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Trash or habitat? Fish assemblages on offshore oilfield seafloor debris in the Santa Barbara Channel, California

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We assessed the significance of offshore oilfield debris as fish habitat in central and southern California using video taken from a remotely operated vehicle to enumerate the fish assemblages and to measure debris characteristics. Among 33 species (belonging to 9 families) identified in four regions (from Pt. Conception to Los Angeles), rockfish (genus *Sebastes*) made up approximately 78%. Total fish abundance varied by region, with greater numbers present in the west than in the east. In comparing abundance of fish per debris item among regions, two rockfish species showed no spatial differences, one species was significantly more abundant in the western region and one had the highest abundance in the central region. Water depth, vertical profile, shelter availability, and item volume may be used to predict presence/absence or abundance of different species of rockfish, but none of these characteristics was consistently applicable to all species.

Keywords: artificial reefs, habitat complexity, offshore oilfield debris, rockfish.

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Introduction

Along the California coastline, many species in the family Scorpaenidae (scorpionfishes and rockfishes) associate with rocks, reefs, and other physically heterogeneous structures. In nearshore areas, physical heterogeneity may be created either purposefully (artificial reefs) or accidentally (debris) by anthropogenic activities (Bohnsack *et al.*, 1991). Artificial reefs have been used mainly to enhance fishing success as well as to mitigate environmental impacts (Ambrose, 1994).

Since the early 1900s, oil industry development on the south/central coast off California has waxed and waned, leaving a variety of debris objects on the seafloor. In the 1930s, numerous piers were extended to place drilling rigs just off the beach. From 1956 to 1994, over 30 offshore production platforms with associated shore bound pipelines were installed in the Santa Barbara (SB) Channel, Santa Maria Basin, and offshore of Los Angeles. In that same period, hundreds of exploratory oil wells were drilled in those areas by dozens of semi-submersible or jack-up offshore drilling rigs. In the course of this development, temporarily abandoned wellheads, seafloor completions, pipeline segments, and an assortment of other offshore drilling equipment have been either purposefully or accidentally left on the seafloor. Although several surveys of the fish assemblages around California's platforms have been conducted since the 1960s (Carlisle *et al.*, 1964; Allen and Moore, 1976; Bascom *et al.*, 1976; Love *et al.*, 1994, 2000), no reports have been published characterizing the fish assemblages on the offshore oilfield debris associated with these platforms.

Love *et al.* (1994, 1999, 2000), found that rockfish of specific sizes may find refuge underneath offshore production platforms in the SB Channel. Similarly, oilfield debris may offer refuge for young-of-the-year, subadult, or adult rockfish that either supplements or replaces natural rock-reef features at similar depths in the Channel. We undertook to identify the kind and number of rockfish and other fish species found in association with offshore oilfield seafloor debris in an effort to assess the significance of this type of "artificial reef" as fish habitat. Ongoing discussions among state and federal agencies regarding abandonment of offshore platforms and other equipment in place (in contrast to

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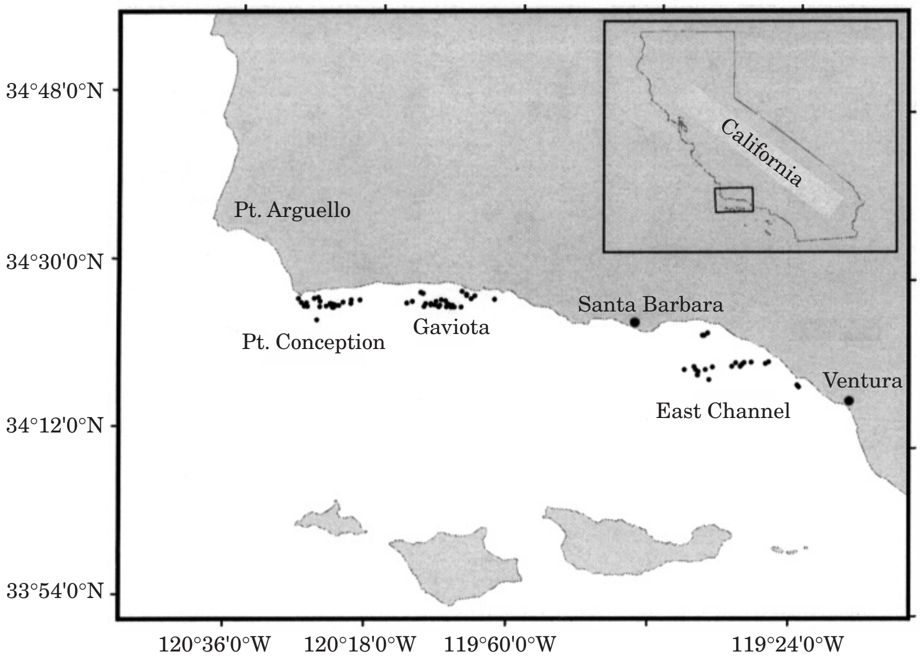

