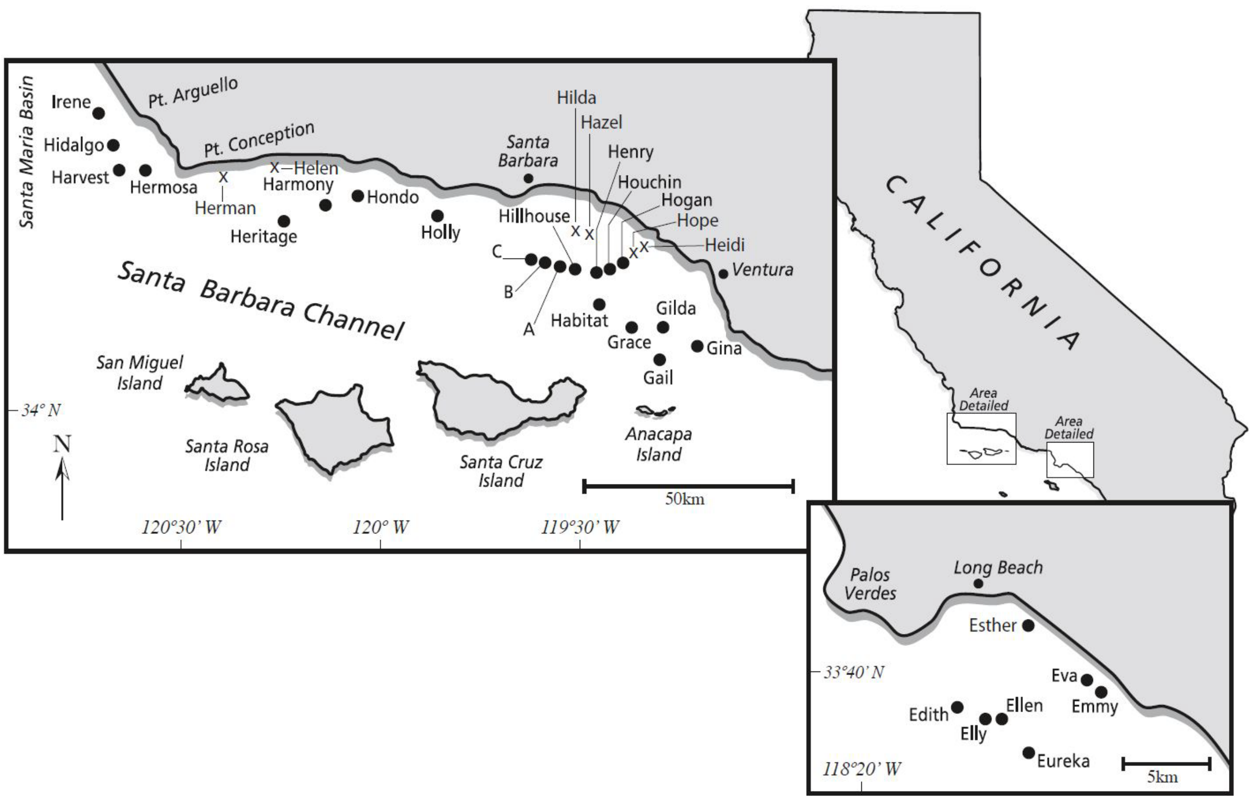
OCS Study
BOEM 2019-052

An Overview of Ecological Research Associated with Oil and Gas Platforms Offshore California



US Department of the Interior
Bureau of Ocean Energy Management
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An Overview of Ecological Research Associated with Oil and Gas Platforms Offshore California

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List of Abbreviations and Acronyms

Ag	Silver
Ba	Barium
$BaSO_4$	Barium Sulphate
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
Cd	Cadmium
CDFG	California Department of Fish and Game
cm	centimeter
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Cr	Chromium
Cu	Copper
EFH	Essential Fish Habitat
ft	feet
ft^2	square feet
GOM	Gulf of Mexico
ha	hectare
ISBN	International Standard Book Number
km	kilometer
m	meter
m^2	square meter
mg/kg	milligram/kilogram
mi	mile
Mo	Molybdenum
Ni	Nickel
NOx	Nitrogen oxides
OCS	Outer Continental Shelf
Pb	Lead
PM	particulate matter
POCS	Pacific Outer Continental Shelf
ROV	Remotely Operated Vehicle
RtR	Rigs-to-Reefs
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
SCUBA	Self-contained Underwater Breathing Apparatus
Sox	Sulphur oxides
THC	Total Hydrocarbon Pollutants
TOC	Total Organic Carbon
TRPH	Total Recoverable Petroleum Hydrocarbons
yd^3	cubic yard
V	Vanadium
YOY	young-of-the-year
Zn	Zinc

1 Executive Summary

The purpose of this study was to increase scientific understanding of the relationships of fish and invertebrate populations at offshore oil and gas platforms and natural reefs within the Southern California Bight; to determine the extent of influence of platform assemblages on southern California and the Pacific coast populations; and, to synthesize relevant reports, existing peer-reviewed literature, and new data analyses. This effort was executed through five tasks listed below.

The first task was to compile a brief account of the development of California offshore oil and gas. The first oil produced from wells situated on piers occurred in 1897 at Summerland, California. By the 1920s dozens of oil-producing piers had been erected both off Summerland and further to the west off Ellwood. The first man-made drilling island was called “Monterey” and was situated 1.5 miles (mi) offshore of Seal Beach in 42 feet (ft) of water; drilling commenced there in 1954. Hazel was the first steel offshore platform built off Summerland in 1958 for the purpose of oil and gas production. Today, there are 27 platforms off California (Figure 1 and Appendix A).

The second task was to produce digests of previous California platform research. This effort compiled the findings of 182 papers and reports from research in both federal and state waters. We organized summaries of this research into subsections titled: “Biology and Ecology of California Platform Organisms,” “Environmental Effects of Offshore Oil Development,” and “Potential Consequences of Platform Decommissioning.”

The third task was to construct a queriable, web-based annotated bibliography encompassing research on oil and gas platforms conducted throughout the world. Here, we describe the parameters of the webpage. The website, http://platformresearch.msi.ucsb.edu, has been established as an annotated repository for worldwide historic and new scientific research directed at organisms and organismal communities associated with offshore oil and gas platforms. The annotated bibliography contains 1) papers in refereed journals, 2) gray literature as research reports, 3) books and book chapters, and 4) theses and dissertations. To date, the repository contains 1,012 abstracts.

The fourth task was to compare the fish and invertebrate assemblages around California platforms with those associated with Gulf of Mexico platforms.

The fifth and final task was to develop a dedicated issue of the *Bulletin of Marine Science*. The purpose of this issue was to stand as a peer-reviewed journal publication that includes review articles and new data analyses that synthesized the scientific research focused on the organisms living in association with oil and gas platforms off California and also acted as a source of information for evaluating potential environmental effects of platform structures on regional marine ecology and consequences of their eventual removal. It is hoped that this collected material will help inform the public, policy makers, and regulators about their upcoming decisions. The issue contains 11 papers; the article titles, bibliographic references, authors, and abstracts are included in Appendix C of this report.

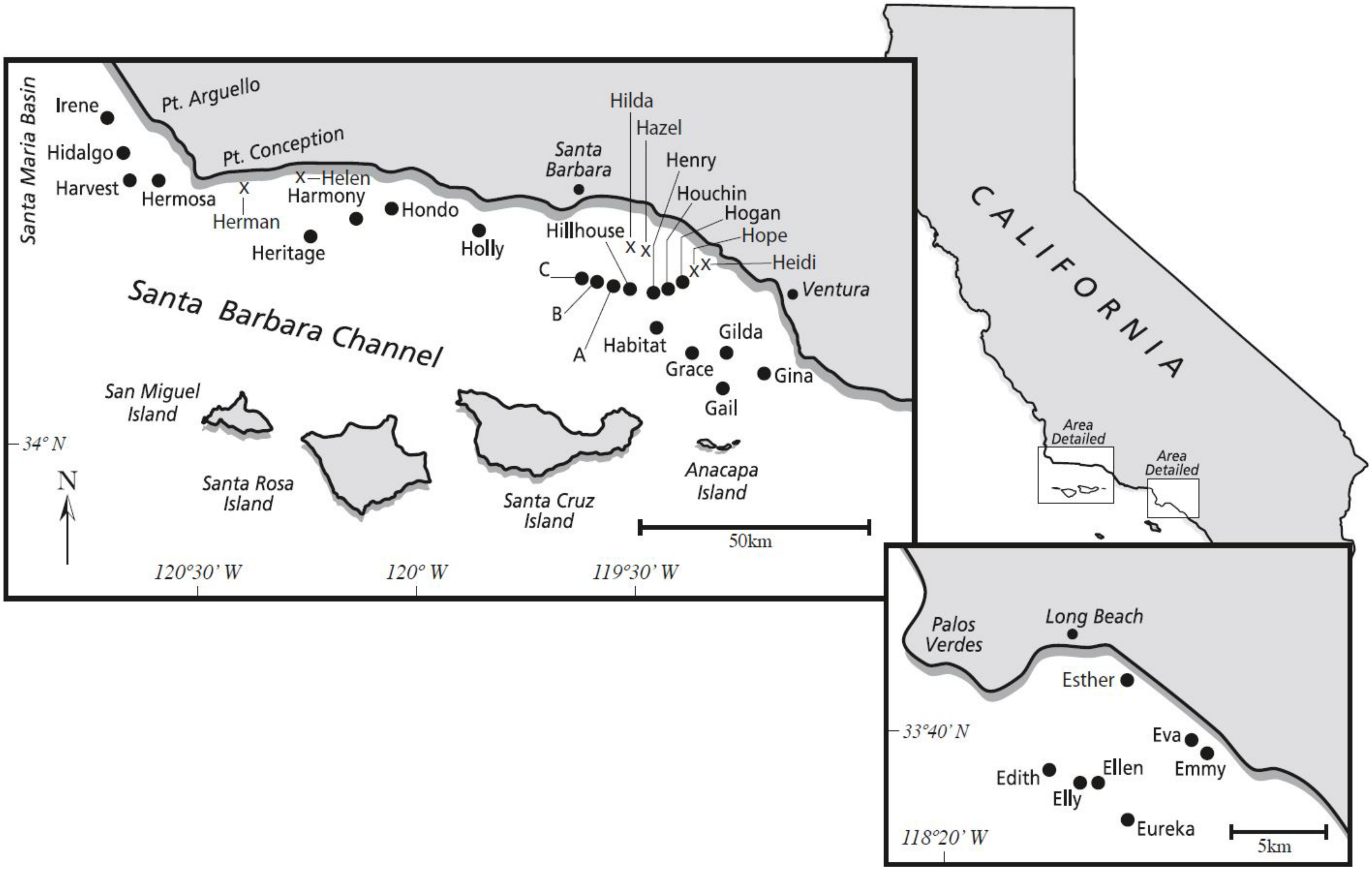

Figure 1. Location of oil and gas platforms offshore California, including 27 existing platforms (●) and 6 decommissioned platforms (x).

2 Background

With the construction of the first offshore oil and gas platforms off California in 1958, the ecology and assemblages of organisms living in association with these platforms has been of continuing interest. Beginning in 1958, state, and later federal, agencies invested both time and funds to conduct research on fishes and invertebrates living in association with California platforms. In particular, the federal government, under the auspices of the Minerals Management Service, and then the Bureau of Ocean Energy Management (BOEM), has directed substantial resources into this research based on BOEM's mandate, summarized as "BOEM's Environmental Studies Program [began in 1973] develops, funds, and manages rigorous scientific research specifically to inform policy decisions on the development of energy and mineral resources on the Outer Continental Shelf (OCS). Research covers physical oceanography, atmospheric sciences, biology, protected species, social sciences and economics, submerged cultural resources and environmental fates and effects. Mandated by Section 20 of the Outer Continental Shelf Lands Act, the Environmental Studies Program is an indispensable requirement informing BOEM's decisions on offshore oil and gas, offshore renewable energy, and the marine minerals program for coastal restoration" (BOEM 2019).

This interest was given a greater urgency under the California Marine Resources Legacy Act (MRLA). MRLA establishes state policy to allow, on a case-by-case basis, Rigs-to-Reefs (RtR); the partial decommissioning of offshore oil and gas platforms with the remaining submerged support structure staying in place and enduring as part of the California Artificial Reef Program. MRLA recognizes the multi-jurisdictional nature of platform decommissioning and the need for a viable RtR program to utilize the established expertise and authority of different state entities. With the passage of the MRLA 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. The bill specifically requires an analysis and proof of a net environmental benefit to fisheries production (California Marine Resources Legacy Act 2010, Scarborough Bull and Love 2019).

The removal of oil and gas platforms offshore California is imminent. Consideration of whether to completely remove a platform or cut it off at some depth below the sea surface and retain the submerged portion as a reef is no longer a decision that will occur in the distant future. Among the platforms off California, Platform Holly in state waters, and Platforms Hidalgo, Harvest, Hermosa, Grace, and Gail in federal waters, are undergoing the initial steps for decommissioning as of 2019. The decommissioning process is expensive, complex, and lengthy, and while RtR may be an option, it is important to appreciate that the California RtR Program is complicated, costly to applicants, and voluntary with owner/operator of platforms in both state and federal waters eligible to participate. Additionally, the Program only addresses state requirements and does not encompass the multitude of federal regulations, permits, and requirements for reefing, although the federal path is well understood and practiced (Scarborough Bull and Love 2019). More platforms may soon be considered for decommissioning despite the intricate planning and complex technical challenges that this poses. The Bureau of Safety and Environmental Enforcement (BSEE) enforces laws and regulations associated with the decommissioning of offshore oil and gas facilities, including pipelines, in federal waters (BSEE 2019).

3 The Development of California Offshore Oil and Gas

Oil and gas seeps, often the result of geological deformation of oil-saturated strata, are a common global occurrence. The famous La Brea tar pits, near downtown Los Angeles, is just one of many seeps found in California. Offshore, seeps are visible on the ocean surface as oil slicks or gas bubbles. As noted by California Resources Agency (1971), "Some [seeps] remain dormant for extended periods of time and then become reactivated, probably by pressure buildup or earth movement. Because of the transient nature of many seeps, an accurate count is difficult to obtain; however, it appears that there are probably 50 to 60 seeps and seep areas on the ocean floor between Point Conception in Santa Barbara County and Huntington Beach in Orange County."

Native Americans in many parts of California, but particularly along the southern California coast, mined those land seeps that contained hard, high-grade asphaltum. California Native Americans used asphaltum in a variety of ways. Baskets and water bottles were made watertight, arrow-points and hook barbs attached to shafts, broken stone vessels repaired, canoes caulked and sealed and shell decorations were inlaid on various objects. The Chumash of coastal southern California melted asphaltum and mixed it with pine resin to create an effective adhesive for many of these uses.

Early European explorers noted the presence of these seeps. "The Spanish explorer Fages, in 1775, said that at a distance of two leagues from this mission [San Luis Obispo] there are as many as eight springs of a bitumen or thick black resin...' Fr. Pedro Font, in 1776, while near Goleta in Santa Barbara County wrote "much tar which the sea throws up is found on the shores, sticking to the stones and dry. Little balls of fresh tar are also found. Perhaps there are springs of it which flow out into the sea, because yesterday on the way the odor of it was perceptible, and today...the scent was as strong as that perceived in a ship or in a store of tarred ship tackle and rope" (Heizer 1943).

While European settlers in California utilized asphalt from terrestrial seeps in limited ways, primarily for water proofing and lubrication, there was relatively little interest in oil seeps until about 1850, when it became more widely known that kerosene, an excellent substitute for whale oil in lamps, could be distilled from crude oil. In California, the first person known to use partially refined oil for illumination was General Andreas Pico, the brother of Pio Pico, the last Mexican governor of California. In 1850, General Pico distilled kerosene from oil taken from hand-dug pits in Pico Canyon (near Newhall, southern California) and used it for lighting a home. By 1854, miners had excavated into Sulphur Mountain in Ventura County (southern California), were hauling out the oil that seeped into their tunnels and had set up stills to produce kerosene. Throughout the 1850 and 1860s, various companies mined seeps for petroleum and produced kerosene or kerosene-like products.

In California, the first well (as opposed to hand-dug pit) that was designed to produce oil was a failure. It was drilled in Humboldt County in 1861 and it, along with others in the same county between 1861 and 1864, came up dry. However, the first productive well, drilled in 1865, came in from Humboldt County. This was quickly followed up by successful wells in Ventura and other localities. It was not until 1876 that the first truly commercial well was developed in Pico Canyon, the site of General Pico's first pit mine. The next 20 years saw production rapidly escalate, with new fields explored and developed in a number of locations in central and southern California.

The first oil production from submarine strata in California occurred in Summerland, a sleepy village south of Santa Barbara formally founded in 1889 as a spiritualist colony. For years, Summerland residents had noted both the heavy scent of oil that frequently hung over the community and the numerous seeps that dotted their coastline. In fact, natural gas was so plentiful that when boys wanted to play baseball at night "They would drive short pieces of pipe into the ground about four or five inches, and would light them, and there would be a gas flame at least a foot high from the top of the pipe. Fifteen or twenty of these pipes along the edge of the road gave plenty of light for them to play after dark. When they got called in to go to bed, each had a flat board, and they would whack the board down over the flame, and out it would go" (Lambert 1975).

In the late 1880s and early 1890s, several Summerland residents had struck oil while digging water wells and at least one would fill barrels from a bucket, haul them by buckboard to Santa Barbara, and sell the oil to laundries. Drilling for oil at the shoreline commenced shortly after and by 1897 both the beaches and the short stretch between ocean and coastal hills were blanketed with drilling rigs. In 1896, W. L. Watts of the California State Mining Bureau reported that "It is also evident that the oil yielding formations extend south into the ocean...At low tide, springs of oil and gas are uncovered on the seashore." (Rintoul 1990).

