BULLETIN OF MARINE SCIENCE. 88(4):863–882. 2012
http://dx.doi.org/10.5343/bms.2011.1101

RECRUITMENT OF YOUNG-OF-THE-YEAR FISHES TO NATURAL AND ARTIFICIAL OFFSHORE STRUCTURE WITHIN CENTRAL AND SOUTHERN CALIFORNIA WATERS, 2008–2010

Milton S Love, Mary Nishimoto, Scott Clark, and Donna M Schroeder

ABSTRACT

Many of the oil and gas platforms off California harbor high densities of young-of-the-year (YOY) fishes, primarily rockfishes (genus *Sebastes*). One decommissioning option for these platforms is “topping,” cutting the structure some distance below the water line and leaving the rest of the jacket in place. Questions have arisen regarding how this option would affect the nursery function of the remaining structure. Between 2008 and 2010, we surveyed the densities of YOY fishes at seven intact platforms, as well as six reefs and three shipwrecks that did not crest near the surface and thus might act as surrogates for topped platforms. Rockfishes of about five species dominated the deeper parts of the platforms, reefs, and shipwrecks, while YOY blacksmith, *Chromis punctipinnis* (Cooper, 1863), were most characteristic of the shallow portions of platforms. Over the course of the study, we observed large fluctuations in the recruitment success of fishes; recruitment of rockfishes was particularly successful in 2010, while particularly poor for blacksmith in the same year. This interannual pattern was observed throughout our study sites. In general, the YOY fish assemblages around the deeper parts of the platforms were similar to those around the reefs and shipwrecks, implying that removing the shallow parts of California platform may have relatively little effect on juvenile rockfish recruitment; however, blacksmith recruitment to platforms will likely decrease.

Although offshore oil and gas structures have been present in US waters since the mid-1900s (Schroeder and Love 2004), new and forthcoming projects include marine renewable energy installations, offshore liquid natural gas ports, and open-ocean mariculture facilities. All of these types of installations add fixed, shallow-water structure into an offshore environment where none existed before, and thereby introduce novel habitat into the ecosystem. Novel habitats may modify local physical and ecological processes. For example, novel habitat may enhance colonization rates of non-indigenous species that in turn alter trophic structure (Page et al. 2006, 2007), or provide unique habitats favored by sensitive species (Clynick 2007). The extent to which novel habitats in the offshore environment affect the ecology of local species is not well understood. Managers require this information to predict and mitigate impacts of an offshore project through its life cycle, including decisions about what to do with the installation once its original purpose has concluded, a process called decommissioning.

There are 27 offshore oil and gas platforms off the coast of California; these are distributed in both state and federal waters from just north of Point Arguello southward to off Long Beach (Fig. 1). These platforms are located between 1.9 and 16.9 km from shore and at bottom depths ranging from 11 to 363 m (details regarding platform dimensions and placement are found in Love et al. 2003). Previous research documents that some of these offshore structures may function as nursery habitats

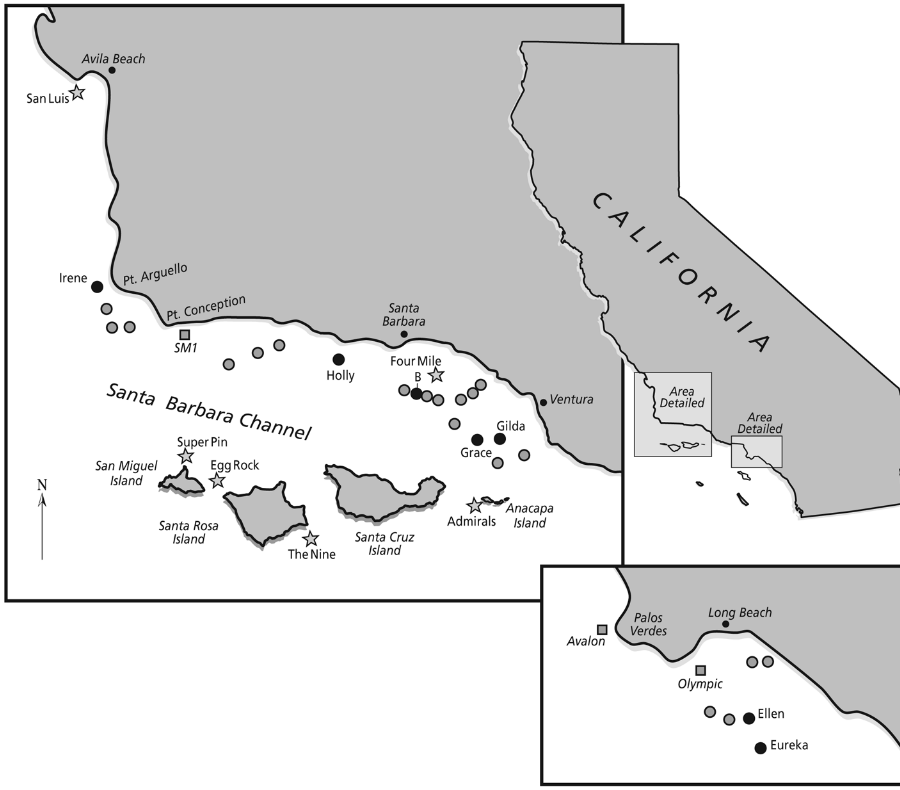

Figure 1. Map of the study area. Scuba surveys were conducted at sites from Avila Beach, central California to off Long Beach, Southern California, during the summers of 2008–2010. Circles demarcate all of the platforms off California. The seven platforms surveyed in this study are designated by darkened circles and by name. Surveyed reefs and shipwrecks are labeled by name and are demarcated by stars and squares, respectively.

for juvenile fishes (sensu Beck et al. 2001) as determined by increased growth and survivorship rates when compared to rates on natural reefs, and the observation that during some years, hundreds of thousands of juvenile rockfishes (*Sebastes* spp.) inhabit the midwaters of these structures (e.g., Love et al. 2003, 2006b, 2007, 2010b, Love and Schroeder 2004) and this nursery function may be important in maintaining or increasing some rockfish populations (Love et al. 2006b).

As platforms become uneconomical to operate, understanding this nursery function is important both to the Department of the Interior and the State of California, as these entities assess the ramifications of different platform decommissioning options (Bernstein et al. 2010). Platform decommissioning alternatives fall into four general categories: complete removal, toppling (laying the structure on its side), partial removal, and leave-in-place (Schroeder and Love 2004). In particular, partial removal or "topping," where a platform would be cut off at some distance below the sea surface, is often mentioned as one of the preferred alternatives. The effect of removing part of a platform on young-of-the-year (YOY) rockfish recruitment is unclear. Carr et al. (2003), utilizing surveys of intact platforms, speculated that platform topping might decrease the number of YOY rockfishes of at least some of the species that recruit to the topped structure. However, Bernstein et al. (2010) estimated that,

Table 1. The number of surveys conducted at each study site in central and Southern California waters in 2008–2010. For platforms, these are the number of complete surveys at each of three depths. For all reefs and shipwrecks, except for Four Mile Reef, these are the number of 30-m belt transects. At Four Mile Reef, 5-min time transects were conducted.

