Ecological Issues Related to Decommissioning of California's Offshore Production Platforms

Report to the University of California Marine Council
by
The Select Scientific Advisory Committee on Decommissioning
University of California

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October 17, 2000

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Executive Summary

The Select Scientific Advisory Committee on Decommissioning explored possible marine ecological implications related to the decommissioning of California's twenty-seven offshore oil production platforms to assess the current state of knowledge and identify a research agenda to fill information gaps. The Committee explored the ecological consequences of five identified decommissioning options for coastal platforms including (1) leaving the intact structure in place, (2) complete removal, (3) top portion of platform removed to 20 to 30 meters subsurface and remaining lower portion left standing in place ("topping"), (4) structure toppled over in the same location ("toppling") and (5) structure moved to a new location and toppled.

Biotic surveys of California platforms indicate that many different species of fish and invertebrates can be found on the current platform structures, with some of these species spending only part of their lives there. The set of species that occupies a platform is influenced by the biogeographic setting of the platform, as well as its depth. Based on existing biological information, some of the local, short-term effects of decommissioning options can be estimated, but the Committee wishes to emphasize that longer-term regional effects cannot be predicted with reasonable scientific certainty. The regional effect on stocks of species is the most important possibility to examine from an ecological perspective.

There is not any sound scientific evidence (that the Committee is aware of) to support the idea that platforms enhance (or reduce) regional stocks of marine species. The primary reason for this conclusion is that the 27 platforms represent a tiny fraction of the available hard substrate in the Southern California Bight, so their contribution to stocks of most reef organisms is likely to be small relative to the contribution from natural reefs. The Committee felt it was important, however, that it fully explore the state of knowledge on possible ecological impacts even though the habitat contribution of these platforms is, as just described, necessarily limited. In doing so, the Committee found that the possible regional effects on a stock of habitat removal are much harder to assess than the short-term ecological impacts localized at the site of the platform because most marine species are composed of a series of local populations that are connected via larval dispersal of young stages. Thus, populations are interdependent, and impacts at any one location (a reef or platform) must be viewed in the context of the regional set of local populations. Regional effects cannot be projected at present because we do not fully understand how local populations are connected (i.e., we know that larvae are transported and older individuals move between various reefs, artificial reefs and oil platforms, but we do not understand specific links among local populations) nor do we know the degree to which populations on artificial structures are self-sustaining.

A research agenda to address the marine ecological consequences of decommissioning should include (1) assessing the quality of habitat for marine species afforded by platforms compared to natural reefs; (2) estimating the connectivity between local populations; and (3) developing models of the effects on the regional population of key

species of the addition or removal of artificial structures (such as would result from the various decommissioning options). Additionally, to best evaluate decommissioning alternatives one would need several other types of information that address (1) spatial and temporal patterns of distribution and abundance of reef-associated species in different parts of the Southern California Bight, including on natural reefs and associated with platforms, (2) distribution, abundance and quality of natural hard substrate in the area, and (3) physical oceanographic data to identify patterns of water circulation off the coast of California, coupled with estimates of population connectivity for species of interest. In the opinion of the Committee, no matter what policy decision about decommissioning is made, the effects should be monitored, and the State should adaptively respond to the consequences of the decision.

At the end of its investigation of marine ecological issues surrounding decommissioning of California's offshore platforms, the Committee drew several general conclusions that could be useful to policymakers. These are reported on pages 35 – 36, and are reproduced here for convenience.

1. Surveys of platforms in California waters reveal that they harbor rich assemblages of marine organisms, including many fishes and invertebrates that typically occur on natural rocky reef substrates. The particular species present on any given platform depend on the biogeographic setting of the platform and its depth, as well as other factors. Despite the fact that platforms can harbor abundant marine life, it is the platform's contribution to regional stocks of species that is the crucial metric for evaluating its ecological impact. This is due to the fact that most marine species consist of a series of local populations (such as would occupy a reef) that are linked together by larval dispersal of young stages. The interdependence of populations means that impacts at any one location must be considered in the context of the regional set of local populations. Most extant assessments of possible biological effects of platforms are fundamentally flawed because they focus on local and not regional effects. At present there is not any sound scientific evidence (that the Committee is aware of) to support the idea that platforms enhance (or reduce) regional stocks of marine species.
2. The total "reef" area represented by the 27 California platforms is extremely small in relation to regional availability of hard bottom substrates, suggesting that for the majority of species any regional impacts (whether positive or negative) of a decommissioning option are likely to be small and possibly not even detectable empirically.
3. However, because species differ greatly in life history, population dynamics, and geographic distribution, it is possible that platforms could have a more substantial effect (either positive or negative) on some key species. These species might be of special interest from a management point of view – rare or endangered, of economic importance, etc. In such cases, further study of effects of decommissioning alternatives, using approaches outlined in this report, could yield the scientific information needed to predict impacts of decommissioning alternatives in the context of overall management strategies. Species of special

concern could include, for example, several rockfishes whose low abundance has triggered severe restrictions on harvest and the creation of rebuilding plans by the Pacific Fishery Management Council (McCall *et al.* 1999). Bocaccio, for example, is estimated to have declined to about 1 percent of virgin biomass. Love *et al.* (2000) reported that Platform Gail had a density of adult bocaccio an order of magnitude greater than the average density found on 61 natural reefs in appropriate depths. The issue, then, is to evaluate whether these higher densities of some populations on platforms persist through time, and if so, whether they could have a positive effect on regional stocks, given the very small surface area that the offshore platforms represent.

4. Decommissioning of offshore oil production facilities will involve offshore as well as onshore structures, and the various alternatives would involve a broad array of possible consequences that include not only the marine ecological effects we have addressed, but also economic, political and social impacts. These factors would need to be evaluated together to reach a final decision as to whether a decommissioning alternative other than platform removal is desirable. Nevertheless, with the current state of knowledge, predicting effects of decommissioning options on regional stocks of marine species is not possible. Indeed, there is no clear evidence of biological benefit (in the sense of enhancement of regional stocks) of the platforms in their present configuration. Thus, in light of the lack of strong evidence of benefit and the relatively small contribution of platforms to reef habitat in the region, evaluation of decommissioning alternatives in our opinion should not be based on the assumption that platforms currently enhance marine resources.

I. Introduction

I.A. Committee objectives

There are twenty-seven oil platforms off the California coast. During the next two decades a number of these facilities will reach the end of their useful life and will be decommissioned. Under the terms of current state and federal leases, platforms would be completely removed at the time of decommissioning. However, it has been suggested that using the structures for artificial reefs might provide significant benefits, and this has led to increased interest in exploring the costs and consequences of various other decommissioning strategies. These strategies could involve leaving the platform or some of its components in the same location or moving materials to form an artificial reef in a new location. At the request of State Senator Dede Alpert, the University of California Marine Council (UCMC), in consultation with the University of California Office of the President, appointed a Select Scientific Advisory Committee to explore marine biological issues related to the decommissioning of offshore oil production facilities. The first task of the Committee was to assess the state of knowledge regarding the potential ecological and environmental consequences of various decommissioning strategies, to determine what is known as well as to identify information gaps for decision makers. Additionally, the Committee has endeavored to articulate the degree of uncertainty in our current understanding of the biological issues and the extent to which this uncertainty affects assessment and evaluation of various decommissioning alternatives. The Committee has articulated a set of research questions that would need to be answered in order to evaluate the consequences of various decommissioning alternatives.

The Committee examined five identified decommissioning options of coastal oil/gas platforms. These are described in Section **II.B**. Decommissioning of offshore oil production facilities in its broad context involves offshore as well as onshore and associated structures, and a wide variety of possible consequences, including ecological, economic, cultural, political, social, ethical and aesthetic. The Committee was given the more specific focus of addressing only *ecological consequences in the marine environment*. Thus, the scope of issues addressed was restricted to marine ecological considerations and did not consider the direct or indirect ecological or environmental consequences to the atmospheric or terrestrial environments, or the many socio-economic or political considerations. Clearly, these factors should be evaluated together if the State were to consider alternatives to the present strategy for decommissioning (complete removal).

Our analysis considered the 27 platforms along the coast of California in light of their regional distribution. There are four platforms north of Point Conception in the Santa Maria Basin, sixteen platforms in the Santa Barbara Channel and seven platforms in San Pedro Bay. The Committee endeavored to identify potential ecological consequences of the various decommissioning alternatives over both short (weeks to months) and long (decades) time periods and at local (at the platform) and regional spatial scales. The importance of understanding consequences at a range of scales was motivated by the biological features of the marine life typically associated with offshore oil structures. First, most of these populations of fish, invertebrates and algae have early life stages (i.e. eggs, larvae, spores) that can be dispersed great distances (in some cases up to hundreds of kilometers) but adult stages that often remain in localized reef areas. This necessitates examining consequences to their populations in the close vicinity of the platform as well as further away, because early life stages are exchanged among local populations. Second, many of the species involved are very long-lived, and numerical effects on their populations (whether beneficial or deleterious) could take years or even decades to accrue.

I.B. Structure of this report

This report has several sections. **Section II** provides several types of background material. We briefly review the physical setting and biological features of offshore platforms in California, and outline five proposed decommissioning alternatives. Since one strategy proposed for decommissioning oil platforms in offshore California is to use portions of platforms to create artificial reefs, we review general management objectives for artificial reefs, and consider processes for evaluation of those objectives. This is followed by a summary of California's artificial reef program, and remarks on decommissioning conducted in the Gulf of Mexico, where a "Rigs to Reef" program has been in place since the 1980's.

In **Section III** biological features of marine species are described to illustrate the spatial and temporal scales that are appropriate for the study of these populations, and the types of information that are needed to assess ecological costs or benefits of any particular management strategy. Next, possible ecological responses and consequences of various decommissioning alternatives are outlined, in the context of what is known about some of the key species of fish and invertebrates that occur on offshore structures such as oil platforms. In this section we point out areas where there is incomplete knowledge to estimate potential effects (either in space or over time). **Section IV** articulates a set of key research issues and questions that could be addressed to fill information gaps, and presents the general conclusions of the Committee.

