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Modeling Fish Production for Southern California's Petroleum Platforms

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EDITOR'S NOTE:

This paper represents 1 of 7 articles that investigate the biological, socioeconomic, and environmental costs and benefits of the most feasible and likely options for decommissioning oil and gas platforms offshore southern California. The articles stem from an in-depth technical analysis conducted as part of a California Department of Natural Resources project that examined decommissioning options for offshore oil and gas platforms.

ABSTRACT

California's oil platforms are nearing the end of their productive lives and therefore will be decommissioned in the near future. These structures have been shown to be important habitats for both settlement and growth for reef fishes. Important information on the biological effects (i.e., loss of biomass and production) of different decommissioning options has not yet been explored in detail. An important step in the assessment of these different decommissioning options is to look at the potential loss of fish production and habitat under the different alternatives. Using the large amount of information available on fish abundances at these structures, we have created a model to estimate the standing stock of fishes and production that would be lost because of both partial (removal from surface to 85 ft) and complete removal (the 2 decommissioning options being considered). Complete removal of a platform will likely eliminate most of its fish biomass; however, this study has shown that for rockfishes, which settle predominantly below 85 feet (26 m) and move deeper as they age, partial removal through topping would leave more than 90% of the fish biomass at the deeper platforms. Modeling of larval dispersal suggests that platforms provide an important opportunity for recruitment of fish larvae and that many larvae produced near the platforms would settle elsewhere in the region. The results presented here indicate that, even if topped, the potential contribution of platform habitat to biological resources (e.g., fish production) in this region is significant. *Integr Environ Assess Manag* 2015;11:584–593. ©2015 SETAC

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Oil platforms offshore southern California support diverse biological communities that can differ from those found on natural rocky reefs (Scarborough Bull 1989; Kasprzak 1998; Carr et al. 2003; Love and York 2005; Bull et al. 2008; Martin and Lowe 2010). Understanding the similarities and differences between platform and natural reef communities and the associated contribution of platforms to the ecology of the Southern California Bight is important for evaluating the biological effects of platform decommissioning options in a regional context. Because decommissioning these platforms is an unavoidable issue that will face California's ocean managers in the near future, understanding the potential effects of the different decommissioning options on the biology of fishes living in such habitats will be important information to consider in the process (Holbrook et al. 2000; Schroeder and Love 2004; Love 2006; Bull et al. 2008; Bernstein et al. 2010).

Most of California's platforms are located in the Santa Barbara Channel (Page et al. 2008). These platforms are complex structures in water depths from 9.1 to 365 m and located from 1 to 16 km offshore (Bernstein et al. 2010). The platform jacket, horizontal crossbeams, conductors, and pilings create an intricate structure that provides a large surface area of hard substrate for sessile invertebrates (e.g., mussels) (Ponti 2002; Bram et al. 2005; Love and Schroeder 2007) as well as important habitat for fishes, including overfished species (Love et al. 2003; MBC 1987a). Most of these platforms are closed to fishing because of security regulations; so many of these areas act as "de facto" marine reserves and in some cases have become nursery grounds for overfished species such as the cowcod (*Sebastes levis*) (Love et al. 2003; Love and York 2005). Currently, 2 decommissioning options are being considered for California's platforms: complete and partial removal (Bernstein et al. 2010). Of these 2 options, only partial removal, in which the platform structure will be topped at a depth of 26 m (85 ft) below the ocean surface, would allow these de facto reefs to continue to exist. The diversity and abundance of fish species at California platforms have been extensively studied (Love et al. 2000; Love et al. 2003; Love and York 2005; Lowe et al. 2009);

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however, estimates of overall fish biomass and secondary production as well as the expected change under the 2 decommissioning scenarios are critical data necessary for analyzing the ecological role of these platforms in the region. This is an unresolved issue in evaluating decommissioning options, because how these types of structures produce fish relative to natural reefs in Southern California and how this production compares with other ecosystems worldwide are unclear. The development of a model to estimate biomass and production on California's platforms will also be helpful in the future to incorporate such metrics into the design of new structures being placed in the marine environment, such as those associated with hydrokinetic and wind energy. Finally, creating a secondary production model is important for contextualizing the ecological role of these structures in the Southern California Bight.

California platforms are characterized by 3 distinct fish assemblages: midwater, bottom, and shell mound, which are associated with these different microhabitats within the platform ecosystem (Love et al. 2000; Love et al. 2003; Love and York 2006). The midwater of platforms serves a nursery function for several fish species; young-of-the-year (YOY) rockfishes represented the most common size classes in this microhabitat (Love et al. 2003; Love and Nishimoto 2009). Adult and subadult rockfishes dominate the bottom assemblages; however, many YOY rockfishes also use the platform bottom for habitat, particularly during strong recruitment years (Love et al. 2000; Love et al. 2003). The settlement of fish larvae onto these offshore structures is related to oceanographic processes such as the location of the platform relative to prevailing currents, and seasonal processes such as El Niño (Love et al. 2003). Therefore, the recruitment of YOY rockfishes to platforms can vary dramatically from year to year (Love et al. 2007). Platform midwaters have been shown to be important nursery grounds for young rockfishes. In fact, the high vertical relief of these structures and the potential for lower mortality rates compared with low-lying natural reefs may make these structures a more optimal habitat for juvenile fishes than natural reefs (Love et al. 2003; Love 2006). Because of their depth, location, and this nursery function, the fish species composition of platform bottom habitats is typically represented by rockfishes (>90%; *Sebastes* spp.) (Love et al. 2000).

