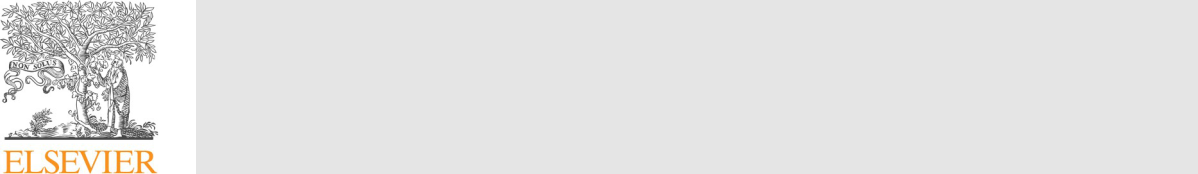
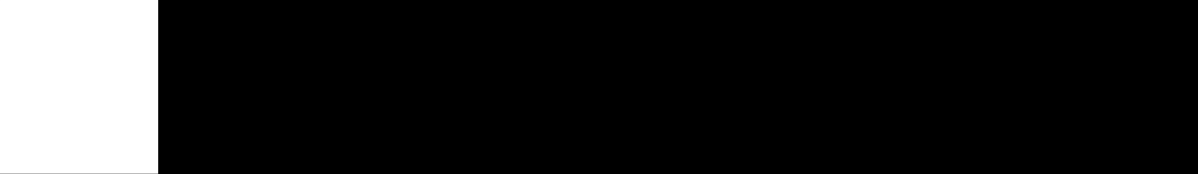
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Worldwide oil and gas platform decommissioning: A review of practices and [T](http://crossmark.crossref.org/dialog/?doi=10.1016/j.ocecoaman.2018.10.024&domain=pdf) reefing options



Ann Scarborough Bull[∗](#page1), Milton S. Love

*Marine Science Institute, University of California, Santa Barbara, CA, 93016, USA*



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ABSTRACT



Consideration of whether to completely remove an oil and gas production platform from the seafloor or to leave the submerged jacket as a reef is an imminent decision for California, as a number of offshore platforms in both state and federal waters are in the early stages of decommissioning. Laws require that a platform at the end of its production life be totally removed unless the submerged jacket section continues as a reef under state spon-sorship. Consideration of the eventual fate of the populations of fishes and invertebrates beneath platforms has led to global reefing of the jacket portion of platforms instead of removal at the time of decommissioning. The construction and use of artificial reefs are centuries old and global in nature using a great variety of materials. The history that led to the reefing option for platforms begins in the mid-20th century in an effort for general artificial reefs to provide both fishing opportunities and increase fisheries production for a burgeoning U.S. population. The trend toward reefing platforms at end of their lives followed after the oil and gas industry installed thousands of standing platforms in the Gulf of Mexico where they had become popular fishing desti-nations. The National Fishing Enhancement Act and subsequent National Artificial Reef Plan laid the foundation for Rig-to-Reefs. Reefing platforms in the Gulf of Mexico is a well-established practice that is also applied globally. Deliberation of reefing decommissioned platforms and many years of scientific study beneath California platforms has culminated in a California State law that now allows consideration of the concept. This paper summarizes the history, practices, published science, and available information involved when considering the reefing option. It is hoped that this material will inform the public, policy makers, and regulators about their upcoming decisions.



**1. Introduction**

Presently 27 oil and gas platforms exist offshore California. State and federal laws require that a platform be decommissioned at the end of its hydrocarbon production life and be totally removed unless the submerged jacket section continues as a reef under state sponsorship. As of April 2018, two platforms (Gail and Grace) in federal waters and one platform (Holly) and one island (Rincon) in state waters within the Santa Barbara Channel are slated for decommissioning and removal. Common practice for platform removal uses explosives or mechanical techniques below the seafloor to sever the jacket so that it can be pulled free and taken to shore for limited recycling and/or ultimate placement in a landfill. In the case of islands, both explosives and mechanical means may be used to break-up large pieces of concrete and metal in order to demolish installations. Discussion of the eventual fate of the populations of fishes and invertebrates beneath platforms has led to global reefing of the submerged portions of offshore platforms at the



time of decommissioning. Deliberation of reefing decommissioned platforms and many years of scientific study beneath California plat-forms has culminated in a California State law that now allows con-sideration of the concept.

Decommissioning is the process of ending operations at an offshore oil and gas platform. Usually during decommissioning, the platform is completely removed and the seafloor returned to its unobstructed pre-lease condition. However, there are other options that entail reefing the submerged sections of the platform structure (BSEE, 2017a). Rigs-to-Reefs (RtR) is the practice of converting decommissioned oil and gas platforms into artificial reefs. Such biotic reefs have been created from oil and gas platforms in the United States (U.S.), Brunei, and Malaysia. In the U.S., ownership and liability for the part of the platform com-prising the RtR belongs to the adjacent coastal state. The reefing option has been most popular in the Gulf of Mexico where thousands of plat-forms have been installed and removed with about 11% of decommis-sioned platforms adopted into state artificial reef programs. Although

* Corresponding author.

*E-mail addresses:* [ann.bull@ucsb.edu](mailto:ann.bull@ucsb.edu) (A.S. Bull), [milton.love@lifesci.ucsb.edu](mailto:milton.love@lifesci.ucsb.edu) (M.S. Love).

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several platforms have been installed and removed offshore southern California, none have been reefed.

Starting in the mid-1960s and ending about 1990, 24 oil and gas production facilities were installed in federal waters offshore California in a scattered string from coastal San Luis Obispo to Orange Counties. The areas of concentration included the offshore Santa Maria Basin, the Santa Barbara Channel, and San Pedro Bay. These facilities were in-stalled to produce hydrocarbons, mostly oil, and some lesser amounts of gas, from the rich formations that extend from onshore to offshore along the central and south-central coast. To date, within federal wa-ters, only one of the facilities, the Offshore Storage and Treatment (OS&

1. Vessel with its Single Anchor Leg Mooring (SALM) system, has been decommissioned and removed, leaving 23 oil and gas production platforms currently on the southern California Outer Continental Shelf (OCS) ([BSEE, 2017b](#page30)).

Within California state waters, offshore oil production from piers began nearly 100 years earlier than development in federal waters. Piers steadily extended over time out from the beach into deeper water. There are four offshore platforms and several artificial islands still op-erating and/or standing within California state waters ([SLC, 2017](#page33)). Only one of these platform, Platform Holly, off the City of Goleta in Santa Barbara County, is in sufficient depth of water to be considered for reefing.

While more than 1 billion barrels of oil and 1.3 trillion cubic feet of gas have been produced from these operations, production volumes from offshore California have been steadily decreasing over the past 20 years ([BSEE, 2017b](#page30), [2017c](#page30)) essentially due to the decreasing amount of petroleum within the developed formations. The majority of platforms have exceeded the projected life expectancy of their operations. Over their many years of existence, the hard substrate of the submerged jacket has provided reef habitat for sessile and motile invertebrates including mussels, barnacles, scallops, sponges, tunicates, corals, oy-sters, polychaetes, amphipods, crabs, and shrimps. The huge structures themselves and the significant layers of invertebrates have, in turn, provided habitat and sustenance for fish species, which in their turn provide for other fish species offshore California.

Decommissioning always includes the total removal of topside fa-cilities with only the jacket available as a potential reef. Consideration of whether to completely remove a platform or to leave the submerged jacket as a reef is no longer a decision for California citizens that will occur in the distant future. The decisions are imminent. The following information presents history, practices, published science, and available information involved when considering the reefing option. It is hoped that this material will inform California citizens, policy makers, and regulators about their upcoming decisions.

*1.1. Platform production*

Along the coasts of North America, the most substantial purpose-built, man-made structures are the offshore facilities created for the extraction of hydrocarbons and other minerals. Worldwide, there are about 6000 offshore platforms that extract oil and natural gas from beneath the global OCS in water depth of 30–7200 ft from 1 to 120 miles from the shore (Schroeder and Love, 2004). Platforms have been installed and are actively producing oil and gas along the coasts of Asia, Middle East, Mediterranean, Africa, Northern and Western Europe, Australia and New Zealand, South America, Mexico, North America, and Canada, with the far greatest number in the Gulf of Mexico. About 3000 of those structures are located in U.S. federal waters in the Gulf of Mexico, most off Louisiana and Texas, with perhaps another 1000 in Gulf state waters.

The first offshore (out of sight of land) oil well in the United States was brought in by Kerr- McGee in 1947 in the Gulf of Mexico, about 45 miles south of Morgan City in the Ship Shoal Bloc 32 field, marking the birth of the offshore oil and gas industry. Since that time, thousands of platforms have been both installed and removed from the Gulf, and,

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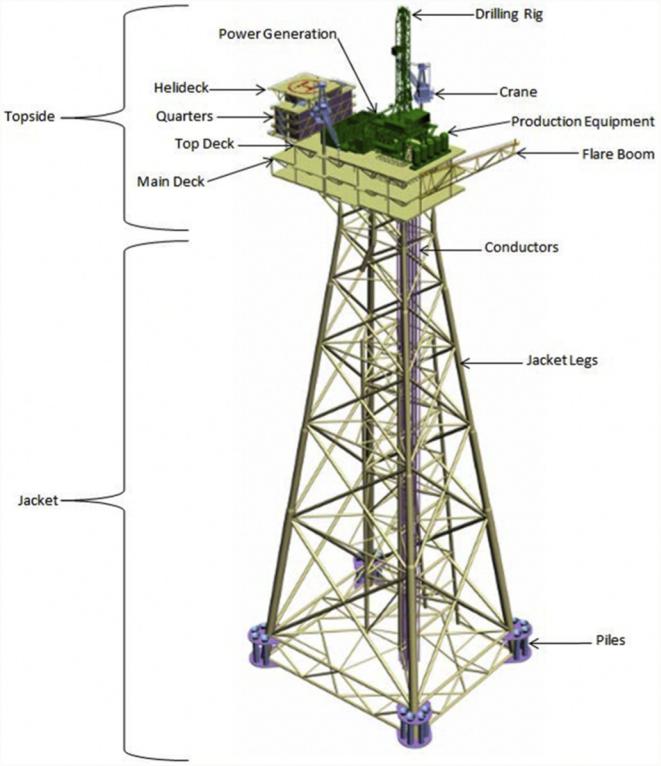
currently, annual removals exceed installations (Peter, pers. comm., [2017](#page32)). Off California, 23 offshore platforms have been installed within federal waters beginning in 1967. Seven platform installations occurred in state waters prior to this time. Development of the OCS on the Pacific coast was delayed by a disastrous blowout and oil spill in 1969; the last platform was sited in 1989 (Nevarez et al., 1998). There is little public support for further petroleum development off California at this time, and it is highly unlikely that will change in the foreseeable future.

*1.2. Platform installation*

A jacket is a steel support structure that rests on the ocean's floor and has columns or legs extending from below the seafloor up through the sea surface. Pilings are driven through the tubular legs of the jacket into the seafloor to hold the jacket in place. According to federal offi-cials at the Bureau of Safety and Environmental Enforcement (BSEE), most fixed platforms are typically found in shallow water, but some fixed platforms are sited in water depths between 400 feet and 1400 feet. Production facilities in deeper water are floating structures, without jackets, that are tethered to the seafloor (see [Fig. 3](#page3)).

Fixed steel petroleum production platforms are set in place by driving steel support legs (hollow pilings) deep into the seafloor. Working machinery and personnel sit above the water supported by an underwater, steel jacket network (Fig. 1) (that is intentionally overbuilt and remarkably secure) (Fig. 2). The vertical conductor pipes that carry the oil and gas up to the platform superstructure from below the sea-floor are guided into place through the jacket structure. The submerged jacket is braced by crossbeams. Horizontal, diagonal, and oblique tub-ular beams extend both around the perimeter of the jacket and reach inside and across the platform (see [Figs. 1 and 2](#page2)).

Oil and gas production platforms span the entire water column from the seafloor through the sea surface like an island. However, distinct from an island, the openness of a petroleum structure allows for water circulation, oceanic energy dissipation, and easy mobility for fishes



**Fig. 1.** Schematic of a generalized offshore oil and gas platform. Adapted from Manago and Williamson (1998).

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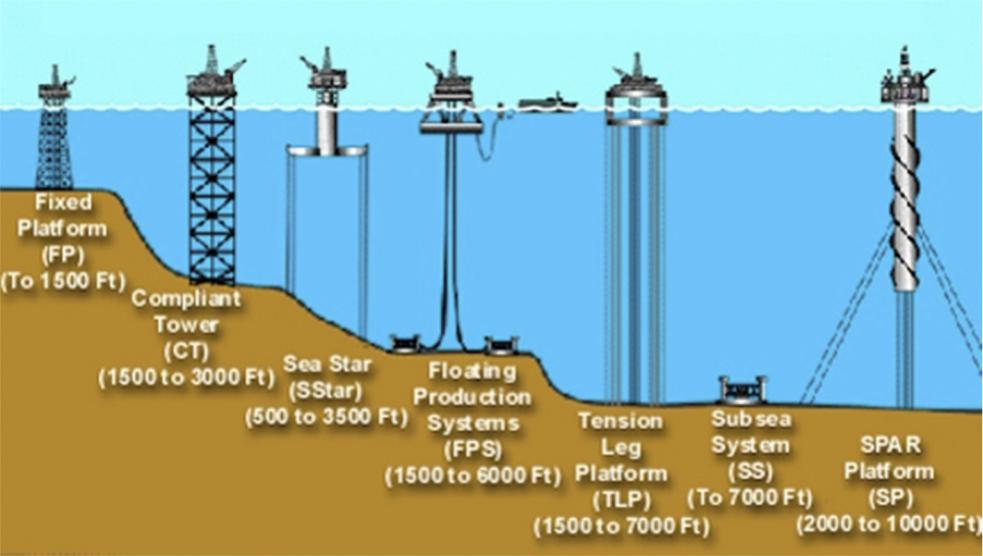
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**Fig. 2.** Construction of jacket support for oil platform offshore California. Note size of crane and large trucks compared to size and configuration of underwater support for offshore platform.

inside the structure. Fishes occur throughout platforms from near sur-face to seafloor (Scarborough Bull and Kendall, 1994; Love et al., 2003). The hard substrate of the submerged platform jacket provides habitat for many sessile invertebrates, including mussels, barnacles, scallops, sponges, tunicates, corals, and oysters. Indeed, in the northwestern and north-central Gulf of Mexico OCS region, where the amount of natural hard substrate is limited, it is estimated that offshore platforms con-tribute nearly 30% of the entire Gulf “reef” habitat (Gallaway and Lewbel, 1982; Scarborough-Bull and Kendall, 1994; Stanley and [Wilson, 2003](#page33)).

Unlike the Gulf of Mexico, there are no quantitative estimates of the extent to which platforms contribute to the total amount of “reef” ha-bitat in the Pacific OCS region (Carr et al., 2003). Estimates based on the general amount of hard substratum in shallower regions of the Santa Barbara Channel, including the Santa Barbara Channel Islands, lead to the conclusion that this contribution may be very small (Holbrook et al., 2000; Helvey, 2002). However, many years of ob-servations imply that rocky outcrops offshore California are relatively scarce below about 150 ft in the areas where platforms occur ([Love](#page31) et al., 2003; Schroeder and Love, 2004; Scarborough Bull et al., 2008). Thus, deeper-water platforms may locally provide considerable hard structure. For instance, it is estimated, from blueprints of the platform



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and a detailed multibeam survey of the surrounding area, that Platform Hidalgo supplies about 46% of the hard surface in its local area off Point Conception (within about 1.5 miles of the platform) (Love et al., [2003](#page31)). In addition, there are few natural reefs that rise as abruptly as platforms and no reefs in any region with the physical vertical relief comparable to these structures. As such, offshore platforms as artificial habitats are unique (Carr et al., 2003). According to Gallaway (see [LGL](#page31) and SAIC, 1998), it may be more ecologically accurate to consider platform reefs as a new and distinct habitat rather than to assume that they are merely additions to existing reef systems.

Plant and animal communities associated with petroleum platforms off California and within the Gulf of Mexico are obviously characterized by distinct regional faunal assemblages and species associations (Scarborough Bull, 1989a; Stanley and Wilson, 1997, [2000](#page33); Love et al., [2003](#page31)). There are ecological features unique to each region, and plat-form assemblages differ from nearby natural environments to varying degrees. In the northwestern and north-central Gulf, where most of the natural habitat is sedimentary, few representatives of local and coastal fauna occur on offshore platforms (Sonnier et al., 1976; Gallaway and Lewbell, 1982; Scarborough Bull, 1989a). It is assumed that originally many of the epibiotic organisms and fish species that now inhabit Gulf offshore platforms traveled to these structures as pelagic larvae for extended periods over relatively long distances; however, they may have also arrived via shipping or large semisubmersible drilling rigs moved from South America. Historically, as a species successfully set-tled on a Gulf platform and reached maturity, its larvae would not necessarily need to travel far to reach a similar habitat (another plat-form).

