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research paper

The role of jacket complexity in structuring fish assemblages in the midwaters of two California oil and gas platforms

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Fishes and invertebrates of oil and gas platforms off California

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ABSTRACT.—Between 2005 and 2011, using manned research submersibles, we compared the fish assemblages associated with the midwater platform structures (at depths between 40 and 195 m) of two southern California oil and gas platforms, Gail and Eureka. Gail is a typical California platform, with rounded crossbeams and pilings, while the midwater jacket of Eureka, studded with bowl-shaped piling guides, is more complex. While the assemblages of both platforms were dominated by rockfishes (*Sebastes* spp.), there were also significant differences. Compared to Gail, Eureka: (1) exhibited higher densities of all species combined and of most species in common, (2) had more mature individuals of most species, (3) exhibited greater species richness, and (4) had higher densities of species typical of complex high relief. We propose that the complex midwater jacket of Eureka, with its many sheltering sites, resembles rugose natural rocky reefs. This research both reinforces the conclusion that many reef species have quite specific habitat requirements and that the platform decommissioning process must consider each platform individually.

There are more than 6000 offshore oil and gas platforms worldwide (Schroeder and Love 2004). When a platform is no longer economical to operate, a decision is made regarding its postproduction disposition, a process known as *decommissioning*. Depending on the location of a platform and its final disposition, both state and federal agencies may be involved in the process. Decommissioning may take a number of forms. Most commonly, platforms are removed from the sea floor and taken to shore. However, a growing number of platforms undergo partial removal, which might include (1) severing from the sea floor and transporting to a designated artificial reef site, (2) toppling in place, or (3) removing the upper portion (often the top 30 m below the ocean surface) and leaving the remaining steel in place (Schroeder and Love 2004), a process often termed *rigs-to-reefs*. In the Gulf of Mexico, home to several thousand platforms, the decommissioning process is well understood, and Louisiana and Texas, in particular, have robust rigs-to-reef programs (LDWF 2017, TPWD 2017).

California, by contrast, has only 26 platforms and none have been decommissioned since 1996. In that year, four structures were totally removed and there was little debate regarding the disposition of these structures, primarily because at that time the state had no statutory framework for partial removal. This regulatory framework changed in 2010 with the creation of the California Marine Resources Legacy Act (CMRLA). The CMRLA establishes a state policy to allow, on a case-by-case basis, the partial decommissioning of offshore platforms. The CMRLA states that, among other factors, a platform's "net environmental benefit" must be established during the decommissioning process.

One of the factors that may contribute to the net environmental benefit calculation is the role that a platform plays as fish habitat. In this regard, the question arises regarding how monolithic these assemblages are and to what extent variability in platform jacket structure influences these assemblages.

Decades of research around California platforms demonstrate that, in general, in waters deeper than about 40 m, there are two distinct fish assemblages living around the jackets (pilings and crossbeams) of deeper-water California oil and gas platforms (with bottom depths >100 m; Love et al. 2000, Love et al. 2019). First, subadult and adult fishes of a number of benthic species (primarily rockfishes, *Sebastes* spp.) inhabit the platform jacket-sea floor complex (Love et al. 2000). Many of these species associate with the bottom crossbeam of the platform, particularly where the crossbeam has been undercut leaving a long crevice (Love and York 2006). The midwaters (at depths below about 40 m) around most California platforms serve primarily as nursery areas for a variety of fishes, again particularly rockfishes (Love et al. 2012).

The midwater structures of most California platforms are similarly configured. The platform jacket is a framework of rounded, steel crossbeams and tubular, vertical sleeves. The main pilings are driven through these sleeves, which are located at the corners and sometimes at intervals between the corners of the jacket (comprised of the underwater crossbeams and vertical members; Fig. 1). While the jacket is covered with sessile invertebrates (e.g., mussels, sea stars, sea anemones), most of these organisms do not form significant vertical relief. However, Platform Eureka is structurally unique among platforms deployed off California. Instead of pilings driven through the vertical sleeves, Eureka has a series of relatively narrow "skirt pilings" that are attached to the outside of the jacket. The skirt pilings are in fascicles of three with a relatively narrow space between each. To guide these pilings into the sea floor, large circular guides were constructed at each crossbeam directly above each piling's location (Fig. 1). Thus, compared with other platforms deployed off California, these skirt pilings and guides add both vertical and horizontal relief to the jacket in midwater. A larger scale study compared the fish assemblages associated with the midwater crossbeams of 23 platforms across southern California (Love et al. 2019). They found that the fish assemblages associated with the Eureka crossbeams from 50 to 150 m depth were most similar to each other and formed a unique cluster that was significantly different from those on all other platforms in the region.

In the present study, we compared the midwater fish assemblage of Eureka with that of Gail, a more typically-configured platform. Through this comparison, some of the roles that jacket complexity plays in structuring fish assemblages may be elucidated.

These two platforms are similar in the following respects: (1) they were deployed at about the same time, Eureka in 1984 and Gail in 1987; (2) both platforms are about 13 km from shore and stand in similar depths—Eureka in 212 m and Gail in 224 m;

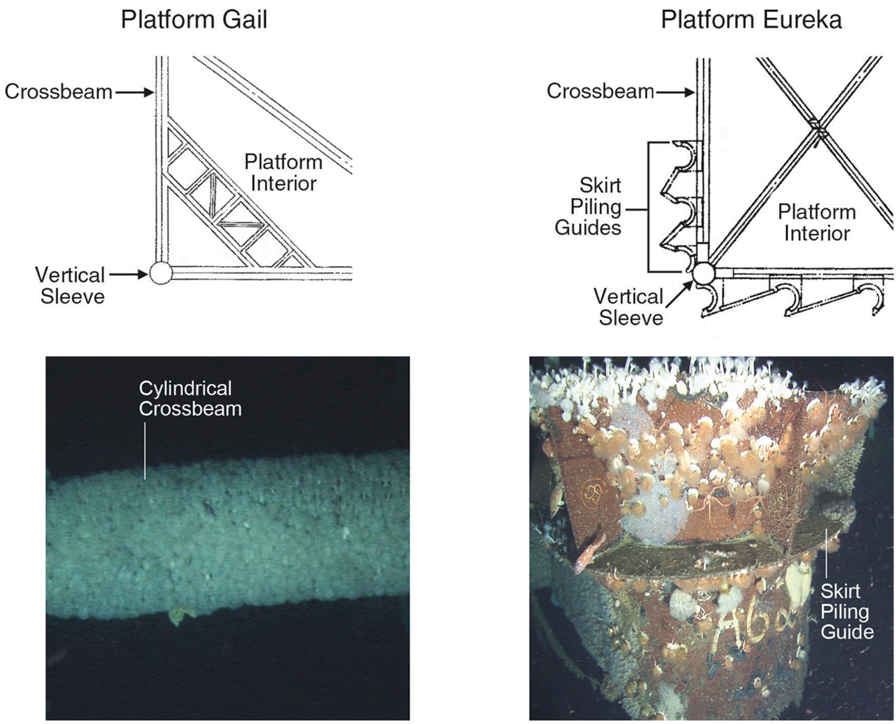

Figure 1. Physical characteristics of the midwater jackets (crossbeams and vertical members) of platforms Eureka and Gail. Crossbeams of Gail are cylindrical and lack structural complexity. Crossbeams of Eureka have bowl-shaped skirt piling guides (viewed from the outside of a piling guide looking inwards). Two rockfishes, an adult *Sebastes hopkinsi* and a *Sebastomus* sp. are pictured associated with a skirt piling guide.