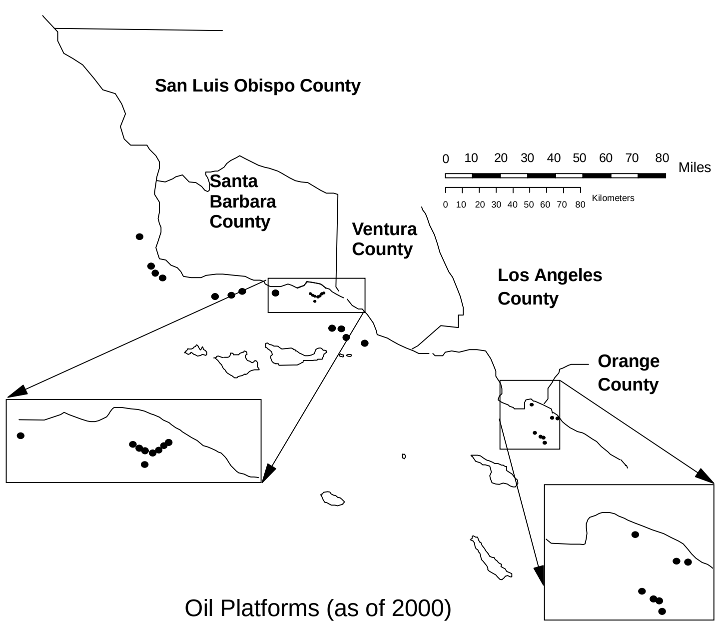
II. Background

II.A. Review of California platforms

II.A.i Geography of California platforms

The 27 existing offshore production platforms are distributed in State and Federal waters from just north of Pt. Arguello (Platform Irene) south to the suite of 7 platforms off Orange County (Figure 1, Table 1). This distribution spans four general regions, Pt. Conception, East and West Santa Barbara Channel, and Orange County. In the north, the Pt. Conception region is bathed by the colder California Current that flows south from central California. This region is also characterized by the presence of low relief rocky reefs throughout depths at which platforms occur, although the extent of this rocky bottom habitat has not been fully delineated. In contrast, the southernmost region off Orange County is bathed in warmer currents flowing northward from Mexico. This area is typified by a predominance of sandy substrate and a paucity of rocky reef habitat, particularly compared to the region around Pt. Conception. Platforms in the two regions within the Santa Barbara Channel are distributed along a gradient between these two extremes. In all locations, water conditions vary seasonally, among years due to El Nino-Southern Oscillation events, and during decade-long regime shifts. The abundance of rocky reef habitat in the Santa Barbara Channel appears to be intermediate to levels to the north and south of the Channel. These regional differences in oceanographic conditions and relative abundance of rocky reef habitat have important implications for the kinds of species inhabiting platforms and the degree to which platforms contribute to regional abundance of hard bottom habitat.

Figure 1. Distribution of offshore platforms along the coast of California.



II.A.ii Physical structure of California platforms

California's offshore production platforms range widely in size, depth and structural complexity (Table 1). The underwater structure of offshore platforms is characterized by a matrix of vertical, diagonal and horizontal pipes of varying diameter. These are referred to collectively as the "jacket". Platforms typically consist of 6 to 8 large (1 to 5 meter diameter) vertical legs with a matrix of horizontal and diagonal members of smaller (0.25 to 1 meter) diameter that extend between the legs at varying depths along the entire length of the legs.

Table 1. Structural characteristics of the 27 offshore platforms along the coast of California.

Number	Name	State / Federal Waters	Region	Depth (m)	Footprint (m^2)	Surface Area (m^2)	Volume (m^3)
1	Irene	Federal	Pt. Conception	73	2633		192,793
2	Hildago	Federal	Pt. Conception	130	4154		564,086
3	Harvest	Federal	Pt. Conception	205	5859		444,720
4	Hermosa	Federal	Pt. Conception	184	5142		944,097
5	Heritage	Federal	West SB Channel	326	nd		nd
6	Harmony	Federal	West SB Channel	363	10606		nd
7	Hondo	Federal	West SB Channel	255	4649		nd
8	Holly	State	West SB Channel	66	nd		21,515
9	A	Federal	East SB Channel	58	1930	15,900	80,541
10	B	Federal	East SB Channel	58	1930	15,900	80,541
11	C	Federal	East SB Channel	58	1930	15,900	80,541
12	Hillhouse	Federal	East SB Channel	58	nd		nd
13	Henry	Federal	East SB Channel	52	1505		50,403
14	Houchin	Federal	East SB Channel	49	1435		68,350
15	Hogan	Federal	East SB Channel	47	1435		68,350
16	Habitat	Federal	East SB Channel	88	2284		nd
17	Grace	Federal	East SB Channel	96	3090		244,196
18	Gilda	Federal	East SB Channel	62	2342		132,800
19	Gail	Federal	East SB Channel	224	5327		1198,176
20	Gina	Federal	East SB Channel	29	561		16,414
21	Edith	Federal	Orange County	49	2879		nd
22	Elly	Federal	Orange County	80	2949		nd
23	Ellen	Federal	Orange County	80	2511		nd
24	Eureka	Federal	Orange County	212	4635		nd
25	Emy	State	Orange County				
26	Eva	State	Orange County				
27	Esther	State	Orange County				

II.A.iii Marine biota associated with California platforms

One prerequisite to predicting the ecological consequences of decommissioning options on communities of coastal marine species is knowledge of what species occur on offshore platforms as well as on nearby natural reefs. Some surveys of biota associated with California platforms have been conducted (Love *et al*. 1994, 1999a, 1999b, 2000, Page and Dugan 1998, Page *et al*. 1999, Carr *et al*. 1999). Data gathered to date indicate that the species composition and abundance on platforms vary spatially (i.e., among the platforms) and also over time on any particular platform. Further, the numbers of some coastal species are very low on platforms and others occur in large numbers, that is, some species appear to have a much higher propensity for occupying platforms than others. One example is provided from surveys of fishes on platforms and natural reefs located in the eastern Santa Barbara Channel (Figures 2 and 3). Relative density (the relative number of fish per volume of water) of some species was far greater on platforms than on nearby natural reefs, while other species were not observed on platforms although they were abundant on nearby natural reefs (Carr *et al*. 1999). Two studies recorded relatively large numbers of some rockfish species on platforms suggesting the possibility that these species could be influenced more by the presence of platforms, whereas several shallow-dwelling, kelp-associated species and surfperches could be less influenced (Love *et al*. 1999b, 2000, Carr *et al*. 1999).

Figure 2. Relative density of shallow-dwelling fish species (excluding rockfish) between platforms and natural reefs in the eastern Santa Barbara Channel (data from Carr *et al*. 1999). SP = Surfperch, G. Kelpfish = Giant Kelpfish

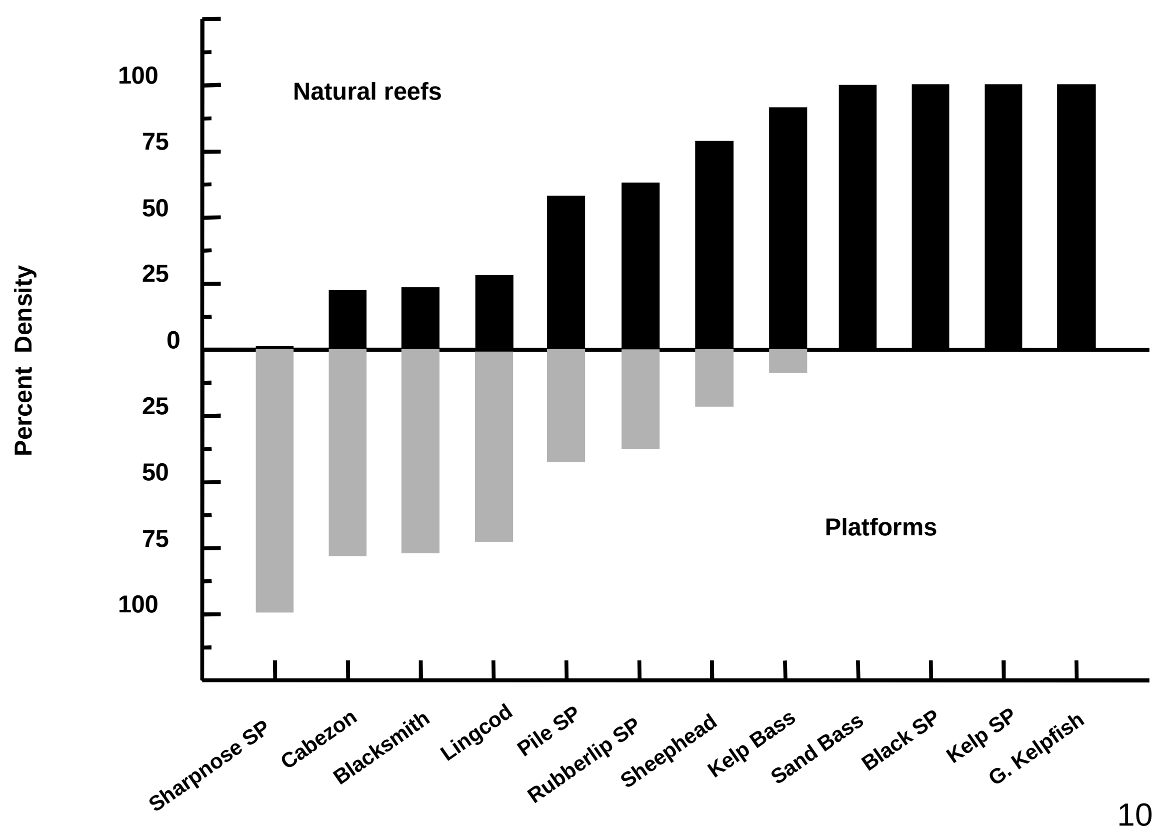
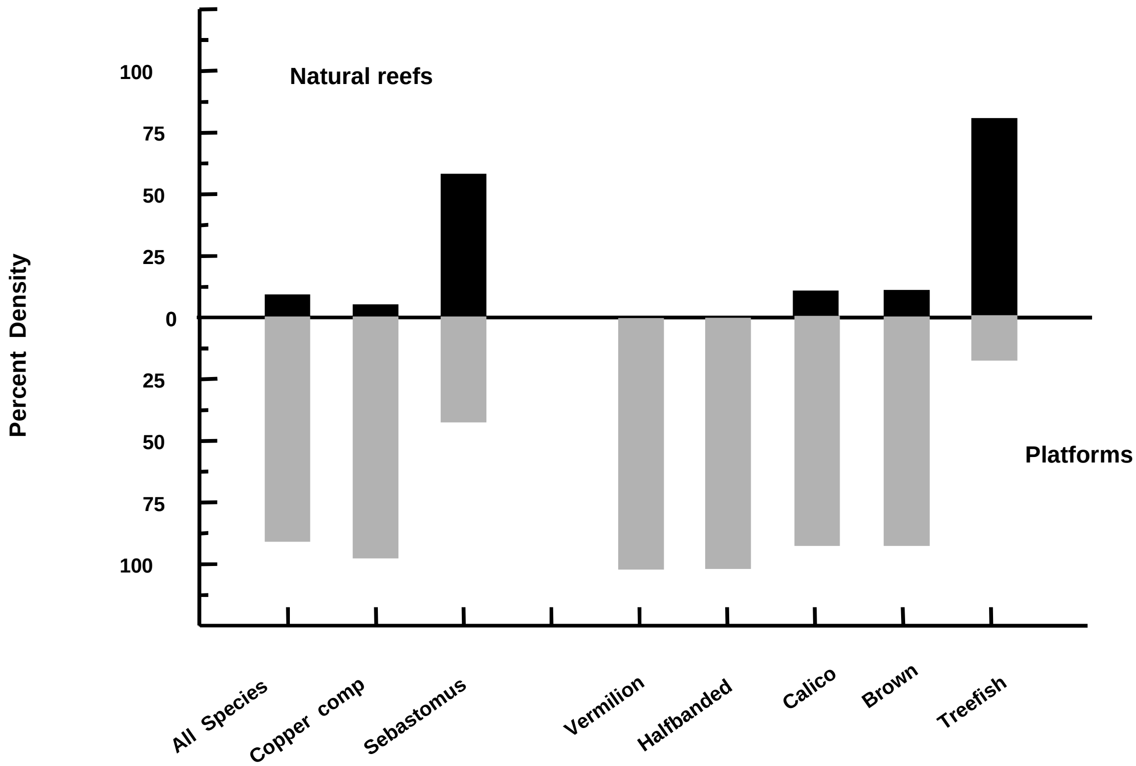


Figure 3. Relative density of some benthic rockfish species between platforms and natural reefs in the eastern Santa Barbara Channel (data from Carr *et al*. 1999).