The vertical distribution of larval settlement, or recruitment, is an important factor in evaluating the impacts of the partial removal decommissioning option. Past discussions of this option have commonly assumed that the bulk of larval fish recruitment to platforms occurs in approximately the upper 10 m of the water column, and that larval settlement would therefore be significantly reduced under the partial removal option (Holbrook et al. 2000). This assumption is not borne out by recent evidence. Although Love et al. (2003) reported YOY bocaccio (*Sebastes paucispinis*) in the upper 30 m of the platform, they also confirmed (Love et al. 2006) that none of these juveniles were found above 26 m. This result was extended to all rockfish by Nishimoto et al. (2008), who confirmed that YOY rockfish are found almost exclusively below 26 m. Thus, these studies demonstrate that partial platform removal to a water depth of 85 feet (26 m) below the surface would most likely not eliminate the potential nursery function of these structures for rockfishes (Love and Nishimoto 2009).

A review of studies on platform fish biology showed that platforms both produce and attract fishes, similar to natural outcrops (Carr et al. 2003; Love et al. 2003; Fabi et al. 2004; Love et al. 2007). Fish assemblages at the deeper offshore platforms likely reflect recruitment from several maternal sources; however, these fishes are unlikely to have migrated from natural outcrops (Love et al. 2003; Lowe et al. 2009). Most fish tend to stay at platforms for extended periods (Lowe et al. 2009), with little movement, showing that these structures are good habitats that support large fish populations.

Fish assemblages on platforms differ from those on natural reefs in terms of both species composition and relative abundance (Scarborough Bull 1989; Carr et al. 2003; Fabi et al. 2004) Fishes that have a limited larval dispersal (i.e., surfperches) are usually underrepresented on platforms compared with natural reef habitats, which reflects the fact that, in general, platforms are located in deeper water and farther away from shore (or any other continuous habitat source) than are natural reefs (Love and York 2006). Most (if not all) of the pelagic juvenile larvae that are transported offshore toward a platform would undoubtedly not survive unless they came in contact with a platform; therefore, the presence of the platform is likely increasing the percentage survival of larvae and juveniles transported offshore away from another habitat source (Emery et al. 2006). The platforms' unique vertical stratification of different species of fishes and their life stages (e.g., older and larger fish tend to be found at deeper depths on platforms) indicates that partial decommissioning will alter the species abundance and overall assemblage on the platform (Carr et al. 2003). Although platforms represent a small contribution to the overall hard substratum in California (Holbrook et al. 2000), these structures may be providing a large amount of the hard substrate below a depth of 50 m (Bull et al. 2008). Therefore, deeper-water platforms may provide considerable hard substrate in the soft-bottom outer shelf regions in which they occur (Bernstein et al. 2010).

California platform fish assemblages resemble those found on natural reefs nearby; likely both assemblages reflect recruitment of larval and pelagic juvenile fishes from both near and distant maternal sources (Love et al. 2003; Bull et al. 2008). These structures have been demonstrated to be important to regional fish production; the higher densities and larger individuals of several fish species found on these structures support the hypothesis that these structures are acting as "de facto" marine reserves.

The amount of connectivity in larval dispersal between 2 hard substrate areas that are separated in many cases by kilometers of soft-bottom habitat (e.g., an offshore platform and natural reef nearby) is a difficult parameter to assess. In addition, YOY fish recruitment to both platforms and natural reefs varies greatly from year to year (Love et al. 2007). Because in many cases platform midwaters support a higher density of YOY rockfishes than nearby natural reefs (Love et al. 2000; Carr et al. 2003; Love et al. 2003; Love 2006), likely a platform's structural complexity and high vertical profile provide juvenile pelagic rockfishes (and larvae of other species) with a strong stimulus to trigger settlement (Carr et al. 2003). Thus, the combination of this settlement queue with the current structure and the opportunistic placement of the structures, which facilitates the attraction and retention of fish larvae (Emery et al. 2006), results in a nursery area function for these platforms.

Because California's platforms are scheduled for decommissioning in the near future, and partial removal (topping) is 1 of the decommissioning options under consideration, a model for estimating biological loss (of fishes) after these decommissioning activities is needed to contextualize these options. This model will be useful in comparing the 2 decommissioning options in terms of loss of habitat, in particular, evaluating the "rigs-to-reefs" option of partial decommissioning. In the case of partial decommissioning, one can look at estimates of biomass saved by topping versus complete removal. This model also can be adapted and applied to other assessments of production on other artificial reefs, especially with regard to new technologies and structures being considered around the world for alternative energy sources (i.e., hydrokinetic and wind energy structures). Furthermore, expanding our knowledge of biological metrics (standing stocks, connectivity, and production) will provide an important context for not only the decommissioning options, but also the role and contribution these structures play in the Southern California Bight. Herein, we make an assessment of the biomass, fish production, and potential connectivity of these platforms under the various decommissioning scenarios.

METHODOLOGY

A biological model has been developed to determine the standing stock and production of fishes based on empirical studies of California platforms. This model starts with the current standing stock defined as the total biomass (B) of each species per platform. It then calculates the future production and standing stocks based on various platform-decommissioning options. Data used in this model were collected during scientific submersible surveys in which observers recorded the frequency and size class of all fishes (total length [TL]) along fixed transect lengths based on the dimensions of the platform (Love et al. 2003; Love et al. 2008). To calculate fish density, the number of individuals encountered (frequency) on a transect was divided by the surface area of the transect. The transect surface area was defined as the length of the transect (which is a function of the platform dimension) times the width (2 m), which gives a density estimate (no. of fishes/m^2). However, to estimate the standing stock, the amount of biomass on each platform, all of the length (TL) estimates were transformed to weight in grams, using a weight–length conversion equation of the form:

$$g = a\mathrm{TL}^b$$

where:

1. g = grams
2. TL = Total Length in millimeters
3. a and b are species-specific coefficients of the power function

For some species only standard length (SL)-to-weight conversion equations were available. In these cases, TL was converted to SL using the linear function:

$$\mathrm{SL} = (\mathrm{TL} - B')/A'$$

A' and B' are species-specific coefficients of the linear conversion between length measures. Length–weight conversion equations were obtained from RecFin (www.recfin.org), from the literature, or generated from Vantuna Research Group unpublished data sets. For fishes or larger taxonomic groups without known conversion parameters, the most similar trophic and taxonomic species were used. All conversion equations were tested for accuracy by using known lengths and weights of fishes overlain on the power equation plots.

