Pacific Outer Continental Shelf Region

OCS Study
BOEM 2014-030

BIOLOGICAL PRODUCTIVITY OF FISH ASSOCIATED WITH OFFSHORE OIL AND GAS STRUCTURES ON THE PACIFIC OCS

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TECHNICAL SUMMARY

Study Title: Biological productivity of fish associated with offshore oil and gas structures on the Pacific OCS

Report Title: Biological productivity of fish associated with offshore oil and gas structures on the Pacific OCS

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Key Words: oil platforms, platforms, California, rockfishes, *Sebastes*, ecological performance, decommissioning, platform decommissioning, bocaccio, *Sebastes paucispinis*, Secondary production, ecosystem services, ecosystem-based management, artificial reef, essential fish habitat

Background and Objectives:

Understanding the similarities and differences in the biological characteristics of the fish communities associated with manmade structures and natural reef habitats in the Southern California Bight is important to evaluating the potential biological effects of oil and gas platform decommissioning options. Since decommissioning these platforms is an unavoidable issue that will face California's ocean managers in the near future, understanding the environmental consequences of the two decommissioning alternatives being considered in this region, partial and complete removal, on local and regional fish populations will be important information to consider.

Secondary production is the formation of new animal biomass from growth for all individuals in a given area during some period of time. It can be a powerful tool for evaluating ecosystem function since it incorporates multiple characteristics of a population or community of organisms such as density, body size, growth and survivorship into a single metric. Recent studies have extended this idea, using secondary fish production to provide a measure of the productive capacity and economic value of specific habitats within an ecosystem. A main unresolved issue is the degree to which artificial reef structures like oil and gas platforms enhance ecosystem function, and in particular secondary fish production, compared to nearby natural reefs.

There are two main goals of this research. The first is to determine the patterns of standing stock (fish biomass) and production at platforms throughout southern California and compare these metrics to natural reefs in the region and to published estimates of production from other marine ecosystems. The second is to estimate the amount of fish biomass and production that will be retained after partial removal and for fish communities that reside on the shell mound habitats which surround some of these platforms.

Description:

The goals for this study were addressed in two chapters.

***Chapter One*: Oil platforms off California are the most productive marine fish habitats globally**

In this chapter we compare the density, biomass and annual secondary production of fish communities on 16 oil and gas platforms to those on 7 natural reefs off the coast of southern California and to secondary production estimates of fish communities from other marine ecosystems. To calculate the annual secondary production for a fish community we developed a model based on previously collected fisheries-independent density and size structure data of fishes from visual surveys performed from a manned submersible once per year for between 5 and 15 years at each site.

***Chapter Two*: The impact of partial removal of southern California oil and gas platforms on the associated fish biomass and production**

In the second chapter we evaluate the potential effects of partial removal on the biomass and production of the fish communities on 16 platforms off of the coast of southern California. We first calculate (1) the overall biomass (kg) and (2) production (kg/yr) for each complete platform. We then predict the percentage of each that will remain after partial removal by removing the habitat structure and the associated fishes from water surface to 26 m depth from the model. The fish biomass and production is also calculated separately for the shell mound habitats which surround some of these platforms. This is done to evaluate additional potential impacts associated with a reduction in these habitats after partial removal since the shells which create the mounds primarily originate from the shallow portion of the platforms that would be removed. Results are then discussed in the context of what is known about the depth ranges of different fish species found on the platforms across this biographic region and the potential impacts of partial removal on fish recruitment.

Significant Results:

***Chapter 1*:** We found that oil and gas platforms off the coast of California have the highest secondary fish production of any marine habitat that has been studied, about an order of magnitude higher than fish communities from other marine ecosystems. Previous estimates have come mainly from estuarine environments, generally regarded as one of the most productive ecosystems globally. High rates of fish production on these platforms ultimately results from high levels of larval and pelagic juvenile fish settlement and subsequent growth of primarily rockfishes (genus *Sebastes*) to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column.

***Chapter 2*:** On 15 out of the 16 platforms in this study, at least 78.0% of fish biomass and 78.2% of secondary fish production would be retained after partial removal, with above 90% retention expected for both metrics on many platforms. We also found that shell mounds are moderately productive fish habitats (range: 0.8 to 68 $g/m^2/yr$), with many similar to or greater than natural rocky reefs in the region (range: 4.4 to 22.4 $g/m^2/yr$).

STUDY PRODUCTS

PAPERS

2014 Claisse J.T., Pondella D.J., Love M., Zahn L.A., Williams C.M., Williams J.P., Bull A.S. Oil platforms off California are the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences. Submitted for publication.

2014 Claisse J.T., Pondella D.J., Love M., Zahn L.A., Williams C.M., Bull A.S. The impact of partial removal of southern California oil and gas platforms on the associated fish biomass and production. In prep for publication.

PAPERS PRESENTED

Presentations by Jeremy Claisse:

Fish production of the oil platforms off the coast of California, USA. Southern California Academy Of Sciences Annual Meeting, Los Angeles, CA. May 2013.

Fish production of the oil platforms off the coast of California, USA. Indo-Pacific Fish Conference, Okinawa, Japan. June 2013.

Fish production of artificial and natural reefs off the coast of California. Western Society of Naturalists, Oxnard, CA. November 2013.

BIOLOGICAL PRODUCTIVITY OF FISH ASSOCIATED WITH OFFSHORE OIL AND GAS STRUCTURES ON THE PACIFIC OCS

EXECUTIVE SUMMARY

Information Needed

There are 27 oil and gas platforms in the waters off California. These platforms are located between 1.2 and 10.5 miles from shore and at depths ranging from 11 to 363 m (35-1,198 ft.). All platforms have a finite economic life and the life spans of some California platforms may be nearing an end. Once an industrial decision is made to cease oil and gas production at a platform, managers must decide what to do with the structure, a process known as decommissioning. Regarding oil and gas platforms, the Bureau of Ocean Energy Management (BOEM) defines decommissioning as the process of ending operations and returning the lease or pipeline right-of-way to a condition that meets the requirements of the regulations. California Bill AB 2503 (the California Marine Resources Legacy Act) passed in August 2010 and establishes a program to allow partial removal of some offshore oil platforms if specified criteria are satisfied. This included a finding that the partial removal provides a net environmental benefit and substantial cost savings compared to complete removal. The net environmental benefit of complete removal and partial removal shall be subject to additional scientific study and evaluation, which includes examining the contribution of the proposed structure to protection and productivity of fish and other marine life, as well as describing adverse impacts to biological resources that would be avoided by partial removal. During the decommissioning process, the BOEM conducts detailed environmental reviews of any proposed projects to evaluate the impacts on regional fish populations. Complete removal of platforms kills numerous fishes, and may have adverse impacts on regional populations of rockfishes and other species on the Pacific OCS. In order to understand the environmental consequences of the decommissioning options on fish populations, there is a need for estimates of the standing stock biomass and annual production of fishes on such platforms and natural reefs off California, as questions about Essential Fish Habitat and the biological productivity of Pacific OCS platforms are still unresolved.

Secondary production is the formation of new animal biomass from growth for all individuals in a given area during some period of time. It can be a powerful tool for evaluating ecosystem function since it incorporates multiple characteristics of a population or community of organisms such as density, body size, growth and survivorship into a single metric. Recent studies have extended this idea, using secondary fish production to provide a measure of the productive capacity and economic value of specific habitats within an ecosystem. A main unresolved issue is the degree to which artificial reef structures like oil and gas platforms enhance ecosystem function, and in particular secondary fish production, compared to nearby natural reefs.

There are two main goals of this research. The first is to determine the patterns of fish biomass and production at platforms throughout southern California and compare these metrics to both natural reefs in the region and to previously published estimates of production from other marine ecosystems. The second is to estimate the amount of fish biomass and production that will remain on platforms after partial removal and for fish communities that reside on the shell mound habitats which surround some of these platforms.

Research Summary

Chapter 1: Oil platforms off California are the most productive marine fish habitats globally

In this study we compare the density, biomass and annual secondary production of fish communities on 16 oil and gas platforms to those on 7 natural reefs off the coast of southern California and to secondary production estimates of fish communities from other marine ecosystems. To calculate the annual secondary production for a fish community we developed a model based on previously collected fisheries-independent density and size structure data of fishes from visual surveys performed from manned submersibles. We found that oil and gas platforms off the coast of California have the highest secondary fish production of any marine habitat that has been studied. The mean annual production per m^2 of seafloor for the platforms was 27.4 times as much as is produced per m^2 on natural reefs. When platforms are evaluated individually, their annual production (range: 104.7 to 886.8 $g/m^2/yr$) tended to be an order of magnitude higher than that of fish communities in other marine ecosystems where similar types of measurements have been made (range: 0.9 to 74.2 $g/m^2/yr$). Most previous estimates have come from estuarine environments, generally regarded as one of the most productive ecosystems globally. High rates of fish production on these platforms ultimately results from high levels of larval and pelagic juvenile settlement and subsequent growth of primarily rockfishes (genus Sebastes) to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column.

Chapter 2: The impact of partial removal of southern California oil and gas platforms on the associated fish biomass and production

In this study we evaluate the potential effects of partial removal on the biomass and production of the fish communities on 16 platforms off of the California coast. We calculate (1) the overall biomass (kg) and (2) production (kg/yr) for each entire platform. We then predict the percentage of each that will remain after partial removal by recalculating values with the habitat structure and the associated fishes from the water surface to 26 m depth removed from the model. On 15 out of the 16 platforms off the coast of California in this study, at least 78.0% of fish biomass and 78.2% of secondary fish production would be retained after partial removal, with above 90% retention expected for both metrics on many platforms. Further, partially removed platforms would still have some of the highest production values (scaled to per m^2 of seafloor) of any marine habitat globally. Many of the rockfishes that make up a substantial proportion of the biomass and production on platforms are important to recreational and commercial fisheries, and two, bocaccio and widow rockfish, are currently managed under federal rebuilding plans. The fisheries rebuilding potential of these platform habitats should not be substantially affected if partial removal is chosen as the preferred option for decommissioned platforms.

We also calculated the fish biomass and production separately for the shell mound habitats which surround some of these platforms. This was done in order to evaluate additional potential impacts associated with a reduction in these habitats after partial removal. The shell mounds which surround some platforms in our study vary greatly in size among platforms (range: 642 to 22,754 m^2) and are moderately productive fish habitats. Some shell mound

habitats (0.8 to 68 $g/m^2/yr$) had similar productive capabilities, or in some cases much greater capabilities than natural rocky reefs in the region located at similar depths (range: 4.4 to 22.4 $g/m^2/yr$). Therefore, if partial removal results in a loss in the complexity and areal extent of these shell mound habitats over time, it would also mean a relatively substantial loss in the associated fish biomass and production. However, their fate would largely be same under both the partial and complete removal options since the shells that create the mounds primarily originate from the platform structure above 26 m depth which would be eliminated under the partial removal option.

Conclusions

We found that oil and gas platforms off the coast of California have the highest secondary fish production of any marine habitat that has been studied. High rates of fish production on these platforms ultimately results from high levels of larval and pelagic juvenile settlement and subsequent growth of primarily rockfishes (genus *Sebastes*) to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column. Complete platform removal is typically done by detonating explosives 5 m below the seafloor to sever the well conductors, platform anchor pilings, and support legs. The use of explosives results in the mortality of most fishes associated with the platform, i.e., effectively the eliminating the entire fish biomass and subsequent production associated with the platform. Our model predicts that partially removed platforms will retain greater than 75% of their biomass and production in 15 out of 16 cases. If the seafloor habitat surrounding the base of partially removed platforms is augmented with additional structure (e.g., partially removed platform superstructure, rock boulders) additional positive impacts on production are expected, potentially mitigating reductions associated with removing structure in the surface waters and the potential losses of shell mound habitats around some platforms.

Chapter 1: Oil platforms off California are the most productive marine fish habitats globally

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Chelsea M. Williams, Jonathan P. Williams and Ann S. Bull*

Abstract

Secondary (i.e., heterotrophic or animal) production is a main pathway of energy flow through an ecosystem as it makes energy available to consumers, including humans. Its estimation can play a valuable role in the examination of linkages between ecosystem functions and services. We found that oil and gas platforms off the coast of California have the highest secondary fish production of any marine habitat that has been studied, about an order of magnitude higher than fish communities from other marine ecosystems. Most previous estimates have come from estuarine environments, generally regarded as one of the most productive ecosystems globally. High rates of fish production on these platforms ultimately results from high levels of larval and pelagic juvenile settlement and subsequent growth of primarily rockfishes (genus *Sebastes)* to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column. Understanding the biological implications of these structures will inform policy related to the decommissioning of existing (e.g., oil and gas platforms) and implementation of emerging (e.g., wind, marine hydrokinetic) energy technologies.

Introduction

Secondary production is the sum of new biomass from growth for all individuals in a given area during a unit of time. Some of the original motivations for understanding biological productivity stem from the need to estimate the annual production of fishes that can be taken from a body of water (Ivlev 1966; Chapman 1968). By integrating multiple metrics that can individually reflect aspects of fitness (e.g., density, biomass, growth, fecundity, survivorship, body size, lifespan), secondary production can be thought of as a general criterion of success for a population (Waters 1977; Benke 2010). Recent studies have extended this idea, using secondary fish production to provide a measure of the productive capacity and economic value of specific habitats within an ecosystem (Randall and Minns 2000; Kamimura et al. 2011) and, in a few instances, to evaluate the efficacy of creating artificial reefs and other forms of habitat restoration (Johnson et al. 1994; Peterson et al. 2003; Powers et al. 2003; Valentine-Rose and Layman 2011). In ecological studies, static properties such as density or biomass are typical structural response variables, while the use of secondary production, a functional measure, has been mostly limited to freshwater and marine benthic invertebrate studies (Benke 2010). Meanwhile, marine ecologists and fisheries scientists continue to advocate for incorporating more ecosystem-based approaches to managing marine resources (Levin et al. 2009; Thrush and Dayton 2010; Hilborn 2011). This includes calls to include elements of community and trophic ecology in the concept of essential fish habitat (Thrush and Dayton 2010) and will likely involve the development of functional measures or indicators which incorporate several processes from within an ecosystem (Murawski 2000; Babcock et al. 2005; Kremen and Ostfeld 2005).

The decommissioning of the >7500 oil and gas platforms around the world (Parente et al. 2006) is an unavoidable issue. 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. These options include "rigs-to-reefs" approaches where some portion of the platform is left in the water to continue functioning as an artificial reef. A main unresolved issue is the degree to which these types of structures enhance ecosystem function, and in particular secondary fish production, compared to nearby natural reefs (Holbrook et al. 2000; Love et al. 2003; Bull et al. 2008; Macreadie et al. 2011; Love et al. 2012).

Here we compare the density, biomass and annual secondary production of fish communities on oil and gas platforms to those on natural reefs off the coast of southern California (Fig. 1) and to secondary production estimates of fish communities from other marine ecosystems. To calculate the annual secondary production for a fish community, referred to here as "Total Production," we develop a model based on fisheries-independent density and size structure data of fishes from visual surveys performed from a manned submersible once per year for between 5 and 15 years at each site. We define Total Production of the fish community as the sum of two components: "Somatic Production" which is the difference between the observed biomass during surveys and the biomass predicted 1 y later using species-specific morphometric, growth and mortality functions, and "Recruitment Production" which estimates production from the immigration, growth and survival of larval and pelagic juvenile fishes over the year time interval. Metrics for a complete platform were scaled to per m^2 of seafloor, i.e., overall values were calculated for an entire platform then divided by the surface area of seafloor beneath the footprint of the platform. This permits a more direct comparison among platforms and natural reefs in the present study, and among estimates of secondary production of fishes in other ecosystems from the literature which are also typically scaled to per m^2 of seafloor (Table 1).

Methods

Data set. Data for this study was obtained from annual visual surveys conducted during daylight hours in the fall using the manned *Delta* research submersible from 1995 through 2009 and the *Dual Deepworker* in 2010–2011. A researcher aboard identified, counted and estimated the total lengths (TL; to the nearest 5 cm) of all fishes along 2 m wide belt transects. Since different subsets of sites were surveyed each fall, we used data from the 16 platforms (in bottom depths of 47–224 m) and 7 natural reefs (in bottom depths of 44–311 m) (Fig. 1) that had been surveyed for at least 5 years, some of which had been surveyed up to 15 years (Table 2). At platforms, transects ran along each of the horizontal beams from near-surface waters to, in most instances, the bottom. Because horizontal beam length increases with depth, survey effort is roughly proportional to the surface area of structure at each depth. Platform transects were classified into two habitat sub-types "platform midwater habitat", from water surface to 2m above the seafloor, and "platform base habitat", the bottom 2 m of the platform (Love et al. 2003). All of the "natural reef" sites used in the analyses were primarily deep rocky outcrops and banks of high-relief bedrock and boulders of various sizes. At natural reef sites, transects typically ran parallel to rocky ridges chosen at the time of survey from previously acquired seafloor data. Further details on the survey methodology and site descriptions are available elsewhere (Love et al. 2003; Love et al. 2006; Love and Schroeder 2007; Love et al. 2009). Annual densities (fish/m^2) at each site for each 5 cm size class in each taxon were calculated for each habitat category (i.e., natural reef, platform base, platform midwater). In some cases fishes could only be identified to genus or species group (Table 3). Transient, highly mobile species (e.g., Jack Mackerel, *Trachurus symmetricus*, Pacific Sardine, *Sardinops sagax*) were excluded from the data set.

Biological Metrics. In addition to calculating secondary fish production, we also calculated the total fish density and total fish biomass for each habitat type, site and year. Observed fish lengths were converted to biomass using species-specific morphometric relationships from the literature (Table 3). To calculate the annual secondary production for a fish community, referred to here as "Total Production," we developed a model based on fisheries-independent density and size structure data of fishes from visual surveys performed from a manned submersible once per year. Our model expands on previous versions of an approach (Valentine-Rose et al. 2011), which calculated annual secondary production for all fish species in a community by subtracting current total biomass estimates from total biomass estimates predicted 1 y later using species-specific weight-length relationships and von Bertalanffy growth functions, but did not account for changes due to immigration, emigration or mortality over the time interval. In our model the "Somatic Production" component, which is the difference between the biomass of fishes observed during the surveys and their biomass predicted 1 y later, also accounts for losses due to mortality by including a species- and size-specific natural survivorship function (Gislason et al. 2010). Since rockfishes tend to have high site fidelity (Matthews 1990; Lowe et al. 2009; Anthony et al. 2012) the calculations of the Somatic Production component also assume immigration and emigration of adults and post-settlement juveniles are equal. However, over the course of the 1 y time interval, additional larval and pelagic juvenile fishes will also recruit to the habitat. Therefore, we account for the production from their subsequent growth and survival in the "Recruitment Production" component of Total Production (following Kamimura et al. 2011). Details of the production model and calculations for other biological metrics are provided below.

In addition to calculating all metrics annually for natural reefs and for each platform habitat sub-type (midwater, base), they were also calculated for the "complete platform" scaled to per m^2 of seafloor beneath the footprint of the platform. This was done by multiplying the platform midwater and platform base metrics by the submerged surface area of platform structure for each habitat type, then dividing by the surface area of seafloor beneath the footprint of the platform (Table 2). The amount of surface area in each habitat sub-type (midwater, base) was allocated in proportion to the volume in each habitat type, calculated from platform dimensions using the formula for a truncated-pyramid (O'Leary 2010). When only one of the two platform habitat sub-types was sampled in a given year, typically due to limited visibility around the platform base (Table 2), its arithmetic mean value was used for that year to calculate the annual complete platform metric.