As mentioned above, the species composition of reef fishes associated with offshore platforms differed among individual platforms, and some of this variation appeared to arise from the geographical locations where platforms occur (Figure 4). Most notably, the relative abundance of rockfishes was greater in more northern colder waters (i.e., near Pt. Conception) whereas the relative abundance of non-rockfish species (e.g., blacksmith, senorita, kelp bass) was greater on platforms in more southern, warmer waters (i.e., eastern Santa Barbara Channel). Most types of rockfishes including the "copper complex" (e.g., kelp, copper, gopher rockfish), mid-water (e.g., blue, black, olive, yellowtail rockfish), benthic (e.g., vermilion, calico, brown rockfish), and deep benthic (e.g., rosy, chilipepper, bocaccio, halfbanded rockfish) occurred at higher densities and comprised a greater proportion of the fish assemblage on platforms around Pt. Conception. Thus, for any particular location, the assemblage structure will depend on biogeographic patterns of fish assemblages, generally mimicking patterns on natural reefs among these regions. The natural patterns of distribution clearly will determine what species of fishes and invertebrates could be influenced by the presence of a platform at a particular site.

Offshore oil platforms extend throughout the water column (from the ocean bottom to the surface). Data gathered to date clearly indicate that different species of fish and invertebrates occur at different depths on the platforms. Information on the vertical (i.e., depth) distribution of species on a platform is necessary for predicting the potential consequences of various decommissioning options such as removing the upper 20 to 30 meters of a platform (i.e., Section II B; Option 3, “topping”) or reducing the height of a platform by placing it on its side (i.e., Section II B; Options 4 and 5 “toppling” in place or relocating the platform elsewhere). [These options are described more fully in Section II.B.] Because of the rapid attenuation of sunlight and the strong depth stratification of larvae of most marine species, the upper 20 to 30 meter portion of a platform supports disproportionate amounts of algae as well as recruit stages and adults of some invertebrate and fish species (Figures 4 and 5, respectively). For example, the rich cover of sessile invertebrates (e.g., sea anemones, mussels, scallops) is restricted to the upper 40 meters of water depth (Figure 5). Likewise, many shallow-dwelling fishes are limited to the upper portions of the platforms.

Some species remain on platforms for only part of their lives. Some recruit from the plankton to platforms, then leave, while others arrive as adults. Some species recruit to platforms and remain for their lifespan. The data available at present indicate that recruitment of not only the shallow-dwelling invertebrates and fishes, but also some deeper-dwelling crabs and fishes, occurs primarily in the upper portions of the platforms (Figure 6, Table 2). As such, removal of this upper portion of the structure may have negative effects on those species that recruit there. In contrast, several species of deep benthic rockfish recruit directly to and remain near the bottom of platforms (Figure 6), in which case loss of the upper platform may not influence their recruitment. However, loss of the upper section of platform may reduce or eliminate production of mussels and other organisms that supply food and habitat at the bottom of the platform (e.g., mussels). Overall, species differ markedly with respect to the depths at which their young recruit and depths that adults inhabit (Table 2). Knowledge of these relationships is incomplete at present but it is necessary for the prediction of how loss of the upper portions of platforms, or reconfiguration of a platform by placing it on the bottom at a deep depth, could alter availability of habitat for recruitment or adults and thus result in changes in biota associated with a (reefed) platform.

Figure 4. Variation in the structure of fish assemblages associated with offshore platforms among regions (eastern Santa Barbara Channel vs. Pt. Conception) and platform depth (shallow and deep are less than and greater than 70 meters, respectively). Shown separately is the assemblage structure in the uppermost 40 meters of platforms (sampled by divers) and below 40 meters (sampled by ROV and submersible). Species A= shallow-dwelling non-rockfish species, B= "copper complex" rockfish species, C= mid-water rockfishes, D= benthic rockfishes and E= deep benthic rockfishes. Group E species in the upper 40-meter depth were young-of-year (i.e., new recruits) (data from Love *et al.* 1999b, and M. H. Carr, unpublished).

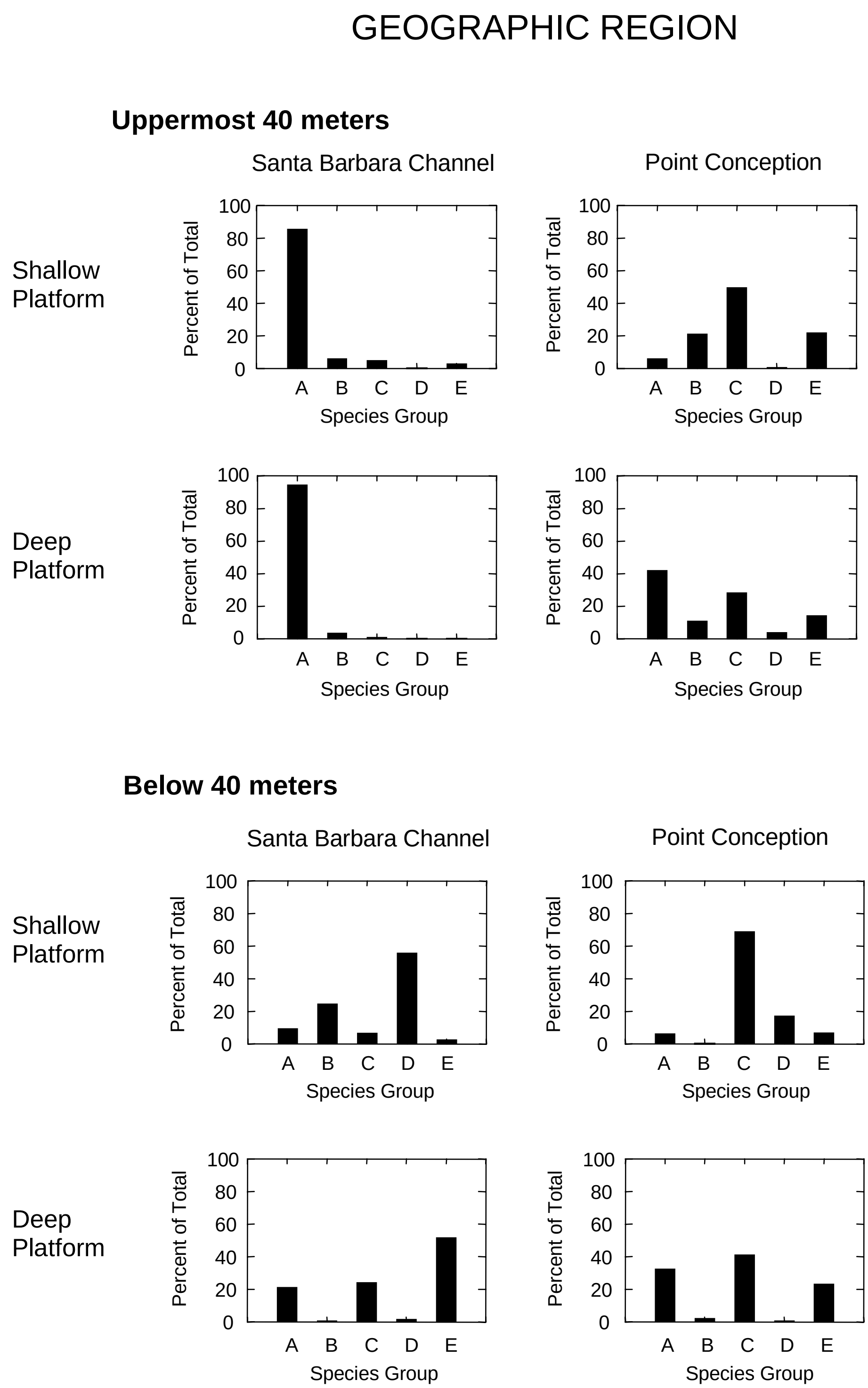


Figure 5. Vertical distribution of abundant or exploited invertebrate species on a platform in the eastern Santa Barbara Channel (data from Page *et al.* 1999, and M. H. Carr, unpublished).