Site	Bottom depth (m)	Shallowest depth (m)	Distance from shore (km)	Depths surveyed (m)	Number of surveys		
					2008	2009	2010
Platforms							
Irene	73	Surface	7.6	11, 21, 29	3[1]	2	0
Holly	64	Surface	2.9	9, 20, 35	5[2]	4	3
B	58	Surface	9.1	8, 20, 31	4	4	3
Grace	96	Surface	16.9	11, 20, 28	4	4	3
Gilda	62	Surface	14.2	5, 11, 25	4	4	3
Ellen	80	Surface	13.8	6, 14, 31	2	2	1
Eureka	212	Surface	14.8	6, 16, 27	2[1]	2[1]	1
Reefs							
San Luis	38	20	2.5	22, 25, 28	11	3	0
Super Pin	61	21	2.3	22 ,26, 29	12	9	6
Egg Rock	61	20	4.5	22, 25, 28	12	9	6
The Nine	31	17	2.6	20	33	9	6
Admiral's	38	21	0.5	25, 28, 31	28	12	6
Four Mile	61	32	7.3	38	9	9	6
Shipwrecks							
SM1	23	19	2.2	23	12	9	6
Avalon	23	17	0.8	23	6	6	3
Olympic	30	20	6.0	30	6	6	3

1 = Partial survey on one occasion, 2 = Partial surveys on two occasions.

again based on indirect evidence, removing perhaps the top 25 m of the underwater portion of a platform might have relatively little effect on rockfish recruitment.

No studies have specifically addressed the issue of how partial removal might impact the rockfish nursery function of platforms. The most rigorous approach for making such an assessment would be to compare rockfish recruitment strength and composition at platforms that have been topped with those that are still intact. However, there are no topped platforms off California. A second method would compare structures that might act as surrogates for topped platforms with intact platforms. We apply this approach here using rocky reefs and shipwrecks that crest well below the sea surface as surrogate structures. Thus, the goal of the present study was to fill gaps in information about the spatial and vertical depth variability in recruitment of fishes to platforms and topped platform surrogates (natural reefs and shipwrecks) off the California coast and particularly to provide data that can be used in future analyses of the environmental consequences of partial platform removal on local and regional fish populations.

Methods

Visual surveys of fishes were conducted by scuba at oil and gas platforms, natural reefs, and shipwrecks from Avila Beach, central California, to Long Beach, Southern California, between May and September, 2008–2010. Location, description, and sampling months of each structure are given in Table 1, Appendix 1, and Figure 1. Sites were surveyed between one and five times in each year. Seven oil platforms, 6 natural reefs, and 3 shipwrecks were surveyed.

Divers identified and estimated the total length (TL) of each fish encountered. All divers engaged in visual surveys were first thoroughly trained in fish species identification and size estimation.

During each platform survey, divers recorded observations within a 2 m wide × 2 m high window while swimming a pattern that covered the four corners and major horizontal support beams of the platform at three different depths (Love et al. 2003). The depths of these levels differed somewhat between platforms because they correspond to the horizontal cross beams of the platform jacket (Table 1). The shallowest depths ranged 5–11 m, middle depths 12–22 m, and deepest levels 26–35 m.

In contrast, a belt transect was used to sample almost all of the reef and shipwreck sites. In these surveys, divers using a retractable transect tape would count and estimate sizes of all fishes encountered along strips 30 m in length × 2 m wide × 2 m high. The one exception to this protocol occurred at Four Mile Reef, a site sufficiently steep and deep (and thus restricting bottom time) to preclude belt transect sampling; here a timed (5 min) transect (a technique summarized in Stephens et al. 2006) was conducted. The timed fish surveys provided relative abundances of YOY by rank. Whenever possible, at least three transects of one of the sampling methods were conducted during each survey (i.e., site visit) to reefs and shipwrecks. At all reefs, except The Nine, the three transects were typically one across the top of the feature and two along the edge at different depths. At The Nine, a feature of relatively lower relief than the others in our study, we conducted three relatively haphazard transects distributed across the top of the feature. The three timed fish counts performed at Four Mile were all conducted on the top of the pinnacle. The wrecks of the shipwrecks Olympic and the Avalon are, for the most part, widely scattered piles of debris (Appendix 1). On each visit, three transects were conducted, the locations chosen to ensure that all 30 m sampled were over wreckage. The wreck of the SM1 is different in that it is largely intact and lying upside down. Here three transects were conducted along the perimeter of the hull where it meets the seafloor.

We defined fishes as YOY based on data from Love et al. (2002) and Love (2011). As we were interested in species that had recruited from the plankton to specific platforms, reefs, and shipwrecks, we did not include in our analyses such transient, highly mobile species as jack mackerel, *Trachurus symmetricus* (Ayres, 1855), Pacific sardine, *Sardinops sagax* Jenyns, 1842, topsmelt/jacksmelt, *Atherinops affinis* (Ayres, 1860), and *Atherinopsis californiensis* Girard, 1854. It is highly likely that individuals of all of these species move about a great deal and had not recruited out of the plankton to any of the study sites. Further, there are two rockfish complexes of several species that at times could not be visually distinguished. KGB consisted of black-and-yellow, copper, gopher, and kelp rockfishes, and OYT of olive and yellowtail rockfishes (see Table 2 for more information about these complexes).

We calculated densities (count × 100 m^{-2}) of YOY for each transect. We used 4th-root transformation of densities for non-metric multidimensional scaling (NMDS). Anderson and Yoklavich (2007) found this transformation appropriate for normalizing similar data. While the scaling technique does not make assumptions about statistical distributions, we wished to reduce the influence of very large densities. We used the metaMDS function of the vegan package of R for NMDS (R Development Core Team 2011). Since we transformed the data before using the function, the transformation option of the function was not used. We used Bray-Curtis dissimilarities and limited the number of dimensions to two to simplify interpretation of results. The metaMDS function used multiple random starts to avoid local minima.

Results

Over all sites and habitats, we observed 1,227,095 YOY fishes of 40 species. Of these, 92.1% were rockfishes, composed of at least 23 species (Tables 2–6).

Platforms.—In the shallowest parts of the platforms, we observed 54,463 YOY (141.9 individuals 100 m^{-2}) of 13 species, at least seven of which were rockfishes (Table 3). Of the three platform depth zones, the shallowest zone harbored the lowest

Table 2. Common and scientific names of young-of-the-year fishes observed at all survey sites in central and Southern California waters, 2008–2010. Note that the black-and-yellow rockfish was not definitively identified and may have been gopher rockfish. KGB and OYT are each complexes of several rockfishes that cannot be visually distinguished at times.