Figure 1. Map showing location of the offshore oilfield debris in Southern California (Los Angeles region not shown).

removal and shore disposal) may benefit from such an analysis of the role of debris. Further, the current discussion regarding attraction versus production of fish on artificial reefs may benefit from an evaluation of the features of existing structures that are correlated with higher fish abundance or more diverse species composition (see Carr and Hixon, 1997).

We established two goals. The first was to determine which fish species inhabit the debris. The second was to learn about characteristics that could help in purposeful siting, design, and/or installation of artificial reefs. Thus, we asked two questions: (1) How are rockfishes and other fishes distributed among regions and among debris items, and (2) do certain characteristics offer any predictive value for determining the presence/absence, abundance or species richness of fish?

Materials and methods

Sachse Engineering Associates, Inc. (SEA) contracted with the Lands Commission to do seafloor debris surveys in the fall–winter of 1989–1990. The surveys spanned the offshore area out to 3 nautical miles from Los Angeles to Point Conception, west of Santa Barbara and focused on specific areas identified by local trawl fisherman as particularly debris-laden: (1) offshore of Long Beach/Los Angeles Harbor; (2) offshore of the Summerland/Carpinteria coastline just west of Ventura; (3) offshore of Gaviota in the western SB Channel; and (4) near Point Conception at the western edge of the SB Channel (Figure 1). The navigation system used was accurate to 2 m (SEA, 1991). A KLEIN 5495 digital recording dual-frequency sidescan sonar and GEOMETRICS® M-801 Magnetometer were initially deployed in each area to locate any debris with vertical relief and/or metal. Targets with both a sidescan sonar and magnetometer reading of any consequence were revisited with a ROV fitted with a video camera, still camera, and MESOTECH® scanning sonar (SEA, 1991).

We reviewed the videotapes made from the survey to identify and count the rockfish and other fish species filmed on 130 seafloor debris objects. These items were extremely variable in their composition, including pieces of pipe of various sizes, concrete rubble, truck tyres, old lobster traps, and wellheads that rise up vertically from the bottom. We estimated the vertical and horizontal dimensions of each item from ROV operator and observer notes and comments as well as through direct observation on the videotapes. We scored each item with respect to a list of physical characteristics that were considered potentially useful as predictors of fish abundance (Table 1).

Using the video images, we identified each fish to species, and counted the number present. Three observers made independent counts of the number of individuals per species and the median value was

Table 1. Description of the physical characteristics of the offshore oilfield debris measured.

Characteristic	Description
Region	One of 4 (see Figure 1)
Depth (De)	(m)
Height (H)	Maximum from substrate (m)
Length (L)	Longest horizontal dimension (m)
Width (W)	Shortest horizontal dimension (m)
Volume (Vo)	L*W*H (m^3)
Shelter (Sh)	Measure of adult-fish-sized crevices, spaces or holes (1–3)
Material (Ma)	Number of types of materials (1–3)
Fouling (Fo)	(1: <1/3 of surface biofouled, 2: 1/3–2/3, 3: >2/3)
Visibility (Vi)	At time of video imaging (scored 1–3)
Complexity (Co)	Sum of scores of H†, L†, W†, Sh, closed/open score, and Ma

†Rank classes H, L and W: 1 if dimension >1, 2 if 1<dimension >2, . . ., 5 if dimension >4.

selected as the most appropriate representative value. Generally, the entire item was included in a single shot. Difficulties in counting arose when abundance for a particular species was very high. To minimize error, we segmented the video shot into views or scenes, began the count with a freeze-frame count of a single species, then moved the frames as necessary to pick up additional fish as they entered the scene. The three estimates for large samples varied by no more than 2%, while counts for small samples were virtually identical among video observers.