Mean biomass density was then calculated by averaging over all transects and years completed on each platform for each stratum. In this model, there were three depth strata used in the stock estimates. The bottom stratum was defined as the lowest 2 m of a platform and is a significant biological area that houses the adult rockfishes for most platforms (Love et al. 2000; Milton Love, University of California, Santa Barbara, personal communication 2009). The middle region (midwater) was from 2 m off the bottom to 26 m from the surface, which was defined as such because 26 m (85 ft) is the proposed topping depth for the partial decommissioning option (Bernstein et al. 2010). The upper region is the section of the platform that will be removed if it is topped (from 26 m to the surface). To calculate the total biomass for each stratum, the biomass (g) per transect area (m^2) for each species by transect was calculated for overall study periods (g/m^2). The mean biomass density per stratum and species were then calculated. These biomass density estimates were then scaled to the surface area of each depth stratum to calculate the standing stock (MBC 1987b).

For Platform Holly, no surface area estimates were available; thus, the surface area estimate for Platform C (a platform in a similar depth and geographic location) was used, adjusted for depth. The total biomass (B) for the platform then can be calculated from 3 depth strata: bottom (B_b), middle (B_m), and upper (B_u). Thus, total biomass for a platform follows:

$$B = B_\mathrm{b} + B_\mathrm{m} + B_\mathrm{u}$$

Complete removal is the loss of B. For topping and removal, the adjusted stock will be:

$$B_\mathrm{adj} = B_\mathrm{b} + B_\mathrm{m}$$

Production is the change in biomass (B) over time (t) (Clarke et al. 1946). When production is positive, this is referred to as the yield (Y) (Ricker 1975) such that:

$$Y = \Delta B/t$$

Because most of the platforms are typically surveyed annually in the fall, and the calculated production rates were from the empirical data, we used annual rates ($t = 1$) for the model. The output of the model is $\mathrm{g{\cdot}m^{-2}{\cdot}y^{-1}}$. The total yield ($Y$) is a function of 2 factors: the standing stock biomass (B) plus the surplus production (Y'). Surplus production is the annual growth (G) in the adult stock (i.e., gonadal and somatic growth) plus recruitment (R), such that for any production component:

$$Y = B + Y' \text{ and } Y' = \mathrm{G} + R$$

Only somatic growth was used to estimate G, and estimates of fecundity were not used because they were generally unavailable. The standing stock biomass (B) is also a factor of immigration (z) and emigration (y) rates, instantaneous natural mortality (M), and instantaneous fishing mortality (F). Fishing mortality was considered negligible, because most platforms are currently acting as de facto closures due to security. No current estimates of z and y are available, and these values were set as equal. To calculate the somatic growth (G) over time, the model began with the mean total length (TL) of each fish species and the total biomass per platform by stratum generated from the empirical data sets. This length was used to calculate the starting age (t_0) for the model run using the von Bertalanfy growth equation:

$$L_t = L_\infty \left(1 - e^{-k(t-to)}\right)$$

and the corresponding length at the end of the time period (t)

Where L_t = length at time t; L_∞ = theoretical maximum length; k = constant expressing the rate of approach to L_∞; and, t_o = theoretical age at which $L_t = 0$. In a few instances, $L_t > L_\infty$, causing a negative value for L_∞-L_t, and in these instances L_∞ was adjusted to the maximum reported size (Table 1). These length estimates were then transformed to a weight estimate by using the species-specific length–weight equations. All modeling life history input parameters are in Bernstein et al. (2010). Biomass increase was calculated from the percentage increase in weight for each period. This percentage increase was then used to adjust the stock estimate (B) over time.

Table 1. Starting total stock estimates (B), growth of stock over 5-year period (G_1-G_5), somatic growth (Y'), recruitment biomass (R_0) and recruitment growth ($R_{1\text{-}5}$), and production (Y) for each platform ($n = 8$) in kilograms

Stock	B	G_1	G_2	G_3	G_4	G_5
ELLEN	6843	2843	3260	3468	3508	3420
EUREKA	8297	2976	3211	3275	3208	3054
GAIL	1030	464	547	594	612	609
GILDA	386	182	203	209	204	193
GRACE	3208	1691	2119	2402	2542	2559
HIDALGO	354	179	215	223	211	189
HOLLY	4360	3338	3564	2411	1365	783
IRENE	942	552	687	764	789	774
Recruitment	R_0	R_1	R_2	R_3	R_4	R_5
ELLEN	32	17	36	52	66	76
EUREKA	161	87	185	264	333	387
GAIL	158	86	182	260	328	381
GILDA	21	11	24	34	43	50
GRACE	33	18	38	54	68	80
HIDALGO	99	54	114	162	204	238
HOLLY	23	12	26	38	47	55
IRENE	16	9	19	27	33	39
Production (Y)	$B + R$	Y'_1	Y'_2	Y'_3	Y'_4	Y'_5
ELLEN	6875	2860	3297	3520	3574	3496
EUREKA	8458	3063	3396	3539	3541	3441
GAIL	1188	550	729	855	940	990
GILDA	407	194	227	243	247	243
GRACE	3241	1709	2158	2457	2611	2639
HIDALGO	453	233	328	385	416	427
HOLLY	4383	3351	3590	2448	1413	839
IRENE	958	561	705	790	823	813

Although some natural mortality rates can be found in the literature, they are generally not size-based as is this model. Annual natural mortality $M(w)$ was estimated by using a size-dependent predation-based mortality rate (Peterson and Wroblewski 1984):

$$M(w) = ckw^{-x}$$

Where $M(w)$ was the annual expectation of death caused by predation; c (1.22) is a constant based on the predator–prey size ratio; k (0.14) is growth efficiency; w is the dry weight of the fish estimated from a wet weight ratio of 0.2; x (0.25) is the weight exponent accounting for growth and metabolic rate. The annual mortality rate was used to adjust the stock size at the beginning of the yearly period (as opposed to the end) before the estimate of somatic growth.