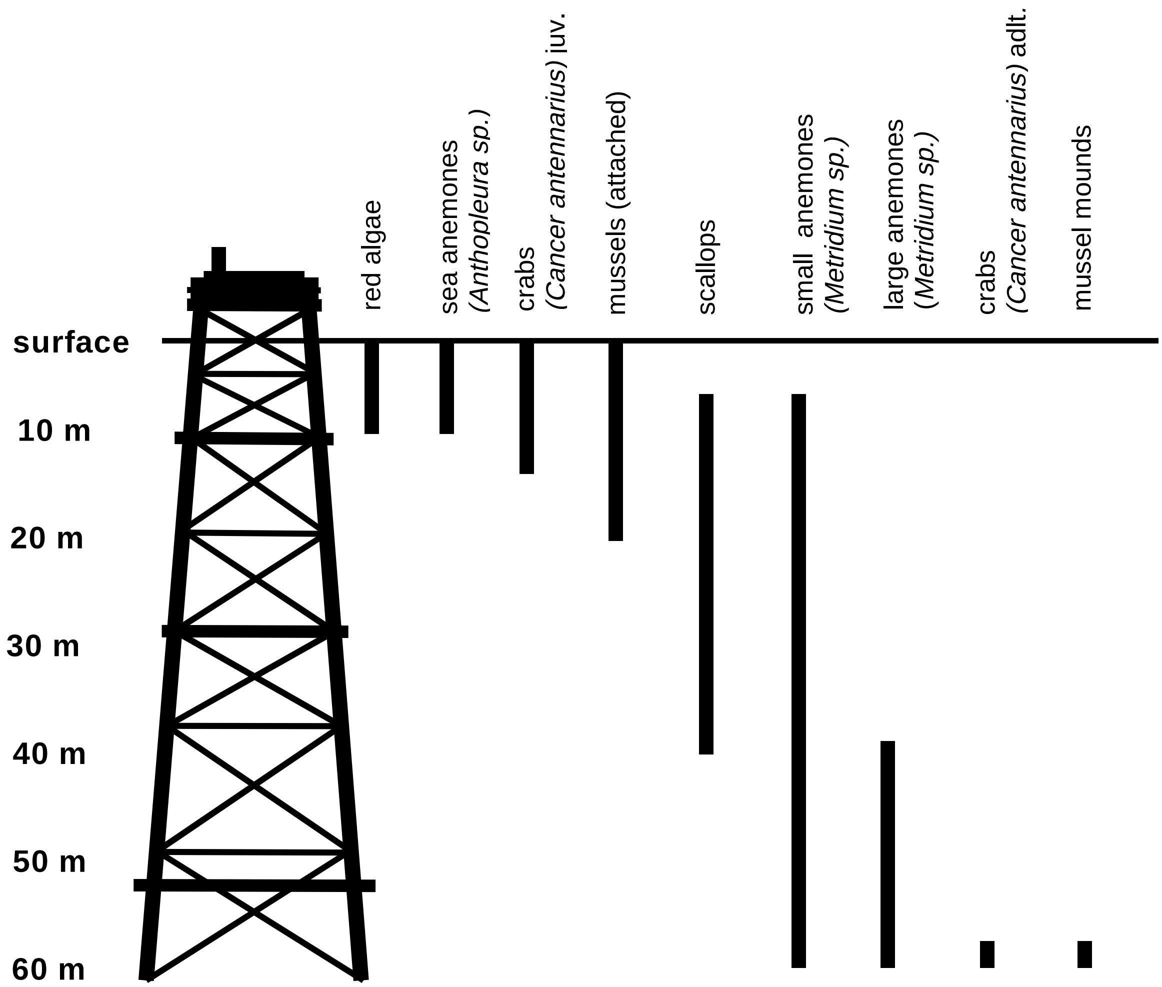


Figure 6. Vertical distribution of recruits (young-of-year) and older shallow-dwelling (copper complex), mid-water and deep benthic rockfishes. See text for implications of the three different patterns of recruitment and adult distribution for possible consequences of decommissioning options (data from Carr *et al*. 1999).

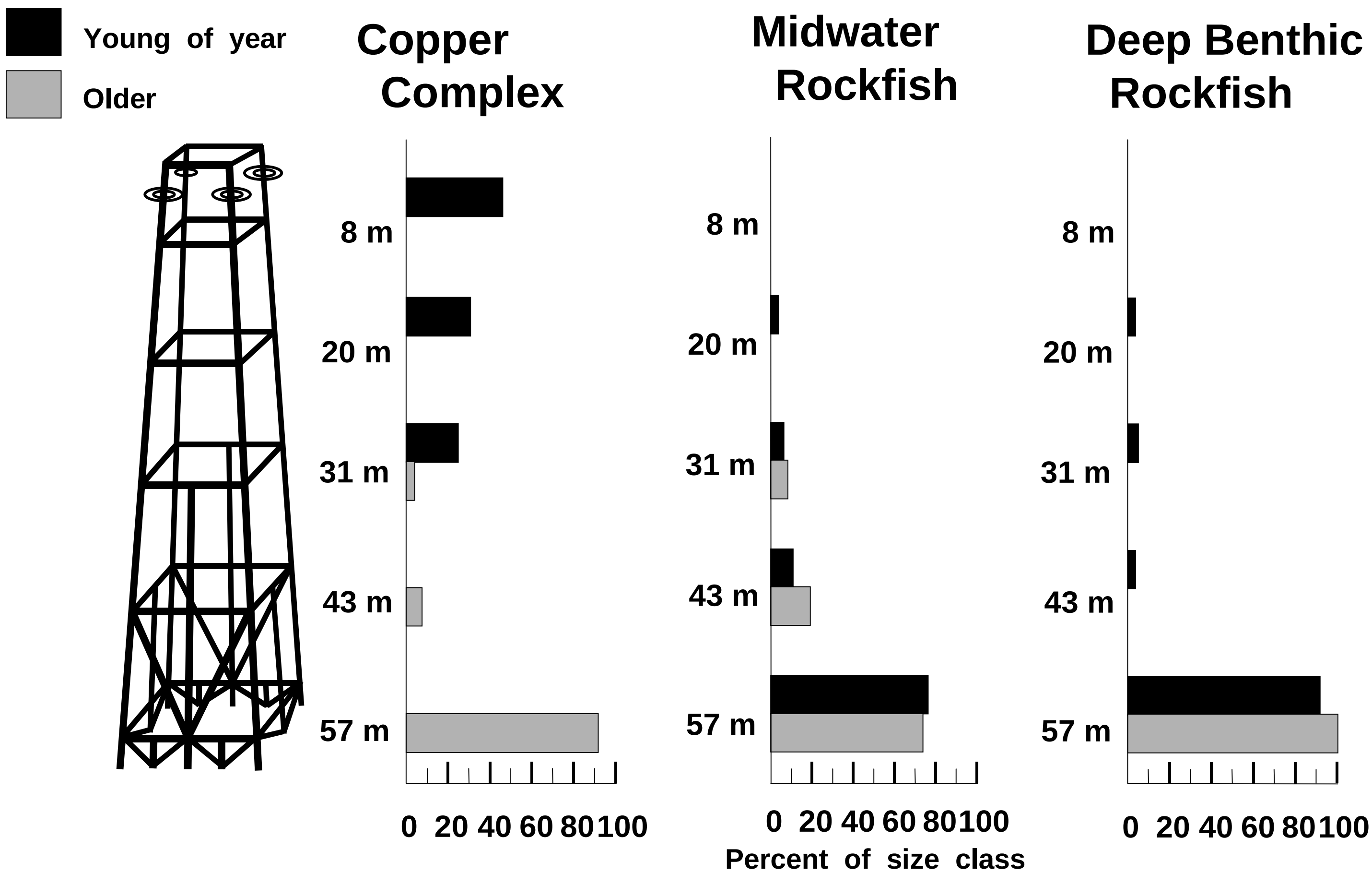


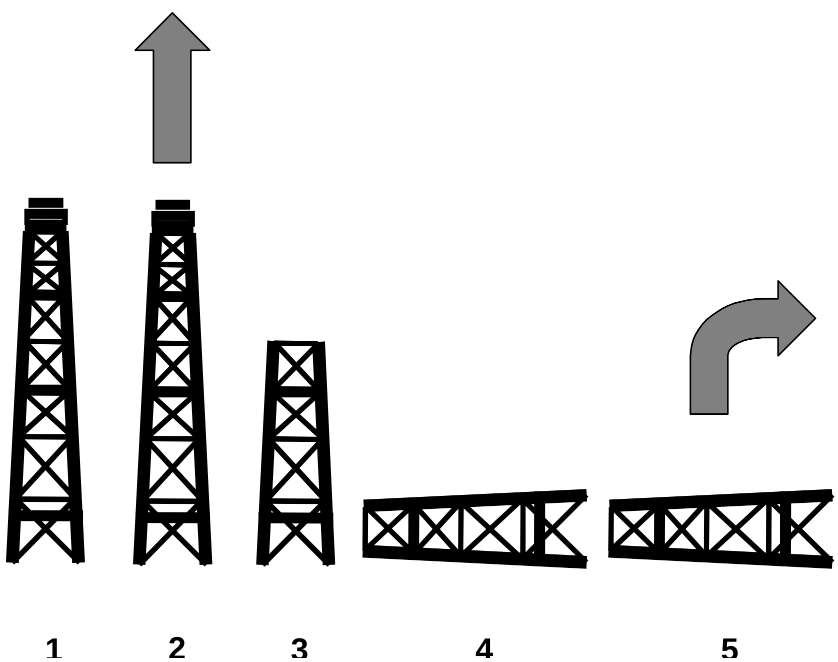
Table 2. Species differences in depth-related patterns of recruitment and adult distribution. Many species recruit to and remain at shallow depths. Other species recruit to shallow depths, then migrate deeper as they grow and age. Still others recruit directly to and remain in the deep-water portion of the platform structure. The 20-meter depth delineates the approximate depth at which a platform would be cut if the "topping" option were exercised.

		Recruitment Depths	
		Shallow (< 20 m)	Deep (> 20 m)
Adult Depths	Shallow (< 20 m)	shallow benthic rockfish, blacksmith, senorita, kelp bass, half moon, mussels, barnacles, red algae, *Anthopleura*, amphipods	none
	Deep (> 20 m)	copper rf, boccacio rf, widow rf, yellowtail rf, olive rf, lingcod, cabezon, *Cancer antennarius*	deep benthic rockfish, *Metridium giganteum*, brittle stars

II.B. Decommissioning alternatives

Here we address five decommissioning options that represent a range of possibilities that could be considered (Figure 7; Manago and Williamson 1998). These five options include (1) leaving the entire structure intact where it is currently located, (2) complete removal of the entire structure as currently legally mandated, (3) removal of the superstructure and uppermost 20 to 30 meters of the underwater structure (referred to as “topping”), (4) removing the superstructure and laying the remainder of the entire structure on its side on the sea floor in its present location, and (5) relocating either the upper portion (created by Option 3 above) or the entire structure elsewhere on the sea floor. Each of these options could have a variety of both short and long-term ecological consequences.

Figure 7. Depiction of the five decommissioning options described in the text.



In conjunction with all of the five options identified above, the mounds of mussel shells that have accumulated beneath and around the platforms might be either removed or left intact. These mounds are created from mussel production on the upper portions of the platforms (see Figure 5; Wolfson *et al.* 1979, Page and Hubbard 1987, Page *et al.* 1999). When mussels on the upper portion of the platform die or are knocked off the platform by water action, they drop to the bottom and accumulate to form large (6.5 to 8.5 meter high) mounds over the area of the structure's footprint (MBC 1987, Love *et al*. 1999a). Because most of these mussels are alive when they arrive at the sea floor beneath the platforms, they are a local source of food to organisms that accumulate beneath the platforms to feed on them. Over time, these mussels die and create a reef structure with small crevices inhabited by invertebrates and small fishes (including juveniles of large rockfishes). In combination with the live mussels, these invertebrates and small fishes attract other species including commercially important crabs (Page *et al*. 1999), sea stars (Wolfson *et al*. 1979), and other fishes (Love *et al*. 1999a) that feed on them. Surveys of fishes associated with mussel mounds indicated two general patterns. Fish assemblages associated with mussel mounds differed among platforms and these differences were in part related to differences in depth. Secondly, the fish assemblage associated with a mussel mound was more similar to the assemblage at its adjacent platform than to other mussel mounds at other platforms (Love *et al*. 1999a). Decommissioning options that remove or leave in place the upper portion of the platform structure could influence the longevity of the mussel mounds. Removal of the upper portion of the structure would prevent any continued replenishment of the mounds by terminating the production and transport of mussels to the bottom. How long the existing mounds would persist before eroding or becoming covered with sediment is not clear.