(3) both platforms have seven midwater crossbeams that are situated at comparable depths (Table 1); (4) although Eureka is found about 118 km to the southeast of Gail (Fig. 2), both platforms are in the Southern California Bight and are bathed by waters of similar origin (Hickey 1993) and temperatures (Fig. 3, *see* detailed statistical method in the data analyses section); (5) both are situated on mud sea floors many kilometers from the nearest substantial natural reef; (6) both experience almost no commercial or recreational fishing pressure; and (7) in the two areas, the dominant reef fish species are comparable (Love et al. 2009).

Table 1. Depths (m) (rounded to the nearest 5 m) and perimeter lengths (m) of crossbeams, platforms Eureka and Gail.

Eureka		Gail	
Depth	Perimeter length	Depth	Perimeter length
60	194	45	189
80	206	70	203
100	218	90	217
125	230	115	232
145	243	140	246
165	254	165	264
190	268	195	283

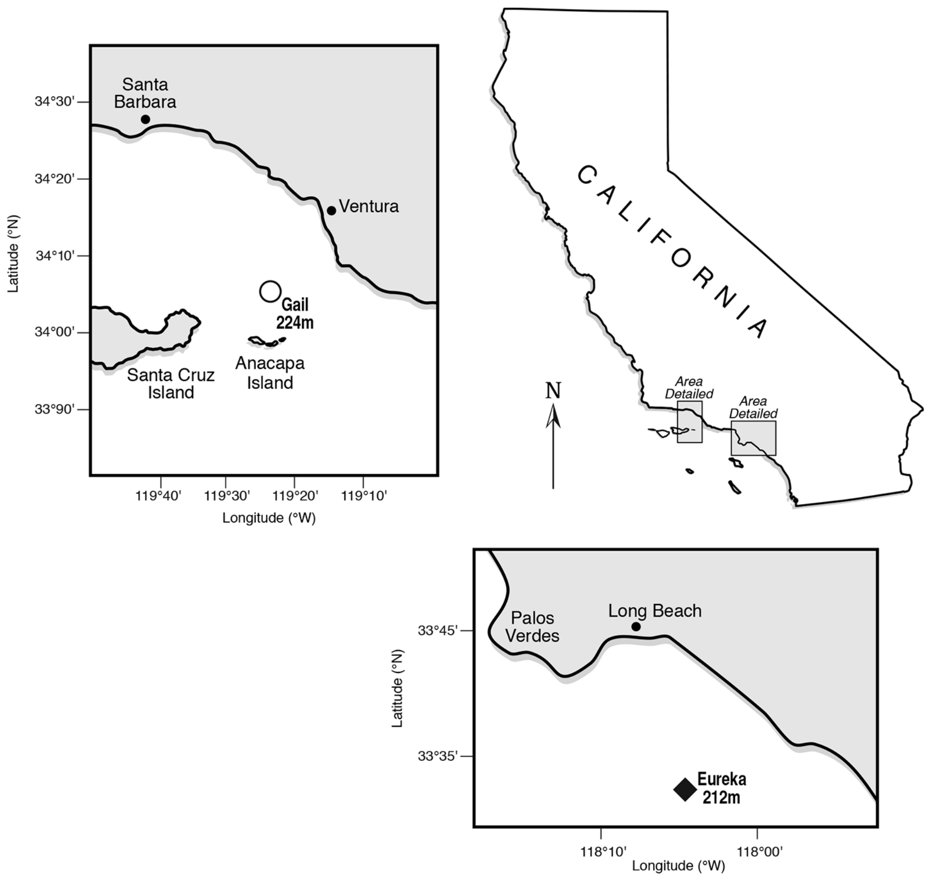

Figure 2. Location and bottom depths of platforms Eureka (closed diamond) and Gail (open circle).

Methods

Fish Surveys

We surveyed fishes in the midwaters of platforms Eureka and Gail (Fig. 2) annually during September or October from 2005 to 2011. In those years, the two platforms were surveyed within 3 d of each other. From 2005 to 2009, we used the Delta research submersible, a 4.6-m long, two-person vessel, operated by Delta Oceanographics of Oxnard, California. In 2010 and 2011, we used the Dual Deepworker, a 7.2-m long, two-person vessel, operated by Nuytco Research, North Vancouver, British Columbia. In the platform midwaters, we conducted surveys along the platform's horizontal crossbeams that are located at 20–30 m intervals between near-surface waters and the bottom (Table 1). We conducted belt transects around the crossbeams at a distance of approximately 2 m from the platform, while the submersible maintained a speed of about 0.5 knots.

Submersible surveys were conducted during daylight, between 1 hr after sunrise and 2 hrs before sunset. During each transect, the researcher made observations

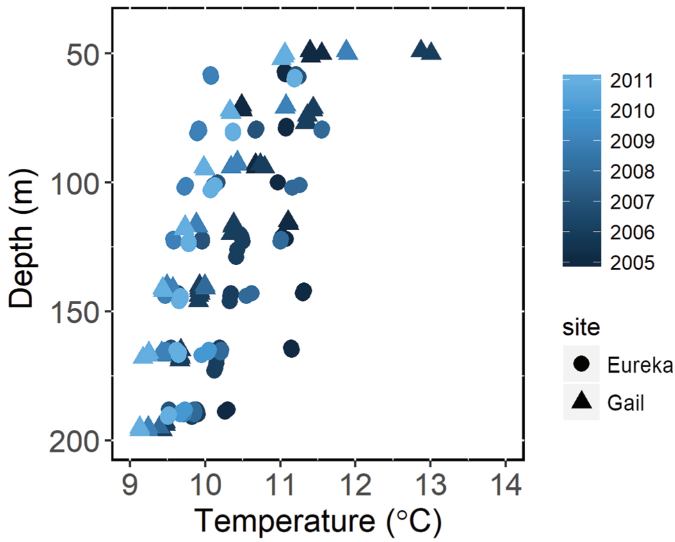

Figure 3. Ambient water temperatures observed during fish surveys of the midwaters of platforms Eureka and Gail during 2005–2011.

from a viewing port on the starboard side of the submersible. An externally mounted high definition video camera (Sony Hi8) with associated lights filmed the same viewing fields as seen by the observer. The observer identified, counted, and estimated fish lengths to the nearest 5 cm of all fishes and verbally recorded those data. The submersible maintained a steady distance of 2 m from the crossbeam and all fishes between the submersible and the crossbeam were included in the survey. Fish lengths were estimated using a pair of parallel lasers mounted on either side of the external video camera. The projected points were 20 cm apart and were visible both to the observer and in the video recorded image. These points were used as a reference tool allowing the observer to, if necessary, compare by eye the distance between these points and the length of a fish's body. This system has been used in other northeast Pacific coast submersible fish studies (e.g., Yoklavich et al. 2007, Laidig and Yoklavich 2016). Many years of experience along the Pacific Coast indicated that if either the Delta or Dual DeepWorker is moving at a constant and slow rate of speed, as in these surveys, there is very little obvious effect on most fishes, particularly rockfishes (Laidig et al. 2012). We noticed virtually no movement from most of the fishes in the study as the research submersible passed by. Unless hidden in complex substrate, fishes as small as about 5 cm in length are readily visible within 2 m of the submersible.

From the analysis, we excluded fish survey data collected on crossbeams at depths <40 m and those data collected from the crossbeam at the base of the platform at the sea floor (i.e., "midwater" only). The transient and highly mobile species jack mackerel, *Trachurus symmetricus* (Ayres, 1855) and Pacific sardine, *Sardinops sagax* (Jenyns, 1842) were excluded from the data set. All data can be accessed through the Santa Barbara Channel Marine Biodiversity Observation Network (SBC-MBON; Love et al. 2017).