For the production model, recruitment data needed to have specific parameters, depth and density. Data for recruitment (R) were obtained for YOY bocaccio (*Sebastes paucispinis*) (Love 2006), where recruit density and depth were reported (Fig. 1). The shallowest density reported for YOY bocaccio in this study was at 26 m. Whereas most YOY bocaccio recruited to the middle strata and some were present at the platform bases, all bocaccio recruited to a depth of 26 m or greater (Love 2006). Those reported at 26 m were included in the upper strata (to be conservative). The grand mean YOY bocaccio density was calculated at all 3 depth strata as the overall average of the reported density values. These were: upper strata, 80.5/100 m^2; middle strata, 56.5/100 m^2; and the bottom strata, 61.8/100 m^2. In the upper strata, the density estimate was applied to only the bottom 2 m for the recruitment biomass estimate to avoid overestimating the total contribution of the strata. Because YOY bocaccio were only observed in the upper strata at platforms Grace and Gilda in the empirical surveys (Love 2006), the recruitment rate at the upper strata for the other platforms was also assumed to be 0. A single-year class was run through the model beginning at t_0. No other fishes were added to the recruitment component of the production model. The recruitment module followed the overall platform module with a starting size class of 75 mm TL.

Eight platforms (Ellen, Eureka, Gail, Gilda, Grace, Hidalgo, Holly, and Irene) were used in the final model. These were well-studied platforms in terms of numbers of replicates per strata and years surveyed (Love et al. 2003). In addition, these platforms had a broad representation of the various depths,

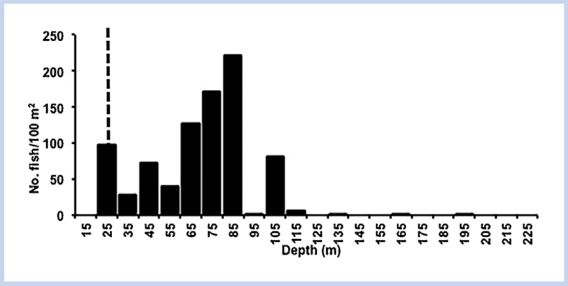

Figure 1. The mean YOY bocaccio (*Sebastes paucispinis*) density (/100 m^2) with depth. The black hatched line indicates the cutoff depth for the partial removal option (85 ft depth to surface).

biogeographic zones, and locations on the continental shelf, slope, or basin (Fig. 2). For Platforms Hidalgo and Irene, upper-strata data from Platform Harvest were used. Total production Y' was calculated as the sum of somatic growth (G) adjusted for mortality (M) and recruitment (R) and adjusted growth of the bocaccio cohort. The model was run for 5 y.

A modeling tool was adapted from the Regional Oceanic Modeling System model, which was used to determine the probability of larval connectivity throughout the Southern California Bight. The model was originally based on estimates of larval production of adult fishes along the coastline derived from CDFG's Cooperative Research and Assessment of Nearshore Ecosystems (Tenera 2006) data and other information on spawning period and pelagic larval duration (PLD). Patterns of potential larval connectivity (Figure 3) were created by simulating millions of water parcel trajectories within a numerical solution of the 4-dimensional circulation of the Southern California Bight (Mitarai et al. 2009, Watson et al. 2010). The numerical ocean circulation model solutions were used to advect passive particles, simulating individual larvae. The ocean model is nested within a larger domain and is forced at the boundaries (top and side) by observations (Dong and McWilliams 2007). The inner nested model's spatial and temporal resolutions are 1 km and 6 h, respectively, and model output is available for the years 1996 to 2003. The model has been validated by using a great number of available data sets (e.g., high-frequency radar data, current meters, current profilers, hydrographic measurements, tide gauges, drifters, and altimeters) and has performed very well (Dong and McWilliams 2007). Trajectories and Lagrangian probability distributions are calculated by following methods presented in Mitarai et al. (2009).

To simulate potential larval connectivity for 2 model species, kelp bass (*Paralabrax clathratus*) and kelp rockfish (*Sebastes atrovirens*), trajectories for the appropriate spawning season and pelagic larval duration were used. Kelp bass typically spawn from June to October and with a PLD of approximately 30 d. Kelp rockfish typically spawn from February to June and have a PLD of approximately 60 d. Particles in this model were released from 10 km diameter patches, which contain the platforms of interest (i.e., Platform Holly is found in patch 51, Platform Habitat is in patch 47, and Platforms Eureka and Emmy are in patch 23). The resulting plots (Figure 3) show the degree of connectivity of patches containing the platforms of interest and patches throughout the Southern California Bight.