Contrary to observations in the Gulf of Mexico, California platform fish assemblages tend to resemble those found on nearby natural ha-bitats (Scarborough Bull, 1989b; Love et al., 2003). Much of the plat-form fish assemblages on Pacific platforms probably reflect recruitment of larval and pelagic juvenile fishes from both near and distant maternal sources as well as some attraction from natural reefs (Love et al., 2003). The fish assemblages that develop at the platforms in both the Gulf and Pacific regions do so over time. The influence that the platform fish communities may exert, and the role that the platforms as long-lived artificial reefs may play in the conservation of economically important species, rests in their vastly different history and use in regional fish-eries.

**Fig. 3.** General schematic of platform production structures.

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**Fig. 4.** Standing fixed platform left and platform removal right.

*1.3. Platform removal*

For decommissioning purposes, platforms generally consist of two distinct parts: the topside (the facilities visible above the waterline) and the substructure (the parts between the sea surface and the seabed, or mudline). During decommissioning, topside facilities that contain the operational components are completely removed and taken to shore for recycling or partial re-use. The substructure supporting jacket is gen-erally severed 15 feet below the mudline, then pulled out of the sea-floor, removed, and barged to shore to sell as scrap for recycling or refurbished for installation at another location with some part(s) ending up in a landfill ([Fig. 4](#page4)) ([NRC, 1996](#page32)).

Outer Continental Shelf Lands Act (OCSLA) regulations require the operator to sever structures and their related components at least 15 feet below the seafloor before removal. Platform operators typically use one of two primary options to sever structures attached to the sea bottom: either “mechanical severance” or “explosive severance”. BSEE regulations do not mandate which method or tool is to be used, as not all cutting options work in every situation. The operators use their knowledge of the facility, its components, and other parameters in coordination with their contractors to determine which method should be used. Neither method creates debris on the seafloor.

“Mechanical severance” options include abrasive-water jets, sand-cutters, diamond-wire saws, carbide-cutters, shears, and guillotine saws. Mechanical methods are used in approximately 35% of all re-moval operations. Mechanical severance proceeds more slowly than “explosive severance” options and may involve use of additional per-sonnel (including divers) and/or additional equipment. Historically, the slower speed and use of additional personnel, including divers, has resulted in more injuries and higher costs when compared to explosive severance (NOAA, 2017a). More recently, mechanical removal has improved with diamond-wire and sand cutters now used in most cases of platform decommissioning by the major, larger companies. The use of mechanical means to dismantle a platform at the time of removal will eliminate habitat (if not reefed), kill fewer fish than explosives, and eliminate some potential harm to marine mammals and sea turtles.

“Explosive severance” options rely on the use of specially-designed bulk or shaped-charges attached to the platform. Charges are made up of explosive material with specific properties (i.e. velocity, density, shattering capability, specific energy, and weight strength) to produce enough stress upon detonation to completely sever the platform's bottom-founded components. These bottom-founded components are typically steel, pipe-like targets of varying diameters and wall thick-ness, depending on the platform's configuration and location on the OCS. An explosive charge is generally deployed from above the water surface inside the pipe-like target and set at a depth of 15–25 feet below the seabed. Implementing OCSLA regulations allow the use of charges with explosive weights up to 500 lbs. Successful severance is typically effective, however, with charges from 50 to 200 lbs in explosive weight.

The use of explosives to cut conductors, well casings, jackets, and piles has been the most reliable method in use for many years. The open water use of explosives has been restricted in recent times, but appli-cations below mudline continue to be permitted with safeguards for

marine mammals. The bottom cuts on anchor piles and conductors re-quired for the removal of jacket structures must be clean to allow for a safe lift from the surface. A barge making such a lift in dynamic con-ditions at sea would certainly exceed its lift capacity if an incomplete cut left the load secured to the sea floor. This potentially dangerous condition dictates the use of the most reliable method for making these cuts, and explosives have proven to be nearly flawless in their relia-bility. An explosive cut is sized according to the diameter and wall thickness of the tubular pipe(s) to be cut. A typical charge for these cuts is a cylindrical explosive container which is lowered down the con-ductor or pipe leg to the designated cut elevation and detonated from both ends to create a “collision charge”. The force of the detonation at the ends moves toward the center of the cylinder and moves out hor-izontally when the two explosions collide. This horizontal force creates the directional cutting energy to sever the pile or conductor. The methodology is extremely safe, as the explosive cannot be detonated without an explosive detonator. The detonator (blasting cap) is at-tached to a detonation cord which is secured to each end of the ex-plosive. Modern blasting caps are detonated by high voltage and are not sensitive to radio waves. Because the detonation cord may be several hundred feet long, the vessel supporting the operation can move clear before a blasting cap is ever installed. The vessel continues to move away, paying out electrical wire to the blasting cap before detonation is applied to the wire with high voltage. The 1996 decommissioning in California state waters of Platforms Hope, Heidi and Hilda employed the use of explosives for the majority of bottom cuts. Spotting aircraft and boats were used to verify that there were no marine mammals in range of the blast area prior to each detonation. The charge size for the typical cuts on shallow water platforms is approximately 45 lbs. (Culwell, 1997). As noted, explosive severance options require fewer people and has historically resulted in fewer human injuries and lower costs compared to mechanical severance (NOAA, 2017a). However, the potential environmental impact, including massive fish kills, has led to increased use of mechanical means. Importantly, when a company chooses to use explosives, it is heavily monitored by NOAA pre- and post-explosives to both prevent and document harm, should that occur, to marine mammals and sea turtles ([NOAA, 2018](#page32)).

OCSLA regulatory and lease requirements for decommissioning offshore platforms are designed to minimize the environmental and safety risks inherent in leaving unused structures in the ocean and to reduce the potential for conflicts with other users of the federal OCS (i.e., commercial fishing/aquaculture, military activities, transportation industry, other oil and gas/renewable energy operations). Decommissioning for total removal of an offshore platform generally entails:

1. Plugging all wells supported by the platform and severing the well casings/conductors 15 feet below the mudline;
2. Cleaning and removing all production and pipeline risers supported by the platform;
3. Removing the platform from its foundation by severing all bottom-founded components at least 15 feet below the mudline;
4. Disposing of the platform in a scrap yard or fabrication yard, or

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placing the platform at an artificial reef site; and

1. Performing site clearance verification at the platform location to ensure that no debris or potential obstructions to other users of the OCS remain.

OCSLA regulations administered by BSEE require that operators obtain approval of the platform removal methodology prior to removal of the platform through an application process. To satisfy National Environmental Policy Act (NEPA) obligations, the Bureau of Ocean Energy Management (BOEM) prepares an environmental assessment for each removal application on behalf of BSEE. BSEE ensures the assess-ment is adequate and imposes any necessary protective mitigation measures as conditions of permit approval.

About 3000 active production platforms exist on the OCS with more than 40% of these facilities greater than 25 years old (NRC, 1996; [Peter,](#page32) pers comm., 2017). The Regional Supervisor of offshore operations in the appropriate BSEE regional office may grant a departure from the requirement to remove a structure by approving towing to a new lo-cation, partial structure removal, or toppling in place for conversion to an artificial reef if the operator meets the requirements of the National Artificial Reef Plan as permitted by several U.S. federal agencies. State government agencies are responsible for managing marine fisheries resources programs.

**2. Development of the federal rigs-to-reef program**

Construction of artificial rock reefs in nearshore waters to increase fish harvest or use as a base to grow seaweed has been used for cen-turies, both in the Mediterranean Sea and southeast Asia. Many wooden artificial reefs were built by Persians and Romans to block harbor en-trances and access by war vessels (Williams, 2006). The earliest re-corded construction of artificial reefs in the United States is from the 1830s when interlaced logs from huts were used off the coast of South Carolina to improve fishing and a New York boatmen's association filled wooden tubs with cement and sank them in piles (Williams, 2006). Castaways, such as old appliances, automobiles, and streetcars, re-placed the logs in ad hoc “private” reefs. It is likely that coastal ship wrecks and numerous other materials that accidently or intentionally occupied a featureless seafloor near towns and villages were used as fishing destinations. Officially, state and federal sanctioned projects have incorporated decommissioned subway cars, vintage battle tanks, armored personnel carriers, and decommissioned oil platforms ([Harrigan and Doubliet, 2011](#page31)).

The interest in establishing coastal artificial reefs increased rapidly during the 20th century in line with population growth and the sub-sequent increase in recreational and commercial fishing and its ex-penditures. Additionally, the decline of U.S. fisheries and their habitats from overfishing and degradation of vital fishery resource habitats was a growing concern (Murray, 1994; Salcido, 2005). By the mid-1950s, Alabama had the first and largest system of artificial reefs and the Carolina states had established nearly 50 artificial reefs in estuaries and coastal waters. Artificial reefs were designed to increase and improve opportunities for coastal sportfishing in Southern California, and by1960 California had established, managed, and planned artificial reef deployments within the Southern California Bight. In 1964, the Cali-fornia Department of Fish and Game (CDFG) was reporting before-and-after underwater surveys on several artificial reefs installed under their program as well as on two producing oil and gas platforms (Platforms Hilda and Hazel) located within state waters ([Carlisle et al., 1964](#page30)).

It wasn't until the 1970s and 80s that state and federal agencies, as well as fishing advocacy groups, began to circulate guides to artificial reef planning (NOAA, 2016). No national oversight of artificial reef development in U.S. waters existed until the mid-1980s, even though a growing number of states had substantial programs underway. By that time concerns had arisen over conflicts between diverse fishing prac-tices and the lack of planning and oversight in many instances. The

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early days of artificial reef development involved mostly single place-ment of “materials of opportunity” including tires, automobiles, street cars, and bridge and highway rubble (NOAA, 2016). The use of obsolete petroleum production structures as dedicated and permitted artificial reefs to enhance fisheries began as early as 1980 when a cooperative effort between the Southeastern Fisheries Association, the Gulf and South Atlantic Fisheries Development Foundation, Exxon, and the State of Florida moved a subsea production template from offshore Louisiana to offshore Pensacola (McGinnis et al., 2001). In 1982, Florida accepted two obsolete Tenneco platform jackets (see Fig. 1) into their artificial reef program for placement off Miami and Pensacola, respectively ([Reggio, 1987a](#page33),[b](#page33)).

The Minerals Management Service (MMS), now BOEM, the agency that manages leasing, exploration and development on federal offshore lands, recognized potential fisheries benefits early and announced in 1983 its support for RtR. A special Interior Department task force was formed called REEFS (Recreational and Environmental Enhancement for Fishing in the Seas), which became instrumental in motivating agencies and organizations to begin planned and organized develop-ment of artificial reefs. In 1983, the then MMS within the Department of the Interior (DOI), issued an interpretive rule directed at encouraging the perpetuation and expansion of the fishery benefits of oil and gas structures in the Gulf of Mexico (Reggio, 1987a) and began developing procedures which enabled states and other responsible parties to ac-quire obsolete structures on formerly active leases for fisheries devel-opment and enhancement projects (Iudicello, 1987; Larson, 1987; Reggio, 1987b).

*2.1. National Fishing Enhancement Act*

RtR was addressed by Congress in the National Fishing Enhancement Act (NFEA) of 1984, and a formal MMS policy followed in 1985 (H.R. 5447, 2017; LII, 2017). According to Villere Reggio of MMS, who helped draft the National Artificial Reef Plan in 1985, “The goal is to encourage states and fishery management planners to select suitable offshore locations where obsolete platforms might continue to serve usefully – providing an ideal environment for marine life as well as enhancing fishing and diving. Ideally the fish, the fishermen and divers, the petroleum companies, and the states will all benefit from RtR” ([Reggio, 1994](#page33)).

The 1984 NFEA was adopted in cooperation with the Departments of Commerce and Interior and the U.S. Army Corps of Engineers (USACE) and was designed to promote fishing and develop fisheries. Acknowledging that “overfishing and the degradation of vital fishery resource habitats have caused a reduction in the abundance and di-versity of United States fishery resources …," NFEA was passed “to promote and facilitate responsible and effective efforts to establish ar-tificial reefs,” and to “enhance fishery resources and commercial and recreational fishing opportunities.

NFEA codified an exception to the OCSLA regulation that platforms had to be completely removed. After 1984, obsolete oil and gas plat-forms could, under the law, be used for artificial reefs. The purpose rather than the effect of habitat enhancement legally defines an artifi-cial reef and distinguishes it from ocean dumping (Salcido, 2005). The notion that obsolete oil production platforms can be good for fishes and good for fishermen has never been universally accepted. However, with the passage of NFEA in 1984, the recognition that obsolete offshore platforms as well as other large structures, such as mothballed ships, made available through the Department of Transportation, could be valuable in developing artificial reefs for fishery enhancement and development became accepted national policy (U.S. Gov., 2017). After Congress enacted NFEA, the MMS promulgated regulations revising its policy and allowed a waiver that could set aside relevant lease ob-ligations that required the removal of all oil platforms. BSEE, at a re-gional level, can now approve conversion of an offshore platform within federal waters into a reef, provided the following requirements

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are met:

1. The structure becomes part of a state artificial reef program;
2. The responsible state obtains a permit from the USACE; and
3. The state accepts title and liability for the structure. NFEA does not, however, provide any funding for state artificial reef programs (Salcido, 2005).

Section 203 of NFEA established the following standards for artifi-cial reef development. Based on the best scientific information avail-able, artificial reefs in waters covered under NFEA “… shall be sited and constructed, and subsequently monitored and managed in a manner which will:

1. Enhance fishery resources to the maximum extent practicable,
2. Facilitate access and utilization by US recreational and commercial fishermen,
3. Minimize conflicts among competing uses of waters covered under this title and the resources in such waters,
4. Minimize environmental risks and risks to personal health and property, and
5. Be consistent with generally accepted principles of international law and shall not create any unreasonable obstruction to navigation” (LII, 2017; U.S. Gov., 2017).

Section 205 (c) of NFEA established a permit shield for liability. NFEA requires that states take on title to the platform and liability for platforms converted to reefs. The subsequent National Artificial Reef Plan (NARP) compares the decision a state makes to assume a permit for reef construction to the decision it makes to construct a public park. NARP states ‘‘When a reef has been properly located, marked on na-vigation charts if necessary, and any required surface markers affixed, there should be very little potential for liability.’’ Parker (1999), notes that no lawsuits have ever been filed against the CDFG with respect to their artificial reef program.

Regardless of whether a platform is removed or reefed, the federal government cannot be held liable. Regarding state liability, NARP notes, ‘‘If the permit holder is a state government, it may have sovereign immunity from liability. It is unclear whether the NFEA affects any state's claim of sovereign immunity’’ (NOAA, 2007; Schroeder and Love, 2004; Salcido, 2005). Strict adherence to all permit requirements will immunize reef managers, typically employees of state fish and wildlife departments, from liability pursuant to section 205 of NFEA (NOAA, 2007; U.S. Gov., 2017). A challenge to state liability exception appears to be unlikely (Salcido, 2005). The permitting process contains measures that help ensure the structural integrity and stability of pro-posed artificial reefs. In addition, artificial reefs are required to be shown on navigation charts, marked with buoys, and otherwise satisfy navigability requirements ([Salcido, 2005](#page33); [NOAA, 2007](#page32)).

Included in the U.S. policy that decommissioned oil and gas plat-forms could be used as artificial reefs was the knowledge of the po-tential saving of at least part of the high cost of removing obsolete platforms, the potential decrease in destruction of several thousand structures functioning as artificial reefs, and the loss of regional fishing opportunities (Reggio, 1987b; Salcido, 2005; Edwards, 2012). When NFEA was adopted, the International Maritime Organization (IMO) was discussing various interpretations of the legal requirements for re-moving redundant petroleum structures as mandated under the 1958 Geneva Convention on the Continental Shelf and as proposed under the Law of the Sea Treaty. At that time, there were an estimated 6000 petroleum structures off the coasts of 40 countries with an estimated removal cost of $25 to $50 billion in 1983 dollars ([Larson, 1987](#page31)).