Results

Regional variation

We observed 33 species belonging to 9 families on the debris in the four regions (Table 2). Overall, rockfish (genus *Sebastes*) made up approximately 78% of all species observed. Of these, brown rockfish (*S. auriculatus*) accounted for approximately 25%. The next three most abundant rockfish were olive and yellowtail rockfish (*S. serranoides* and *S. flavidus*), copper rockfish (*S. caurinus*) and vermilion rockfish (*S. miniatus*). Olive and yellowtail rockfish are difficult to distinguish from one another on video tape and so were lumped (hereafter referred to as OYT). For the majority of the analyses, we focused on these four most abundant rockfish species (group). Another common family on the debris was the surfperches (Embiotocidae), which accounted for approximately 7% of all species observed.

Fish assemblages on the debris in the Los Angeles region differed from the other regions in two respects. First, species richness was low (Table 2). Second, the species composition deviated markedly. Barred sand bass and blacksmith made up approximately 56% of the total fish observed in the Los Angeles region, while only one OYT rockfish was observed. Because our focus was on rockfish, we chose to drop the Los Angeles region from all analyses of debris characteristics. However, the almost complete absence of rockfish in this southernmost region remains interesting.

Diversity indices varied among regions and showed a geographic pattern (Table 2). Species diversity (H′) was highest in the westernmost region (Pt. Conception and Gaviota) and lower in the east. Species richness showed the same general trend.

Table 3 compares the percentage of items that were occupied by at least one fish of each species (group) among the three regions. Spatial differences were not significant for any species (group) except for copper rockfish, largely owing to its scarcity in the Santa Barbara region.

Total fish abundance declined from west to east, with Pt. Conception and Gaviota having approximately three times as many fish of all species as Santa Barbara and Los Angeles (Table 2). Although the volume of debris items varied slightly, there were no significant differences in the mean volume by region (one-way ANOVA excluding Los Angeles, $F_{2,92}=0.12$, $p=0.9$). Consequently, fish abundance data are presented as number of fish present per item as opposed to number per unit area (Table 2).

For comparing mean number of fish per item among regions (ANOVA), we excluded any item that had no fish (of any species) present (Table 4). Brown and OYT rockfish showed no significant spatial differences in abundance, although brown rockfish were more than twice as abundant at Pt. Conception and Gaviota than at Santa Barbara, while OYT rockfish showed the opposite trend. Vermilion rockfish were significantly more abundant at Pt. Conception than at Gaviota or Santa Barbara, which were not different from one another. For copper rockfish, Gaviota had the highest abundance followed by Pt. Conception; lowest abundance was recorded at Santa Barbara. All rockfish combined showed a slight (non-significant) trend of higher abundance in the west and lower abundance towards the east. This same pattern was strong and significant for non-rockfish. Abundance of non-rockfish

Table 2. Number of marine oilfield debris items investigated and species list (OYT: olive and yellowtail rockfish) showing numbers and percent of total numbers (in parentheses) of all fish observed by region (PC: Pt. Conception; G: Gaviota; SB: Santa Barbara; LA: Los Angeles).