Data Analyses

Species Assemblages.—To examine the relationships among the fish assemblages observed at the seven depths (crossbeams) sampled at each of the two platforms, we constructed a similarity matrix on fourth-root transformed fish densities using the Bray-Curtis similarity coefficient. We then performed a cluster analysis with a SIMPROF test ($\alpha = 0.05$) using the simprof function in the clustsig package (Clarke et al. 2008, Whitaker and Christman 2014) in R (R Core Team 2017) to identify significant clusters of fish assemblages associated with crossbeams (taxa-specific densities averaged over all years sampled). To visualize these relationships we also created two-dimensional, nonmetric multidimensional scaling (nMDS) plots using the metaMDS function in the vegan package (Oksanen et al. 2017) in R. We used the averaged (across years) taxa-specific densities to illustrate spatial patterns (depth and platforms), with the significant clusters of crossbeam fish assemblages identified from the SIMPROF test indicated on the nMDS ordination with minimum convex polygons. We also produced an nMDS ordination using annual survey densities to illustrate temporal variation in fish assemblages on crossbeams. The data from two crossbeams in 1997 (Gail 165 m and 45 m) were excluded from the crossbeam by year analysis because they shared no or only one common species (at a very low density) with the other crossbeams by year and would not permit the nMDS ordination to be resolved during initial runs. To examine similarities and differences in the numerically dominant species among each of the significant fish assemblage clusters, we plotted the mean densities (averaged across all crossbeams and years surveyed), with young-of-the-year plotted separately, for the top six most abundant species across all groupings. These common species constituted the vast majority of the fish observed (*see* Results for further details).

Not all taxa could be identified to species and therefore for the assemblage analyses (e.g., nMDS ordination), related taxa were combined or, in some instances, removed from analysis to ensure that individuals of the same species would not be present in the analysis under two or more taxonomic levels. In cases where a higher-level taxon was more abundant in the data set (e.g., more individuals identified to a genus than a species), densities were summed to the higher taxonomic level. If a lower level taxon was more abundant in the data set, the individuals identified at the higher taxonomic level were excluded from the analysis. Thus, for example, more fishes were identified as within the family Agonidae than those identified as either genera or species within that family and we combined all of these fish under Agonidae. For rockfishes, as there were more individuals identified to the species level than identified to genus, fishes that we could only identify to genus (*Sebastes* spp.) were removed from the assemblage analyses.

Assemblage Comparisons.— To examine the relationships among the fish assemblages observed at the seven depths (crossbeams) sampled at each of the two platforms, we constructed a similarity matrix on fourth-root transformed fish densities using the Bray-Curtis similarity coefficient. We then performed a cluster analysis with a SIMPROF test ($\alpha = 0.05$) using the simprof function in the clustsig package (Clarke et al. 2008, Whitaker and Christman 2014) in R (R Core Team 2017) to identify significant clusters of fish assemblages associated with crossbeams (taxa-specific densities averaged over all years sampled). To visualize these relationships we also created two-dimensional, nonmetric multidimensional scaling (nMDS) plots using the metaMDS function in the vegan package (Oksanen et al. 2017) in R. We used the averaged (across years) taxa-specific densities to illustrate spatial patterns (depth and platforms), with the significant clusters of crossbeam fish assemblages identified from the SIMPROF test indicated on the nMDS ordination with minimum convex polygons. We also produced an nMDS ordination using annual survey densities to illustrate temporal variation in fish assemblages on crossbeams. The data from two crossbeams in 1997 (Gail 165 m and 45 m) were excluded from the crossbeam by year analysis because they shared no or only one common species (at a very low density) with the other crossbeams by year and would not permit the nMDS ordination to be resolved during initial runs. To examine similarities and differences in the numerically dominant species among each of the significant fish assemblage clusters, we plotted the mean densities (averaged across all crossbeams and years surveyed), with young-of-the-year plotted separately, for the top six most abundant species across all groupings. These common species constituted the vast majority of the fish observed (*see* results for further details).

We compared fish densities, size, and species richness among depths and platforms using R (R Core Team 2017). Richness was computed by summing the number of species present in each transect. Linear regression models were constructed to determine if fish density, number of fishes, and species richness were different between platforms and their distributions across depths over time. The fish density (number per 100 m^2) and the number of species (species richness) were the response variables, whereas platform (Eureka and Gail), year (numerical values from 2005 to 2011), and depths (numerical values from 45 to 195 m) were the independent variables. If any independent variable was not statistically significant ($P > 0.05$), we removed the variable (e.g., year was not a significant factor for predicting fish size). The interactions among the main factors were not considered in our analyses because the rates of increase/decrease in fish-related characters across depths and over time were not our focus.

Ambient temperatures at survey depths were measured coincident with the fish surveys. Potential differences between the two platforms at a similar depth and a given year were tested used a mixed model linear regression (nlme package in R). Year and depth were random factors that accounted for the intra-annual variation of the temperature, as well as temperature gradients over depths. The results indicated that there was no significant difference in temperature between two platforms ($P = 0.22$).

Results

We observed 46,919 fishes of at least 35 species at Platform Eureka and 4805 fishes of at least 22 species at Platform Gail (Tables 2, 3). Of these species, 17 were unique to Eureka and 4 were unique to Gail. Total average fish density was much higher at Eureka (283.4 individuals per 100 m^2) than at Gail (33.4 individuals per 100 m^2). Rockfishes (genus *Sebastes*) dominated both assemblages, comprising 99.7% and 95.4% of all fishes observed at Eureka and Gail, respectively. A minimum of 30 rockfish species (29 species at Eureka and 17 at Gail) inhabited the platform midwaters. Those species or species complexes with highest densities at Eureka included squarespot, bank, widow, and speckled rockfishes, while squarespot rockfish and bocaccio dominated the midwaters of Gail (Table 2; *see* Table 3 for species names and

Table 2. Total numbers and average densities (fish per 100 m^2) of all fishes observed at the crossbeams of platforms Eureka and Gail. Species with an asterisk were observed at only one of the two platforms. YOY = young-of-the-year. *See* Table 3 for species authorities.