In 1987, the U.S. had about 4000 structures off its coasts with es-timated removal costs of $7.5–$10 billion (Larson, 1987). Several sources estimate that current decommissioning costs for total removal of all offshore production facilities, including about 3000 platforms,

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and pipelines in the Gulf of Mexico OCS are between $38–$40 billion (BSEE, 2017c; GAO, 2015) with almost 700 additional leases, many of which contain platforms, expected to expire by 2020 (Howlett, 2017). In 2014 dollars, BSEE estimated that it will cost approximately $1.5 billion to decommission the 23 platforms residing in federal waters off California, with costs increasing over 10% each year, and only if the platforms are removed in groups, not individually, due to high mobi-lization and demobilization costs for removal equipment for the Pacific coast (BSEE, 2016a, [2016b](#page30)). A recent update of the mean potential costs for individual removal of 23 platforms in federal waters off Ca-lifornia increased the potential expenditure to nearly $8 billion ([Byrd](#page30) et al., 2018). When a structure is converted to a reef, generally 50% of the savings realized by a petroleum company is donated to the geo-graphically closest state Artificial Reef Program and has historically been used for related program costs, as well as biological and geological research (LDWF, 2017; TPWD, 2017; Reggio, 1994). The percentage and sharing of cost-savings between the state and the petroleum com-pany is written into the individual state law that implemented the state program.

*2.2. National Artificial Reef Plan*

NFEA directed the Department of Commerce, and by extension the National Oceanic and Atmospheric Administration (NOAA), to create a long-term, national plan and guide for states in their development of artificial reef programs in U.S. waters. NOAA produced NARP in 1985 and published a draft revision in 2002. NFEA directed that NARP guide states to develop their own state, not federal, comprehensive artificial reef programs. NARP provides state and local artificial reef program managers, policy makers, and interested parties with guidelines and resources on siting, construction, development, and assessment of ar-tificial reefs. In addition, NARP outlines the respective roles of federal, state, and local governments in the permitting, oversight, and ongoing management of artificial reefs. Despite the federal government's broad role, there is currently no federally coordinated program regulating artificial reef activities in U.S. waters (BSEE, 2017a; Salcido, 2005). However, the vast majority of state- and federal-sponsored Commis-sions and Council include appropriate state and federal counterparts ([BSEE, 2017a](#page30); [Lukens and Selberg, 2004](#page31)).

Coincident with passage of NARP, the Wallop-Breaux Amendment to the Federal Aid in Sportfishing Act of 1950 (the Dingell-Johnson Act) became law in 1984. The amendment substantially expanded the fed-eral funds that went to states to help develop sportfishing restoration projects including the building of artificial reefs in both fresh and saltwater. The funding has aided in formation of technical advisory committees in the Pacific, Atlantic, and Gulf of Mexico that directly function to coordinate reef development programs. These commissions provided the early basis for coastal states to assume the responsibility of implementing provisions of NARP with the intention to enhance fish-eries ([Christian et al., 1998](#page30)).

Many states have taken a leadership role in the development of artificial reef programs. Both the Gulf States Marine Fisheries Commission (TX, LA, MS, AL, and FL) and the Atlantic States Marine Fisheries Commission (ME, NH, MA, RI, CT, NY, NJ, PA, DE, MD, VA, NC, SC, GA, and FL) have artificial reef subcommittees. These Commissions and their subcommittees play a coordinating role for state efforts to develop and implement artificial reef programs (Lukens and Selberg, 2004). Representatives from DOI and NOAA serve on each of these committees, providing a mechanism for the federal government to engage with states on artificial reef issues, including federal RtR policy issues. In effect, the states have been responsible for implementing NARP, in cooperation with the USACE, and collecting information ne-cessary for updating guidance in NARP, and for strengthening provi-sions of the 1984 NFEA ([BSEE, 2017a](#page30)).

NARP itself is in the form of a technical memorandum, published by NOAA, and was revised in 1997, 1998, 2002, and a formal revision was

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executed in 2007, with the help of the Atlantic, Gulf, and Pacific States Marine Fisheries Commissions and interested state and federal agencies (NOAA, 2007). The amended NARP provides guidance on the roles of federal, state, and local governments and on artificial reef building, including types of construction materials, and planning, siting, de-signing, and managing of artificial reefs for the benefit of aquatic life. Several agencies also contributed to the contents, including DOI and the Environmental Protection Agency (EPA). The executive summary of NARP explains that its three major functions are;

1. Provide guidance to individuals, organizations and government agencies on the technical aspects of reef construction and manage-ment, based on the best available scientific information;
2. Serve as a guide to state and federal agencies who permit and manage artificial reefs to ensure national standards and objectives of the NFEA are achieved;
3. Encourage comprehensive planning of artificial reefs with emphasis on the consideration of local conditions.

To this end, NARP noted that local reef siting plans were being developed in 1985 and that NARP may encourage additional planning in other areas of the country interested in artificial reef construction. NOAA's NARP, as revised, suggests that a properly sited and marked artificial reef poses little possibility for liability (Salcido, 2005; [NOAA,](#page32) [2007](#page32)).

In the case of RtR, the offshore platform operator has sole control and complete responsibility for placing the structure in the state-de-termined location of the structure to be reefed. Once the state is sa-tisfied that all conditions have been met, and only after this agreement, the title and any consequent liability transfers to the adjacent coastal state. The platform owner/operator retains no obligation or duty for maintenance, repair, or any other legal requirement of the platform jacket, such as navigational markings; however, ownership, liability, and maintenance of all wells remain with the operator ([BSEE, 2017a](#page30)).

NARP is intended to respond to the information needs of a wide variety of users, including reef regulators, fishery and environmental managers, prospective donors of reef material, government officials, and the general public by facilitating effective artificial reef programs and performance monitoring. NARP emphasizes the use of the most recent and best information available, establishes standard terminology to improve communication between parties interested in reefs, and assists in developing more uniform permitting procedures and clear guidance on materials acceptable for construction of marine artificial reefs. The USACE is responsible for permitting the placement of de-commissioned platforms as artificial reefs under section 10 of the Rivers and Harbors Act of 1899. NARP also encourages the states to develop plans for artificial reefs in state waters and to participate in the plan-ning for reefs in nearby federal waters. Today approximately half of U.S. coastal states have artificial reef program planning documents or strategic plans based, at least in part, on guidance from NARP ([BSEE,](#page30) [2017a](#page30); [NOAA, 2016](#page32)).

NARP focuses on the use of high-quality materials for the con-struction of artificial reefs and evaluates proposed structures by fo-cusing on four factors; function, compatibility, durability, and stability. Obsolete platform jackets fulfill all four factors. According to artificial reef builders, platform jackets are superior to some materials because of their durability and the minimal likelihood for drift or movement due to their weight and open structure once reefed (Quigel and Thornton, [1989](#page33)). Using a simple corrosion model, it is estimated that a typical platform jacket would last for three centuries without maintenance before disintegrating (Quigel and Thornton, 1989). According to NARP, the “advantages of petroleum structures as reef material derive from their diverse locations and water depths, large numbers, inherent de-sign, modification flexibility, longevity, and stability” (NOAA, 2007).

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*2.3. Federal policy*

Responsibility for artificial reef permitting and oversight is divided among five federal government agencies in the U.S. (NOAA, 2007). The U.S. Department of Commerce, NOAA, implements NARP, working with state and federal agencies to promote responsible and effective artificial reef use based on the best scientific information available. NOAA serves in a consultative role for activities such as providing comments on the creation, siting, and permitting of artificial reefs as well as standards for the transfer, cleaning, and preparation of certain reef materials. For the Endangered Species Act, NOAA consults under Section [7](#page28) on federal actions that may affect listed species. A program-matic consultation for OCS federal waters was completed in August 2006 (NOAA, 2017a). The Marine Mammal Protection Act directs NOAA to allow, upon request, the incidental taking of small numbers of marine mammals within a specified geographical region if certain findings related to negligible impacts and subsistence use are made. NOAA promulgated regulations governing the taking of marine mam-mals incidental to explosive removal of offshore structures on June 19, 2008.

DOI has broad authority under OCSLA to protect natural resources of the OCS. With the reorganization of the DOI's Mineral Management Service in 2011, the role of DOI in RtR was split, as follows:

Within DOI, BSEE is responsible for regulatory, safety, environ-mental and conservation compliance for the development of the na-tion's offshore oil and gas and renewable energy resources. BSEE en-sures that the regulatory requirements for decommissioning of oil and gas platforms are met. These regulations allow the appropriate con-version of decommissioned platforms to artificial reefs when such platforms are permitted for that purpose by the U.S. Army Corps of Engineers.

Within DOI, BOEM manages the exploration and development of the nation's offshore resources. BOEM's role in RtR is to conduct the en-vironmental review required under NEPA and other laws for the de-commissioning of unused, idle platforms in support of the removal permit issued by BSEE. BOEM analyzes the environmental and cultural effects of BSEE's action in issuing the permit through the mechanism of a NEPA document such as an Environmental Impact Statement or Environmental Assessment, either Programmatic or Site-Specific, or other type, and may impose actions to mitigate those effects, both at the removal site and the reefing location, if that is proposed outside the approved reefing areas ([BOEM, 2005](#page30)).

In addition, the DOI U.S. Fish and Wildlife Service administers the Federal Aid in Sport Fish Restoration Program, which provides funding to the states to undertake sport fish restoration and boating access projects. Money for this program is collected from excise taxes on fishing tackle and motorboat fuels. The program provides reimburse-ment to state fish and wildlife agencies for 75% of the cost of eligible projects, subject to the overall annual funding apportionment to each state, which is determined by a formula in the Dingell-Johnson Act of 1950. Costs to state fish and wildlife agencies for artificial reef projects designed to provide or improve recreational fish habitat are eligible for reimbursement under the program.

USACE permits certain structures or work in or affecting navigable waters of the United States pursuant to section 10 of the Rivers and Harbors Act of 1899 to prevent obstruction to navigation by artificial islands, installations, and other devices. Also, under section 404 of the Clean Water Act, USACE regulates certain activities, such as the pla-cement of dredged or fill material (which includes the placement of an artificial reef), in the waters of the U.S. USACE permitting applies to placement of decommissioned platforms under state RtR programs on the OCS. Before granting an artificial reef permit, the USACE considers the best scientific information available as it relates to a number of criteria, ensures that title to the artificial reef material is unambiguous, and requires the permittee to clearly establish liability for damages and financial responsibility.

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**Fig. 5.** Examples of standing fixed steel platforms. Caisson platform (left) in the Gulf of Mexico. Multi-leg platform offshore California (center) and the Gulf of Mexico (right).

EPA reviews proposed reefing projects to ensure that only accep-table material is used as artificial reef material and that the placement of these materials on the ocean floor will not violate federal laws or regulations that protect the marine environment. EPA is consulted for applications for USACE permits for placement of artificial reefs and confirms authorization of sites to receive certain materials for the purpose of enhancing the aquatic environment.

United States Coast Guard (USCG) responsibility in the proper re-moval of decommissioned platforms addresses the safety, security, and efficiency of marine navigation. USCG regulations provide that any solid underwater structure must be marked with varying degrees of navigational buoys, or on navigation charts, or both, depending on submerged depth. The determination is accomplished through the ap-propriate USCG District.

*2.4. Implementation of the rigs-to-reefs program*

NOAA supports implementation of the U.S. RtR program provided that it benefits and is advantageous to the marine environment when a platform used as an artificial reef has been prepared appropriately and has been placed in a designated artificial reef site. NOAA policy in-dicates that platforms as artificial reefs can benefit the environment by enhancing fish habitat for the sponsoring state and community by en-hancing recreational opportunities, tourism, and commercial fishing, and for structure owners through cost savings and beneficial reuse of platforms that otherwise would become scrap metal and material ([NOAA, 2017a](#page32)).

The DOI RtR policy for platforms in federal waters encourages the reuse of obsolete oil and gas facilities as artificial reefs and describes the conditions under which DOI would waive platform removal require-ments within OSCLA. The decision to pursue donation of a decommis-sioned platform to a coastal state under the RtR process is optional and completely at the discretion of the offshore lease owner/operator.

In the face of increasing attention on the removal of these important fish structures, in June 2013, BSEE released an amended DOI “RtR” policy. The new policy supports and encourages the use of obsolete oil and gas structures as artificial reefs; provides greater opportunities for reefing by reducing the five-mile buffer zone between reefing areas to two miles; allows for reefing in place when appropriate in Special Artificial Reef Sites; and provides for extensions to regulatory decom-missioning deadlines for companies actively pursuing a “RtR” proposal (BSEE, 2013).

The DOI RtR policy is implemented by BSEE and BOEM, which administer different provisions of OCSLA. These platform removal waiver conditions include:

1. The structure must become part of a State artificial reef program that complies with the criteria in the NARP;
2. The appropriate State agency acquires a Rivers and Harbors Act section 10 permit from the USACE and accepts title and liability for

the reefed structure once removal and reefing operations are con-cluded;

1. The reefing proposal complies with BSEE Regional Engineering, Stability, and Environmental Reviewing Standards and Reef-Approval Guidelines, as well as consistent with the best manage-ment practices and cleanup standards in national guidance prepared by EPA and the Maritime Administration regarding the preparation of vessels intended for use as artificial reefs;
2. The operator satisfies USCG navigational safety requirements; and,
3. The structure does not pose an unreasonable impediment to future mineral and energy development.

OCSLA and implementing regulations, under which both BSEE and BOEM operate, established decommissioning obligations to which an oil and gas platform operator must commit when they sign an offshore lease under the OCSLA, including the requirement to apply for and obtain a permit for subsequent removal of platforms. OCS leases typi-cally require the operator to remove seafloor obstructions, such as offshore platforms, that by their presence impede other ocean activities within one year of lease termination, or prior to termination of the lease if either the operator or DOI deems the structure unsafe.

Since 1985, DOI has supported and encouraged the reuse of obsolete oil and gas platform jackets as artificial reef material. Obsolete petro-leum structures are inspected before any reefing takes place to locate environmental hazards. All decks (where oil production occurs) are removed and taken to shore for recycling or reuse to the extent possible. All equipment associated with the deck (such as drilling equipment, tanks, pumps, buildings and so on) is removed in the process. Insides of legs are inspected to assure they contain no petroleum. All wells below the structure are plugged by the company according to standards set by BSEE ([BOEM, 2017](#page30); [BSEE, 2017a](#page30)).

The RtR program in the Gulf of Mexico officially started when Louisiana and Texas passed legislation for an artificial reef program in 1986 and 1989, respectively. Approximately 35–40% of the petroleum production structures installed in the Gulf of Mexico have been caissons (also known as minimum-facility platforms) (Fig. 5). Nine fixed steel structures or compliant towers have been installed between 1000 and 1754 ft water depth. Fixed steel platforms can easily span 1000 + ft of water and usually extend another 40–50 stories above the surface. Floating production platforms that are anchored or cable-moored to the seafloor are typically installed in deeper water and may be 75 stories above the sea surface (see Fig. 3). There are no floating petroleum structures off California.

The timing of future decommissioning activities is dependent on many factors. It depends on the time limit and specifications of the state or federal lease, the geologic type and size of oil and/or gas reservoir, the rate of petroleum production and subsequent depletion of the re-servoir, the ability to move the product to market, the market value of oil or gas, potential resale or reuse value of the structure, and whether the platform might serve an extended use for the operator, such as a

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gathering or pass-through station for production from other platforms. And, considering all these factors, it is not always economical for in-dustry to convert a decommissioned platform into an artificial reef. The size of the structure, water depth, distance from shore, distance to final reef site (if it is being moved to another location after decom-missioning) (Fig. 6a) further influence the decision on whether or not a decommissioned platform becomes a reef (Wilson et al., 1997; [Schroeder and Love, 2004](#page33)).

There are three major phases and numerous sub-stages in the de-commissioning process: planning, permitting, and implementation. The suite of decommissioning alternatives that proposes to leave part of the decommissioned platform structure in the marine environment is col-lectively referred to as RtR. Deepwater disposal is often considered to be a separate alternative from a shallow-water reefing option, but from an ecological perspective, the functional impacts (addition of hard substrate into a marine environment) could be considered similar.

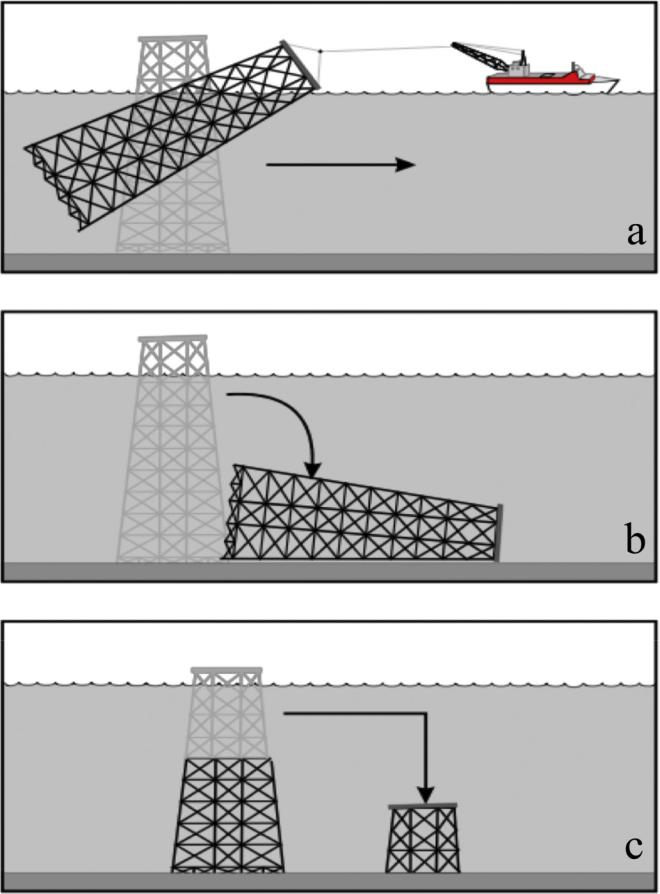
Pipelines run from all platforms either to shore or to other platforms that collect the oil or gas and then pipe production to shore, and the decommissioning process also considers the fate of obsolete pipelines. McGinnis et al. (2001) note that ‘‘Both federal and California regula-tions allow decommissioned OCS pipelines to be abandoned in place so long as they do not constitute a hazard to navigation, commercial fishing, or unduly interfere with other uses of the OCS.” In the Gulf of Mexico, few pipelines have been completely removed in the course of decommissioning ([Breaux et al., 1997](#page30)).