True to the prediction, the first pier holding a well was built in 1897. This was perhaps the world's first well brought in over water, a record also reportedly claimed for the Baki (formerly Baku) (Republic of Azerbaijan) oil fields in the Caspian Sea and by Pennsylvania for drilling into Lake Erie. Within a few years there were 11 piers (harboring over 200 wells), one of them stretching 1,230 ft offshore. The Summerland piers continued to produce oil until 1939, when the last well was destroyed by high tides and high surf.

In the 1920s, a series of discoveries along the Santa Barbara Channel, particularly at Rincon (northwest of Ventura) and Ellwood and Capitan (west of Santa Barbara) led to additional offshore drilling. While all of these discoveries were made on land, development quickly extended onto piers. However, rather than being built of wood, these piers were more heavily constructed of steel pilings and reinforced concrete caissons.

The year 1932 saw the erection of the first oil platform off California and perhaps in the world. In that Depression year, the Indian Petroleum Company was faced with a dilemma. Geological evidence implied that productive oil-bearing strata lay offshore of Rincon. However, the costs of building a pier out to that formation were prohibitive. The company solved the problem by building part of a pier, located about 1,200 ft beyond the end of the nearest pier. Constructed of steel in 38 ft of water, the aptly named "Steel Island" was eventually home to three wells. It lasted until 1 January 1940, when "...mountainous waves battered the platform. The structure went down. There was no loss of life, but equipment was destroyed and wells damaged. Rohl-Connolly Company, marine contractors, removed equipment, derrick and steel pilings from the ocean floor; cut off casing at the floor of the ocean; and placed 6-foot cement plugs in the tops of the water strings" (Rintoul 1990).

Later oil and gas discoveries that were of importance to offshore development included those at Huntington Beach, Wilmington and Seal Beach. However, it was not until 1954, that the next step in offshore production occurred with the creation of the first man-made drilling island: "Monterey" situated 1.5 mi offshore of Seal Beach in 42 ft of water. Construction on the island commenced in 1952, but a lawsuit by the city of Seal Beach prevented drilling until 1954. The circular island "75 feet in diameter, had an outer rim formed of interlocking sheet-steel piling driven into the ocean floor to depths of 15 to 20 feet. The interior was filled with rock and sand barged in from Catalina Island" (Rintoul 1990). In succeeding years five other oil islands (Grissom, White, Freeman, Chaffee, and Esther) were built.

Oil islands were only practical in relatively shallow waters and when industry-led seismic surveys and bottom coring discovered potential fields in deeper offshore waters, the stage was set for the development of oil platforms. In June 1958, the California State Lands Commission held its first sale of tidelands leases, ending a freeze that had held up offshore drilling on new sites. The first platform constructed was Platform Hazel, located about 2 mi offshore of Summerland in 100 ft of water. As noted in Rintoul (1990) regarding Hazel's construction, "In that same month, Standard [Oil] towed an imposing tower a distance of 210 miles... to the Summerland tract. The tower was 75 feet square and 170 feet high. It was a major component of Platform Hazel and was to serve as the foundation on which the 110-foot square deck would be mounted...The tower was floated to the job site on the four big caissons that formed the bottom portion of the tower's legs, each 40 feet high and 27 feet in diameter. Each caisson was pressurized to prevent leakage and also ballasted with 90 tons of sand for stability... Once on bottom, the caissons were sunk 22 feet into the ocean floor by means of high pressure water and air jets that literally hosed away the bottom sands, allowing the caissons to rest on hard ground. The final anchoring was accomplished by filling the caissons with 6,000 tons of sand and concrete…The cost of building and installing the platform was $4 million." In September 1958, Standard Oil began drilling from the newly constructed platform and within one month the first well, bottoming out at 7,531 ft began producing 865 barrels per day. This followed two years later by the construction of nearby Platform Hilda.

In subsequent years, a number of platforms were installed in both state and (beginning in 1967 with Platform Hogan) federal waters in southern California (existing platforms as of 2019 are shown in Figure 1 and described in Appendix A). However, expansion of offshore oil drilling came to an abrupt halt in 1969, with the blowout and subsequent oil spill at Platform A (installed in 1968) in the Santa Barbara Channel. And while discussion of both opposition and support for oil development are beyond the scope of this paper (but see Beamish et al. 1998, Nevarez et al. 1998, and Paulsen et al. 1998), the subsequent environmental concerns about the safety of offshore oil exploration, development, and production delayed further drilling for a number of years. It was not until the late 1970s that installation of new platforms resumed. No new platforms have been erected in California since 1989 (Nevarez et al. 1998).

4 A Summary of Previous California Platform Research

4.1 Biology and Ecology of California Platform Organisms

The first surveys of the organisms living around California platforms were conducted by scuba from 1958–1961, primarily around the newly erected Platform Hazel (in 30 m) and, to a lesser extent, Hilda (32 m) [both platforms were removed in 1996] (Carlisle et al. 1964) (Figure 1). Both fishes and the jacket invertebrate community were monitored throughout the three-year survey at Hazel. Over the course of the study, an average of 6,000 fish (ranging from 3,000 to 62,000) inhabited Hazel, representing 42 species. Seaperches (e.g., *Cymatogaster aggregatus* Gibbons, 1854, *Rhacochilus toxotes* Agassiz, 1854, and *Embiotoca jacksoni* Agassiz, 1853) and rockfishes (e.g., *Sebastes paucispinis* Ayres, 1854, *Sebastes auriculatus* Girard, 1854, *Sebastes caurinus* Richardson, 1844, and *Sebastes serranoides* (Eigenmann and Eigenmann, 1890)) dominated this assemblage, with a wide range of other typical reef-dwelling taxa, as well as pelagic visitors, observed. Of particular importance, Carlisle et al. (1964) noted that both Hazel and Hilda acted as nursery grounds for young fishes and that often young-of-the-year (YOY) outnumbered adults. A total of 142 invertebrate species were identified at Hazel. Hydroids (i.e., *Campanularia* sp.), sea anemones (*Anthopleura elegantissima* (Brandt, 1835), *Corynactis californica* Calgren, 1936, and *Metridium senile* (Linnaeus, 1761)), barnacles (i.e., *Megabalanus tintinnabulum* (Linnaeus, 1758), *Semibalanus cariosus* (Pallas, 1788)), and tubeworms (i.e., *Eudistylia polymorpha* (Johnson, 1901)) were early colonizers, but within one year of the platform's installation mussels (referred to as *Mytilus edulis* Linnaeus, 1758, but likely *Mytilus galloprovincialis* Lamarck, 1819) had become dominant to depths of about 15 m. After three years, no large shell mound had formed around the base of Hazel. The five dives around nearby Platform Hilda demonstrated that the fish assemblages and populations were similar to those at Hazel.

The California Department of Fish and Game (CDFG) conducted additional fish surveys around Hazel and Hilda in 1970. This appears to have been a brief reconnaissance; there is no available data on species composition, but Bascom et al. (1976), citing unpublished CDFG data, state that by 1970 fish populations had increased to about 18,000 at Hazel and 12,500 at Hilda. During spring–fall 1975, researchers returned to Hilda and Hazel and conducted a series of surveys comparing fish and invertebrate populations around the platforms with those associated with a soft seafloor control station and a shallow-water nearshore reef (Allen and Moore 1976, Bascom et al. 1976, Mearns and Moore 1976). On average, there were about 20,000 fishes each around Hilda and Hazel, of at least 21 species. The fish assemblages were similar to those documented by Carlisle et al. (1964) as rockfishes (particularly *S. serranoides*, *S. auriculatus*, and *Sebastes mystinus* (Jordan and Gilbert, 1881)), seaperches (e.g., *Embiotoca jacksoni* and *Phanerodon furcatus* Girard, 1854), *Chromis punctipinnis* (Cooper, 1863), and *Paralabrax clathratus* (Girard, 1854) were all abundant. High densities of both juvenile and subadult fishes were noted at both platforms. There were 21 fish species at the platforms compared to 7 species on the soft seafloor habitat and 11 at the natural reef. The invertebrate assemblage occupying the platform jackets were also similar to those reported in the earlier study. However, unlike the earlier survey (Carlisle et al. 1964), Bascom et al. (1976) found large shell mounds around both platforms; these were occupied by *Metridium senile*, crabs (e.g., *Metacarcinus anthonyi* (Rathbun, 1897) known today as *Cancer anthonyi*), sea stars (e.g., *Pateria miniata* (Brandt, 1835)), and sea cucumbers (e.g., *Parastichopus* sp.).

During 1975 and 1976, research focused on the invertebrates living on and near the shell mound associated with Platform Eva (Wolfson et al. 1979), located in state waters in 57 meters (m) of water off Huntington Beach (Figure 1 and Appendix A). As in the previous studies at Hilda and Hazel, this research found that the jacket invertebrate assemblage was dominated by *Mytilus* sp. and that *Pisaster* spp. were also found in relatively high densities on the jacket. Wolfson et al. estimated that a cubic meter of shells fell to the seafloor per day. On the shell mound, echinoderm (i.e., *Pisaster* spp., *Patiria miniata* (Brandt, 1835), *Pycnopodia helianthoides* Brandt, 1835, and *Parastichopus* spp.) densities were extremely high, much higher than densities documented in other Pacific North America habitats. All of these species were rare on the surrounding sandy seafloor. An estimated 19,000 asteroids and 5,000 sea cucumber lived in a 24 x 27 m area beneath the platform. Wolfson et al. found that echinoderm densities on the jacket, although higher than in natural habitats, were lower than on the shell mound below. They speculated that the band of *C. californica*, lying just below the mussel layer, prevented shell mound sea stars from moving up the jacket legs. The shell mound also had an effect on the invertebrate assemblage adjacent to it. As an example, densities of the tube-dwelling polychaete *Diopatra ornata* Moore, 1911, a dominant species in the sand at the edge of the shell mound, rapidly declined with distance from the shells. Further analysis of this data (Davis et al. 1982) indicated that at least one unidentified ophiuroid and 18 species of infaunal polychaetes were either positively or negatively associated with the shell mound.

Increasing interest in Outer Continental Shelf platforms led the Minerals Management Service to fund a study (Allen et al. 1986, MBC Applied Environmental Sciences 1987a,b) that summarized information on the ecology and fisheries of important fishes and invertebrates that might associate with platforms off California and tried to address the question of whether these platforms produced or aggregated these taxa. In addition, it created an annotated bibliography of this research. The document consists of more than 950 annotated citations of the biology and fisheries of 32 fish and invertebrate species of commercial and recreational importance in the marine waters of California.

Growth rates of invertebrates living on Platform Holly (in the state waters of the Santa Barbara Channel, Figure 1) were measured by Page (1986) and Page and Hubbard (1987). Page (1986) compared the growth rates and population structure of the barnacle *Pollicipes polymerus* Sowerby, 1833 living on the jacket of Holly and a rocky headland just inshore of the platform. He found that the growth rates of that barnacle were higher at Holly (0.114 mm d^{-1}) compared to that of the rocky headland (0.033 mm d^{-1}). He also found that barnacles grew larger at the platform and had a bimodal (as opposed to unimodal) size structure. In contrast, the size structure at the rocky headland is subject to “poor long-term survival, in part because of erosion of the soft shale rock substratum.” The mussels growing on California platforms were the subject of work by Page and Hubbard (1987), who reported on the growth rates of *M. galloprovincialis* living on the jacket of Platform Holly. In general, growth rates were some of the highest reported for this species. Unlike in other studies, which had noted decreasing growth rates with increasing depth, growth rates were higher at 9 m than at 2 or 18 m. Growth rates were highest in late spring to early summer (perhaps due to phytoplankton food availability). Water temperature did not appear to affect growth rates.

Bull (1989) reported on the sessile invertebrates inhabiting the jacket of Platform Hogan, located in the Santa Barbara Channel (Figure 1). She found that barnacles (*Balanus* spp. and *Megabalanus californicus* (Pilsbry, 1916)) dominated the splash zone, mussels (*M. galloprovincialis*), brittlestars (*O. spiculata*), sea stars (*Astropecten verrilli* de Loriol, 1899), and purple urchins (*Strongylocentrotus purpuratus* Stimpson, 1857) were the most abundant taxa in 2–9 m, and from 10 m down to at least 25 m, many of the same species occurred, although *M. californianus*, *M. senile*, *R. antennarium,* and *C. californica* also became more abundant. She noted that two other seastars, *Pisaster giganteus* (Stimpson, 1857) and *Pisaster ochraceus* (Brandt, 1835), were present and unusually large in size.

As part of a survey on the movement of rockfishes, the California Department of Fish and Game tagged 2,471 juvenile *S. paucispinis* at platforms A, B, and C in federal waters in the Santa Barbara Channel. Of these fishes, 96 (3.9%) were recaptured and some fish were recaptured as adults as much as 148 km away on natural habitats (Hartmann 1987).

Love and Westphal (1990) documented the role that platforms played in the Santa Barbara Channel commercial passenger fishing vessel recreational fishery. They found that over a three-year period close to 20% of the fishing day was spent at five platforms. Specifically comparing catches at the platform versus at two nearby natural reefs, 28 species were captured at the platforms versus 34 and 17 species at two natural reefs, respectively. The vast majority of fishes taken at both platforms and natural reefs were rockfishes (genus *Sebastes*). Almost all of the fishes taken at the platforms were juveniles; more mature fishes were taken at the reefs. While midwater rockfish species were abundant at both platform and natural reefs, species compositions were different. Benthic rockfishes characteristic of high-relief substrata were absent or rare around the platforms.

The first study off California that directly surveyed the fish populations of an OCS platform was conducted in 1990 at Platform Hidalgo, located between Point Arguello and Point Conception (Figure 1) and at several near-by natural reefs (Imamura et al. 1993a,b, Love et al. 1994). Using a remotely operated vehicle (ROV) much of the jacket of this platform (situated at a depth of 123 m) was surveyed. Surveys conducted from July–September observed large numbers of YOY rockfishes (primarily *Sebastes entomelas* (Jordan and Gilbert, 1880), *Sebastes flavidus* (Ayres, 1862), *Sebastes hopkinsi* (Cramer, 1895), S. *mystinus*, and *S. paucispinis*) in 20–60 m and again at the bottom of the structure. In addition, the upper portion of the platform also harbored YOY *Oxylebius pictus* (Cooper, 1863), *Scorpaenichthys marmoratus* (Ayres, 1854), and *C. punctipinnis.* During an October survey, few fish were found in the upper portions of the platform, although fishes were still abundant at the platform base. The fish assemblages in the platform midwaters differed significantly from those at the platform base. In addition, the assemblages at the natural reefs were also significantly different from those at the platform.

From 1995–2000, Love and colleagues conducted fish surveys around many of the platforms in the Santa Barbara Channel and Santa Maria Basin (north of Point Conception), using both scuba and a manned submersible (Love et al. 1997, 1999a,b, 2000, 2001, 2003). The midwaters, bases, and associated shell mounds of platforms with bottom depths between 49–224 m were surveyed. In general, platform midwaters were dominated by YOY or juvenile rockfishes (e.g., *S. atrovirens*, *S. entomelas*, *S. flavidus*, *S. hopkinsi*, *S. mystinus*, *S. paucispinis*, and *Sebastes rubrivinctus* (Jordan and Gilbert, 1880)), and *O. pictus*, as well as juvenile and adult seaperches (i.e., *Damalichthys vacca* Girard, 1855, *Phanerodon atripes* (Jordan and Gilbert, 1880), *C. punctipinnis*, *Paralabrax clathratus* (Girard, 1854), and *Semicossyphus pulcher* (Ayres, 1854)). Fish assemblages at platform bases were statistically distinct from their associated midwaters and, in fact, midwater assemblages across the range of platforms, were more similar to each other than to their associated bases. The platform base assemblages were, again, dominated by rockfishes. However, while there was some overlap in their species, a number of dominant taxa on the bottom (e.g., *Sebastes chlorostictus* (Jordan and Gilbert, 1880), *Sebastes miniatus* (Jordan and Gilbert, 1880), and *Sebastes semicinctus* (Gilbert, 1897)) were rare or absent in midwater. In addition, while the majority of fishes in the midwaters were juveniles, fishes at the base tended to be subadults or adults. The fish assemblages inhabiting the shell mounds were similar to those at the adjacent platform base. Taxa inhabiting shell mounds were non-randomly distributed and tended to be associated with different percentages of shell cover.

Page and Dugan (1999) and Page et al. (1999) investigated the distribution, abundance, and population characteristics of four species of crabs (*Cancer productus* Randall, 1840, *Loxorhynchus grandis* Stimpson, 1857, *M. anthonyi*, and *Romaleon antennarium* (Stimpson, 1856) (currently known as *Cancer antennarius*)) living on the shell mound surrounding Platform Holly and on the soft seafloor surrounding the shell mound. Their findings included: 1) *R. antennarium* young recruited to the mussels on the platform's jacket and that larger individuals preferentially lived on the shell mound compared to the surrounding seafloor; 2) Adult female *M. anthonyi* were more abundant on the shell mound than on soft sediment (and hence may have been using the habitat preferentially to reproduce); 3) *C. productus* and *L. grandis* catch rates were similar between shell mound and soft seafloor. The authors point out that their results demonstrate the importance of examining how each individual taxa responds to artificial structure.