RESULTS AND DISCUSSION

The standing stocks (B) at the beginning of the model run (t_0 and mean TL), somatic growth (G), recruitment biomass (R_0), and recruitment growth ($R_{1\text{-}5}$) and production (Y) are presented in Table 1. These biomass estimates were verified by comparison with previous estimates from the same platforms (Love et al. 2000, bottom strata only). Stock estimates for the 8 platforms varied from 354 to 8297 kg per platform (Table 1, Figure 4). The platforms off Orange County, Eureka and Ellen, had the highest standing stocks, which were fairly comparable despite the variation in depth (Eureka = 212 m, Ellen = 80 m). Both of these platforms had high biomass densities of widow rockfish (*Sebastes entomelas*), squarespot rockfish (*S. hopkinsi*), and blacksmith (*Chromis punctipinnis*). Of the Santa Barbara Channel platforms, Holly and Grace had the highest biomass. Widow rockfish and bocaccio had the highest biomass estimates at these platforms. Somatic growth varied primarily as a factor of the standing stock (Table 1). Because the bocaccio

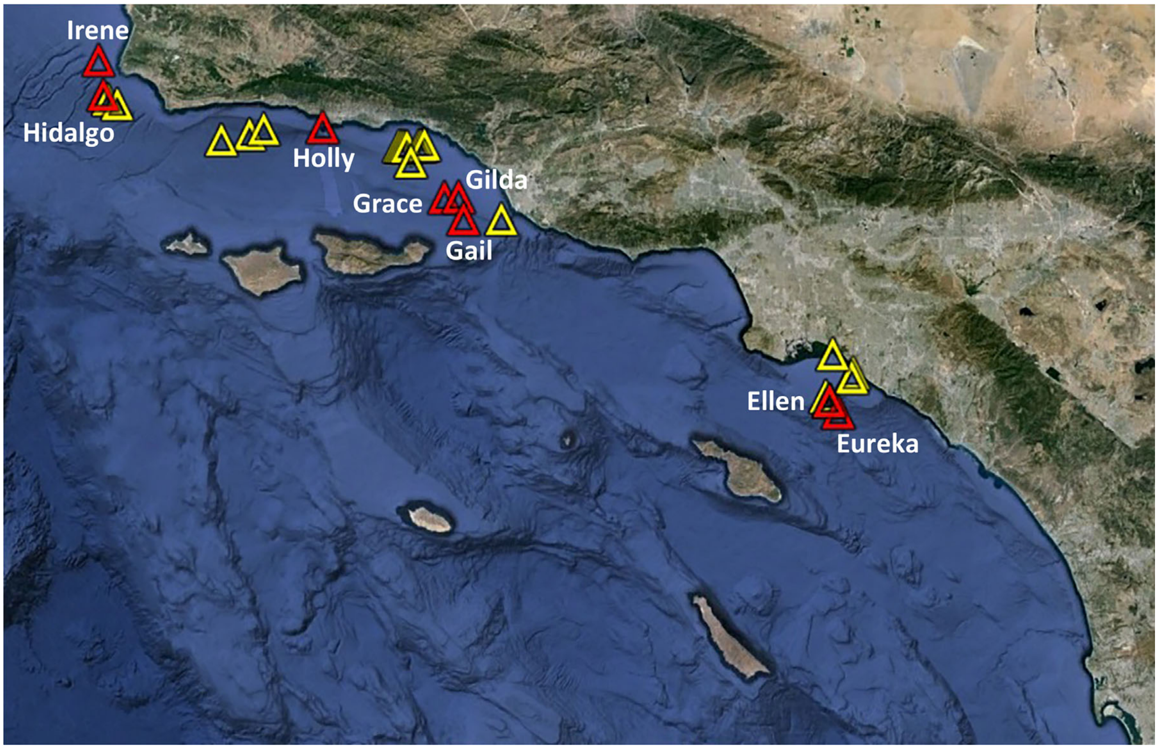

Figure 2. Locations of all offshore platforms in southern California, with the platforms used in this model labeled with platform names and highlighted in red.