Also associated with the offshore oil platforms are the pipelines used to transport oil from the structure to shore. These pipelines differ in dimension and the extent to which they are exposed or buried by sediment. At installation, pipelines are usually left exposed on the sea floor below 8-meter water depths and are buried or covered with rock in areas that are shallower than 8 meters. Most of those that are laid on the sea floor eventually become buried. Exposed pipelines and the rocks used to cover them create hard surface for attachment of sessile invertebrate species and shelter for mobile benthic invertebrate and fish species. Like platforms and mussel mounds, organisms associated with these structures attract other species and create reef-based communities, which likely modify nearby soft-bottom communities.

II.C. Management issues

II.C.i Management objectives of artificial structures

To understand the motivation for and possible intended and unintended consequences of deploying artificial structures in the marine environment, it is important to recognize why emplacement of such structures is considered by managers. This section reviews the range of management objectives associated with the construction of artificial reefs.

The oldest objective, dating back centuries, is still the most common reason for building artificial reefs: to improve local fishing success. Early experiences demonstrated that fish gathered around man-made objects in lakes or oceans, providing higher catch rates than would otherwise occur there. More recent scientific studies have shown that fish densities are, in fact, often higher on artificial reefs than on nearby natural reefs (Fast and Pagan 1974, Russell 1975, Smith *et al*. 1979, Walton 1979, Jessee *et al*. 1985, Laufle and Pauley 1985, Matthews 1985, Ambrose and Swarbrick 1989). Artificial reefs are sometimes built to increase the catch of fish in an area, and sometimes to “move” the fishing to more convenient areas, perhaps close to a port. Artificial reefs built for fishing can be constructed from a wide range of materials, including natural rock, concrete, decommissioned ships, tires, and many types of scrap materials (although not all of these materials would be acceptable for use in California).

Over the past 20 years, there has been increasing recognition that artificial reefs could be used to replace aquatic resources that have been lost due to anthropogenic impacts (Swanson *et al*. 1978, Stephens and Palmer 1979, Grove 1982, Spanier and Pisanti 1983, Sheehy 1985, Sheehy and Vik 1985, Ambrose 1986). Artificial reefs have been used or proposed as mitigation for impacts to estuaries, bays or harbors (Alevras and Edwards 1985, Davis 1985, Duffy 1985, Feigenbaum *et al*. 1989, Lindeman 1989), seagrass beds (Calinski and Whalen 1987, Thorhaug 1989) and rocky habitats (Hueckel and Buckley 1986, Hueckel *et al*. 1989, Cheney *et al*. 1994, Cummings 1994). In the United States, reefs have been used for mitigation in several locations, including Delaware Bay (Sheehy and Vik 1982), Chesapeake Bay (Feigenbaum *et al*. 1989), Washington (Hueckel *et al*. 1989), and Florida (Davis 1985). In California, mitigation reefs have been built in Long Beach Harbor and San Diego Bay. In addition, the Pendleton Artificial Reef was constructed to test the feasibility of using a constructed reef for mitigation (Grove 1982, Ambrose and Anderson 1989). The largest mitigation reef in the United States has recently been required as mitigation for impacts to a kelp forest caused by the San Onofre Nuclear Generating Station (Ambrose 1994, California Coastal Commission 1991, Parry and Ambrose 1993), with the first phase of construction completed in Fall 1999.

A third objective of artificial reefs is to provide recreational opportunities for scuba divers. Some of the decommissioned ships placed as artificial reefs have been specifically designed to provide “wreck diving” opportunities. In addition to high abundances of fish, other species such as algae and invertebrates also are frequently abundant on artificial reefs, providing excellent opportunities for underwater sight-seeing or photography.

Finally, artificial reefs may be constructed for conservation purposes or to enhance the environment. Since artificial reefs constructed for mitigation must provide resources as replacement for project impacts, these reefs are tightly linked to resource impacts. Artificial reefs for environmental enhancement are not linked to resource impacts, nor are they built to enhance fishing opportunities. Rather, these reefs aim to improve the ocean environment in general. Relatively few artificial reefs have been built for environmental enhancement or conservation. One example is the reef constructed near Diablo Canyon, California, whose principal objective has been to enhance rockfish recruitment. A different conservation objective has been employed in the

Mediterranean Sea, where reefs have been constructed with projections that will snag trawl nets in order to exclude trawlers from environmentally sensitive seagrass habitats.

The different management objectives require different designs for artificial reefs. Furthermore, the constructed reefs need to provide different ecological functions and services in order to be considered successful. A key difference is whether fish production must be increased, and indeed this has long been a controversy about artificial reefs (Osenberg *et al*. 1999). Because artificial reefs attract fish, as can be seen clearly when adult fish are abundant on a reef shortly after it has been constructed, some scientists have been concerned that the reefs could be simply attracting fish rather than contributing to fish production. Much has been written about this "attraction versus production" issue (reviewed by Bohnsack and Sutherland 1985, Carr and Hixon 1997, Bohnsack *et al*. 1997), but this phrase is an oversimplification that does not do justice to the complex issue of how an artificial reef contributes to the production of fish and other organisms. In fact, attraction of fish may be a sufficient mark of success for some reefs. For example, if the purpose of the reef is to provide non-consumptive recreational use, success is based on presence of desired species and scenery; it does not matter if the reef has increased fish production. For fishing enhancement, increased fish production is not necessarily important, although it may be desirable. Sound fisheries management using artificial reefs depends on the status of the fish stock. If the stock is under-exploited, use of artificial reefs to increase efficiency by concentrating fish may be appropriate. However, if the stock is fully exploited or overexploited, employing artificial reefs could have negative consequences for the stock unless the stock is enhanced through increased production by the reefs. The use of artificial reefs as mitigation requires that the reefs produce new resources to compensate for losses due to anthropogenic impacts. We return to the issue of fish production later in this report.

The different objectives would require different criteria for evaluation of artificial reef success. For some of these objectives, such as non-consumptive recreational use or fishing enhancement, it is easy to evaluate the success of an artificial structure. But for conservation and resource enhancement, evaluation can be very complicated due to the difficulty of discerning regional, not just local, consequences of the deployment of artificial reefs.

II.C.ii California's Artificial Reef Program

Recognizing the potential of artificial reefs for enhancing sport fish habitat and catch, the California Legislature enacted AB 706 (Fish and Game Code, Article 2, Section 6420-6425) in 1985. The Legislature found that declines in marine fish species in Southern California had adversely affected sport and commercial fishing, and called for a program of artificial reef research and development to investigate enhancement of these species. It established the CDFG as the lead agency for a state artificial reef research and construction program that would coordinate ongoing studies and construction. The program was to include study of existing reefs and all new reefs placed by the program to determine the design criteria for reefs to be capable of increasing fish and invertebrate production (Wilson *et al*. 1990).

The CDFG Artificial Reef Plan for Sport Fish Enhancement (Wilson *et al*. 1990) describes the history of artificial reef studies, the materials used, and catalogues the State's inventory of reefs. Three categories of artificial reefs are designated: developmental reefs for developing better techniques and related scientific investigations, production reefs primarily intended to enhance the production of living marine resources, and fish attracting devices constructed to attract sport fishes without necessarily contributing to an increase in standing crop. The plan details the procedures to be followed for establishing a new artificial reef: defining purpose, gathering information relevant to placement and design, site selection, reef design, preparing a project narrative, obtaining necessary permits, developing a general artificial reef permit, as well as a system of fisheries enhancement areas. It also outlines procedures for reef construction, mapping, and studies of reef biota. The development of the Pendleton Artificial Reef is used as an example. To meet the goals of the program, CDFG plans to continue reef studies through 2005 and reef building through 2011. Finally, the Department believes that properly-constructed artificial reefs can be used as mitigation for impacts to rocky reef habitat, and in certain cases, for damage to giant kelp (Wilson *et al*. 1990).

Material specification guidelines and a notification procedure for augmentation of artificial reefs with surplus materials were formulated by the Department (April 4, 1991; revised October 30, 1997 and February 16, 1998). Criteria for suitable reef materials include persistence, a specific gravity at least twice that of seawater and thus dense enough to survive strong winter storms, and the absence of toxic substances such as found in automobile tires. Commonly-used materials include quarried rock and high density concrete rubble; other materials may be considered on a case by case basis.

The California Department of Fish and Game has developed a set of guidelines that it would use to evaluate any proposed rigs-to-reef project. These guidelines stipulate that the project must benefit living marine resources, habitat, and user groups; that disposal or use of contaminated materials is not permitted; that wherever possible the subsurface structure of the platform should remain in place; that where possible, subsurface structure that must be removed could be relocated to the base of the rig or other appropriate sites; and that the remaining structure be augmented by rocks or other materials to assure that the site functions as a diverse and productive reef habitat. To replace the biotic productivity from that part of the platform removed for navigational purposes, rock or concrete reefs should be placed in nearshore locations. A rigs-to-reef project sponsor must provide sufficient funds to the Department to evaluate the benefits to biotic productivity, user groups, and the overall management of fishery resources. The process would be subject to all normal review processes by appropriate regulatory agencies (FGOM Section 4322.5).

II.C.iii Decommissioning conducted in the Gulf of Mexico

There are several thousand oil and gas production platforms in Federal waters of the northern Gulf of Mexico (mostly off of Louisiana), and decommissioned rigs have been used for construction of artificial reefs by several states (Bull and Kendall 1994, Wilson *et al*. 1996). Louisiana and Texas established state-run artificial reef programs through legislation enacted in 1986 and 1989, respectively. These states set up trust funds to receive monetary donations for artificial reef development and operations, and mechanisms to transfer ownership and liability from the oil companies to the state. Although both of these states have used a variety of materials for building artificial reefs, "Rigs to Reefs" is a main focus of each of their programs (Dodrill 1999, Gibbs 2000). To a lesser extent, Mississippi, Alabama and Florida have also accepted decommissioned rigs and deployed them as artificial reefs (Seaman *et al*. 1989, Dodrill 1999). One reason underlying development of rigs-to-reefs programs in the Gulf States is that operational platforms have become a major focus of offshore fishing and recreational diving during the past several decades. For example, in Louisiana there is little natural hard substrate in offshore areas, and a majority of angling occurs in the vicinity of oil platforms where fish congregate (Stanley and Wilson 1989). In anticipation of the removal of these structures upon decommissioning as they reached the end of their production, Louisiana developed an artificial reef plan and since 1986 components of 71 platforms have been used in the creation of 25 artificial reef sites (Quigel and Thornton 1989, Kasprzak 1998). Participating companies realize cost savings by redeploying platforms as artificial reefs rather than removing them, and a portion of these savings are donated to the state to run the artificial reef program.