Carr et al. (2003) surveyed the fishes living on six east Santa Barbara Channel platforms (A, B, C, Hogan, Houchin, and Henry, Figure 1), from the surface to the bottom (to a maximum of 57 m) and five nearby natural reefs. A suite of fishes, at the natural reefs, were also tagged. Twenty-seven species were observed at platforms and 29 species were observed at natural reefs. While having many species in common, fish assemblages at platforms and reefs were different. Dominant species at platforms included a range of rockfishes (e.g., *S. atrovirens*, *S. miniatus*, *S. entomelas*, *S. serranoides*, and *S. mystinus*), as well as unidentified juvenile rockfishes and *Medialuna californiensis*, *C. punctipinnis*, and *O. pictus*. Dominant species at natural reefs included *C. punctipinnis*, *P. clathratus*, *O. californica*, *Paralabrax nebulifer* (Girard, 1854), and a range of sea perches. In general, densities of rockfishes, particularly of the YOY stages, as well as *M. californiensis*, and *Phanerodon atripes*, were higher at platforms. By contrast, densities of a number of reef species (*P. clathratus*, *O. californica*, *G. nigricans*, *Rhacochilus toxotes* Agassiz, 1854, and *Embiotoca jacksoni* Agassiz, 1853) were higher at natural reefs. At platforms, YOY "copper complex" rockfishes lived primarily in 31 m and shallower. By contrast, most YOYs of the "benthic rockfish" and "midwater rockfish" groups were found in waters deeper than 20 m.

Surveys of the invertebrates and algae living on platform jacket legs and nearby natural reefs were conducted between 1998–2000 at six platforms (in the Santa Maria Basin and eastern Santa Barbara Channel) and two natural reefs (in the Santa Barbara Channel) (Continental Shelf Associates 2005). A total of 173 invertebrate and algal taxa were identified on the platforms. Typical groups included a wide range of algae, barnacles, crabs, sea stars, urchins, brittle stars, bivalves, gastropods, polychaetes, anthozoans, and sponges. Platforms had 4–6 distinct, depth-related, biotic zones; deeper platforms had more zones than shallower ones. These zones, from shallowest to deepest, were characterized as 1) Intertidal, 2) *Mytilus*, 3) Barnacle/Scallop, 4) *Corynactis*/Encruster, 5) Vase sponge/Encruster, and 6) Encruster/Sea Star/Cup Coral. Two taxa, *M. senile* and *Mytilus* spp., were dominant on all platform legs, while *Balanus* spp., *C. californica*, *Anthopleura elegantissima* (Brandt, 1835), various ophiuroids, filamentous red algae, and tube-dwelling polychaetes were among the taxa that were also nearly ubiquitous. In comparing platforms and natural reefs, a number of dominant taxa (e.g., *Ophiothrix spiculata* Le Conte, 1851, *Mytilus californianus* Conrad, 1837, *C. californica*, *M. senile*, and filamentous red algae) were held in common. However, algal species diversity, in particular, was higher at the natural reefs.

Bram et al. (2005) examined the successional patterns of the sessile invertebrate communities attached to a platform jacket. They conducted their experiments at Platform Houchin (Figure 1), in the Santa Barbara Channel, at depths of 6, 12, and 18 m using a series of ceramic tiles that were replaced at frequencies of 2, 4, 6, 12, and 24 months. More than 40 taxa settled on the plates. Tunicates and bryozoans were among the early colonizers, along with lower densities of tubiculous amphipods, barnacles, and sponges. By the end of the study, barnacles, and sponges and, secondarily, mussels, were most dominant. Water depth affected recruitment intensity and the distribution of taxa, but did not affect the sequence of colonization, particularly early on. Bram et al. noted that "development of the invertebrate assemblage on the tiles submerged at Platform Houchin could not be categorized as classical succession…because some species/taxa that were present in high cover after 12 and/or 24 months (e.g., barnacle, sponges) could also colonize the tiles early in the successional sequence…"

Love and York (2005) conducted a survey of the fishes associated with a pipeline (in 95–235 m) running from Platform Gail to shore in the eastern Santa Barbara Channel and compared that to the fish assemblages on the seafloor near that pipeline. Love and York found that there were four distinct fish assemblages, shallow and deep pipeline and shallow and deep natural seafloor. Fish densities along the shallow portion of the pipeline were about seven times higher than on the adjacent seafloor and densities along the deep pipeline portion were nearly six times that of the deeper seafloor. Along the pipeline, rockfishes comprised 84% of the fish assemblage, and included 22 species over all. Unidentified sanddabs (probably most or all *Citharichthys sordidus* (Girard, 1854)), and combfishes (*Zaniolepis frenata* Eigenmann and Eigenmann, 1889, and *Zaniolepis latipinnis* Girard, 1858) dominated the soft seafloor. Most of the pipeline fishes were either juveniles of larger taxa (e.g., *Ophiodon elongatus* Girard, 1854, *Sebastes levis* (Eigenmann and Eigenmann, 1889), *Sebastes melanostomus* (Eigenmann and Eigenmann, 1890), *S. miniatus*, and *S. rubrivinctus*), lingcod or dwarf species (e.g., Agonidae, *Sebastes saxicola* (Gilbert, 1890), and *Sebastes semicinctus* (Gilbert, 1897)). Areas of the pipeline that were undercut tended to harbor higher densities of fishes.

The role that platforms might play as exporters of fish larvae was examined by Love et al. (2005) and Love and Schroeder (2006). Based on data regarding both densities and size-frequencies, they compared the potential larval export of two overfished rockfishes, *S. levis* and *S. paucispinis*, from platforms and natural reefs. Generally, densities of these taxa were low at both platforms and natural reefs. However, quoting Love et al. (2005) "The mean densities for both species were higher around platforms than at natural reefs. Two of the three platforms (Gail and Hidalgo) that harbored mature bocaccio had larger mature individuals than did any natural reef. Platform Gail had by far the highest densities of both mature bocaccio (*S. paucispinis*) and cowcod (*S. levis*) of any natural or human-made habitat and the potential larval production of both species at Platform Gail was much higher than at any other site surveyed. We estimated the removal of Platform Gail would be the equivalent of removing 12.57 ha of average-producing natural habitat in southern California for cowcod or 29.24 ha of average-producing natural habitat for bocaccio."

Love et al. (2006) estimated that in 2003, associated with eight California oil and gas platforms, there was a minimum of 430,000 juvenile *S. paucispinis*. Using a model employed by the stock assessment teams at the National Marine Fisheries Service, they estimated that 430,000 juveniles were about "20% of the average number of juvenile bocaccio that survive annually for the geographic range of the species." Moreover, "when these juveniles become adults, they will contribute about one percent (0.8%) of the additional amount of fish needed to rebuild the Pacific Coast population."

Given the high densities of YOY fishes in some years around some California platforms, recurrent questions were: what might have happened to these young fishes if that platform had not been installed?, where might the pelagic larvae or juveniles have been carried? and, would those fishes have been carried to natural nursery habitats? Using high-frequency radar to map currents, Emery et al. (2006) simulated the drift pathways of pelagic juvenile *S. paucispinis* during two recruiting seasons at Platform Irene, off Point Arguello (Figure 1). This research assumed that appropriate shallow water juvenile habitat existed inshore from Irene. "Results from 1999 indicated that 10% of the trajectories represent transport to habitat, whereas 76% represent transport across the offshore boundary [and would be lost to the population]. For 2002, 24% represent transport to habitat, and 69% represent transport across the offshore boundary. Remaining trajectories (14% and 7% for 1999 and 2002, respectively) exited the coverage area either northward or southward along isobaths" (Emery et al. 2006).

Similarly, the very high densities of YOY rockfishes observed at some platforms during some years led to questions regarding the ecological performance of fishes in those situations where food might be limiting.

The birthdates and daily growth rates of YOY *S. mystinus* were determined and compared among two platforms and two natural reefs (Love and Schroeder 2006, Love et al. 2007). "We found a significant though modest lunar pattern in birthdates where blue rockfish produced (or successfully recruited) more larvae in the week leading up to the full moon. At one of the two site pairs (platform-natural reef), YOY rockfish growth rates were significantly higher at the platform habitat; there was no statistical difference in growth rates between fish living at the other site pair" (Love et al. 2007).

Love and York (2006) demonstrated that, around the base of California platforms, the amount of "sheltering habitat" (created by undercut bottom-most crossbeams) affects the associated fish community. "A few species, such as blackeye goby (*Rhinogobiops nicholsii* Bean, 1882), greenstriped rockfish (*Sebastes elongatus* Ayres, 1859), and pink seaperch (*Zalembius rosaceus* Jordan and Gilbert, 1880) tended to avoid the beam. However, many species that typically associate with natural rocky outcrops, such as bocaccio (*S. paucispinis*), cowcod (*S. levis*), copper (*S. caurinus*), greenblotched (*S. rosenblatti*), pinkrose (*S. simulator* Chen, 1971) and vermilion (*S. miniatus*) rockfishes, were found most often where the beam was exposed. This research also indicates that adding structures that form sheltering sites in and around decommissioned platforms will likely lead to higher densities of many species typical of hard and complex structure" (Love and York 2006).

Page et al. (2006) documented the occurrence of three non-native invertebrates on platforms off California. These species were the bryozoan, *Watersipora subtorquata*, the anemone *Diadumene* sp., and the caprellid ampipod, *Caprella mutica* Schurin, 1935. The authors noted that all three species had also been previously reported from some embayments and harbors in southern California.

Goddard and Love (2007, 2010), used videotapes from a manned submersible that surveyed invertebrates living on the shell mounds surrounding 15 oil and gas platforms (in waters 49–365 m) in the Santa Barbara Channel and Santa Maria Basin to identify major species. Sea stars (particularly *P. miniata*, *Pisaster* spp., and *Stylasterias forreri* (de Loriol, 1887), the pleurobranch sea slug (*Pleurobranchaea californica* MacFarland, 1966), and rock crabs (*Cancer jordani* Rathbun, 1900, *M. anthonyi*, and *C. productus*) were the most abundant taxa. At several of the deeper platforms, high densities of spot prawns, *Pandalus platyceros* Brandt, 1851 and the sea urchin *Strongylocentrotus fragilis* Jackson, 1912 (also known as *Allocentrotus fragilis*) were also observed. Brittle stars were also abundant on a number of shell mounds but were patchily distributed on any particular shell mound.

Page et al. (2007) examined the variability in prey resources on two platforms and two natural reefs in the Santa Barbara Channel. They compared the composition and abundance of small benthic invertebrates and the associated condition of the painted greenling, *O. pictus*, a predator on these invertebrates. At both platforms and one natural reef, gammarid and caprellid amphipods comprised most of the small invertebrate taxa. At the second natural reef, these taxa comprised about 50% of the individuals, with polychaetes comprising much of the rest. At the platforms, most of the caprellid amphipods were the non-native *C. mutica*, these were absent from the natural reefs. Amphipods comprised between 89 to 98% (by number) of the diet of *O. pictus*, and, at the two platforms, most of these prey were *C. mutica*. The condition of *O. pictus* during at least one sampling period was highest at Platform Holly and the condition of this species during one period was lowest at Mohawk Reef.

Page et al. (2008) examined the variability in the subtidal macroinvertebrate assemblages on the conductors and legs of seven platforms within the Santa Barbara Channel to a depth of 24 m. They found that the major invertebrate groups included sea anemones, mussels, barnacles, tubiculous amphipods, hydroids, and sponges. When the non-native species *W. subtorquata* and *Diadumene* sp. were excluded from the analyses, platforms near each other tended to have the most similar invertebrate assemblages. Inter-platform variation in both barnacle recruitment and mussel growth rate reflected differences in oceanographic parameters. In particular, mussel growth was slowest in the fall and spring and most rapid in the summer; highest growth rates were during the summer at the southeastern platforms and declined to the northwest.

To what extent do the fishes that associate with platforms exhibit site fidelity? This was the issue addressed in research reported upon by Lowe et al. (2009) and Anthony et al. (2012). In the Lowe et al. (2009) study, 100 rockfish and lingcod were tagged with acoustic tags and their movements monitored. A variety of movement patterns were observed, including: 1) no movements from platforms, 2) movements between platforms, 3) movements away from platforms and to natural reefs, and 4) movement to and from platforms and natural reefs. There was evidence that 1) "many-reef associated rockfishes make ontogenetic shifts to deeper water," 2) "shallower platforms export fishes faster than deeper platforms," and 3) "despite having higher densities of conspecifics, [platform habitat] may be of higher quality to some individuals than natural reefs." Anthony et al. (2012) conducted translocation experiments, again with acoustically tagged rockfishes and lingcod. Fishes were captured at three eastern Santa Barbara platforms and translocated across the channel to reefs within newly designated Marine Protected Areas (MPA) across the channel at Anacapa Island. "Twenty-five percent of all tagged fishes translocated to a natural reef returned to their home platforms relatively quickly, traveling distances from 11 km to ≥18 km, in 10.5 h to 17 d. Those that did not home took up residency at Anacapa Island, moved to Santa Cruz Island or out of the range of detection…Lingcod had the highest probability of homing back to their platform of capture, typically doing so in <1 day."

Krause et al. (2010, 2012), using fish traps, reported on surveys of the organisms living on the shell mounds of the 4-H platforms more than a decade after the platforms had been removed and conducted similar surveys over nearby soft seafloor and a natural reef. They found that "the shell mounds have more fish and invertebrates and a more diverse benthic community than the soft-bottom reference areas. These data support the conclusion that the fish habitat value of the shell mounds is greater than that of the surrounding soft bottom habitat and similar to the deep natural reefs of the area" (Krause et al. 2012).

Martin and Lowe (2010) reported on a two-year scuba study of the fish assemblages around six platforms (three offshore and three nearshore) on the San Pedro Shelf in waters as deep as 31 m. A total of 53 species were observed and typical nearshore reef species (including *S. pulcher*, *C. punctipinnis*, *H. rubicundus* (Girard, 1854), *Girella nigricans* (Ayres, 1860), and *P. clathratus*) predominated. The more offshore platforms included both reef-associated taxa and pelagic species (such as *Trachurus symmetricus* (Ayres, 1855) and *Sardinops sagax* (Jenyns, 1842)) that were not found around the inshore structures. Rockfishes, while relatively abundant on the offshore structures, were not present in the nearshore. Inshore platforms had greater species richness and total fish biomass, but total fish densities were similar between offshore and nearshore platforms. Overall, fish communities did not vary between the two years of the study. Seasonal differences in fish communities were observed at the offshore platforms but not the inshore ones. The largest effect of depth on species assemblages was observed at the offshore platforms, with a shift from warm-temperate species in shallow water to colder-water species at deeper depths. Spawning by both *H. rubicundus* and *S. marmoratus* was observed.

Mireles (2010) investigated the site fidelity of the adults of four reef species, *S. marmoratus*, *S. pulcher*, *Sebastes rastrelliger* (Jordan and Gilbert, 1880), and *S. atrovirens*, at four platforms (Edith, Ellen, Elly, and Eureka) on the San Pedro Shelf (Figure 1). Over a two-year period, he tagged and acoustically tracked 63 individuals. At the end of the study, most individuals had not moved away from their original platform. Fishes made significant vertical movements over each 24-hour period. Most fishes utilized the top 30 m of the jacket, however some individuals of all species made descents deeper than 30 m and *S. marmoratus* primarily utilized those parts of the jacket deeper than 30 m.

Page et al. (2010) summarized world-wide research (including that off California) regarding sessile invertebrate assemblages on platform jackets. They concluded that in all of these assemblages a few species are dominant. These assemblages often are quite thick, the thickest accumulations are in relatively shallow waters, and the thickest assemblages are on platforms colonized by mussels. Water depth is the most important driver of species composition, invertebrate biomass, and assemblage thickness, although variability between platforms, based on local environmental parameters, does occur. Platforms are quickly colonized by sessile invertebrates and changes in species composition can occur over time.

Johnson et al. (2011) documented the interactions between birds and platforms, in particular the effects of night lighting on birds, over a two-year period; observations were made almost entirely at six platforms situated from the northernmost (Irene) to one of the southernmost (Edith) (Figure 1). They found that "Of 3,300 sightings [of over 75 species], less than 15 percent of the birds were observed interacting with the platforms." Three species, Western Gull, Red-necked Phalaropes, and California Gulls, comprised 81% of all birds observed. The study concluded that "adverse effects of night lighting on POCS [Pacific Ocean Continental Shelf] petroleum production platforms in the San Pedro Basin, Santa Barbara Channel, and Santa Maria Basin appears to be an infrequent phenomenon. POCS platforms may provide temporary refuge and opportunistic foraging opportunities for both resident and migratory birds, as well as roosting sites…With the exception of Peregrine falcons, the platforms are unlikely to provide a sustainable foraging resource." The report goes on to state that on several, rare, occasions at Platform Irene phalaropes and migratory land birds were observed continuously circling the platform and "swarming in proximity to and in some instances coming into contact with banks of lights" on the platform.

Martin et al. (2012) investigated the effect of cleaning a portion of a platform jacket of sessile invertebrates on the associated fish assemblage. In this study, the invertebrate community living on Platform Elly (Figure 1) was removed during routine cleaning down to a depth of 20 m. Previous fish surveys had been conducted on this platform and on three adjacent platforms, Ellen, Edith, and Eureka. Fish surveys were then conducted post Elly cleaning at these four structures. These surveys demonstrated that the densities of at least one species, *C. punctipinnis*, decreased at Elly after the cleaning. However, within 10 months after the cleaning, densities of this species had increased to about pre-disturbance levels coincident with the re-establishment of the mussel community on the jacket.

Analyses by Claisse et al. (2014a,b) compared the secondary (i.e., fish) production of California platforms and natural reefs with that of other marine and estuarine ecosystems. Using fish density and length information from surveys around 16 platforms, Claisse et al. (2014a,b) estimated both somatic production and recruitment production for fishes, based on species-specific morphometric, growth, and mortality functions. They found that "oil and gas platforms off the coast of California have the highest secondary fish production per unit area of seafloor of any marine habitat that has been studied." These high rates were at least partially due to the often high densities of fast-growing young rockfishes and the likely lower predation rates on these fishes at platforms compared to natural reefs.