Family Scorpaenidae	
	Black-and-yellow rockfish, *Sebastes chrysomelas* (Jordan and Gilbert, 1881)
	Black rockfish, *Sebastes melanops* Girard, 1856
	Blue rockfish, *Sebastes mystinus* (Jordan and Gilbert, 1881)
	Bocaccio, *Sebastes paucispinis* Ayres, 1854
	Calico rockfish, *Sebastes dalli* (Eigenmann and Beeson, 1894)
	Canary rockfish, *Sebastes pinniger* (Gill, 1864)
	Copper rockfish, *Sebastes caurinus* Richardson, 1844
	Flag rockfish, *Sebastes rubrivinctus* (Jordan and Gilbert, 1880)
	Gopher rockfish, *Sebastes carnatus* (Jordan and Gilbert, 1880)
	Grass rockfish, *Sebastes rastrelliger* (Jordan and Gilbert, 1880)
	Halfbanded rockfish, *Sebastes semicinctus* (Gilbert, 1897)
	Honeycomb rockfish, *Sebastes umbrosus* (Jordan and Gilbert, 1880)
	Kelp rockfish, *Sebastes atrovirens* (Jordan and Gilbert, 1880)
	KGB rockfishes (kelp rockfish, gopher rockfish, black-and-yellow rockfish, and copper rockfish)
	Olive rockfish, *Sebastes serranoides* (Eigenmann and Eigenmann, 1890)
	OYT rockfishes [olive rockfish and yellowtail rockfish, *Sebastes flavidus* (Ayres, 1862)]
	Unidentified *Sebastomus* (primarily rosy rockfish, *Sebastes rosaceus* Girard, 1854)
	Shortbelly rockfish, *Sebastes jordani* (Gilbert, 1896)
	Squarespot rockfish, *Sebastes hopkinsi* (Cramer, 1895)
	Stripetail rockfish, *Sebastes saxicola* (Gilbert, 1890)
	Treefish, *Sebastes serriceps* (Jordan and Gilbert, 1880)
	Unidentified young-of-the-year rockfishes, *Sebastes* spp.
	Vermillion rockfish, *Sebastes miniatus* (Jordan and Gilbert, 1880)
	Widow rockfish, *Sebastes entomelas* (Jordan and Gilbert, 1880)
Hexagrammidae	
	Kelp greenling, *Hexagrammos decagrammus* (Pallas, 1810)
	Painted greenling, *Oxylebius pictus* Gill, 1862
Cottidae	
	Cabezon, *Scorpaenichthys marmoratus* (Ayres, 1854)
Kyphosidae	
	Halfmoon, *Medialuna californiensis* (Steindachner, 1876)
Embiotocidae	
	Black perch, *Embiotoca jacksoni* Agassiz, 1853
	Pile perch, *Rhacochilus vacca* (Girard, 1855)
	Spotfin seaperch, *Hyperprosopons anale* Agassiz, 1861
	Striped seaperch, *Embiotoca lateralis* Agassiz, 1854
	White seaperch, *Phanerodon furcatus* Girard, 1854
Pomacentridae	
	Blacksmith, *Chromis punctipinnis* (Cooper, 1863)
	Garibaldi, *Hypsypops rubicundus* (Girard, 1854)
Labridae	
	Señorita, *Oxyjulis californica* (Günther, 1861)
	California sheephead, *Semicossyphus pulcher* (Ayres, 1854)
Anarchichadidae	
	Wolf-eel, *Anarrhichthys ocellatus* Ayres, 1855
Gobiidae	
	Blackeye goby, *Rhinogobiops nicholsii* (Bean, 1882)

Table 3. Young-of-the-year fishes observed at seven oil and gas platforms off California, 2008–2010. Density = number of individuals 100 m^{-2}. (A) Shallow depths ranged 5–11 mm, (B) middle depths 12–22 m, and (C) deepest levels 26–35 m. See Table 2 for species names.

A. Shallow	Year								
	2008		2009		2010		Total		
Fishes	*n*	Density	*n*	Density	*n*	Density	*n*	Density	SE
Blacksmith	20,846	153.3	30,034	191.7	1,492	18.0	52,372	121.0	52.7
Bocaccio	0	0.0	40	<1.0	857	12.0	897	4.1	3.9
Squarespot rockfish	0	0.0	0	0.0	670	7.2	670	2.4	2.4
Blue rockfish	0	0.0	0	0.0	206	2.3	206	<1.0	<1.0
Halfmoon	56	<1.0	107	1.0	0	0.0	163	<1.0	<1.0
KGB rockfishes[1]	1	<1.0	48	<1.0	20	<1.0	69	<1.0	<1.0
Widow rockfish	0	0.0	0	0.0	20	<1.0	20	<1.0	<1.0
Copper rockfish	0	0.0	0	0.0	19	<1.0	19	<1.0	<1.0
Cabezon	1	<1.0	0	0.0	11	<1.0	12	<1.0	<1.0
OYT rockfishes[2]	0	0.0	1	<1.0	11	<1.0	12	<1.0	<1.0
Painted greenling	0	0.0	4	<1.0	5	<1.0	9	<1.0	<1.0
California sheephead	0	0.0	6	<1.0	0	0.0	6	<1.0	<1.0
Garibaldi	4	<1.0	2	<1.0	0	0.0	6	<1.0	<1.0
Treefish	0	0.0	0	0.0	2	<1.0	2	<1.0	<1.0
Total	20,908	153.8	30,242	193.3	3,313	40.7	54,463	141.9	45.7
Percent composed of rockfishes = 3.5%									
Minimum number of species = 13									

B. Middle	Year								
	2008		2009		2010		Total		
Fishes	*n*	Density	*n*	Density	*n*	Density	*n*	Density	SE
Blacksmith	24,185	150.6	10,805	64.5	3,524	38.5	38,514	84.5	33.8
Widow rockfish	11,000	73.7	11	<1.0	4,259	56.4	15,270	43.4	22.2
Bocaccio	0	0.0	5,371	36.9	6,589	71.0	11,960	35.8	20.4
Squarespot rockfish	24	<1.0	6	<1.0	7,926	84.0	7,956	28.1	27.9
Blue rockfish	1	<1.0	0	0.0	2,894	31.7	2,895	10.5	10.5
OYT rockfishes[2]	3	<1.0	107	1.0	875	10.1	985	3.7	3.2
KGB rockfishes[1]	3	<1.0	11	<1.0	151	1.6	165	<1.0	<1.0
Copper rockfish	0	0.0	9	<1.0	83	1.2	92	<1.0	<1.0
Painted greenling	8	<1.0	45	<1.0	29	<1.0	82	<1.0	<1.0
Halfmoon	16	<1.0	6	<1.0	0	0.0	22	<1.0	<1.0
Kelp greenling	2	<1.0	9	<1.0	4	<1.0	15	<1.0	<1.0
Treefish	4	<1.0	2	<1.0	7	<1.0	13	<1.0	<1.0
Garibaldi	5	<1.0	1	<1.0	0	0.0	6	<1.0	<1.0
Cabezon	0	0.0	3	<1.0	2	<1.0	5	<1.0	<1.0
California sheephead	1	<1.0	3	<1.0	1	<1.0	5	<1.0	<1.0
Grass rockfish	0	0.0	2	<1.0	0	0.0	2	<1.0	<1.0
Total	35,252	224.8	16,391	102.9	26,344	295.0	77,987	196.5	56.1
Percent composed of rockfishes = 50.4%									
Minimum number of species = 15									

Table 3. Continued.

C. Deepest	Year								
	2008		2009		2010		Total		
Fishes	*n*	Density	*n*	Density	*n*	Density	*n*	Density	SE
Bocaccio	42	<1.0	156,538	974.2	275,829	2,710.2	432,409	1,228.0	792.5
Shortbelly rockfish	0	0.0	10,000	62.5	244,507	2,399.3	254,507	820.6	789.5
Squarespot rockfish	3,440	21.4	7,709	50.5	69,240	710.5	80,389	260.8	225.0
Widow rockfish	15,000	87.9	1,002	6.1	20,547	232.0	36,549	108.7	66.0
Blacksmith	801	4.6	1,746	9.7	608	6.0	3,155	6.8	1.5
Blue rockfish	6	<1.0	141	1.0	1,198	11.7	1,345	4.2	3.7
OYT rockfishes[2]	125	1.0	77	1.0	1,123	11.1	1,325	4.1	3.4
KGB rockfishes[1]	86	1.0	237	1.5	228	2.2	551	1.4	<1.0
Painted greenling	36	<1.0	71	<1.0	30	<1.0	137	<1.0	<1.0
Copper rockfish	8	<1.0	24	<1.0	8	<1.0	40	<1.0	<1.0
Treefish	16	<1.0	13	<1.0	6	<1.0	35	<1.0	<1.0
Halfbanded rockfish	0	<1.0	21	<1.0	11	<1.0	32	<1.0	<1.0
Kelp greenling	5	<1.0	14	<1.0	10	<1.0	29	<1.0	<1.0
Sebastomus sp.[3]	10	<1.0	6	<1.0	1	<1.0	17	<1.0	<1.0
Kelp rockfish	8	<1.0	3	<1.0	0	0.0	11	<1.0	<1.0
Grass rockfish	0	0.0	4	<1.0	0	0.0	4	<1.0	<1.0
Honeycomb rockfish	4	<1.0	0	0.0	0	0.0	4	<1.0	<1.0
Canary rockfish	3	<1.0	0	0.0	0	0.0	3	<1.0	<1.0
Rockfishes species	0	0.0	2	<1.0	1	<1.0	3	<1.0	<1.0
Cabezon	1	<1.0	1	<1.0	0	0.0	2	<1.0	<1.0
Calico rockfish	0	0.0	2	<1.0	0	0.0	2	<1.0	<1.0
Flag rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Total	19,592	116.0	177,611	1,107.0	613,347	6,083.5	810,550	1,871.8	1,846.3
					Percent composed of rockfishes = 99.9%				
					Minimum number of species = 19				