Production Model. In addition to calculating secondary fish production, we also calculated the total fish density and total fish biomass. Total fish density (fish/m^2) of the observed fish assemblage is:

$$D_{f,\mathrm{y}} = \sum_{j=1}^{n} \sum_{i=1}^{m} N_{i,j,f,y} \tag{1}$$

where $N_{i,j,f,y}$, the density of size class i of species j at each habitat type and site f in each year y surveyed, is summed across all size classes m and species n observed. The standing stock biomass density (g/m^2) of the assemblage is:

$$B_{f,y} = \sum_{j=1}^{n}\sum_{i=1}^{m} N_{i,j,f,y} w_{i,j} \tag{2}$$

where $w_{i,j}$ (g) is the average weight at length. Average weight at length is obtained from the standard equation:

$$w_{i,j} = a_j L_{i,j}^{b_j} \tag{3}$$

where $L_{i,j}$ *is* length (cm), and a and b are species-specific curve parameters (Table 3). When a length-weight equation was based on standard length (SL) or fork length (FL), the observed TL was converted using standard species-specific length-length conversion equations. For fishes or larger taxonomic groups without known conversion parameters, best professional judgment was used to assign a proxy species considering taxonomy, morphology and relative abundance (Table 3).

Total Production (g/m^2/yr):

$$P_{f,y}^{T} = P_{f,y}^{S} + P_{f,y}^{R} \tag{4}$$

is the sum of Somatic Production $P_{f,y}^{S}$ and Recruitment Production $P_{f,y}^{R}$. Somatic Production (g/m^2/yr) is:

$$P_{f,y}^{S} = \sum_{j=1}^{n}\sum_{i=1}^{m} N_{i,j,f,y} G_{i,j}^{W} S_{i,j} \tag{5}$$

where $G_{i,j}^{W}$ is the annual growth in weight and $S_{i,j}$ is the annual survivorship. Annual growth is based on the expected increase in length over the one year time interval $\Delta\hat{L}_{i,j}$. This is estimated according to the Fabens version of the von Bertalanffy growth function(Haddon 2011):

$$\Delta\hat{L}_{i,j} = (\mathrm{L}_{\infty,j} - L_{i,j})(1 - e^{-K_j}) \tag{6}$$

where $L_{i,j}$ is the observed fish size class (TL, cm), and $\mathrm{L}_{\infty,j}$ and K_j are the species-specific von Bertalanffy parameters. $\mathrm{L}_{\infty,j}$ is the mean asymptotic length and K_j is the rate at which $\mathrm{L}_{\infty,j}$ is approached (Table 3). $G_{i,j}^{W}$ is the difference between the weight after one year of growth in length and its initial estimated weight at the observed length:

$$G_{i,j}^{W} = a_j (L_{i,j} + \Delta\hat{L}_{i,j})^{b_j} - w_{i,j} \tag{7}$$

Annual survivorship is calculated according to (Haddon 2011):

$$S_{i,j} = e^{-M_{i,j}} \tag{8}$$

where $M_{i,j}$ (1/year) is a length- and species-specific annual instantaneous natural mortality rate. To estimate $M_{i,j}$ we used the empirical formula described in(Gislason et al. 2010):

$$\ln(M_{i,j}) = 0.55 - 1.61\ln(L_{i,j}) + 1.44\ln(\mathrm{L}_{\infty,j}) + \ln(K_j) \tag{9}$$

which estimates natural mortality as a function of the observed fish size class and its von Bertalanffy parameters (Table 3). A recent review suggests this may be the best supported estimator that is currently available (Kenchington 2013). Mortality is applied here at the start of the production interval (i.e., fish die then grow).

Annual Recruitment Production is defined here as the amount of new biomass produced due to the settlement, growth and survival of larval fishes during the time interval. We estimate $P_{f,y}^{R}$ using the biomass of all fishes less than L_j^1, the average length at 1 year post settlement (similar to Kamimura et al. 2011) as predicted by the von Bertalanffy growth function:

$$L_j^1 = L_{\infty,j}(1-e^{-K_j(\mathrm{t}-\mathrm{t}_{0,j})}) \tag{10}$$

where $t_{0,j}$ is the von Bertalanffy parameter for the theoretical age when length is 0 (Table 3). This thus incorporates variability in annual recruitment patterns over the previous year, and the cumulative effect of species-specific survival and growth up to the point these fishes were observed on surveys. In most cases we solved for $L_{i,j}^1$ by setting t to 0.5 yr. However, for species where t_0 was 0.0, typically resulting from the parameter being fixed there during model fitting due to a lack of young individuals in the sample, we then set t to 1.0 yr to estimate $L_{i,j}^1$. $P_{f,y}^{R}$ is then calculated according to Eq. (1), setting the density ($N_{i,j,f,y}$) to 0 for all size classes greater than size at 1 yr post-settlement.

Statistical Analyses. The effect of habitat type on each metric calculated [i.e. density (fish/m^2), biomass (g/m^2), Somatic Production (g/m^2/yr), Recruit Production (g/m^2/yr) and Total Production (g/m^2/yr)] was evaluated using linear mixed models (LMM). The first set of LMM analyses compared metrics between natural reefs and the complete platform metric. Data from platforms that never had their bases surveyed (i.e., Platform A, B, Habitat and Hillhouse) were excluded from analyses involving complete platform scaled metrics. A second set of LMM analyses compared metrics among natural reef, platform base and platform midwater habitat sub-types. Model formulations and the analysis procedure followed Bolker et al.(2009) for an unbalanced sampling design with crossed random effects. Models were fitted with the 'lmer' function in the 'lme4' package(Bates et al. 2013) in R(R Core Team 2013) using restricted maximum likelihood (REML). In each model, habitat type was the fixed factor, combined with a random intercept term for Year and separate random intercept terms for Site within each habitat type. Considering Year as a random factor appears most appropriate due to minimal evidence of temporal autocorrelation in the autocorrelation functions (ACF) for each site. Additionally, there was limited data from successive years for many sites. To meet normality assumptions, response variables were Log_{10}(x) transformed, or $\log_{10}$(x+1) transformed in the case of Recruitment Production due to the presence of zeros. For each habitat type in each model we calculated estimated marginal means and 95% CIs for the means, which account for site and year variation, based on 5000 simulations using the package 'arm'(Gelman et al. 2013) in R. These values were transformed back to their original scales for reporting. Note that these anti-logs of the mean of logged data are estimates of the geometric mean which also approximates the median on the original scale. Differences were considered significant if the 95% CIs of their marginal means did not overlap.

Results and Discussion

Oil and gas platforms off the coast of California have the highest secondary fish production of any marine habitat that has been studied. All complete platform metrics (including the density, biomass and secondary production of the fish community) were significantly greater than metrics calculated for natural reefs (Table 4) in the region. The geometric mean (or approximate median) of annual Total Production per m^2 of seafloor for the complete platform was 27.4 times as much as is produced per m^2 on natural reefs (Fig. 2B, Table 4). When platforms are evaluated individually, their annual Total Production (range of platform arithmetic means: 104.7 to 886.8 $g/m^2/yr$; Fig. 3) tended to be an order of magnitude higher than that of fish communities in other marine ecosystems where similar types of measurements have been made (range: 0.9 to 74.2 $g/m^2/yr$; Table 1). Most previous estimates have come from estuarine environments, generally regarded as one of the most productive ecosystems globally (Costanza et al. 1993).

High rates of fish production for the complete platforms are achieved because the platform jacket, horizontal crossbeams, conductors, and pilings create a complex structure that provides a large surface area (Table 2) of hard substrate throughout the water column (Love et al. 2003; Macreadie et al. 2011). This supports a diverse community of sessile and motile invertebrates that, along with planktonic food resources, provide the base of the food web for platform fishes (Page et al. 2007). The high vertical relief “platform midwater habitat” of these structures, i.e., that from the water surface to 2m above the seafloor, are important nursery grounds for young rockfishes (Love et al. 2003; Love et al. 2006). Recruitment Production per m^2 of midwater habitat surveyed was 3.7 times as much as that on natural reefs (Table 4). As they grow older, rockfishes of many species tend to move into deeper waters (Love et al. 2009) and this was evident in the patterns of fish production on the platforms. The highest Total Production and Somatic Production values were from the “platform base habitat,” i.e. the bottom 2m of the platform structure, and were significantly greater than that in either natural reef or platform midwater habitat [Fig. 2A, Table 4]. The geometric mean (or approximate median) Total Production and Somatic Production in platform base habitat was 4.8 and 5.2 times as much as that on natural reefs, respectively. The structure at the bases of the platforms form complex “sheltering habitats” created by the large horizontal beams typically at or near the seafloor which are often partially buried with fallen mussel shells and sediments further increasing the habitat complexity(Love and York 2006). Ultimately however, the surface area of the platform structure is mostly midwater habitat (average 96.8%; SE 0.4%; range 95.1 - 98.5). As a result, platform midwater habitat tended to contribute much more than platform base habitat to the complete platform production metrics scaled to per m^2 of seafloor (average contribution of platform midwater habitat: Somatic Production 88.6%, SE 3.7%, range 57.7 -99.0%; Recruitment Production 94.9%, SE 2.8%, range 67.8 - 100.0%; Total Production contribution 91.7%, SE 2.8%, range 69.0 - 99.5%).

High interannual variability in rockfish recruitment is well documented (Wilson et al. 2008; Love et al. 2012) and this was evident in the distributions of the annual values for all metrics each being highly positively skewed (see ranges in Table 4). Somatic and Recruitment Production varied highly across space (Fig. 4, see site arithmetic means) and over time (Fig. 4, see site SEs which reflect year to year variability). A large recruitment event will increase the Recruitment Production component that year. If the strong year class persists (Love et al. 2006), it will also make a substantial contribution to the Somatic Production component over the subsequent years with the highest levels of production occurring when a given species reaches intermediate lengths (Fig. 5). Given the high temporal and spatial recruitment variability in fishes across ecosystems (Caley et al. 1996) and the prevalence of relatively few species contributing the majority of annual secondary production (see references in Table 1), caution should be taken when generalizing secondary production values to an ecosystem or habitat type from other studies with only a single year of data.

Relatively few taxa contributed more than 5% of the Total Production across all habitats (Table 3). This is a common pattern in other ecosystems, where the production of a fish assemblage is typically dominated by a few of the species (see references in Table 1). In all habitats studied here, the biggest contributors were various rockfish species (genus *Sebastes)* and Lingcod *(Ophiodon elongatus)*. Larger-bodied species such as Lingcod (*Ophiodon elongatus*) and Bocaccio (*Sebastes paucispinis*), contributed more to production because they have relatively high growth and survival rates (Fig. 5) even though they were not the most abundant species. However, some smaller-bodied species, such as Halfbanded Rockfish (*S. semicinctus*) and Squarespot Rockfish (*S. hopkinsi*), also contributed substantial amounts of secondary production because they were very abundant. We should also note that the contributions of species that tend to be more prevalent in shallow water (Love et al. 2003; Martin and Lowe 2010) are likely underestimated in our platform estimates since these depths were not well sampled on some platforms (Table 2). However, this effect will be minimized for deeper platforms since shallow depths make up a relatively small proportion of their submerged surface area.

Aspects of both the survey methodology and our production model suggest that our complete platform fish production estimates are conservative. First, fishes in the substantial water volume within the platform that are away from the immediate vicinity of the platform structure are not accounted for in the surveys (only fishes within 2m of the platform structure are counted along a transect). Large numbers of rockfishes are often observed there within the water column, particularly during years when fish densities are highest (Love et al. 2006). Second, annual survivorship is applied in our model at the start of the time interval, and therefore production estimates do not include fishes that do not survive the entire interval. This production is typically accounted for in methods where fishes can be sampled on multiple occasions during the time interval (see references in Table 1). Finally, our model, using the same growth parameters from the literature for fish in all habitats, does not account for variability in species-specific growth rates. However, it has been demonstrated that rockfish and mussels (*Mytilus spp.*), one of the dominant filter feeding invertebrates on platforms, can grow faster in these offshore artificial environments than they do in their corresponding natural habitats (Page and Hubbard 1987; Blanchette et al. 2007; Love et al. 2007).

As the most productive marine fish habitat currently known, oil platforms off the coast of California can provide insight into what drives high rates of fish production for both natural and artificial habitats. 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 meters (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). Additionally, even though these structures were not designed to be high production artificial reefs, understanding what aspects drive their high production could inform the design of structures associated with emerging (e.g., wind, marine hydrokinetic) energy technologies in the marine environment (Nelson et al. 2008; Macreadie et al. 2011; Langhamer 2012) so that enhanced fish production is more likely associated with their deployment. Our results suggest that engineering modifications that may increase fish production (and productive associated elements like shell mounds) could be a consideration during the design process of renewable energy structures to maximize potential conservation and fishery benefits from their deployment.

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Chapter 2: The impact of partial removal of southern California oil and gas platforms on the associated fish biomass and production.

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Abstract

When oil and gas platforms become obsolete they go through decommissioning. Decommissioning options include partial (removal from surface to 26 m) and complete removal. While complete removal would likely eliminate most the existing fish biomass and subsequent secondary fish production, we find that the impacts of partial removal would be limited on all but one platform. On 15 out of the 16 platforms off the coast of California in this study, at least 78.0% of fish biomass and 78.2% of secondary fish production would be retained after partial removal, with above 90% retention expected for both metrics on many platforms. “Shell mounds” are biotic reefs that surround some of these platforms resulting from an accumulation of shells that have fallen from the shallow areas of the platforms (structure mostly above the depth of partial removal). We found that shell mounds are moderately productive fish habitats, similar to or greater than natural rocky reefs in the region. The complexity and areal extent of these habitats, and the associated fish biomass and production, will likely be reduced after either partial or complete platform removal. Habitat augmentation by placing the partially removed platform superstructure or some other additional habitat enrichment material (e.g., rock boulders) on the seafloor adjacent to the base of partially removed platforms provides additional options to enhance fish production, potentially mitigating reductions in shellmound habitat. Globally thousands of oil and gas platforms are set to be decommissioned over the coming decades, new structures associated with emerging wind and wave energy technologies are being deployed in the marine environment, and human activities are threatening fish populations on natural reefs. Therefore, understanding the biological productivity of artificial structures is a key for conservation of marine resources.

Introduction

The decommissioning of the greater than 7500 oil and gas platforms around the world (Parente et al. 2006) is an unavoidable issue (Macreadie et al. 2011). Decommissioning is the process by which the fate of these structures is determined once they become obsolete. It typically results in one of four alternatives: complete removal, toppling (laying the structure on its side), partial removal (i.e., “topping”) or leave-in-place (Schroeder and Love 2004; Macreadie et al. 2011). With the passage of AB 2503 in 2010, “The California Marine Resources Legacy Act”, the State of California will allow consideration of the partial removal of decommissioned offshore oil platforms as an alternative to complete removal if specified criteria are met, including a finding that conversion to an artificial reef would provide a "net benefit" to the environment as compared to removal of the facility (California Marine Resources Legacy Act 2010). The determination of what constitutes a “net benefit” is still under consideration, and therefore there is a critical need to understand the biological productivity of these structures and how partial removal may impact associated processes (Holbrook et al. 2000; Helvey 2002; Love et al. 2003; Schroeder and Love 2004; Bull et al. 2008; Bernstein et al. 2010; Martin and Lowe

2010; Macreadie et al. 2011; Langhamer 2012). At least 188 decommissioned platforms in the Gulf of Mexico have remained in the ocean to continue functioning as artificial reef habitat since 1947; however, the ecological impact assessment of these structures (e.g., Gallaway et al. 2009) has been limited relative to the research performed on the biological communities associated with platforms off of the California coast. This is likely due to less controversy associated with the process in the Gulf of Mexico region, resulting in less social need for the associated scientific information (Schroeder and Love 2004). Therefore, (1) given the quantity of biological information now available for platforms in California (e.g., Love et al. 1999; Love et al. 2003; Schroeder and Love 2004; Love et al. 2006; Love et al. 2012) and (2) the likelihood that the Pacific may be first region where platforms in deeper water are going to be decommissioned (Schroeder and Love 2004), the process in California has an opportunity to serve as a model for decommissioning elsewhere (Fowler et al. 2014).

Secondary (i.e., heterotrophic or animal) production is the sum of new biomass from growth for all individuals in a given area during a unit of time (Ivlev 1966; Chapman 1968). It is a main pathway of energy flow through an ecosystem as it makes energy available to consumers, including humans (Waters 1977; Benke 2010). Some of the original motivations for understanding biological productivity stem from the need to estimate the annual production of fishes that can be taken from a body of water (Ivlev 1966). Recent studies have extended this idea, using secondary fish production to provide a measure of the productive capacity and economic value of specific habitats within an ecosystem (Randall and Minns 2000; Kamimura et al. 2011) and, in a few instances, to evaluate the efficacy of creating artificial reefs and other forms of habitat restoration (Johnson et al. 1994; Peterson et al. 2003; Powers et al. 2003; Valentine-Rose and Layman 2011). While secondary production is often measured at the population level (Benke 2010), it can also be summed across members of a fish assemblage to yield an estimate of community secondary production (e.g., Allen 1982; Cowley and Whitfield 2002; Valentine-Rose et al. 2011).

Estimates of secondary fish production, particularly those which attempt to estimate the production of an entire community, have been relatively limited in marine ecosystems and most involve shallow nearshore and estuarine environments (Table 1). Methods employed in these studies most commonly calculate fish production as the product of average biomass and specific growth rate over a time interval, typically 1 yr (Chapman 1968; Ricker 1975; see references in Table 1). A key feature of this method is that *average* biomass is used, as this can account for immigration and emigration (of settlers, juveniles and adults), assuming that samples are taken frequently enough to accurately quantify fish in the sampling area during the time interval (Chapman 1968; Adams 1976).

We developed a model to estimate the annual secondary production for a fish community, referred to here as "Total Production," based on fisheries-independent density and size structure data of fishes from visual surveys performed once per year (Claisse et al. Submitted 2014). It is similar to a fishery-independent version of Ricker's (1975) definition for Surplus Production: "*Production of new weight by a fishable stock, plus recruits added to it, less what is removed by natural mortality*". Our model defines "Total Production" of the fish community as the sum of two components: (1) "Somatic Production," which is the difference between the observed biomass during surveys and the biomass predicted 1 y later using species-specific morphometric, growth and mortality functions, and (2) "Recruitment Production" which estimates production from the immigration, growth and survival of larval and pelagic juvenile fishes over the year time interval. Applying this model, it was found that oil and gas platforms off the coast of

California have the highest secondary fish production of any marine habitat that has been studied, about an order of magnitude higher than fish communities from other marine ecosystems. These high rates of fish production on these platforms ultimately results from high levels of larval and pelagic juvenile settlement and subsequent growth of primarily rockfishes (genus *Sebastes)* to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column (Claisse et al. Submitted 2014).

Of the two decommissioning options primarily being considered in California, only partial removal (the other being complete removal) would allow the remaining structure to continue functioning as a reef. In the U.S., partial removal of platforms has typically removed the platform structure down to a depth of 85 ft in order to maximize safe navigation of the area, allow for use of buoys to mark the location, and reduce unnecessary aids to navigation (Stephen et al. 1990). Often referred to as "rigs-to-reefs," this is terminology that is somewhat of a misnomer, since the complex hardscape habitat created by the platform structure distributed throughout the water column already functions as very productive habitat for invertebrates (Page and Hubbard 1987; Blanchette et al. 2007; Page et al. 2007) and fishes (Love et al. 2003; Love et al. 2006; Claisse et al. Submitted 2014) while energy extraction is occurring. However, the question remains regarding how partial removal may impact these processes.

Shell mounds, or "mussel mounds", are biotic reefs that are an accumulation of mostly mussel shells (*Mytilus californianus* and *M. galloprovincialis*) that have fallen from the shallow areas of the platforms. The fish communities on a mussel mound are typically more similar to the community on the base of the adjacent platform than those on other shell mounds, although fishes on shell mounds tend to be smaller and less dense (Love et al. 1999). Subsequent to partial removal we would expect a reduction in the habitat complexity associated with shell mounds at the base of some platforms and the surrounding seafloor. A thick layer of dozens of sessile invertebrate taxa, including barnacles, sponges, anemones and mussels, covers the submerged platform structure (Bram et al. 2005). Mussels can be the dominant species down to around 15 m depth, and they occur, although less frequently, down to around 40 m (Carlisle et al. 1964; observations of the authors). Given this depth range, the mussel's habitat would be almost non-existent on platforms after partial removal down to 26 m depth. Without a continued input of new shells over time, and assuming that a platform resided in a depositional area, where sedimentation rate surpassed flushing rate, the thickness and the complexity of shell mound would be reduced over time. Therefore, the impacts of partial removal should also consider the potential loss of the fish biomass and production associated with the shellmound habitat.