Love et al. (2010), Love and Nishimoto (2012), and Love et al. (2015) reported on a series of fish surveys conducted around most California platforms and over 100 unique natural sites. Surveys were conducted using both manned submersibles and scuba. On average, fish densities tended to be higher at platforms than at natural reefs. Rockfishes of at least 45 species dominated both platforms and natural reefs. At platforms, there tended to be three fish assemblages: midwaters, base, and shell mound. Midwater assemblages were similar across platforms, while bottom and shell mound assemblages varied with platform depth. In midwaters, juvenile fishes, primarily rockfishes and *C. punctipinnis*, dominated, and densities of these fishes varied greatly between years. On the shallower platforms, the three habitat assemblages are linked and thus fish densities at all depths and habitats varied greatly interannually. Platform bases were often occupied by relatively large fishes, particularly compared to midwater taxa. Shell mound fish assemblages tended to be composed of 1) juvenile fishes of larger species and juveniles and adults of dwarf species that utilize small sheltering sites (e.g., juvenile *S. levis* and *O. elongatus*, *R. nicholsi*, and *Sebastes dallii*), 2) ecotonal species that favor soft seafloor and low, hard-relief bottom (*S. elongatus* and *S. saxicola*), and 3) a few schooling taxa (notably *S. semicinctus*) that are habitat generalists.

Orr et al. (2016) examined the use of California platforms as hauling out grounds by pinnipeds at five platforms: Elly, Gina, Habitat, Heritage, and Harvest. California sea lions, *Zalophus californianus* (Lesson, 1828), were by far the most abundant species, although Steller sea lions, *Eumetopias jubatus* (Schreber, 1776), were observed on two of the platforms. Harbor seals, *Phoca vitulina* (Linnaeus, 1758), were observed in the waters around some platforms, but did not haul out on the jacket. Large numbers of pinnipeds were observed on all platforms and there was no geographic (north-south) trend in pinniped abundances. There were also no seasonal trends in abundances, nor day-night trends in numbers hauling out.

4.2 Environmental Effects of Offshore Oil Development

The first study to examine possible contamination of marine organisms living around California oil and gas platforms was reported upon by Bascom et al. (1976) and Mearns and Moore (1976). In this study, tissues collected in 1975 from fishes (i.e., *S. caurinus* and *S. auriculatus*) and invertebrates (i.e., *Metacarcinus anthonyi* and mussels *Mytilus californianus* Conrad, 1837) at Hilda, Hazel, and a natural reef control site were analyzed for a range of trace elements (i.e., Ag, Cd, Cr, Cu, Mo, Ni, Pb, V, and Zn). With the exception of elevated levels of vanadium in the rockfishes living at platforms, there were no differences between levels at the three sites. Sediments below the platforms contained slightly elevated levels of zinc and hydrocarbons. Lastly, quoting Mearns and Moore (1976): "Petroleum hydrocarbon levels in platform fishes and invertebrates were not elevated" and "Petroleum hydrocarbon fractions in sediments were generally high relative to areas with no natural oil seeps, however the hydrocarbons measured were identified as highly weathered natural seep oil indicating no recent contamination."

Benech et al. (1980) surveyed the invertebrates living on the four pontoons supporting a semi-submersible drilling platform in southern California. They found that the assemblages on the two pontoons exposed to drilling fluids more closely resembled each other than the assemblages on the pontoons less influenced by drilling fluids. The assemblage on the pontoon directly in the path of the drilling fluid discharge was the most different.

Meek and Ray (1980) and Ray and Meek (1980) studied the accumulation and bottom transport of drilling discharges from a semi-submersible drilling platform on Tanner Bank. Measurable concentrations of discharged materials containing barium, chromium, and lead were measurable to a distance of about 150 m from the discharge source.

Barrick et al. (1985) and Continental Shelf Associates (1985) produced a study that used computer simulations to estimate how drilling muds and cuttings are deposited on the seafloor. They found that water and discharge depth, fluid weight, current speed, and oceanographic conditions (such as upwelling and downwelling) all played a role. Such factors as "predilution, altered discharge rate, and seasonal differences in water column density structure" had little effect. They found that long-term, most drilling muds and cuttings would likely be transported off the continental shelf or into deep basins.

From 1983 to 1995, the Minerals Management Service funded research on the possible long-term cumulative effects of offshore drilling and production in the Santa Maria Basin (located between Point Arguello and Point Conception) (Lissner et al. 1985, 1986, Hyland and Neff 1988, Brewer et al. 1989, 1991, SAIC and MEC 1989, 1993, 1995, Crecelius 1990, Hardin et al. 1990, 1991, Hyland et al. 1990, 1991, 1994, Steinhauer and Imamura 1990, Steinhauer and Steinhauer 1990, Imamura et al.1993a,b, Steinhauer et al. 1991, 1994, Coats 1994, and Phillips et al. 1998). The goals of the Phase I study (Lissner et al. 1985, 1986) were to "catalogue and statistically analyze data from previous studies of soft-bottom benthic environments," "Identify sources and develop a directory of archived benthic fauna samples collected from the California outer continental shelf (OCS) during previous studies," and "Conduct a benthic reconnaissance survey of soft-bottom and hard-bottom areas of the Santa Maria Basin and western Santa Barbara Channel" (Lissner et al. 1986). Data from these studies were used to develop monitoring sites (in the Santa Maria Basin) in the Phase II and III studies. The Phase II and III studies (SAIC and MEC 1989, 1993, 1995) monitored the effects of oil and gas platform discharges on hard-bottom biological communities through: 1) measurements of long-term water movements, 2) analysis of chemical contaminants in bottom sediments and water column, 3) laboratory and in situ experiments regarding larval invertebrate responses to drilling discharges, and 4) assessing the invertebrate communities on low and high-relief reefs primarily close to and away from Platform Hidalgo.

Among the findings in the studies are those of:

- Crecilius (1990) who found that "barium concentration in sediments and sediment traps located within several kilometers (km) of Platform Hidalgo increased during 1987 and 1988 due to drilling activities at three platforms in the area. Following termination of drilling, the barium concentrations decreased at these stations. Barium profiles in sediment cores indicate drilling fluid is mixed to a depth of 6–8 cm. The tissue chemistry data [in benthic invertebrates] were highly variable. However, in *Pleurobranchaea*, there appeared to be occasional barium contamination that was related to drilling activity."
- Studies on barium levels in sediment congruent with further drilling in 1993 and 1994 found "only minor increases in Ba concentrations in suspended sediments" (Phillips et al. 1998).
- Steinhauer and Steinhauer (1990) examined hydrocarbon concentrations in surface sediments and found that "At some stations in the Platform Hidalgo area, higher levels of hydrocarbons were detected in both surface sediments and in sediment-trap material. Based on composition, the elevated PAHs are definitely sourced in petroleum (e.g., presence of alkylated dibenzothiophenes and phenanthrenes). However, because this signal was not accompanied by similarly elevated levels of barium in the sediments, it seems unlikely that drilling discharges are the specific source of the petrogenic hydrocarbons."
- Hardin et al. (1990) surveyed the hard-bottom epifaunal assemblages close to and away from Platform Hidalgo. They found that "six of the ten taxa tested suggest [platform] discharge-related effects on abundance. At deeper sites, the densities of four low-relief taxa, *Caryophyllia* sp.(p), *Paracyanthus stearnsii*, *Ophiacanthus diplasia*, and *Halocynthia hilgendorfi igaboja*, all decreased at the high-dose station after drilling discharges began, while they generally increased at the mid- and low-dose stations. Nevertheless, these results could be either an artifact of unusually high densities of these taxa at the high-dose station during the sampling period immediately prior to the initiation of drilling or simply year-depth interactions rather than year-dose interactions. Two high-relief taxa, *Stomphia didemon* and sabellids, displayed lower increases in densities at the high-dose station than at the low-dose station after drilling began."
- Steinhauer et al. (1991, 1994) determined that, during drilling, barium concentrations increased in some surface sediments, then decreased after drilling ceased, but after 1.5 years had not reached background levels.
- Lastly, Neff and Hyland (1990) found that "because concentrations of metals are not significantly elevated in drilling muds and cuttings discharged from Platform Hidalgo, and because most are in inert forms, it is unlikely that they represent a toxicological hazard to marine organisms in the vicinity of the platform. Concentrations of metals in the tissues of benthic animal species collected from the Platform Hidalgo site, were not elevated above background concentrations... In contrast, the short-term fate of ∑PAH in drilling mud deposited by individual plumes is uncertain. Although drilling-related increases in ∑PAH concentrations were not observed in sediments or in the majority of sediment-trap samples, elevated concentrations of hydrocarbons are predicted from the model. Concentrations of drilling-mud-related hydrocarbons, either in the thin veneer of surface sediments deposited locally by individual plumes or in suspended sediments, can be well in excess of ambient concentrations. It is uncertain whether the predicted concentrations of total or individual PAHs in solution in bottom water would ever reach concentrations known to be

toxic to marine organisms. However, some localized drilling-related effects on benthic communities, such as those described above for hard bottom fauna, cannot be dismissed."

- Overall, the results of these studies were that the Phase II and III phases "did not indicate severe, large-scale impacts to the hard-bottom communities from drilling discharges, although possible effects to larvae could influence some long-term trends in abundance and species composition" (SAIC and MEC 1995).

To some extent the immediate effects became moot when the discharge of drilling fluids and cuttings was stopped in 1989.

Alldredge et al. (1986), in a laboratory experiment, examined the possible effects of drilling muds and mud additives on marine phytoplankton, particularly on primary production. Drilling muds at a range of concentrations had no effect on primary production. Primary production was reduced in experimental treatments with very long exposure times, although these exposure times were not realistically expected to occur in nature.

Jenkins et al. (1989) examined the accumulation of barium near an exploratory drilling jack-up rig in the sediments and tissues of three benthic invertebrates in the Santa Barbara Channel. Of the three test species, two, the clam *Cyclocardia ventricosa* (Gould, 1850) and the polychaete *Pectinaria californiensis* Hartman, 1941 were found to have elevated levels of barium. The authors state that "Statistically significant increases in the accumulation of Ba were found in the sediments down current from the well site after drilling. Statistically significant increases in the bioaccumulation of Ba were also observed in two of the three species examined, *Cyclocardia ventricosa* and *Pectinaria californiensis*…These data indicated that although significant bioaccumulation of Ba occurs in some species immediately down current from the well most of it remains in an insoluble form, presumably as $BaSO_4$. The labile fraction of the accumulated Ba, which is associated with the other subcellular fractions, represents less than 3% of the total and does not appear to be present in sufficient quantities to cause toxicity."

Preparatory to an expansion of oil and gas exploration and production, the Bureau of Land Management and Minerals Management Service (MMS) funded several studies summarizing the Outer Continental Shelf environment off California and how it might be impacted by mineral exploration and development. Winzler and Kelly Consulting Engineers (1977) addressed this for the abiotic environment, including geology and physical oceanography, and Southern California Ocean Studies Consortium (1977) addressed this for the biological environment. Later, MMS funded studies summarizing the existing knowledge regarding the life histories of a range of fishes and invertebrates along the coast of the United States, including off California (Sullivan and Zacherle 1989, Tear 1989, and Technical Resources Inc. 1989).

Lissner et al. (1991) examined the potential impacts of offshore oil development on deeper-water (60–300 m), hard-substrate benthic invertebrates by summarizing existing information on invertebrate communities. They found that the most likely impacts would be from anchoring and from sedimentation from discharges of drilling muds and cuttings. They estimated that recovery from these disturbances would take "a few to several years" after the stimulus had ended.

A number of studies investigated the possible effects on the marine environment from produced water. Produced water is water that is extracted from oil during the drilling process. Typical constituents of produced water from offshore California deposits are found in MacGowan and Surdam (1988) and Witter and Jones (1999). The following studies were conducted on produced water released from a subsurface diffuser near Carpinteria, Santa Barbara Channel. Raimondi and Schmitt (1992) exposed red abalone (*Haliotis rufescens* Swainson, 1822) larvae to produced water by attaching containers with red abalone to moorings at various distances between 5 and 1,000 m from the diffuser. Survivorship of these larvae was inversely correlated with distance from the diffuser. At the same site, Osenberg et al. (1992) examined the growth rates of the mussels *M. californianus* and *M. edulus* at a variety of distances away from the diffuser. Growth rates decreased and the general condition of the animals declined at distances up to 1,000 m away from the diffuser. As with the abalone study, this pattern was inversely correlated with distance from the diffuser. Osenberg et al. also measured the densities of some benthic invertebrate taxa at varying distances from the diffuser. They found that the densities of some taxa (e.g., nematodes and some polychaetes) were higher closer to the diffuser, some taxa (e.g., echinoderms, larval crustaceans, and some polychaetes) were less dense near the diffuser, some taxa were probably more abundant near the diffuser, and a fourth group exhibited no pattern with distance.

In laboratory experiments, adult purple sea urchins (*S. purpuratus*) were exposed to varying concentrations of produced water from the Carpinteria site (Krause et al. 1992). On first analysis, these experiments appeared to show that exposure to produced water decreased the rate of fertilization of sea urchin eggs. However, cohort analysis of the rate of eggs developing to the pluteus stage did not show this effect. The authors go on to state that "The results indicate that early indicators of fertilization grossly underestimated the fraction of eggs that were actually fertilized and subsequently began embryonic development" and that "Our embryo cohort analyses revealed that the fraction of eggs eventually fertilized was unaffected by produced water. However, produced water did slow down the developmental rate of sea urchin embryos. Washburn et al. (1999) studied the dispersion of produced water from an outfall in the Santa Barbara Channel. They concluded that "our results support the conclusion of Krause (1993) that toxic effects [to invertebrate larvae] are detectable at least 1,000 m from the diffuser." Fan et al. (1992) reported that exposure to produced water caused ovarian degeneration in *M. californianus*. The fractions in produced water that are toxic to sea urchin sperm and to mussel embryos were differentiated by Higashi et al. (1992). Lastly, Garman et al. (1994) exposed gametophytes of the brown alga, *Macrocystis pyrifera*, to concentrations of 4% produced water and found inhibition of nuclear migration.

Benech et al. (1995) investigated the possible effects of exploratory oil drilling on invertebrates living on reefs off the coast of Point Purisima and in the Santa Barbara Channel. The study focused on nine sites that had seen exploratory drilling from a semi-submersible and might be expected to show the effects of anchoring and drilling-related sedimentation. They reported that "The epifaunal communities were significantly altered in anchor scar areas having fewer species and lower density of organisms. These community changes were largely due to alteration of the physical habitat by anchoring operations." Moreover, "The physical damage to hard-bottom habitat caused by anchoring operations is long-lasting (e.g., 26 years or greater)… Because hard-bottom epifauna have preferences for relief height, size of substrate, and different tolerances to sediment fluxes, communities will not recover to pre-disturbed conditions where the substrate has been altered. Where the hard-bottom substrate was disturbed by anchoring operations but not crushed or removed, complete recovery of the dominant, hard-bottom invertebrate groups can occur within 26 years. Certain long-lived taxa that are rare on hard-bottom, such as various sponge species, may require longer than 26 years to completely recover. For fast growing opportunistic species recovery was complete within 12 years. Motile species probably recover much faster due to immigration… Impacts associated with drilling muds and cuttings appear to be less severe than those associated with anchoring impacts." The authors cautioned that these results came from short-term exploratory operations and that longer-term production might have longer-term effects.

In a lab setting, researchers tested the effects of drilling muds from Platform Hidalgo on the larvae of the red abalone (*Haliotis rufescens*) and adults of brown cup coral (*Paracyathus stearnsii* Verrill, 1869) (Barnett et al. 1995, Raimondi et al. 1997). For *H. rufescens*, exposure to drilling muds "did not have an effect on abalone fertilization or early development. However, several exposures to drilling muds resulted in weak, but significant, positive effects…on settlement of competent larvae." The study demonstrated that for adult *P. stearnsii* "survivorship, proportion of individuals showing tissue loss increased, and relative viability decreased over time with increasing drill muds concentrations (Raimondi et al. 1997)."

A risk analysis model assessing the chances of resuspension of drilling muds post deposition was created by Lick (2003). The model consisted of "a two-dimensional, vertically-integrated, time-dependent hydrodynamic and mass transport model coupled with a three-dimensional time-dependent model of the sediment bed and its properties." Two platforms, the relatively deep Hidalgo (130 m) off California, and shallower Eugene Island (7 m) in the Gulf of Mexico were studied. The model found that "the non-linear effects of shear stresses on sediment resuspension dominate both regimes, with a few large storms causing almost all of the resuspension of bottom sediments. Waves generated by large, low-probability storms resuspend buried sediment layers that remain stationary during ordinary winter storms in the deep-water regime near Hidalgo. By contrast, sediments in the Gulf of Mexico are much more easily eroded by typical storm waves due to the higher bottom shear stress generated in this shallow-water environment."

A study (Applied Ocean Science and MEC Analytical Systems 2004) at platforms Hogan, Harvest, Habitat, and Gina examined the spatial extent and dilution of produced water plumes. They noted that "Produced water discharges have the potential to affect marine life and primary productivity by light inhibition or effects from produced water contaminants. However, the effects that produced water turbidity would have on light attenuation based on the in situ nephelometric measurements suggest that the impact on water column light attenuation [in this study] was negligible… In addition, since the discharge plumes are all beneath the phytoplankton maxima, changes in light attenuation due to the produced water plumes would not be expected to have a large effect on phytoplankton."