1 = Potentially composed of kelp, gopher, black-and-yellow, and copper rockfishes, 2 = Potentially composed of olive and yellowtail rockfishes, 3 = Probably primarily rosy rockfish.

densities of fishes, comprised of the fewest number of species (Table 3, Fig. 2). In each year, YOY blacksmith were the most abundant taxa and, in fact, over the 3-yr period, rockfishes composed only 3.5% of all individuals. This was particularly true in 2008 and 2009, during which time rockfish species other than blacksmith were only occasionally observed. In 2010, although YOY blacksmith remained the most abundant species, their number dropped precipitously, while the abundance of several rockfish species (e.g., bocaccio, squarespot, and blue rockfishes) increased. Despite the increase in rockfish recruits in 2010, overall fish density was low compared to previous years and compared to deeper platform depths.

Compared to the shallowest portions of the platforms, we observed higher YOY numbers (77,987), densities (196.5 individuals 100 m^{-2}), and number of species (15) at the middle level (Table 3, Fig. 2). At least eight of these species were rockfishes. As at the shallower parts of the platforms, densities of blacksmith were again the highest among all species, although they were lower than in that shallower zone. Rockfishes increased in importance at these depths; 50.4% of all individuals were in this group. As in the shallower depths, 2010 saw a sharp decrease in blacksmith recruitment and a large increase in rockfish recruitment. However, unlike the shallow depths, in

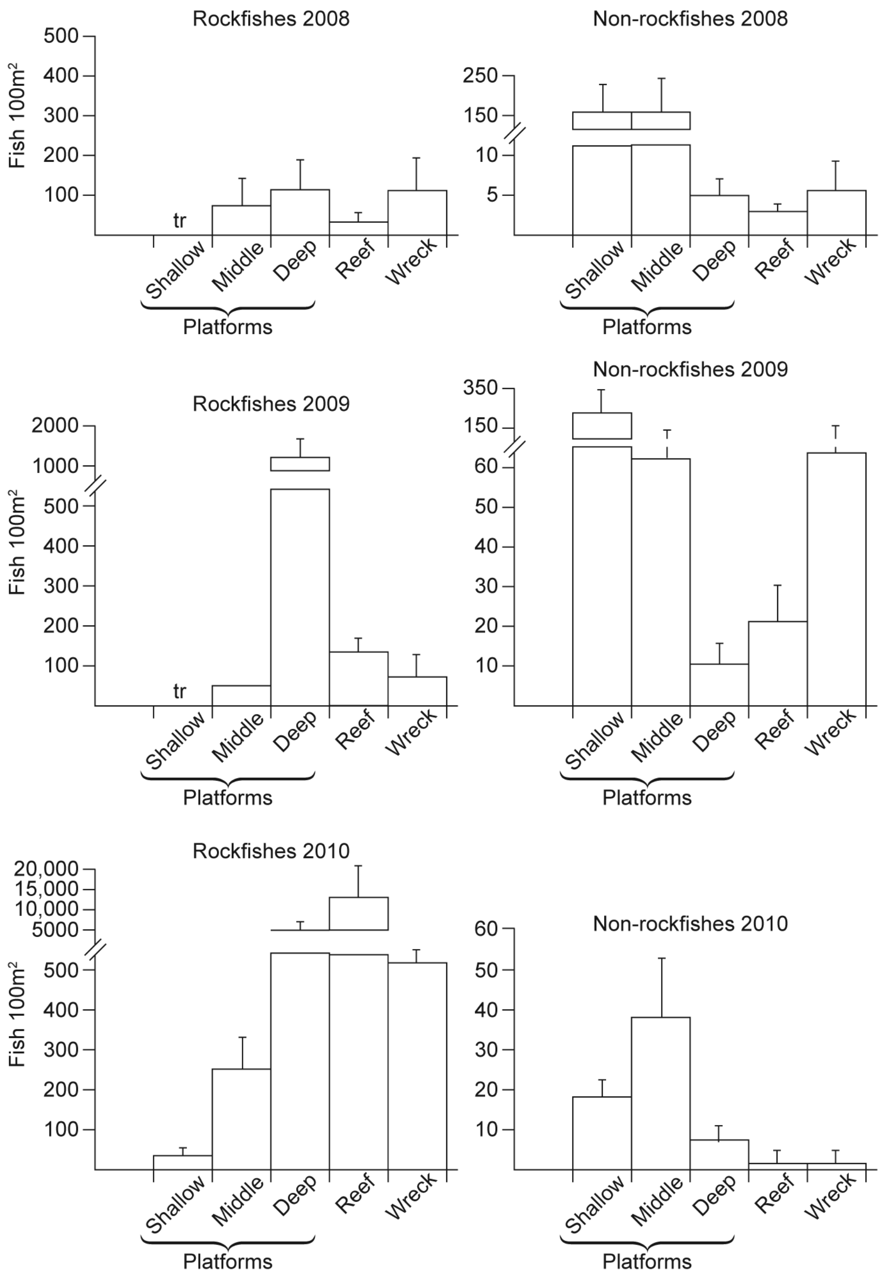

Figure 2. Densities of rockfish and nonrockfish young-of-the-year at platforms (in three depth zones), reefs, and shipwrecks, by year, 2008–2010. Note that the scale on the y-axis varies among plots. tr indicates ≤1 fish 100 m^{-2}. Error bars represent standard errors.

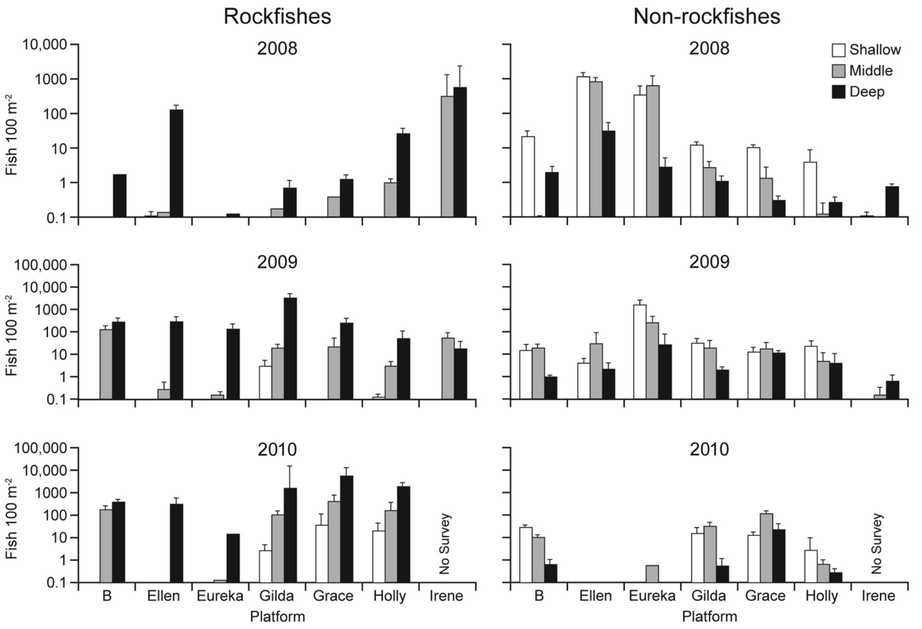

Figure 3. Densities of rockfish and non-rockfish young-of-the-year, by platform surveyed, by year, 2008–2010. Note that the y-axis (density) varies between figures and is on a logarithmic scale. Error bars represent standard errors.