	PC	G	SB	LA	Total
No. debris items	26	39	30	35	130
Brown rockfish	245 (17.2)	481 (36.5)	144 (33.0)	0	870 (24.3)
Unidentified rockfish	398 (28.0)	323 (24.5)	27 (6.2)	0	748 (20.9)
OYT	62 (4.4)	38 (2.9)	199 (45.6)	1 (0.2)	300 (8.4)
Copper rockfish	62 (4.4)	192 (14.6)	23 (5.3)	0	277 (7.7)
Juvenile rockfish	244 (17.1)	0	7 (1.6)	0	251 (7.0)
Unidentified fish	97 (6.8)	34 (2.6)	5 (1.1)	28 (6.9)	164 (4.6)
Unidentified perch	142 (10.0)	2 (0.2)	2 (0.4)	51 (12.6)	197 (5.5)
Barred sand bass	1 (0.1)	16 (1.2)	0	113 (27.8)	130 (3.6)
Blacksmith	0	0	0	118 (29.0)	118 (3.3)
Juvenile blacksmith	0	0	0	71 (17.4)	71 (2.0)
Vermilion rockfish	43 (3.0)	25 (1.9)	3 (0.7)	0	71 (2.0)
Bocaccio	52 (3.6)	11 (0.9)	5 (1.1)	0	68 (1.9)
Calico rockfish	6 (0.4)	54 (4.1)	3 (0.7)	0	63 (1.8)
Blue rockfish	21 (1.5)	18 (1.4)	0	0	39 (1.1)
Widow rockfish	15 (1.1)	22 (1.7)	1 (0.2)	0	38 (1.1)
Pile surfperch	9 (0.6)	9 (0.7)	1 (0.2)	10 (2.5)	29 (0.8)
Flag rockfish	0	23 (1.7)	2 (0.5)	0	25 (0.7)
Halfbanded rockfish	1 (0.1)	12 (0.9)	0	0	13 (0.4)
Greenspotted rockfish	0	8 (0.6)	0	0	8 (0.2)
White surfperch	0	8 (0.6)	0	0	8 (0.2)
Black surfperch	0	0	0	8 (2.0)	8 (0.2)
Sharpnose surfperch	2 (0.1)	5 (0.4)	0	0	7 (0.2)
California sheephead	5 (0.4)	0	0	2 (0.5)	7 (0.2)
Kelp rockfish	0	6 (0.5)	0	0	6 (0.2)
Canary rockfish	6 (0.4)	0	0	0	6 (0.2)
Gopher rockfish	4 (0.3)	0	0	0	4 (0.1)
Rubberlip surfperch	1 (0.1)	3 (0.2)	0	0	4 (0.1)
Blackeye goby	0	1 (0.1)	2 (0.5)	0	3 (0.1)
Painted greenling	2 (0.1)	0	1 (0.2)	0	3 (0.1)
Kelp bass	0	0	0	3 (0.7)	3 (0.1)
Lingcod	2 (0.1)	0	0	0	2 (0.1)
Speckled rockfish	0	1 (0.1)	0	0	1 (<0.1)
Black rockfish	0	0	1 (0.2)	0	1 (<0.1)
Thornback	0	0	0	1 (0.2)	1 (<0.1)
California halibut	0	0	0	1 (0.2)	1 (<0.1)
Kelp greenling	1 (0.1)	0	0	0	1 (<0.1)
Total	1423	1317	436	407	3583
Species richness	20	21	13	9	33
Diversity (H′)	1.9	1.8	1.2	1.0	2.1

at Pt. Conception was 12 times greater than at Gaviota and 43 times higher than at Santa Barbara.

Variation among debris items

Between 0 and 9 species were present per debris item with a mean of 2.1 ± 0.2. However, some species were very patchily distributed. For example, of the 244 juvenile rockfish observed at Pt. Conception, 240 were found on a single item. We used stepwise multiple regression to understand debris characteristics that

Table 3. Percentage of items colonized by at least one fish of listed species (groups), with chi-squared tests on differences in proportion and associated p-values.

	PC	G	SB	χ^2	p
Brown rockfish	42	51	50	0.6	0.76
OYT	35	21	23	1.7	0.42
Vermilion rockfish	27	28	10	3.8	0.15
Copper rockfish	42	53	10	14.5	0.0007
All rockfish	67	80	77	5.6	0.06
Non-rockfish	46	39	27	2.3	0.31

Table 4. A. Mean number of fish per item (s.e.) by region and F-ratio and p-values from one-way ANOVA tests of differences between locations (only items having at least one fish of any species present were used to calculate means). B. Pairwise t-tests on means where ANOVA indicated significant differences (lines connect regions that were not significantly different from one another).