There are three methods for converting the subsurface jacket section of an obsolete oil and gas platform into an artificial reef. Partial re-moval (Fig. 6c) typically relies on non-explosive means to cut the platform, often at 85 ft below the mean waterline. Compared to top-pling in place (Fig. 6b), partial removals result in higher reef profiles and less trauma to and loss of habitat by associated reef organisms. Biofouling organisms have created a unique habitat on the seafloor surrounding platforms off California. Known as shell mounds, bivalve shells such as mussels and scallops that have settled on jacket legs in the upper surf zones and fallen under their own weight or been knocked off by storms or cleaning of platforms to reduce mechanical drag for op-erational safety create deep layers of shells (Sea Surveyor, 2003). The different community of biofouling organisms in the Gulf of Mexico are not as robust as Pacific communities and shell mounds are not found in the Gulf. A partial removal of the standing jacket does not require the removal or disturbance of shell mound habitat (Fig. 6c). Topple-in-place (Fig. 6b), as the name implies, may use some explosive severance to cut piles and lay the jacket on its side. The tow-and-place platform method (Fig. 6a) entails severing the platform from below the seafloor often using explosives and towing it to a designated reefing area ([BSEE,](#page30) [2013](#page30), [2017a](#page30)). On the occasions where upper deck sections are also proposed for reefing, the operator must demonstrate that the deck is clean and clear of all contamination and that the material is consistent with the EPA and U. S. Maritime Administration's National Guidance ([NOAA, 2017a](#page32)).

For an 85 ft clearance depth below mean waterline, the USCG re-quires states to maintain a relatively low-cost, usually yellow, unlighted reef buoy, and that exact artificial reef locations be put on navigation charts. However, the clearance depth can be shallower when combined with more sophisticated navigation aids, as required by the applicable USCG District, and as long as the structure is not too close to a desig-nated shipping lane. In 1999, the Louisiana Artificial Reef Program created the world's largest artificial reef from an offshore sulfur mine built from platform structures about seven miles off Grand Isle, Louisiana. The sulfur mine reef area, with over 1.5 miles of inter-plat-form bridgework, is composed of more than 29 separate platform structures, and frequented by recreational sport fishers. The reef is in 42–50 feet of water and has 27 feet of clearance. For safety of navi-gation, it is marked by 5 lighted buoys ([LDWF, 2017](#page31)).

During an MMS review of the initial application by the industry for a toppling-in-place platform removal, a concern came up about

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**Fig. 6.** Platform reefing methods. a. Tow-and-place platform reefing. b. Topple-in-place platform reefing. c. Partial removal platform reefing. Methods a and b often use explosives to severe steel jacket legs below the seafloor. Methods b and c often use mechanical tools to severe steel jacket legs either below or above the seafloor. Method c may or may not include placement of shallow water severed jacket on the seafloor as additional reef material.

potential bending of the well conductor(s) pipes (see Fig. 1) if they were cut off above the seafloor and the platform were toppled over (Dauterive, 2000). The concern was what effect might the separation of the well conductor have on the wellbore's integrity and surface plug? Consequently, the MMS conducted a structural failure analysis of a typical well conductor and found that failure would occur around 16 feet below the seafloor, whether or not the top of the conductor was above or at 85 feet below the sea surface. This finding agreed with industry experience of well abandonments caused by Hurricane Andrew (a category 4 storm that traversed the Central Gulf of Mexico in 1992), which found that, when toppled, well conductors remained vertical until about 15 feet below the seafloor. Since wellbore surface plugs are required to be set per MMS regulation at 150 feet below the seafloor, loss of surface plug integrity should not occur because of the toppling of a platform that has become a reef. Thus, the MMS adopted the policy, on a case by case basis, that allows for the retention of well conductors at the same cut depth (usually −85 ft) at which industry proposed to cut the platform jacket for partial removal when converting a decom-missioned platform into a reef. This policy eliminates the need for ex-plosives to cut conductors, during partial removal or topping-in-place, below the seafloor while the jacket is cut at some shallower depth during the removal process and diminishes impacts on the platform's fish and reef communities (BSEE, 2017a; Dauterive, 2000). In addition, retaining platform conductors adds additional complexity to the re-maining structure (Schroeder and Love, 2004). Fish kills associated with the use of explosives are self-evident and were studied by NOAA

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and the MMS during the 1990s ([Gitschlag et al., 2000](#page30), [2003](#page31)).

As of September 2012, the states of Louisiana, Texas, Mississippi, and California have passed specific legislation to establish programs for building artificial reefs from oil and gas platforms. To date, the Louisiana Department of Wildlife and Fisheries (LDWF), the Texas Parks and Wildlife Department (TPWD), and the Mississippi Department of Marine Resources (MDMR) have administered state-sponsored artificial reef plans that include ongoing offshore RtR pro-jects. The artificial reef coordinators from these states assess the interest of their respective states in acquiring oil or gas structures offered for artificial reef development, work with the structure operator (or agent) in securing any permit required under statutes administered by the USACE (including Section 10 of the Rivers and Harbors Act), negotiate an agreement for a structure donation, and accept title and responsi-bility on behalf of the state for the structure as a permanent state-ap-proved artificial reef. California has an inactive artificial reef program and recently enacted RtR legislation. As of 2018, however, no platforms have been reefed off of California (NOAA, 2017a).

**3. Reefing by Gulf of Mexico states**

By the late 1970s, offshore platforms were recognized as having significant direct benefits on offshore commercial trolling for reef fish, recreational and commercial hook-and-line fishing, and spear fishing using scuba in the northern Gulf of Mexico (Auyog et al., 1985; [Reggio,](#page33) [1987b](#page33)). This recognition, plus the inevitable increase in platform re-movals on the shallow OCS relative to platform installations over time, and the understanding that Gulf reef fish resources were greatly de-pendent on the presence of offshore platforms, prompted Louisiana and Texas to create artificial reef programs in which retired petroleum platforms are the material of choice (Stephan et al., 1990; Wilson et al., [1987](#page33)). One aspect of the positive attitude that residents in the Gulf of Mexico region have toward reefing offshore platforms is that the modern industry of petroleum extraction and commercial and recrea-tional reef fishing developed together.

Most extended families in Texas, Louisiana, Mississippi, and Alabama have family members that have worked in offshore energy extraction or fisheries, and sometimes both, many for generations. The two livelihoods expanded together, each is familiar on land as well as sea, neither is generally perceived as a threat to the other, and plat-forms are the usual destination for most recreational and commercial fishers who are targeting reef fish (Reggio and Kasprzak, 1991; [Nieland](#page32) and Wilson, 2003). The idea of a RtR policy represents a recombination of an old solution (a reliance on artificial reefs to increase carrying capacity and fish stocks in habitat-limited fisheries) to a perceived new problem (a lack of natural habitat and potential consequences asso-ciated with complete removal of many OCS oil and gas structures) ([Carr](#page30) [et al., 2003](#page30); [Linton, 1994](#page31)).

The major red snapper fishing grounds from the commercial in-dustry's inception in the mid-19th century until the mid-20th century was off the nearshore west coast of Florida, the Florida Panhandle with some edging toward Alabama, and the Campeche grounds of southeast Mexico, with few landings off Mississippi, Louisiana, or southward to the Texas-Mexico border (Shipp and Bortone, 2009). However, in-stallation of thousands of petroleum platforms across the northwest and north-central Gulf of Mexico and expansion of red snapper into these habitats during the last 60 + years has corresponded with major shifts in harvest locations and areas of red snapper concentrations (Fig. 7) (McLaughlin, 2013; Nieland and Wilson, 2003). This suggests that ha-bitat was a limiting factor for snapper population abundance during the first 100 years of the fishery and that platforms unintentionally con-tributed reef habitat across the Gulf that increased the carrying capacity of red snapper and its fishery (Linton, 1994: Nieland and Wilson, 2003; [Shipp and Bortone, 2009](#page33)).

Certainly by 1985, most of the commercial and recreational fish-ermen in the Gulf of Mexico, that harvested red snapper, grouper, and

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other reef fishes, relied on operating oil and gas platforms to hold fish assemblages in convenient near-shore areas, and anticipated that the removal of platforms would reduce fishing opportunities. The general proliferation of artificial reefs and the attractiveness of platforms to both fish and fishermen popularized the idea that oil rigs could be converted into artificial reefs. Proponents of RtR conversions in the Gulf of Mexico, particularly recreational fishermen, noted that “restrictions on fishing” and “increasing demands on marine fish” made RtR a win-win situation for fishing interests and oil companies (Reggio, 1987b; McGinnis et al., 2001). In addition to the platform structures, partici-pating companies have donated tens of millions in disposal savings to sponsoring state RtR programs for fisheries conservation, research, and management (Dauterive, 2000). Presumably, these companies, saved a comparable amount in structure disposal costs. Clearly, it is to the economic benefit of the company if a productive use were found for obsolete oil and gas platforms, a use that can mitigate the cost of platform removal and disposal as scrap onshore.

Offshore platforms and fisheries of the Gulf of Mexico continue to coexist. Over 90% of commercial red snapper landings (approximately 4 million pounds per year) originate in Louisiana waters, and while the exact amount harvested at petroleum platforms is unknown, it is known to be a significant portion of the harvest (Fig. 7). In addition to the commercial fishers frequenting offshore structures, recreational fishers and scuba divers are common platform visitors. Surveys of recreational use found that 70% of all fishers in coastal Louisiana utilized petroleum platforms as fishing destinations and that the catches of anglers at these structures were the highest, compared to any other Gulf sites, in the published scientific literature (Dimitroff, 1982; Witzig, 1986; [Reggio,](#page33) [1994](#page33); [Dauterive, 2000](#page30); [McKay et al., 2000](#page32); [Hiett and Milon, 2002](#page31)).

It is recognized by many scientists and most fishermen that the presence of platforms in the northern Gulf of Mexico has affected the distribution and increased the population of red snapper by the addition of hard substrate habitat (GOMFMC, 1996, [2000](#page31); Peabody and Wilson, [2006](#page32); Shipp and Bortone, 2009; McLaughlin, 2013). However, for fisheries managers of red snapper in the Gulf of Mexico the attraction versus production debate continues as some researchers have concluded that standing platforms, RtR, or other artificial reefs have severely in-creased the vulnerability of red snapper to fishing by attracting and aggregating fish closer to shore (Cowan et al., 1999). This judgement doubts that platforms are aiding any reef fish species including red snapper. Because there are no RtR or other artificial reef areas desig-nated as no-take (no fishing allowed), and the fishing pressure is un-derstood to be high on all accessible platforms and reefs, some Gulf of Mexico scientists believe reefing Gulf platforms, which would continue attraction and aggregation, is not a fisheries conservation effort ([Cowan](#page30) et al., 2011). This position is countered by other scientists who judge the stocks to be larger than they have ever been. They cite two reasons:

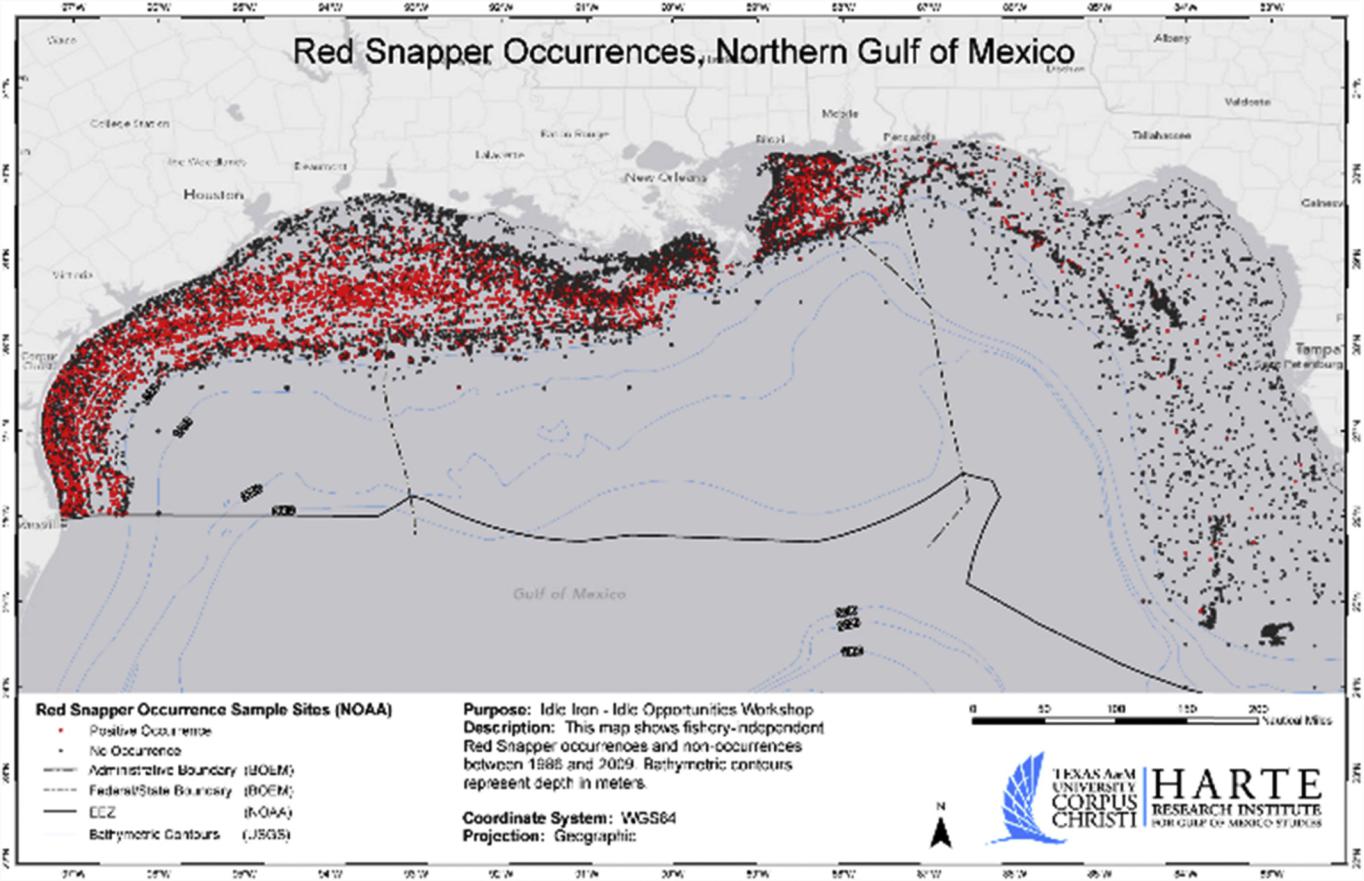
1. the harvest restrictions from fisheries management have been largely successful in tempering the take and ending over-fishing; and 2) the increase in artificial-reef habitat and platforms has dramatically in-creased the potential expansion of red snapper populations ([Shipp and](#page33) Bortone, 2009).

*3.1. Louisiana Artificial Reef Program*

With great anticipation Louisiana awaited NARP. In the mid-1980's, unlike Alabama or Texas, Louisiana did not have a previously estab-lished artificial reef plan. The Louisiana Fishing Enhancement Act (LFEA) was signed into law in 1986, creating the Louisiana Artificial Reef Program (LARP). Both LFEA and LARP were a collaboration be-tween the LDWF, Louisiana State University, the state legislature, the offshore oil and gas industry, and powerful fishing organizations. Offshore and inshore shrimping, using otter trawls, is a great domestic tradition and a highly lucrative industry for coastal Louisiana. However, trawling the seafloor and the structures of artificial reefs compete for space; presence of one precludes the other.