2010 aggregate rockfish YOY outnumbered young blacksmith. Important rockfish species included widow, bocaccio, squarespot, and blue, as well as fishes in the OYT complex.

The deepest parts of the platform surveyed harbored substantially larger numbers (810,550), densities (1871.8 individuals 100 m^{-2}), and species (19) of fishes than did the shallow and middle ranges (Table 3, Fig. 2). Almost all of these fishes were YOY rockfishes (of at least 15 species); they comprised 99.9% of all fishes observed. Bocaccio, shortbelly, squarespot, and widow rockfishes were by far the most abundant taxa, although blue, OYT, and KGB rockfishes, and blacksmith were also often observed. As with the two shallower zones, rockfish recruitment of all of the most important rockfish species was highest (sometimes by a factor of 10 or more) in 2010 and blacksmith recruitment was lowest in that year.

During all three years, almost without exception, densities of rockfishes were highest in the deepest zone and lowest in the shallowest one (Fig. 3). In contrast, non-rockfish species (dominated by blacksmith) tended to be most dense in the shallowest zone (Fig. 3). This pattern of a rockfish-rich deep zone and a blacksmith-rich shallow zone, with the middle zone acting as a transition habitat, is reflected in a NMDS analysis of platform species assemblages (Fig. 4). In all years, there was a tendency for the deepest and shallowest stations to uniquely clump together, while the middle zone was more variable (Fig. 4). Tellingly, in 2010, when YOY rockfish recruitment was successful at all platform depths surveyed (and when blacksmith recruitment was considerably poorer), the various species assemblages tended to become more equitable (Fig. 4).

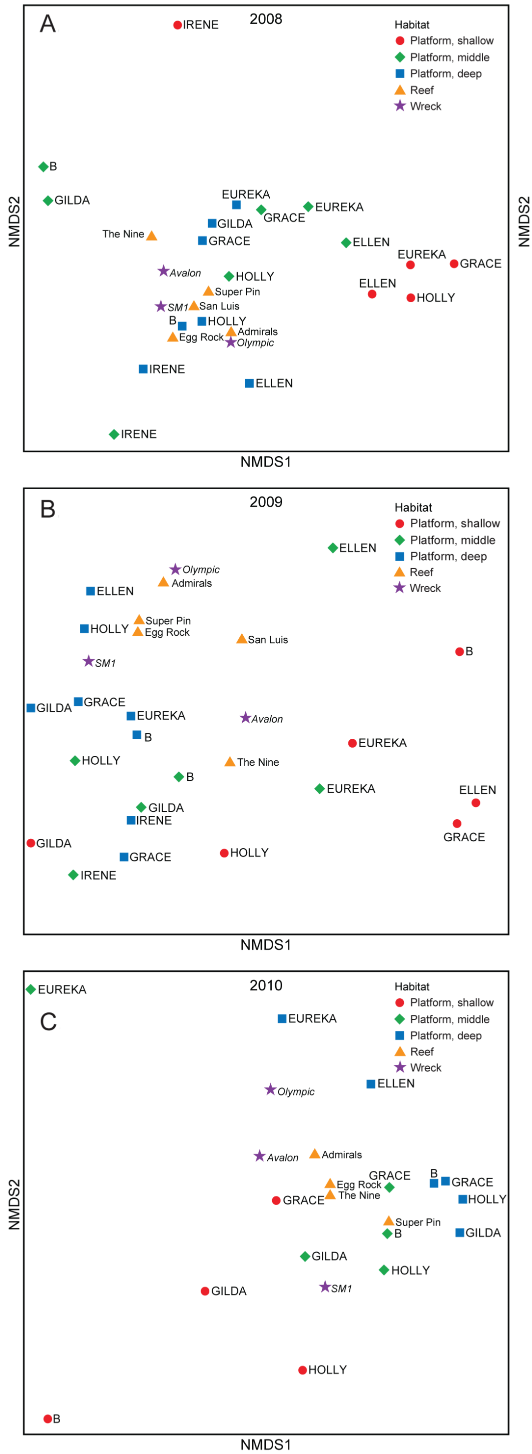

Figure 4. Non-metric multidimensional scaling configurations of platform (three depth zones), reef, and shipwreck (italicized names) young-of-the-year fish assemblages for (A) 2008, (B) 2009, and (C) 2010. Stresses for 2008, 2009, and 2010 are 0.164, 0.173, and 0.134, respectably.

Table 4. Young-of-the-year fishes observed at five natural reefs off California, 2008–2010. Density = number of individuals 100 m^{-2}. See Table 2 for species names.

	Year								
	2008		2009		2010		Total		
Fish	*n*	Density	*n*	Density	*n*	Density	*n*	Density	SE
Shortbelly rockfish	0	0.0	0	0.0	110,000	6,790.0	110,000	2,263.3	2,263.3
Bocaccio	0	0.0	1	<1.0	92,915	5,735.5	92,916	1,912.0	1,911.9
Squarespot rockfish	1,537	113.7	3,071	113.7	15,948	700.0	15,948	413.4	344.8
Blue rockfish	148	2.4	135	5.0	1,595	98.5	1,878	35.6	31.8
Blacksmith	21	<1.0	392	14.5	0	0.0	413	11.1	10.9
Señorita	24	<1.0	124	4.6	0	0.0	148	1.6	1.4
KGB rockfish[1]	10	<1.0	98	3.6	25	1.5	133	1.7	1.0
Spotfin surfperch	128	2.1	0	0.0	0	0.0	128	1.2	<1.0
Painted greenling	39	1.0	22	1.0	14	1.0	75	1.0	<1.0
Unidentified rockfishes	0	0.0	0	0.0	73	4.5	73	1.5	<1.0
Widow rockfish	0	0.0	0	0.0	55	3.4	55	1.1	<1.0
OYT rockfishes[2]	13	<1.0	0	0.0	40	2.5	53	<1.0	<1.0
Treefish	12	<1.0	5	<1.0	3	<1.0	20	<1.0	<1.0
Bluebanded goby	0	0.0	30	1.1	0	0.0	30	<1.0	<1.0
Halfbanded rockfish	0	0.0	0	0.0	24	1.5	24	<1.0	<1.0
California sheephead	2	<1.0	11	<1.0	0	0.0	13	<1.0	<1.0
Gopher rockfish	12	<1.0	0	0.0	1	<1.0	13	<1.0	<1.0
Kelp rockfish	13	<1.0	0	0.0	0	0.0	13	<1.0	<1.0
Unidentified *Sebastomus*[3]	9	<1.0	0	0.0	1	<1.0	10	<1.0	<1.0
Black perch	5	<1.0	2	<1.0	2	<1.0	9	<1.0	<1.0
Blackeye goby	8	<1.0	0	0.0	0	0.0	8	<1.0	<1.0
Black rockfish	1	<1.0	2	<1.0	0	0.0	3	<1.0	<1.0
Striped seaperch	0	0.0	0	0.0	3	<1.0	3	<1.0	<1.0
Zebra goby	0	0.0	0	0.0	3	<1.0	3	<1.0	<1.0
Canary rockfish	2	<1.0	0	0.0	0	0.0	2	<1.0	<1.0
Pile perch	0	0.0	2	0.0	0	0.0	2	<1.0	<1.0
GBY rockfish[4]	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Wolf-eel	0	0.0	1	<1.0	0	0.0	1	<1.0	<1.0
Total	1,985	32.8	3,866	142.4	220,699	13,338.0	226,550	2,138.2	4,548.4
					Percent composed of rockfishes = 99.6%				
					Minimum number of species = 22				

1 = Potentially composed of kelp, gopher, black-and-yellow, and copper rockfishes, 2 = Potentially composed of olive and yellowtail rockfishes, 3 = Probably primarily rosy rockfish, 4 = Potentially composed of gopher and black-and-yellow rockfishes.