	PC	G	SB	F	p
A.					
Brown rockfish	14.41 (4.59)	13.36 (4.24)	5.76 (2.98)	1.21	0.3
OYT	3.65 (1.55)	1.06 (0.50)	7.96 (6.36)	1.04	0.4
Vermilion rockfish	2.35 (1.20)	0.69 (0.25)	0.12 (0.07)	4.21	0.01
Copper rockfish	3.65 (1.07)	5.33 (1.18)	0.92 (0.80)	4.42	0.01
All rockfish	52.35 (14.22)	33.94 (6.96)	16.64 (9.27)	2.92	0.06
Non-rockfish	31.35 (15.49)	2.64 (0.98)	0.72 (0.32)	6.55	0.002

B.

	SB	PC	G
Copper rockfish	——————	——————	
		——————	——————
Vermilion rockfish	——	——————	——————
All rockfish	——————	——————	
		——————	——————
Non-rockfish	——	——————	——————

Table 5. Results (partial r^2) of forward stepwise multiple regression analysis of debris characteristics (see Table 1) explaining variance in species richness and abundance of four (groups of) rockfish species and non-rockfish (— criterion for inclusion not met; *p<0.05; **p<0.01; ***p<0.001).

Source	Richness	Brown	OYT	Vermilion	Copper	Non-rockfish
De	—	—	—	—	0.10***	—
H	—	0.13***	0.12***	—	—	0.03*
W	—	—	—	—	—	—
L	—	—	—	—	—	—
Vo	—	—	—	—	—	0.30***
Sh	0.06**	—	—	0.06**	0.02*	0.04**
Co	0.29***	—	—	—	0.23***	0.05**

could explain variability in species richness. The results indicated that both complexity and availability of shelter related significantly and positively to species richness (Table 5).

Our next question was whether differences in characteristics existed between items on which particular species were present and items where they were not present. To test for differences among class and continuous variables, we compared the mean values of each character using the chi-squared test and Student's t-test, respectively (Table 6). A sequential Bonferroni correction was applied for multiple comparisons according to Rice (1989). Significance levels were adjusted based on all tests (i.e. chi-squared tests and t-tests; n=60; for each test d.f.=94).

Water depth was important only for copper rockfish (presence: mean depth=189 m; absence: 145 m). Vertical profile (height) was significantly larger for items with brown and OYT rockfish than items without these fish. Although volume was not significantly different for any species (group), debris with fish present always had a larger volume than debris with no fish present. Complexity was significantly different for three rockfish species (groups) considered and for all rockfish combined. In all cases, items with rockfish and non-rockfish present had greater complexity than items with no fish belonging to these groups present. Similarly, higher average shelter scores also predict the presence of most species groups.

In general, the features predicting whether or not species were present on particular items also tended to explain their abundance on those items. Vertical profile was positively and significantly related to the abundance of both brown and OYT rockfish. Shelter was positively related to the abundance of vermilion rockfish whereas shelter, complexity, and water depth were all significant for copper rockfish. Non-rockfish abundance was related to vertical profile, volume, shelter, and complexity. Although these debris characteristics were significant in the multiple regression models, the amount of variance explained was quite low, as indicated by the partial r^2 terms (Table 5).

Table 6. Characteristics (see Table 1) of debris with fish present (+) and absent (−) by taxon (pairs shown in bold were significantly different after applying Bonferroni sequential correction; p<0.05; see also text): A. Means and s.e. in parentheses (Student's t-test). B. Mean scores (chi-squared test).

