 16.80	28.50 \pm 26.10	143.0 \pm 116.0
Kelp bass <i>Paralabrax clathratus</i>	R	13.01 \pm 2.18	11.78 \pm 1.51	0.03 \pm 0.02	0.004 \pm 0.004	0.21 \pm 0.005	0.42 \pm 0.08
Kelp rockfish <i>Sebastes atrovirens</i>	R			0.47 \pm 0.04	0.15 \pm 0.06	1.19 \pm 0.14	0.25 \pm 0.04
KGB (age 0) ^a <i>Sebastes</i> spp.	R			0.51 \pm 0.21		2.46 \pm 1.14	
Lingcod <i>Ophiodon elongatus</i>	R			0.012 \pm 0.009			
Northern anchovy <i>Engraulis mordax</i>	P			0.73 \pm 0.73	9.99 \pm 9.99	3.35 \pm 3.35	4.22 \pm 4.22

TABLE 2.—Continued.

Species	Group	Inshore		Offshore			
		Esther	Eva	Edith	Elly	Ellen	Eureka
Ocean sunfish <i>Mola mola</i>	P			0.007 ± 0.005		0.01 ± 0.01	
Opaleye <i>Girella nigricans</i>	R	4.87 ± 0.69	1.35 ± 0.15	0.03 ± 0.02	0.13 ± 0.06	0.25 ± 0.07	0.36 ± 0.19
Pacific bonito <i>Sarda chiliensis</i>	P			0.01 ± 0.01			
Pacific chub mackerel <i>Scomber japonicus</i>	P				0.95 ± 0.95	0.05 ± 0.05	0.12 ± 0.08
Pacific sardine <i>Sardinops sagax</i>	P	0.42 ± 0.42		31.10 ± 22.0	22.0 ± 22.0	2.91 ± 2.07	5.09 ± 5.09
Painted greenling <i>Oxylebius pictus</i>	R	16.27 ± 3.39	2.07 ± 0.21	0.29 ± 0.05	0.22 ± 0.05	0.32 ± 0.07	0.07 ± 0.02
Pile perch <i>Rhacochilus vacca</i>	R	16.27 ± 3.39	2.07 ± 0.21	0.27 ± 0.14	0.08 ± 0.08	0.07 ± 0.05	
Rainbow seaperch <i>Hypsurus caryi</i>	R	0.05 ± 0.05	0.05 ± 0.04				
Rock wrasse <i>Halichoeres semicinctus</i>	R	2.82 ± 0.98	0.32 ± 0.10				
Rockfish, unidentified <i>Sebastes</i> spp.	R			0.01 ± 0.01		0.70 ± 0.40	
Rockfish, age 0, unidentified <i>Sebastes</i> spp.	R			0.32 ± 0.21		0.16 ± 0.13	
Rosy rockfish <i>Sebastes rosaceus</i>	R					0.003 ± 0.003	
Round stingray <i>Urobatis halleri</i>	T	0.02 ± 0.01	0.02 ± 0.01				
Rubberlip seaperch <i>Rhacochilus toxotes</i>	R	0.39 ± 0.1	0.02 ± 0.007				
Sargo <i>Anisotremus davidsonii</i>	R	1.35 ± 0.43	1.05 ± 0.58	0.04 ± 0.04			
Señorita <i>Oxyjulis californica</i>	R	9.68 ± 1.93	0.14 ± 0.06	0.77 ± 0.19			0.004 ± 0.004
Squarespot rockfish <i>Sebastes hopkinsi</i>	R					2.92 ± 1.74	
Striped seaperch <i>Embiotoca lateralis</i>	R		0.03 ± 0.03				
Surfperch, unidentified <i>Embiotocidae</i>	R		0.008 ± 0.008	0.009 ± 0.009			
Treefish <i>Sebastes serripes</i>	R			0.009 ± 0.009	0.007 ± 0.005	0.03 ± 0.03	
White seaperch <i>Phanerodon furcatus</i>	R	0.008 ± 0.008	0.19 ± 0.18	1.08 ± 0.43	0.07 ± 0.05	0.13 ± 0.13	
White-spotted rockfish, unidentified <i>Sebastes</i> spp.	R			0.01 ± 0.004		0.03 ± 0.03	
Zebraperch <i>Hermosilla azurea</i>	T					0.007 ± 0.007	

^a Kelp, gopher, or brown rockfish not further identifiable.

ANOSIM differences were further analyzed with a similarity percentages (SIMPER) analysis to assess influential species.

A recurrent-group analysis (Fager 1963) was conducted on species presence–absence data to identify species with high affinities for one another and to ascertain habitat characteristics that influence species distribution. Species that had an index of affinity value greater than 0.495 were grouped together, and connex values described positive affinities between members of different recurrent groups.