Natural Reefs.—Note: because Four Mile Reef was sampled differently from the other five reefs (see Methods), we present data from the Four Mile Reef separately.

Over five natural reefs, we observed 226,550 fishes of 22 species; rockfishes (at least 12 species) comprised 99.6% of all fishes observed (Table 4). Over the 3-yr survey, densities of all fishes averaged 2138.2 fishes 100 m^{-2} (Table 4) and while shortbelly and squarespot rockfishes and bocaccio were dominant, blue rockfish and blacksmith were also fairly abundant. However, it should be noted that, as at both platforms and shipwrecks, there was extreme interannual variability in both overall fish densities and species assemblages at natural reefs; this was almost certainly driven by very successful rockfish recruitment in 2010. In particular, both shortbelly rockfish and

Table 5. Young-of-the-year fishes observed at Four Mile Reef, 2008–2010. TC = total count, AC = average count. See Table 2 for species names.

	Year								
	2008		2009		2010		Total		
Fish	TC	AC	TC	AC	TC	AC	TC	AC	SE
Squarespot rockfish	1,031	114.6	547	60.8	35,665	5,944.2	37,243	2,039.8	1,952.2
Widow rockfish	0	0.0	0	0.0	7,551	1,258.5	7,551	419.5	419.5
Halfbanded rockfish	0	0.0	1,325	153.9	130	21.7	1,515	58.5	48.0
Bocaccio	0	0.0	3	<1.0	1,018	169.7	1,021	56.5	56.5
Unidentified *Sebastomus*[1]	44	4.9	18	2.0	1	<1.0	63	2.3	1.3
Blacksmith	25	2.8	0	0.0	0	0.0	25	1.0	<1.0
Blue rockfish	2	<1.0	2	<1.0	0	0.0	4	<1.0	<1.0
Treefish	4	<1.0	0	0.0	0	0.0	4	<1.0	<1.0
Copper rockfish	0	0.0	2	<1.0	0	0.0	2	<1.0	<1.0
Vermilion rockfish	0	0.0	2	<1.0	0	0.0	2	<1.0	<1.0
Gopher rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
KGB rockfishes[2]	0	0.0	0	0.0	1	<1.0	1	<1.0	<1.0
Stripetail rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Total	1,108	123.1	1,959	217.7	44,366	7,394.3	47,433	1,976.4	2,408.4
					Percent composed of rockfishes = 99.6%				
					Minimum number of species = 22				

1 = Probably primarily rosy rockfish, 2 = Potentially composed of kelp, gopher, black-and-yellow, and copper rockfishes.

bocaccio were essentially absent from the reefs in 2008 and 2009, only to settle out of the plankton in very large numbers in 2010. Rockfish densities over reefs were on average higher than those around the shallow platform zone and less than at the deepest zone in 2 of 3 yrs (Fig. 2). In 2010, rockfish densities were higher at the reefs than at any other habitat (Fig. 2). Non-rockfish densities tended to be low over reefs, similar to those over the deepest platform zone (Fig. 2).

At least 12 species and 47,433 individuals (99.9% rockfishes) were observed at Four Mile Reef (Table 5). At least 11 of these species were rockfishes. Of these, squarespot, widow, and halfbanded rockfishes and bocaccio comprised virtually all of the fishes (99.7%). As at the other reefs, while recruitment strength varied with year and species, the overwhelming number of fish, comprised primarily of squarespot, widow, halfbanded rockfishes, and bocaccio, recruited in 2010. Of the relatively important species, only squarespot rockfish were abundant in every year.

Shipwrecks.—We observed 7627 fishes (223 individuals 100 m^{-2}), comprised of 87.8% rockfishes, over three shipwrecks (Table 6). Nineteen species (at least 12 of which were rockfishes) inhabited these waters. Squarespot rockfish, bocaccio, blue rockfish, blacksmith, and halfbanded and OYT rockfishes, in this order, were most abundant. However, with the exception of the consistently abundant squarespot rockfish, all of these species exhibited great fluctuations in annual densities. As with all other habitat types, overall recruitment of rockfishes was most intense in 2010 (Fig. 2).

Overall, the fish assemblages on reefs and wrecks were similar to those at platforms (Fig. 4). In particular, in 2008 and 2009 reef and wreck assemblages often clustered with those of the deeper platform zones and, secondarily, with middle zone assemblages. In 2010, reflecting the massive and widespread influx of YOY rockfishes, and

Table 6. Young-of-the-year fishes observed at three shipwrecks off California, 2008–2010. Density = number of individuals 100 m^{-2}. See Table 2 for species names.

	Year								
	2008		2009		2010		Total		
Fish	*n*	Density	*n*	Density	*n*	Density	*n*	Density	SE
Squarespot rockfish	1,351	93.8	724	50.3	1,160	80.6	3,235	104.1	30.3
Bocaccio	0	0.0	1	<1.0	1,419	98.5	1,420	65.7	65.6
Blue rockfish	213	14.8	49	3.4	683	47.4	945	37.8	28.6
Blacksmith	55	3.8	830	57.6	6	<1.0	891	23.5	21.2
Halfbanded rockfish	0	0.0	0	0.0	572	39.7	572	26.4	26.4
OYT rockfishes[1]	74	5.1	180	12.5	218	15.1	472	16.6	7.3
Painted greenling	10	1.0	7	<1.0	2	<1.0	19	<1.0	<1.0
KGB rockfishes[2]	5	<1.0	3	<1.0	6	<1.0	14	<1.0	<1.0
Copper rockfish	1	<1.0	6	<1.0	3	<1.0	10	<1.0	<1.0
California sheephead	1	<1.0	5	<1.0	3	<1.0	9	<1.0	<1.0
Vermilion rockfish	0	0.0	9	1.0	0	0.0	9	<1.0	<1.0
White seaperch	5	<1.0	0	0.0	0	0.0	5	<1.0	<1.0
Olive rockfish	4	<1.0	0	0.0	0	0.0	4	<1.0	<1.0
Treefish	0	0.0	0	0.0	4	<1.0	4	<1.0	<1.0
Blackeye goby	1	<1.0	0	0.0	2	<1.0	3	<1.0	<1.0
Gopher rockfish	0	0.0	0	0.0	3	<1.0	3	<1.0	<1.0
Pile perch	2	<1.0	1	<1.0	0	0.0	3	<1.0	<1.0
Black perch	1	<1.0	1	<1.0	0	0.0	2	<1.0	<1.0
Honeycomb rockfish	2	<1.0	0	0.0	0	0.0	2	<1.0	<1.0
Canary rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Flag rockfish	0	0.0	0	0.0	0	0.0	1	<1.0	<1.0
Kelp rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Unidentified *Sebastomus*[3]	0	0.0	0	0.0	1	0.0	1	<1.0	<1.0
Widow rockfish	1	<1.0	0	0.0	0	0.0	1	<1.0	<1.0
Total	1,728	120.0	1,816	144.1	4,083	567.1	7,627	223.0	145.2
							Percent composed of rockfishes = 87.8%		
							Minimum number of species = 21		

1 = Potentially composed of olive and yellowtail rockfishes, 2 = Potentially composed of kelp, gopher, black-and-yellow, and copper rockfishes, 3 = Probably primarily rosy rockfish.

to a certain extent the decline in blacksmith recruitment, we saw increasing similarity among fish assemblages at almost all habitats, including at several of the usually outlying shallow platform stations.