Eureka			Gail		
Species	Average density	Number	Species	Average density	Number
Squarespot rockfish	211.0	34,789	Squarespot rockfish	12.8	1,806
Unidentified rockfishes YOY	31.9	4,923	Bocaccio	7.6	1,162
Widow rockfish	8.1	1,416	Unidentified rockfishes YOY	6.6	944
Bank rockfish	7.9	1,620	Widow rockfish	3.2	320
Speckled rockfish*	6.5	1,122	Painted greenling	1.1	178
Unidentified rockfishes	6.1	1,077	Flag rockfish	0.6	95
Blue rockfish*	7.9	555	Unidentified rockfishes	0.5	90
Unidentified *Sebastomus*[1]	1.7	289	Unidentified *Sebastomus*[1]	0.3	58
Bocaccio	0.9	147	Rosethorn rockfish	0.2	40
Dwarf-red rockfish*	0.7	116	Copper rockfish	0.2	31
Rosy rockfish*	0.7	108	Unidentified fishes	0.1	21
Copper rockfish	0.7	98	Cabezon	0.1	12
Starry rockfish*	0.4	81	Greenspotted rockfish	0.1	8
Flag rockfish	0.4	71	Greenblotched rockfish	0.1	8
Greenblotched rockfish	0.4	62	Darkblotched rockfish	<0.1	6
Pygmy rockfish*	0.4	62	Halfbanded rockfish	<0.1	5
Pinkrose rockfish*	0.4	61	Kelp greenling	<0.1	4
Kelp rockfish*	0.4	61	Pacific hake*	<0.1	3
Painted greenling	0.3	48	Unidentified sculpins	<0.1	3
Cabezon	0.2	31	Bank rockfish	<0.1	2
Greenspotted rockfish	0.2	31	Sharpchin rockfish	<0.1	2
Darkblotched rockfish	0.1	21	Yelloweye rockfish	<0.1	2
Honeycomb rockfish*	0.1	20	Calico rockfish*	<0.1	1
Blacksmith*	0.1	19	Gopher rockfish	<0.1	1
Unknown fishes	0.1	16	Lingcod*	<0.1	1
Gopher rockfish	0.1	13	Shortbelly rockfish	<0.1	1
Shortbelly rockfish	0.1	13	Swordspine rockfish	<0.1	1
Swordspine rockfish	0.1	13			
Freckled rockfish*	0.1	10			
Treefish*	<0.1	5			
Halfbanded rockfish	<0.1	4			
Rosethorn rockfish	<0.1	4			
Yelloweye rockfish	<0.1	3			
Sharpchin rockfish	<0.1	2			
California sheephead*	<0.1	2			
Vermilion rockfish[2]*	<0.1	2			
Unknown sculpin	<0.1	1			
Blackgill rockfish*	<0.1	1			
Pacific sanddab*	<0.1	1			
Popeye catalufa*	<0.1	1			
Average total density	283.4		Average total density	33.4	
Minimum number of species	35.0		Minimum number of species	22.0	
Total	46,919.0		Total	4,805.0	

[1]Potentially freckled, greenblotched, greenspotted, honeycomb, pinkrose, rosy, swordspine, or starry rockfishes.
[2]Either *Sebastes miniatus* or *Sebastes crocotulus*.

Table 3. Common and scientific names mentioned in this paper.

Common name	Species and authority
Bank rockfish	*Sebastes rufus* (Eigenmann and Eigenmann, 1890)
Blackgill rockfish	*Sebastes melanostomus* (Eigenmann and Eigenmann, 1890)
Blacksmith	*Chromis punctipinnis* (Cooper, 1863)
Blue rockfish	*Sebastes mystinus* (Jordan and Gilbert,1881)
Bocaccio	*Sebastes paucispinis* Ayres, 1854
Cabezon	*Scorpaenichthys marmoratus* (Ayres, 1854)
Calico rockfish	*Sebastes dalli* (Eigenmann and Beeson, 1894)
California sheephead	*Bodianus pulcher* (Ayres, 1854)
Copper rockfish	*Sebastes caurinus* Richardson, 1844
Darkblotched rockfish	*Sebastes crameri* (Jordan, 1897)
Dwarf-red rockfish	*Sebastes rufianus* Lea and Fitch, 1972
Flag rockfish	*Sebastes rubrivinctus* (Jordan and Gilbert, 1880)
Freckled rockfish	*Sebastes lentiginosus* Chen, 1971
Garibaldi	*Hypsypops rubicundus* (Girard, 1854)
Gopher rockfish	*Sebastes carnatus* (Jordan and Gilbert, 1880)
Greenblotched rockfish	*Sebastes rosenblatti* Chen, 1971
Greenspotted rockfish	*Sebastes chlorostictus* (Jordan and Gilbert, 1880)
Greenstriped rockfish	*Sebastes elongatus* Ayres, 1859
Halfbanded rockfish	*Sebastes semicinctus* (Gilbert, 1897)
Honeycomb rockfish	*Sebastes umbrosus* (Jordan and Gilbert, 1882)
Kelp bass	*Paralabrax clathratus* (Girard, 1854)
Kelp greenling	*Hexagrammos decagrammus* (Pallas, 1810)
Kelp rockfish	*Sebastes atrovirens* (Jordan and Gilbert, 1880)
Lingcod	*Ophiodon elongatus* Girard, 1854
Opaleye	*Girella nigricans* (Ayres, 1860)
Pacific hake	*Merluccius productus* (Ayres, 1855)
Pacific sanddab	*Citharichthys sordidus* (Girard, 1854)
Painted greenling	*Oxylebius pictus* Gill, 1862
Pinkrose rockfish	*Sebastes simulator* Chen, 1971
Popeye catalufa	*Pristigenys serrula* (Gilbert, 1891)
Pygmy rockfish	*Sebastes wilsoni* (Gilbert, 1915)
Rosethorn rockfish	*Sebastes helvomaculatus* Ayres, 1859
Rosy rockfish	*Sebastes rosaceus* Girard, 1854
Sharpchin rockfish	*Sebastes zacentrus* (Gilbert, 1890)
Shortbelly rockfish	*Sebastes jordani* (Gilbert, 1896)
Speckled rockfish	*Sebastes ovalis* (Ayres, 1862)
Squarespot rockfish	*Sebastes hopkinsi* (Cramer, 1895)
Starry rockfish	*Sebastes constellatus* (Jordan and Gilbert, 1880)
Swordspine rockfish	*Sebastes ensifer* Chen, 1971
Treefish	*Sebastes serriceps* (Jordan and Gilbert, 1880)
Vermilion rockfish	*Sebastes miniatus* (Jordan and Gilbert, 1880) or *Sebastes crocotulus*[1]
Widow rockfish	*Sebastes entomelas* (Jordan and Gilbert, 1880)
Yelloweye rockfish	*Sebastes ruberrimus* (Cramer, 1895)

[1] *Sebastes crocotulus* was shown to be genetically separate from *S. miniatus* in Hyde et al. (2008), but has not been formally described.