In the present study we evaluate the potential effects of partial removal on the standing stock biomass (SSB) and annual secondary production of the fish communities living on 16 platforms off of the California coast (Figure 6). We calculate (1) the overall SSB (kg) and (2) production (kg/yr) for each entire platform. We then predict the percentage of each that will remain after partial removal by recalculating values with the habitat structure and the associated fishes from water surface to 26 m depth removed from the model. The SSB and fish production is also calculated separately for the shell mound habitats which surround some of these platforms, in order to evaluate additional potential impacts associated with a reduction in these habitats after partial removal. Following this, we discuss these results in the context of what is known about how fish communities vary with depth and across this biographic region (e.g., Love et al. 2003; Martin and Lowe 2010) and the potential impacts of partial removal on fish recruitment (e.g., Love et al. 2012).

Methods

Data set

Data for this study was obtained from annual visual surveys conducted during daylight hours in the fall using the manned *Delta* research submersible from 1995 through 2009 and the *Dual Deepworker* in 2010–2011. A researcher aboard identified, counted and estimated the total lengths (TL; to the nearest 5 cm) of all fishes along 2 m wide belt transects. Since different subsets of platforms were surveyed each fall, we used data from the 16 platforms (in bottom depths of 47–224 m) (Figure 6) that had been surveyed for at least 5 years, some of which had been surveyed up to 15 years (Table 5). Transects ran along each of the horizontal beams of the platforms from near-surface waters to, in most instances, the bottom. Because horizontal beam length increases with depth, survey effort is roughly proportional to the surface area of structure at each depth. Transects were classified into three habitat sub-types: "platform shallow habitat", from water surface to 26 m depth (i.e., partial removal depth), "platform midwater habitat," from 26 m depth to 2m above the seafloor, and "platform base habitat", the bottom 2 m of the platform (Love et al. 2003). Further details on the survey methodology and platform descriptions are available elsewhere (Love et al. 2003; Love et al. 2006). Annual densities (fish/m^2) at each platform for each 5 cm size class in each taxon were calculated for each habitat category (i.e., platform base, platform midwater). In some cases fishes could only be identified to genus or species group (Table 3). Transient, highly mobile pelagic species (e.g., Jack Mackerel, *Trachurus symmetricus*, Pacific Sardine, *Sardinops sagax*) were excluded from the data set.

Platform Biological Metrics

Here we calculate the annual secondary production for a fish community (i.e., "Total Production") as the sum of two components: "Somatic Production" and "Recruitment Production" based on a previously developed model which uses fisheries-independent density and size structure data of fishes from visual surveys performed once per year (for a detailed description of the model see Claisse et al. Submitted 2014). In some cases fishes were not identified to species during surveys (Table 3). For the most common of these cases, unidentified rockfishes (*Sebastes spp.*), we chose to use *Sebastes hopkinsi* as a proxy because (1) it was the most frequently observed species across all surveys and (2) as a relatively small-bodied rockfish with a relatively low annual production per individual (Figure 7), it would provide a conservative production estimate. Additionally, transient, highly mobile species (e.g., Jack Mackerel, Trach*urus symmetricus*, Pacific Sardine, *Sardinops sagax*) were excluded from the data set.

In addition to calculating secondary fish production, we also calculated the total fish density, recruitment density (fishes less than TL at 1 year of age as predicted by the Von Bertalanffy Growth Function (VBGF); Claisse et al. Submitted 2014) and total fish biomass (Standing Stock Biomass) for each platform and year. Observed fish lengths were converted to biomass using species-specific morphometric relationships from the literature (Table 3).

To evaluate the impacts of partial removal, annual metrics were calculated for each "complete platform" and "partially removed" platform. This was done by multiplying the density metrics by the submerged surface area of platform structure for each habitat type (i.e., shallow, midwater, base) (Table 5). Complete platform metrics included all three, while partially removed platform metrics included the midwater and base platform habitat. The amount of surface area in each habitat sub-type was allocated in proportion to the volume in each habitat type, calculated from platform dimensions using the formula for a truncated-pyramid (O'Leary 2010). If, during a year when a platform was sampled, the platform base habitat was not sampled (Table 5), typically due to limited visibility, the mean of its available annual values were used. Since platform base habitat was never surveyed for platforms A, B, Hillhouse and Habitat, the mean platform base values from Holly were used as a proxy given its geographic proximity and habitat similarity. This was chosen as a better alternative than applying the midwater density values from the respective platforms to their base habitat because of differences in species composition and size structure of the fish assemblages between base and midwater habitat are substantial (Love et al. 2003; Claisse et al. Submitted 2014). If, during a year when a platform was sampled, the platform shallow habitat was not sampled (Table 5), midwater density values from the same year were used to calculate the annual complete platform metric.

All biological metrics were also converted to densities per m^2 of seafloor by dividing the overall values for an entire platform by the surface area of seafloor beneath the footprint of the platform. This permits a more direct comparison with previous results scaled in this manner (Claisse et al. Submitted 2014) and among estimates of secondary production of fishes in other ecosystems from the literature which are also typically scaled to per m^2 of seafloor (Table 1).

Shell Mound Biological Metrics

Since partial removal will likely result in some reduction in the thickness and the complexity of shell mound habitats surrounding platforms over time, and a complete loss of this habitat is also possible, all previously described biological metrics were also calculated for this habitat type to estimate the maximum potential associated losses. Shell mound habitats were typically surveyed during annual platform surveys as previously described (Table 6). All biological metrics were reported as densities per m^2. The surface area of the shell mounds associated with a platform (MMS 2003) was also available in some cases (Table 6). If available, the surface area was multiplied by the various annual density based metrics to yield overall estimates of fish abundance, SSB and production for the entire shellmound habitat surrounding a given platform.

Results

Platform SSB and Total Production

Mean annual Total Production and SSB for Complete Platforms was highly variable, spanning an order of magnitude across platforms. SSB ranged from 11,468 kg on platform Eureka to 816 kg on platform B (Table 7). Total Production ranged from 3,725 kg/yr on platform Eureka to 241 kg/yr on platform A (Figure 8; Table 7). Across platforms, the Somatic Production component tended to account for more of the Total Production (mean 58.7%, SE 3.8%, min 31.8%, max 86.7%) than the Recruitment Production component (Figure 9). Relatively few taxa, largely rockfishes from the genus *Sebastes*, contributed the majority of SSB and Total Production on each platform (Table 8). In terms of Total Production across all platforms, the top four contributors were Bocaccio *Sebastes paucispinis* (18.4%), Squarespot Rockfish *Sebastes hopkinsi* (15.6%), Widow Rockfish *Sebastes entomelas* (15.5%), and Lingcod *Ophiodon elongatus* (9.0%) (Table 3). Across individual platforms the top contributors varied and typically one to three species accounted for more than two-thirds of the Total Production (Table 8).

Seafloor depth does not appear to be a sufficient proxy for SSB or Total Production. As expected, there was a clear relationship with submerged surface area of the platform structure and the seafloor depth (Figure 10a; Surface Area (m^2) = 531 * Seafloor Depth(m)-14464; R^2=0.93; F=185.2; $DF_{1,14}$; p-value <0.001). However, there was no significant linear relationship between Log_{10} SSB and Seafloor Depth (Figure 10b; R^2=0.14; p-value = 0.16). Further, while marginally significant, the relationship between platform Log_{10} Total Production and seafloor depth was very weak (Figure 10c; R^2=0.20; p-value=0.05), being largely driven by the relatively low production values on platforms A, B and Holly (Table 7; Figure 10c) which are located in relatively shallow depths (Table 5).

Effects of Partial Removal on Platform Fish

The impact of partial removal would be limited on all but one platform. With the exception of platform Edith, at least 78.0% of SSB and 78.2% of Total Production would be retained after partial removal, with above 90% retention expected for many platforms for both metrics (Figure 8; Table 7, 9). The much lower values for platform Edith (only 25% retained for both metrics) can partially be attributed to it being located in the shallowest water depth (49 m) of the platforms in this study. As such, only 51% of the submerged surface area of the platform structure would remain after partial removal. However, there were multiple other platforms located in similar depths (Table 5) which all had much higher retention percentages (Table 7, 9, 10, 11). Another major difference was that the majority of the Complete Platform SSB and Total Production on Platform Edith, located in the southern end of the geographical range of platforms in our study (Figure 6), was contributed by Blacksmith *Chromis punctipinnis* (53.8% and 63.9%, respectively), a species which tends to reside near the surface. This species was observed almost entirely in the Shallow Platform depth range above 26 m, and thus was removed under the partially removed platform model scenario.

Shellmound SSB and Total Production

Biological metrics were estimated on the shell mounds surrounding 12 platforms (Table 6) located at seafloor depths ranging from 47 to 200 m. SSB density and Total Production density on shell mounds varied considerably across sites. SSB density ranged from 139 g/m^2 on shell mounds around platform Gilda to 4.93 g/m^2 on shell mounds around platform Eureka and Total Production density ranged from 68 g/m^2/yr on shell mounds around platform Gilda to 0.8 g/m^2/yr on shell mounds around platform Eureka (Figure 11; Table 12). Across all sites Lingcod was one of the top two contributors to Total Production at the shell mounds surrounding almost all platforms (Table 13). While it also accounted for a relatively high percentage of the SSB for multiple sites, this was not always the case (Table 13). As the species with the highest individual production rate at most sizes (Figure 7), it has the potential to produce a high rate of annual production from relatively fewer individuals compared to the common *Sebastes* species found on the shell mounds (Table 13, Figure 7). On most shell mounds the Recruitment Production component of Total Production was minimal (Figure 7), with the primary exception being shell mounds around Platform Gilda. Here Recruitment Production accounted for 49.8% of the Total Production, and was almost exclusively Bocaccio (76.0%) and Lingcod (22.4%).

Estimates of the areal extent of the shell mounds were available for those surrounding 5 platforms for which we also had fish survey data (Table 6) permitting estimation of the overall SSB and Total Production for all fishes on the entire shellmound. The three shell mounds with relatively large areal extents (Irene, Gilda, Grace; Table 6), similar to the total surface area of some platforms (Table 5), had overall SSB and Total Production estimates (Table 14) that were also similar to overall estimates from some platforms (Table 7). The other two shell mounds covered small areas of seafloor (Hermosa 642 m^2, Gail 655 m^2) and had very low estimates of SSB and Total Production (Table 14).

Discussion

While the SSB and Total Production for complete platforms varied substantially across individual platforms, our model of the potential impact of partial removal of decommissioned platforms suggests a high percentage of both metrics will be retained on almost all platforms off of the coast of California. Further, partially removed platforms would still have some of the highest production values (scaled to per m^2 of seafloor) of any marine habitat globally (Table 1, 4). Many of the rockfishes that make up a substantial proportion of the biomass and production on 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). The fisheries rebuilding potential of these platform habitats (e.g., Love et al. 2006) should not be substantially affected if partial removal is chosen as the preferred alternative for decommissioned platforms.

Aspects of both the survey methodology and our production model suggest that our complete platform fish production estimates are conservative. First, fishes in the substantial water volume within the platform that are away from the immediate vicinity of the platform structure are not accounted for in the surveys (only fishes within 2 m of the platform structure are counted along a transect). Large numbers of rockfishes are often observed out in the water column at greater than 2 m distance from the platform structure, particularly during years when fish densities are highest (Love et al. 2006). Second, annual survivorship is applied in our model at the start of the time interval, and therefore production estimates do not include fishes that do not survive the entire interval. This production is typically accounted for in methods where fishes can be sampled on multiple occasions during the time interval (see references in Table 3). Finally, our model, using the same growth parameters from the literature for fish in all habitats, does not account for variability in species-specific growth rates. However, it has been demonstrated that rockfish and mussels (*Mytilus spp.*), one of the dominant filter feeding invertebrates on platforms, can grow faster in these offshore artificial environments than they do in their corresponding natural habitats (Page and Hubbard 1987; Blanchette et al. 2007; Love et al. 2007).

Recruitment of larval and pelagic juvenile rockfishes to platform habitat, the ultimate driver of both the somatic and recruitment components of Total Production (Claisse et al. Submitted 2014), appears unlikely to be impacted substantially by partial removal. Love et al. (2012) found that young-of-the-year (YOY) fish assemblages on midwater platform habitats were similar to those around deeper pinnacle reefs and shipwrecks. Combined with additional lines of evidence, they conclude that recruitment of rockfishes does not appear dependent on surface habitat platform structure. In the specific case of bocaccio, all YOY were observed at 25m or deeper, and those on platforms represent a substantial portion (about 20%) of juvenile boccacio that survive annually in the species range (Love et al. 2006). Additionally, most bocaccio which recruit to platforms off California, would likely have been transported offshore and not survived, adding to argument that production on platforms is not at a cost to production on natural reefs elsewhere in the region (Emery et al. 2006). Therefore, overall we would not expect to see substantial reductions in recruitment and subsequent production on partially removed platforms, with the exception of some more typically shallow-water nearshore species (e.g., blacksmith), which do not account for a large proportion of the production on most platforms in this study (Table 8).

Martin and Lowe (2010) used data from scuba surveys down to 30 m depth to evaluate the fish community structure on the San Pedro Shelf platforms at the southern end of our study area (those starting with the letter E in Figure 6, plus Esther and Eva). They report that partial removal would "*result in a potential loss of 95% of the total fish density and 77% of the total fish biomass, thus reducing the productivity advantages of some of these structures.*" However, they only account for the fishes residing on the platform structure down to 30 m depth. It is likely that our study, where minimum depths sampled were10 - 15m for these platforms, will tend to underestimate the impact of partial removal on warmer-water species that typically reside in more shallow, nearshore natural habitats (e.g., blacksmith *Chromis punctipinnis* and kelp bass *Paralabrax clathratus*), species that accounted for most of the total fish density and biomass in the Martin and Lowe (2010) study. However, while our results were similar for platform Edith (only 25.2% of Total Production would remain after partial removal), our results for Elly, Ellen and Eureka showed a much more limited impact of partial removal (84.8%, 91.7% and 94.2% of Total Production retained after partial removal, respectively), typical of the rest of the platforms in our study.

For the platforms at the northern end of our study area (Figure 6), for which conditions did not permit sampling within the shallow habitat type (Irene, Hidalgo, Harvest; Table 5), we expect the opposite bias in our results compared to the southern platforms. For these platforms we applied the midwater platform habitat values for fishes to the unsurveyed shallow platform habitat when calculating complete platform biological metrics. However, these midwater values are likely to be much higher than the low densities of fishes which have been observed on these platforms at shallow depths (Love et al. 2012; personal observations of the authors). Therefore, our results probably overestimate the impact of partial removal on these platforms and an even greater percentage of the SSB and Total Production is likely to be retained than what our model predicts.

The shell mounds which surround some platforms in our study, and also vary greatly in size among platforms, were moderately productive fish habitats. While shellmound Total Production density values (0.8 to 68 g/m^2/yr) were about an order of magnitude less than that of Complete Platforms when scaled to per m^2 of seafloor (103.2-908.4 g/m^2/yr; Table 9), at least some shell mounds had similar productive capabilities, or in some cases were much greater than, those from natural rocky reefs in the region located at similar depths (natural rocky reef fish production: 4.4 to 22.4 g/m^2/yr)(Claisse et al. Submitted 2014). When their Total Production density values are scaled to yield an overall estimate for the entire shellmound habitat around a platform, in the few cases where the shellmounds cover large areas, their overall production can be quite substantial. The mean Total Production on the shell mounds surrounding Platforms Irene (324 kg/yr), Gilda (1253 kg/yr) and Grace (238 kg/yr) are equivalent to that of a low to moderately productive complete platform (Table 7). Therefore, if partial removal results in a loss in the complexity and areal extent of these shell mound habitats over time, it would also mean a relatively substantiation loss in the associated fish SSB and production. However, their fate would be same under both the partial and complete removal options.

Options also exist to enhance or augment the habitat on the seafloor around the base of partially removed platforms. Larger and older rockfishes of many species tend to move deeper as they grow (Love et al. 1991; Love et al. 2009). Those on platforms are able to take refuge in complex “sheltering habitats” created by the large horizontal beams typically at or near the seafloor under the platform (Love and York 2006). Given that in California the platform base habitat (bottom 2 m) has the highest production of any platform sub-habitat type per unit area (Claisse et al. Submitted 2014), adding additional structure at the seafloor will likely have substantial positive impacts on production. Seafloor habitats can be augmented by placing the partially removed platform superstructure or some other additional habitat enrichment material (e.g., quarry rock or pieces of concrete) adjacent to the platform base (Love et al. 2003; Schroeder and Love 2004; Macreadie et al. 2011). Rock boulders have been placed around the bases of monopile offshore wind turbines in the North Sea to prevent erosion or scour of soft sediments and they subsequently were found to create nursery habitat for commercially important crustaceans (Langhamer 2012). Some or all of the superstructure of decommissioned platforms has been placed on the seafloor adjacent to the platform base in the Gulf of Mexico and the east coast of Florida (Scarborough Bull 1993; Schroeder and Love 2004). A critical consideration when doing this is the final orientation of crossbeams or other structures relative to the seafloor, as this greatly influences the performance of these habitats (Love and York 2006). Habitat augmentation after partial removal would maximize the potential for YOY fishes to eventually populate the new structure as they matured, taking advantage of the positive effects of the nursery recruitment habitat located through the midwater portion of the remaining platform structure (Claisse et al. Submitted 2014). This has the potential to mitigate reductions in production associated with removing platform structure in the surface waters and the potential loss of shell mound habitats around some platforms.

Neither seafloor depth nor total submerged platform surface area appears to be a sufficient proxy for estimating the SSB or Total Production on a platform off of the California Coast. As an example, Platform Eureka had the highest SSB and Total Production by far. This is partially attributable to its large submerged surface area, the 2nd highest of the platforms in our study (103268 m^2; Table 5). However, platform Gail, with the largest submerged surface area in our study (106427 m^2), was on the lower end in terms of SSB (Table 7) and Total Production (Figure 9). Unlike all other California platforms, the crossbeams of Platform Eureka are formed of flattened shelves and large three-dimensional sleeves, forming a very large expanse of complex habitat. By comparison all other California platforms are composed of rounded and cylindrical cross beams which form a more simple habitat. Decisions related to the appropriate decommission option for individual platforms in California are supposed to consider the magnitude of the "net benefit" to the environment that the remaining platform structure would provide as compared to complete removal (California Marine Resources Legacy Act 2010). Given the high platform-to-platform and year-to-year variability in SSB and production (Claisse et al. Submitted 2014) multiple years of survey data should be used to effectively evaluate its fish SSB and production capabilities. Similar suggestions were also provided in a previous review (Langhamer 2012) regarding the necessity for long term monitoring to evaluate the biomass production from offshore renewable energy installations.

Although platforms represent a small contribution to the overall hard substratum here in California (Holbrook et al. 2000), these structures may be providing a large amount of the hard substrate below a depth of 50 meters (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). Complete platform removal is typically done by detonating explosives 5 m below the seafloor to sever the well conductors, platform anchor pilings, and support legs. The use of explosives results in the mortality of most fishes associated with the platform (Scarborough Bull and Kendall 1994), i.e., effectively eliminating the entire SSB associated with the platform. Removing the platform structure also means any subsequent productive value of platform habitat is also lost, and potentially the production associated with any surrounding shell mounds. Therefore our estimates of the remaining SSB and Total production can be considered one element of "net benefit" that would be provided by choosing partial over complete removal, with even greater benefits expected if the seafloor habitat surrounding the base of platforms is augmented with additional structure. With thousands of these structures set to be decommissioned over the coming decades (Parente et al. 2006; Macreadie et al. 2011), new structures associated with emerging wind and wave energy technologies being deployed in the marine environment (Nelson et al. 2008; Langhamer 2012), and human activities threatening fish populations on natural reefs globally (Hoegh-Guldberg and Bruno 2010; Mora et al. 2011), understanding the biological productivity of artificial structures and natural reefs is a key for conservation of marine resources.