Discussion

The similarity of juvenile fish assemblages on deep portions of oil and gas platforms to assemblages found on pinnacles and shipwrecks suggests that, for juvenile rockfishes, a partial removal alternative in decommissioning would not disrupt the nursery function observed in operating platforms. This is also evidenced by the vertical stratification among YOY of the most abundant taxa. Densities of YOY rockfishes in the deepest platform zone were often higher by a factor of two or more when compared to those at the shallowest levels. This pattern held true not only for platforms in the aggregate (Fig. 2), but with the exception of Platform Irene in 2009 and (barely) platforms Grace and Holly in 2010, also for every platform surveyed in every year

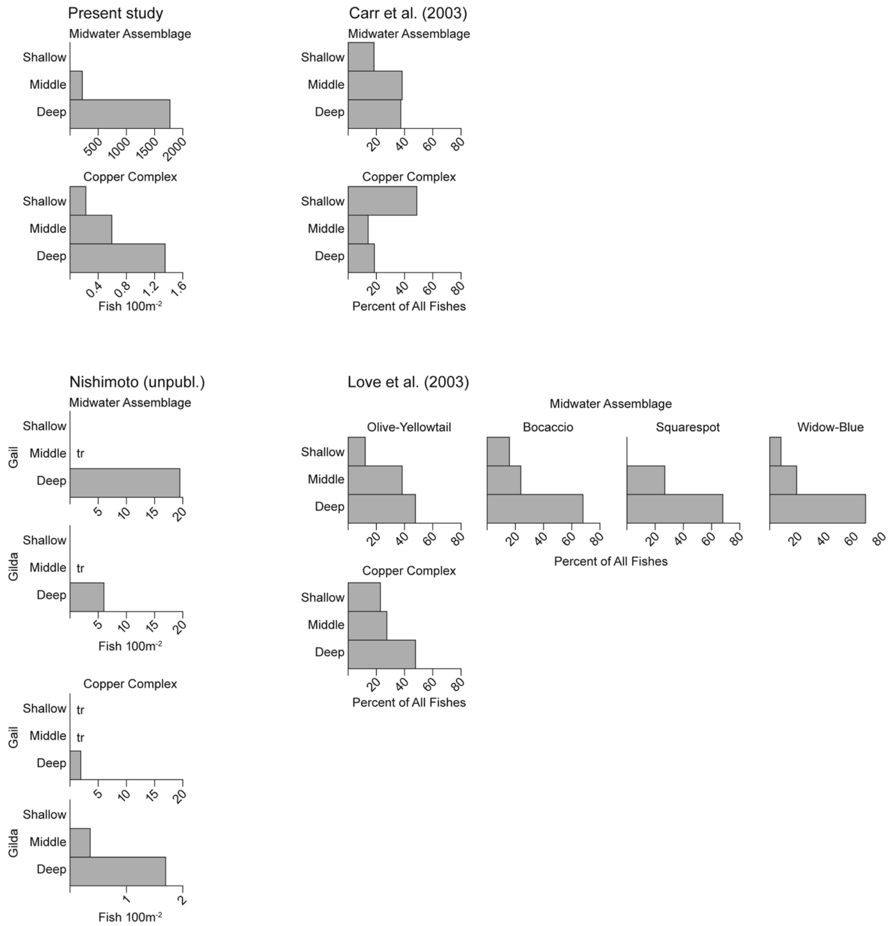

Figure 5. A comparison of the vertical distribution of rockfish young-of-the-year recruits around oil and gas platforms off California. Following Carr et al. (2003), we grouped recruits into a Midwater Assemblage (i.e., bocaccio, black, blue, olive, widow, and yellowtail rockfishes) and Copper Complex (i.e., black-and-yellow, copper, gopher, and kelp rockfishes). The figure labeled "Nishimoto (unpubl)" represents data that were analyzed and published in Nishimoto et al. (2008); however, this particular analysis was not included in that report. Note that data from the present study and from Nishimoto (unpubl) are expressed in densities (fish 100 m^{-2}), while those from Carr et al. (2003) and Love et al. (2003) are in percent of all rockfishes observed.

(Fig. 3). This pattern is similar to that observed in three other California platform studies conducted over the last 15 yrs (Fig. 5). In all of these studies (with the one exception of the "copper complex" observed by Carr et al. (2003; see Fig. 5), densities of YOY rockfishes were lowest in the shallowest portions of the platform and tended to increase with depth.

Previous work provides additional information on the life history of pelagic juvenile rockfishes that is consistent with our supposition that the nursery function does not require novel, fixed-surface structure (Shenker 1988, Lenarz et al. 1991, Doyle 1992, Ross and Larson 2003). In particular, Ross and Larson (2003) demonstrated that the vertical distributions of the pelagic juveniles of a number of rockfish species (including such typical platform species as bocaccio, widow, squarespot, and blue) were quite large. In many instances, juveniles of a size equivalent to newly recruited platform and reef individuals were collected at depths from a minimum of 10 m to at least 100 m. This vertical distribution would facilitate encountering the structure of a topped platform at a time when these rockfishes were ready to settle out of the plankton. This distribution also helps explain the observations that juveniles of the rockfishes that recruit to operating platforms can also recruit to natural rock outcrops deeper than 40 m (Love et al. 2006a, 2010a, Love and Schroeder 2007).

An additional line of evidence that suggests novel habitat is not required to establish a platform's rockfish nursery function comes from a study by Nishimoto et al. (2008). They surveyed two platforms in the Santa Barbara Channel every 3–4 d and observed very few YOY rockfishes in shallow platform waters and dense aggregations at depths similar to those in our study. Given the high frequency of observations at each platform, had most or all of these fishes recruited to shallow waters, we posit that observers would have seen significant numbers of YOY both in shallow waters and in the process of making their way down the platform jackets. In addition, if most rockfish recruitment occurred at the shallowest platform depths, we would hypothesize that the densities of YOY at the relatively deep-cresting reefs and shipwrecks would also have been consistently low. This would have been particularly evident at Four Mile Reef, which is steep-sided, crests at a relatively deep depth of 32 m, and arguably is most similar to a topped platform. However, rockfish recruitment, particularly in 2010, was quite strong at these habitats, including at Four Mile Reef.

However, for offshore structure to function as nursery grounds for other species, novel habitat may be important. Blacksmith, a common shallow-water reef species in Southern California, predominated in the shallowest parts of the platform, while around the deeper parts of platforms, as well as over reefs and shipwrecks, this species was present but in much lower densities. This suggests that blacksmith recruitment and productivity would decrease following platform topping.

The YOY of a number of typical nearshore species, fishes that might be expected to recruit to our sites, particularly to the shallower parts of platforms, were conspicuously uncommon or absent. These taxa include kelp bass [*Paralabrax clathratus* (Girard, 1854)], wrasses such as señorita and rock wrasse, *Halichoeres semicinctus* (Ayres, 1859), and most of the surfperches. YOY kelp bass tend to recruit to algal beds (Love 2011), habitat that is mostly missing from platforms, as well as from the deeper reefs and shipwrecks that we surveyed. The surfperches are viviparous and their fully formed YOY do not appear to disperse well away from the adults; the adults of many surfperch species are uncommon around many of the sites (particularly the platform sites) that we surveyed (Love et al. 2003). Señorita and rock wrasse depend on nocturnal sheltering areas (señorita bury themselves in the sand) and the platforms we surveyed rest in bottom depths that are mostly too deep for nighttime sheltering by these nearshore fishes.

The rockfishes that characterized our survey platforms tended to be the same species that dominated these structures in underwater surveys conducted as far back as the late 1950s (Carlisle et al. 1964, Bascom et al. 1976, Love et al. 1994, 2003, Carr et al. 2003, Nishimoto et al. 2008). One notable exception is the shortbelly rockfish, a major species in the present study. It was previously reported only by Love et al. (2003). This discrepancy may be due to this species' very large fluctuations in recruitment success (Field et al. 2007) or earlier to confusion with YOY bocaccio.