Steinberger et al. (2004) estimated the total discharges (from both drilling and production) of 23 oil and gas platforms in the Southern California Bight (SCB) and compared these with discharges from wastewater treatment facilities (POTWs). They found that "Oil platforms discharged 5,374 and 5,638 million liters of produced water and 12,128 and 2,955 metric tons (mt) of solids to the SCB in 1996 and 2000, respectively. Oil platform discharges were minor compared to effluents from large and small POTWs in terms of both volume and constituent mass emissions."

Love et al. (2009, 2013) and Love and Goldberg (2009) conducted several studies aimed at understanding pollution in platform fishes. They collected *P. clathratus*, *S. atrovirens*, and *C. sordidus* from five offshore platforms and 10 associated natural areas. Whole-body analysis of 63 elements were then performed on these fishes. In addition, they examined the ovaries of C. *sordidus* from two platforms in the Santa Barbara Channel (B and Gilda) and from two natural reference sites for any indicators of impaired reproductive abilities. Regarding pollutant loads "Forty-two elements were excluded from statistical comparisons for one of three reasons: they consisted of major cations that were unlikely to accumulate to potentially toxic concentrations under ambient exposure conditions; they were not detected by the analytical procedures; or they were detected at concentrations too low to yield reliable quantitative measurements. The remaining 21 elements consisted of aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, gallium, iron, lead, lithium, manganese, mercury, nickel, rubidium, selenium, strontium, tin, titanium, vanadium, and zinc. Statistical comparisons of these 21 elements indicated that none consistently exhibited higher concentrations at oil platforms than at natural areas" (Love et al. 2009). Regarding reproductive impairment "While pronounced atresia was observed in a few fish at one natural site and one platform, there was no evidence of widespread pronounced atresia at any of the four sites. This study implies that fishes that lie on the bottom around platforms and consume prey that lives in that sea floor are not reproductively impaired" (Love et al. 2009).

In a parallel study, Gale et al. (2012, 2013) measured the body burdens of the metabolites polycyclic aromatic hydrocarbons (PAH, a very important marker of oil contamination) in the same fishes used in the Love et al. (2009, 2013) and Love and Goldberg (2009) study. Again, *P. clathratus*, *S. atrovirens*, and *C. sordidus* were collected from five offshore platforms and 10 associated natural areas. In general, levels of PAH metabolites were low at both platforms and natural sites.

Johnson et al. (2011) reported on a study examining the possible deleterious effects of the artificial lighting on offshore platforms to birds. Bird interactions with offshore petroleum production platforms in the San Pedro Basin, Santa Barbara Channel, and Santa Maria Basin were assessed during surveys conducted in spring (April/May/June) 2010 and 2011 and fall (September/October) 2010. "The objective of these surveys was to observe and characterize avian interactions with oil and gas production platforms in the POCS during fall and spring migrations, with particular focus on whether platform nighttime lighting had any effect on bird behaviors…Based on the 524 hours of nighttime observations made during this study, no incidence of light disorientation or light entrapment by nocturnally migrating birds was observed. Based on both daytime and nighttime observations, there does not appear to be any differences in bird occurrence or interaction with the platforms relative to their proximity to geographic features such as the mainland, the Channel Islands, or a key geographic boundary such as Point Conception or Point Mugu" (Johnson et al. 2011).

4.3 Potential Consequences of Platform Decommissioning

Manago and Williamson (1998) was the first document that specifically focused on the decommissioning of California offshore platforms. This document was the result of a workshop designed to familiarize the public with the decommissioning process. General topics included: 1) The regulatory framework for decommissioning at the state and federal levels, 2) details regarding how platforms are physically decommissioned, 3) statements by potentially affected groups (i.e., fishermen and environmentalists), and how the remaining structure might potentially affect the environment.

The first study regarding how platform removal might affect air quality was Sheehan (1997). Sheehan noted that for the 1996 removal of four platforms in the Santa Barbara Channel (Hazel, Heidi, Hilda, Hope) the project required more than 120,000 gallons of diesel fuel with criteria pollutant emissions of 21.6 tons NOx, 1.3 tons reactive organic compounds, 14.2 tons CO, 0.5 tons SOx, and 1.3 tons PM.

Holbrook et al. (2000) summarized the outstanding biological issues regarding California platform decommissioning. They used as a metric the potential role of the organisms living on platform to regional, as opposed to local, stocks. Holbrook acknowledged that platforms harbored "rich assemblages of marine organisms, including many fishes and invertebrates." However, they noted that "the total 'reef' area represented by the 27 California platforms is extremely small in relation to regional availability of [natural] hard bottom substrates" and that "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."

Twachtman Snyder and Byrd Inc. (2000) summarized the methodologies involved in removing platforms from deep water. The costs (and other issues) related to various removal options were analyzed for three platforms on the Pacific Outer Continental Shelf (Hidalgo, Gail, and Harmony) and also in the Gulf of Mexico. Three removal methods (Complete Removal, Partial Removal, and Remote Reefing) were evaluated. Of these, the study found that "the Partial Removal scenario, combined with proven heavy lift, severing, and subsea technologies, is currently the safest, most cost-effective way to remove offshore platforms located in deepwater. However, since a number of the new technologies reviewed are close to becoming viable, an ongoing assessment of these technologies will be necessary to remain abreast of the deepwater decommissioning state-of-the-art in the future."

When four platforms in state waters were removed in 1996, the disposition of the surrounding shell mounds remained open. De Wit (2001) summarized his review of the physical and environmental aspects of these mounds. Among his findings were 1) "The shell mounds at all four sites have similar physical characteristics comprising three distinct strata: an upper layer of shells, an intermediate layer of drill muds and cuttings, and an underlying layer of "native" seafloor sediments. 2) Sediment test results conclude that the Effects Range Medium ("ERM") concentrations for nickel and PCBs are exceeded at the Platform Hazel shell mound. 3) The concentrations of metals and organics in the mounds at Platforms Hope, Heidi, and Hilda are not expected to be toxic to water column organisms. However, elutriate bioassay-testing

results show that shell mound sediments at the Platform Hazel site are toxic enough at 48% concentration to kill 50% of the test organism, a mysid shrimp (*Mysidopsis bahia*). 4) Shell mound-associated biota appears to have decreased in species richness and abundance since removal of the platforms. The shell mounds in their current form (absent the platform structures) provide limited biological habitat value. Removal of the mounds would not result in the loss of significant or unique biological resources. The macroepibiota associated with the mounds is dominated by the bat star (*Asterina miniata*) while fish and the gorgonian coral *Lophogorgia chilensis* are more abundant around an exposed concrete leg at the Platform Hazel site and near an exposed pipeline at the Platform Hilda site. 5) The major water quality impact of removal would be re-suspension of contaminated material. Some petroleum could be released resulting in the potential for an oily sheen to appear on the sea surface. Of particular concern would be the removal of the mound at Platform Hazel due to the concentrations of petroleum, nickel and PCBs.
6) Under worse case conditions, shell mound removal would likely result in exceeding the state standard for PM10 [air particulate] emissions. 7) It is not clear whether shell mound contaminants are leaching into the water column. 8) Neither commercial nor recreational fishers are expected to benefit from the continued existence of the shell mounds."

The question of the ultimate disposition of the shell mounds associated with California platforms as part of the decommissioning process was addressed by Krause et al. (2010, 2012). Krause et al. (2010, 2012), using fish traps, reported on surveys of the organisms living on the shell mounds of the 4-H platforms more than a decade after the platforms had been removed and conducted similar surveys over nearby soft seafloor and a natural reef. They found that "Results indicate that the shell mounds have more fish and invertebrates and a more diverse benthic community than the soft-bottom reference areas. These data support the conclusion that the fish habitat value of the shell mounds is greater than that of the surrounding soft bottom habitat and similar to the deep natural reefs of the area" (Krause et al. 2012).

The feasibility of characterizing the contaminants in the shell mounds under platforms was assessed by Weston Solutions Inc. and Science Applications International Corporation (2005). They determined that "sampling of shell mounds centered directly beneath active platforms is not feasible at this time because of safety, cost, and scheduling concerns, and because of the limited information that would be collected when sampling only a single location on a shell mound." They state that sampling shell mounds from a vessel, using a vibracore, on the outside of a platform is feasible, as long as the shell mound is in 300 ft of water or less. The study suggested two candidate platforms for trial surveys, Gina and Gilda, which were within the appropriate depth and had shell mounds centered on the outside of the platforms. These organizations followed up on their earlier study with a physical and chemical analysis of the Platform Gina shell mound (Weston Solutions Inc. and Science Applications International Corporation 2007). The study found that "Total organic carbon (TOC) concentrations in the core samples were relatively uniform and within a factor of three of reference sediment concentrations, whereas sulfides concentrations varied by more than one order of magnitude and were significantly correlated with total recoverable petroleum hydrocarbon (TRPH) concentrations. Barium, a chemical marker for drilling fluids, was present at elevated concentrations (up to 2,700 mg/kg) in several samples, particularly in the surface and middle layers of cores, along with elevated lead and zinc levels. TRPH concentrations also varied within the mound, with a maximum concentration of 4,000 mg/kg, reflecting a wide range of petroleum hydrocarbon levels within the shell mound. Individual volatile and semi-volatile hydrocarbons, including polycyclic aromatic hydrocarbons (PAH), occasionally were detected but at concentrations less than 1 mg/kg. Detailed hydrocarbon analyses, using more sensitive analytical methods, of a subset of core samples detected substantially higher PAH concentrations along with other hydrocarbon characteristics that are indicative of weathered petroleum from a local crude oil source (i.e., Monterey Formation)." This paper notes that these results shared some similarities but also some differences from those reported from the four Summerland platforms (Hilda, Hazel, Hope, and Heidi) (Phillips et al. 2006, see below).

Phillips et al. (2006) conducted surveys of the chemical contaminants in the shell mounds of the four platforms (Hilda, Hazel, Hope, and Heidi) that were removed in 1996 from off Summerland, California. Cores in these shell mounds found elevated concentrations of barium, cadmium, lead, and zinc; elements associated with drilling wastes as well as elevated levels of monocyclic and polycyclic aromatic hydrocarbons. In addition, "sediments composited from all core strata caused significant acute toxicity and bioaccumulation of Ba and PAHs in test organisms during laboratory exposures. In contrast, caged mussels placed at each of the shell mounds for a period of 57–58 days had greater than 90% survival, and there were no significant differences in survival of mussels placed at the shell mounds and corresponding reference sites. While all mussel samples exhibited increases in shell length, whole animal weight, and tissue lipid content, in some cases growth metrics for the shell mound mussels were significantly higher than those for the reference sites. Concentrations of metals, PAHs, and polychlorinated biphenyls (PCBs) in tissues of the shell mound mussels were not significantly different from those at reference sites." Phillips et al. (2006) go on to state that "in the absence of physical disturbances, contaminants are expected to remain sequestered in the shell mounds."

Referring to the process of decommissioning California platforms, McGinnis et al. (2001) examined the process from an artificial reef perspective. They determined that among the outstanding issues were 1) who accepts liability for decommissioned platforms, 2) scientific uncertainty regarding whether platforms produce or aggregate fishes, and the limited funding provided by the state for any artificial reef program.

Carr et al. (2003) discussed platform decommissioning in the context of societal influences in both the Gulf of Mexico and off California. They argued that the relative ease with which a "rigs-to-reef" policy was created in the Gulf of Mexico was the product of a long history of artificial reef creation, the perceived limited availability of fishable habitat, and the potential economic impacts of complete removal. Carr et al. then state that the societal influences in California are different from those in the Gulf of Mexico states and note that bills to create a legal model for rigs-to-reef off California had failed in the legislature [note that this legislation later passed into law via the California Marine Resources Legacy Act].

Frumkes (2002), representing the United Anglers of Southern California, discussed the possibility that the State of California would create a rigs-to-reef program. He discussed what he considered to be the benefits of a rigs-to-reef program to air quality, water quality, marine mammals, seafloor habitat, and fish populations, among other topics. He noted that there was some evidence that California platforms might be important habitats for fishes, particularly for rockfishes. On what he considered a related topic, he suggested that commercial fishing, particularly trawling, be banned as this type of fishing was destructive to marine seafloor habitats, caught too many fishes, and had unacceptable bycatches. Lastly, he emphasized the economic importance of recreational fishing to the California economy.

Helvey (2002) addressed the question of whether California platforms were essential fish habitat (EFH) as defined by the federal government. He concluded that while there were substantial numbers of fishes, particularly rockfishes, around platforms, there was insufficient information available to make an EFH determination based on the criteria of "the structures are necessary to support a sustainable fishery or contribute to a healthy ecosystem." The Pacific Fishery Management Council (PFMC) considered the designation of offshore platforms as a Habitat Area of Special Concern in a proposed Alternative within the Draft Environmental Impact Statement, EFH for Groundfish (PFMC 2005), and voted to recommend this designation for 13 offshore platforms during their June 2005 Council meeting. The Administrator of NOAA for the Southwest Region did not agree and the designation did not occur.

During 2001, the shell mounds surrounding 16 California platforms were mapped and delineated and the results were reported in MEC Analytical Systems and Sea Surveyor (2003). With the exceptions of Platforms Harmony, Heritage, and Harvest, all platforms in the Santa Maria Basin and Santa Barbara Channel were surveyed. The survey determined that the largest shell mounds were associated with platforms in less than 350 foot depths and on seafloors with less than a 1% slope. Shells tended to be more widely dispersed around deeper platforms as the longer fall time in these deeper depths allowed currents to carry the shells away from the structures.

Bomkamp et al. (2004) and Page et al. (2005) investigated the distribution and abundance of mobile invertebrates on those shell mounds associated with intact platforms (and thus experience a continuing rain of mussels) and those whole platforms have removed (and thus do not have any new mussel input). They found that "predatory and omnivorous echinoderm and mollusk species were more abundant and generally larger on shell mounds under platforms than on shell mounds without platforms. Omnivorous and deposit feeding echinoderms were the most abundant macroinvertebrate taxa sampled on mound-only sites. The brown rock crab (*Cancer antennarius*), known to have a strong preference for hard substrate, was significantly more abundant on shell mounds, with or without platforms, than adjacent soft bottom sites." In general, then, "Although the shell mound habitat persists after removal of platform structures, species abundance and the composition of the associated benthic community is altered by removal of the platform structure."

Regarding the possible complete removal of Pacific Outer Continental Shelf platforms, Twachtman Snyder and Byrd Inc. (2003) addressed a variety of health and safety issues. They arrived at the following conclusions: "Complete Removal In-Situ will be more time consuming and demand more human resources than the Hopping method [hopping the jacket into successively shallow water]. This assumes the use of the technology and methods that are readily available today. The Hopping method appears to be much safer in a relative sense, when compared to in-situ jacket removal. Risk of accidents increase with water depth for both methods, both it increases much faster with the In-situ method. Review of the accident rate data presented in the study and the analysis results point to underwater work with divers as the major risk area. Every effort should be made to eliminate or reduce diver usage and to shorten the time required for decommissioning in general."

Schroeder and Love (2004) approached the issue of platform decommissioning from both an ecological and political perspective. They noted that while the political climate for platform reefing was generally favorable in the Gulf of Mexico, there were a range of perspectives among southern California stakeholders ranging from total platform removal to allowing some or all of a platform to remain. Regarding the potential ecological importance of California platforms, Schroeder and Love recommended "further assessment of platform habitat quality, estimation of regional impacts of decommissioning alternatives to marine populations, and determination of biological effects of any residual contaminants [in and to marine organisms]". In addition, they suggested that the National Oceanic and Atmospheric Administration "should consider the consequences of decommissioning alternatives in their overall management plans."

As part of assessing the potential impacts of platform decommissioning, Lenihan and Brooks (2006) explored the importance of Platform Gina to the blackeye goby, *Rhinogobiops nicholsii*, population in the eastern Santa Barbara Channel. They compared a range of demographic data of blackeye goby living around Gina to those of fish living at three natural reefs at Santa Cruz Island. They found that "abundance did not differ among the oil platform and natural reefs; that recruitment was slightly lower at OP [Ocean Platform] Gina than at natural reefs, that the size structure of the population was greater at OP Gina than natural reefs; that the differences in size structure may be explained by reduced predation mortality; that fecundity may be relatively low at OP Gina, but that fish may live longer and therefore produce more population output over the long-term." In general, they estimated "that populations of blackeye goby at OP Gina do not make a substantial contribution to the regional stock of blackeye goby, indicating that OP Gina's removal, or modification based on other decommissioning strategies, would have little effect on the regional abundance and population dynamics of this species."

At the direction of the State of California, Bernstein et al. (2008) evaluated removal alternatives for California platforms. They reported that "There are a number of potential options that could be implemented when the offshore platforms reach the end of their useful lifetimes, but only two of them are likely to be feasible: complete removal and partial removal to 85 feet with the remainder of the platform converted to an artificial reef. The legal and regulatory frameworks for both options are clearly defined, although the partial removal option would require new state legislation to allow the state to accept ownership of platforms in federal waters. The full range of impacts to be expected as a result of both options can be described qualitatively and some can be quantified to varying degrees. However, significant data gaps prevent the full quantification of all potential impacts. Despite these limitations, the information gathered here enables an in-depth comparison of the two primary platform removal options and the interactive decision model that accompanies the report allows users to more fully investigate the implications of the two options and of different ways of valuing or weighting the costs and benefits of the options."