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**Fig. 7.** Occurrence of red snapper, *Lutjanus campechanus*, in the Gulf of Mexico. Fisheries-independent red snapper occurrence (red = positive occurrence) and non-occurrence (black = negative occurrence) between 1986 and 2009. Bathymetric contours in meters (McLaughlin, 2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 1**

Oil and gas petroleum production platforms installed, removed, and reefed.

Source: Peter, pers. Comm., 2017.



|  |  |
| --- | --- |
| Gulf of Mexico Federal Oil and Gas Platforms 1942–2016 |  |
| Total Number Platforms Installed[a](#page11) | 7074 |
| Total Number Platforms Removed | 4959 |
| Total Number Platform Jackets Reefed | 515 |
| Percent Platforms Reefed During Decommissioning | 11.19% |



1. Includes about 50 floating platforms and subsea templates that are not reefed.

The LFEA (Act 100) became law during the 1986 regular legislative session. The Louisiana Artificial Reef Plan, mandated by Act 100 and prepared under the guidance of LFEA, outlined steps for implementing the legislation that created the LARP in 1986 (Wilson, et al. 1987).



Working with many interested parties including fishing organizations, LARP developed nine artificial reef planning areas on the federal OCS for RtR proposals along its coast and has accepted over 500 decom-missioned platforms as reefs (Table 1.) There are also 17 special arti-ficial reef sites established under the State's artificial reef plan that are outside of the planning areas and that have space available for more oil and gas structures to be reefed. LARP has designated offshore waters deeper than 400 ft as a deepwater artificial reef planning area (Kasprzak, 1998). To date, eight platform structures have been reefed in deepwater. Recently Louisiana designated two additional sites for a total of 11 designated artificial reef planning areas and is currently working with the TPWD to develop two new artificial reef planning areas off the coast of Corpus Christi (Fig. 8) (LDWF, 2017). Approxi-mately 70% (nearly 5000) of the Gulf petroleum structures were in-stalled in less than 100 ft of water, but only 1% of reefed platforms are located within this depth zone where much of the offshore bottom

**Fig. 8.** General distribution of artificial reefs created from decommissioned platforms, RtR, in the Gulf of Mexico.

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**Table 2**

Percentage of reefed platforms by water depth.

Source: Peter, pers. Comm., 2017.



Gulf of Mexico Rigs-to-Reefs for all Gulf States 1986–2016



Percent Reefed by Water Depth



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Water Depth Range | 515 | 0–100 ft. | 101–150 ft. | 150–200 ft. | > 200 ft. |
| Platform Jackets Reefed | 1.06 | 18.37 | 41.62 | 62.11 |



trawling occurs. Greater than 80% of decommissioned reefed platforms have been reefed in water depths greater than 150 ft (Table 2) ([Peter,](#page32) pers. comm., 2017). In these depths, there is limited bottom trawling, less petroleum infrastructure, and, therefore, fewer space-use conflicts.

At the final stage of jacket donation, which involves change of ownership and transfer of title through deed of ownership from in-dustry to Louisiana, into the artificial reef program, 50% of the savings from reefing versus the cost estimate for total removal and site clear-ance is contributed to the state. The state does the computation for the estimated savings. The state of Louisiana has previously determined where and how the funds will be used though its artificial reef planning and legislation. Most often the funds go to the agency within which the fisheries and fishing oversight is located.

*3.2. Texas*

In the 1980's, Texas was the second Gulf state to initiate an artificial reef program. Currently almost all of these reefs are based on oil and gas platforms (Stephan et al., 1990; TPWD, 2017). In 1989, the Texas Legislature directed TPWD to promote, develop, maintain, monitor, and enhance the artificial reef potential in state and federal waters adjacent to Texas to enhance fishery resources and commercial and recreational fishing opportunities. Texas collaborates with a wide range of stake-holders including conservation organizations, corporations, commu-nities, and sportsmen to create and maintain more than 4000 acres of artificial reef structures within Texas Gulf waters. Thirteen ships have been intentionally sunk as part of the Texas Artificial Reef Program, the largest being the USTS Texas Clipper., a 473-ft long vessel. There are 82 artificial reef sites offshore Texas with 18 large areas designated for RtR ([TPWD, 2017](#page33)) (see [Fig. 8](#page11)).

RtR are the heart of the Texas Artificial Reef Program as is the 50% cost-savings contribution used to develop, maintain, and monitor its program. Texas favors the partial removal method for their RtR. According to the Texas Program, partially removed, reefed-in-place platform structures make ideal reefs because they are environmentally safe, are constructed of highly durable and stable material, and already support a thriving reef ecosystem since many of the structures have been in the water for 30 years or longer (TPWD, 2017).

*3.3. Mississippi*

The first known efforts at artificial reef construction off the Mississippi coast took place in the 1960's with the deployment of au-tomobile bodies in offshore waters near the barrier islands. In 1972, a unified effort between state and federal agencies began to construct artificial reefs. This effort was facilitated by Public Law 92–402 for marine life conservation, which made available numerous World War II Liberty Ships from the National Defense Reserve Fleet for the creation of artificial reefs in coastal environments. The DOI has designated the federal OCS waters off the State of Mississippi as a reef planning area. Eight Mississippi reef sites have been developed using 12 obsolete oil and gas platforms either partially removed in place or towed-and-placed in the designated areas. (BSEE, 2017a; MDNR, 2017).

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*3.4. Alabama*

Alabama has the largest artificial reef program in the U.S. and one of the largest artificial reef programs in the world. The natural seafloor off Alabama is predominately flat sand/mud. This bottom type attracts few fish that are either commercially or recreationally valuable. However, Alabama fishermen have found that if vertical relief is created on this bottom, many sought-after reef fish such as snappers and groupers will be produced. Alabama calls itself the “Red Snapper Capital of the World” (ADNR, 2017). Distribution of red snapper within the Gulf of Mexico shows a high concentration close to the Alabama coast (see Fig. 7). On-going research within Alabama's artificial reef general permit areas indicates that juvenile red snapper recruit to artificial reefs, age with the reef, and recruit to the fishery at an appropriate size. It is believed that Alabama State artificial reefs function similar to natural reefs ([ADNR, 2017](#page29)).

Alabama's artificial reef building program started in 1953 when the Orange Beach Charter Boat Association asked for the authority to place 250 car bodies off Baldwin County, Alabama. This proved to be very successful and in the years since many different types of materials have been placed offshore. These have included additional car bodies, cul-verts, bridge rubble, barges, boats, and planes. In 1974, in an early example of state/federal cooperation for artificial reefs, “ghost-fleeted" liberty ships were sunk in five locations off Mobile and Baldwin Counties in 80–93 feet of water. And in 1993, 100 M-60 surplus army tanks were sunk in a special reef area ([ADNR, 2017](#page29)).

In late 1997, the USACE authorized an expansion of Alabama's ar-tificial reef construction areas to allow for greater freedom in reef placement and greater variety in depth. The combined area for all reef permit zones now encompasses approximately 1260 square miles. At the same time, the protocol for reef construction was modified. This modification limited the types of materials for the construction of ar-tificial reefs. Obsolete platform jackets meet all the material criteria and six jackets have been either partially removed in place or towed-and-placed offshore Alabama. The state has also approved several more RtR and is awaiting their decommissioning from oil and gas production and eventual placement into their Artificial Reef Program (Rainer, 2017).

*3.5. Florida*

Artificial reef development in Florida began in the late 1970's when increased numbers of state funded and sponsored projects were con-ducted and more dependable funding sources were established. The first RtR conversion took place in Florida in 1979 –1980 with the re-location of an Exxon experimental subsea template from offshore Louisiana to a permitted artificial reef site off Florida (Reggio, 1987a, [b](#page33)).

Florida has one of the most active artificial reef programs among the

14 Gulf and Atlantic coastal states involved in reef development. Starting in the 1940s through August 2012, more than 2700 planned public artificial reefs have been placed in state and federal waters off these counties. Most of the artificial reef development has taken place since the inception of the Florida Artificial Reef Program (FARP) in 1982. FARP is the only state program that is not exclusively run at a state agency level. Because of the extent of coastline and statewide involvement in reef activities, the Florida Department of Wildlife and Conservation (FWC) program continues a cooperative partnership with local coastal county governments. Thirty-four of Florida's 35 coastal counties spread along 8426 miles of tidal coastline (1200 miles fronting the Gulf of Mexico and Atlantic Ocean) are, or have been, involved in artificial reef development. Today, some local coastal cities, universities and qualified nonprofit corporations also work directly with the FWC in artificial reef development and monitoring activities (FWC, 2017). Local coastal governments hold all of the more than 300 active artificial reef permits off both Florida coasts. About half of these sites are in federal waters. Fishing clubs, nonprofit corporations, and interested

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private individuals work through their local governments as the liable permit holders to provide input into public reef building activities ([FWC, 2017](#page30)).

There is no oil and gas production or platforms offshore Florida in either state or federal waters. All RtR are tow-and-place (see Fig. 6a) over great distances from offshore Louisiana or Texas. The present cost of transportation precludes any savings from the reefing option and RtR is now rare off Florida. Today, approximately 70–100 public artificial reefs are constructed annually off Florida using a combination of fed-eral, state and local government and private funds (Williams, 2006). A total of five platforms have been donated to the State of Florida on behalf of fishery management.

**4. Rigs-to-reefs beyond the United States**

The earliest relevant international law, the 1958 Geneva Convention on the Continental Shelf, required the complete removal of disused marine infrastructure. But the United Nations Convention on the Law of the Sea states that decisions should take into account “generally accepted international standards established … by the competent international organization.” In this case, it is again, the IMO. The IMO's 1989 guidelines allowed structures to be left in place on a case-by-case basis (UN, 1989). Due consideration must have been given to safety of navigation, rate of deterioration, risk of structural move-ment, environmental effects, costs, technical feasibility and risks of injury associated with removal. The guidelines also refer to the possi-bility of “new use or other reasonable justification” for *in situ* disposal. This opened up the potential to convert an obsolete oil or gas platform into a dedicated artificial reef (Salcido, 2005). However, this loophole did not continue for operations in the North Sea or Europe (see below).

The United States government and most of the individual coastal states have been involved in developing artificial reefs for over a hundred years. Overseas artificial reef planning has moved toward a more integrated program of research and development for resources enhancement, conservation, and management in order to attain both short and long-term goals (Baine, 2001).

*4.1. Asia*

Artificial reefs have been constructed outside the United States for many centuries, especially in the western Pacific. By far, Japan has always been the global leader in enhancing fishery productivity through the design and manipulation of both species-specific and gen-eral artificial reefs and their reef designs have undergone steady mod-ification with experience. Japan continues an impressive artificial reef program, on which it spends millions of dollars per year. In 1976, concerned over the declaration of the 200-mile exclusive economic zones by a number of global nations, which threatened to reduce the fish catches of Japan's far-seas fleet, the government made a major commitment to increase fish production in its own coastal waters. Japan anticipated that artificial reefs would increase fish catches and initiated a six-year program with about $40 million a year to be spent on construction and deployment of artificial reefs. In 1982, a second six-year program continued the first six-year program with annual funding for artificial reef construction and deployment at about $50 million a year ([Polovina, 1985](#page32); [Polovina and Saiki, 1989](#page33)).

In recent years, continued funding has been directed toward large-scale artificial reef projects. They are installed in areas where there is no existing fishery with the objective of creating new fishing grounds. The national government now funds about 50% of the costs of the smaller projects, those which are used to enhance existing fishing grounds, and about 70% of the costs of the larger projects. The re-mainder of the funding comes from prefectural governments with a small contribution from fishing villages and cooperatives. Japan's ar-tificial reefs are designed for either aquaculture or commercial fishing. The Japanese develop different types of artificial reefs depending on the

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species they wish to harvest. They have made much of their information available to artificial reef proponents in other countries including the U.S. Japanese experts consider oil and gas structures ideal reef mate-rials very similar to the fabricated structures that the Japanese spend a great deal of money to build ([Bohnsack and Sutherland, 1985](#page30)).

The coastal zones of most nations in the Association of Southeast Asian Nations (ASEAN) are subjected to increasing population and economic pressures brought about by a variety of coastal activities, notably, fishing, coastal aquaculture, waste disposal, oil drilling, tanker traffic, rural construction, and industrialization. This situation is ag-gravated by the expanding economic activities that attempt to uplift the standard of living of coastal people within ASEAN (White et al., 1990). The ocean water of southeast Asia hosts over 1000 offshore oil and gas installations (with some estimates as high as 1500) about a third of which are probably several decades old (Liu et al., 2016). These off-shore platforms hug the coasts of the Philippines, Vietnam, Cambodia, Thailand, Malaysia, and Indonesia.

Many of these offshore installations are located in close proximity to maritime boundaries, adding to transboundary tensions in the region (Lyons et al., 2013; Liu et al., 2016). Realization of the age of platforms and ultimate responsibility of facility removal led to a two-year mul-tidisciplinary discussion at the National University of Singapore be-tween ocean law and policy researchers, marine biologists, and offshore engineers on offshore decommissioning, which then led to global and regional discussions on RtR and participation in numerous regional conferences and workshops ([NUS, 2017](#page32)).

In Malaysia, artificial reefs were established in the early 1970s where they started as local initiatives of the small-scale fishermen on the east coast. Government-sponsored development of reefs was in-itiated by the Fisheries Research Institute at Penang in 1975 with the placement of reefs made of used tires. Since then, reef development has progressed steadily with about 60 sites set aside for artificial reef pla-cement in Peninsular Malaysia and 17 in Sabah and Sarawak. In the past, 90% of the reefs were made of concreted tires while the rest were of concrete culverts, scrap vessels, and a few decommissioned platforms (White et al., 1990). More recently, the Department of Fisheries Ma-laysia also uses derelict and confiscated fishing vessel, concrete, poly-vinyl chloride pipes, ceramic pipes, as well as decommissioned oil platform as new materials for construction of artificial reefs. In Ma-laysian waters, there has been one major RtR program implemented to date. In 2005, the Baram-8, now well known as the Kenyalang Reef, was the first RtR development in the South China Sea. The conversion of Baram-8 to an artificial reef was requested by the local fisheries de-partment. The toppled structure was relocated by the tow-and-place method to a shallow water depth of around 60 ft offshore Miri, Sarawak ([Jagerroos and Krause, 2016](#page31); [Umar et al., 2016](#page33)).

The nation of Brunei Darussalam, along the northwestern edge of Borneo facing the Malaysia and South China Seas, has had a coastal RtR policy since 1988. Offshore operator Shell Brunei Petroleum has towed decommissioned platform jackets to two designated artificial reef areas located away from shipping lanes. Brunei has used these obsolete oil and gas platforms in their coastal fisheries enhancement program and has requested additional platforms from neighboring counties where offshore facilities are being decommissioned (Awang, 2013). Since 1988, at least seven large platforms have been used as artificial reefs with the most recent reported RtR project occurring in 2004. Mon-itoring of RtR by Brunei scientists within the past five years has shown extensive populations of both soft and hard corals on the sunken plat-forms with associated fish species from small forms to large, juveniles to adults, and transient to resident (Awang, 2013). Similar research in the Gulf of Mexico has confirmed that reef-building hard corals will settle and grow profusely on platforms (Sammarco, 2013). Many countries in southeast Asia have seen degradation of natural reefs from human ac-tivities such as indiscriminate trawling and intentional overfishing (NUS, 2017). Artificial reefs that have included portions of decom-missioned platform jackets have been intentionally placed in select

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zones to deter and prevent trawling of reefs and nearshore protected areas in Peninsular Malaysia, Sabah, Burnei Darussalam, and Sarawak ([Awang, 2013](#page29); [White et al., 1990](#page33)).

Since the early 1980s, Thailand has developed and implemented artificial reef programs to enhance fisheries production in shallow, coastal areas. As the many oil production platforms age, industry and government is evaluating potential RtR options within the Gulf of Thailand. An assessment of RtR feasibility evaluated selected reefing sites and selected platforms with regard given to the physical marine environment and condition of the jacket material. Through this eva-luation, it was determined that converting selected platforms into reefs would likely contribute to the overall productivity of the Gulf of Thailand’s marine ecosystems. Higher fisheries productivity in turn is expected to generate both local and regional socio-economic benefits and aid in ecosystem rehabilitation through the prevention of indis-criminate trawling (Great Ecology, 2018).

*4.2. Australia*

Australia's offshore oil and gas industry is relatively new compared to other areas of the Pacific, Europe, or the U.S. As a result, the fate of decommissioned offshore infrastructure is still an emerging issue. However, the Australian oil and gas industry is anticipating a large increase in decommissioning activity in the relatively near future (Noetic, 2015). A pragmatic approach to the management of decom-missioning activities may facilitate better management of the decom-missioning of pipelines, wells and subsea equipment, with flexibility to address decommissioning on a case-by-case basis. Similar to many other nations, Australia's current regulations favor complete removal. How-ever, the National Offshore Petroleum Safety and Environmental Management Authority is exploring the possibility of supporting an *in situ* decommissioning policy. This would involve amending the law toallow certain new uses, as well as to resolve issues of decommissioning standards, safety and risk, liability and ownership. Developing an Australian version of the “RtR” policy would require input from en-gineers,marine scientists, environmental managers, oil and gas econo-mists, lawyers and others, to work out precisely what is possible and preferable in different locations (Gourvenec and Techera, 2016).