	Brown		Vermilion		Copper		OYT		All rockfish		Non-rockfish	
	−	+	−	+	−	+	−	+	−	+	−	+
No. of items	50	46	75	21	61	35	72	24	28	68	61	35
A. Continuous variables												
De	161	160	156	179	**144**	**189**	171	133	147	167	164	155
	(9)	(8)	(7)	(12)	(8)	(8)	(7)	(9)	(13)	(7)	(8)	(11)
H	**1.3**	**2.8**	1.7	3.1	1.8	2.3	**1.5**	**3.4**	1.2	2.4	2.0	2.0
	(0.2)	(0.4)	(0.2)	(0.6)	(0.3)	(0.3)	(0.2)	(0.6)	(0.2)	(0.3)	(0.3)	(0.3)
W	1.2	1.8	1.3	2.0	**1.1**	**2.1**	1.4	1.7	1.1	1.6	1.4	1.6
	(0.1)	(0.2)	(0.1)	(0.3)	(0.1)	(0.3)	(0.1)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)
L	6.5	4.1	5.4	5.2	5.9	4.4	5.8	4.2	4.3	5.8	5.7	4.8
	(2.1)	(0.5)	(1.4)	(1.0)	(1.7)	(0.5)	(1.5)	(1.7)	(1.1)	(1.5)	(1.7)	(0.8)
Vo	8.1	22.4	10.7	30.3	9.8	24.0	10.1	29.7	4.0	19.5	13.1	18.3
	(2.4)	(5.2)	(2.5)	(9.2)	(2.4)	(6.4)	(1.9)	(9.6)	(1.1)	(3.9)	(3.0)	(5.9)
Co	**9.3**	**12.1**	**10.0**	**12.9**	**9.6**	**12.5**	10.1	12.4	**8.7**	**11.5**	10.1	11.7
	(0.4)	(0.4)	(0.3)	(0.7)	(0.4)	0.5)	(0.4)	(0.6)	(0.6)	(0.4)	(0.4)	(0.5)
B. Class variables												
Sh	**1.86**	**2.52**	**2.03**	**2.71**	**1.92**	**2.63**	2.06	2.54	**1.61**	**2.41**	**1.97**	**2.54**
Ma	1.20	1.28	1.23	1.29	1.20	1.31	1.19	1.38	1.18	1.26	1.18	1.34
Fo	2.06	2.33	2.12	2.43	2.11	2.31	2.08	2.50	2.07	2.24	2.11	2.31
Vi	2.24	2.30	2.20	2.52	2.20	2.40	2.19	2.50	2.39	2.22	2.18	2.43

Discussion

Out of a total of 33 species observed, 85% of all individuals belonged to one of two families with quite different feeding modes: rockfishes (78%) are primarily benthic predators, while surfperches (7%) are generally more mobile, algal grazers. Species composition on the offshore oilfield debris was generally similar to that found on offshore oil platforms in the same region and at similar depths (Love *et al.*, 2000). Rockfishes made up approximately 90% of all fish seen on platforms, with greenlings (Hexagrammidae) and surfperches as the next most abundant groups. Most rockfish observed on the debris were adults, whereas juveniles were largely restricted to a single piece of debris in the Pt. Conception region. Rockfish juveniles are extremely clumped on oil platforms as well (Love *et al.*, 2000).

In general, abundance, species richness, and species diversity on debris were greater in the western region(s) and less in the eastern part of the Santa Barbara Channel. Given that the average debris characteristics did not differ among regions in any systematic manner, the differences in fish assemblages observed are likely due to water mass differences or other environmental conditions.

The survey was conducted in an area with a complex oceanographic regime. The Santa Barbara Channel is semi-enclosed and east–west facing, bordered by the Northern Channel Islands on the south and the mainland on the North. It is embedded within the much larger California–Baja California coastal current regime (Brink and Muench, 1986; Hickey, 1992). Surface waters to the west of the Channel are typically cool because of the California Current flowing equatorward from high latitudes year-round and upwelling in the Point Conception region during spring and summer. At the same time, the cyclonic circulation pattern in the southern California bight brings warm water flowing poleward along the coast from the east of the Santa Barbara Channel. In general, water is cooler and more productive in the regions of Point Conception and Gaviota than at Santa Barbara or Los Angeles. Oil platforms north of Pt. Conception harbour far more juvenile rockfishes as well as a higher density and biomass of all species than those in the Santa Barbara Channel and these geographic differences have been related to differences in water masses between the two regions (Love *et al.*, 2000).