Fish size-class structure was examined via the densities of young-of-the-year (age-0) and post-age-0 reef-associated species that were numerically predominant and economically important: blacksmith, cabezon, kelp bass, barred sand bass, California sheephead, all *Sebastes* species, and garibaldi. Age-0 fish were defined as those with an estimated total length of 10 cm or less; individuals larger than 10 cm were considered to be post age 0. For the species we considered, 10 cm is the smallest possible size at maturity (Cailliet et al. 2000) and the largest possible size after 1 year (Love

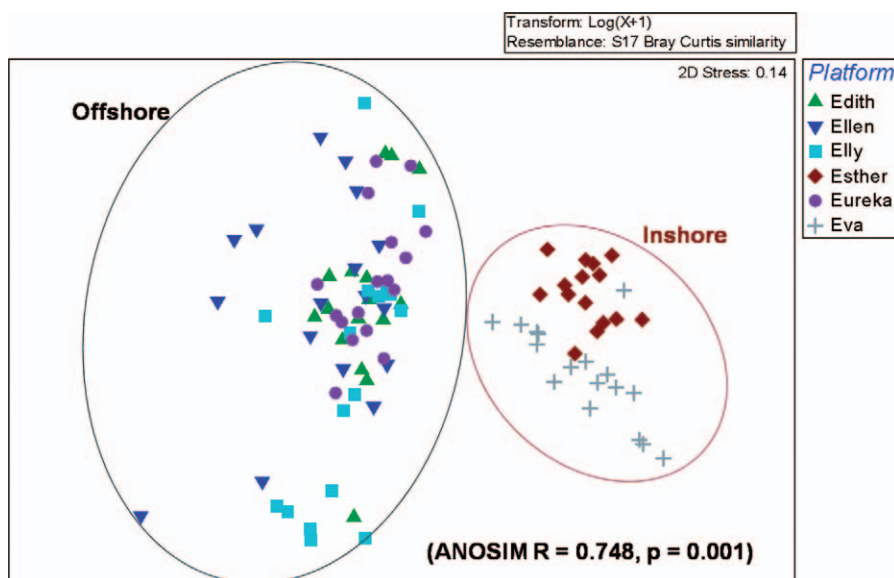


FIGURE 2.—A nonmetric multidimensional scaling analysis of total platform fish species composition data for the six petroleum platforms (two inshore, four offshore) on the San Pedro Shelf based on the Bray–Curtis similarity index (ANOSIM = analysis of similarity).

1996). The mean densities of both size-classes were compared using a two-factor GLM.

Results

Assemblage Structure

A total of 215,509 fish from 53 different species within 24 families were observed through the course of this study (Table 2). Only 8 of the 53 species were observed at all six of the surveyed platforms: California sheephead, kelp bass, garibaldi, blacksmith, painted greenling, opaleye, halfmoon, and cabezon. With such a small number of common species, the inshore and offshore species composition differed significantly (ANOSIM $R = 0.748$, $P = 0.001$; Figure 2).

Fish communities at the offshore platforms were numerically dominated by schooling species, including blacksmith (38.7% of the total abundance), jack mackerel (38.4%), and Pacific sardine (9.5%). Of the nearshore reef-associated species, the most abundant were California sheephead (1.1%), garibaldi (1.08%), and kelp rockfish (0.75%; Table 2). The inshore communities exhibited a greater influence from nearshore reef species, including blacksmith (30.8% of the abundance), kelp bass (18.2%), pile perch (12.9%), barred sand bass (10.7%), and señorita (6.3%). A SIMPER analysis revealed the greatest dissimilarity between the inshore and offshore communities was from higher inshore densities of barred sand bass (14.4% of the difference), kelp bass (11.3%),

and pile perch (9.9%), as well as higher offshore densities of blacksmiths (10.9%) and jack mackerel (4.2%). Additionally, observations of rockfishes were made only in the offshore communities (Table 2).

A core recurrent group, typical of all the platform communities, consisted of six nearshore reef species: California sheephead, garibaldi, blacksmith, halfmoon, opaleye, and kelp bass (Figure 3). At the offshore platforms this core group commonly co-occurred with kelp rockfish and cabezon, two cold-temperate species typical of the deeper regions. Two recurrent groups were found at the inshore communities; one included black perch, barred sand bass, pile perch, and rock wrasse, which were present at both inshore platforms. The other group frequently observed together included rubberlip seaperch and señorita, which were mostly found at platform Esther.

The inshore platform communities had significantly greater species richness ($F_{1,4} = 16.50$, $P = 0.015$), evenness ($H_{1,100} = 37.61$, $P < 0.0001$), diversity ($H_{1,100} = 54.38$, $P < 0.0001$), and total fish biomass ($F_{1,4} = 87.80$, $P = 0.0007$) than the offshore communities. However, there was no significant difference in total fish density ($F_{1,4} = 0.61$, $P = 0.480$) between the inshore and offshore platforms (Figure 4).

Temporal Variability

Neither inshore nor offshore platform fish communities exhibited significant annual differences with

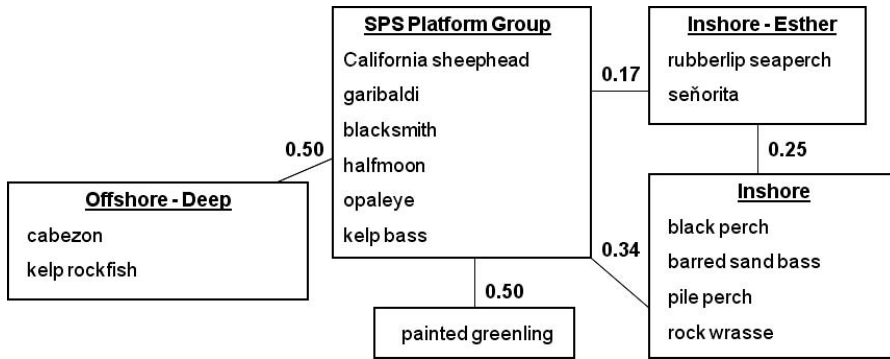


FIGURE 3.—Recurrent-group analysis of species composition data for all observations of fish species at two inshore and four offshore petroleum platforms on the San Pedro Shelf. The connex values next to the group association lines indicate the proportions of positive affinities between the members of the two groups. Two recurrent groups were typical of all platform communities, although inshore and offshore platforms both had some unique species associations.