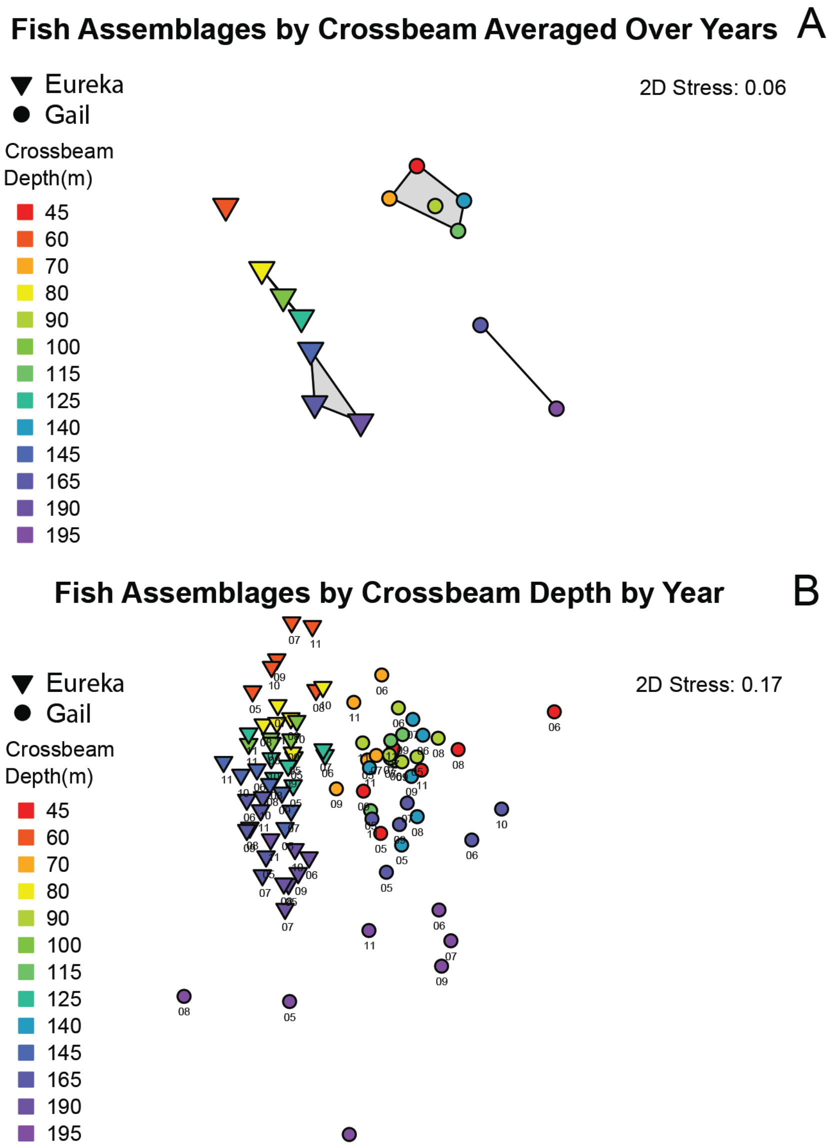

Figure 4. Nonmetric multidimensional ordination plots of fish assemblages using Bray-Curtis similarity coefficients based on the fourth-root, transformed fish densities associated with crossbeams surveyed from 60 to 190 m depth at platform Eureka and 45 to 195 m depth at platform Gail. (A) Points represent the fish assemblages using averaged densities (across years) for clarity, and the five significant crossbeam depth clusters (determined by SIMPROF cluster analysis) are indicated by minimum convex polygons. (B) Points represent the fish assemblages using densities from annual surveys (years labeled) to illustrate annual variation in fish assemblages on crossbeams.

authorities). Of the 17 species shared by the two structures, the densities of most fish were higher at Eureka.

Fish assemblages associated with platforms Eureka and Gail were distinct (horizontal point separation in Fig. 4 A, B) with additional differentiation of the assemblages along a depth gradient (roughly vertical point separation in Fig. 4 A, B). The cluster analysis with SIMPROF test ($\alpha = 0.05$) identified five significant clusters of fish assemblages associated with crossbeams at various depths: (1) Gail at 45, 70, 90, 115, and 140 m; (2) Gail at 165 and 195 m; (3) Eureka at 60 m; (4) Eureka at 80, 100, and 125 m; and (5) Eureka at 145, 165, and 190 m (Fig. 4A). The fish assemblages at specific crossbeams (depths) were relatively more stable across years at Eureka than at Gail (tighter grouping and less point overlap among different Eureka crossbeams as compared with Gail in Fig. 4B).

The most striking difference between the fish assemblages at these two platforms was the extremely high densities of squarespot rockfish at Eureka. They were an order of magnitude higher than any other species on either platform, with a mean of 64 per 100 m^2 along the deepest (145 and 160 m) crossbeams, increasing to 524 per 100 m^2 along the 60 m crossbeam (Fig. 5). Most of these were young-of-the-year (YOY) that decreased in density with depth. The highest densities of larger, non-YOY squarespot rockfish were found at the mid-depth crossbeam cluster. While squarespot rockfish densities were much lower at Gail compared to Eureka, they still had a higher density in the Gail deeper-depth cluster (19.2 per 100 m^2) than any other species in the two Gail clusters.

In additional to patterns in squarespot rockfish, Eureka fish assemblage clusters were characterized by moderate densities (1–16 per 100 m^2) of other *Sebastes* species whose densities tended to increase or decrease with depth (Fig. 5). The Eureka 60-m crossbeam had the highest mean density of blue rockfish. Eureka's deepest midwater crossbeams (145–190 m cluster) had the highest mean densities of widow rockfish, speckled rockfish, and bank rockfish (including YOY). Finally, the fish assemblage on Eureka's mid-depth crossbeams (80–125 m cluster) contained intermediate densities of most of the previously-mentioned *Sebastes* species (Fig. 5). This pattern is also reflected in the nMDS plot, with the mid-depth Eureka crossbeam points being located in-between the points from the shallower and deeper crossbeams (Fig. 4A).

In contrast, fish assemblages at platform Gail were dominated by only three species that occurred at relatively moderate densities (about 1–19 individuals per 100 m^2). These three species represented 70% and 92% of all the fishes observed in the mid-depth (45–140 m) and deep (165–195 m) crossbeam clusters, respectively. Along the mid-depth crossbeams, squarespot rockfish (32%) and bocaccio (24%) had the highest densities, both of which were almost exclusively YOY, followed by widow rockfish (14%; Fig. 5). On the deeper crossbeams, squarespot rockfish (51%) had the highest density, followed by bocaccio (29%), both being predominately YOY, with widow rockfish (12%) again the third most abundant. The assemblage being characterized by lower fish densities of fewer species is also related to the increased spread in Gail assemblages among years (Fig. 4B) because a smaller absolute change in the density of a single species year to year has the potential to cause a relatively larger difference in the relative abundances of species that go into calculating the assemblage similarity coefficients.

Fish densities were significantly higher at Eureka (Fig. 6, Table 4). At both platforms, fish densities varied with depth and tended to peak in the mid-depth ranges

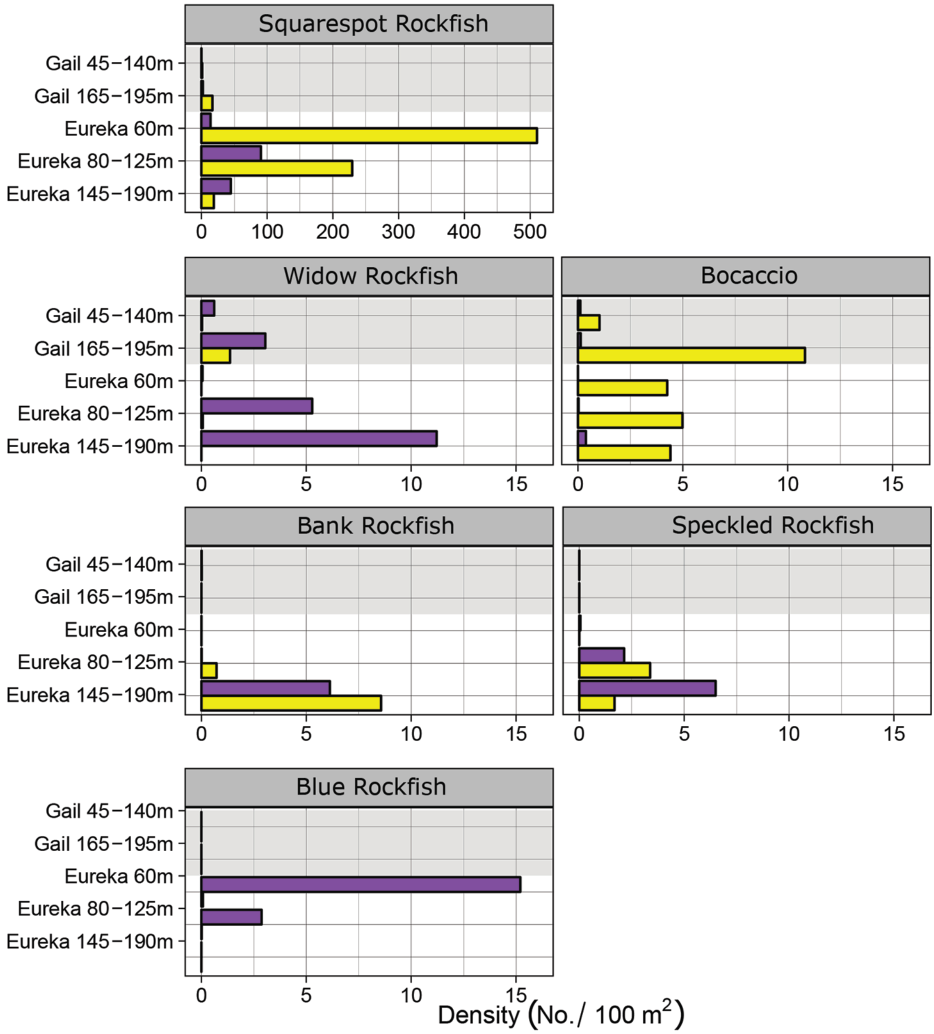

Figure 5. Densities (number of fishes per 100 m^2) of the six most abundant fish species within the five significant crossbeam depth fish assemblage clusters on platforms Eureka and Gail. Significant clusters of fish assemblages associated with crossbeams were determined using a SIMPROF test (α = 0.05). Values are averages across all transects and years surveyed, with young-of-the-year plotted separately (yellow bars) from the rest of the observed fish (purple bars) for each species. Note that a different density scale was used for *Sebastes hopkinsi* due to its relatively high densities on Eureka.