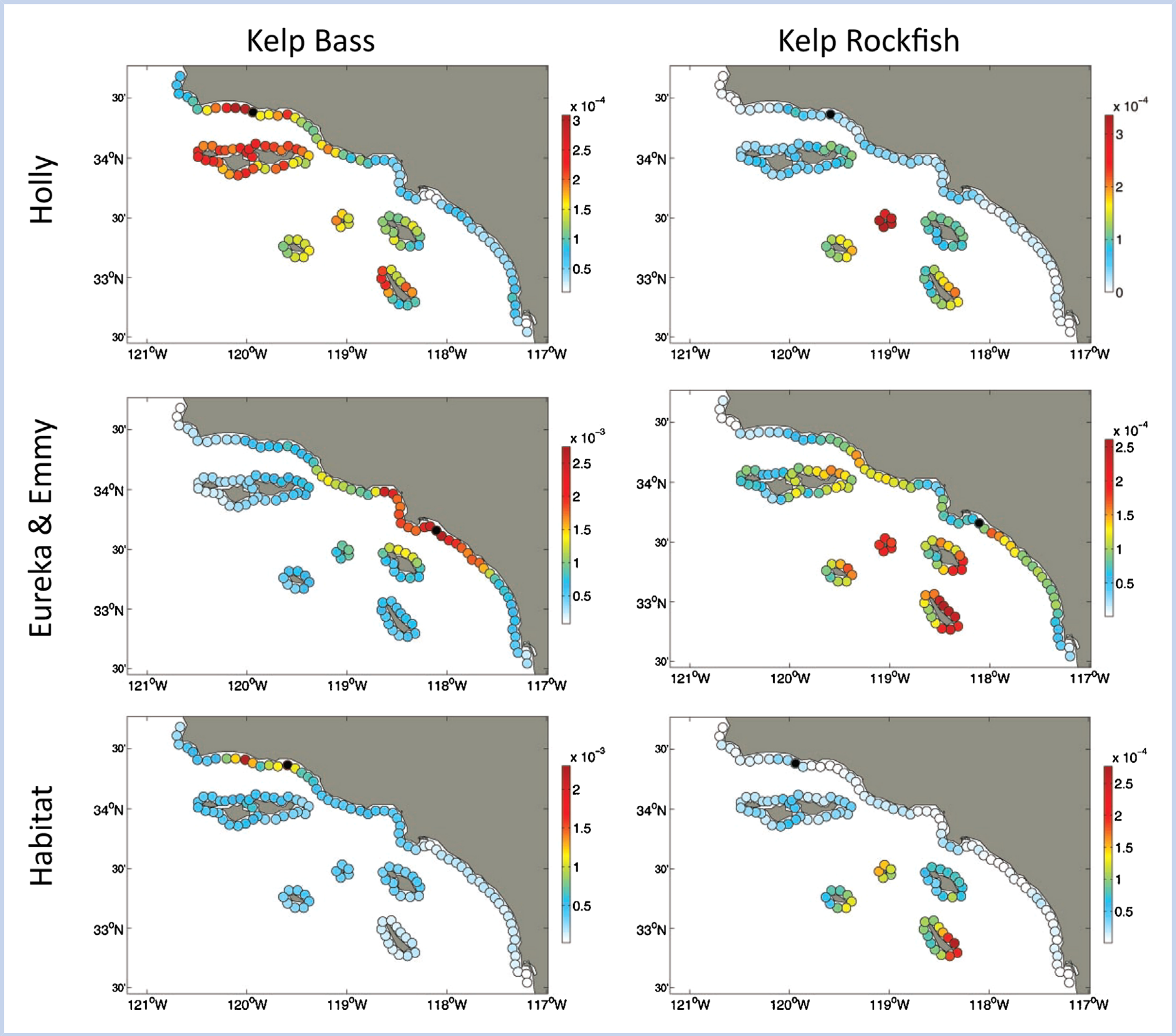

Figure 3. Potential connectivity patterns for kelp bass and kelp rockfish larvae released from the simulation patches containing platforms Holly, Habitat, and Eureka and Emmy. The black patch on each plot is the nearest simulation patch to the oil drilling rigs. Values of potential connectivity quantify the probability (color corresponds to the probability) that larvae from the source patch are advected to other sites within the Southern California Bight given the spawning season for the organism (kelp bass = Jun–Oct; kelp rockfish = Feb–Jun) and its pelagic larval duration (kelp bass = 30 d; kelp rockfish = 60 d). Results follow work by Watson et al. 2010.

recruitment pulse was set primarily as a factor of surface area, its effect was inversely related to biomass. At Platform Hidalgo, it accounted for 30% of the yield after the first year, and 19% of the first year's yield at Platform Gail. The adjusted stocks (B_{adj}, Figure 4), bocaccio recruitment estimates (R and R_{adj}, Figure 5), and production estimates (Y' and Y'_{adj}) are presented in Table 2.

Under the complete removal option, the simplest scenario is to apply 100% mortality to the standing stocks of fishes (Table 1) and invertebrates. Although this could be mitigated

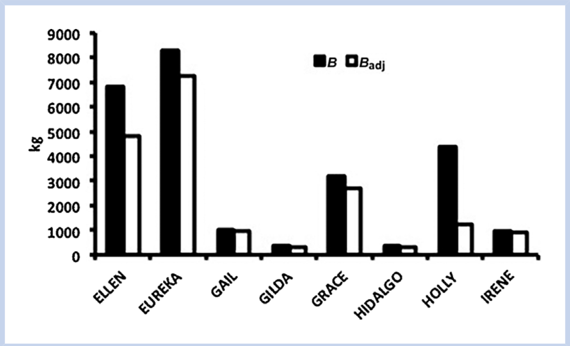

Figure 4. Standing stocks (B) and the adjusted standing stock (B_{adj}) under the topping option at 8 Southern California oil platforms.

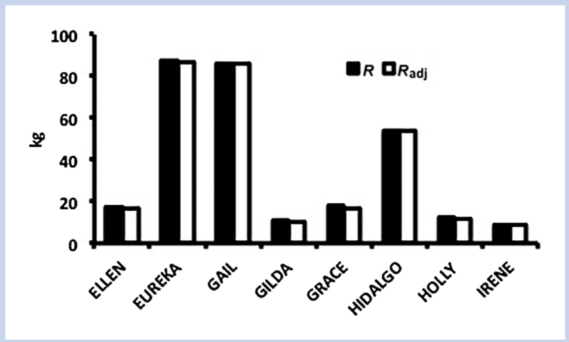

Figure 5. Bocaccio recruitment estimates (R), and adjusted recruitment (R_{adj}) under the topping option at the end of year 1 for each platform in kilograms.

Table 2. Starting total stock estimates (B_{adj}), somatic growth (G_{adj}), recruitment biomass (R_{adj}) and recruitment growth ($R_{adj1\text{-}5}$) and production (Y') for each platform in kilograms for eight topped southern California platforms

Stock	B_{adj}	$G_{adj(1)}$	$G_{adj(2)}$	$G_{adj(3)}$	$G_{adj(4)}$	$G_{adj(5)}$
ELLEN	4799	2140	2413	2537	2533	2432
EUREKA	7269	2533	2713	2745	2668	2518
GAIL	974	432	508	550	565	561
GILDA	321	156	175	183	180	172
GRACE	2712	1518	1901	2147	2260	2261
HIDALGO	327	170	205	214	204	184
HOLLY	1232	760	816	640	471	368
IRENE	920	545	679	757	784	770
Recruitment	$R_{adj(0)}$	$R_{adj(1)}$	$R_{adj(2)}$	$R_{adj(3)}$	$R_{adj(4)}$	$R_{adj(5)}$
ELLEN	32	17	36	52	66	76
EUREKA	161	87	185	264	333	387
GAIL	158	86	182	260	328	381
GILDA	19	10	22	31	40	46
GRACE	32	17	37	52	66	76
HIDALGO	99	54	114	162	204	238
HOLLY	23	12	26	38	47	55
IRENE	16	9	19	27	33	39
Production (Y)	$B_{adj} + R_{adj}$	$Y'_{adj(1)}$	$Y'_{adj(2)}$	$Y'_{adj(3)}$	$Y'_{adj(4)}$	$Y'_{adj(5)}$
ELLEN	4831	2157	2450	2589	2599	2509
EUREKA	7430	2620	2898	3010	3000	2905
GAIL	1133	518	690	811	893	942
GILDA	340	166	197	214	220	218
GRACE	2744	1536	1937	2199	2326	2337
HIDALGO	425	223	319	377	409	421
HOLLY	1255	773	842	677	518	423
IRENE	937	554	698	784	817	809