regard to community structure or species composition. However, at the offshore platforms, interannual differences were observed in cabezones, which exhibited a significant increase in density ($H_{1, 170} = 6.22, P = 0.013$) and biomass ($H_{1, 170} = 5.88, P = 0.015$) from year 1 to year 2. Pelagic fishes, however, decreased in both density ($H_{1, 170} = 5.17, P = 0.023$) and biomass ($H_{1, 170} = 5.29, P = 0.022$) from year 1 to year 2.

Inshore communities showed no significant seasonal differences in species composition. Total fish density was significantly lower in winter of year 2 compared with summer of year 2 (Tukey's HSD test: $P = 0.0188$) (Figure 5a). No significant differences were found with respect to total fish biomass (Figure 5c), species diversity (Figure 5e), evenness (Figure 5 g), or species richness (Figure 5i).

Offshore communities showed significant changes in species composition with season (ANOSIM: $R = 0.187, P = 0.01$); however, no pairwise differences were found between summer and autumn (ANOSIM: $R = 0.014, P = 0.29$) or between winter and spring (ANOSIM: $R = 0.044, P = 0.1$). Instead, significant differences were only observed between the winter–spring and summer–autumn periods.

Significant differences in total fish density ($F_{6, 18} = 6.08, P = 0.0013$) followed the same winter–spring and summer–autumn patterns (Figure 5b); however, total biomass was not different ($F_{6, 18} = 2.23, P = 0.0879$; Figure 5d). Much like density, species richness was significantly higher ($F_{6, 18} = 5.32, P = 0.0026$) in summer–autumn than winter–spring (Figure 5j). Species evenness showed an inverse pattern, higher evenness occurring in winter–spring than summer–autumn ($z = 2.77, P = 0.033$). No significant differences were found in species diversity.

Seasonal Variation by Depth

Inshore community structure was not significantly different among depth levels by season and year. At the offshore communities, total fish density was not significantly different by depth levels nested by season and year ($F_{16, 32} = 1.94, P = 0.0537$; Figure 6a). Conversely, biomass showed significant differences ($F_{16, 32} = 6.79, P < 0.0001$) generally resulting from greater biomass during the winter and spring at the 20-m and 30-m level during year 2 (Figure 6b). Species diversity was significantly greater at 30 m ($H_{2, 169} = 52.75, P < 0.0001$) than at 10 m ($z = 7.19, P < 0.0001$) and 20 m ($z = 5.51, P < 0.0001$) by year and season. Species evenness was also found to be

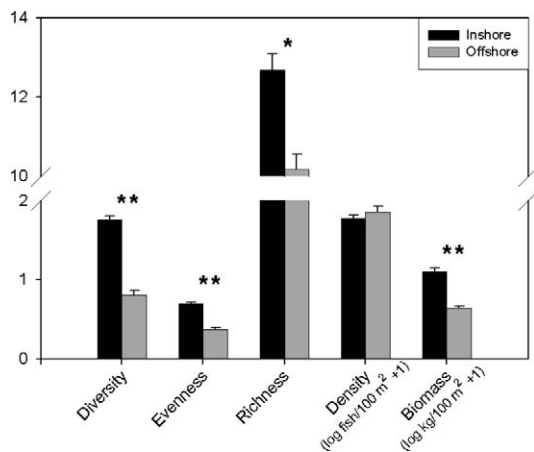


FIGURE 4.—Mean + SE fish community-structure metrics comparing two inshore and four offshore petroleum platforms on the San Pedro Shelf. Except for total fish density, the inshore platforms had significantly greater mean values for all metrics ($P < 0.05^*$; $P < 0.001^{**}$).