The pattern of fish recruitment over the 3-yr study demonstrated the pervasive and episodic nature of fish recruitment, as we observed substantial interannual variation in both species compositions and densities at platforms, reefs, and shipwrecks. In particular, 2010 saw significant increases in the densities of a number of rockfish species, particularly of shortbelly and squarespot rockfishes and bocaccio, and a large decrease in densities of blacksmith. Interannual differences in recruitment success of rockfishes is a well-known phenomenon (Wilson et al. 2008) and is probably related to several oceanographic factors, while the inverse relationship of blacksmith and nearshore rockfish recruitment was first noted by Love et al. (1991).

Although Siegel et al. (2008) emphasized the stochastic nature of recruitment (the partial result of unknowable oceanographic processes), we observed that some events, such as the heavy rockfish recruitment and the concomitant decrease in blacksmith recruitment of 2010, took place over a relatively large geographic scale; both throughout much of Southern California and over a variety of habitats. As an example, a large increase in densities of YOY of a number of rockfish species was also noted in 2010 fish surveys conducted in the Santa Barbara Channel and northern Channel Islands (D Kushner, National Park Service, pers comm) and around Palos Verdes farther south near Los Angeles (D Pondella, Occidental College, pers comm). Similar to our observations, these surveys documented substantial increases in both frequency of occurrence and densities of bocaccio, blue, and olive rockfishes, as well as the first observations of YOY widow rockfish in many years.

A number of rockfish species observed to recruit as juveniles to offshore oil and gas platforms are important to recreational and commercial fisheries, and two, bocaccio and widow rockfish, are currently managed under federal rebuilding plans (Pacific Fishery Management Council 2008). Protection and restoration of nursery habitats is considered a priority by marine conservation biologists (Beck et al. 2001, 2003). Therefore, for oil and gas platforms facing decommissioning, a partial removal alternative that preserves the rockfish nursery role can be viewed as an option than enhances both fishery management and marine conservation goals. If managers select this decommissioning option, ongoing monitoring of the consequences of this decision will provide needed feedback to improve our understanding of the potential ecological function of offshore installations.

Acknowledgments

This research was funded by the Minerals Management Service Cooperative Number M08AX12732. We thank F Hurd, M McCrea, and J Ruvalcaba for helping to conduct the surveys, D Pondella, D Kushner, and K Moore for additional information on rockfish recruitment within the Southern California Bight, and B Lenarz for the statistical analyses.

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Date Submitted: 15 September, 2011.
Date Accepted: 17 July, 2012.
Available Online: 22 August, 2012.

Addresses: (ML, MN, SC) *Marine Science Institute, University of California, Santa Barbara, California 93106.* (DMS) *Bureau of Ocean Energy Management, Regulation and Enforcement, 770 Paseo Camarillo, 2nd flr, Camarillo, California 93010.* Corresponding Author: (ML) *Email: <love@lifesci.ucsb.edu>.*

Appendix 1. Locations and descriptions of reefs and shipwrecks surveyed in central and Southern California waters from May to September, 2008–2010. Specific years and months surveyed are in parenthesis. See also Figure 1 for locations.

Structure	Coordinates	Description
Reefs		
San Luis	35°08'N, 120°46'W	This pinnacle is the smallest of the seafloor features surveyed in our study. It is a small bladelike spire of rock that is approximately 25 m long and 5 m wide at its peak. It rises to a depth of 20 m and drops nearly vertically along smooth walls on all sides to a depth of 38 m. It is surrounded by sand. This pinnacle is covered with anemones, the upper portion by the strawberry anemone, *Corynactis californica* Carlgren, 1936, the deeper region by the large white anemone, *Metridium senile* (Linnaeus, 1761). (2008: September; 2009: August).
Super Pin	34°05'N, 120°21'W	This pinnacle lies off the north coast of San Miguel Island, rising from 49 to 61 m deep up to a depth of 21 to 24 m. The top is roughly circular measuring 30 to 37 m across, dropping steeply on all sides. The anemone *Cornactis californica* is the dominant structure-forming invertebrate. (2008: May, June, September; 2009: May, August, September; 2010: July, August).
Egg Rock	34°03'N, 120°15'W	Egg Rock lies between Santa Rosa and San Miguel Islands, rising from a depth of about 61 m. The top is relatively flat, measures 44 m long by 26 m wide, and is 20 to 23 m deep. It drops steeply on all sides, the walls having many overhangs and caves. The anemone *Corynactis californica* dominates the substrate, although a stand of the southern palm kelp, *Pterygophora californica* Ruprecht, 1852, occupies the top of the pinnacle. (2008: May, June, September; 2009: May, August, September; 2010: July, August).
The Nine	33°55'N, 119°57'W	The Nine is an oblong rise off the southeast corner of Santa Rosa Island. It rises to a depth of 17 to 21 m. The flat rock is crossed by numerous channels of gravel and sand. Much of the rock is bare or covered with crustose coralline algae. Dense stands of *Pterygophora californica* also occur. The edges drop off gradually to sandy gravel on all sides. Northward toward Santa Rosa Island the surrounding sand flats are 26 m deep. To the south the sand begins at approximately 31 m deep. (2008: May, June, August, September; 2009: May, August, September; 2010: July, August).
Admiral's	34°00'N, 119°26'W	This pinnacle is one of several that rise from the sea floor off the east side of Anacapa Island. It rises sharply from a depth of 38 m. The top of the feature is a plateau approximately 15 by 21 m long that ranges from 21 to 27 m deep. To the north and west it drops nearly vertically to the sea floor, while the other sides slope somewhat more gradually to boulder piles that begin at 30 m deep. Much of this feature is covered in a dense mat of brittle stars (class Ophiuroidea). (2008: May, June, July, August, September; 2009: May, June, July, September; 2010: July, August).
Four Mile	34°21'N, 119°38'W	The Four Mile is a small, roughly circular, seafloor feature that is perhaps 30 m across. It rises from a depth of 46 to 61 m to a peak at 32 m. The top is of very high relief and much of it is 37 m deep. It has numerous overhangs, crevices, and channels running across it. Much of the rock is bare or covered with crustose coralline algae. (2008: June, July, September; 2009: June, July, September; 2010: July, August).

Appendix 1. Continued.

Structure	Coordinates	Description
Shipwrecks		
SM1	34°26'N, 120°23'W	The SM1 was a metal US Navy landing ship that was converted to an oil drilling rig in the 1950s. It sank in 1961 and now lies upside down in 23 m of water just east of Government Point. It has numerous holes in it ranging from several inches to several meters in diameter. The top of the wreck (or the bottom of the hull) rises 6 m off the seafloor and much of it is covered with foliose red algae. (2008: June, July, August, September; 2009: May, July, August; 2010: July, August).
Avalon	33°47'N, 118°25'W	The Avalon was a steel 82 m passenger ship that sank off Palos Verdes in 1964 in 23 m of water on a bottom of sand and boulders. Today it is nothing more than a widely scattered pile of debris, although some sections of the hull are still recognizable and stand 6 m off the bottom. Some sections of the rusting steel are covered in *Corynactis californica*. (2008: July, September; 2009: July, August).
Olympic	33°39'N, 118°13'W	The Olympic was an iron 79 m fishing barge that sank off San Pedro after a collision with the Japanese freighter Sakito Maru in 1940. Considered a hazard to navigation, the wreckage was blown up soon after. As a result the wreckage is strewn about widely, most lying flat on the bottom although a few sections of the hull still stand as high as 10 m off the bottom. The remains lie in 30 m of water on a sandy bottom. *Corynactis californica* is the dominant invertebrate on the wreckage (2008: July, September; 2009: July, August).