depending on the engineering solutions used to remove the platforms for fishes, in the worst-case scenario, which involves using explosives to topple the platform, assuming very high mortality is realistic. No studies have been done of the effects of explosives on Southern California fishes. However, physoclistous fishes (i.e., rockfishes) will suffer severe trauma or death. Additionally, if fishes successfully emigrated from a decommissioning site, they would then be subjected to the fishing mortality that is present throughout the Southern California Bight. The long-term prognosis for a complete removal option is a total loss of the standing stocks.

Under the topping scenario, the fishes of the upper (<26 m) level of the platforms were considered lost. Because the platforms would likely be cut, these fishes would undoubtedly move away from the deconstruction activity and would not likely be killed. However, to be conservative, fishes above the 26-m isobath were considered lost. The loss of standing stock because of topping was not uniform among the 8 platforms (Figure 4). For instance, a much greater effect was seen at Platform Holly versus Platform Irene. For most platforms, no effect of topping on recruitment was found. A 7.3% reduction at Platform Gilda and 3.9% reduction at Platform Grace (Figure 4) were seen. Most of the recruitment of rockfishes is below 26 m (Love et al. 2008; Nishimoto et al. 2008), and topping would have virtually no effect. Variable responses also were seen to the adjusted production estimates (Y'_{adj}) among the platforms (Figure 6). Platform Holly exhibited a 72.2% reduction in yield, and Irene had a 0.9% reduction in yield.

The results of the larval connectivity modeling runs demonstrate potential regional connectivity via larvae produced at platforms dispersing to both the mainland and islands. These dispersal and recruitment patterns are likely dependent

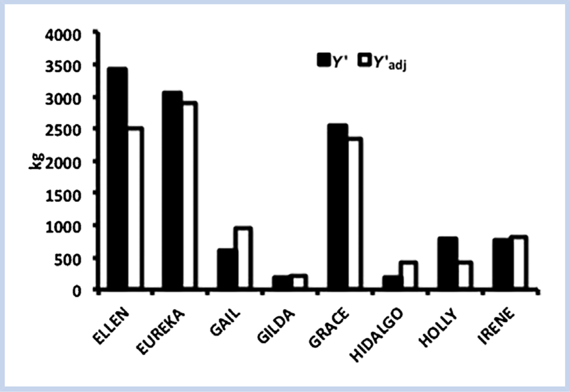

Figure 6. Mean yield (Y') and adjusted yield (Y'_{adj}) under the topping option at the end for each platform in kilograms.

on location and species. For instance, model runs of kelp bass recruitment (Figure 3) suggest that larvae released from platforms Habitat, Emmy, and Eureka recruit primarily on the mainland, whereas larvae released from Holly likely recruit heavily at the Channel Islands. Kelp bass and kelp rockfish in all 3 simulations have very different results, indicating large variation in recruitment patterns. Kelp rockfish in all 3 simulations (Figure 3) recruit heavily at the Channel Islands, especially Santa Barbara Island, San Clemente Island, and Santa Catalina Island, a pattern that differs significantly from that displayed by kelp bass.

Other decommissioning options that have been described include enhancement with quarry rock or concrete or placing the toppling structure on the bottom (Love et al. 2003; Schroeder and Love 2004). Toppling the structure and placing the top portion on the bottom is not currently being considered as a decommissioning option; however, this could be a viable consideration. No empirical data are available from the southern California arena applicable to these options (i.e., this has never been done), but it has been done in the Gulf of Mexico and east coast of Florida (Scarborough Bull 1993; Gregg Gitschlag, Galveston Laboratory, NMFS, personal communication, 2009). If a topped structure was placed on the bottom proximate to the current structure, production rates may be similar to the current platform adjusted for the missing depth strata, with some caveats. A critical consideration would be the final orientation of the crossbeams relative to the bottom, because this greatly influences the performance of these strata (Love and York 2006). This concern could be greatly mitigated by the addition of reef material. In such a scenario, the bottom 2-m niche that these large fishes prefer would be augmented significantly. Recruitment to these structures would be lower than the topped platforms. If they were placed proximate to the current structures, then possibly YOY fishes would eventually populate the new structure as they matured.

Quarry rock and concrete have been used successfully in reefing projects in Southern California since the early 1960s (Carlisle et al. 1964). Recently, concrete and quarry manmade reefs have been examined in side-by-side comparisons (Pondella et al. 2006; Reed et al. 2006), and in both cases these reefs were similar in fish composition. Either type of material would be successful in enhancing these structures. Considerations for such enhancement strategies would need to include sediment characterization in slope and basin environment (at a minimum), because enhancement structures may sink in the mud or clay bottoms.

Calculations of potential larval connectivity presented here are useful for examining the behavior of larvae whose transport is dominated by near-surface and near-coastal currents. However, many platforms and species of interest are in offshore waters; spawning may occur at depths greater than 100 m, and recruitment (particularly for rockfish) occurs below 26 m in depth. As a result, the surface water particle analysis described here would not be valid for these locations and species, a limitation especially important for deep-living rockfishes. A similar targeted analysis can easily be conducted for these species, for which data requirements would be spawning season, location and depth, pelagic larval duration, and settlement depth. Probability distributions of larval recruitment could then be calculated to indicate where larvae spawned by these deep living species would be transported. This model can readily be adapted for all platforms and various spawning depths, and this capability would prove extremely useful for future decommissioning analyses.