There are a number of critical differences between the Gulf States and California with respect to both the marine environment and the offshore oil and gas activity, and these differences must be considered when evaluating the experience of the Gulf States with respect to various decommissioning alternatives.

The first key difference between the Gulf of Mexico and California is the amount of natural nearshore rocky bottom and reef area. In the northern Gulf of Mexico where the majority of the oil and gas platforms are located, the ocean bottom is typically clay, silt or sand with little or no relief (Kasprzak 1998) and the few natural reefs that do occur are located 75 or more miles offshore (Stanley and Wilson 1989). There is a paucity of nearshore rocky reef habitat, particularly off the coasts of Louisiana and Texas. It has been estimated that hard bottom and reef habitats constitute about 1.6% of the total area of the Gulf of Mexico (Wilson *et al*. 1996). By contrast, rocky reef habitat is far more abundant along the coast of Southern California and within the Southern California Bight. Although the precise amount of subtidal rocky habitat off the California coast is not known, there are extensive areas of rocky intertidal and shallow subtidal habitats as well as offshore reefs.

A second difference between the Gulf States and California involves the level of oil and gas development in each region. There are several thousand oil and gas platforms in the Northern Gulf, and only twenty-seven off California. Thus the operating Gulf platforms contribute much more hard substrate to the marine environment, both in an absolute sense, because there are so many platforms, and in a relative sense, because hard substrate is so rare in the northern Gulf of Mexico, than do the platforms off of California. The operational Gulf platforms have been estimated to increase the overall amount of reef fish habitat in the Gulf of Mexico by twenty seven percent (Kasprzak 1998); if only nearshore waters off Louisiana were considered where natural hard substrate is essentially absent, the effect of the platforms situated there would be many times higher. Of course, since there are so many platforms in the Gulf there is a much larger potential for creation of artificial reefs at the time of decommissioning than there is in California.

A third important difference between the Gulf and California is that the biota - particularly the fish - differ. Different groups of species occur in the two geographic areas, and the effects on their populations of various decommissioning alternatives will no doubt differ as a result of differences in life history, mobility, longevity, etc. as well as in harvesting pressure. Thus, inferences about effects of any particular decommissioning strategy based on information gathered in one region on the fish assemblage in the other region would need to be made with utmost caution.

Despite the intensity of fishing and recreational diving on both operational and decommissioned (reefed) Gulf platforms (Stanley and Wilson 1989), and despite some data (reviewed in Kasprzak 1998) that abundances of a number of species of fish are higher near platforms than on nearby soft bottom habitat, there is a paucity of information regarding the influence of the platforms on fishery resources, or the effects of harvesting on platform-associated species (Bull and Kendall 1994). Species of fish most often sought by recreational anglers and divers are snappers (species in the Family Lutjanidae), but a variety of other fishes are also targeted including cobia, red drum, seatrout and mackerel (Stanley and Wilson 1989). To date, careful stock assessment studies of these taxa that estimate effects of platforms (standing or reefed) and implications of current harvesting practices at a regional scale appear not to have been conducted.

III. Biological attributes of marine species and potential ecological consequences of decommissioning alternatives

III.A. Population structure and life history characteristics of marine species

Short and long-term ecological consequences of decommissioning options are greatly influenced by the life history traits and population structure of species in the region where platforms occur. To understand the effects of human activities at the relevant spatial and temporal scales, it is important to have a basic understanding of the life histories and population structure of the various species of marine organisms involved. Many sessile and mobile marine invertebrates (e.g., mussels and crabs, respectively), as well as most marine fishes, produce young stages (usually larvae) that disperse in the plankton. Similarly, macroalgae produce spores. These offspring disperse in the plankton, and, after settling in a new area, grow to adulthood. This process of planktonic dispersal links together many subpopulations that occupy discrete habitats such as reefs, resulting in an interbreeding population that covers a large area. In some species the range of dispersal can be up to hundreds of kilometers. Individuals are transported largely by water currents.

We first consider impacts on a single, isolated population, perhaps occupying a reef (Figure 8a). This population of adults produces larvae, some of which return to provide new recruits to the population. For the population to persist through time, lifetime reproduction of adults on the reef must be sufficient to overcome the losses during the planktonic larval and recruitment phase. Essentially, individuals must replace themselves. Lifetime reproduction depends on an individual surviving until it is old enough and/or large enough to reproduce. Many marine populations appear to have excess lifetime reproduction, enabling them to tolerate some reduction in survival (by fishing for example), while still maintaining adequate larval production for sustainability.

Marine populations actually consist of a number of subpopulations similar to the single one just described that are distributed over space and linked by larval dispersal. The young produced by each local population of a reef-associated species are likely to be transported away to contribute to the replenishment of populations elsewhere (Figure 8b). This leaves the replenishment of that parental population reliant to some degree on the recruitment from the plankton of young that are produced by distant populations. Thus, each of the subpopulations (reefs in Figure 8b) need not have adequate lifetime larval production to replace themselves; they could actually be subsidized by greater larval input from other subpopulations. If that were the case, of course, other populations would have to have greater lifetime larval production than needed for replacement. It is easy to see that patterns of water currents in the region, which transport larvae among local populations, could influence the persistence of populations at various locations in that region. Population configurations such as these are much more complex than the single isolated population and their structure and function are very poorly understood. Although in recent years there has been rapid development of ecological theory that explores the population dynamics of these systems, there is still little empirical evidence that allows estimation of how strongly individual populations of marine species are linked by larval dispersal. Similarly, knowledge about the physical environment (direction and strength of water currents for example, that carry the larvae among populations) is still incomplete for the California coast.

Because of this decoupling of local offspring production from local recruitment, local effects on adult populations (e.g., creating or altering their habitat) can influence populations many kilometers away. Thus, the addition or removal of an artificial piece of structural habitat (Figure 8c) not only influences species locally, but can also influence populations elsewhere in the region. Among other things, the patterns of water currents in the region in which a platform is located will influence rates of replenishment of populations on a platform, as well as the potential for the platform to contribute larvae to other reef sites.

The resulting population structure is complex, and the details are not known, but it suggests productive ways to think about the ecological consequences of adding an artificial structure into a collection of local populations. For example, if an artificial structure intercepted larvae that would otherwise have died (perhaps before finding a suitable reef to inhabit), it would likely not have a negative effect on regional population structure. It could even have a positive impact if the intercepted larvae thrived on the artificial structure, and each produced enough larvae in its lifetime to do more than replace itself, and if the larvae then could disperse and reach suitable habitat. By contrast, if an artificial structure intercepted larvae that would have successfully settled elsewhere, and it provided poorer habitat for growth and reproduction than natural reefs, there ultimately could be a negative impact on the regional population. Introduction of an artificial structure can also affect populations if movement of adults occurs. For example, if adults migrated to the artificial structure from their natural reefs, and this diminished larval production at their reef of origin, there could be a negative effect on the regional population, unless the adults made up for that loss at the new location.

While this situation seems hopelessly complicated, and highly uncertain, we can at least identify aspects of populations associated with artificial structures that would be favorable to overall population persistence and abundance. First, the fraction of successful larvae intercepted by any particular artificial structure is likely to be low, because of the small area of the artificial structures and the mortality of larvae involved in traveling a large distance. Second, it is important for an artificial structure to provide good habitat for all juvenile and adult stages; if it does not, it is less likely that it will mitigate potential negative effects of entraining larvae that could have settled on natural reefs.

Assessment of the effects of artificial reefs is further complicated by the fact that species differ in characteristics that determine the spatial structure of populations. Because species vary markedly in such life history traits as propagule (spores, eggs, larvae) dispersal, longevity, generation time and adult mobility, the extent to which decommissioning effects are manifested only locally at a platform or extend more regionally will vary among species. The duration of propagules in the plankton also varies markedly (hours to months) among species (Table 3), which means that potential transport distances vary among species.

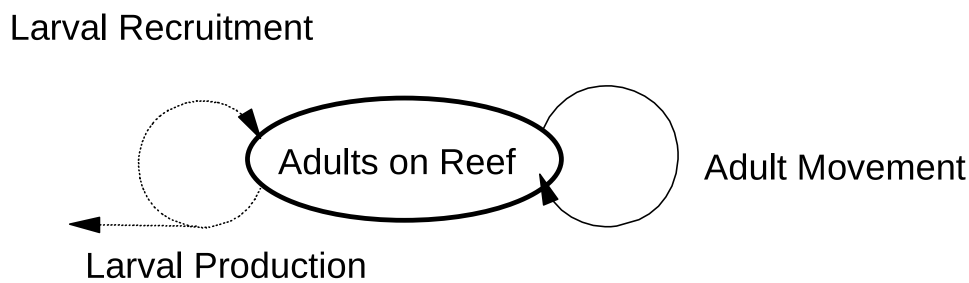
Species also differ in the degree to which their older benthic (i.e. bottom-associated) juveniles and adults move among reefs (Table 3). Many sessile algae and invertebrates do not move once the propagule stage recruits to a reef. In contrast, juveniles and adults of some reef fishes freely move kilometers between reefs. Thus, the life stages that can move to and from reefs vary among species and these differences are critical to understanding how and to what extent species can be “attracted” (i.e. move) to reefs. These distinctions are important when trying to ascertain whether species are attracted or produced by the presence of a reef and how attraction or production is manifested locally or regionally (i.e. within or among populations, respectively).

To summarize, it is not yet possible to predict the effects of adding or removing an artificial structure on long-term regional abundance of any species of interest. Even observations verifying that juveniles or adults are present (or even abundant) on rigs are not sufficient, unless they can be placed into a regional context. Ideally this would include posing the question of whether regional stock (that is, the size of all the component populations together) was ultimately enhanced by the addition of the artificial structure.