*4.3. North Sea and Europe*

Consideration of the decision to allow an offshore structure, in whole or part, to remain on the seafloor, has been considered through a number of international agreements and United Nation resolutions since, at least, 1982 (UN Convention on the Law of the Sea, 1982; [UN,](#page33) [1989](#page33), [2018](#page33)). Although these declarations and rules are not signed by all members nations they recommend that abandoned or disused structures be removed to safeguard navigation, the marine environment, and allow for multiple-uses of the seafloor. The guidelines and rules also allow for a “reasonable justification” on a case-by-case basis for a new use to be determined by the coastal state with jurisdiction.

Additionally, European attention to decreasing real or potential pollution from exploration and exploitation of the Mediterranean con-tinental shelf seafloor and subsoil was addressed through the Barcelona Convention in 1994 (European Commission, 2016). This broad-ranging document was first adopted in 1976 and amended in 1994–95. Its aim is to prevent and decrease pollution from ships, aircraft, and land-based sources and includes but is not limited to dumping, run-off, and dis-charges. The 1995 update specifically covers a wide range of subsea-floor exploration and exploitation activities and the removal of aban-doned or disused offshore installations among its many other subjects.

A large concentration of offshore platforms lies within the North Sea. These platforms belong to multiple international companies and are located within national waters of several countries including the United Kingdom, Norway, Netherlands, Germany, and Denmark (Verbeek, 2013). It has been over 20 years since an oil company

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attempted to reef an offshore structure in the North Sea (Shell, 2008). In the mid-1990s, the Brent Spar was a large, floating North Sea oil storage and tanker loading buoy within waters of the United Kingdom (UK). After completion of a pipeline from the Brent oilfield to shore, the Spar was no longer needed. The UK arm of Royal Dutch Shell evaluated decommissioning options from shore-side to deepwater disposal. The British government as well the Oslo and Paris Commission agreed with numerous scientists and specialists that disposing of the Brent Spar in the deep ocean would have negligible environmental effects ([Shell,](#page33) [2008](#page33)). Having been an oil storage facility, the Brent Spar could not be completely sanitized and cleaned, and oily sludge and silt remained coating the inside of the structure (Shell, 2008). Greenpeace organized a worldwide, high-profile media campaign against the plan; Greenpeace boarded and occupied Brent Spar in 1995 and claimed that several thousand tons of oil were on the structure (a claim later proved false). European governments issued formal objections to ocean disposal and influential companies in the offshore construction sector who stood to make money from onshore dismantling supported Greenpeace ([Molloy,](#page32) [2017](#page32)).

Shell Oil was boycotted in Germany, and across much of Northern Europe, violence threatened against staff, and one service station was riddled with bullets. Quickly, Shell decided that due to falling sales and a drop in share price, their position was no longer tenable, and with-drew their plan to sink the Brent Spar (Molloy, 2017). It was towed to Norway and dismantled in a Norwegian shallow water fjord. A large part of the base was reused in a harbor extension at Stavanger in Norway. While the Brent Spar was being dismantled, quantities of an endangered cold-water coral were found growing on the surface of the submerged spar (Bell and Smith, 1999). Experts suggested leaving ex-ternal surfaces of such structures on the sea bed in the future, but Greenpeace opposed this plan. Shell admitted to have ‘unwittingly’ failed to communicate their plans sufficiently to the public and that they had severely underestimated the strength of public opinion. The company seemed to have failed to understand environmental awareness in Europe and failed to recognize that the issue was not restricted to the United Kingdom – instead the impact reached all Europe and beyond ([Molloy, 2017](#page32)).

Greenpeace's own reputation also suffered during the campaign, when it had to acknowledge that its assessment of the oil remaining in Brent Spar's storage tanks had been grossly overestimated. Greenpeace admitted they made mistakes. The overestimation of the contents da-maged the credibility of Greenpeace in their wider campaigns; they were criticized in an editorial column in the scientific journal ‘Nature’ for their lack of interest in facts ([Molloy, 2017](#page32)).

At the time, the North Sea offshore industry did not envisage that the case of the Brent Spar would set a precedent for disposal of facilities in the future; however, the incident had a significant influence in shaping a decision of the Protection of the Marine Environment of the North-East Atlantic (OSPAR), which was opened for nation signature at the Oslo and Paris Commissions in 1992 (Verbeek, 2013). Member nations that signed the agreement (but not the UK or Norway) agreed, soon after the Bret Spar incident, that offshore oil facilities should be disposed of onshore and prohibited submerging or leaving in place, totally or partially, disused offshore facilities (Molloy, 2017). Later in the decade, the OSPAR Decision 98/3, signed by the UK and Norway, addressed ocean dumping and, adopting a preventive approach, in-cluded the disposal of disused offshore installations as dumping within the definition of pollution (Warbrick and McGoldrick, 1998). Secon-darily, OSPAR 98/3 encourage the recycling and reuse of offshore materials. Decision 98/3 does include a few exceptions, such as a concrete caisson base used to anchor a platform or certain steel plat-form footings, that could be left in place if allowed under a special permit and after studying the disposal assessment, the appropriate na-tional authority is satisfied that disposal at sea is preferable to recycling or reuse on land. Determining that disposal at sea is preferable would likely require an extensive evaluation of risks projected for disposal

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options including reuse, recycling, or ocean disposal, that would fully consider potential adverse effects on marine environment, terrestrial environment, human health, technical and practical feasibility, strict economic considerations, and latent conflicts with multiple-users.

Oil production has decreased from the North Sea as many offshore operators have produced for 40–50 years from reservoirs now dwind-ling and uneconomical to continue production. Offshore oil production platforms everywhere are overbuilt strong structures proven to with-stand hurricanes, typhoons, collision, and earthquakes. Perhaps espe-cially true in the North Sea, decommissioning the enormous platforms will be a substantial, long-term, expensive, and technically demanding venture. With OSPAR Decision 98/3 in effect, adherence to the agree-ment requires full removal of oil platforms with onshore disposal at the end of their economic lives. Over the next 35 years or so, about 470 platforms and 10,000 km of steel pipeline will need to be removed from the North Sea. Within those numbers, according to the decom-missioning forecasts of the UK's Oil and Gas Authority, 109 platforms (95 of them in the UK sector, 14 in the Norwegian sector) will go be-tween now and 2025 (Jack, 2017). Given, the massive amount of work that is expected to take place before 2025, a number of industry and public discussions to revisit OSPAR and/or to reconsider possible reefing (at least partially) have taken place both in the UK and the U.S. However, it would be unusual for the UK government to disregard OSPAR and there is no indication that this could occur. In any event there is need for a large, skilled workforce, and those skills could be developed within the UK for North Sea platform decommissioning and provide economic security for another generation in the oil fields.

**5. The California experience**

*5.1. Artificial reef program*

California began a program of artificial reef development and study in 1958. Construction of artificial reefs was part of the California Nearshore Sportfish Habitat Enhancement Program, likely with some federal funds from the Dingell-Johnson/Wallop Breaux Act of 1950, Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777k, 64 Stat. 430), as amended, for the restoration or enhancement of sportfishing habitat along the southern coast. The state was experiencing steady increases in population, especially in the southern coastal counties, and a simultaneous increase in sportfishing for recreation and subsistence purposes. Reef fish species were the most highly prized, and existing fishable reefs were, and still are, heavily fished year-round. In response, the state began a program to build more coastal reefs and enhance existing fishing piers and jetties with more materials spread on the seafloor ([Lewis and McKee, 1989](#page31)).

Some of the early projects were aimed at determining what mate-rials were best suited for building artificial reefs that would both attract and hold marine organisms, particularly the popular sport fish species. The first two reefs in coastal California were constructed of donated materials. The operators of Paradise Cove Landing in northern Santa Monica Bay contributed 20 old automobile bodies to the CDFG. These old cars were placed in 50 feet of water at Paradise Cove in May 1958. In September 1958, six old wooden streetcars were placed in 60 feet of water near Redondo Beach. The donated streetcars were sunk at the site by the U.S. Navy, which towed them from Los Angeles Harbor ([Carlisle](#page30) [et al., 1964](#page30)).

The car body and streetcar artificial reefs were designed to test the effectiveness of such structures in attracting fishes. They proved very successful. CDFG marine biologists, using scuba, carried out extensive observations of the reefs for several years. Fishes began to aggregate around the Paradise Cove car body reef within hours of construction and kelp settled upon the car bodies and grew into enduring stands rather quickly. The diversity and density of fishes continued to increase at both Paradise Cove and Redondo reefs over the 3-year period that they were surveyed (Lewis and McKee, 1989). Car bodies and streetcars

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have a relatively short life of less than 10 years before collapsing into low relief rubble, which presents the most serious drawback to the use of these materials ([Carlisle et al., 1964](#page30)).

The success of these artificial reefs in attracting and concentrating fishes encouraged the CDFG to initiate a program to investigate the cost-effectiveness and practicality of various reef building materials. To determine the best materials for the least investment, three separate reefs were built in the early 1960s at Malibu, Santa Monica, and Hermosa Beach in 60 ft of water, each with four different materials; car bodies, a streetcar, quarry rock and concrete boxes. These reefs were built on relatively barren sand areas remote from productive, natural rocky substrate. Observations over several years indicated that concrete boxes were the most effective in attracting fishes, with quarry rock a very close second. Quarry rock, at half the cost of the fabricated con-crete boxes proved to be the most cost-effective material. While sub-sequent studies have further substantiated the value of quarry rock due to its potential for colonization by, and production of, reef organisms, the availability of surplus concrete from port side demolition projects has proven to provide both a cost effective and productive material as well ([Lewis and McKee, 1989](#page31)).

Since the 1960s many artificial reefs have been intentionally built to enhance nearshore fishing opportunities off southern California. Southern California Edison (SCE), a major utility company, operates a number of coastal power plants including the San Onofre Nuclear Generating Station (SONGS), which uses a seawater intake and pass-through system for cooling. It was understood that the intake could entrap small fishes and the hot water exiting could negatively affect nearby kelp beds. To address this concern and to develop more effective reefs for enhancing sport fish populations, CDFG and SCE began a co-operative project leading to construction of Pendleton Artificial Reef (PAR). Studies were conducted by CDFG biologists to evaluate the PAR's potential for enhancing marine resources. In fall 1980, PAR, a “state-of-the-art" quarry rock reef, was constructed in northern San Diego County. Intensive studies were conducted at PAR from 1980 to 1986, by CDFG biologists and others, to learn how to more effectively enhance stocks of marine fishes, shell fishes, and plants using artificial reefs.

In 1990, the Carlsbad Artificial Reef was constructed from quarry rock, in anticipation of the re-opening of the mouth of Batiquitos Lagoon. In 1991, the International Artificial Reef was constructed from quarry rock in deeper water (165 ft) near the international border with Mexico. Bolsa Chica Artificial Reef off Orange County was increased at about the same time from 10,000 tons to 120,000 tons and then to 160,000 tons of materials. During 1992, 9000 tons of broken concrete rubble was scattered over 11 acres at the Mission Beach Artificial Reef off San Diego. In less than one year this reef supported a large kelp bed. The kelp remained ten years later. This represented the first time a kelp bed had been sustained on a long-term basis on an artificial reef in southern California.

Special shipwreck reefs have been built off the coast of southern California, mainly for scuba diving opportunities. Wreck Alley, begun in 1987, is located a few miles off the beach in Mission Bay, San Diego. In addition to the artificial reefs created by the wrecks, the area also includes a National Oceanographic Communication tower and the re-mains of the old Ingraham Street Bridge.

During the fall of 1999, SCE built an experimental mitigation reef system off San Clemente, covering 22 acres of bottom. The project, now called the Wheeler North Reef, was built to use artificial reefs to restore historic reef habitat that has been buried by sediments. The ultimate purpose was to mitigate for lost kelp production caused by the outflow of SONGS. This reef now supports extensive kelp canopy over most of its 22 acres and demonstrates that artificial reefs can mitigate some lost functions of natural rocky reefs (Reed et al., 2006). The construction of artificial reefs is now accepted as a category of accepted mitigation for coastal harm offshore California.

Off some of the most valuable property in Los Angeles with some of

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the most stunning views of the Pacific lies the Montrose seafloor su-perfund site. Many thousands, if not millions, of fish and hundreds of acres of fish habitat were damaged along the offshore Palos Verdes shelf due to waste discharge of contaminated effluent from the manufacture of DDTs and PCBs by Montrose Chemical Corporation beginning after WWII through the mid-1980s. The contamination moved up through the food-web from the sediments through fish to eventually affect all layers of the system including recreational and commercial fish and fisheries. The Montrose Settlements Restoration Program is responsible for identifying projects that restore important fish habitat in the vicinity of the Palos Verdes Shelf. The proposed projects include restoration of existing reefs using artificial materials as well as construction of new artificial reefs at multiple sites (NOAA, 2017b).

*5.2. State and federal oil and gas leasing*

Many petroleum industry historians trace the origin of offshore drilling and production to California. Offshore drilling for oil began off the coast of Summerland, California, just south of Santa Barbara, in 1896. Local tar seeps, both on the beach and oozing out of the ground in nearby Ventura County foothills, demonstrated that petroleum existed beneath the area. In fact, the Chumash indigenous people were known for using asphaltum from seeps to waterproof their tomol boats and containers for thousands of years. Early European settlers refined and distilled the seeping tar for use in lamps. In the late 1800s and early 1900s, the most productive oil wells marched seaward from the foot-hills in southern California across the beach and soon moved onto wooden piers extending more than a quarter-mile over the ocean. Using the same techniques as then used on land, steel pipes were pounded hundreds of feet below the seabed, water was then pumped out of the well-conductor pipes, and the same equipment that was used on dry land could be used to drill a well through the conductor. The hunt for oil close to shore ultimately produced only a modest yield compared to fields much further inland in Kern and adjacent California counties (McGinnis et al., 2001; Salcido, 2005; Schempf, 2004). However, geologists at the time speculated that oil bearing formations extended westward under the Pacific Ocean. Indeed, the oil rich Monterey For-mation which holds most of California's known oil resources and is of major economic and energy importance extends well offshore.

In 1921, the California State Legislature created the first state seabed (tidelands) oil and gas leasing program. Between 1921 and 1929, approximately 100 permits and leases were issued and over 850 wells were drilled in state waters offshore Santa Barbara and Ventura Counties. In 1929, the Legislature prohibited any new leases or permits. In 1933, however, the prohibition was partially lifted in response to an alleged theft of tidelands oil in Huntington Beach off southern California. The first strictly offshore oil field in California was the Belmont Offshore Field, discovered in 1948, but not produced until 1954, when the man-made Belmont Island was built in 40 ft of water, about a mile and a half offshore, to hold drilling and production equipment (Smith and Schambeck, 1966). The first true offshore oil production platforms, Helen and Herman, were installed in the late 1950s in water depths of 100 and 85 ft, respectively, offshore Gaviota, California ([Culwell and McCarthy, 1997](#page30)).

Leasing California state tidelands is now controlled by the California State Lands Commission (SLC), which halted further leasing of state offshore tracts after the Santa Barbara oil spill in 1969 (Smith and Schambeck, 1966). The Santa Barbara oil spill occurred in January and February 1969 in the Santa Barbara Channel, near the city of Santa Barbara in Southern California. It was the largest oil spill in U.S. or state waters at the time, and now ranks third after the 2010 Deepwater Horizon and 1989 Exxon Valdez spills. It remains the largest oil spill to have occurred in the waters off California. The source of the spill was a blow-out on January 28, 1969, 6 miles (10 km) from the coast on Union Oil's Platform A. Within a ten-day period, an estimated 80,000 to 100,000 barrels of crude oil spilled into the Channel and onto the

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beaches of Santa Barbara and Ventura Counties in Southern California, fouling the coastline from Goleta to Ventura as well as the northern shores of the four northern Channel Islands. The spill had a significant impact on marine life in the Channel, killing at least 3500 sea birds, as well as marine animals such as dolphins, elephant seals, and sea lions. The public outrage caused by the spill, which received prominent media coverage in the U.S. and visit from the then U.S. President, Richard Nixon, resulted in numerous pieces of federal and California state en-vironmental legislation within the next several years, legislation that forms the legal and regulatory framework for the modern environ-mental movement in the U.S ([Clarke and Hemphill, 2002](#page30)).