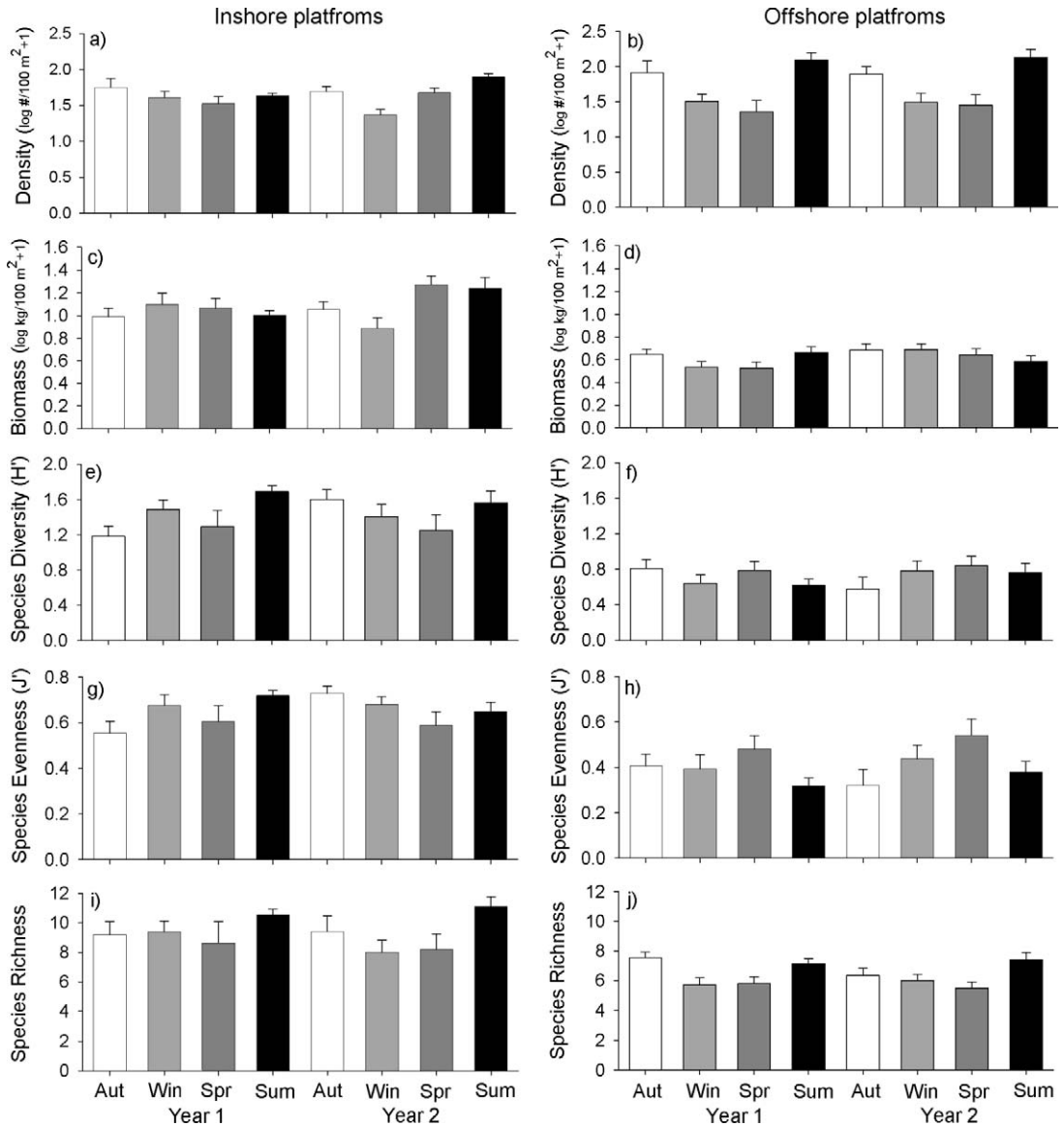


FIGURE 5.—Mean + SE fish community-structure metrics showing the seasonal and annual differences at two inshore and four offshore petroleum platforms on the San Pedro Shelf. The metrics are as follows: (a)–(b) total density, (c)–(d) total biomass, (e)–(f) species diversity, (g)–(h) species evenness, and (i)–(j) species richness. The seasons are autumn (Aut [no shading]), winter (Win [light gray shading]), spring (Spr [dark gray shading]), and summer (Sum [black shading]).

significantly different among depth levels ($H_{2, 169} = 35.80$, $P < 0.0001$), greater evenness occurring at 30 m than at 10 m ($z = 5.31$, $P < 0.0001$) and 20 m ($z = 5.19$, $P < 0.0001$).

Platform Variation

Species composition was significantly different between the inshore platform communities (ANOSIM:

$R = 0.924$, $P = 0.01$). The greatest dissimilarities were caused by higher densities of señoritas (SIMPER: 15.3% of the dissimilarity), black perch (11.2%), pile perch (11.2%), and blacksmiths (10.2%) at platform Esther. Total fish density ($F_{1, 14} = 7.71$, $P = 0.0149$), species richness ($F_{1, 14} = 74.22$, $P < 0.0001$), evenness ($H_{1, 81} = 12.85$, $P = 0.0003$), and diversity ($F_{1, 14} = 51.02$, $P < 0.0001$) were significantly greater at

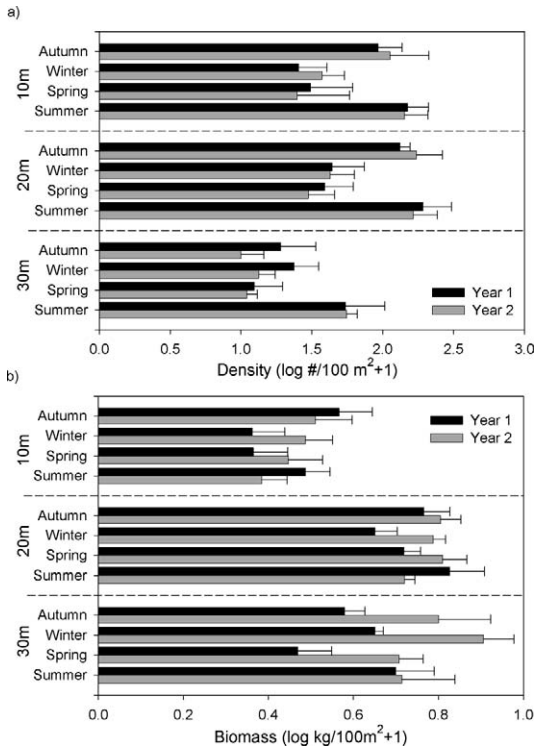


FIGURE 6.—Mean + SE (a) fish density and (b) biomass at four offshore petroleum platforms on the San Pedro Shelf showing the depth and seasonal differences for each of two years. Greater densities were observed at 10 and 20 m, significantly higher values occurring during summer and autumn. Biomass showed little seasonal trend, but higher values were typically observed at 20 and 30 m; annually, biomass differences were greatest at 30 m.

platform Esther than at Eva (Figure 7a). Despite the higher densities at Esther, total biomass was greater at Eva ($F_{1, 14} = 9.55$, $P = 0.008$) (Figure 7a).