One of the issues involving the potential removal options for California platforms is the effects of "topping" ("partial removal" or removing an upper portion of the platform jacket) on the recruitment of YOY fishes. Nishimoto et al. (2008), Nishimoto and Love (2011), and Love et al. (2012) addressed this issue by surveying the densities of YOY fishes at seven intact platforms as well as six reefs and three shipwrecks that did not come near the surface (the latter structures acting as surrogates for topped platforms). Young-of-the-year rockfishes dominated the deeper parts of the platforms, reefs, and shipwrecks, while YOY *C. punctipinnis* were characteristic of the shallower parts of platforms. Thus, in general, this study found that platform topping would likely not substantially decrease *Sebastes* recruitment but would likely decrease recruitment of *C. punctipinnis*. The study also found that in years with poor recruitment of rockfishes to natural reefs, platforms might play a more significant role as nursery habitat.

Macreadie et al. (2011) produced an overview of the potential biological and ecological effects of retaining some parts of a platform's jacket as an artificial reef as part of a removal program. They conclude that "such decommissioned rigs could enhance biological productivity, improve ecological connectivity, and facilitate conservation/restoration of deep-sea benthos (e.g., cold-water corals) by restricting access to fishing trawlers. Preliminary evidence indicates that decommissioned rigs in shallower waters can also help rebuild declining fish stocks. Conversely, potential negative impacts include physical damage to existing benthic habitats within the "drop zone", undesired changes in marine food webs, facilitation of the spread of invasive species, and release of contaminants as rigs corrode." They discuss areas where further research is needed, suggest methods to offset any negative impacts of reefing, and allow that a rigs-to-reefs program may be a valid option for deep-sea benthic conservation."

Fowler et al. (2014) followed up the study by Macreadie et al. (2011) and proposed a "multi-criteria decision approach" (MA) to the platform decommissioning process. This approach would emphasize flexibility and examine each platform on a case-by-case basis. The decision analysis approach would compare alternative removal decommissioning options and focus on "environmental, financial, socioeconomic, and health and safety considerations." In addition, "To deal with knowledge gaps concerning environmental impacts of decommissioning, we suggest that expert opinion feed into the MA approach until sufficient data become available. We conducted a limited trial of the MA decision approach to demonstrate its application to a complex and controversial decommissioning scenario; Platform Grace in southern California. The approach indicated, for this example, that the option 'leave in place intact' would likely provide best environmental outcomes in the event of future decommissioning."

The issue of how decisions will be made in the California decommissioning process was also addressed by Bernstein (2015). This paper describes the overall decision framework based on current California law and regulations. In this process, the California Natural Resources Agency will be one of the lead agencies and will help "identify and investigate issues surrounding possible decommissioning alternatives. Bernstein (2015) notes that nearly 30% of all California platforms lie in water depths that are deeper than any other decommissioning activities in the world. Thus, "decommissioning decisions will grapple with a more complex decision context involving greater technological and logistical challenges and cost, a wider range of viable options, tradeoffs among environmental impacts and benefits, and an intricate maze of laws, regulations, and authorities. The specific engineering differences between complete and partial removal provide an explicit basis for a thorough evaluation of their respective impacts."

Bressler and Bernstein (2015) is a companion paper to Bernstein (2015). This research designed a mathematical model, called PLATFORM, that could be used in making decisions of what kind of decommissioning option should be followed for any given California platform. Using two decommission options, partial and complete removal, the model used "Bureau of Safety and Environmental Enforcement (BSEE) and Bureau of Ocean Energy Management (BOEM) costs for complete removal, along with costs for partial removal calculated for this study and estimates of the uncertainty associated with decommissioning cost estimates. PLATFORM allows users to define a wide range of decommissioning and costing scenarios (e.g., number of platforms, choice of heavy lift vessel, shell mound removal, reef enhancement)." The paper then estimates that complete removal of all California platforms, based on 2010 cost estimates, would cost $1.09 billion and partial removal would cost $478 million.

Cantle and Bernstein (2015) discussed the air emissions associated with decommissioning California platforms. As with the model created by Bressler and Bernstein (2015), Cantle and Bernstein made estimates based on two scenarios: complete and partial removal. They "describe major emissions categories, and the environmental and human health issues associated with each, and examine how the regulatory system would operate in specific projects… [They] then describe methods to estimate emissions for a worst-case example involving the largest platform, Harmony… [They] estimate that complete versus partial removal of Harmony would result, respectively, in 600 or 89 tons of NOx, 50 or 7 tons of carbon monoxide, 29 400 or 4400 tons of CO_2, 21 or 3 tons of PM10, and 20 or 3 tons of PM2.5. Complete removal of Harmony's jacket and topsides creates approximately 6.75 times more air pollution than partial removal down to 85 feet below the sea surface."

Kruse et al. (2015) evaluated the potential socioeconomic impacts of two removal options: complete and partial removal. They estimated the "impacts on commercial fishing, commercial shipping, recreational fishing, nonconsumptive boating, and nonconsumptive SCUBA diving. Available data supported quantitative estimates for some impacts, semiquantitative estimates for others, and only qualitative approximations of the direction of impact for still others. Even qualitative estimates of the direction of impacts and of user groups' likely preferred options have been useful to the public and decision makers and provided valuable input to the project's integrative decision model. Uncertainty surrounds even qualitative estimates of the likely direction of impact where interactions between multiple impacts could occur or where user groups include subsets that would experience the same option differently. In addition,… [they] were unable to quantify effects on ecosystem value and on the larger regional ecosystem, because of data gaps on the population sizes and dynamics of key species and the uncertainty surrounding the contribution of platforms to available hard substrate and related natural populations offshore southern California."

To help address the ultimate fate of platform shell mounds during the decommissioning process, the issue of whether the shell mounds of Pacific Outer Continental Shelf platforms were emitting PAHs into the marine environment was investigated by Bemis et al. (2014). They measured the PAHs in the vicinity of two platforms in the Santa Barbara Channel, platforms A and B, and at a natural reference site. They found very low concentrations of PAHs in the water column associated with the shell mounds. The most likely source of these PAHs were natural oil seepage, rather than from the shell mounds. Lastly, "PAH concentrations observed in the water column, regardless of the source of the PAHs, were more than an order of magnitude lower than regulatory water quality objectives established by the State of California…"

One of the issues likely to be raised in any removal process is the amount of fish production that would be lost under complete versus partial removal of a California platform. Pondella et al. (2015) estimated the potential loss of production under these two scenarios. They found that "Complete removal of a platform will likely eliminate most of its fish biomass; however, this study has shown that for rockfishes, which settle predominantly below 85 feet (26 m) and move deeper as they age, partial removal through topping would leave more than 90% of the fish biomass at the deeper platforms. Modeling of larval dispersal suggests that platforms provide an important opportunity for recruitment of fish larvae and that many larvae produced near the platforms would settle elsewhere in the region. The results presented by Pondella et al. indicate that, even if topped, the potential contribution of platform habitat to biological resources (e.g., fish production) in this region is significant."

BSEE funded a study by TSB Offshore Inc. (2015a,b) that updated the costs of decommissioning the platforms in the Pacific OCS Region. This two-volume work (volume 1 is the detailed report and volume 2 is the appendices) specifically addresses the following: "reviewing and updating the decommissioning scenarios for OCS platforms, reviewing and updating the engineering cost assumptions and methodologies, and reviewing and updating the costs for each phase of the decommissioning process." In addition, the report "covers operator compliance with OCS oil and gas regulations (30 CFR 550 and 556) for permanent plugging of wells; removal of well conductors and platform jackets to 15 feet below the mud-line; decommissioning and removal of pipelines and power cables; decommissioning and removal of platform decks and jackets; site clearance; and other lease and permit requirements." Overall costs to decommission 23 OCS platforms rose from $1,253,000,000 in 2010 to $1,461,000,000, a 1.6% increase.

Claisse et al. (2015) revisited the issue of the effects of platform topping on fish biomass and production. Across all California platforms, they found that "On average 80% of fish biomass and 86% of secondary fish production would be retained after partial removal, with above 90% retention expected for both metrics on many platforms. Partial removal would likely result in the loss of fish biomass and production for species typically found residing in the shallow portions of the platform structure. However, these fishes generally represent a small proportion of the fishes associated with these platforms." They also looked at the productivity of the surrounding shell mounds and found that "shell mounds are moderately productive fish habitats, similar to or greater than natural rocky reefs in the region at comparable depths. The complexity and areal extent of these biogenic 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 shell mound habitat."

Byrd et al. (2018) reviewed the challenges facing the oil and gas industry in decommissioning platforms off California. They found that these challenges were often different from those in the Gulf of Mexico. Unique challenges included 1) a lack of the infrastructure and services needed to remove deep-water platforms, 2) a complex regulatory process, and 3) uncertain prospects for reefing. The authors state that, because of these factors, the industry is unable to compute the costs of decommissioning. The authors go on to state that this paper "addresses the major issues and attempts to put boundaries on the cost risk" of decommissioning in California waters.

5 An Annotated Bibliography of Research Conducted Worldwide on Organisms and Organismal Communities Associated with Oil and Gas Platforms

This publicly available online bibliography covers a range of topics regarding oil and gas platforms throughout the world. Among the topics covered are 1) organisms and organismal communities associated with oil and gas platforms, 2) environmental effects of drilling and platforms, and 3) platform decommissioning. Entries in the bibliography include 1) papers in refereed journals, 2) gray literature such as research reports, 3) books and book chapters, and 4) theses and dissertations. Included for each work are 1) an abstract, 2) title, 3) the author(s), 4) date of publication, 5) name of journal (if paper), 6) publisher (if book or report), 7) geographic area covered in work, and 8) ISBN. The site allows for searches by author, words in the title, and drop-down menus covering 144 tags (i.e., "decommissioning," "corals," "fisheries," "sea birds"), and locations (i.e., "California," "North Sea," "Gulf of Mexico"). The bibliography is located at: http://platformresearch.msi.ucsb.edu/. As of October 2019, there were 1,012 entries in the system. The bibliographic citations are listed in Appendix B of this report.

6 Comparisons with Gulf of Mexico Platform Fish and Invertebrate Assemblages

The following presents some contrasts regarding fish and invertebrate assemblages around California platforms and those residing around Gulf of Mexico (GOM) structures. It is important to note that both the abiotic and biotic environments associated with GOM platforms are substantially different from those off California. All of the 26 California platforms reside on the narrow continental shelf, arguably within the same water mass; the water mass is characterized by seasonal coastal upwelling. In contrast, the thousands of GOM platforms are situated from very nearshore waters to those far offshore and from eutrophic to oligotrophic waters and with ambient water temperatures that are generally higher than those off California (Stanley and Wilson 2000). In addition, the fouling communities vary between these regions. While mussels predominate in the upper parts of all California platforms and anemones and sponges dominate deeper waters (Continental Shelf Associates 2005), in the GOM the platform biofouling community tends to reflect each platform's location and may be dominated by algae, barnacles, hydroids, bivalves, and, in some instances, scleractinian corals (Gallaway and Lewbel 1982, Lewbel et al. 1987, Scarborough Bull 1989, Carney 2005, Atchison et al. 2008). Therefore it follows that the seafloors associated with most California platforms are covered in thick layers of shells that are absent from GOM platforms

Scarborough-Bull et al. (2008) contrasted the ecological roles that Gulf of Mexico and California platforms may play as fish habitat. "Platforms in the Gulf of Mexico are concentrated in the north-central and northwestern regions where few natural reefs exist; they harbor unique communities bearing little resemblance to those in the natural surrounding habitat. There is evidence that the artificial habitat supplied by platforms in the Gulf of Mexico has increased the regional carrying capacity for economically important reef fish species such as red snapper. Platforms in the Gulf of Mexico are customary destinations for both commercial and recreational fishing and Rigs-to Reefs programs of Gulf States are actively expanding each year. Contrary to the Gulf of Mexico experience, California platforms are concentrated in the Santa Barbara Channel area among natural reefs and offshore islands and they harbor fish assemblages that resemble those found in nearby habitats. Observations at natural reefs and platforms off California found that platforms have become refugia for increasingly rare and overfished species, which is thought to be, in part, a result of light to non-existent fishing pressure at those platforms."

Additional comparisons and contrasts can be made between the two regions:

1) Water depth is a major driver of fish community structure at both California and GOM platforms (Ajemian et al. 2015).
2) At both California and GOM platforms, juvenile fishes tend to be most abundant in shallow and mid-depths, declining in deeper waters (Hernandez et al. 2003).
3) From near-surface waters to the platform bottom, fish densities are relatively high at California platforms to depths of at least 300 m. In the GOM, fish densities around platforms vary greatly with depth and there does not appear to be a consistent pattern among platforms (Stanley and

Wilson 1997, 1998, Reynolds et al. 2018). At the extreme, Stanley and Wilson (1998) documented almost no fishes in waters deeper than 100 m at a platform (GC 18) on the continental slope with a bottom depth of 219 m. Stanley and Wilson (2000) speculate that platforms situated in the oligotrophic waters of the continental slope (such as GC 18) will, in general, harbor lower densities of fishes than platforms on the more eutrophic, nearshore waters of the continental shelf.

4) Unlike off California, in the GOM the dominant fish species tend to vary with distance from shore (Bedinger 1981, Stanley and Wilson 1991).
5) The vast majority of California platform taxa are reef-dependent as pelagic or semi-pelagic taxa (i.e., jacks, tunas, clupeids, engraulids, and pelagic elasmobranchs) are either absent or, with a few exceptions, very transient. On the other hand, of the 246 fish species observed on GOM platforms, over 50% (132) were not reef associated (Cowan and Rose 2016). Rather, pelagic species, such as tunas, jacks, and various elasmobranchs routinely occupy GOM platform waters, particularly those associated with more offshore structures (Dugas et al. 1979, Scarborough Bull 1989, Childs 2002, Edwards and Sulak 2003, Gallaway and Lewbel 1982, Brown et al. 2010, Reynolds and Cowan 2015) However, with the exception of such taxa as *Seriola rivoliana* Valenciennes, 1833, *Caranx crysos* (Mitchill, 1815), *Rachycentron canadum* (Linnaeus, 1766) and *Sphyrna* spp. many of these taxa are transitory visitors (Gallaway and Lewbel 1982, Brown et al. 2010). Keenan et al. (2003) hypothesize that GOM platforms accumulate zooplankton resulting in increased densities for prey for such pelagic predators as *C. crysos*.
6) Similarly, while one group, the rockfishes, dominate many California platform assemblages, a very wide range of both reef-associated and pelagic taxa are found in the GOM (Cowan and Rose 2016).
7) Most California platforms serve as nursery grounds for a number of species (primarily *Sebastes* spp. and *C. punctipinnis*) and during some years hundreds of thousands of YOYs may recruit to a single platform. In contrast, while young fishes are found around GOM platforms, they do not appear to occur in the high densities routinely observed off California (Boland 2002, Hernandez and Shaw 2002).

7 An Issue of the *Bulletin of Marine Science* Dedicated to California Platform Science

The dedicated issue of the *Bulletin of Marine Science* is a peer-reviewed journal publication that includes review articles and new data analyses that synthesizes the scientific research focused on the organisms living in association with oil and gas platforms off California. The dedicated issue, entitled *Fishes and invertebrates of oil and gas platforms off California*, was published as Volume 95, Number 4 on October 1, 2019. It provides additional information for evaluating potential environmental effects of platform structures on regional marine ecology and consequences of their eventual removal. It is hoped that this collected material will help inform the public, policy makers, and regulators about their upcoming decisions. The dedicated issue contains 11 papers; the article titles, bibliographic references, authors, and abstracts are included in Appendix C of this report.

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Appendix A: A Synopsis of Extant California Oil and Gas Platforms

This appendix presents a synopsis of information about extant (as of 2019) oil and gas platforms offshore California (Figure 1). The platforms are listed in alphabetical order.

Wherever possible, we have included the following information on each platform: 1) the original operator; 2) the current operator of record; 3) the platform location; 4) the platform's distance from shore (including whether it is in state or OCS waters); 5) the bottom depth of the platform (water depth); 6) the date the platform was installed; 7) the first production date; 8) the number of well slots; 9) the number of conductors; 10) what the platform produces (oil and/or gas); 11) the platform jacket dimensions (generally at the seafloor [bottom]); 12) the platform's footprint; 13) the midwater surface area; 14) the total removal weight; 15) the shell mound size; 16) the shell mound volume; 17) the shell mound height; 18) the center of the shell mound location; and 19) the shell mound bottom slope.

This data was taken from California Resources Agency (1971), Manago and Williamson (1998), Holbrook et al. (2000), MEC Analytical Systems and Sea Surveyor (2003), Love et al. (2003), Claisse et al. (2014), TSB Offshore Inc. (2015a,b), and BSEE. Note that the estimated platform removal weights include jacket, piles, conductors, and deck (TSB Offshore Inc. 2015a,b). This information was compiled by the report author and has not been verified by BOEM or BSEE.