The first of 10 federal offshore lease sales for California was held in 1963. The federal government has had no new lease sales for offshore California since 1982. In 1994, the California legislature codified the ban on new leases by passing the California Coastal Sanctuary Act, which prohibited new leasing of state offshore tracts. Offshore drilling has continued from existing platforms in state and federal waters ([SLC,](#page33) [2017](#page33)). There are approximately 26 offshore oil and gas lease agree-ments in California state waters, between the state and various oil and gas industry owner/operators, which are what remain of those origin-ally issued. These leases were issued prior to the 1969 oil spill from Platform A in federal waters off Santa Barbara County, and some pre-date the formation of SLC. Between 2010 and 2014, the bulk of the approximately $300 million generated annually for the state's General Fund from oil and gas agreements was from these offshore leases ([SLC,](#page33) [2017](#page33)).

The controversy over the development of California's oil and gas resources, the most valuable of which are located in and adjacent to state water has been going on since the first legislation permitting such development in 1921. Since the spill in 1969, the concern about po-tential environmental damage resulting from a spill and concern with aesthetics and viewshed has outweighed the desire to generate revenue from new offshore oil development. While the SLC has not issued a new offshore oil development lease in nearly 50 years, the leases issued prior to 1969 continue to generate significant revenue to the state, as they have for 80 years. To ensure that the public fully benefits from existing development, the Commission operates a rigorous financial auditing program to ensure that California receives all the money it is owed from the development ([SLC, 2017](#page33)).

There are 27 offshore platforms in the Southern California Bight, 23 on the OCS and four in state waters (Fig. 5 and Table 3). All platforms are located off the coasts of Orange, Los Angeles, Ventura, and Santa Barbara Counties (Fig. 9). The 23 federally regulated platforms on the OCS are at least 3 miles from shore with depth ranging to 1200 ft, and only one stands in a water depth less than 150 ft. Pacific platforms have individual names starting with a designated letter by zone per USCG specifications. The four state regulated platforms (Holly, Eva, Esther, Emmy) are located within 3 miles of shore in state waters. There are also four large man-made islands built for oil production off Long Beach, known as the Long Beach Unit, and one small man-made island, Rincon Island, located off Rincon Beach in Ventura County.

*5.3. Decommissioning oil-related structures in state waters*

The Aminoil Ellwood Pier is located west of Goleta, California, and is one of several oil production pier facilities still remaining in California. This pier is no longer a producing facility and is now used for crew and material transfer. The pier was made of steel H-pile col-umns supporting a timber deck that extended 100s of feet seaward terminating in five large concrete caissons which were connected by steel trusses and covered with a continuous timber deck. Each caisson supported multiple oil production wells that were decommissioned in the late 1970s. The extended section of pier that was not needed for supply boat and shore operations and the caissons were decommis-sioned in 1979. The timber deck was removed and the piles were cut off by divers below mudline. The concrete caissons were demolished using

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**Table 3**

List of standing, fixed petroleum platforms in both state and federal waters as of 2018, their names, location, water depth, and year of installation offshore California. Names are given by agreement and initial letter determined by USCG coastal area designation.

Source: BSEE, 2017c; Love et al. (2003); Martin and Lowe (2010).



|  |  |  |  |
| --- | --- | --- | --- |
| Name | General Offshore Location and | Water | Year of |
|  | Distance from Shore | Depth | Installation |
|  | In Miles | In feet |  |
| A | East Santa Barbara Channel | 190 | 1968 |
| B | 5.8 | 190 | 1968 |
| East Santa Barbara Channel |
| C | 5.7 | 193 | 1977 |
| East Santa Barbara Channel |
| Edith | 5.7 | 161 | 1983 |
| San Pedro |
| Ellen | 8.5 | 266 | 1980 |
| San Pedro |
| Elly | 8.6 | 256 | 1980 |
| San Pedro |
| Emmy | 8.6 | 46 | 1963 |
| Huntington Beach |
| Esther | 1.9 | 29 | 1990 |
| Seal Beach |
| Eureka | 1.9 | 699 | 1984 |
| San Pedro |
| Eva | 9.0 | 56 | 1964 |
| Huntington Beach |
| Gail | 2.9 | 740 | 1987 |
| Eastern Santa Barbara Channel |
| Gilda | 9.9 | 208 | 1981 |
| Eastern Santa Barbara Channel |
| Gina | 7.8 | 97 | 1980 |
| Eastern Santa Barbara Channel |
| Grace | 3.7 | 318 | 1979 |
| Eastern Santa Barbara Channel |
| Habitat | 10.5 | 293 | 1981 |
| Central Santa Barbara Channel |
| Harmony | 7.8 | 1200 | 1989 |
| Western Santa Barbara Channel |
| Harvest | 6.4 | 676 | 1985 |
| Santa Maria |
| Henry | 6.7 | 172 | 1979 |
| Eastern Santa Barbara Channel |
| Heritage | 4.3 | 1075 | 1993 |
| Western Santa Barbara Channel |
| Hermosa | 8.2 | 604 | 1985 |
| Santa Maria |
| Hidalgo | 6.8 | 430 | 1986 |
| Santa Maria |
| Hilllhouse | 5.9 | 190 | 1969 |
| Eastern Santa Barbara Channel |
| Hogan | 5.5 | 152 | 1967 |
| Eastern Santa Barbara Channel |
| Holly | 3.7 | 211 | 1966 |
| Western Santa Barbara Channel |
| Hondo | 1.8 | 840 | 1976 |
| Western Santa Barbara Channel |
| Houchin | 5.1 | 163 | 1968 |
| Eastern Santa Barbara Channel |
| Irene | 4.1 | 240 | 1985 |
| Santa Maria |
|  | 4.7 |  |  |



explosive shape charges. The 15 pound conical charges were positioned around the perimeter of the structures and detonated to reduce the caissons to pieces with maximum dimensions of approximately six feet. Reinforcing steel was cut by divers. The steel trusses were cut above water by rigging crews and below water by divers using arc-oxygen torches. The concrete rubble was reduced to a pile which did not extend above a water depth of −15 feet at low tide and was left in place. The steel was recovered and scrapped onshore (Culwell and McCarthy, [1997](#page30)).

Numerous structures, such as piers and wharfs, exploration drilling

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rigs, production towers, storage tanks, and wooden and steel platforms, all associated with oil production along the southern California coast, have been constructed, decommissioned, and removed, recycled, re-used, or scrapped over the last 150 years. At least seven platforms in California State waters and at least one artificial island for oil produc-tion (Belmont Island), have been decommissioned and removed. Of these, three large platforms, Harry (in 1974), Helen (in 1988), and Herman (in 1988) were totally removed without a great deal of con-troversy. Pipelines between those platforms and the surf zone were cut, cleaned, and abandoned in place, while all onshore pipes were removed ([SLC, 2017](#page33)).

Installed in 1961, Platform Harry was a modified jack-up rig in

100 ft of water that produced oil until decommissioning and removal in 1974. No information is readily available on Harry or the methods used for removal. Standard practice at the time for removal would probably have used explosives to sever support legs and well conductors below the seafloor. It is likely that some mechanism, perhaps tubular pipes, were driven into the seafloor to stabilize and anchor the rig through 13 years of production. If the jack-up legs were functional, perhaps the legs could have been vertically retracted; however, the amount of in-vertebrate growth on the legs would have weighed more than the power of the rig to lift unless perfectly clean. It is unknown where onshore disposal took place.

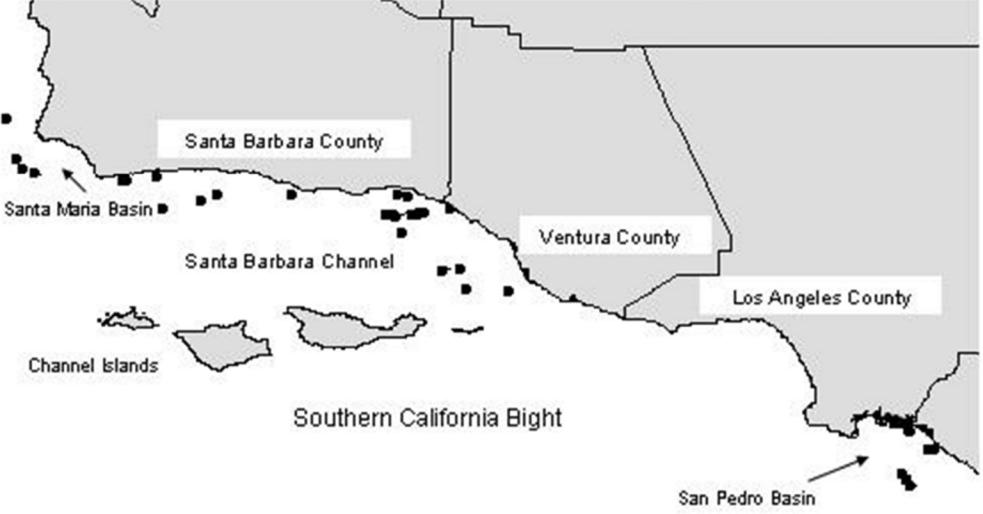
Platforms Helen and Herman, originally installed in the late 1950's in State waters, 100 and 85 ft water depth, respectively, were decom-missioned in 1988 following production shutdown and well plugging in 1973. These structures were located offshore Gaviota and represented early designs for offshore oil platforms with simple tubular construction and anchor piles driven down through the center of the platform jacket (see Fig. 1). Helen was large and complicated with 20 legs while Herman was a 4-legged structure with multiple conductor piles located centrally. The decommissioning of these platforms was the first large-scale offshore oil platform decommissioning project performed in Ca-lifornia with many failed disassembly methods attempted while still offshore and multiple disposal options under question. Explosives were not used, which greatly delayed removal after the wells were plugged. Instead, cuts of the steel pipes below the seafloor were repeatedly at-tempted using mechanical tools, which proved unreliable in most cases, such that commercial divers were called upon to perform the extremely hazardous job of completing cuts to free the jackets while suspended inside 33-inch diameter pipes (Culwell, 1997). Construction of an ar-tificial reef from the jacket materials was proposed during the project permitting and planning phase; however, political opposition to the proposed site in Santa Monica Bay prevented reefing. Explosives were used to severe with consequent massive fish kills. Counts and species identification was not done pre- or post-explosive. The platforms were barged to Long Beach where they were dismantled and disposal took place onshore ([Culwell, 1997](#page30)).

The rig-to-reef concept was revived in 1992, when Chevron moved toward decommissioning its 4H platforms (Hazel, Heidi, Hilda, Hope) from state waters. Disposal options for materials decommissioned during the 4H removal project that included onshore scrapping were weighed in the permitting and project planning phase. At the time, CDFG decided that the decommissioned platform materials were not suitable for reefing. Nonetheless, in 1994, a proposal was made to use portions of these structures for the construction of test reefs in the newly created Sycamore Canyon Ecological Reserve, which is a rela-tively flat seafloor area dominated by sandy sediments off Ventura County A recreational angler's group, United Anglers of Southern California, began to lobby for retention of the 4H platforms as reefs and the concept was seriously analyzed; however, the late timing created permitting obstacles and there were questions as to the cost effective-ness of the method for this particular project. The artificial reef option was not selected as the SLC and the California Coastal Commission

1. were not favorably disposed toward this disposal method. In addition, the Artificial Reef Program in California was waning, from a

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**Fig. 9.** Distribution of oil and gas platforms offshore the coast of Southern California.

lack of funds and personnel, with future support in doubt, within the CDFG. The proposal failed amid controversy and delays, to the dismay of southern California sportfishing and other recreation interests.

Platforms Hope, Heidi, Hilda and Hazel were installed offshore Carpinteria, California, between 1958 and 1965, and were in good condition when decommissioned and removed in 1996, within a few years after the wells were plugged. The Hazel platform, a huge gravity-based structure, was partially decommissioned in place. The gravity-base caissons were nearly covered with accumulated materials and shells in a mound under the structure. Because of the caissons' excessive weight and the disturbance to the sea floor which would be caused by their removal, this part of the structure remains decommissioned in place (Culwell, 1997). As reefing of all other platforms and materials was not an option, onshore scrapping was used again as the disposal method of choice. Several potential sites in the Terminal Island area of the Port of Long Beach were selected for a dismantling and scrapping process similar to the one performed in 1988 for Platforms Helen and Herman. One of the lessons learned here was that future projects should include analysis of the artificial reef option for disposal from the outset of the permitting and planning phase (Culwell, 1997; Schroeder and [Love, 2004](#page33)).

The 4H platforms had 20 intra-oilfield and field-to-shore pipelines ranging from 6 inches to 12 inches in diameter and 9 power cables, although some of the power cables were out of service. These cables were abandoned in place by cutting the end free from the structure and burying the end three feet below mudline. The pipelines were used by other platforms further offshore and their multi-use configuration re-quired rerouting or partial replacement. Other pipelines used only within the four platforms were disconnected, capped, and the ends were buried 3 feet below mudline. Most of these pipelines are buried where they reached shore, and those that sometimes became exposed were adjacent to pipelines still in production. Therefore, no landfall pipeline removals were performed; however, the decommissioned pipelines were grouted internally through the surf zone and decommissioned in place. The grouting operation serves to keep the pipeline weighted down to discourage any exposure in the future through the surf zone area ([Culwell, 1997](#page30); [Culwell and McCarthy, 1997](#page30)).

The entire decommissioning project, sometimes called the 4H Project, was postponed for one year due to air emission permitting delays, caused by strict limitations on air emissions imposed by the EPA on Santa Barbara County and the classification of decommissioning emissions by the Santa Barbara County Air Pollution Control District (APCD) as non-exempt. Emission offsets were required by the APCD to keep emission levels below target ceilings, and the time required to find

and create those in-kind offsets resulted in the delay of the project. During the platforms' operation, “shell mounds” built up under each

one. The mounds are composed of the shells of biofouling organisms from the upper layers of the platform jacket, such as mussels and scallops, that slough-off under their own weight, are knocked off during storms, or are purposely cleaned-off to prevent weight and drag on the structure. The biofouling can measure at least a foot thick around the jacket legs. At one time, mussels were harvested during cleaning from the legs of the California platforms and sold commercially ([Meek,](#page32) [1987](#page32)). Additionally, drilling fluids and drill cuttings were deposited on the sea floor underneath the platforms prior to this practice being banned. The drilling materials contain contaminants such as PCBs, hydrocarbons, and metals. All of these materials are now bonded to-gether in the mounds which were left in place when the platforms were decommissioned. The mounds are 25–28 feet high, and 200–250 feet in diameter ([Culwell, 1997](#page30)).

Decommissioning at the 4H sites required the full removal of the shell mounds and all site debris, and that a “trawl test” with standard equipment be performed. According to reports, the site is untrawlable and the industry operator of the removed platforms continues to hold the leases. Removing the shell mounds would result in a range of short-term impacts to water and sediment quality, with possible secondary toxic effects on marine life (SAIC, 2003). As reported by Bernstein et al. [(2010)](#page30), studies concluded that contaminants are currently not being released from the shell mounds to other areas but that there is some evidence of low-level contamination in organisms living on the mounds. A decision by the SLC has been made to leave the mounds in place, but the status of the shell mounds remains not fully resolved some twenty years later ([Schroeder and Love, 2004](#page33); [Bernstein et al., 2010](#page30)).

In all instances where some portion of the platform remains in the ocean, provisions must be taken to ensure safe navigation and mark potential fishing or possible no-take areas. Trawl fishermen may de-mand compensation for the continued loss of fishing grounds. In the 4H case, the proposed compensation (in the form of differential GPS na-vigation systems) for exclusion due to the shell mound was on the order of $75,000/fishing boat in mid-1990 (McGinnis et al., 2001). These costs can substantially be higher or lower depending upon the location and number of fishermen affected.

Belmont Oil Island was the first man-made oil production island installed and removed from the ocean waters off the California shore-line. Belmont Island was initially conceived in 1947 and construction began in 1953. An incredibly complex structure, it took many years to complete construction and remained for over 50 years in place about 1.5 miles off the coast of southern California. Oil production continued

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into the mid-1990s when production rates began to fall. Wells were plugged and abandoned in 1996. After a nearly five year permitting process, the physical removal required nearly two years and was completed in 2002.

Again, an effort to reef some part of Belmont Island came too late in the process. Divers and sports fisherman had pleaded with the SLC to leave at least part of the island intact because it acted as an artificial reef, attracting a multitude of marine life (Mehta, 2000). In addition, an environmental group called Heal the Harbor offered to Exxon, the owner of the island at that time, to assume ownership and legal liability if Exxon put about half of the estimated removal costs in a trust account for maintenance, liability and administration. At the time, removal costs were estimated at about $30 million dollars (Ahuja et al., 2003). The commission found that complete removal of the island was the environmentally preferred option because there was no evidence that the island provided unique habitat in the area. Additionally, USCG determined, given the shallow depth, that leaving the base of the island behind would create a navigational hazard. All of the Island's compo-nents were completely removed except for components buried below the natural seafloor (Ahuja et al., 2003). CDFG used rocks from the decommissioned Belmont Oil Island to enhance the Bolsa Chica Artifi-cial Reef (Schroeder and Love, 2004). Belmont Island was the most recent offshore oil facility to be removed from California's waters ([SLC,](#page33) [2017](#page33)).