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APPENDIX A. TABLES AND FIGURES

Table 1. Estimates of secondary production of fishes from various marine ecosystems. After (Cowley and Whitfield 2002) and (Allen et al. 2006). Also note that while fish production of 29–901[b] $g/m^2/yr$ was reported for Bahamian tidal creeks(Valentine-Rose et al. 2011), surveys were performed at low-tide when fishes were aggregated into a fraction of the total available habitat, therefore the authors caution against comparing these values with those from other studies (Lori Valentine Rose personal communication; (Valentine-Rose et al. 2011)).

Ecosystem	Fish Production ($g/m^2/yr$)	Reference
Oil platforms, California, USA	104.7–886.8[b]	Present study
Coral reef, Moorea	74.2[b]	(Galzin 1987)
Estuary, Louisiana, USA	35.0–72.8[b]	(Day et al. 1973) as cited in (Cowley and Whitfield 2002)
Coastal lagoon, (Pacific) Mexico	24.6–66.7[b]	(Yanez-Arancibia 1978) as cited in (Cowley and Whitfield 2002)
Artificial rocky reef, California, USA	66.5[b,d,e]	(Johnson et al. 1994)
Coastal lagoon, Texas, USA	12.1–57.6[b]	(Jones et al. 1963) as cited in (Cowley and Whitfield 2002)
Estuary, South Africa	55.9[b]	(Cowley and Whitfield 2002)
Estuary, California, USA	37.6[a,b]	(Allen 1982)
Coastal lagoon, Mexico	34.5[b]	(Warburton 1979)
Salt marsh, New Jersey, USA	33.5[a,c]	(Teo and Able 2003)
Salt marsh, Delaware, USA	32.4[a,c]	(Meredith and Lotrich 1979) recalculated in (Teo and Able 2003)
Coastal lagoon, Cuba	22.0–27.6[b]	(Holcik 1970) as cited in (Cowley and Whitfield 2002)
Deep rocky reef, California, USA	4.4–22.4[b]	Present study
Coastal lagoon, Mexico	20[b]	(Yanez-Arancibia 1983) as cited in (Cowley and Whitfield 2002)
Eelgrass bed, North Carolina, USA	18.4[a,b]	(Adams 1976)
Estuary, Italy	9.0–17.0[b]	(DeAngelis 1960) as cited in (Cowley and Whitfield 2002)
Chesapeake Bay, USA	11.2–16.4[b,d]	(Lubbers et al. 1990)
Seagrass bed, southern Australia	2.7–15.8[a,b]	(Edgar and Shaw 1995)
Coastal lagoon, Texas, USA	15.4[b]	(Hellier Jr 1962)
Mangrove habitat, Florida, USA	6.1–12.1[c]	(Faunce and Serafy 2008)
Salt marsh, Massachusetts, USA	6.4[a,c]	(Valiela et al. 1977) recalculated in (Teo and Able 2003)
Soft bottom, California, USA	5.9[b,d]	(Johnson et al. 1994)
Estuary, Scotland	4.3[b]	(Elliot and Taylor 1989) as cited in (Cowley and Whitfield 2002)
Coastal lagoon, Portugal	0.9–2.5[b]	(Pombo et al. 2007)

[a] Original estimate was in g dry weight and converted to g wet weight by multiplying by 4 (Allen 1982).
[b] Based on summation of production estimates from multiple species in an assemblage
[c] Production estimate for a single species
[d] Original estimate for partial yr time interval was standardized to 1 yr interval.
[e] Original estimate contained gonadal production component, only somatic production component is reported here.

Table 2. Survey statistics and platform structural dimensions. No.: number of years surveyed. Length: Average total length of transects from annual surveys. Platform Statistics: Estimated surface area of platform structure in each habitat sub-type and the surface area of seafloor beneath the "footprint" of the platform (MBC 1987).

			Survey			Platform	
Site	**Habitat**	**No.**	**Length (m)**	**Min. Depth (m)**	**Max. Depth (m)**	**Surface Area (m^2)**	**Seafloor Footprint Area (m^2)**
IRENE	base	11	207	72	72	621	2664
	midwater	11	193	28	50	14243	
HIDALGO	base	10	264	129	129	1662	4333
	midwater	10	600	32	105	71629	
HARVEST	base	5	316	202	202	1544	5890
	midwater	6	994	20	170	77577	
HERMOSA	base	6	262	179	179	1319	5203
	midwater	6	896	41	156	83784	
HOLLY	base	11	186	60	60	984*	1952*
	midwater	13	292	7	35	20431*	
B	midwater	5	500	5	40	20804	1979
A	midwater	7	420	5	32	20996	1890
HILLHOUSE	midwater	5	375	5	35	21206*	2014
HABITAT	midwater	5	527	10	65	25766	2242
GILDA	base	5	195	56	62	862	2081
	midwater	7	247	7	41	18626	
GRACE	base	13	246	92	95	777	3004
	midwater	14	601	20	80	25068	
GAIL	base	14	300	220	224	1675	5390
	midwater	15	1606	10	168	104752	
EDITH	base	8	212	47	47	846	2590
	midwater	7	267	10	30	16360	
ELLY	base	7	220	75	75	568*	2664*
	midwater	7	397	12	55	13850*	
ELLEN	base	7	203	77	77	1064*	2664*
	midwater	7	330	12	55	26779*	
EUREKA	base	3	281	210	215	1809*	5390*
	midwater	7	1533	15	190	107074*	
Harvest Reef	natural reef	11	837	98	108		
12 Mile Reef	natural reef	5	5938	105	130		
Hueneme Canyon	natural reef	5	1175	90	95		
Anacapa Passage	natural reef	11	1836	44	47		
Footprint	natural reef	14	4047	92	148		
Piggy Bank	natural reef	5	1501	270	311		
Short Banks	natural reef	5	1365	47	60		

* When platform dimensions or surface area estimates were unavailable (MBC 1987), the following proxies were used from platforms with similar structures from similar water depths: IRENE for ELLEN and ELLY surface and base platform dimensions, GAIL for EUREKA surface and base platform dimensions, C for HOLLY surface area and surface and base platform dimensions, and A for HILLHOUSE surface area and surface platform dimensions.

Table 3. Observed taxa that contributed to production estimates and life history parameter sources. The percent contribution to the Total Production (and rank order in parentheses) of each taxon for each habitat type or sub-type and the references for the weight-length equation (WL), Von Bertalanffy Growth Function (VBGF) and length-length conversion (LL) parameters used in the production model. The proxy species used is listed when the life history parameters were unavailable for the species.

Taxon	**Natural Reef**	**Platform Base**	**Platform Midwater**	**Platform Complete**	**WL**	**VBGF**	**LL**
Agonidae	<0.1(84)	<0.1(78)		<0.1(92)	*Xeneretmus latifrons*	*Aspidophoroides monopterygius (Arbour et al. 2010)*	(Arbour et al. 2010)
Alloclinus holderi	<0.1(100)				Love unpublished	*Heterostichus rostratus* (Stepien 1986)	
Anarrhichthys ocellatus	<0.1(60)	<0.1(58)	<0.1(60)	<0.1(69)	(RecFIN 2009)	*Cebidichthys violaceus* (Marshall and Echeverria 1992)	
Anoplopoma fimbria	<0.1(79)				(RecFIN 2009)	(Echave et al. 2012)	(FishBase 2012)
Argentina sialis	<0.1(52)		<0.1(68)	<0.1(87)	Love unpublished	(Fitch and Lavenberg 1968)	
Brosmophycis marginata	<0.1(85)				(Burge and Schultz 1973)	*Cebidichthys violaceus* (Marshall and Echeverria 1992)	
Careproctus melanurus	<0.1(102)				(Stein 1980)	*Palmoliparis beckeri* (Tokranov and Orlov 2003)	(FishBase 2012)
Caulolatilus princeps	<0.1(76)				(RecFIN 2009)	(Cooksey 1980)	
Cephaloscyllium ventriosum	0.1(42)				(Williams et al. 2013)	*Mustelus californicus*	
Chilara taylori	<0.1(108)				(Miller et al. 2008)	(Fitch and Lavenberg 1968)	(FishBase 2012)
Chromis punctipinnis	2.1(11)	<0.1(59)	4.2(6)	1.9(10)	(Edwards et al. 2014)	*Embiotoca jacksoni*	(FishBase 2012)
Citharichthys sordidus	<0.1(88)	0.2(30)	<0.1(72)	0.1(37)	Love and Nishimoto unpublished	(Beverton and Holt 1959)	
Citharichthys spp.	0.1(49)	0.2(29)	<0.1(56)	0.1(36)	*Citharichthys sordidus*	*Citharichthys sordidus*	
Cottidae	<0.1(58)	<0.1(62)	<0.1(36)	<0.1(57)	*Artedius corallinus*	*Scorpaenichthys marmoratus*	*Artedius corallinus*
Cryptotrema corallinum	0.1(50)	<0.1(77)		<0.1(92)	*Alloclinus holderi*	*Heterostichus rostratus* (Stepien 1986)	
Cymatogaster aggregata	<0.1(115)	<0.1(55)		<0.1(67)	(Williams et al. 2013)	(Eckmayer 1979)	(Williams et al. 2013)
Embiotoca jacksoni	<0.1(96)				(Miller et al. 2008)	(Froeschke et al. 2007)	(RecFIN 2009)
Embiotocidae	0.1(43)	0.1(36)	0.1(20)	0.1(34)	*Embiotoca jacksoni*	*Embiotoca jacksoni*	(RecFIN 2009)
Enophrys taurina		<0.1(54)		<0.1(64)	Love unpublished	*Scorpaenichthys marmoratus*	
Eopsetta jordani	<0.1(109)				(RecFIN 2009)	(Lai et al. 2005)	
Eptatretus spp.	<0.1(90)				*Eptatretus stoutii*	*Heterostichus rostratus* (Stepien 1986)	
Eptatretus stoutii	<0.1(89)				(Reid 1990)	*Heterostichus rostratus* (Stepien 1986)	
Girella nigricans			0.1(23)	<0.1(48)	Love unpublished	(Bredvik et al. 2011)	(FishBase 2012)
Glyptocephalus zachirus	<0.1(98)				(Abookire 2006)	(Hosie and Horton 1977)	

Halichoeres semicinctus			<0.1(66)	<0.1(86)	(RecFIN 2009)	(Adreani 2003)	(FishBase 2012)
Hexagrammos decagrammus	<0.1(62)	0.2(31)	<0.1(31)	0.1(35)	(Moulton et al. 1977)	(Cope and MacCall 2005)	(FishBase 2012)
Hexanchus griseus	<0.1(115)				(Crawford 1993)	*Galeorhinus galeus*	
Hydrolagus colliei	1.1(15)	<0.1(50)		<0.1(59)	(Barnett et al. 2009)	(Pauly 1978)	(Barnett et al. 2009)
Hypsurus caryi	<0.1(104)				(Miller et al. 2008)	*Embiotoca jacksoni*	(FishBase 2012)
Hypsypops rubicundus			0.1(19)	0.1(41)	(Williams et al. 2013)	*Embiotoca jacksoni*	(FishBase 2012)
Icelinus filamentosus	<0.1(103)				*Clinocottus analis*	*Scorpaenichthys marmoratus*	
Icelinus spp.	<0.1(95)		<0.1(63)	<0.1(83)	*Clinocottus analis*	*Scorpaenichthys marmoratus*	
Icelinus tenuis	<0.1(115)				*Clinocottus analis*	*Clinocottus analis*	
Lepidopsetta bilineata	<0.1(107)				(Wildermuth 1986)	(Stark and Somerton 2002)	(FishBase 2012)
Lycodes pacificus	<0.1(97)				Love unpublished	(Erzini 1994)	
Lyopsetta exilis	<0.1(91)				Love unpublished	(Demory et al. 1976)	
Lythrypnus dalli			<0.1(77)	<0.1(93)	Love unpublished	*Heterostichus rostratus* (Stepien 1986)	
Medialuna californiensis			0.3(16)	0.1(31)	Love unpublished	(Bredvik et al. 2011)	(FishBase 2012)
Merluccius productus	<0.1(70)	<0.1(74)	<0.1(51)	<0.1(77)	(RecFIN 2009)	(Dark 1975)	(FishBase 2012)
Microstomus pacificus	<0.1(61)	<0.1(67)		<0.1(78)	(Brodziak and Mikus 2000)	(Brodziak and Mikus 2000)	
Odontopyxis trispinosa			<0.1(76)	<0.1(93)	(Kinnetic_Laboratories 1980)	*Xeneretmus latifrons*	
Ophidiidae	<0.1(86)				*Ophidion scrippsae*	*Heterostichus rostratus* (Stepien 1986)	(FishBase 2012)
Ophiodon elongatus	13.9(2)	16(2)	0.3(15)	9(4)	(RecFIN 2009)	(Jagielo and Wallace 2005)	(FishBase 2012)
Oxyjulis californica	0.6(21)		<0.1(38)	<0.1(62)	(RecFIN 2009)	*Halichoeres semicinctus*	(FishBase 2012)
Oxylebius pictus	<0.1(51)	0.2(26)	0.3(14)	0.3(25)	(Williams et al. 2013)	(DeMartini and Anderson 1980)	(FishBase 2012)
Paralabrax clathratus			0.1(24)	<0.1(49)	(Williams et al. 2013)	(Love et al. 1996)	(Williams et al. 2013)
Paralichthys californicus		<0.1(65)		<0.1(75)	(Williams et al. 2013)	(MacNair et al. 2001)	(Williams et al. 2013)
Parophrys vetulus	<0.1(77)				(Holland 1969)	(Demory et al. 1976)	(FishBase 2012)
Phanerodon atripes	0.3(31)	0.2(27)	0.2(18)	0.2(27)	(RecFIN 2009)	*Phanerodon furcatus*	*Phanerodon furcatus*
Phanerodon furcatus	0.1(48)	<0.1(48)	<0.1(28)	<0.1(50)	(Miller et al. 2008)	(Eckmayer 1979)	(Eckmayer 1979)
Plectobranchus evides	<0.1(72)				Love unpublished	*Cebidichthys violaceus (Marshall and Echeverria 1992)*	
Pleuronectidae	<0.1(110)				*Parophrys vetulus*	*Hypsopsetta guttulata*	(FishBase 2012)
Pleuronectiformes	<0.1(56)	<0.1(52)	<0.1(80)	<0.1(61)	*Citharichthys sordidus*	*Hypsopsetta guttulata*	(FishBase 2012)
Pleuronichthys verticalis	<0.1(112)				Love unpublished	*Hypsopsetta guttulata*	(FishBase 2012)
Porichthys notatus	<0.1(107)				(Williams et al. 2013)	(Sak 1990)	(FishBase 2012)

Pristigenys serrula			<0.1(71)	<0.1(90)	*Embiotoca jacksoni*	*Paralabrax clathratus*	(RecFIN 2009)
Pronotogrammus multifasciatus		<0.1(69)		<0.1(80)	*Paralabrax nebulifer*	*Paralabrax clathratus*	
Raja binoculata	<0.1(75)				(RecFIN 2009)	(Gburski et al. 2007)	
Raja inornata	<0.1(82)				*Raja binoculata*	*Raja binoculata*	
Raja rhina	0.1(41)				*Raja binoculata*	(Gburski et al. 2007)	
Rathbunella alleni	0.1(47)	<0.1(42)	<0.1(57)	<0.1(54)	*Rathbunella hypoplecta*	*Cebidichthys violaceus (Marshall and Echeverria 1992)*	
Rathbunella hypoplecta	<0.1(57)	<0.1(43)	<0.1(45)	<0.1(52)	(Burge and Schultz 1973)	*Cebidichthys violaceus (Marshall and Echeverria 1992)*	
Rathbunella spp.	0.2(35)	0.2(25)	<0.1(53)	0.1(30)	*Rathbunella hypoplecta*	*Cebidichthys violaceus (Marshall and Echeverria 1992)*	
Rhacochilus toxotes	<0.1(81)	<0.1(53)	<0.1(59)	<0.1(63)	(Miller et al. 2008)	*Embiotoca jacksoni*	(FishBase 2012)
Rhacochilus vacca	<0.1(71)	0.1(34)	<0.1(27)	0.1(40)	(Miller et al. 2008)	*Embiotoca jacksoni*	(FishBase 2012)
Rhinogobiops nicholsii	0.2(33)	<0.1(45)	<0.1(62)	<0.1(56)	(Williams et al. 2013)	*Clinocottus analis*	(FishBase 2012)
Scorpaena guttata	2.4(10)	1.1(15)		0.6(18)	(Williams et al. 2013)	(Love et al. 1987)	(Williams et al. 2013)
Scorpaenichthys marmoratus		0.6(19)	0.8(8)	0.7(17)	(Lea et al. 1999)	(Grebel and Cailliet 2010)	
Sebastes atrovirens	<0.1(83)	0.1(38)	0.4(11)	0.2(26)	(Love et al. 2002)	(Romero 1988)	(Romero 1988)
Sebastes auriculatus		1.3(14)	0.1(22)	0.7(16)	(Love and Johnson 1998)	(Love and Johnson 1998)	
Sebastes babcocki	<0.1(94)	<0.1(68)		<0.1(79)	(RecFIN 2009)	*Sebastes chlorostictus*	*Sebastes chlorostictus*
Sebastes carnatus	0.2(37)	0.1(41)	<0.1(29)	<0.1(46)	(Williams et al. 2013)	(Lea et al. 1999)	(FishBase 2012)
Sebastes caurinus	0.5(25)	5.8(6)	0.6(10)	3.5(9)	(Lea et al. 1999)	(Love et al. 2002)	(Love et al. 2002)
Sebastes chlorostictus	1.5(14)	1.6(10)	<0.1(37)	0.9(11)	(Love et al. 1990)	(Benet et al. 2009)	(Benet et al. 2009)
Sebastes constellatus	0.7(20)	0.1(35)	<0.1(40)	0.1(43)	(Lea et al. 1999)	(Love et al. 1990)	
Sebastes crameri	<0.1(65)	<0.1(64)	<0.1(47)	<0.1(68)	(Wilkins 1980)	(Rogers et al. 2000)	
Sebastes dallii	<0.1(101)	0.7(17)	<0.1(41)	0.4(21)	(Love et al. 1990)	(Chen 1971)	(FishBase 2012)
Sebastes diplopроa	0.2(38)				(Love et al. 2002)	(Wilson and Boehlert 1990)	(Echeverria and Lenarz 1984)
Sebastes elongatus	0.2(39)	0.2(28)		0.1(33)	(Love et al. 1990)	(Shaw and Gunderson 2006)	(Echeverria and Lenarz 1984)
Sebastes ensifer	0.8(18)	<0.1(63)	<0.1(64)	<0.1(74)	(Love et al. 2002)	(Chen 1971)	(Love et al. 2002)
Sebastes entomelas	4.9(5)	3.6(8)	30.3(1)	15.5(3)	(Love et al. 2002)	(Williams et al. 2000)	(Echeverria and Lenarz 1984)
Sebastes eos	<0.1(73)	<0.1(61)	<0.1(75)	<0.1(72)	(RecFIN 2009)	*Sebastes chlorostictus*	*Sebastes chlorostictus*
Sebastes flavidus	2(12)	0.2(24)	0.3(13)	0.3(23)	(Love et al. 1990)	(Tagart et al. 2000)	(Echeverria and Lenarz 1984)
Sebastes gilli	<0.1(55)				(RecFIN 2009)	*Sebastes levis*	*Sebastes levis*
Sebastes goodei	<0.1(53)	<0.1(46)	<0.1(30)	<0.1(53)	(Love et al. 2002)	(Ralston 1998)	(Echeverria and Lenarz 1984)