(Fig. 6); this was particularly apparent at Eureka. In addition, densities and numbers at platform Eureka tended to be higher in the later years of the survey. Unlike density, species richness did not vary statistically with depth at either platform (Fig. 7, Table 4). Between the two platforms, species richness was higher at all depths at Eureka (by 2–3 times; Fig. 7, Table 4). However, species richness varied considerably among years at each crossbeam. At both platforms, average fish lengths increased with depth and fishes tended to be statistically larger at Eureka (Figs. 8, 9, Table 4).

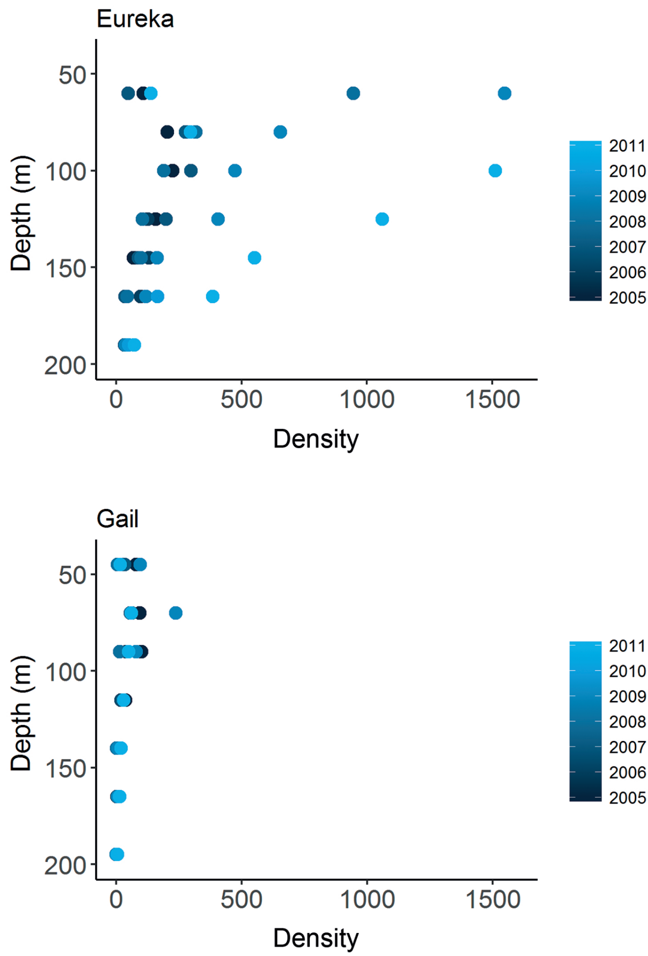

Figure 6. Densities (number of fishes per 100 m^2) of all fishes observed at Eureka and Gail, by year and by crossbeam, 2005–2011.

Most of the fishes that we observed were small individuals, primarily ≤25 cm total length (TL; Fig. 9A). Of those individuals >25 cm TL, all were observed at Eureka. We observed very few adult-sized fishes around the midwaters of Gail. Of the three species that were relatively abundant at Gail (squarespot rockfish, bocaccio, and widow rockfish), almost all were either YOYs or larger juveniles (Fig. 9B–D). By contrast, at Eureka, we observed large numbers of YOY, larger juvenile, and adult life stages of these three species. We note that this was also the case for the other two species (bank and speckled rockfishes) that were most abundant at Eureka (Fig. 9E, F).

Table 4. A comparison of fish densities, species richness, and fish sizes between Eureka and Gail and among depths (refer to Figs. 6, 7, and 8, respectively). The "platform" value relates to Gail and describes how the average density, species richness, and length relates to Eureka.

	Estimate	SE	*t*	*P*
Densities				
Platform	−262.300	52.340	−5.012	<0.001
Year	39.010	12.850	3.037	0.003
Depth	−1.970	0.550	−3.566	<0.001
Species richness				
Platform	−6.346	0.441	−14.400	<0.001
Year	0.268	0.108	2.480	0.015
Depth	−0.002	0.005	0.446	0.657
Average lengths				
Platform	−3.526	1.422	−2.480	0.030
Depth	0.065	0.015	4.248	0.001

Discussion

First, we note that we surveyed only the outside perimeters of each platform. Thus our observations and conclusions may only be applicable to this part of the platform structure.

We observed major differences between the midwater fish assemblages at Eureka and Gail. Specifically, compared to Gail, Eureka exhibited: (1) higher overall fish densities and higher densities of most of the species that were held in common; (2) greater species richness, reflecting the presence of species that are usually found around high-relief natural habitats and are absent or uncommon around the midwaters of most California platforms; (3) a greater size range of individuals within many species; and (4) higher densities of mature fishes.

To what extent might these differences be ascribed only to geographic variability in the abundances of some species? For instance, a few of the species unique to Eureka (i.e., popeye catalufa, freckled rockfish, and dwarf-red rockfish) are species that are more abundant in the more southerly parts of southern California. However, the bulk of the species that were either unique to, or more abundant at, Eureka (i.e., bank, blue, rosy, speckled, starry, and pygmy rockfishes) are abundant throughout southern California (Love 2011).

It is more likely that dissimilarities in habitat complexity between the two platforms play the major role, as there is a substantial body of research demonstrating that reef fish assemblages are structured by, among other qualities, habitat characteristics like sea floor relief, complexity, and composition (Anderson and Yoklavich 2007, Lecchini and Tsuchiya 2008, Granneman and Steele 2015). Among deeper-water US Pacific coast reefs, many species differentially associate either with high relief such as boulders (e.g., bank, speckled, and rosy rockfishes) or low-relief cobble (e.g., halfbanded and greenstriped rockfishes; Anderson and Yoklavich 2007, Love et al. 2009). At an even finer scale, within high-relief structure the presence of caves, crevices, and other reef complexity also has a significant effect on species composition (Caselle et al. 2002; Love and York 2006; Love et al. 2006a). Indeed, there are a number of rockfish species, such as bocaccio, pinkrose, and copper rockfishes that, although not limited to complex habitat, are far more abundant there (Love and