Significant differences in species composition were found among the offshore communities (ANOSIM: $R = 0.235$, $P = 0.01$). Pairwise ANOSIM tests showed relatively equal dissimilarity among the offshore platforms, driven largely by the relative abundances of blacksmiths, jack mackerel, halfmoons, and garibaldi. Community structure at platform Elly had significantly lower density ($F_{3, 48} = 5.95$, $P = 0.0016$), biomass ($F_{3, 48} = 9.99$, $P < 0.0001$), and richness ($F_{3, 48} = 9.58$, $P < 0.0001$) than at the other offshore platforms. Platform Eureka had significantly lower species evenness than platforms Edith ($z = 2.829$, $P = 0.028$) and Elly ($z = 3.198$, $P = 0.008$). Additionally, Edith had significantly higher diversity than Eureka ($z = 2.866$, $P = 0.025$; Figure 7b).

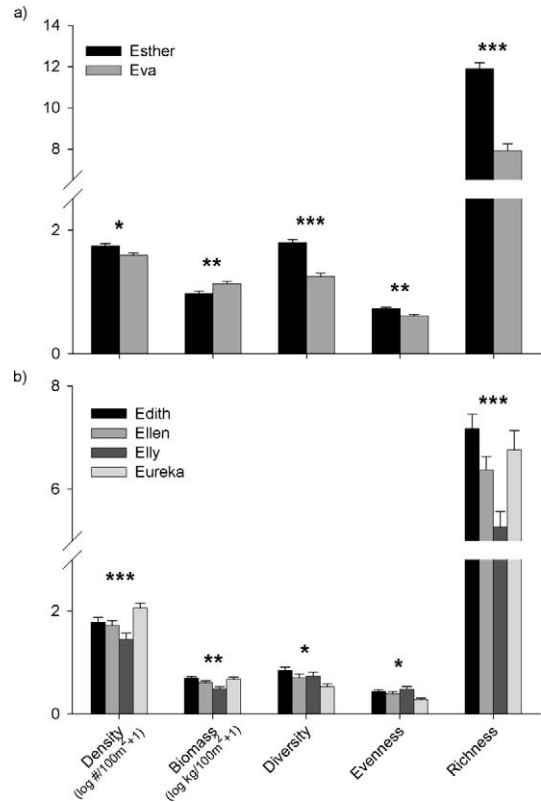


FIGURE 7.—Mean + SE fish community-structure metrics at (a) two inshore petroleum platforms and (b) four offshore platforms on the San Pedro Shelf. Significant differences between or among platforms were found for all five metrics ($P < 0.05$; $P < 0.005$; and $P < 0.0001$ ***).

Depth Levels

Species composition at the inshore platforms differed among depth levels (ANOSIM: $R = 0.418$, $P = 0.001$), which was caused by increased kelp bass and blacksmith density in the shallower depth and elevated barred sand bass at the deeper levels. Overall fish density was significantly higher at the 4-m (Tukey's HSD test: $P = 0.0144$) and 10-m (Tukey's HSD test: $P = 0.0008$) levels of platform Esther than at 4 m at platform Eva. Density at Eva was significantly higher at 10 m than at 4 m (Tukey's HSD test: $P = 0.0004$). Total biomass was significantly greater at deeper levels at both platforms than at 4 m ($F_{3, 46} = 8.09$, $P = 0.0002$), and species richness was significantly greater at both the depth levels of Esther than at all levels of Eva ($F_{3, 46} = 2.84$, $P = 0.0484$).

At the offshore platforms species composition showed a significant difference between 30 m and both 10 m (ANOSIM: $R = 0.613$, $P = 0.001$) and 20 m

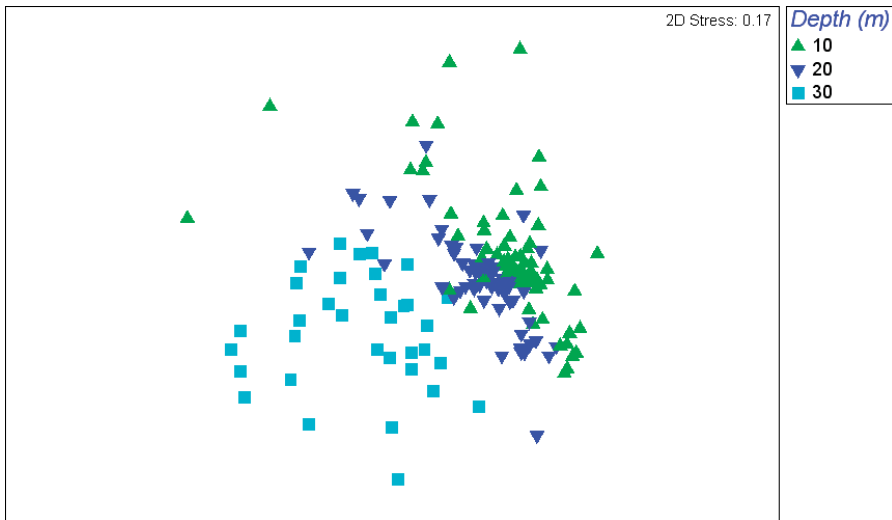


FIGURE 8.—Nonmetric multidimensional scaling analysis of fish species composition at three depth levels at four offshore petroleum platforms on the San Pedro Shelf, based on Bray–Curtis similarity index values. The data were $\log_{10}(x+1)$ transformed.