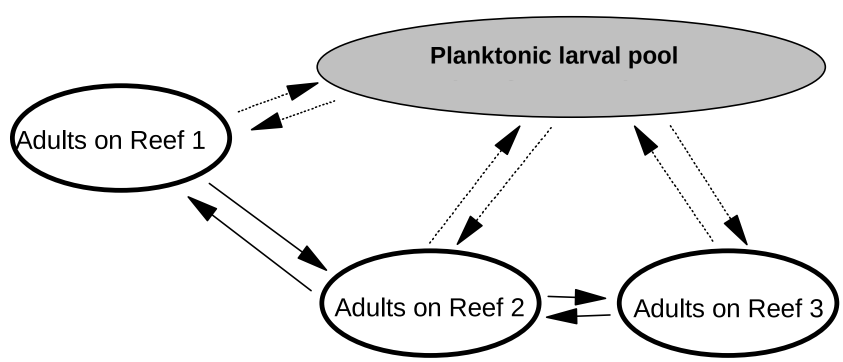
A further contribution of an artificial structure to population persistence is the reduction in risk of extinction of a species that results when another semi-independent subpopulation is added to the population. If the subpopulations are subject to independent environmental variability or independent catastrophes, the presence of an additional local population simply reduces the probability of all populations being driven to low levels simultaneously. It increases the likelihood that there will be one left to repopulate the others.

Figure 8. Spatial population structure of a typical benthic, mobile marine species (e.g., fish). Fig. 8a depicts a single isolated population of adults on a reef whose larval production and dispersal (dotted lines) consist of both export and retention, and adult movement (solid line) is confined to that population. Fig. 8b and 8c depict three natural subpopulations and a platform-associated subpopulation, each of whose larval production contributes to a regional larval pool, from which larval recruitment is derived.

8a



8b



8c

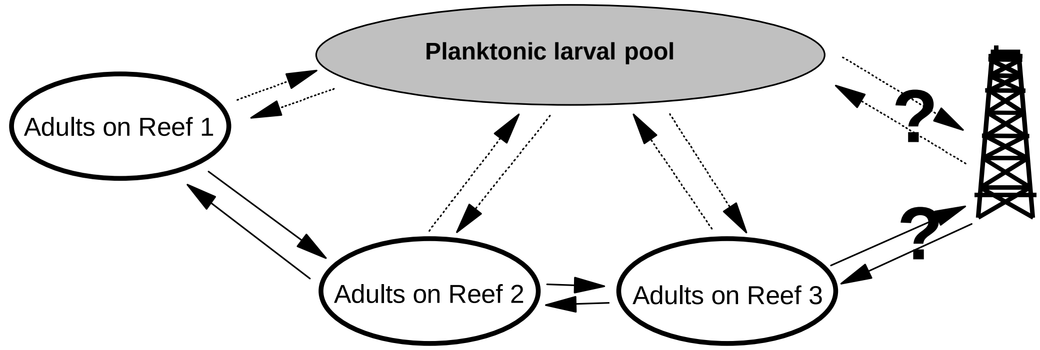


Table 3. Differences among species in relative dispersal abilities of reproductive propagules and benthic stages (adults). Propagule dispersal is estimated from its duration in the pelagic environment; longer duration (> 7 days) equates to greater dispersal. Propagules include algal spores, and eggs and larvae of invertebrates and fishes.

		Propagule Duration	
		Short (< 7 days)	Long (> 7 days)
Adult Movement	Sessile	scallops red algae *Corynactis* tunicates sponges	mussels barnacles *Metridium*
	Limited (< 1 km)	amphipods sculpins surfperch	sea stars crabs cabezon blacksmith benthic rockfish
	Long (> 1 km)	pinnipeds	kelp bass half moon mid-water rockfish

III.B. Potential effects of decommissioning alternatives

Each of the five identified options for decommissioning oil platforms could result in a variety of impacts to marine biota. Although some effects of each decommissioning option can be identified at this time, others are much more difficult to predict because we have incomplete knowledge of the biology of many marine species as well as the physical aspects of the offshore environment. Further, effects could vary depending on environmental fluctuations and stochastic events. Ecological impacts of any decommissioning alternative could occur during and just following the decommissioning event (removal, topping, etc.), mainly due to the procedures involved in removing or moving a platform, or effects could accrue slowly over much longer time periods (years to decades). In this report we refer to the former class of effects as short-term, and the latter effects as long-term. Additionally, effects may occur to populations only at the location of the platform and its immediate surroundings (local), or they may be expressed as a regional change in distribution or abundance of one or more species. Below we briefly point out some possible biological effects of various decommissioning alternatives. The examples are not meant to represent an exhaustive list but rather to illustrate potential differences in effects to the marine biota of various decommissioning alternatives. In general, short-term, local effects will be the easiest to quantify; longer-term, regional effects will be less likely to be detected readily and would probably have to be estimated by calculation.

The limited information that is available about patterns of distribution and abundance of platform-associated biota indicate that effects of any particular decommissioning alternative will need to be evaluated relatively specifically in the context of the biogeographic setting and water depth of the platform (and of the potential reefing site if this is a consideration). Further, the amount and quality of hard substrate in the near vicinity of the platform as well as in the region could potentially affect impacts of the alternatives. With our current knowledge it is possible to only roughly estimate potential impacts of the various options. Very few ecologically-important impacts can be predicted with certainty given the present state of knowledge. Information that would be necessary for a more complete assessment is described in Section IV.

Option 1: Leave entire structure intact in place

In this option, the entire subsurface structure is left standing in place. Since nothing would be done to move or alter the structure there would be no additional new ecological impacts at the time of decommissioning. However, whatever (positive or negative) impacts as a result of the structure being where it is that are already occurring would continue. Future environmental variation or climate fluctuation could result in additional (long-term) impacts or could change the size or direction (positive or negative) of ongoing impacts.

Option 2: Removal of entire structure from ocean

In the short term there could be several kinds of local impacts of removing the entire platform structure from the ocean. One class of effects could result from the removal procedure itself. For example, use of explosives could result in mortality to fish and other species on or near the platform. Organisms on adjacent or nearby natural hard substrate could be damaged by anchors of support vessels or barges; and anchor scars could result that alter this substrate and impact its value as habitat for benthic species. When the platform is removed from the ocean all the sessile organisms on it will die, and the mobile species (fish and invertebrates) would survive only if they could successfully relocate to suitable habitat elsewhere. On a long-term local basis, anchor scars and/or damage to the bottom could persist, thus altering the habitat quality for species associated with hard bottom substrate. A set of species associated with soft bottom would likely develop in the area previously occupied by the platform, and this would have different species composition and biomass than the assemblage that occupied the platform. Whether the long-term regional effects of platform removal would be positive or negative clearly would depend on the regional effect the platform was already having. Removal could ultimately result in enhanced regional populations if the operational platform had been negatively affecting them. But if a regional increase in stock of a species had resulted from the presence of a platform, removal could result in a negative impact on the stock.

Several of the options described, including removal of the platform, could greatly impact the mounds of mussels located underneath the platforms. In cases where all or the top part of the platform is removed, the mussel mounds would no longer have a supply of shells, organic material, settled larvae and young stages, etc. arriving from the top layers of the water column. This could have a profound impact on the biomass and species composition of the community associated with the mussel mounds. There are insufficient data at this stage to predict how long the structure of the mussel mounds would persist in the absence of the input of debris from above. Further, in some options (such as removal of the entire platform) it is possible that the mussel mound would be removed during decommissioning. Removal of the mussel mounds could have a variety of impacts. For instance, if explosives were used, many organisms in the vicinity could die. Removal of the mound structure would obviously result in a loss of this habitat for organisms. Sessile organisms would die and mobile ones would only survive if they could find suitable natural habitat nearby. To the degree that chemicals or other anthropogenic materials have become entrained in the mussel mound, these might be released during the process of removal and might potentially affect the biota.

Option 3: Topping – removal of upper 30 meters of the structure

In this scenario, the top portion (perhaps about 20 or 30 meters) of the platform is removed to reduce navigational hazard. This portion might be placed on the ocean bottom or removed from the ocean. The rest of the platform is left standing. Short-term local effects of explosives, boat traffic and the like would be similar to those outlined for Option 2. In the short-term, sessile organisms on the top (removed) part of the platform would die if it were removed from the ocean and would not be likely to survive if the top was placed in deep depths. Most of the organisms that live on the top part of the platform depend on high levels of light and nutrients that would be lacking in deep areas. Similarly, mobile species associated with the top portion of the platform may or may not be able to relocate successfully to the deeper portions left intact, depending on their habitat requirements. In the long term, local effects could include anchor scars left behind on any nearby hard substrate, and the loss of all hard substrate and associated species from the top portion of the water column. The removal of the top portion of the platform may have great effects on the biota on the lower part, and over the long term that assemblage may not be sustained. For example, the vertical transport of organic matter (especially mussels) from the highly productive top of the platform would stop when that portion was removed. The mussel mound would cease accumulating, and the organic material that provided a food supply to many species near the bottom would be greatly reduced. Patterns of larval recruitment could be affected greatly because many larvae travel in the top few meters of the water column and they might not find substrates that are 20 or 30 meters below the surface. This could result in a reduction in larval recruitment to the truncated platform. Lastly, water motion in the top portion of the water column would be different because the platform would no longer produce eddies that might entrain larvae, particulate matter, zooplankton, etc. The long-term regional effects of this option are difficult to predict, but similar to the previous options, the effects could be positive or negative depending on the prior regional impact of the operating platform.

Option 4: Topple structure in place

For this option the platform would be toppled over and left in place, either intact or cut up and positioned in a desired configuration. The impacts resulting from the procedures involving explosives, anchor placement, etc. would be similar to Options 2 and 3. In addition, there could be short-term local impacts on the bottom where the rig is placed. Habitat would be disturbed during placement, with potential negative effects on any organisms in the vicinity. In the short-term, many (sessile or mobile) organisms on the top portions of the platform would not be likely to survive if the rig was toppled at a deep depth, because their habitat requirements would likely not be met in the new location. Long-term local effects could be similar to those outlined for Option 3, and would include loss of hard substrate and associated biota high up in the water column, effects on biota located underneath the platform (such as species in the mussel mounds) due to cessation of organic input from the near surface, as well as effects on larval recruitment and on water motion in the top of the water column. There would be an increase in hard substrate near the bottom as a result of toppling. The long-term regional effect of toppling will depend greatly on the depth at which the rig is located. Toppling a rig at a great depth (a hundred or more meters) could result in a much less productive community because it is cut off from the highly productive surface waters, compared to toppling a rig in relatively shallow depths. Depending on the regional impact of the platform in its standing position, the long-term effects of toppling could be positive or negative.

Option 5: Topple and move structure to a new location

In this option the platform is moved from its operational site to a new location. Depending on the specific procedures used to accomplish the relocation, short-term local effects from use of explosives or from anchoring activities will be similar to those previously described for Options 2 and 4. The bottom and associated organisms are likely to be disturbed, the severity of this would depend on whether the platform makes contact with the bottom during the process of removal. Both sessile and mobile species that occupy the platform would be impacted during the movement process, and might not survive in the new location if their habitat requirements were not met. In the new location the natural bottom substrates could be damaged by anchoring, and will be covered up by the introduction of the platform. The long-term local impacts at the removal site would be the same as for Option 2. At the new location there would be a loss of soft-bottom habitat and an increase in hard substrate, along with associated changes in biota. Whether the regional long-term impact of this option is positive or negative would depend on the previous impact of the platform on regional populations compared to the regional impact that accrues from relocation to the new site.