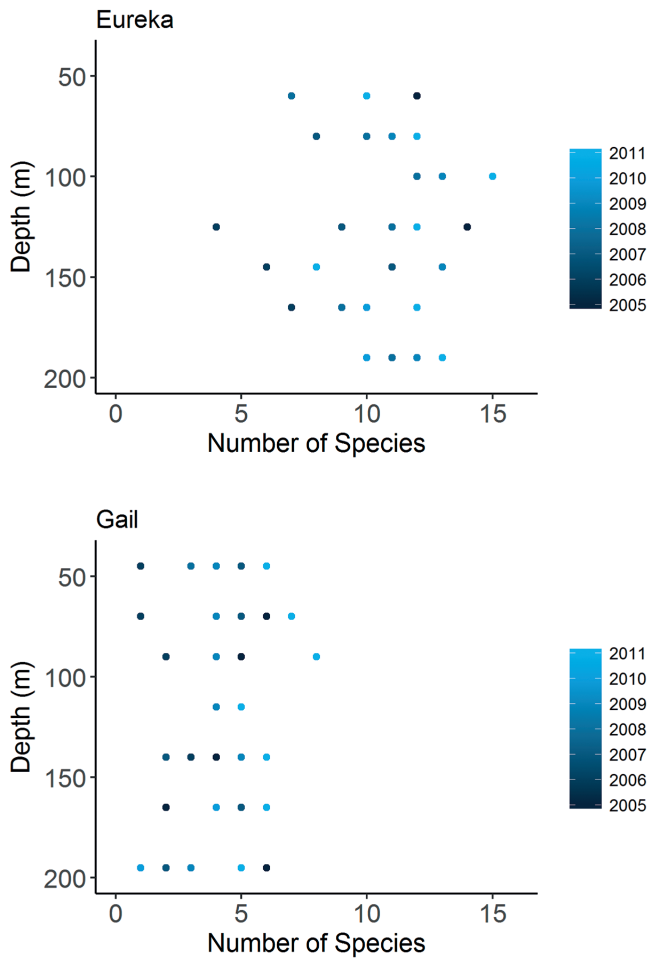

Figure 7. Number of species observed at platforms Eureka and Gail, by year and by crossbeam, 2005–2011.

York 2006; Love et al. 2006a). In addition, habitat requirements may change as fish mature. For instance, newly recruited YOY cowcod, *Sebastes levis* (Eigenmann and Eigenmann, 1889), live primarily among cobbles and proceed to move into complex, high relief as they mature (Love and Yoklavich 2008).

It appears that the crossbeams and vertical pilings of most platforms lack substantial rugosity and sheltering sites. Because most of the invertebrates covering the crossbeams are small, sheltering sites in the midwaters of a typical platform occur only where horizontal crossbeams meet vertical or diagonal struts. We have observed that on a typical platform, in the depths surveyed, these junctions are the primary places where fishes congregate. We should note that the high densities of fishes along Eureka's crossbeams occur mostly in the vicinity of the bowl-shaped piling guides (Fig. 1B). Interestingly, the large schools of squarespot, speckled, and widow rockfishes do not form within the bowls, but rather behind them, where the guides meet the crossbeams.

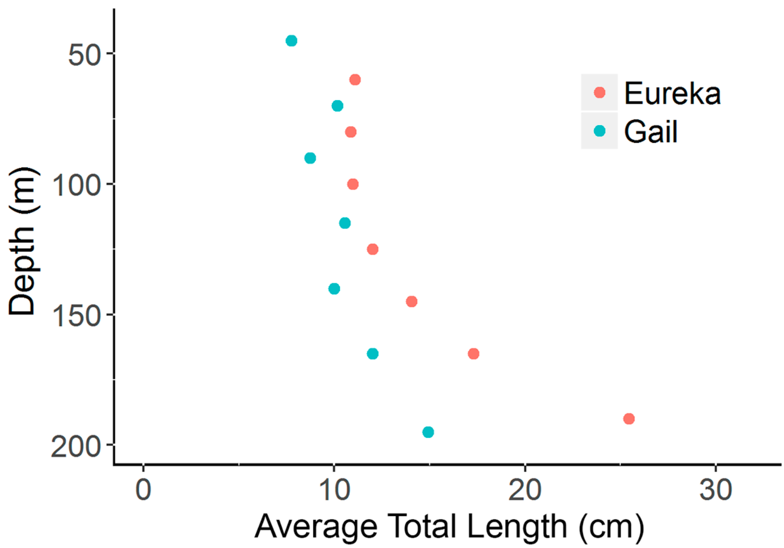

Figure 8. Average total length of all fishes observed at Eureka and Gail by crossbeam, 2005–2011.

At both platforms, the characteristic fish species we observed in the midwaters are those typical of high-relief habitats. Among these species are squarespot, bank, widow, blue, speckled, copper, pinkrose, and rosy rockfishes, bocaccio, and painted greenling (Anderson and Yoklavich 2007, Love et al. 2009, Love 2011). Conspicuously rare or absent from the midwaters of either platform, and from the midwaters of any California platform, are such species as greenstriped and stripetail rockfishes (Love et al. 2000, 2003, Nishimoto et al. 2008). These latter taxa (1) live along mud-rock interfaces, (2) inhabit comparable depths, (3) are abundant in the Southern California Bight, and (4) are found on the shell mounds surrounding some platforms (Love et al. 2000, 2009).

Ultimately, then, many of the reef fishes living in the depths studied utilized the two structures in somewhat different ways. At Gail, the crossbeams function almost strictly as a nursery area for most species with young fishes remaining in the midwaters for a few months to perhaps several years. At this time, a few species, such as bocaccio and probably flag rockfish, migrate down the jacket and take up residence at the bottom of the platform (Love et al. 2006b), while others (i.e., widow rockfish) migrate away from the structure. At Eureka, crossbeams serve both as a nursery for a range of species and then continue to serve as habitat for these fishes as they mature.

All platforms have finite economic lives and all will eventually be decommissioned. Decommissioned platforms can be totally or partially removed, or left in place (Schroeder and Love 2004). One of the issues that will likely be addressed in the decommissioning of California oil and gas platforms is the role that a platform plays as fish habitat. And, as this research demonstrates, although there may be substantial similarities among many platforms, the fish assemblages of California oil and gas platforms do not always lend themselves to generalizations. Indeed, our results highlight the need to carefully assess each platform's net environmental benefit. In