(ANOSIM: $R = 0.632$, $P = 0.001$), but no significant difference between 10 and 20 m (Figure 8). A SIMPER analysis revealed these depth gradients in community structure were largely driven by increased densities of blacksmiths, garibaldis, halfmoons, and jack mackerel at the shallower levels and decreased densities of kelp rockfish and cabezons.

Overall fish density was significantly different ($F_{6, 96} = 4.87$, $P = 0.0002$), lower values occurring at 30 m for platforms Edith and Ellen. Total biomass was also significantly different ($F_{6, 96} = 18.92$, $P < 0.0001$), being higher biomass at 30 and 20 m. Species richness ($F_{6, 96} = 11.66$, $P < 0.0001$) was generally higher at 30 and 20 m than at 10 m.

Size-Class Structure

At the inshore platforms, a higher density of post-age-0 fish was assumed for cabezons, barred sand bass, and sheephead because of an absence of observed age-0 fish. No significant difference in size-class density was observed for blacksmiths, but a significantly greater density of post-age-0 kelp bass was observed ($F_{1, 1} = 260.78$, $P = 0.0394$).

Of the resident reef fish species tested at the offshore platforms, blacksmith was the only species to have significantly higher densities of age 0 than post age 0 ($F_{1, 3} = 58.27$, $P = 0.0047$). Cabezons ($F_{1, 3} = 80.47$, $P = 0.003$), kelp bass ($F_{1, 3} = 24.74$, $P = 0.016$), garibaldis ($F_{1, 3} = 49.23$, $P = 0.006$), and California sheephead ($F_{1, 3} = 410.05$, $P = 0.0003$) all had significantly higher densities of post-age-0 size-classes.

No significant difference was observed with total rockfish species (GLM: $F_{1, 3} = 3.88$, $P = 0.1436$).

Environmental Variables

Only community structure metrics which could be normalized were used for GLM analysis. A preliminary correlation analysis was conducted of all the environmental variables to identify any significant relationships. As with aquatic environments, moderate correlation between water depth and some of the other variables were observed; however, these correlations mostly had a Pearson's r -value of less than 0.5 and were therefore included in the analysis.

At the inshore communities, water temperature was consistently present in the best fit model and exhibited significantly positive relationships with total fish density ($F_{1, 52} = 7.63$, $P = 0.0079$), species richness ($F_{1, 44} = 10.59$, $P = 0.002$), and species diversity ($F_{1, 50} = 11.88$, $P = 0.0012$) (Figure 9). Water temperatures at the offshore communities were shown to have a significant positive relationship with total fish density ($F_{1, 124} = 27.70$, $P < 0.0001$), species richness ($F_{1, 122} = 12.83$, $P = 0.0005$), and a negative relationship with total fish biomass (GLM: $F_{1, 129} = 5.34$, $P = 0.022$; Figure 10a).

Inshore fish community structure was not significantly influenced by water depth. However, offshore communities exhibited a significant positive relationship between water depth and total fish biomass ($F_{2, 4} = 7.00$, $P = 0.0495$) as well as a significant negative relationship with total fish density ($F_{2, 4} = 41.50$, $P = 0.002$; Figure 10b). Fish species richness was also

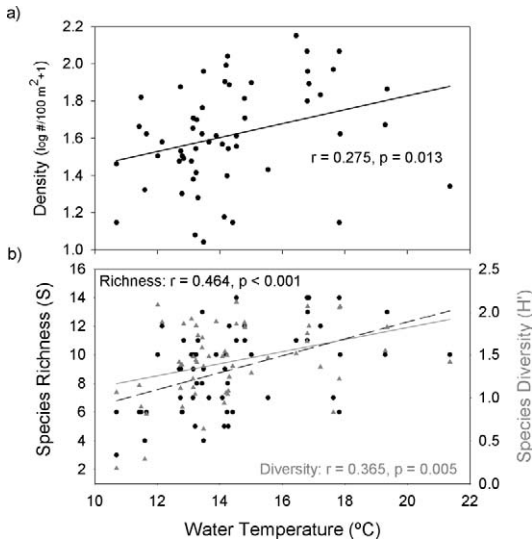


FIGURE 9.—Relationships between water temperature and three metrics of fish community structure—(a) density and (b) species richness and diversity—at two inshore petroleum platforms on the San Pedro Shelf.

observed to increase with water depth ($F_{2,4} = 18.86, P = 0.009$).