Sebastes helvomaculatus	<0.1(64)	<0.1(73)	<0.1(67)	<0.1(82)	(Love et al. 2002)	(Shaw 1999)	(Love et al. 2002)
Sebastes hopkinsi	29.2(1)	11.3(3)	20.9(2)	15.6(2)	(Love et al. 2002)	(Love et al. 1990)	
Sebastes jordani	0.3(29)	5.1(7)	8.3(5)	6.5(6)	(Love et al. 2002)	(Pearson et al. 1991)	
Sebastes lentiginosus	<0.1(80)	<0.1(56)	<0.1(58)	<0.1(66)	*Sebastes umbrosus*	*Sebastes umbrosus*	*Sebastes umbrosus*
Sebastes levis	0.9(17)	1.4(11)	<0.1(55)	0.8(14)	(Love et al. 2002)	(Love et al. 2002)	(Love et al. 2002)
Sebastes macdonaldi	<0.1(87)	1(16)		0.6(19)	(RecFIN 2009)	*Sebastes paucispinis*	*Sebastes paucispinis*
Sebastes melanops			<0.1(39)	<0.1(65)	(Lea et al. 1999)	(Bobko and Berkeley 2004)	(Echeverria and Lenarz 1984)
Sebastes melanosema	<0.1(111)				(Shaw et al. 2000)	*Sebastes hopkinsi*	used Sebastes aleutianus
Sebastes melanostomus	<0.1(54)		<0.1(69)	<0.1(88)	(Love et al. 1990)	(Butler et al. 1998)	
Sebastes miniatus	2.5(9)	7(5)	<0.1(49)	3.9(8)	(Love et al. 1990)	*Sebastes chlorostictus*	*Sebastes chlorostictus*
Sebastes moseri	<0.1(78)	<0.1(72)	<0.1(32)	<0.1(58)	(RecFIN 2009)	*Sebastes hopkinsi*	
Sebastes mystinus	6.5(4)	0.4(22)	1.4(7)	0.8(12)	(Lea et al. 1999)	(Laidig et al. 2003)	(Echeverria and Lenarz 1984)
Sebastes nigrocinctus	<0.1(92)				(Moulton et al. 1977)	*Sebastes chlorostictus*	*Sebastes chlorostictus*
Sebastes ovalis	0.3(30)	<0.1(71)	0.1(21)	0.1(42)	(Love et al. 1990)	(Love et al. 1990)	
Sebastes paucispinis	3.9(6)	22.5(1)	13.5(4)	18.4(1)	(RecFIN 2009)	(Wilkins 1980)	(Echeverria and Lenarz 1984)
Sebastes phillipsi	<0.1(99)				(RecFIN 2009)	*Sebastes chlorostictus*	*Sebastes chlorostictus*
Sebastes pinniger	0.8(19)	1.4(13)	<0.1(76)	0.8(15)	(Lea et al. 1999)	(Stanley et al. 2009)	(FishBase 2012)
Sebastes rastrelliger			<0.1(48)	<0.1(73)	(Wilson et al. 2012)	(Wilson et al. 2012)	
Sebastes rosaceus	0.4(28)	0.3(23)	<0.1(42)	0.2(28)	(Lea et al. 1999)	combined (Chen 1971)and (Lea et al. 1999)	(Echeverria and Lenarz 1984)
Sebastes rosenblatti	0.5(24)	1.4(12)	<0.1(34)	0.8(13)	(Love et al. 1990)	(Love et al. 1990)	
Sebastes ruberrimus	0.1(46)	0.1(39)	<0.1(50)	<0.1(44)	(Lea et al. 1999)	(O'Connell et al. 1998)	(Echeverria and Lenarz 1984)
Sebastes rubrivinctus	0.1(45)	0.6(18)	0.1(25)	0.4(22)	(RecFIN 2009)	*Sebastes hopkinsi*	
Sebastes rufinanus	<0.1(74)		<0.1(44)	<0.1(70)	(Shaw et al. 2000)	(Love et al. 2002)	*Sebastes aleutianus*
Sebastes rufus	1.7(13)	<0.1(60)	0.3(17)	0.1(32)	(Love et al. 1990)	(Watters et al. 2006)	
Sebastes saxicola	<0.1(67)	0.1(37)	<0.1(62)	<0.1(45)	(Love et al. 1990)	(Love et al. 1990)	
Sebastes semicinctus	3.8(7)	11.2(4)	<0.1(33)	6.2(7)	(RecFIN 2009)	(Love et al. 1990)	
Sebastes serranoides	0.4(27)	0.4(21)	0.7(9)	0.5(20)	(Lea et al. 1999)	(Love and Westphal 1981)	
Sebastes serriceps	0.2(36)	0.2(32)	<0.1(46)	0.1(38)	(Colton and Larson 2007)	(Colton and Larson 2007)	
Sebastes simulator	0.1(44)	0.1(40)	<0.1(54)	<0.1(51)	Love unpublished	*Sebastes ensifer*	*Sebastes ensifer*
Sebastes spp.	3.8(8)	1.8(9)	15.7(3)	8(5)	*Sebastes hopkinsi*	*Sebastes hopkinsi*	
Sebastes umbrosus	0.2(40)	0.5(20)	<0.1(52)	0.3(24)	(RecFIN 2009)	(Chen 1971)	(Echeverria and Lenarz

							1984)
Sebastes wilsoni	8.1(3)	<0.1(44)	<0.1(43)	<0.1(55)	*Sebastes zacentrus*	*Sebastes hopkinsi*	*Sebastes zacentrus*
Sebastes zacentrus	<0.1(59)	<0.1(47)	0.1(26)	<0.1(47)	(Shaw et al. 2000)	(Malecha et al. 2007)	(FishBase 2012)
Sebastolobus alascanus	<0.1(63)	<0.1(76)		<0.1(85)	(Ianelli et al. 1994)	(Rogers et al. 1998)	
Sebastolobus spp.	<0.1(93)				*Sebastolobus altivelis*	*Sebastolobus altivelis*	
Sebastomus	1(16)	0.1(33)	<0.1(35)	0.1(39)	*Sebastes zacentrus*	*Sebastes ensifer*	(FishBase 2012)
Semicossyphus pulcher	0.6(22)	<0.1(49)	0.4(12)	0.2(29)	(Williams et al. 2013)	(Caselle et al. 2011)	(Hamilton et al. 2011)
Stichaeidae spp.	<0.1(69)				*Xiphister mucosus*	*Cebidichthys violaceus* (Marshall and Echeverria 1992)	
Synodus lucioceps	<0.1(105)	<0.1(70)		<0.1(81)	(Williams et al. 2013)	*Paralabrax clathratus*	(Williams et al. 2013)
Torpedo californica	0.2(32)				(Miller et al. 2008)	(Neer et al. 2001)	
Zalembius rosaceus	0.6(23)	<0.1(66)	<0.1(78)	<0.1(76)	Love unpublished data	*Cymatogater aggregata*	(FishBase 2012)
Zaniolepis frenata	0.4(26)	<0.1(51)	<0.1(66)	<0.1(60)	Love unpublished data	(Fitch and Lavenberg 1968)	
Zaniolepis latipinnis	<0.1(68)	<0.1(76)	<0.1(74)	<0.1(84)	Love unpublished data	*Zaniolepis frenata*	
Zaniolepis spp.	0.2(34)	<0.1(57)	<0.1(70)	<0.1(71)	*Zaniolepis latipinnis*	*Zaniolepis frenata*	
Zoarcidae	<0.1(66)				*Lycodes pacificus*	*Lycodes brunneofasciatus* (Hildebrandt et al. 2011)	

Table 4. Estimated marginal means and 95% CIs from linear mixed model (LMM) analyses and the range of annual values. Mean and CI values of logged data were transformed back to their original scales and therefore estimates are of the geometric mean (which is also an approximate of the median) on the original scales. Differences were considered significant if the 95% CIs of their marginal means did not overlap.

Metric		**Natural Reef**	**Platform Base**	**Platform Midwater**	**Platform Complete**
Density (fish/m^2)	Geometric Mean	0.5	1.8	0.9	15
	95%CI	(0.3 to 1.1)	(0.9 to 3.5)	(0.5 to 1.5)	(8.9 to 25.3)
	Range	(0.1, 5.3)	(0.2, 38.4)	(0.02, 29.0)	(0.6, 178.0)
Biomass (g/m^2)	Geometric Mean	42.5	203.0	30.8	514.8
	95%CI	(27.4 to 65.8)	(131.0 to 312.5)	(17.5 to 54)	(329.9 to 804.1)
	Range	(4.7, 327.6)	(12.9, 1210)	(0.3, 643.5)	(48.4, 6577)
Somatic Production (g/m^2/yr)	Geometric Mean	5.6	28.9	7.0	110.9
	95%CI	(3.2 to 10.0)	(18.9 to 44.5)	(4.2 to 11.5)	(74.5 to 165.6)
	Range	(0.9, 31.2)	(3.0, 164.3)	(0.1, 227.6)	(11.5, 2299)
Recruit Production (g/m^2/yr)	Geometric Mean	1.2	2.5	4.4	55.3
	95%CI	(0.4 to 2.6)	(0.8 to 5.8)	(2.6 to 7.2)	(34.2 to 90.3)
	Range	(0.0, 17.8)	(0.0, 253.4)	(0.0, 253.9)	(0.7, 1363)
Total Production (g/m^2/yr)	Geometric Mean	6.9	33.3	11.9	188.9
	95%CI	(3.6 to 13.0)	(20.5 to 53.8)	(7.2 to 19.9)	(125.1 to 286.5)
	Range	(0.9, 46.1)	(4.3, 417.6)	(0.1, 379.7)	(14.8, 2608)

Table 5. Survey statistics and platform structural dimensions. No.: number of years surveyed. Length: Average total length of transects from annual surveys. Platform Statistics: Seafloor Depth, estimated surface area of platform structure at each level and the surface area of seafloor beneath the "footprint" of the platform (MBC 1987).

		Survey				Platform		
Platform	**Level**	**No.**	**Length (m)**	**Min. Depth (m)**	**Max. Depth (m)**	**Depth (m)**	**Surface Area (m^2)**	**Footprint Area (m^2)**
Irene	base	11	207	72	72	74	621	2664
	midwater	11	193	28	50		10706	
	shallow						3537	
Hidalgo	base	10	264	129	129	131	1662	4333
	midwater	10	600	32	105		62227	
	shallow						9402	
Harvest	base	5	316	202	202	204	1544	5890
	midwater	6	966	38	170		73122	
	shallow	1	164	20	20		4455	
Hermosa	base	6	262	179	179	183	1319	5203
	midwater	6	896	41	156		77766	
	shallow						6018	
Holly	base	11	186	60	60	64	984*	1952*
	midwater	13	246	32	35		14043*	
	shallow	7	85	7	20		6388*	
B	base					57	1129	1979
	midwater	5	312	30	40		13335	
	shallow	5	189	5	20		7469	
A	base					57	1116	1890
	midwater	7	266	29	32		13325	
	shallow	6	180	5	20		7671	
Hillhouse	base					58	1141*	2014
	midwater	5	161	35	35		13705*	
	shallow	5	214	5	20		7501*	
Habitat	base					92	967	2242
	midwater	5	335	40	65		21616	
	shallow	5	192	10	25		4150	
Gilda	base	5	195	56	62	64	862	2081
	midwater	7	142	39	41		12591	
	shallow	5	148	7	25		6035	
Grace	base	13	246	92	95	97	777	3004
	midwater	14	587	25	80		20279	
	shallow	2	97	20	25		4789	
Gail	base	14	300	220	224	225	1675	5390
	midwater	15	1581	30	168		99596	
	shallow	2	183	10	10		5156	
Edith	base	8	212	47	47	49	846	2590
	midwater	7	169	27	30		8056	
	shallow	6	114	10	12		8304	
Elly	base	7	220	75	75	78	568*	2664*
	midwater	7	297	33	55		10663*	
	shallow	6	117	12	14		3187*	
Ellen	base	7	203	77	77	81	1064*	2664*
	midwater	7	265	30	55		20849*	
	shallow	5	92	12	14		5930*	
Eureka	base	3	281	210	215	213	1809*	5390*
	midwater	7	1446	35	190		101459*	
	shallow	4	153	15	16		5615*	

* When platform dimensions or surface area estimates were unavailable (MBC 1987), the following proxies were used from platforms with similar structures from similar water depths: Irene for Ellen and Elly surface and base platform dimensions, Gail for Eureka surface and base platform dimensions, C for Holly surface area and surface and base platform dimensions, and A for Hillhouse surface area and surface platform dimensions.

Table 6. Shellmound survey statistics and area. No.: number of years surveyed. Length: Average total length of transects from annual surveys. Platform Statistics: Seafloor Depth, estimated surface area of platform structure at each level and the surface area of seafloor beneath the "footprint" of the platform (MBC 1987).

Platform	No.	Length (m)	Min. Depth (m)	Max. Depth (m)	Shellmound Area (m^2)
Irene	10	246	72	72	13484
Hidalgo	9	320	128	129	
Harvest	5	493	202	203	
Hermosa	5	251	179	179	642
Holly	6	188	59	62	
Gilda	5	238	56	62	18290
Grace	14	300	92	92	22754
Gail	13	366	220	224	655
Edith	8	210	47	47	
Elly	7	265	75	75	
Ellen	7	276	77	77	
Eureka	3	390	210	216	

Table 7. Mean of annual values for Complete (C) and partially removed (PR) platforms and the percent retained after partial removal (%). Standard errors are in parentheses. Platforms are in ordered from North to South.

	Biomass (kg)			Somatic Production (kg/yr)			Recruitment Production (kg/yr)			Total Production (kg/yr)		
Platform	**C**	**PR**	**%**	**C**	**PR**	**%**	**C**	**PR**	**%**	**C**	**PR**	**%**
Irene	1875	1456	80.7	733	558	79.1	611	462	77.5	1344	1020	78.2
	(409)	(307)	(1.8)	(194)	(146)	(1.7)	(320)	(240)	(1.1)	(458)	(345)	(1.3)
Hidalgo	1415	1278	91.7	412	365	89.9	885	769	87.0	1297	1134	88.3
	(319)	(277)	(1.0)	(108)	(94)	(0.8)	(329)	(286)	(0.0)	(433)	(376)	(0.5)
Harvest	1710	1632	95.6	473	450	95.4	559	527	94.9	1031	977	95.3
	(631)	(595)	(0.8)	(206)	(195)	(0.8)	(502)	(473)	(0.4)	(703)	(662)	(0.8)
Hermosa	2950	2750	93.4	824	766	93.1	843	782	92.8	1667	1548	93.0
	(805)	(749)	(0.2)	(250)	(232)	(0.1)	(632)	(587)	(0.0)	(839)	(779)	(0.1)
Holly	1012	815	79.6	222	182	81.6	111	98	82.6	333	280	82.4
	(139)	(124)	(2.6)	(43)	(37)	(2.6)	(40)	(40)	(4.0)	(74)	(68)	(2.9)
B	816	654	83.3	185	170	90.1	70	70	99.3	256	240	91.4
	(285)	(235)	(8.6)	(78)	(76)	(6.9)	(57)	(57)	(0.6)	(114)	(113)	(6.2)
A	1156	801	67.0	209	171	80.2	32	31	95.2	241	203	84.0
	(214)	(180)	(4.2)	(58)	(51)	(3.4)	(13)	(14)	(3.0)	(54)	(47)	(2.7)
Hillhouse	1020	855	78.0	321	305	83.1	400	376	83.1	721	681	81.0
	(494)	(501)	(7.9)	(231)	(234)	(7.9)	(353)	(356)	(12.9)	(584)	(590)	(10.5)
Habitat	1401	1375	97.9	443	438	98.5	87	84	98.0	530	522	98.5
	(527)	(516)	(0.6)	(200)	(198)	(0.5)	(37)	(35)	(1.3)	(225)	(220)	(0.4)
Gilda	720	634	87.4	251	232	92.5	184	176	95.4	435	408	94.4
	(150)	(133)	(3.5)	(55)	(50)	(2.3)	(72)	(69)	(2.7)	(107)	(102)	(2.2)
Grace	4256	3625	86.6	1452	1247	85.7	430	359	84.6	1881	1606	85.4
	(1119)	(933)	(1.6)	(420)	(358)	(1.9)	(152)	(124)	(1.7)	(425)	(362)	(1.9)
Gail	1238	1169	95.8	280	268	96.3	276	263	95.5	556	531	95.9
	(156)	(139)	(1.8)	(68)	(65)	(1.1)	(118)	(112)	(0.3)	(182)	(174)	(0.8)
Edith	1924	354	25.2	206	59	32.9	208	39	28.2	413	98	25.2
	(519)	(52)	(6.9)	(42)	(12)	(8.1)	(60)	(26)	(15.1)	(55)	(37)	(9.8)
Elly	3271	2954	86.5	433	408	89.2	379	358	72.5	812	766	84.8
	(670)	(708)	(4.5)	(123)	(126)	(4.4)	(200)	(200)	(13.9)	(300)	(306)	(6.7)
Ellen	6740	6326	90.6	1564	1512	92.2	856	793	89.0	2420	2304	91.7
	(2319)	(2312)	(2.8)	(741)	(742)	(3.0)	(492)	(494)	(4.9)	(1079)	(1060)	(2.6)
Eureka	11468	10890	94.1	1889	1791	93.9	1836	1768	92.8	3725	3558	94.2
	(2229)	(2236)	(1.3)	(352)	(363)	(1.6)	(615)	(621)	(2.8)	(937)	(951)	(1.3)

Table 8. Percent contribution of individual taxa to complete platform metrics. Only taxa that contribute at least 1.0% of the Total Production are included. Platforms are ordered from North to South and taxa are sorted by percent contribution to Total Production. Note that this is only based on surveyed platforms (i.e. substitutions are not made as is the case with total platform metric calculations)

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
Irene	*Sebastes jordani*	14.3	19.2	44.6	30.7
	Sebastes entomelas	46.9	54.0	1.9	30.5
	Sebastes spp.	15.8	11.0	29.2	19.3
	Sebastes paucispinis	5.8	7.9	18.2	12.5
	Sebastes caurinus	5.7	3.1	0.6	2.0
	Ophiodon elongatus	1.0	1.2	1.6	1.4
	Sebastes flavidus	0.7	0.6	1.9	1.2
Hidalgo	*Sebastes spp.*	58.8	70.3	96.6	88.1
	Sebastes entomelas	9.8	13.0	0.7	4.7
	Sebastes hopkinsi	1.0	1.1	1.4	1.3
	Ophiodon elongatus	2.8	3.0	0.2	1.1
	Sebastes semicinctus	7.4	3.4	0.0	1.1
Harvest	*Sebastes spp.*	27.5	31.1	77.3	56.0
	Sebastes entomelas	26.2	36.2	0.0	16.7
	Sebastes hopkinsi	15.9	12.9	19.4	16.4
	Sebastes zacentrus	10.7	8.3	0.0	3.8
	Sebastes paucispinis	0.7	1.2	1.8	1.5
	Oxylebius pictus	4.4	2.4	0.2	1.2
Hermosa	*Sebastes spp.*	38.4	40.3	96.4	68.6
	Sebastes entomelas	21.3	31.7	0.6	16.0
	Sebastes mystinus	21.6	18.4	0.0	9.1
	Sebastes paucispinis	0.5	1.0	1.6	1.3
	Oxylebius pictus	4.7	1.8	0.4	1.1
Holly	*Sebastes hopkinsi*	18.5	16.6	51.1	28.2
	Sebastes entomelas	23.6	41.5	0.0	27.6
	Chromis punctipinnis	7.2	4.2	14.9	7.8
	Sebastes caurinus	6.3	6.1	8.5	6.9
	Sebastes spp.	2.9	2.9	12.6	6.1
	Sebastes atrovirens	9.0	5.4	0.0	3.6
	Sebastes paucispinis	0.7	1.5	5.6	2.8
	Sebastes serranoides	1.6	3.1	1.3	2.5
	Oxylebius pictus	3.6	2.7	0.9	2.1
	Ophiodon elongatus	0.7	1.6	3.0	2.1
	Sebastes auriculatus	2.4	2.4	0.0	1.6
	Sebastes miniatus	3.3	2.1	0.0	1.4
	Scorpaenichthys marmoratus	0.7	1.4	0.5	1.1
B	*Sebastes paucispinis*	8.2	18.6	78.8	36.4
	Sebastes entomelas	29.9	40.9	0.0	28.8
	Sebastes serranoides	6.8	11.3	3.0	8.8
	Sebastes mystinus	6.4	7.3	0.0	5.1
	Chromis punctipinnis	14.0	5.1	0.1	3.6
	Ophiodon elongatus	0.7	1.6	5.1	2.7
	Paralabrax clathratus	3.6	3.0	0.0	2.1
	Sebastes spp.	1.7	0.8	5.2	2.1
	Sebastes atrovirens	5.2	2.4	0.1	1.7
	Oxyjulis californica	0.3	0.3	2.9	1.1
	Sebastes melanops	0.2	0.5	2.3	1.0