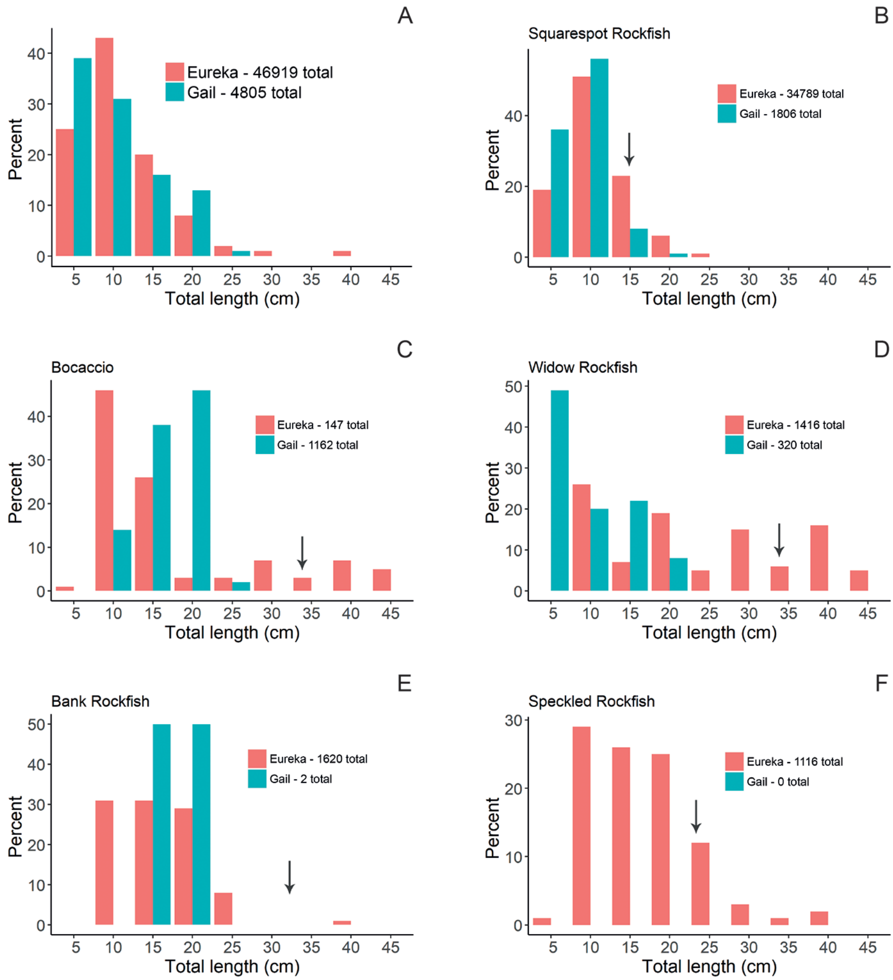

Figure 9. Size frequencies of (A) all species, (B) *Sebastes hopkinsi*, (C) *Sebastes paucispinis*, (D) *Sebastes entomelas*, (E) *Sebastes rufus*, and (F) *Sebastes ovalis* observed at the midwater crossbeams of Eureka and Gail, 2005–2011. Vertical arrows denote length at 50% maturity (Love et al. 2002, Love 2011).

addition, the present study suggests that increasing the complexity of the midwaters of decommissioned platforms will likely lead to increases in fish density and species richness.

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Literature Cited

Anderson TJ, Yoklavich MM. 2007. Multiscale habitat associations of deepwater demersal fishes off central California. Fish Bull. 105:168–179.

Caselle JE, Love MS, Fusaro C, Schroeder D. 2002. Trash or habitat? Fish assemblages on offshore oilfield seafloor debris in the Santa Barbara Channel, California. ICES J Mar Sci. 59:S258–S265. https://doi.org/10.1006/jmsc.2002.1264

Clarke KR, Somerfield PJ, Gorley RN. 2008. Testing of null hypotheses in exploratory community analyses: similarity profiles and biota-environment linkage. J Exp Mar Biol Ecol. 366:56–69. https://doi.org/10.1016/j.jembe.2008.07.009

Granneman JE, Steele MA. 2015. Effects of reef attributes on fish assemblage similarity between artificial and natural reefs. ICES J Mar Sci. 72:2385–2397. https://doi.org/10.1093/icesjms/fsv094

Hickey BM. 1993. Physical oceanography, *In:* Dailey MD, Reish DJ, Anderson JW, editors. Ecology of the Southern California Bight. University of California Press, Berkeley. p. 19–70.

Hyde JR, Kimbrell CA, Budrick JE, Lynn EA, Vetter RD. 2008. Cryptic speciation in the vermilion rockfish (*Sebastes miniatus*) and the role of bathymetry in the speciation process. Mol Ecol. 17:1122–1136. https://doi.org/10.1111/j.1365-294X.2007.03653.x

LDWF (Louisiana Department of Wildlife and Fisheries). 2017. Artificial reef program. Available from: http://www.wlf.louisiana.gov/fishing/artificial-reef-program

Laidig TE, Yoklavich MM. 2016. A comparison of density and length of Pacific groundfishes observed from 2 survey vehicles: a manned submersible and a remotely operated vehicle. Fish Bull. 114:386–396. https://doi.org/10.7755/FB.114.4.2

Laidig TE, Krigsman LM, Yoklavich MM. 2012. Reactions of fishes to two underwater survey tools, a manned submersible and a remotely operated vehicle. Fish Bull. 112:54–67.

Lecchini D, Tsuchiya M. 2008. Spatial structure of coral reef fish communities at Kudaka Island (Ryuku Archipelago), Japan. Ichthyol Res. 55:321–327. https://doi.org/10.1007/s10228-008-0039-0

Love MS, Claisse JT, Roeper A. 2019. An analysis of the fish assemblages around 23 oil and gas platforms off California with comparisons with natural habitats. Bull Mar Sci. 95(4):477–514. https://doi.org/10.5343/bms.2018.0061

Love MS. 2011. Certainly more than you want to know about the fishes of the Pacific coast. Santa Barbara, California: Really Big Press.

Love MS, Yoklavich MM. 2008. Habitat characteristics of juvenile cowcod, *Sebastes levis* (Scorpaenidae), in southern California. Environ Biol Fishes. 82:195–202. https://doi.org/10.1007/s10641-007-9290-x

Love MS, York A. 2006. The relationships between fish assemblages and the amount of bottom horizontal beam exposed at California oil platforms: fish habitat preferences at a man-made platforms and (by inference) at natural reefs. Fish Bull. 104:542–549.

Love MS, Caselle JE, Snook L. 2000. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. Fish Bull. 98:96–117.

Love MS, Schroeder DM, Nishimoto MM. 2003. The ecological role of oil and gas production platforms and natural outcrops on fishes in southern and central California; a synthesis of information. US Dep In., US Geol Survey, Biol Res Div, Seattle, WA, OCS Study MMS 2003-032.

Love MS, Yoklavich M, Schroeder DM. 2009. Demersal fish assemblages in the Southern California Bight based on visual surveys in deep water. Environ Biol Fishes. 84:55–68. https://doi.org/10.1007/s10641-008-9389-8

Love MS, Nishimoto M, Clark S, Schroeder DM. 2012. Recruitment of young-of-the-year fishes to natural and artificial offshore structure within central and southern California waters, 2008–2010. Bull Mar Sci. 88:863–882. https://doi.org/10.5343/bms.2011.1101

Love MS, Schroeder DM, Lenarz B, Cochrane GR. 2006a. Gimme shelter: the importance of crevices to some fish species inhabiting a deeper-water rocky outcrop in southern California. CCOFI Rep. 47:119–126.

Love MS, Schroeder DM, Lenarz W, MacCall A, Scarborough Bull A, Thorsteinson L. 2006b. Potential use of offshore marine structures in rebuilding an overfished rockfish species, bocaccio (*Sebastes paucispinis*). Fish Bull. 104:383–390.

Nishimoto MM, Love MS, Washburn L, Schroeder DM, Emery BM. 2008. Assessing the fate of juvenile rockfish at offshore petroleum platforms and natural reefs in the Santa Barbara Channel. MMS OCS Study 2007-008. Marine Science Institute, University of California, Santa Barbara, California. MMS Cooperative Agreement Number 1435-01-04-CA-34031.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, et al. 2017. vegan: community ecology package. R package version 2.4-3. Available from: https://CRAN.R-project.org/package=vegan

R Core Team. 2017. R: a language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. Available from: http://www.R-project.org

Schroeder DM, Love MS. 2004. Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. Ocean Coast Manage. 47:21–48. https://doi.org/10.1016/j.ocecoaman.2004.03.002

TPWD (Texas Parks and Wildlife Department). 2017. Artificial reefs. Rigs-to-reefs Texas. Available from: http://tpwd.texas.gov/landwater/water/habitats/artificial_reef/rigs-to-reefs.phtml

Whitaker D, Christman M. 2014. clustsig: significant cluster analysis. R package version 1.1. Available from: http://CRAN.R-project.org/package=clustsig

Yoklavich MM, Love MS, Forney KA. 2007. A fishery-independent assessment of an overfished rockfish stock, cowcod (*Sebastes levis*), using direct observations from an occupied submersible. Can J Fish Aquat Sci. 64:1795–1804. https://doi.org/10.1139/f07-145