Discussion

The species associated with the San Pedro Shelf petroleum platforms were all typical of the offshore island kelp bed habitats of the warm-temperate San Diegan biogeographic province (Pondella et al. 2005). Despite the similarities of six core species, significant differences existed between the inshore and the offshore fish communities. The most apparent disparity was the absence of rockfishes at the inshore communities, which is in stark contrast offshore, where rockfishes of all life stages were observed. This disparity is of interest because of the presence of rockfishes at every other platform in California (Love et al. 2003) and at the Outer Los Angeles Federal Breakwater, which is 1 km away from platform Esther (Froeschke et al. 2005). Furthermore, anecdotal observations of platform Eva in 1979 indicate several species of rockfish and a scarcity of bass species (M. Moore, Orange County Sanitation District, personal communication); however, these observations occurred during a cool phase of the Pacific Decadal Oscillation (PDO). Therefore, the present lack of cool-temperate rockfishes in favor of warm-temperate bass species may be related to the documented shift towards warmer oceanographic conditions in the late 1970s and early 1980s (Holbrook et al. 1997; Horn and Stephens 2006).

Another difference observed among the San Pedro

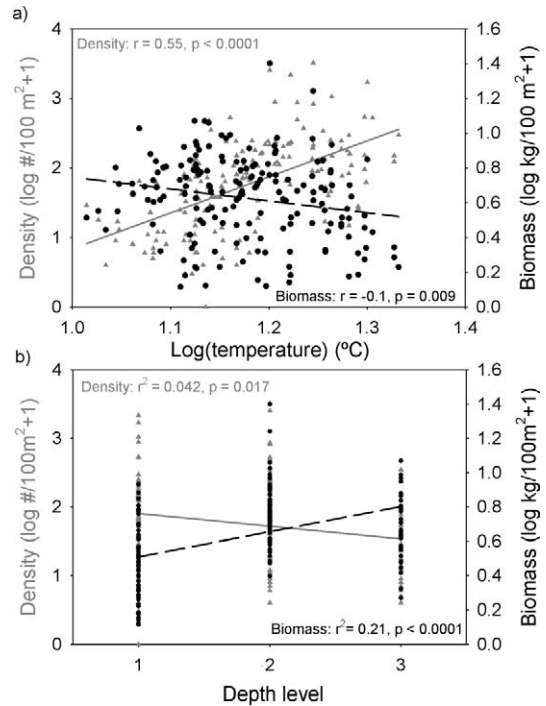


FIGURE 10.—Relationships between two metrics of fish community structure—density and biomass—and (a) water temperature and (b) depth at four offshore petroleum platforms on the San Pedro Shelf. Depth levels are defined as follows: 1 = 5–10 m, 2 = 12–20 m, and 3 = 26–31 m.

Shelf platforms was the influence of seasonally abundant species. At the offshore platforms, significant differences were observed between the winter–spring and summer–autumn periods, a result caused by the seasonally abundant schooling of carnivorous jack mackerel, which occurs in open ocean waters away from shore (Allen and DeMartini 1983; Allen and Cross 2006). Meanwhile, the inshore platform communities were largely absent of schooling pelagic species, including the summer–autumn months. However, the inshore platform communities had significantly less fish during the winter months, a result largely attributed to increases in barred sand bass during their spawning season (April–September) (Love et al. 1996). Although the platform structures themselves are probably not used as spawning habitat, barred sand bass may use inshore platforms as a staging area before spawning. Therefore, these structures may provide some protection to barred sand bass while in their prespawning aggregations (Roberts and Sargent 2002).

A third difference was the observation of several shallow-water reef species at the inshore platforms,

particularly surfperches (Embiotocidae) and sea basses (Serranidae). These species often exhibit affinities for reef–sand ecotone habitat (Ebeling et al. 1980; Larson and DeMartini 1984; Mason 2008); therefore, the inclusion of this habitat inshore elevated the prominence of these species. However, the offshore platforms were outside or near the extreme depth limits of most of these nearshore species, possibly leading to their exclusion (Love et al. 2003, 2005).

Platform Differences

The species composition of the inshore communities differed largely by densities of sea basses and surfperches species. Although many surfperch species were common between the two inshore platforms, Esther was in their typical depth range (Love et al. 2005), probably resulting in the higher densities. Eva had an abundance of larger kelp bass and barred sand bass, resulting in increased biomass despite a lower density. Because Eva was in a more suitable depth range than Esther, Eva was better suited to both kelp and barred sand bass (Love et al. 2005).

At the offshore platforms, differences in species composition were largely influenced by the relative differences of seasonally abundant species as opposed to resident or unique species. These differences were probably influenced by different habitat characteristics. The fish assemblage at Elly was observed to have lower fish density, biomass, and richness than the other offshore platforms. Because Elly is a processing facility, the structure lacked vertical conductor pipes used to pump oil as well as the horizontal support latticework. Therefore, compared to the other offshore platforms, Elly had reduced surface area and complexity, which would have reduced the amount of available habitat and lowered species richness and diversity (Friedlander and Parrish 1998; Ferreira et al. 2001).

Depth Levels

At the inshore communities, depth-associated differences in species composition were observed; however, significant differences were not apparent in other community-structure metrics, particularly total fish density and biomass. This is reflective of the habitat preferences of kelp bass and barred sand bass, both of which were predominant in terms of density and biomass. Barred sand bass were predominant along the seafloor habitat (18 m), whereas kelp bass predominated at the 4-m level, reflective of their preference for midwater positions in high vertical-relief habitat (Larson and DeMartini 1984; Love et al. 2003). These two behavioral characteristics created a zone of overlap between the two bass species at the 10-m level, increasing total bass density and biomass.