Table 8. (*continued*)

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
A	*Sebastes mystinus*	19.7	30.5	0.0	26.4
	Sebastes serranoides	9.3	21.0	4.7	18.8
	Chromis punctipinnis	20.6	16.0	1.4	14.1
	Sebastes hopkinsi	1.0	2.0	37.2	6.7
	Phanerodon atripes	10.0	6.0	0.0	5.2
	Sebastes spp.	0.7	1.2	21.0	3.8
	Sebastes jordani	0.5	1.5	18.5	3.7
	Embiotocidae	5.1	3.9	0.2	3.4
	Sebastes entomelas	1.5	3.5	0.0	3.1
	Sebastes paucispinis	0.4	0.7	14.5	2.5
	Sebastes auriculatus	1.7	2.2	0.0	1.9
	Sebastes atrovirens	3.2	2.1	0.0	1.8
	Phanerodon furcatus	1.9	1.4	1.3	1.4
	Rhacochilus vacca	6.0	1.5	0.0	1.3
	Paralabrax clathratus	0.9	1.3	0.0	1.1
	Semicossyphus pulcher	13.5	1.2	0.0	1.1
Hillhouse	*Sebastes paucispinis*	39.5	63.6	83.4	75.0
	Sebastes spp.	4.1	3.6	8.0	6.1
	Chromis punctipinnis	6.1	3.4	5.8	4.8
	Sebastes entomelas	6.6	8.2	0.0	3.5
	Sebastes serranoides	7.7	8.0	0.0	3.4
	Embiotocidae	19.7	4.7	0.1	2.0
	Sebastes hopkinsi	1.2	1.2	2.4	1.9
	Sebastes mystinus	5.3	3.9	0.0	1.7
Habitat	*Sebastes entomelas*	58.3	73.5	0.0	61.3
	Sebastes hopkinsi	24.3	11.6	46.0	17.3
	Sebastes paucispinis	3.0	4.8	38.0	10.3
	Sebastes mystinus	3.7	2.8	0.0	2.3
	Sebastes spp.	1.1	0.8	7.7	2.0
	Sebastes serranoides	1.3	1.8	1.0	1.7
	Chromis punctipinnis	1.3	0.6	3.5	1.1
Gilda	*Sebastes jordani*	34.3	43.5	44.9	44.2
	Sebastes paucispinis	8.7	14.6	26.6	20.5
	Ophiodon elongatus	3.2	5.1	9.7	7.4
	Sebastes spp.	2.9	2.6	7.1	4.8
	Sebastes entomelas	6.6	8.4	0.0	4.3
	Scorpaenichthys marmoratus	3.9	4.3	2.8	3.6
	Sebastes miniatus	9.8	5.8	0.0	3.0
	Phanerodon atripes	1.6	1.1	4.6	2.8
	Sebastes semicinctus	5.0	4.5	0.0	2.3
	Sebastes hopkinsi	0.8	0.8	2.4	1.6
	Sebastes caurinus	1.6	1.2	1.0	1.1
	Oxylebius pictus	3.5	1.9	0.2	1.1

Table 8. (*continued*)

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
Grace	*Sebastes entomelas*	59.8	75.4	0.2	58.8
	Sebastes paucispinis	8.7	13.5	60.0	23.8
	Sebastes spp.	4.5	3.5	23.0	7.8
	Sebastes hopkinsi	4.7	2.8	15.7	5.7
	Sebastes mystinus	1.6	1.8	0.0	1.4
Gail	*Sebastes paucispinis*	32.5	49.9	49.4	49.6
	Sebastes spp.	6.7	10.1	32.7	20.6
	Sebastes hopkinsi	3.5	4.8	12.9	8.6
	Medialuna californiensis	6.2	6.7	0.0	3.6
	Chromis punctipinnis	20.0	5.4	1.5	3.6
	Ophiodon elongatus	7.0	5.9	0.0	3.2
	Sebastes entomelas	1.8	3.7	0.2	2.1
	Sebastes rubrivinctus	1.6	1.2	2.0	1.5
	Sebastes levis	6.7	2.8	0.0	1.5
	Sebastes rosenblatti	4.4	2.5	0.0	1.3
	Sebastes macdonaldi	3.0	2.2	0.0	1.2
Edith	*Chromis punctipinnis*	53.8	44.1	83.4	63.9
	Semicossyphus pulcher	16.4	14.8	0.0	7.3
	Sebastes jordani	0.8	4.0	7.3	5.7
	Sebastes hopkinsi	0.6	2.1	5.2	3.6
	Hypsypops rubicundus	6.4	6.3	0.6	3.4
	Medialuna californiensis	3.1	6.0	0.0	3.0
	Scorpaenichthys marmoratus	2.9	5.0	0.2	2.6
	Girella nigricans	2.8	5.1	0.0	2.5
	Sebastes spp.	0.3	0.9	2.6	1.8
	Sebastes semicinctus	4.9	2.9	0.3	1.6
	Scorpaena guttata	1.7	2.9	0.0	1.4
Elly	*Sebastes hopkinsi*	68.7	69.7	76.5	72.9
	Sebastes spp.	1.7	4.6	14.0	9.0
	Chromis punctipinnis	1.6	2.3	7.5	4.7
	Sebastes entomelas	1.6	4.9	0.0	2.6
	Scorpaenichthys marmoratus	6.4	4.7	0.0	2.5
	Ophiodon elongatus	4.2	3.5	0.0	1.8
	Sebastes paucispinis	0.5	1.3	1.6	1.5
	Sebastes semicinctus	2.7	2.0	0.0	1.0
	Medialuna californiensis	1.8	1.9	0.0	1.0
Ellen	*Sebastes hopkinsi*	50.5	43.4	77.8	55.9
	Sebastes entomelas	25.1	45.3	0.7	29.2
	Chromis punctipinnis	4.1	2.3	10.1	5.1
	Sebastes spp.	0.9	1.4	6.7	3.3
	Sebastes paucispinis	0.6	1.4	4.6	2.6
	Scorpaenichthys marmoratus	7.7	2.0	0.0	1.2
Eureka	*Sebastes hopkinsi*	39.7	48.0	76.5	62.0
	Sebastes entomelas	22.0	17.6	0.0	8.9
	Sebastes spp.	3.1	3.8	9.8	6.8
	Chromis punctipinnis	4.4	5.5	4.5	5.0
	Sebastes rufus	3.7	4.3	5.3	4.8
	Sebastes mystinus	5.0	5.7	0.0	2.9
	Sebastes paucispinis	1.7	2.9	2.0	2.5
	Sebastes ovalis	4.8	3.4	1.0	2.2

Table 9. Mean of annual values scaled to per m^2 of seafloor beneath the platform for Complete (C) and partially removed (PR) platforms and the percent retained after partial removal (%). Standard errors are in parentheses.

	Biomass Density (g/m^2)			Somatic Production (g/m^2/yr)			Recruitment Production (g/m^2/yr)			Total Production (g/m^2/yr)		
Platform	**C**	**PR**	**%**	**C**	**PR**	**%**	**C**	**PR**	**%**	**C**	**PR**	**%**
Irene	703.8	546.7	80.7	275.0	209.6	79.1	229.3	173.4	77.5	504.4	383.0	78.2
	(153.4)	(115.4)	(1.8)	(72.7)	(54.7)	(1.7)	(119.9)	(90.2)	(1.1)	(172.0)	(129.4)	(1.3)
Hidalgo	326.6	294.9	91.7	95.2	84.2	89.9	204.2	177.5	87.0	299.4	261.8	88.3
	(73.6)	(64)	(1.0)	(24.9)	(21.6)	(0.8)	(76.0)	(66.0)	(0.0)	(99.9)	(86.7)	(0.5)
Harvest	290.3	277.0	95.6	80.2	76.5	95.4	94.9	89.4	94.9	175.1	165.9	95.3
	(107.1)	(101.0)	(0.8)	(35.0)	(33.0)	(0.8)	(85.2)	(80.3)	(0.4)	(119.4)	(112.4)	(0.8)
Hermosa	566.9	528.5	93.4	158.3	147.2	93.1	162.0	150.4	92.8	320.3	297.6	93.0
	(154.8)	(143.9)	(0.2)	(48.1)	(44.6)	(0.1)	(121.5)	(112.8)	(0.0)	(161.3)	(149.7)	(0.1)
Holly	518.2	417.6	79.6	114.0	93.2	81.6	56.8	50.5	82.6	170.8	143.6	82.4
	(71.1)	(63.7)	(2.6)	(22.2)	(19.1)	(2.6)	(20.8)	(20.6)	(4.0)	(37.6)	(34.8)	(2.9)
B	412.4	330.3	83.3	93.5	85.9	90.1	35.6	35.5	99.3	129.1	121.5	91.4
	(143.9)	(118.9)	(8.6)	(39.5)	(38.5)	(6.9)	(28.7)	(28.7)	(0.6)	(57.3)	(57.3)	(6.2)
A	611.7	423.8	67.0	110.7	90.7	80.2	16.8	16.6	95.2	127.6	107.3	84.0
	(113.2)	(95.3)	(4.2)	(30.7)	(27.1)	(3.4)	(7.1)	(7.2)	(3.0)	(28.7)	(24.8)	(2.7)
Hillhouse	506.2	424.6	78.0	159.5	151.6	83.1	198.5	186.4	83.1	358.0	338.0	81.0
	(245.3)	(249.0)	(7.9)	(114.9)	(116.3)	(7.9)	(175.5)	(177)	(12.9)	(289.9)	(293.1)	(10.5)
Habitat	624.9	613.4	97.9	197.5	195.3	98.5	38.9	37.7	98.0	236.4	233.0	98.5
	(235.3)	(230.0)	(0.6)	(89.3)	(88.3)	(0.5)	(16.3)	(15.8)	(1.3)	(100.2)	(98.3)	(0.4)
Gilda	346.0	304.9	87.4	120.6	111.4	92.5	88.6	84.6	95.4	209.2	196.0	94.4
	(71.9)	(63.8)	(3.5)	(26.4)	(24.2)	(2.3)	(34.6)	(33.3)	(2.7)	(51.6)	(49)	(2.2)
Grace	1416.7	1206.8	86.6	483.2	415.2	85.7	143.0	119.4	84.6	626.3	534.5	85.4
	(372.5)	(310.4)	(1.6)	(140.0)	(119.1)	(1.9)	(50.7)	(41.2)	(1.7)	(141.4)	(120.4)	(1.9)
Gail	229.7	216.8	95.8	52.0	49.7	96.3	51.2	48.8	95.5	103.2	98.5	95.9
	(28.9)	(25.8)	(1.8)	(12.6)	(12.0)	(1.1)	(21.9)	(20.8)	(0.3)	(33.8)	(32.3)	(0.8)
Edith	742.8	136.8	25.2	79.4	22.7	32.9	80.1	15.0	28.2	159.6	37.8	25.2
	(200.3)	(20.2)	(6.9)	(16.2)	(4.7)	(8.1)	(23.1)	(10.2)	(15.1)	(21.2)	(14.2)	(9.8)
Elly	1228.0	1108.7	86.5	162.7	153.2	89.2	142.1	134.2	72.5	304.8	287.4	84.8
	(251.3)	(265.7)	(4.5)	(46.1)	(47.3)	(4.4)	(75.1)	(75.1)	(13.9)	(112.6)	(114.8)	(6.7)
Ellen	2529.9	2374.6	90.6	587.0	567.4	92.2	321.4	297.7	89.0	908.4	865.1	91.7
	(870.4)	(868)	(2.8)	(278.2)	(278.4)	(3.0)	(184.7)	(185.6)	(4.9)	(404.9)	(397.7)	(2.6)
Eureka	2127.6	2020.3	94.1	350.4	332.2	93.9	340.6	328.0	92.8	691.0	660.2	94.2
	(413.5)	(414.9)	(1.3)	(65.3)	(67.3)	(1.6)	(114.1)	(115.2)	(2.8)	(173.9)	(176.4)	(1.3)

Table 10. Mean of annual values for Complete (C) and partially removed (PR) platforms and the percent retained after partial removal (%). Standard errors are in parentheses.

	Abundance			Recruitment Abundance (No./yr)		
Platform	**C**	**PR**	**%**	**C**	**PR**	**%**
Irene	101575	76922	76.8	77124	58199	75.9
	(34602)	(26014)	(0.8)	(36750)	(27637)	(0.2)
Hidalgo	156137	136313	87.9	146265	127092	86.9
	(51050)	(44318)	(0.3)	(52202)	(45355)	(0.0)
Harvest	68150	64496	95.3	45472	42887	94.7
	(37142)	(34954)	(0.8)	(29740)	(28026)	(0.3)
Hermosa	196147	182332	93.3	165694	153795	92.8
	(121210)	(112509)	(0.2)	(119741)	(111140)	(0.0)
Holly	22194	18653	82.3	10966	9423	82.1
	(4523)	(4257)	(3.3)	(3086)	(3001)	(4.3)
B	8234	7398	89.4	3107	3040	95.5
	(1911)	(1885)	(5.4)	(1556)	(1558)	(3.4)
A	14705	12379	83.7	5469	5416	94.1
	(2582)	(2245)	(2.9)	(2493)	(2499)	(3.7)
Hillhouse	17286	14344	79.1	11241	8953	83.1
	(9476)	(9136)	(9.1)	(7185)	(6658)	(12.5)
Habitat	25108	23657	96.1	7671	6501	88.1
	(8718)	(7928)	(2.0)	(3362)	(2729)	(6.5)
Gilda	29543	28688	94.2	20033	19695	95.2
	(10713)	(10750)	(2.3)	(9355)	(9428)	(2.4)
Grace	82682	70520	86.6	31618	26303	84.2
	(15105)	(12633)	(1.8)	(10671)	(8629)	(1.6)
Gail	20294	19124	94.1	16018	15257	94.9
	(4453)	(4231)	(1.3)	(4363)	(4158)	(0.5)
Edith	87756	14834	26.2	76988	11204	28.6
	(21147)	(5292)	(12.2)	(22726)	(5346)	(14.6)
Elly	93570	84323	79.9	62257	54526	69.3
	(35009)	(35396)	(8.9)	(29997)	(29369)	(12.1)
Ellen	239985	207206	88.5	157182	128535	85.4
	(80239)	(75370)	(4.8)	(59651)	(54204)	(6.9)
Eureka	300817	290173	95.5	218170	212320	94.2
	(78020)	(77080)	(0.8)	(72630)	(72256)	(2.4)

Table 11. Mean of annual values scaled to per m^2 of seafloor beneath the platform for Complete (C) and partially removed (PR) platforms and the percent retained after partial removal (%). Standard errors are in parentheses.

	Density (No./m^2)			Recruitment Density (No./m^2/yr)		
Platform	**C**	**PR**	**%**	**C**	**PR**	**%**
Irene	38.1	28.9	76.8	29.0	21.8	75.9
	(13.0)	(9.8)	(0.8)	(13.8)	(10.4)	(0.2)
Hidalgo	36.0	31.5	87.9	33.8	29.3	86.9
	(11.8)	(10.2)	(0.3)	(12)	(10.5)	(0.0)
Harvest	11.6	11.0	95.4	7.7	7.3	94.7
	(6.3)	(5.9)	(0.8)	(5)	(4.8)	(0.3)
Hermosa	37.7	35.0	93.3	31.8	29.6	92.8
	(23.3)	(21.6)	(0.2)	(23)	(21.4)	(0.0)
Holly	11.4	9.6	82.4	5.6	4.8	82.1
	(2.3)	(2.2)	(3.3)	(1.6)	(1.5)	(4.3)
B	4.2	3.7	89.5	1.6	1.5	95.5
	(1.0)	(1.0)	(5.4)	(0.8)	(0.8)	(3.4)
A	7.8	6.5	83.7	2.9	2.9	94.1
	(1.4)	(1.2)	(2.9)	(1.3)	(1.3)	(3.7)
Hillhouse	8.6	7.1	79.0	5.6	4.4	83.1
	(4.7)	(4.5)	(9.1)	(3.6)	(3.3)	(12.5)
Habitat	11.2	10.6	96.1	3.4	2.9	88.1
	(3.9)	(3.5)	(2.0)	(1.5)	(1.2)	(6.5)
Gilda	14.2	13.8	94.2	9.6	9.5	95.2
	(5.1)	(5.2)	(2.3)	(4.5)	(4.5)	(2.4)
Grace	27.5	23.5	86.6	10.5	8.8	84.2
	(5.0)	(4.2)	(1.8)	(3.6)	(2.9)	(1.6)
Gail	3.8	3.5	94.1	3.0	2.8	94.9
	(0.8)	(0.8)	(1.3)	(0.8)	(0.8)	(0.5)
Edith	33.9	5.7	26.2	29.7	4.3	28.6
	(8.2)	(2)	(12.2)	(8.8)	(2.1)	(14.6)
Elly	35.1	31.7	79.9	23.4	20.5	69.3
	(13.1)	(13.3)	(8.9)	(11.3)	(11.0)	(12.1)
Ellen	90.1	77.8	88.5	59.0	48.2	85.4
	(30.1)	(28.3)	(4.8)	(22.4)	(20.3)	(6.9)
Eureka	55.8	53.8	95.5	40.5	39.4	94.2
	(14.5)	(14.3)	(0.8)	(13.5)	(13.4)	(2.4)

Table 12. Shellmound mean of annual values. Standard errors are in parentheses. The platforms that the shellmounds are around are in ordered from North to South.

Platform	Density ($No./m^2$)	Recruitment Density ($No./m^2$)	Biomass Density (g/m^2)	Somatic Production ($g/m^2/yr$)	Recruitment Production ($g/m^2/yr$)	Total Production ($g/m^2/yr$)
Irene	1.32	0.88	41.15	12.31	11.70	24.01
	(0.69)	(0.55)	(8.66)	(2.58)	(2.63)	(4.90)
Hidalgo	0.80	0.04	22.37	5.91	2.45	8.36
	(0.50)	(0.01)	(6.14)	(2.12)	(1.00)	(2.79)
Harvest	0.32	0.00	18.60	3.33	0.23	3.56
	(0.05)	(0.00)	(2.22)	(0.66)	(0.10)	(0.65)
Hermosa	1.86	0.01	47.88	6.50	0.45	6.95
	(0.64)	(0.00)	(4.99)	(2.47)	(0.16)	(2.48)
Holly	0.62	0.13	53.02	7.59	1.85	9.44
	(0.12)	(0.06)	(22.48)	(2.08)	(0.34)	(2.10)
Gilda	4.44	0.44	138.58	34.35	34.14	68.49
	(3.68)	(0.37)	(84.85)	(18.66)	(29.08)	(45.18)
Grace	1.19	0.05	72.76	8.08	2.38	10.46
	(0.37)	(0.02)	(17.27)	(1.53)	(1.03)	(2.32)
Gail	0.26	0.01	31.11	4.57	0.20	4.77
	(0.07)	(0.00)	(7.36)	(0.89)	(0.04)	(0.87)
Edith	5.55	2.17	113.94	25.64	4.06	29.71
	(2.78)	(0.87)	(52.52)	(11.83)	(1.57)	(12.63)
Elly	4.75	2.01	176.29	24.77	11.91	36.68
	(1.61)	(1.05)	(28.38)	(6.10)	(8.09)	(13.82)
Ellen	3.21	0.48	99.73	13.83	2.48	16.30
	(1.42)	(0.28)	(24.68)	(3.86)	(0.79)	(4.37)
Eureka	0.08	0.01	4.93	0.73	0.10	0.83
	(0.01)	(0.00)	(1.41)	(0.23)	(0.07)	(0.30)

Table 13. Shellmound percent contribution of individual taxa. Only taxa that contribute at least 1.0% of the Total Production are included. The platforms that the shellmounds are around are ordered from North to South and taxa are sorted by percent contribution to Total Production.