A	
Original operator:	Union Oil
Current operator of record:	DCOR
Location:	34°19'N, 119°36'W
Distance from shore:	9.3 km (5.8 mi) (OCS)
Water depth:	57 m (188 ft)
Date installed:	1968
First production:	1969
Number of well slots:	57
Number of conductors:	55
Produces:	oil and gas
Platform jacket dimensions:	40 x 48 m (133 x 158 ft) (bottom)
Platform footprint:	1,890 m^2
Platform midwater surface area:	20,996 m^2
Total removal weight:	4,896 tons
Shell mound size:	140 x 260 ft
Shell mound volume:	7,260 yd^3
Shell mound height:	20 ft
Shell mound center location:	centered
Shell mound bottom slope:	1.02%

B	
Original operator:	Union Oil
Current operator of record:	DCOR
Location:	34°19'N, 119°37'W
Distance from shore:	9.2 km (5.7 mi) (OCS)
Water depth:	58 m (190 ft)
Date installed:	1968
First production:	1969
Number of well slots:	63
Number of conductors:	57

Produces:	oil and gas
Platform jacket dimensions:	40 x 48 m (133 x 158 ft) (bottom)
Platform footprint:	1,979 m^2
Platform midwater surface area:	20,804 m^2
Total removal weight:	4,959 tons
Shell mound size:	160 x 210 ft
Shell mound volume:	8,590 yd^3
Shell mound height:	18 ft
Shell mound center location:	centered
Shell mound bottom slope:	1.03%

C

Original operator:	Union Oil
Current operator of record:	DCOR
Location:	34°19'N, 119°37'W
Distance from shore:	9.2 km (5.7 mi) (OCS)
Water depth:	58 m (192 ft)
Date installed:	1977
First production:	1977
Number of well slots:	60
Number of conductors:	43
Produces:	oil and gas
Platform jacket dimensions:	40 x 48 m (133 x 158 ft) (bottom)
Platform footprint:	1,920 m^2
Total removal weight:	5,718 tons
Shell mound size:	160 x 235 ft
Shell mound volume:	4,590 yd^3
Shell mound height:	13 ft
Shell mound center location:	southwest
Shell mound bottom slope:	1.14%

Edith

Original operator:	Standard Oil
Current operator of record:	DCOR
Location:	33°35'N, 118°08'W
Distance from shore:	13.7 km (8.5 mi) (OCS)
Water depth:	49 m (161 ft)
Date installed:	1983
First production:	1984
Number of well slots:	72
Number of conductors:	23
Produces:	oil and gas
Platform jacket dimensions:	58 x 50 m (190 x 165 ft) (bottom)
Platform footprint:	2,590 m^2
Platform base surface area:	846 m^2
Platform midwater surface area:	16,360 m^2
Total removal weight:	8,556 tons
Shell mound size:	unknown

Ellen

Original operator:	Shell Oil
Current operator of record:	Beta Operating Company
Location:	33°34'N, 118°07'W
Distance from shore:	13.8 km (8.6 mi) (OCS)
Water depth:	80 m (265 ft)
Date installed:	1980
First production:	1981
Number of well slots:	80
Number of conductors:	63
Produces:	oil and gas
Platform jacket dimensions:	45 x 56 m (147 x 186 ft) (bottom)
Platform footprint:	2,511 m^2
Total removal weight:	11,665 tons
Shell mound size:	unknown

Elly

Original operator:	Shell Oil
Current operator of record:	Beta Operating Company
Location:	33°35'N, 118°07'W
Distance from shore:	13.8 km (8.6 mi) (OCS)
Water depth:	77 m (255 ft)
Date installed:	1980
Produces:	Elly is a processing facility for Platforms Ellen and Eureka.
Platform jacket dimensions:	48 x 61 m (159 x 202 ft) (bottom)
Platform footprint:	2,949 m^2
Total removal weight:	9,400 tons
Shell mound size:	unknown

Emmy

Original operator:	Signal Oil and Gas
Current operator of record:	California Resources Corporation
Location:	33°39'N, 118°02'W
Distance from shore:	1.9 km (1.2 mi) (state)
Water depth:	14 m (47 ft)
Date installed:	1963
First production:	1963
Number of well slots:	53
Produces:	oil and gas
Platform jacket dimensions:	unknown
Shell mound size:	unknown

Esther

Original operator:	Chevron
Current operator of Record:	DCOR
Location:	unknown
Distance from shore:	2.4 km (1.5 mi) (state)
Water depth:	9 m (30 ft)
Date installed:	1990
Number of well slots:	64
Produces:	oil and gas

Platform jacket dimensions:	unknown
Shell mound size:	unknown

Eureka

Original operator:	Shell Oil
Current operator of record:	Beta Operating Company
Location:	33°33'N, 118°06'W
Distance from shore:	14.5 km (9.0 mi) (OCS)
Water depth:	212 m (700 ft)
Date installed:	1984
First production:	1985
Number of well slots:	60
Produces:	oil and gas
Platform jacket dimensions:	54 x 85 m (179 x 282 ft) (bottom)
Platform footprint:	4,635 m^2
Total removal weight:	33,377 tons
Shell mound size:	unknown

Eva

Original operator:	Union Oil
Current operator of record:	DCOR
Location:	33°39'N, 118°03'W
Distance from shore:	2.9 km (1.8 mi) (state)
Water depth:	17 m (57 ft)
Date installed:	1964
First production:	1966
Number of well slots:	39
Produces:	oil and gas
Platform jacket dimensions:	unknown
Shell mound size:	unknown

Gail

Original operator:	Standard Oil
Current operator of record:	Venoco
Location:	34°07'N, 119°24'W
Distance from shore:	15.9 km (9.9 mi) (OCS)
Water depth:	224 m (739 ft)
Date installed:	1987
First production:	1988
Number of well slots:	36
Number of conductors:	27
Produces:	oil and gas
Platform jacket dimensions:	21 x 52 m (70 x 170 ft) (surface) 60 x 90 m (197 x 297 ft) (bottom)
Platform footprint:	5,390 m^2
Platform base surface area:	1,675 m^2
Platform midwater surface area:	104,752 m^2
Total removal weight:	37,057 tons
Shell mound size:	four small scattered mounds
Shell mound volume:	<500 yd^3
Shell mound height:	3 ft
Shell mound bottom slope:	3.6%

Gilda

Original operator:	Union Oil
Current operator of record:	DCOR
Location:	34°10'N, 119°25'W
Distance from shore:	14.1 km (8.8 mi) (OCS)
Water depth:	62 m (205 ft)
Date installed:	1981
First production:	1981
Number of well slots:	96
Number of conductors:	64
Produces:	oil and gas
Platform jacket dimensions:	45 x 52 m (150 x 170 ft) (bottom)
Platform footprint:	2,081 m^2
Platform base surface area:	862 m^2
Platform midwater surface area:	18,626 m^2
Total removal weight:	11,293 tons
Shell mound size:	220 x 285 ft
Shell mound volume:	7,370 yd^3
Shell mound height:	18 ft
Shell mound center location:	north side
Shell mound bottom slope:	1.1%

Gina

Original operator:	Union Oil
Current operator of record:	DCOR
Location:	34°07'N, 119°16'W
Distance from shore:	6.0 km (3.7 mi) (OCS)
Water depth:	29 m (95 ft)
Date installed:	1980
First production:	1982
Number of well slots:	15
Number of conductors:	12
Produces:	oil and gas
Platform jacket dimensions:	28 x 20 m (94 x 65 ft) (bottom)
Platform footprint:	561 m^2
Total removal weight:	1,380 tons
Shell mound size:	150 x 210 ft, oval, oriented northwest-southeast
Shell mound volume:	4,200 yd^3
Shell mound height:	13 ft
Shell mound center location:	northwest side
Shell mound bottom slope:	1.01%

Grace

Original operator:	Standard Oil
Current operator of record:	Venoco
Location:	34°10'N, 119°28'W
Distance from shore:	16.9 km (10.5 mi) (OCS)
Water depth:	96 m (318 ft)
Date installed:	1979
First production:	1980
Number of well slots:	48

Number of conductors:	36
Produces:	oil and gas
Platform jacket dimensions:	27 x 44 m (90 x 145 ft) (surface)
	48 x 65 (158 x 213 ft) (bottom)
Platform footprint:	3,004 m^2
Platform base surface area:	777 m^2
Platform midwater surface area:	25,068 m^2
Total removal weight:	13,074 tons
Shell mound size:	200 x 390 ft, oval, oriented northwest-southeast
Shell mound volume:	5,500 yd^3
Shell mound height:	13 ft
Shell mound bottom slope:	0.38%

Habitat

Original operator:	Texaco
Current operator of record:	DCOR
Location:	34°17'N, 119°35'W
Distance from shore:	12.6 km (7.8 mi) (OCS)
Water depth:	88 m (290 ft)
Date installed:	1981
First production:	1993
Number of well slots:	24
Number of conductors:	20
Produces:	gas
Platform jacket dimensions:	60 x 38 m (199 x 125 ft) (bottom)
Platform footprint:	2,242 m^2
Platform midwater surface area:	2,242 m^2
Total removal weight:	9,611 tons
Shell mound size:	250 ft diameter
Shell mound volume:	6,840 yd^3
Shell mound height:	19 ft
Shell mound center location:	centered
Shell mound bottom slope:	0.4%

Harmony

Original operator:	Exxon
Current operator of record:	ExxonMobil
Location:	34°22'N, 120°10'W
Distance from shore:	10.3 km (6.4 mi) (OCS)
Water depth:	363 m (1,198 ft)
Date installed:	1989
First production:	1993
Number of well slots:	60
Number of conductors:	52
Produces:	oil and gas
Platform jacket dimensions:	91 x 117 m (300 x 385 ft) (bottom)
Platform footprint:	10,606 m^2
Total removal weight:	86,513 tons
Shell mound size:	unknown

Harvest

Original operator:	Texaco
Current operator of record:	Freeport McMoRan Oil & Gas
Location:	34°28'N, 120°40'W
Distance from shore:	10.8 km (6.7 mi) (OCS)
Water depth:	202 m (662 ft)
Date installed:	1985
First production:	1991
Number of well slots:	50
Number of conductors:	25
Produces:	oil and gas
Platform jacket dimensions:	61 x 97 m (200 x 319 ft) (bottom)
Platform footprint:	5,890 m^2
Platform base surface area:	1,544 m^2
Platform midwater surface area:	77,577 m^2
Total removal weight:	35,150 tons
Shell mound size:	unknown

Henry

Current operator of record:	DCOR
Location:	34°19'N, 119°33'W
Distance from shore:	6.9 km (4.3 mi) (OCS)
Water depth:	52 m (173 ft)
Date installed:	1979
First production:	1980
Number of well slots:	24
Number of conductors:	24
Produces:	oil and gas
Platform jacket dimensions:	45 x 33 m (149 x 110 ft) (bottom)
Platform footprint:	1,505 m^2
Total removal weight:	4,006 tons
Shell mound size:	250 ft diameter, circular
Shell mound volume:	7,200 yd^3
Shell mound height:	19 ft
Shell mound center location:	centered
Shell mound bottom slope:	0.67%

Heritage

Original operator:	Exxon
Current operator of record:	ExxonMobil
Location:	34°21'N, 120°16'W
Distance from shore:	13.2 km (8.2 mi) (OCS)
Water depth:	326 m (1,075 ft)
Date installed:	1989
First production:	1993
Number of well slots:	60
Number of conductors:	49
Produces:	oil and gas
Platform jack dimensions:	unknown
Total removal weight:	69,192 tons
Shell mound size:	unknown

Hermosa

Original operator:	Chevron
Current operator of record:	Freeport McMoRan Oil & Gas
Location:	34°27'N, 120°38'W
Distance from shore:	10.9 km (6.8 mi) (OCS)
Water depth:	179 m (587 ft)
Date installed:	1985
First production:	1991
Number of well slots:	48
Number of conductors:	16
Produces:	oil and gas
Platform jacket dimensions:	61 x 85 m (200 x 280 ft) (bottom)
Platform footprint:	5,203 m^2
Platform base surface area:	1,319 m^2
Platform midwater surface area:	83,784 m^2
Total removal weight:	30,868 tons
Shell mound size:	two mounds: 30 x 60 ft and 20 ft diameter
Shell mound volume:	<500 yd^3
Shell mound height:	2 ft
Shell mound bottom slope:	5%

Hidalgo

Original operator:	Chevron
Current operator of record:	Freeport McMoRan Oil & Gas
Location:	34°29'N, 120°42'W
Distance from shore:	9.5 km (5.9 mi) (OCS)
Water depth:	129 m (423 ft)
Date installed:	1986
First production:	1991
Number of well slots:	56
Number of conductors:	14
Produces:	oil and gas
Platform jacket dimensions:	78 x 53 m (257 x 176 ft) (bottom)
Platform footprint:	4,333 m^2
Platform base surface area:	1,662 m^2
Platform midwater surface area:	71,629 m^2
Total removal weight:	23,384 tons
Shell mound size:	small and scattered
Shell mound volume:	<500 yd^3
Shell mound height:	<2 ft
Shell mound bottom slope:	4.3%

Hillhouse

Original operator:	Sun Oil
Current operator of record:	DCOR
Location:	34°19'N, 119°36'W
Distance from shore:	8.9 km (5.5 mi) (OCS)
Water depth:	58 m (190 ft)
Date installed:	1969
First production:	1970
Number of well slots:	60

Number of conductors: 52
Produces: oil and gas
Platform jacket dimensions: 49 x 40 m (163 x 133 ft) (bottom)
Platform footprint: 2,014 m^2
Total removal weight: 5,834 tons
Shell mound size: 180 x 270 ft
Shell mound volume: 6,800 yd^3
Shell mound height: 22 ft
Shell mound center location: western side
Shell mound bottom slope: 0.88%

Hogan

Original operator: Phillips Petroleum/Continental Oil/Cities Services Oil
Current operator of record: Pacific Offshore Operators
Location: 34°20'N, 119°32'W
Distance from shore: 6.0 km (3.7 mi) (OCS)
Water depth: 47 m (154 ft)
Date installed: 1967
First production: 1968
Number of well slots: 66
Number of conductors: 39
Produces: oil and gas
Platform jacket dimensions: 38 x 38 m (125 x 125 ft) (bottom)
Platform footprint: 1,444 m^2
Total removal weight: 5,098 tons
Shell mound size: 260 ft diameter
Shell mound volume: 12,500 yd^3
Shell mound height: 26 ft
Shell mound center location: western side
Shell mound bottom slope: 0.33%

Holly

Original operator: Atlantic Richfield
Current operator of record: quitclaimed by Venoco to the California State Lands Commission
Location: 34°22'N, 119°52'W
Distance from shore: 2.9 km (1.8 mi) (state)
Water depth: 60 m (197 ft)
Date installed: 1966
First production: 1966
Number of well slots: 30
Produces: oil and gas
Platform jacket dimensions: 18 x 30 m (60 x 100 ft) (surface)
36 x 48 m (119 x 158 ft) (bottom)
Platform footprint: 1,728 m^2
Shell mound size: unknown

Hondo

Original operator: Exxon
Current operator of record: ExxonMobil
Location: 34°23'N, 120°07'W
Distance from shore: 8.2 km (5.1 mi) (OCS)

Water depth: 255 m (842 ft)
Date installed: 1976
First production: 1981
Number of well slots: 28
Number of conductors: 28
Produces: oil and gas
Platform jacket dimensions: 68 x 68 m (225 x 225 ft) (bottom)
Platform footprint: 4,649 m^2
Total removal weight: 29,478 tons
Shell mound size: three mounds: 40 x 170 ft, 60 x 130 ft, 50 x 100 ft
Shell mound volume: 1,500 yd^3
Shell mound height: 9 ft
Shell mound bottom slope: 5.6%

Houchin

Original operator: Phillips Petroleum/Continental Oil/Cities Services Oil
Current operator of record: Pacific Offshore Operators
Location: 34°20'N, 119°33'W
Distance from shore: 6.6 km (4.1 mi) (OCS)
Water depth: 49 m (163 ft)
Date installed: 1968
First production: 1969
Number of well slots: 60
Number of conductors: 35
Produces: oil and gas
Platform jacket dimensions: 38 x 38 m (125 x 125 ft) (bottom)
Platform footprint: 1,444 m^2
Total removal weight: 5,615 tons
Shell mound size: 85 m (280 ft) in diameter, circular
Shell mound volume: 10,900 yd^3
Shell mound height: 6 m (21 ft)
Shell mound center location: centered
Shell mound bottom slope: 0.38%

Irene

Original operator: Union
Current operator of record: Freeport McMoRan Oil & Gas
Location: 34°36.37'N, 120°43.45'W
Distance from shore: 7.6 km (4.7 mi) (OCS)
Water depth: 72 m (236 ft)
Date installed: 1985
First production: 1987
Number of well slots: 72
Number of conductors: 26
Produces: oil and gas
Platform jacket dimensions: 37 x 56 m (155 x 185 ft) (bottom)
Platform footprint: 2,664 m^2
Platform base surface area: 621 m^2
Platform midwater surface area: 14,243 m^2
Total removal weight: 8,762 tons
Shell mound size: 215 ft in diameter

Shell mound volume:	3,720 yd^3
Shell mound height:	9 ft
Shell mound center location:	western side
Shell mound bottom slope:	0.71%

Appendix B: Citations in the Online Annotated Bibliography

This appendix lists bibliographic citations in the online *Annotated Bibliography of Research Conducted Worldwide on Organisms and Organismal Communities Associated with Oil and Gas Platforms* (see Section 5 of this report). The list was extracted and reviewed by the author from the online bibliography in October 2019. The citations are listed alphabetically by author's last name.

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Appendix C: Abstracts from the *Bulletin of Marine Science* Issue

This appendix lists the article title, bibliographic reference, authors, and abstract of each paper in the dedicated issue of the *Bulletin of Marine Science*. The dedicated issue, entitled *Fishes and invertebrates of oil and gas platforms off California*, was published as Volume 95, Number 4 on October 1, 2019 (see Section 7 of this report).