A long-term concern about artificial structures involves the belief that they were only fish-attracting devices. This is a widely used role for artificial structures throughout the world as opposed to production reefs—the attraction versus production controversy (Osenberg et al. 2002). The crux of this debate stems from the theoretical and experimental difficulty of demonstrating that reefs are truly producing biomass (Pondella et al. 2002). This becomes problematic when these structures act only as fish attracting devices, because when used as a fishing destination, they will then actually decrease the nearshore resources. Two studies were able to document the production of fishes on artificial reefs in southern California. The first was a 3-decade comparison of the King Harbor, Redondo Beach breakwater, and the nearby natural reef on the Palos Verdes Peninsula. Surfperches were produced at a greater density and biomass on the artificial structure (Pondella et al. 2002). Later, the US Navy, the Unified Port of San Diego, and the National Marine Fisheries Service created 4 fisheries production reefs in San Diego Bay. These reefs were placed contiguous with an eelgrass restoration site. After a 5-year experimental study, kelp bass (*Paralabrax clathratus)* and barred sand bass (*P. nebulifer*) were produced by these fishery enhancement reefs (Pondella et al. 2005). At these platforms, the evidence indicates that fish larvae that would otherwise be lost are attracted and then grow to adults, resulting in an overall increase in fish production.

At the time of this study, no fish biomass estimates existed of California platforms. One previous study estimated fish biomass on platforms in the Adriatic Sea (Fabi et al. 2004). Using a trammel net, the authors found that platforms in this region had higher fish biomass and abundance than did natural reefs nearby. A greater fish aggregation effect on larger and farther offshore (deeper water) platforms was found than on platforms closer to shore, supporting their ability to act as artificial reefs in the region. These findings are consistent with the processes we have described in this paper.

The other major focus in the design of artificial reefs in our arena has been giant kelp *(Macrocystis pyrifera)* production. Giant kelp is a key habitat-forming algae in California. The necessity of this kelp research was because of mitigation for the loss of kelp bed resources associated with the San Onofre Nuclear Generating Station (Deysher et al. 2002). Attempts to grow kelp during this decade were focused on the construction of quarry rock reefs of the San Diego coastline, which were not successful and sparked a large experimental design along the San Clemente coastline (Reed et al. 2006) and the recently created Wheeler North Reef, which was finished in 2010. Two major bottlenecks occur concerning the public's view of artificial reefs. The first is that they are just trash being dumped into the ocean. Re-energizing this perception is the recently sunk Yukon, a 366′ destroyer, off Mission Bay, San Diego, California in July 2000. This ship was sunk to stimulate the scuba diving industry, but it was not designed as a production reef. The second perceptual problem is that they merely facilitate the extractive sport fisheries. Although both policy and technology have allowed the resource community the tools to deal with these issues, these perceptions remain in the public's eye. Herein, we presented evidence that manmade structures, when properly designed, can be productive features in the Southern California Bight.

CONCLUSIONS

Results of this study indicate significant growth and biomass of fishes on southern California platforms. The structure of California's platforms includes microhabitats for both settlement and growth for reef fishes. Rockfish settle predominantly below 85 feet (26 m) and move deeper as they age. Thus, because 85 feet is the depth at which the platform would be cut off under the partial removal option, partial platform removal would not eliminate the platforms' potential nursery function (Love et al. 2000; Love et al. 2003; Love 2006). This is important information moving forward in analyzing these decommissioning options as we move closer to the ends of the finite lives of these California platforms (current planned estimates are that decommissioning will start sometime between 2015 and 2017). Complete removal of these structures will undoubtedly remove all of the previous biogenic habitat (and therefore associated communities of fishes and invertebrates) created by these structures; however, for some California platforms, partial removal of these structures through topping (to 85 ft) will leave much of the fish biomass and potential for future recruitment to these structures (Figures 4–6).

Modeling of larval dispersal suggests that platforms provide an important opportunity for recruitment of fish larvae, which get entrained in the Santa Barbara Channel because of the current structure of the region (Emery et al. 2006). In addition to this nursery function, we have demonstrated that many larvae created on the platforms would settle elsewhere in the Bight. Therefore, calculations of potential larval connectivity presented here could prove useful in future analyses and production estimates for these platforms as they are decommissioned. Because of the rarity of deep rock habitat in the Bight, these platforms may provide a large percentage of such habitat to federally protected and overfished species such as cowcod (*Sebastes levis*) and bocaccio (*Sebastes paucispinis*), which prefer such habitats (Love 2006; Bull et al. 2008). Data gaps prevent more quantitative comparisons of platform production with that in other ecosystems in Southern California; however, results presented in this study indicate that the potential contribution of platform habitat to biological resources in this region may be significant.

In addition to providing new biological metrics, we were specifically tasked with creating a model that could output data to be used in a complex decommissioning scenario. The resulting production model achieves this objective by providing a link between various stock assessment scenarios and socioeconomic data. In a simple socioeconomic scenario, annual biomass outputs (production) could be translated to economic value from a fishery perspective. This study begins to provide a template for understanding the role that current and future potential offshore structures play in their respective ecosystems. Somatic production and the fate of larvae produced at these platforms varied appreciably, demonstrating that understanding their contributions in a regional context expanding on previous research is important. This new modeling also may facilitate future comparisons among various natural and manmade habitats, because this production model can be applied to any well-studied marine ecosystem. In the case of the partial removal decommissioning option, in many cases a large percentage of the fish biomass present on the platform can be preserved, whereas with complete removal, all of the contribution of biological resources provided by California oil platforms would be lost. Clearly these Southern California platforms are very productive (Claisse et al. 2014), and insights into the mechanisms supporting this production hopefully will inform this decommissioning process and also the assessment and development of other offshore projects.

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