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
Irene	*Ophiodon elongatus*	44.6	7.1	82.1	68.9
	Sebastes caurinus	20.5	12.4	6.2	12.2
	Sebastes semicinctus	9.3	47.2	6.6	7.5
	Sebastes miniatus	7.0	5.6	0.0	2.3
	Citharichthys sordidus	1.4	2.0	2.8	2.3
	Oxylebius pictus	6.3	9.3	0.0	1.1
	Sebastes pinniger	1.4	0.6	0.0	1.1
Hidalgo	*Ophiodon elongatus*	49.6	2.3	95.3	65.1
	Sebastes semicinctus	39.9	87.4	0.0	26.7
	Sebastes elongatus	2.0	2.3	0.0	1.3
	Citharichthys sordidus	1.5	0.7	0.6	1.2
Harvest	*Ophiodon elongatus*	9.2	0.9	71.3	30.3
	Sebastes saxicola	37.4	49.7	0.0	20.1
	Sebastes elongatus	28.0	15.7	0.0	18.4
	Sebastes zacentrus	5.3	8.7	0.0	10.3
	Sebastes chlorostictus	6.7	4.7	0.0	7.4
	Sebastes semicinctus	5.6	11.4	0.0	4.6
	Sebastes rosenblatti	1.3	0.9	0.0	1.9
	Sebastes spp.	1.1	1.0	12.7	1.5
Hermosa	*Sebastes semicinctus*	83.7	90.3	0.6	70.9
	Ophiodon elongatus	0.8	0.1	82.3	8.4
	Sebastes jordani	5.6	2.8	0.0	6.9
	Sebastes chlorostictus	1.7	0.8	0.0	2.8
	Sebastes saxicola	3.1	3.0	0.0	2.7
	Zaniolepis frenata	1.4	0.9	3.2	2.0
	Citharichthys spp.	0.8	0.3	2.6	1.6
	Sebastes elongatus	1.2	0.5	0.0	1.3
Holly	*Sebastes caurinus*	10.6	8.4	28.3	24.8
	Ophiodon elongatus	4.5	0.9	22.7	18.2
	Sebastes miniatus	10.2	9.0	0.0	11.5
	Rathbunella spp.	1.1	1.2	16.3	7.3
	Sebastes dallii	23.0	44.0	0.3	6.1
	Sebastes auriculatus	2.7	1.1	0.0	5.3
	Citharichthys sordidus	0.4	1.0	10.3	3.1
	Sebastes pinniger	1.2	0.5	0.0	3.1
	Hexagrammos decagrammus	1.9	0.6	0.0	2.2
	Sebastes semicinctus	1.9	7.1	1.0	2.1
	Sebastes rubrivinctus	1.6	2.3	4.6	1.9
	Citharichthys spp.	0.2	0.4	5.0	1.5
	Merluccius productus	0.5	0.2	0.0	1.5
	Sebastes rosaceus	2.4	3.4	0.0	1.5
	Sebastes hopkinsi	0.6	3.1	3.6	1.3

Table 13. (*continued*)

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
Gilda	*Sebastes paucispinis*	18.8	5.8	76.0	59.3
	Ophiodon elongatus	5.9	0.7	22.4	17.6
	Sebastes semicinctus	60.6	85.3	0.0	15.9
	Sebastes miniatus	6.0	3.3	0.0	2.9
	Sebastes entomelas	1.5	0.4	0.0	1.3
Grace	*Ophiodon elongatus*	8.4	1.0	60.6	41.8
	Sebastes semicinctus	42.2	64.3	0.0	15.0
	Sebastes paucispinis	1.9	0.7	30.1	12.9
	Sebastes miniatus	13.0	3.1	0.0	7.9
	Citharichthys spp.	4.4	2.1	2.3	5.2
	Cymatogaster aggregata	18.6	18.0	0.0	4.9
	Sebastes hopkinsi	1.1	2.0	2.8	1.9
	Sebastes chlorostictus	1.3	0.7	0.0	1.5
	Sebastes mystinus	1.0	0.3	0.0	1.3
	Sebastes spp.	0.7	1.3	2.0	1.2
Gail	*Ophiodon elongatus*	41.2	1.5	21.2	27.6
	Sebastes elongatus	14.6	30.8	0.0	17.1
	Merluccius productus	4.3	2.3	0.0	10.1
	Sebastes rosenblatti	7.9	7.6	0.0	10.0
	Sebastes paucispinis	5.6	1.1	10.1	10.0
	Sebastes saxicola	6.2	17.0	0.0	3.6
	Torpedo californica	2.8	0.1	0.0	3.6
	Sebastes simulator	6.6	18.5	0.0	2.5
	Sebastes macdonaldi	2.0	0.2	0.0	2.4
	Microstomus pacificus	0.4	1.2	23.1	1.9
	Sebastes chlorostictus	0.8	1.1	0.0	1.1
Edith	*Scorpaena guttata*	59.0	13.8	0.0	47.2
	Sebastes semicinctus	21.5	54.9	21.1	28.9
	Sebastes hopkinsi	1.6	12.5	45.3	8.6
	Sebastes spp.	1.0	4.5	26.8	5.0
	Scorpaenichthys marmoratus	5.5	0.3	0.0	3.3
	Ophiodon elongatus	1.9	0.1	0.8	3.3
	Rhinogobiops nicholsii	1.8	9.9	0.0	1.1
	Sebastes jordani	0.2	0.5	5.2	1.1
Elly	*Sebastes hopkinsi*	10.4	27.7	71.7	35.9
	Ophiodon elongatus	50.4	0.9	0.5	28.7
	Sebastes semicinctus	28.9	58.1	6.1	21.2
	Sebastes spp.	1.0	6.8	14.0	6.2
	Sebastes paucispinis	0.3	0.1	3.7	1.8
	Sebastes jordani	0.3	0.8	1.9	1.2

Table 13. (*continued*)

Platform	Taxon	Biomass	Somatic Production	Recruitment Production	Total Production
Ellen	*Sebastes semicinctus*	53.7	81.8	9.0	45.7
	Ophiodon elongatus	15.7	0.3	7.0	15.9
	Citharichthys spp.	2.2	1.2	21.7	7.5
	Sebastes hopkinsi	2.8	4.0	26.8	7.1
	Sebastes umbrosus	5.5	3.2	0.0	4.6
	Sebastes spp.	0.6	2.6	17.7	3.7
	Sebastes miniatus	3.8	1.0	0.0	3.3
	Rathbunella alleni	0.4	0.2	4.9	2.3
	Sebastes paucispinis	0.2	0.1	7.0	1.6
	Sebastes rubrivinctus	0.9	0.7	4.8	1.5
	Scorpaenichthys marmoratus	2.9	0.1	0.0	1.2
	Sebastes rosaceus	3.1	1.4	0.0	1.1
Eureka	*Microstomus pacificus*	4.0	5.2	88.6	19.0
	Sebastes simulator	44.7	51.3	0.0	15.8
	Sebastes rosenblatti	8.4	4.9	0.0	13.5
	Sebastes elongatus	9.6	9.0	0.0	11.2
	Zoarcidae	1.8	0.9	0.0	9.6
	Scorpaenichthys marmoratus	6.5	0.5	0.0	9.6
	Zaniolepis frenata	8.1	8.2	0.0	8.0
	Zaniolepis spp.	2.4	3.0	2.8	3.4
	Sebastes helvomaculatus	1.9	2.2	0.0	2.5
	Sebastomus	6.8	7.9	0.0	2.5
	Sebastes chlorostictus	1.1	0.7	0.0	1.5
	Stichaeidae spp.	0.2	0.3	8.0	1.4

Table 14. Shellmound mean of annual values. Standard errors are in parentheses. The platforms that the shellmounds are around are in ordered from North to South.

Platform	Abundance	Recruitment Abundance	Biomass (kg)	Somatic Production (kg/yr)	Recruitment Production (kg/yr)	Total Production (kg/yr)
Irene	17821	11936	555	166	158	324
	(9249)	(7435)	(117)	(35)	(35)	(66)
Hermosa	1196	8	31	4	0	4
	(409)	(2)	(3)	(2)	(0)	(2)
Gilda	81187	8014	2534	628	624	1253
	(67379)	(6811)	(1552)	(341)	(532)	(826)
Grace	27120	1132	1655	184	54	238
	(8426)	(346)	(393)	(35)	(24)	(53)
Gail	173	5	20	3	0	3
	(48)	(1)	(5)	(1)	(0)	(1)

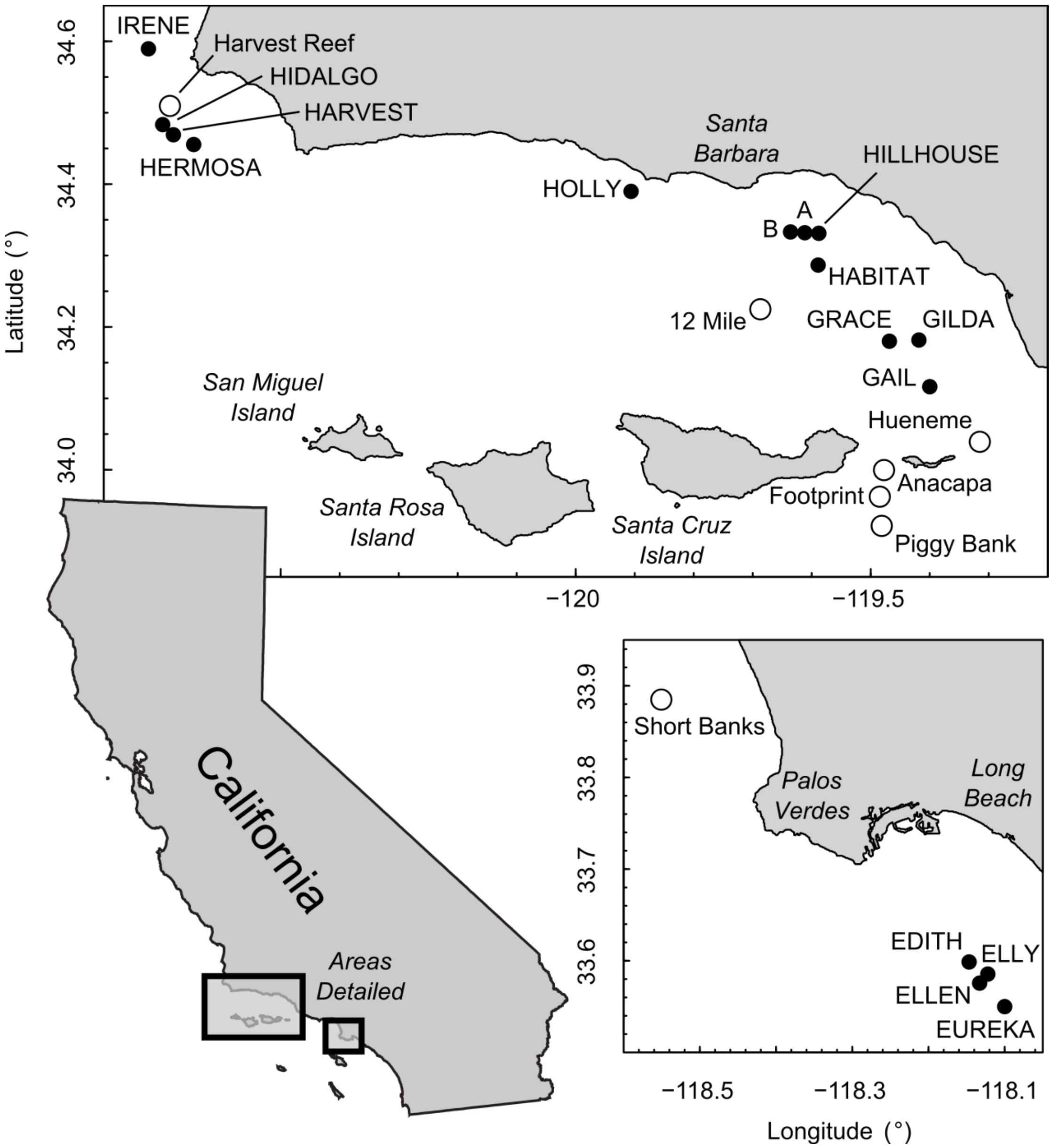

Figure. 1. Map of the study area. The 16 platforms (filled circles, names in all capital letters) and 7 natural reefs (open circles) used in the study were surveyed for at least 5 (up to 15) years between 1995 and 2011.

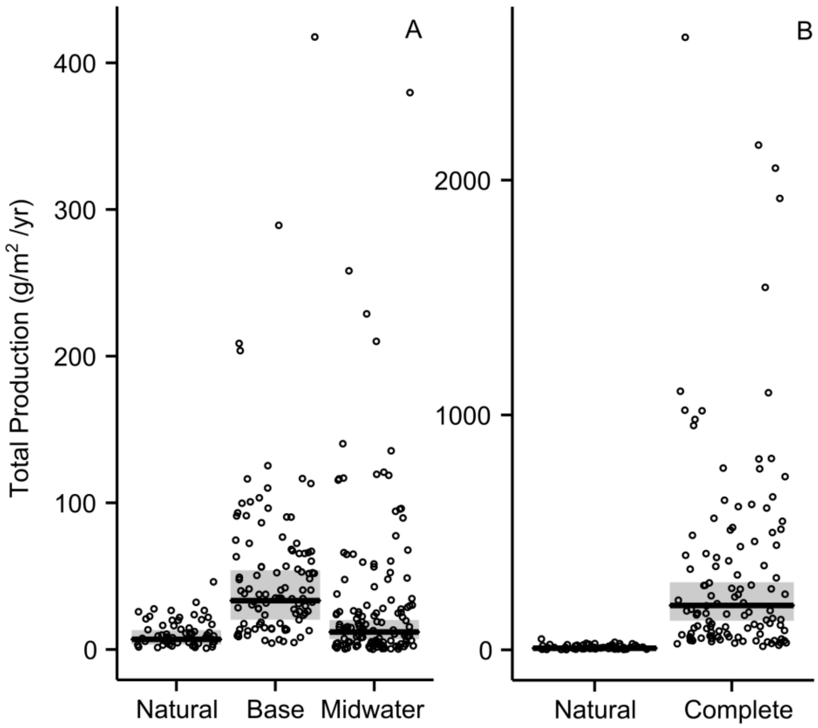

Figure 2. Total Production. (A) Natural reefs (n=56) and platform habitat sub-types [base (n=11), midwater (n=132)] and (B) natural reefs (n=56) and complete platform values (n=111). Circles indicate individual data points and are jittered for visibility. Horizontal lines show the back-transformed estimated marginal means. These geometric means also approximate the median on the original scale presented here. The shaded box represents the 95% CI of the mean. Differences were considered significant if the 95% CIs of their marginal means did not overlap.

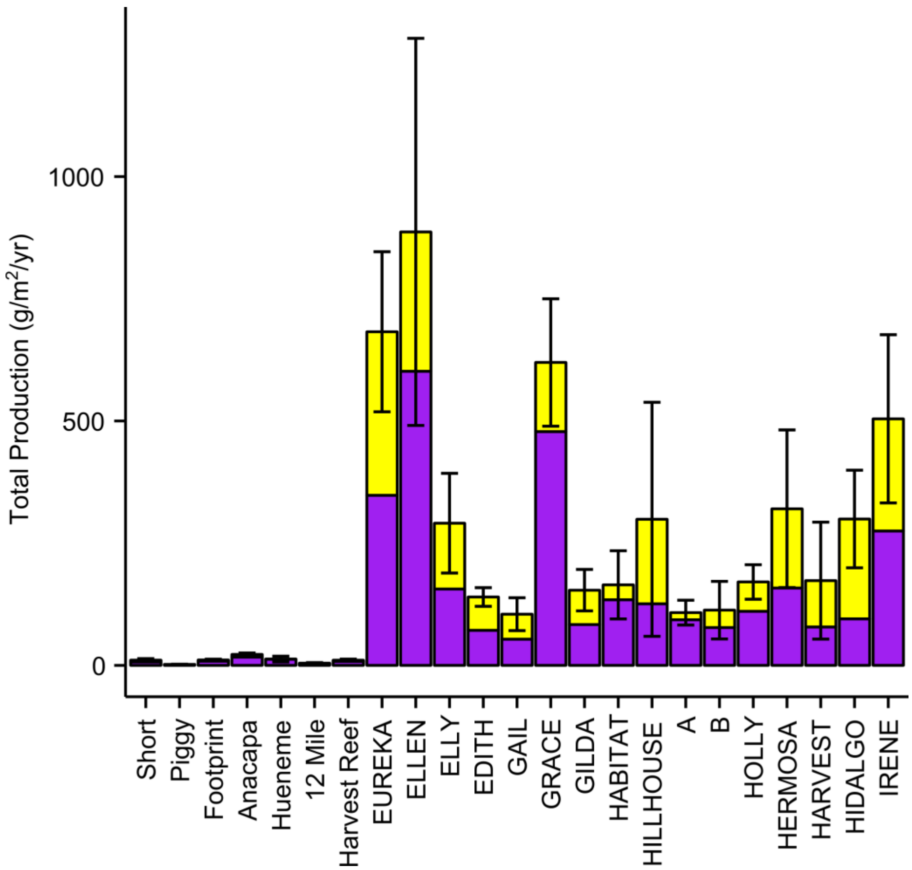

Figure 3. Annual Total Production by site. Arithmetic means with SE error bars are divided into Somatic Production (purple) and Recruitment Production (yellow). Sites of each type are ordered from south to north and platform site names are in capital letters. Note that the base habitat of platforms Habitat, Hillhouse, A and B were never surveyed and therefore not included in these calculations, so their values will be underestimated.