The percentage of debris items in each region occupied by at least one individual of the species investigated did not vary geographically – with one exception. Copper rockfish occupied a greater percentage of items in the western regions than in the east. This species appears to avoid warmer waters and although they do range into southern California, they tend to occur deep in the eastern part of the Santa Barbara Channel (Love *et al.*, 2002). The lack of a geographic pattern in most presence/absence data suggests that all more common rockfish species have a chance of associating with offshore oilfield debris. That is, no region was out of a species range. Thus, the differences in fish abundance in the different regions are more likely due to the oceanographic or environmental conditions that any systematic regional differences in the debris.

The offshore oilfield debris in California presents a unique opportunity to assess the fish assemblages in relation to the morphology of artificial structures because they are extremely variable in their physical characteristics. Several of these proved to be important determinants of the presence/absence of particular species as well as of their abundance. These included vertical profile, amount of shelter and complexity (a composite measure of size, shelter, and material variables and therefore not entirely independent). The results were fairly complex. No single characteristic was important for all species. However, all these aspects have been found to affect fish assemblages and population structure of individual species at both natural and artificial reefs in different ways and therefore this result may not come unexpectedly.

Vertical profile has been found to positively affect species richness, individual species abundance as well as recruitment of both benthic and pelagic fishes (Klima and Wickham, 1971; West *et al.*, 1994; Brock and Kam, 1994; Kellison and Sedberry, 1998; Rilov and Benayahu, 1998). According to our results, item height was positively related to the presence and abundance of 2 out of 4 rockfish species. Several possibilities exist to explain why the presence and abundance of benthic rockfishes might be positively related to vertical profile. Taller structures may provide a better visual cue for attraction. It has been suggested that reef height might be more important for attraction of pelagic species while the horizontal dimension might be more important for benthic species (Grove and Sonu, 1985). Although we have not been able to characterize the pelagic fish community associated with debris, one possibility is that the increased vertical component was correlated with higher densities of small pelagic fishes which provided a prey resource for the benthic rockfish. Another possibility is that adult rockfish may be more mobile and occur more frequently off-bottom than previously thought, and higher structures may provide a visual orientation cue also for these species. Repeated debris surveys to better understand temporal variability in rockfish abundances may shed more light on this issue.

Shelter was also positively related to species richness, as well as to presence and abundance of most rockfishes. Cracks and crevices provide shelter from predators and sometimes have a strong effect on fish assemblages on natural (Risk, 1972; Luckhurst and Luckhurst, 1978) as well as artificial reefs (Hixon and Beets, 1989; Kellison and Sedberry, 1998). Kellison and Sedberry (1998) found that the size of holes in their artificial reefs did not affect number of species or individuals, but that reefs with holes had significantly more species and individuals than reefs without holes. Hixon and Beets (1989) found a positive correlation between fish size and hole size and an inverse relationship between abundance of large predatory fish and of small prey fish that was influenced by shelter size availability. We simply assessed the number of cracks, crevices, and holes within a large size range that would broadly fit adult rockfish. This may explain the positive relationship observed between shelter and species richness. Future work could strive to identify fish sizes as well as shelter sizes to understand better the function of debris. Complexity was a composite measure of several characteristics and therefore not independent. It is perhaps not surprising, then, that complexity was the most prevalent feature correlated with various metrics.

The data presented represent only a "snapshot" and issues of seasonality and interannual variation remain to be addressed. Previous studies have shown that seasonal variation in fish assemblages at natural and artificial reefs can be substantial (Carlisle *et al.*, 1964; Hastings *et al.*, 1975; Molles, 1978). Temperature changes, seasonal migrations, and patchy recruitment episodes are three potential factors accounting for temporal variability. Nevertheless, the relationships observed between fish fauna and particular features of oilfield debris may be worthwhile to include in artificial reef designs.

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