The most dramatic effects of depth were observed at the offshore platforms. Although fish community structure metrics did not significantly vary between 10 and 20 m, significant differences were seen between those shallower depths and the 30-m level. These differences were driven by a shift from warm–temperate to cold–temperate species with increasing water depth. The deeper level had a greater frequency of large, predatory species, characteristic of the Oregonian biogeographic province, particularly rockfishes and cabezons. In comparison, above 20 m, the fish community was more greatly influenced by species characteristic of the San Diegan biogeographic province, including schooling pelagic species, blacksmiths, California sheephead, and garibaldi. The Oregonian species were far less abundant but, as larger predators, provided greater biomass. Due to this transition, the greater fish densities observed in the shallower levels contributed less fish biomass.

Environmental Variables

Previous studies have shown physical oceanographic characteristics, particularly water temperature, shape species assemblage, and community structure in temperate systems (e.g., Stephens and Zerba 1981; Love et al. 1991; Blanchette et al. 2006; 2008). Therefore, in vertically structured habitats such as offshore platforms and pinnacles, depth stratification of the physical environment may significantly change the distribution patterns of fishes. This structuring was not seen at the inshore platforms, where water column homogeneity would be greater because of nearshore mixing (Nezlin et al. 2004). In the absence of strong stratification of the environmental variables, only water temperature was found to have significant positive relationships with community-structure metrics including fish density, species richness, and species diversity.

At the offshore communities, several environmental variables showed significant correlations with water depth; however, water depth and temperature had the greatest influence over fish community structure. The increase in pelagic schooling species during the summer and autumn establish a positive relationship between water temperature and total fish density. However, as these species and warmer waters moved into the platform region, the cold–temperate species would have moved deeper to maintain thermal preferences (Ehrlich et al. 1978; Shrode et al. 1982; Tsuchida 1995). Therefore, the less abundant, yet larger species, moved to deeper and cooler water, creating a negative relationship between water temperature and total fish biomass. The cold–temperate species exhibited a negative relationship between water depth and total fish density and a positive relationship

between water depth and total fish biomass. Therefore, the interplay between water temperature and thermocline presence and depth, appear to greatly influence fish community structure at the offshore platforms.

Temporal Variation

Both the inshore and offshore platforms showed differences between the summer–autumn and winter–spring periods. Because warmer water temperatures occur during summer–autumn, an abundance of schooling pelagic species, as well as blacksmith recruitment, entered the community. However, this pattern changed from year 1 to year 2. Decreases in the density and biomass of pelagic species along with increases in cabezons from year 1 to year 2 coincided with a transition into a cooler La Niña oceanographic regime in the California Current System (McClatchie et al. 2008). Therefore, the platform communities may be exhibiting changes in species composition and abundance that are related to changing oceanographic conditions and need to be considered in future management actions.

Due to the use of 5-cm size bins, significant differences in biomass between year 1 and year 2 would not be expected because of the slower growth rates of the adult fishes. Some of the observed species are known to exhibit high site fidelity to natural reef habitat (Lowe et al. 2003; Topping et al. 2005; Mason 2008; C. Mireles et al., California Polytechnic State University, unpublished data). Additionally, four species of economic importance have been shown to exhibit similar site fidelity levels to the offshore San Pedro Shelf platforms (C. Mireles et al., unpublished data). Therefore, some individuals live at these structures and increasing overall biomass via growth. Furthermore, evidence of reproductive biomass production was observed at the offshore platforms. Although nesting species including garibaldi and cabezon were observed guarding egg masses at the offshore platforms during their spawning seasons, it is unclear whether larvae of these species recruit back to the platforms from which they were spawned. Nevertheless, this indicates that the offshore platforms provide habitat suitable for growth and reproduction for some species of fishes.

Management Implications

The San Pedro Shelf, adjacent to one of the most heavily human populated regions of the eastern North Pacific, has a relatively small amount of natural reef habitat, so these natural reef areas experience extremely high levels of fishing pressure. To increase the amount of fishable habitat, artificial reefs have been construction along the shelf (Wilson et al. 1990); however, the

costs of such projects are relatively high. Given these expenses, the shelf's platforms could provide established sites or raw materials for future reefing projects.

If decommissioning options are to be contemplated for these platforms, a partial removal strategy (i.e., removal of the structure to a depth of 25 m) would remove much of the habitat utilized by the predominant nearshore reef and schooling pelagic species. In fact, a partial removal strategy would remove usable habitat for several species and has the potential to remove up to 95% of the total fish density and 77% of the total fish biomass from the midwater environment. Altering the vertical habitat characteristics could therefore eliminate some ecological advantages these structures may be providing to local fisheries.

The San Pedro Shelf platforms have the potential to act as marine reserves. Some fish species have shown evidence of platform-associated reproduction, and larvae produced there could be exported to natural reefs (Bohnsack 1998). A common concern regarding platform decommissioning (reefing options) is that once recreational access is permitted, the fish community will be reduced by the increased fishing pressure (Schroeder and Love 2004). This may be true for partial platform removal or toppling, but for strategies that leave the upper portions intact, the structural complexity of the interior portions of the platform would restrict fishing access and thereby abate overharvest. An alternative option would be to designate reefed platforms as part of Marine Protected Areas (MPA). Currently the California Department of Fish and Game is in the process of designing and implementing a network of MPAs in southern California under the guidelines of the Marine Life Protection Act of 1999. With no exclusions for artificial habitat in the MPA definition, the San Pedro Shelf platforms could provide established structures that support habitats for a wide range of species, some of growing management concern.

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