IV. Research agenda and general conclusions

The key marine ecological question that needs to be addressed in the context of decommissioning is, “What is the effect of each decommissioning alternative on regional stocks of reef-associated species in general, or of particular targeted species?” As outlined earlier, because regional stocks of reef-associated species are composed of linked local populations, it is not sufficient to evaluate any particular local population (whether a natural reef or a platform) in isolation (Osenberg *et al*. 1999). The fact that an artificial structure has lots of organisms on it does not necessarily imply its presence has enhanced regional stocks. The artificial structure may have merely attracted individuals from more suitable habitats, via larval settlement or movement of adults. Those individuals might have made a larger (or smaller) contribution to their regional population stock had they lived in a different location, due to higher (or lower) survival, growth and reproduction.

It is unlikely that the positive or negative effects of any particular decommissioning option on regional stock of, for example, a fish species, could be assessed confidently by direct measurement. There are a number of reasons for this, but a central one is that the magnitude of the effect of an individual artificial structure (or indeed a single natural reef) is likely to be very small relative to the size of the overall regional population, and both of these (the impact of the structure on the stock and the size of the regional population) cannot be measured precisely. This is not to say that a particular decommissioning configuration could not have a strong local effect. For example, if a reefed rig is placed in an area that is primarily covered with soft bottom, a community of reef-associated species will likely develop there. Obviously there has been a strong local effect, but it is the regional effect that truly matters from an ecological perspective. While direct measurement of a regional effect seems infeasible, the effect could be estimated using a combination of empirical information and modeling. This effort would be comprised of several parts.

1. <u>Assessment of quality of platforms as reef habitat</u>. It would be critical to evaluate the ecological performance of different local populations on natural reefs and on platforms, by assessing demographic rates such as individual growth, reproduction and mortality. Such estimates would need to take into account both temporal and spatial variability such that sampling to derive the estimates would need to be conducted at a number of locations (perhaps regionally over the range of California’s platforms) and over time. The appropriate spatial and temporal scales also would depend on the lifespan and spatial distribution of the particular species of interest. These estimates

of demographic rates would allow some comparisons to be made of the quality of the various natural (reef) and artificial (platform) habitats.

2. <u>Estimate connectivity between local populations</u>. The second set of measurements to be made would estimate connectivity between the various component populations (platforms and natural reefs). The dispersal potential of various species of interest could potentially be estimated by physical oceanographic monitoring of surface and subsurface currents, in relation to the distribution of natural and artificial patches of habitat. This information would be combined with information about the timing of larval release, length of larval life and location of larvae in the water column (surface or subsurface) to model movement of larvae over the relevant spatial scale. Emerging genetic and chemical techniques to identify source populations could also be utilized in this effort.
3. <u>Model effects on the regional population of adding or removing artificial structures</u>. Finally, it should be possible to develop population dynamics models for species whose demographic performance on natural reefs and artificial structures is known, and for whom population connectivity has been estimated. These models could be used to estimate effects on the regional population of adding or removing artificial structures with certain (predicted) quality in specific locations of the region, and in relation to the distribution of biota on natural reefs.

The approach just outlined would need to be implemented in an environmental and biogeographic context, and take into account the impact on species of specific decommissioning actions. Clearly, removal, topping, toppling, etc. would likely have very different effects on the species of interest, and these effects might vary regionally due to depth, availability of hard substrate, and biogeographic constraints. And, as stated previously, since different species are likely to be affected in different ways by each decommissioning option, it would be most informative if this approach were used for a variety of species of representative life histories, including those of special economic or regulatory interest. An example of the latter are some of the rockfishes whose low abundance has triggered severe restrictions on harvest and the creation of rebuilding plans by the Pacific Fishery Management Council (e.g., McCall *et al.* 1999).

If, in fact, the approaches described just above were employed and the results suggested that decommissioning options that involve reefing of platforms could have a strong positive effect on regional stocks of species of interest, then alternate reefing options could be more explicitly explored. These studies would probably only be conducted if there was relatively clear evidence of the beneficial impact of reefing. Several types of information for this effort would be critical, and a number of different approaches are possible. Below are some possible options for such studies.

1. Detailed natural history information based on surveys of biota in deep and shallow areas, and across the biogeographic range from Pt. Conception southward would shed light on the appropriate depths and locations for placement of structures. Some of this information may be available at the present time since some areas have been sampled, but

the data appear to be incomplete, especially for the southern region. Without this information an informed decision could not be made regarding reefing options (if they were to ever occur), especially if particular species are being targeted for enhancement.

2. Information on temporal patterns of distribution and abundance of key mobile species on platforms is needed. Little temporal sampling of mobile species (particularly fish) has been conducted to date on the platforms, but the data suggest that populations of fish associated with any particular platform can be quite variable in time. Additional information is needed to estimate how temporally variable these populations are compared to populations that inhabit natural reefs. The underlying source of the temporal variability could be movement, mortality, or both, and understanding the causes for platform-associated populations will be a critical element in the evaluation of the value of platform structures as artificial reefs.
3. Information available at present suggests that topping (and leaving the rest of the platform standing in place) could have profound effects on the biota that would persist there in the future. Uncertainty regarding this option could potentially be reduced by experimentally topping one or two platforms and following the biota over time (with untopped rigs as controls). In this experiment the tops would be removed from the marine environment for disposal. After a set period of time (maybe 5 years) the performance of the structure and its contribution to regional stocks could be evaluated (using methods described above), and the structure could be completely removed (or reconfigured in some other way) if the effects on regional stocks were not positive.
4. Another experimental approach for exploring decommissioning options could involve the use of a Before-After – Control-Impact Paired Sampling (BACIPS) design, where an option (say toppling in place) is exercised for a single platform. In a BACIPS experimental design, a temporal series of data on species of interest taken on the platform prior to decommissioning and following it is compared to data sampled from a Control (comparison) platform over the same time period. Statistical techniques can be employed to test whether there has been an effect of a perturbation (in this case the decommissioning action). The information derived from this approach could also be used to estimate effects on regional stocks of implementing the decommissioning.

If decommissioning alternatives are evaluated experimentally (as in (3) and (4) above), or if a decision is made to reef one or more rigs (outside of an experimental context), it will be crucial to conduct careful monitoring studies to track the ecological performance of the biota. Monitoring would be conducted at the reefed site as well as on natural (comparison) reefs. This monitoring will be important to assessing impacts of the reef on stocks and will provide information to be used in future evaluations of potential decommissioning options.

There are several other research themes that, if explored, could greatly add to the information base needed for the decision-making process. One of these regards the mussel mounds that accumulate under platforms. During decommissioning these would likely be removed, but their removal could have impacts on marine biota (that derive from loss of hard substrate, release of toxins, etc.). It might be possible to assess the impacts of removing mussel mounds, as well as project their longevity if left in place after platform removal. For example, studies could be conducted on the mussel mounds of several platforms recently removed from the Santa Barbara coast, to assess toxicity of the sediments underlying and inside the mounds, and to gauge their deterioration and biological features by comparing them to mounds under active platforms.

Several of the research initiatives mentioned above, and indeed, the full assessment of decommissioning options, require environmental information. At least two major types are needed. The first is information about the amounts and quality of hard substrate off California south of Pt. Conception. As mentioned previously, this information is largely lacking, yet it would be needed to evaluate reef placement if decommissioning involved something other than complete removal. This information would also be of tremendous benefit to any modeling effort on effects of artificial structures on regional stocks. Similarly, a second information need in these contexts (modeling stock effects, potential reef placement) is physical oceanographic information. Our understanding of patterns of water circulation off the coast of California is still incomplete, yet this information would be of great utility in the evaluation of decommissioning options.

General Conclusions and Synthesis

1. Surveys of platforms in California waters reveal that they harbor rich assemblages of marine organisms, including many fishes and invertebrates that typically occur on natural rocky reef substrates. The particular species present on any given platform depend on the biogeographic setting of the platform and its depth, as well as other factors. Despite the fact that platforms can harbor abundant marine life, it is the platform’s contribution to regional stocks of species that is the crucial metric for evaluating its ecological impact. This is due to the fact that most marine species consist of a series of local populations (such as would occupy a reef) that are linked together by larval dispersal of young stages. The interdependence of populations means that impacts at any one location must be considered in the context of the regional set of local populations. Most extant assessments of possible biological effects of platforms are fundamentally flawed because they focus on local and not regional effects. At present there is not any sound scientific evidence (that the Committee is aware of) to support the idea that platforms enhance (or reduce) regional stocks of marine species.
2. The total “reef” area represented by the 27 California platforms is extremely small in relation to regional availability of hard bottom substrates, suggesting

that for the majority of species any regional impacts (whether positive or negative) of a decommissioning option are likely to be small and possibly not even detectable empirically.

3. However, because species differ greatly in life history, population dynamics, and geographic distribution, it is possible that platforms could have a more substantial effect (either positive or negative) on some key species. These species might be of special interest from a management point of view – rare or endangered, of economic importance, etc. In such cases, further study of effects of decommissioning alternatives, using approaches outlined in this report, could yield the scientific information needed to predict impacts of decommissioning alternatives in the context of overall management strategies. Species of special concern could include, for example, several rockfishes whose low abundance has triggered severe restrictions on harvest and the creation of rebuilding plans by the Pacific Fishery Management Council (McCall *et al*. 1999). Bocaccio, for example, is estimated to have declined to about 1 percent of virgin biomass. Love *et al.* (2000) reported that Platform Gail had a density of adult bocaccio an order of magnitude greater than the average density found on 61 natural reefs in appropriate depths. The issue, then, is to evaluate whether these higher densities of some populations on platforms persist through time, and if so, whether they could have a positive effect on regional stocks, given the very small surface area that the offshore platforms represent.
4. Decommissioning of offshore oil production facilities will involve offshore as well as onshore structures, and the various alternatives would involve a broad array of possible consequences that include not only the marine ecological effects we have addressed, but also economic, political and social impacts. These factors would need to be evaluated together to reach a final decision as to whether a decommissioning alternative other than platform removal is desirable. Nevertheless, with the current state of knowledge, predicting effects of decommissioning options on regional stocks of marine species is not possible. Indeed, there is no clear evidence of biological benefit (in the sense of enhancement of regional stocks) of the platforms in their present configuration. Thus, in light of the lack of strong evidence of benefit and the relatively small contribution of platforms to reef habitat in the region, evaluation of decommissioning alternatives in our opinion should not be based on the assumption that platforms currently enhance marine resources.

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