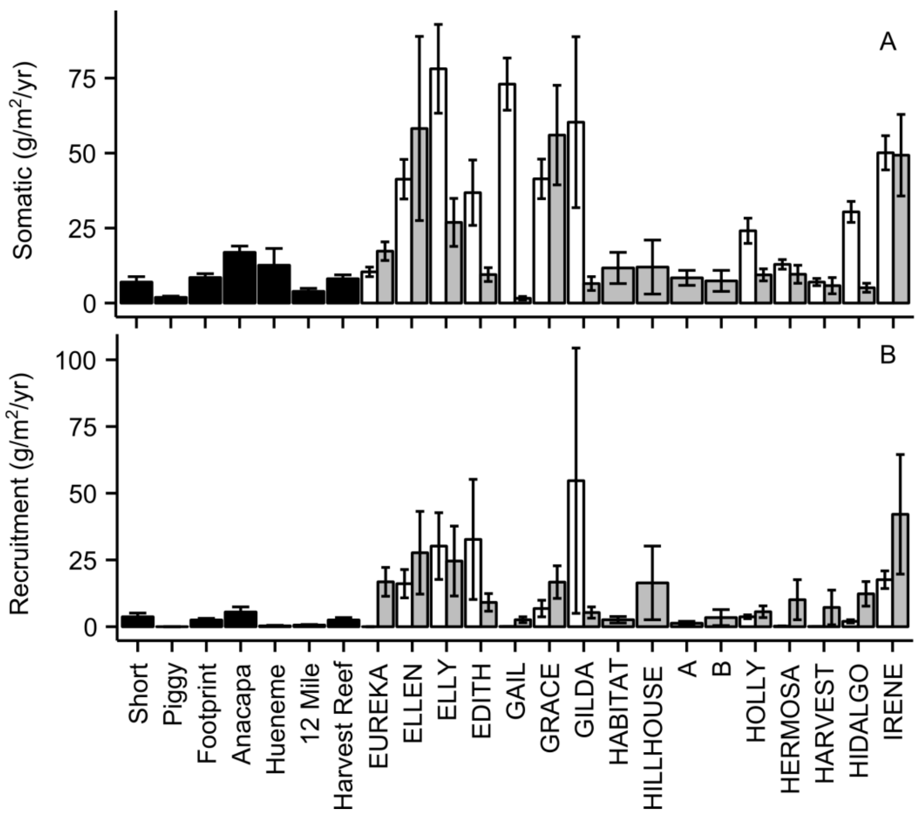

Figure 4. Annual Production by site and habitat type. Annual Somatic Production (A) and annual Recruitment Production (B) (arithmetic mean with SE error bars) by habitat type (natural reefs: black bars; platform base: white bars; platform midwater: grey bars). Sites of each type (natural reefs, platforms) are ordered from south to north and platform site names are in capital letters.

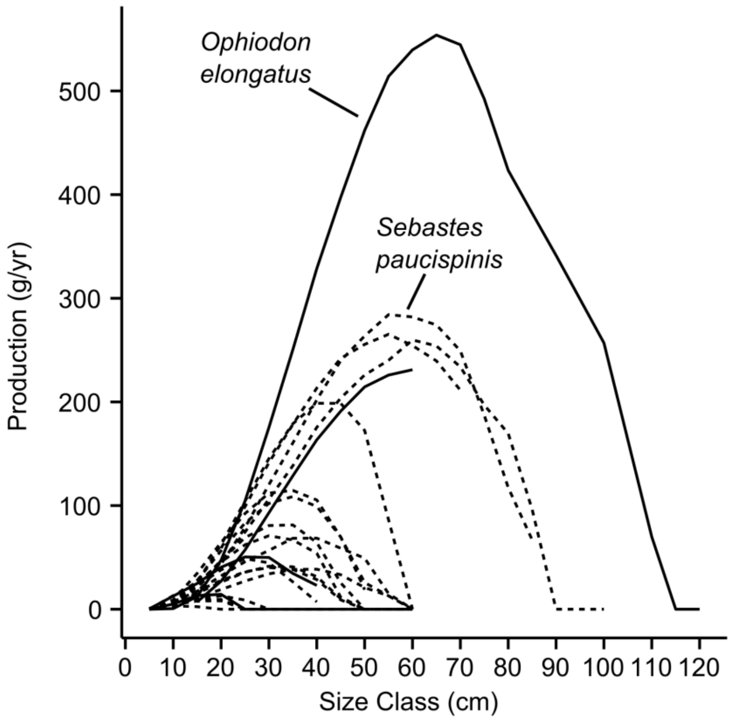

Figure 5. Annual somatic production per individual observed by total length. The values presented here are the product of $G^{W}_{i,j}$, the annual growth in weight and $S_{i,j}$, annual survivorship (see equation 5) and plotted for each species that contributed at least 1% of Total Production in any habitat (Table 3). Values are plotted over the size classes that a species was observed and rockfishes, *Sebastes spp.* were plotted with dashed lines. Note that while growth in length according to the von Bertalanffy growth equation is highest at the smallest size, production here is maximized at intermediate lengths due to the exponential increase with weight at length and low survival at small sizes. Also, production goes to 0 when fishes grow larger than the mean asymptotic length predicted by the von Bertalanffy growth function.

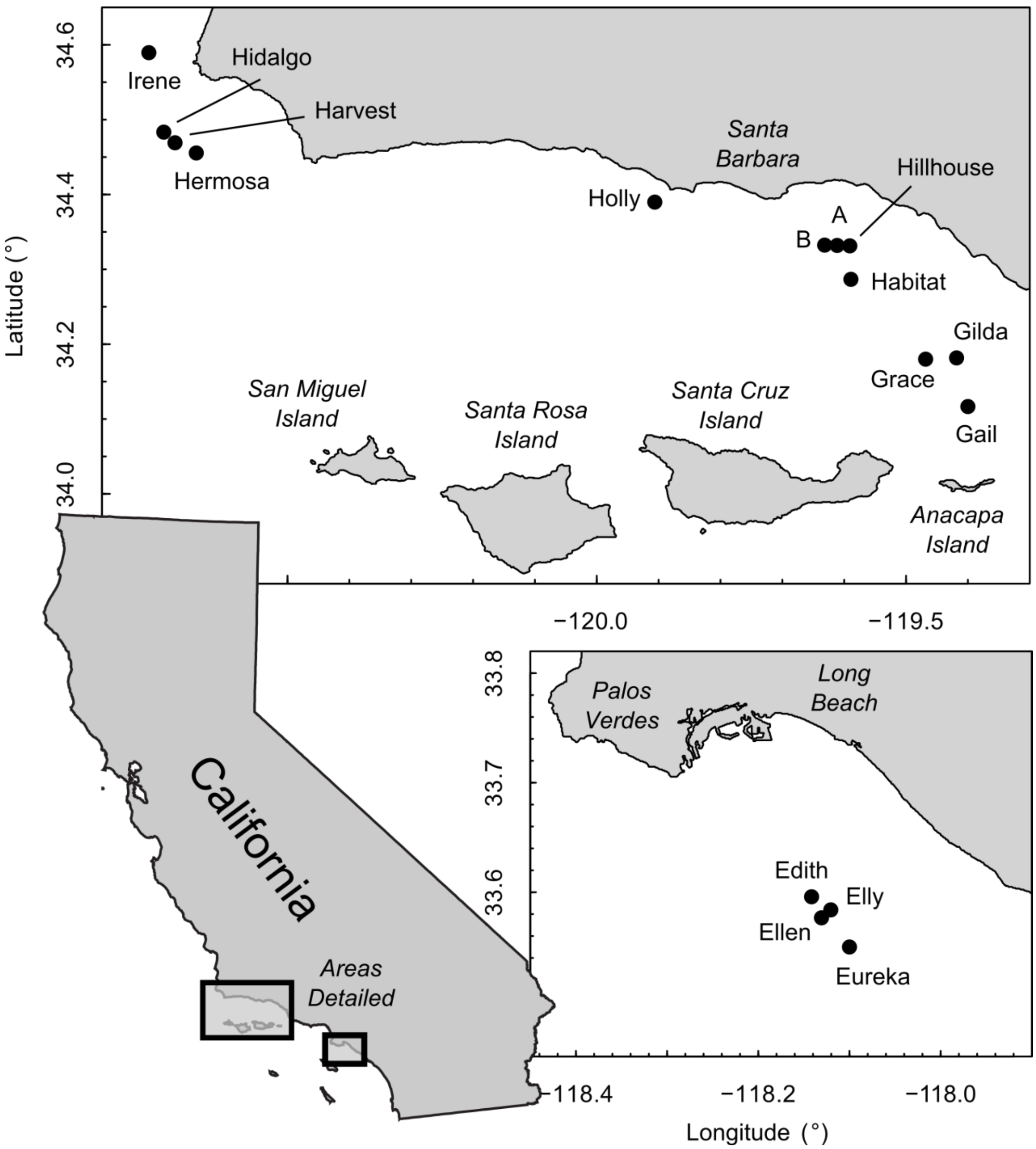

Figure 6. Map of the study area. The 16 oil and gas platforms (filled circles) used in the study were surveyed for at least 5 (up to 15) years between 1995 and 2011.

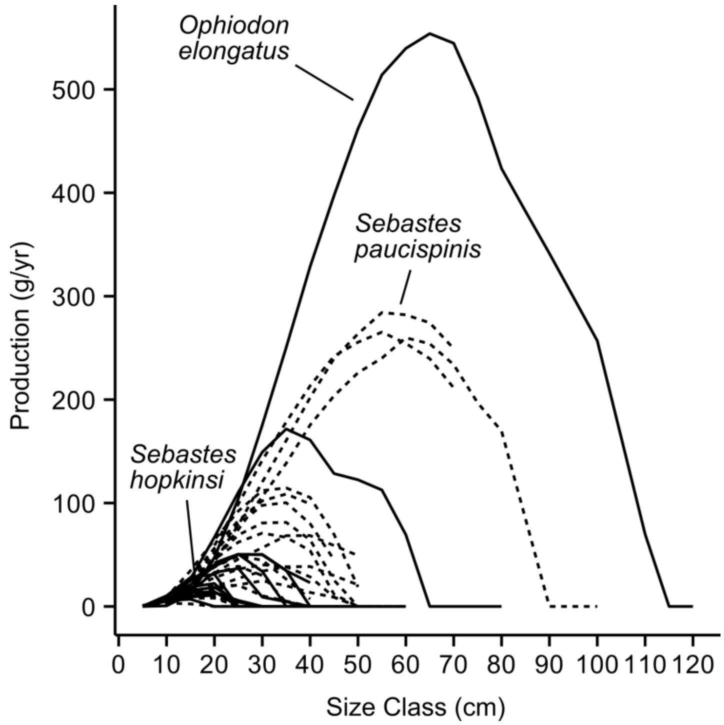

Figure 7. Annual somatic production per individual observed by size class. The values presented here are the product of $G_{i,j}^{W}$, the annual growth in weight and $S_{i,j}$, annual survivorship (see equation 5) and plotted for each species that contributed at least 1% of Total Production on any platform (Table 8). Values are plotted over the size classes that a species was observed and rockfishes, *Sebastes spp.* were plotted with dashed lines. Note that while growth in length according to the von Bertalanffy growth equation is highest at the smallest size, production here is maximized at intermediate lengths due to the exponential increase with weight at length and low survival at small sizes. Also, production goes to 0 when fishes grow larger than the mean asymptotic length predicted by the von Bertalanffy growth function.

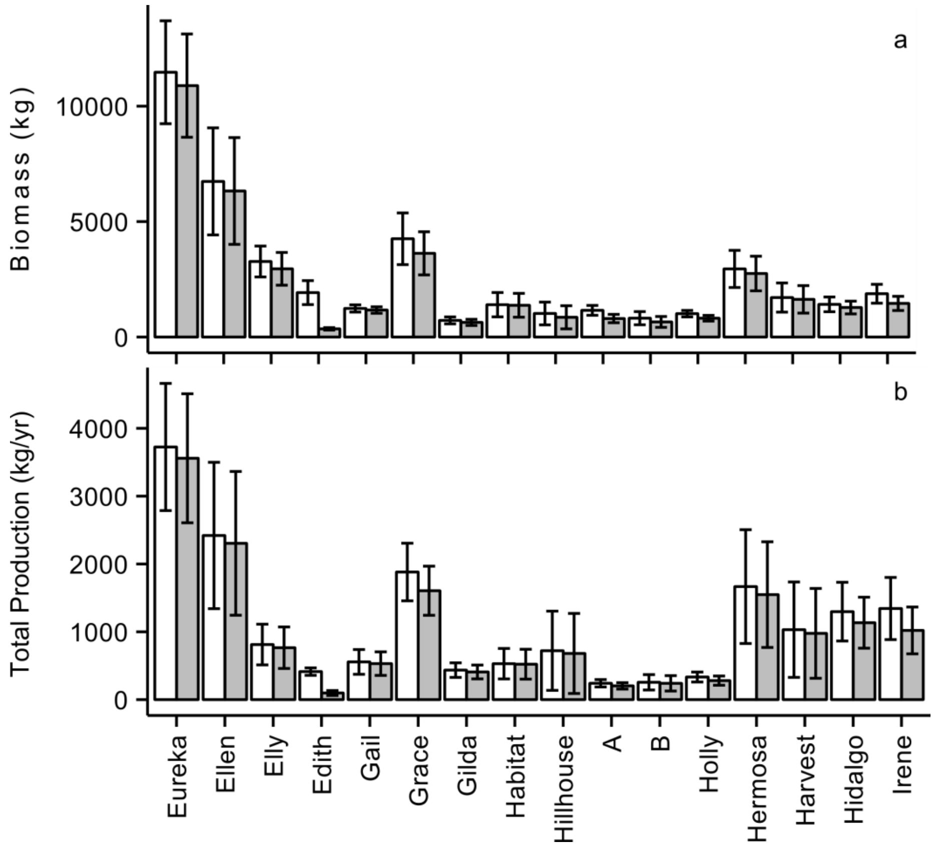

Figure 8. Biomass (a) and Total Production (b) for Complete (white bars) and partially removed (gray bars) platforms with SE error bars. Platforms are ordered from south to north (Figure 6).

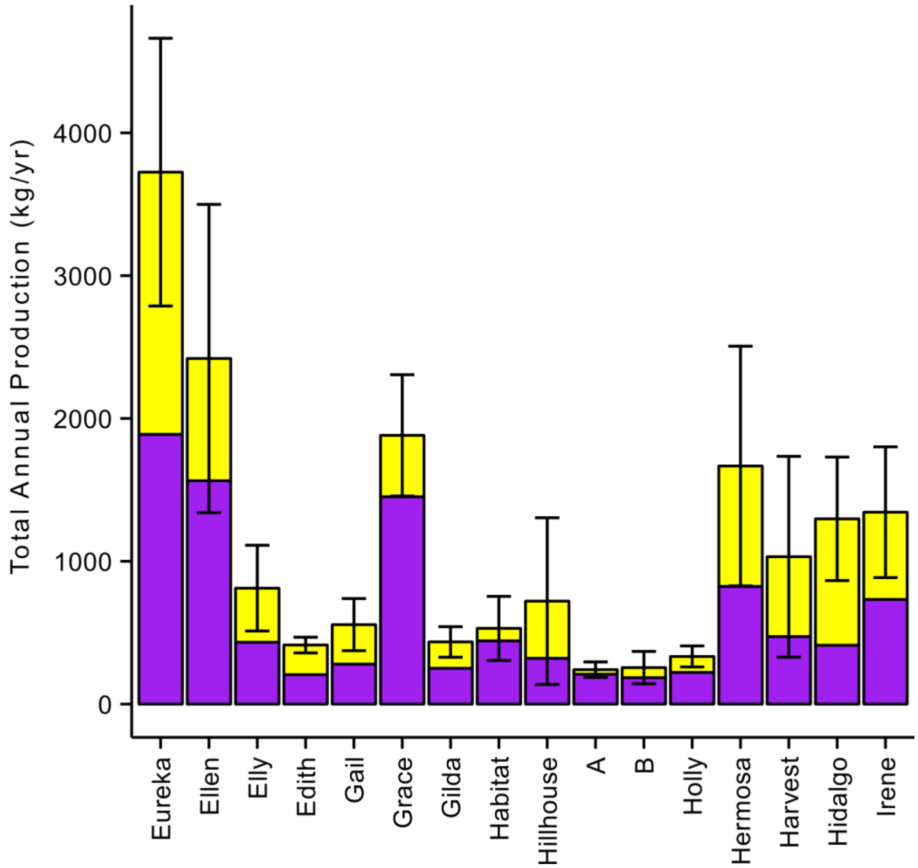

Figure 9. Annual Total Production by platform. Arithmetic means with SE error bars are divided into Somatic Production (purple) and Recruitment Production (yellow). Platforms are ordered from south to north.

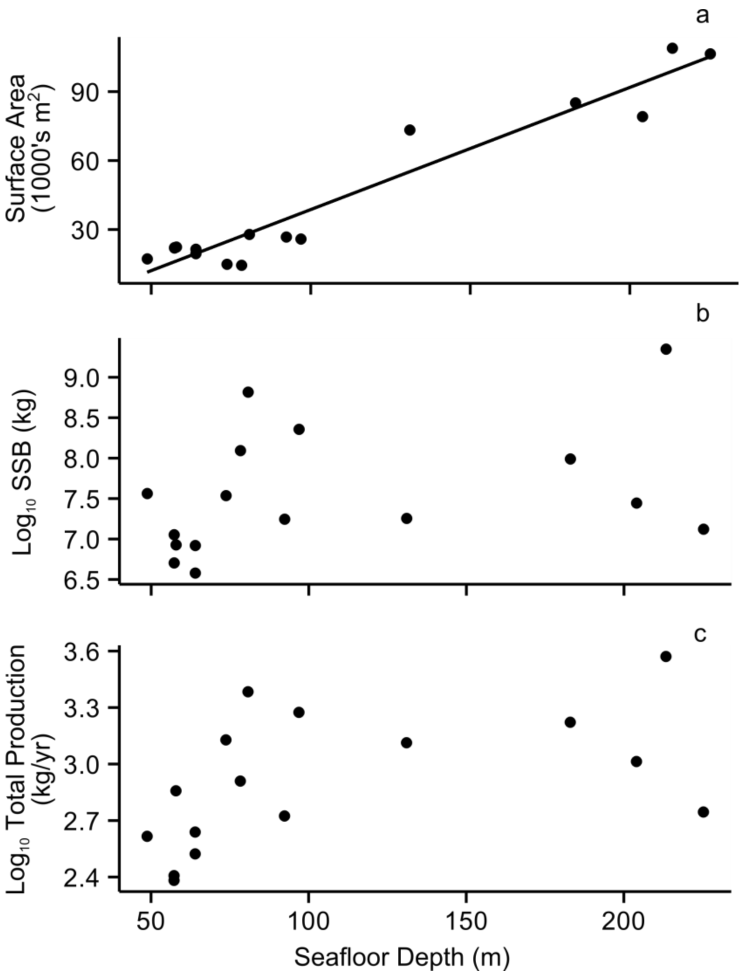

Figure 10. Relationship between platform seafloor depth and platform submerged surface area (Surface Area (m^2) = 531 * Seafloor Depth(m)-14464; R^2=0.93; F=185.2; $DF_{1,14}$; p-value <0.001) (a), Log_{10} complete platform standing stock biomass (SSB) (b) and Log_{10} complete platform Total Production (c).

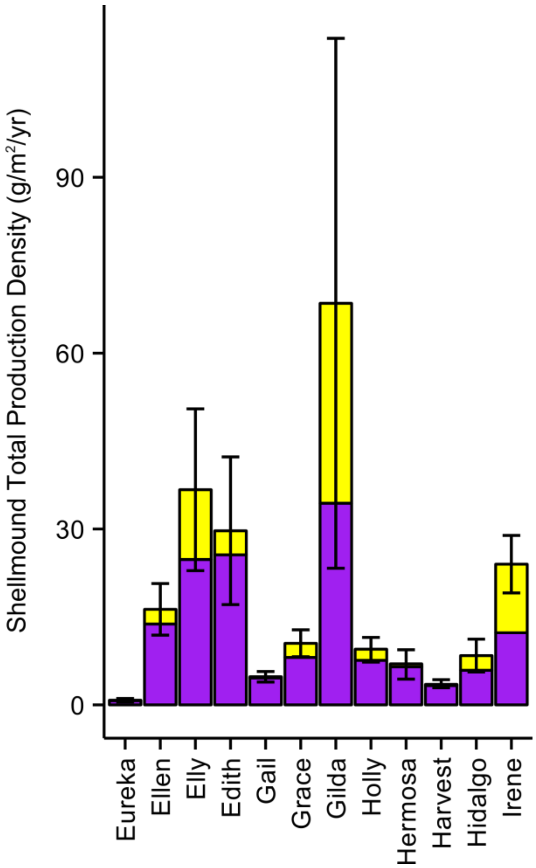

Figure 11. Shellmound annual Total Production density by site. Arithmetic means with SE error bars are divided into Somatic Production (purple) and Recruitment Production (yellow). The platforms that the shellmounds surround are ordered from south to north.