C.1 Fishes and invertebrates of oil and gas platforms off California: an introduction and summary

Love MS. 2019. Fishes and invertebrates of oil and gas platforms off California: an introduction and summary. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):463-476. https://doi.org/10.5343/bms.2019.0043

AUTHOR—Milton S. Love

ABSTRACT—This paper serves as an introduction to a symposium on the role that California oil and gas platforms serve as habitats for fishes and invertebrates. As of 2019, there are 27 platforms in state and federal waters off California, and the decommissioning of some of these platforms is imminent. Thus, consideration of whether to completely remove a platform or cut it off at some depth below the sea surface and retain the submerged portion as a reef is a decision that will occur in the near future. The objectives of the 10 papers in this dedicated issue of the *Bulletin of Marine Science* are to: (1) increase scientific understanding of the inter- and intrarelationships of fish and invertebrate populations at offshore oil and gas platforms and natural reefs within the Southern California Bight; (2) determine the extent of influence of platform assemblages on southern California and the Pacific coast populations of fish and invertebrates; and (3) synthesize relevant reports, existing peer-reviewed literature, and new data analyses into a single peer-reviewed reference. This introductory paper contains a synopsis of all extant California platforms including information on: (1) the original operator, (2) the current operator of records, (3) the date the platform was installed, (4) the first production date, (5) the platform's distance from shore [including whether it is state or outer continental shelf (OCS) waters], (6) the bottom depth of the platform, (7) the number of well slots, (8) the number of conductors, (9) what the platform produces (oil and/or gas), (10) the platform jacket dimensions [generally at the seafloor (bottom)], (11) the platform's footprint, (12) the midwater surface area, (13) the total removal weight, (14) the platform location, (15) the shell mound size, (16) the shell mound volume, (17) the shell mound height, (18) the center of the shell mound location, and (19) the bottom slope. In addition, we present an overview of all previous research on the biology and ecology of California platform organisms.

C.2 An analysis of the fish assemblages around 23 oil and gas platforms off California with comparisons with natural habitats

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

AUTHORS—Milton S. Love, Jeremy T. Claisse, Alexa Roeper

ABSTRACT—Between 1995 and 2013, we surveyed fishes living around 23 California offshore oil and gas platforms (midwaters, bases, and shell mounds) and 70 natural habitats. These platforms were distributed between about Point Arguello, central California, and Huntington Beach, southern California, had seafloor depths between 49 and 363 m, and were surveyed between one and 16 times. A total of 1,526,437 fishes were observed. Fish densities were highest around platform bases, followed by platform midwaters, shell mounds, and natural habitats. Of all fishes observed, 90.4% were in the genus *Sebastes*. Water depth was the strongest driver of the fish species assemblages, although habitat type and geographic location were also important. Most of the fishes living around platforms and natural habitats were relatively small, primarily ≤20 cm in length. Many of these individuals were the juveniles of larger taxa or the juveniles and adults of dwarf species. Larger fishes were less common and these were most often found around platform bases and on natural habitats. Most young-of-the-year (YOY) fishes occurred at water depths of ≤150 m at all four habitats. At platforms, YOY densities were highest in platform midwaters and bases. On average, densities of these young fishes were somewhat higher compared to natural habitats and it is likely that many, although not all, California platforms play a significant role as nursery grounds for a variety of fishes, particularly for a number of *Sebastes* species.

C.3 Fishes with high reproductive output potential on California offshore oil and gas platforms

Claisse JT, Love MS, Meyer-Gutbrod E, Williams CM, Pondella DJ II. 2019. Fishes with high reproductive output potential on California offshore oil and gas platforms. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):515–534. https://doi.org/10.5343/bms.2019.0016

AUTHORS—Jeremy T. Claisse, Milton S. Love, Erin L. Meyer-Gutbrod, Chelsea M. Williams, Daniel J. Pondella II

ABSTRACT—Reproductive output can serve as an important metric to assess the value of a marine habitat as it combines fish densities, size at maturity, and the exponential increase of fecundity with body length. California may permit some portion of the structures of offshore oil and gas platforms to remain in place if a “net benefit to the marine environment” can be demonstrated. Here we assess habitats at 23 oil and gas platforms in terms of site- and species-specific estimates of potential reproductive output. We identified 17 fish species (15 rockfishes *Sebastes* spp.) that have potential reproductive output densities (no. eggs m^{-2}) on individual platforms that were tens to hundreds of times their average on natural reefs in the study area, with the highest potential reproductive output values being observed on platforms for all but two of these species. These extreme values were typically observed in platform base habitats, and likely result from the combined effects of high levels of fish recruitment to midwater platform habitats, relatively low fishing activity on these structures, and ontogenetic habitat use (depth-specific) patterns that make some platforms better habitats for some species based on the seafloor depth where they are sited. However, spatial variability was also very high across both platform and natural reef sites, including reproductive potential for almost all focal species being zero at the majority of surveyed sites. The contribution of fish reproductive potential to the discussion of decommissioning alternatives should therefore be considered on a case-by-case basis for each platform in California.

C.4 Offshore oil production platforms as potential sources of larvae to coastal shelf regions off southern California

Nishimoto MM, Simons RD, Love MS. 2019. Offshore oil production platforms as potential sources of larvae to coastal shelf regions off southern California. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):535–558. https://doi.org/10.5343/bms.2019.0033

AUTHORS—Mary M. Nishimoto, Rachel D. Simons, Milton S. Love

ABSTRACT—A diverse assemblage of adult reef fishes and invertebrates occurs at offshore oil production platforms in the Southern California Bight (SCB). Coincident with the initiation of the decommissioning of six platforms in the SCB, the goal of this study was to examine how a platform's geographical location plays a role in its potential contribution of larval recruits to natural areas. Using a three-dimensional biophysical model, we quantified the potential connectivity of larvae, particularly relevant to reef fishes, from three offshore platforms to four coastal shelf regions where the majority of rocky settlement habitat occurs in the SCB. The regions cover the shelves of the mainland coast and islands and offshore banks in the southern SCB. The main findings indicate that (1) the potential for larval subsidies from platforms in the southern SCB to populations in the northern SCB are greater than the potential for larval subsidies from platforms in the northern SCB to the southern SCB; (2) there is greater seasonal variability of potential connectivity from platforms to the mainland shelf region of the northern SCB than to the mainland shelf region of the southern SCB or shelves around islands and banks; and (3) there is consistency across years in the relative magnitude of potential connectivity from the platforms to the four shelf regions. We conclude that a platform's function as a larval source should be considered an ecological criterion when evaluating whether a platform is to be converted to an artificial reef and implementing marine spatial planning.

C.5 Timing of juvenile fish settlement at offshore oil platforms coincides with water mass advection into the Santa Barbara Channel, California

Nishimoto MM, Washburn L, Love MS, Schroeder DM, Emery BM, Kui L. 2019. Timing of juvenile fish settlement at offshore oil platforms coincides with water mass advection into the Santa Barbara Channel, California. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):559–582. https://doi.org/10.5343/bms.2018.0068

AUTHORS—Mary M. Nishimoto, Libe Washburn, Milton S. Love, Donna M. Schroeder, Brian M. Emery, Li Kui

ABSTRACT—Recent pathways taken by pelagic juvenile fishes to offshore oil platforms were reconstructed from remotely sensed and in situ measurements of currents and hydrography. Juvenile fishes comprised 52.8% (16,952 of 23 species) of all individuals (32,080 juveniles and adults of 35 species) observed during scuba surveys conducted about twice per week at two platforms in the eastern Santa Barbara Channel from May to August 2004. Blacksmith, *Chromis punctipinnis* (Cooper, 1863), and rockfishes (genus *Sebastes*, at least 18 taxa) comprised 95.1% of the recruits. Almost all rockfishes recruited to the deepest part of the platforms surveyed (26 and 31 m), while most blacksmith recruited in shallower waters. The onset of the recruitment season for juvenile rockfishes (genus *Sebastes*, Scorpaenidae) coincided with the advection of a low salinity water mass into the channel from the Southern California Bight. Before arrival of this water mass, water at the platforms resembled upwelled, high salinity water around the Point Conception region at the western channel entrance. Settlement pulses of rockfishes and blacksmith were observed during advective events when salinity decreased in the upper 40 m and currents turned northwestward or intensified in that direction. Two abundant rockfish species [bocaccio, *Sebastes paucispinis* Ayres, 1854, and treefish, *Sebastes serriceps* (Jordan and Gilbert, 1880)] showed synchronous patterns of juvenile settlement between platforms separated by 7 km. Our findings indicate that currents from the bight, rather than from central California, supplied recruits to settlement habitat in the eastern channel and that the spatial scale of connectivity for some fish populations in this region is greater than the channel itself.

C.6 An analysis of the sessile, structure-forming invertebrates living on California oil and gas platforms

Love MS, Nishimoto MM, Snook L, Kui L. 2019. An analysis of the sessile, structure-forming invertebrates living on California oil and gas platforms. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):583–596. https://doi.org/10.5343/bms.2017.1042

AUTHORS—Milton S. Love, Mary M. Nishimoto, Linda Snook, Li Kui

ABSTRACT—Using video transects of oil and gas platform crossbeams off central and southern California, we characterized the structure-forming invertebrates (with a height of at least 20 cm) found around 23 oil and gas platforms at depths between 20 and 363 m. We observed 20,357 individual invertebrates, comprising 19,800 Cnidaria and 557 Porifera of at least 15 species or species groups. *Metridium farcimen* (Brandt, 1835) was by far the most commonly observed cnidarian, forming 97.6% of all invertebrates catalogued. The alcyonacean, *Leptogorgia chilensis* (Verrill, 1868), and the scleractinian, *Lophelia pertusa* (Linnaeus, 1758), were the most commonly observed corals. White vase sponges (most or all in the family Aphrocallistidae) were the most abundant of the sponges (comprising 38.4% observed). We also documented a variety of unidentified foliose, barrel, and other various-shaped sponges. The height of these invertebrates ranged from 20 to 80 cm. Taxa displayed a variety of depth patterns. Some, such as *M. farcimen*, unidentified white vase sponges, and *L. pertusa*, were found throughout most or all of the survey depth range, while others (notably the gorgonians *L. chilensis*, *Placogorgia* spp., and *Acanthogorgia* spp.) were found over a relatively narrow range. Invertebrate assemblages tended to be similar among many platforms reflecting species similarities over a broad range of platform depths. Based on these relationships, it is apparent that the assemblages of structure-forming invertebrates varied by depth rather than geography.

C.7 The role of jacket complexity in structuring fish assemblages in the midwaters of two California oil and gas platforms

Love MS, Kui L, Claisse JT. 2019. The role of jacket complexity in structuring fish assemblages in the midwaters of two California oil and gas platforms. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):597–615. https://doi.org/10.5343/bms.2017.1131

AUTHORS—Milton S. Love, Li Kui, Jeremy T. Claisse

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

C.8 Regional patterns in shallow water invertebrate assemblages on offshore oil and gas platforms along the Pacific continental shelf

Page HM, Zaleski SF, Miller RJ, Dugan JE, Schroeder DM, Doheny B. 2019. Regional patterns in shallow water invertebrate assemblages on offshore oil and gas platforms along the Pacific continental shelf. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):617–638. https://doi.org/10.5343/bms.2017.1155

AUTHORS—Henry M. Page, Susan F. Zaleski, Robert J. Miller, Jenifer E. Dugan, Donna M. Schroeder, Brandon Doheny

ABSTRACT—We explored biogeographical and local patterns in the composition of shallow water (≤18 m depth) invertebrate assemblages inhabiting California offshore oil and gas platforms using multivariate analysis of diver-conducted photographic data collected from 23 platforms in 2013–2014. We evaluated the potential importance of sea surface temperature (SST) and other physical and biological factors in driving observed patterns in these assemblages. Prior to this analysis, platforms were grouped into four regions based on local differences in annual mean SST. The composition of invertebrate assemblages varied significantly among the four regions, reflecting differences in the relative abundances of certain anemone, bryozoan, sponge, and bivalve taxa. However, invertebrate assemblages varied idiosyncratically among platforms within a region. Variation in platform assemblages was associated with SST across regions; however, assemblages of platforms in the southeast Santa Barbara Channel were distinct due to the high cover of a non-native bryozoan, *Watersipora subatra* (Ortmann, 1890). The existence of geographical patterns in the composition of platform invertebrate assemblages and the colonization of one platform by a native bryozoan with southern affinities during elevated SST of 2014–2015 suggest that these assemblages may be useful over broad spatial scales as barometers of short- and longer-term changes in ocean climate. However, over smaller spatial scales, the idiosyncratic differences in invertebrate assemblages among platforms within regions indicates that these assemblages would have to be considered on a platform-by-platform basis under various decommissioning scenarios.

C.9 Fish densities associated with structural elements of oil and gas platforms in southern California

Meyer-Gutbrod EL, Kui L, Nishimoto MM, Love MS, Schroeder DM, Miller RJ. 2019. Fish densities associated with structural elements of oil and gas platforms in southern California. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):639–656. https://doi.org/10.5343/bms.2018.0078

AUTHORS—Erin L. Meyer-Gutbrod, Li Kui, Mary M. Nishimoto, Milton S. Love, Donna M. Schroeder, Robert J. Miller

ABSTRACT—There are thousands of offshore oil and gas platforms worldwide that will eventually become obsolete, and one popular decommissioning alternative is the "rigs to reefs" conversion that designates all or a portion of the underwater infrastructure as an artificial reef, thereby reducing the burden of infrastructure removal. The unique architecture of each platform may influence the size and structure of the associated fish assemblage if different structural elements form distinct habitats for fishes. Using scuba survey data from 11 southern California platforms from 1995 to 2000, we examined fish assemblages associated with structural elements of the structure, including the major horizontal crossbeams outside of the jacket, vertical jacket legs, and horizontal crossbeams that span the jacket interior. Patterns of habitat association were examined among three depth zones: shallow (<16.8 m), midwater (16.8–26 m), and deep (>26 m); and between two life stages: young-of-the-year and non-young-of-the-year. Fish densities tended to be greatest along horizontal beams spanning the jacket

interior, relative to either horizontal or vertical beams along the jacket exterior, indicating that the position of the habitat within the overall structure is an important characteristic affecting fish habitat use. Fish densities were also higher in transects centered directly over a vertical or horizontal beam relative to transects that did not contain a structural element. These results contribute to the understanding of fish habitat use on existing artificial reefs, and can inform platform decommissioning decisions as well as the design of new offshore structures intended to increase fish production.

C.10 Site fidelity, vertical movement, and habitat use of nearshore reef fishes on offshore petroleum platforms in southern California

Mireles C, Martin CJB, Lowe CG. 2019. Site fidelity, vertical movement, and habitat use of nearshore reef fishes on offshore petroleum platforms in southern California. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):657–681. https://doi.org/10.5343/bms.2018.0009

AUTHORS—Carlos Mireles, Christopher J.B. Martin, Christopher G. Lowe

ABSTRACT—Off California, economically important nearshore reef fishes inhabit the shallow (<20 m) regions of offshore petroleum platforms on the San Pedro Shelf (SPS). It is essential to understand the degrees to which platforms support fish over time to indicate whether biological requirements (e.g., shelter, diet, reproduction) are being met. To determine the ecological importance of platforms as fish habitat, the site fidelity and depth/habitat use of adult cabezon, *Scorpaenichthys marmoratus* (Ayres, 1854), grass rockfish, *Sebastes rastrelliger* (Jordan and Gilbert, 1880), kelp rockfish, *Sebastes atrovirens* (Jordan and Gilbert, 1880), and California sheephead, *Semicossyphus pulcher* (Ayres, 1854) were investigated at platforms Edith (50 m bottom depth) and Eureka (212 m). A total of 63 fish were acoustically tagged and monitored for up to 578 d. Sixty-three percent of individuals were still present at platforms at the end of the study (long-term site fidelity), with 55 individuals detected a mean of 66.9% (SD 36.0%) of their total days at liberty (daily site fidelity). All species displayed a shift in seasonal depth use. The shallowest horizontal level, consisting of various horizontal beams at platform Edith (15 m depth) and Eureka (17 m), was the most utilized habitat by grass rockfish, kelp rockfish, and California sheephead. Cabezon at platform Eureka utilized depths (21–31 m) unassociated with horizontal levels, while at platform Edith they primarily utilized the second horizontal level (30 m). Decommissioning options that remove the shallowest 26 m of structure would eliminate the habitat most utilized by three of the four study species that dominate the nearshore reef fish communities at SPS platforms.

C.11 Decommissioning impacts on biotic assemblages associated with shell mounds beneath southern California offshore oil and gas platforms

Meyer-Gutbrod EL, Love MS, Claisse JT, Page HM, Schroeder DM, Miller RJ. 2019. Decommissioning impacts on biotic assemblages associated with shell mounds beneath southern California offshore oil and gas platforms. In *Fishes and Invertebrates of Oil and Gas Platforms Off California.* Bull Mar Sci. 95(4):683–701. https://doi.org/10.5343/bms.2018.0077

AUTHORS—Erin L. Meyer-Gutbrod, Milton S. Love, Jeremy T. Claisse, Henry M. Page, Donna M. Schroeder, Robert J. Miller

ABSTRACT—The decommissioning of southern California offshore oil and gas platforms will create major economic, engineering, and environmental challenges in the next decade. Platform jackets, conductors, and shell mounds often host a diverse and productive marine community, and among the myriad considerations associated with decommissioning planning, platform operators and federal and state regulatory agencies will consider the ecological value of existing underwater structures as artificial reefs. In the event of partial removal of platform structure, fish assemblages on decommissioned platforms may remain unchanged in areas where structure is left intact. However, on the seafloor beneath the platforms, a mound of debris often called the shell mound will likely change over time if the supply of falling mussels and other organisms from the productive surface part of the structure is removed. In this study, we review shell mound research relevant to decommissioning, including mound formation, contaminant loads, associated biological communities, and transitions following the removal of platform structures at four sites. To address the gap in knowledge of shell mound fish community structure, we used manned submersible and remotely operated vehicle surveys from 1997 to 2013 to estimate the biomass, density, species composition and similarity between shell mounds at 22 southern California platforms. We found a wide range of variability in fish density and shell mound areal extent. Species composition also varied among sites, with three significant community clusters primarily distinguished by species depth preferences. These results will help inform a comprehensive net environmental benefit analysis of southern California offshore platform decommissioning alternatives.

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).