*5.4. Decommissioning oil-related structures in federal waters*

Exxon obtained rights to develop petroleum from several subsea reservoirs and consolidated the leases on the federal OCS into the Santa Ynez Unit (SYU) from 1968 through 1982. On April 1, 1981, Exxon initiated oil production from the Hondo Field in federal waters of the western Santa Barbara Channel, through the interdependent operation of Platform Hondo, the OS&T Vessel on a SALM (Fig. 10), with three pipelines and a power cables running from Hondo to the OS&T facility ([OGJ, 1993](#page32); [Olson et al., 1983](#page32)).

The Pacific Offshore Pipeline Company (POPCO) constructed the Las Flores Canyon Gas Processing Facility in the hills west of Santa Barbara in 1982, and operations began in 1983, although not fully operational. The POPCO facility processed natural gas transported from Platform Hondo through their offshore/onshore pipeline system. The processed natural gas was sold to the Southern California Gas Company, and raw natural gas liquids were transported via highway trucking to handling facilities in Kern County for processing into propane, iso-butane, butane, and heavier products ([OGJ, 1993](#page32); [Olson et al., 1983](#page32)).

During the first 14 years of oil production from Platform Hondo, Exxon sent oil to the OS&T facility for processing and then subsequently loaded the oil onto a marine tanker for shipment to refineries up and down the Pacific coast. The SALM/OS&T facilities were installed in



**Fig. 10.** Exxon's Oil Storage and Treatment Vessel moored offshore Santa Barbara County.

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1980 to transfer, process and store oil production from platform Hondo until the onshore processing facility became fully operational. The OS& T was a converted oil tanker that operated from 1981 to 1994 and was moored via the SALM about 3.5 miles from shore. By 1994, POPCO had expanded its processing facility and Exxon had built an adjacent on-shore oil processing facility. Exxon subsequently obtained approval to process its oil onshore in Las Flores Canyon. With the addition of pet-roleum from Platforms Harmony and Heritage, all Santa Ynez Unit production was piped onshore to the new Las Flores Canyon oil pro-cessing facility in 1994, making the SALM/OS&T facilities redundant. Exxon decommissioned the OS&T and SALM in 1995. POPCO sold its gas processing facility to ExxonMobil after the two energy companies merged in 1998 ([OGJ, 1993](#page32); [Olson et al., 1983](#page32)).

The SALM and OS&T complex was located in about 500 ft of water. Their removal in 1994/95 was the first deepwater decommissioning project performed in California and may have been the deepest oil-re-lated facility removal globally at the time. The structures were in good condition, marketable for reuse in other areas. A major consideration for complete removal was that the OS&T pivoted in a circle around the SALM and excluded commercial trawling from a large and potentially lucrative fishing zone near harbors and markets. The pipelines and power cable from Platform Hondo were disconnected, capped, and the ends were buried 3 feet below mudline and covered by a flexible con-crete mat to prevent interference with trawling. There was no serious consideration of reefing any part of the OS&T or SALM. The material from the decommissioning activities were reused, recycled, sold, or deposited in landfills ([Culwell, 1997](#page30)).

Power cables that electrify the three existing ExxonMobil platforms within the Santa Ynez Unit have been repaired and/or replaced several times since 2000. Disconnected lengths of cable were removed from shore to the 3-mile state water boundary and the ends of disconnected cables in federal waters were buried. Decommissioning, removal, and site clearance, of the SYU platforms, pipelines, and power cables, as required by the federal government regulations, may be postponed on a case-by-case basis until all petroleum production has ceased from the Unit (BSEE, 2017d).

*5.5. California state rigs-to-reefs legislation*

In 1992 Chevron proposed decommissioning of the 4H platforms in State waters. The proposal served as a catalyst for more directed at-tention toward removal issues and options, including RtR, for California's offshore platforms. Partial removal after decommissioning has been of ongoing California Legislative interest for at least 20 years. There were three formal, but unsuccessful, attempts, CA Senate Bill (SB) 2173 by Brian McPherson, 1998, SB 241 by Dede Alpert, 2000; and SB 1, by Dede Alpert, 2001, to promulgate state legislation prior to the successful passage of the state's RtR law, CA Assembly Bill (AB) 2503, by John Pérez, c. 687, Statutes of 2010, (McGinnis et al., 2001; [Bernstein et al., 2010](#page30); [Edwards, 2012](#page30)).

The first bill to propose RtR for California was SB 2173, in 1998. Entitled “Artificial Reefs”, it was cast as a proposal to extend the state's artificial reef program to the OCS off the California coast. As in-troduced, the bill cited declines in southern California's marine species and the adverse effects such declines had on the state's recreational and commercial fishing industries. The concern over the declines and sub-sequent economic effects acted as the foundation for expansion of the state's artificial reef program, both within and beyond state waters (McGinnis et al., 2001). Moreover, it asserted that artificial reefs have the ability to duplicate natural conditions and stimulate production for fisheries.

SB 2173 highlighted the state CDFG Artificial Reef Program's 40-year history of construction, research, and management as an indica-tion of its capability to effectively carry out proposed expanded activ-ities that would include RtR. The bill also cited the 1984 NFEA, which provided for the establishment of artificial reefs by states within federal

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OCS waters for the enhancement of recreational fishing and tourism (LII, 2017). It also provided for the development of artificial reef pro-gram elements to address other technical aspects, including the de-termination of design criteria for increasing biomass of marine flora and fauna, the specification of siting and placement requirements, and the development of mechanisms for program planning, coordination, management and evaluation; monitoring and enforcement; environ-mental impact assessment and compliance; and damage assessment. It also would have established several dedicated accounts that would have funded the uncertainty of costs of an artificial reef program expanding into federal waters further offshore. The establishment of a dedicated account for the artificial reef program in CDFG addressed not only funding needs of a RtR program, but also long-standing funding pro-blems for California's artificial reef program in general (McGinnis et al., [2001](#page32)). Perhaps, more importantly, issues concerning liability arose, and a myriad of potential amendments, including the preclusion of the transfer of liability from the platform operator to the state, were put forward that prevented passage.

The idea of enhancing fisheries production while also gaining funding through a RtR program was reintroduced to state legislation in 2000. SB 241 was entitled “Decommissioned Oil Platforms and Production Facilities: California Endowment for Marine Preservation.” It brought many other state agencies into the process and outcome of a RtR program. It spread the burden of technical support from CDFG to multiple state agencies and expanded the distribution of funds the state would receive from the cost savings of partial removal rather than total removal. SB 241 was very similar to its predecessor in some respects, but also reflected greater attention to issues of technical feasibility, value acceptability, and resistance to budget and political constraints over the long term.

In an effort to address value and public acceptance of RtR for fish-eries biomass production, SB 241 required that CDFG designate plat-forms converted to reefs as marine reserves (i.e., no-take marine pro-tected areas, with a surrounding buffer). The marine reserves requirement linked any California RtR Program to the state's fisheries management system. This provision certainly alienated specific com-mercial and recreational fishermen because in stark contrast to the Gulf of Mexico, most California platforms have been seldom, if ever, fished since the late 1980s, in part because of security zones established by the USCG. The four platforms off Los Angeles and Orange Counties are the exception, where a small number of boats may occasionally fish on their return to port from offshore, as was done at Belmont Island over the years ([McCrea, pers. comm., 2017](#page32)).

In an effort to bolster the notion of reefing platforms to support fisheries enhancement and production, as well as the viability of the bill itself, the bill's proponent, California State Senator Dede Alpert re-quested assistance from the state university system in convening a “Blue Ribbon Panel” to identify scientific questions to be resolved, evaluate existing data on potential ecological and environmental consequences of decommissioning alternatives, and identify uncertainties regarding such assessments. Ultimately SB 241 languished and the 2000 legisla-tive session ended.

In 2001, Alpert reintroduced her legislation as SB 1. Changes to the previous SB 241, plus much stronger support from a variety of groups including United Anglers, the Channel Islands Council of Divers, the Sportfishing Association of California, the Recreational Fishing Alliance, the San Diego Oceans Foundation, and San Francisco Reef Divers, was sufficient to move the measure through both houses of the legislature and onto the desk of Governor Gray Davis. Under pressure from environmental groups, Davis vetoed SB 1 stating that there was insufficient scientific evidence that RtR would be environmentally beneficial (McGinnis et al., 2001). It would take nearly a decade of additional research and discussion before another RtR bill would once again be put before the California legislators. During that time Texas and Louisiana reefed hundreds of decommissioned platforms in federal waters and comprehensive new scientific studies were published

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revealing that California's platforms supported millions of fishes and invertebrates, acted as nurseries for fisheries production, and served as de facto marine preserves for a number of officially declared overfished species ([Bernstein et al., 2010](#page30); [Claisse et al., 2014](#page30); [Love et al., 2012](#page31)).

In 2010, Chairman of the State Assembly, John Perez introduced AB 2503. This new legislation adopted ideas from the previous bills but added a range of new provisions addressing concerns voiced during earlier proposals. AB 2503 passed both houses by significant margins. Governor Arnold Schwarzenegger signed it into law on Sept. 15, 2010, as the California Marine Resources Legacy Act (MRLA). MRLA estab-lishes state policy to allow, on a case-by-case basis, the partial de-commissioning of offshore oil and gas platforms. Its basic framework creates a process with specified requirements for a platform owner to apply to the state for approval of partial platform removal. MRLA re-cognizes the multi-jurisdictional nature of platform decommissioning and the need for a viable RtR program to utilize the established ex-pertise and authority of different state entities. The bill specifically requires an analysis and proof of a net environmental benefit to fish-eries production by the California Ocean Science Trust. It also expands the scope of requirements for platform operators to share savings from partial rather than full platform removal with the state for marine conservation programs with savings deposited in an endowment (the California Endowment for Marine Preservation) whose moneys is to be used to the benefit of coastal marine resources ([MRLA, 2010](#page32)).

MRLA provides primary authority to the newly renamed department (from CDFG to California Department of Fish and Wildlife) (CDFW) to accept and approve RtR applications submitted by those authorized to do so. The initial applicant(s) must fund the RtR Program start-up that requires CDFW develop application materials, determine when an ap-plication is complete, develop a reef management plan, hold a public hearing in the county nearest to the proposed reef, review and provide conditional and final approval to an application, and manage and op-erate an approved artificial reef, among other things. In addition, it clarifies language related to specific state agency responsibilities in a case-by-case review and approval process that would also include other state reviews and requirements such as those under the California Environmental Quality Act (CEQA) and consistency ruling regarding the California Coastal Management Plan from the CCC (MRLA, 2010). It is important to understand that the California RtR Program is compli-cated, costly to applicants, and voluntary with owner/operator of platforms in both state and federal waters eligible to participate. Ad-ditionally, the Program only addresses state requirements and does not encompass the multitude of federal regulations, permits, and require-ments for reefing, although the federal path is well understood and practiced.

There have been at least four attempts, since 2010, to alter the MRLA and the California RtR Program since its inception and address perceived shortcomings in its requirements: AB 2267, AB 207, SB 233 (Hertzberg, 2015), and SB 588 (Hertzberg, 2017). The most recent amendment would modify the MRLA to make the SLC the CEQA lead; allow the applicant to withdraw its RtR application at any time; po-tentially re-set the financial incentives from specific to no-year dates; require an analysis of the net environmental benefit to air quality of greenhouse gas emission savings of partial removal versus total re-moval; and, add a public meeting to review environmental documents (California Senate Committee, 2017; Hertzberg, 2017).

*5.6. Workshops and public meetings*

In 1974, artificial reef researchers organized the first International Conference on the subject of ‘Reefs’ that included discussion on RtR. The conference was held in March 1974 in Houston, Texas, to provide an international forum for the exchange of information, experiences and thoughts among persons involved with or interested in any aspect of artificial reef research, construction, or use (Bortone, 2015). Over forty years have passed since that initial meeting and, while there have

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been many other conferences held on the subject of artificial reefs, the need for these meetings continues. Over the years, there have been changes in approaches, technology, political climate, and financial conditions with regard to artificial reef research. Stone (1974) and Bortone (2015) presented summaries of the previous International Conference on Artificial Reefs and Related Aquatic Habitats (CARAHs). Those summaries emphasize the milestones with regard to technology, direction, emphasis, scope, and accomplishment of the efforts of the international artificial reef research community. There have been many CARAH conferences in such diverse locations as the U.S., Turkey, Ma-laysia, and Brazil; all with petroleum platforms off their coasts (Bortone, 2015). Most, if not all, have included session dealing with RtR.

For nearly 30 years, MMS, now BOEM, held an annual public “Information Transfer Meeting” in the Gulf of Mexico Region that in-cluded a specific session on RtR and/or the ecology of population be-neath offshore platforms. BOEM and SLC have jointly sponsored public workshops in California since the mid-1990s when the 4H platform removals were performed amid controversy: “Abandonment and Removal of Offshore Oil and Gas Facilities: Education and Information Transfer” in 1994, “Decommissioning and Removal of Oil and Gas Facilities Offshore California: Recent Experiences and Future Deepwater Challenges” in 1997, and a “RtR” Workshop in 1999. In Spring 1999, the Southern California Academy of Sciences' Annual Meeting included a Symposium on Artificial Reefs, which included scientific and interest group presentations on the platforms as potential reef sites/materials.

In California, a small group of federal, state, and local agencies agreed to form an Interagency Decommissioning Working Group (IDWG) in 1997 to develop an action plan to guide agency efforts in addressing decommissioning issues. The California IDWG is composed of representatives from BOEM, SLC, CCC, CDFW, National Marine Fisheries Service, Ventura County, Santa Barbara County, USCG, and USACE with the goal to facilitate communication among the relevant local, state and federal agencies.

In 1999, the IDWG released a draft Action Plan. The Action Plan was prepared to “guide agency efforts in addressing the technical, en-vironmental, disposition, and site clearance issues associated with de-commissioning operations” (IDWG, 2017). The Plan does not address or resolve policy issues, but identifies information needs relative to the selected policy issues the group can address. The specific goals of the IDWG Action Plan are to develop a process for: (1) addressing decom-missioning issues; (2) collecting, disseminating, and sharing informa-tion with all interested parties; (3) promoting dialogue and commu-nication among all parties; and (4) improving interagency planning and coordination in advance of future decommissioning projects. The action plan identifies 28 separate issues that were raised by participants at a decommissioning workshop held by SLC and MMS in 1997. The issues were grouped into five major categories: (1) Technical, (2) Environ-mental, (3) Disposition and disposal, (4) Site Clearance, and (5) Policy ([Manago and Williamson, 1998](#page32)).

IDWG member agencies, led by the federal government efforts, have been funding scientific research, collecting information, and sponsoring workshops, symposia, and other public forums to disseminate in-formation in a timely manner and facilitate dialogue and discussion among all interested parties. BOEM sponsored a separate workshop in 2003 in order to prioritize its platform research program (MMS, 2003).

1. **Ecology and potential effects of platform removal offhore California**

The 1985 NARP noted that, at the time, there were serious defi-ciencies in our knowledge of how to construct and manage artificial reefs to enhance fishery resources. The knowledge gap was also the subject of a comprehensive review of current science and literature on artificial reefs published by fisheries scientists shortly after the adoption

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of the NFEA. At that time, relatively little was known about the biology and ecology of artificial reefs, optimal design, or design criteria (Bohnsack and Sutherland, 1985). The NARP recognized that artificial reefs could be, and perhaps were being, improperly planned, con-structed, located, and not monitored.

*6.1. Early studies and identification of research needs*

During the early days of the California Artificial Reef Program, CDFG marine biologists investigated the effectiveness of various reef materials to increase sportfishing opportunities and fishing success. In 1958, the CDFG and the Western Oil and Gas Association (WOGA) entered into a 3-year agreement, by which the Department would ob-serve and evaluate the effects of offshore oil drilling, including the ef-fects on marine life of man-made structures and of depositing washed drill cuttings on the ocean floor. Special attention was to be paid to the possible deleterious effects of the latter operation.

During the course of the investigation, biologist divers made monthly observations on the Atlantic Richfield Oil Island at Rincon and on the Standard-Humble Platform Hazel off Summerland. After its construction in August 1960, Platform Hilda was included in these observations. Logs were carefully maintained for all dives and monthly reports were made to WOGA. During the study, divers found no evi-dence of deleterious effects from any part of the platform operations. The reports stated that the island and platforms served to enhance the sandy seafloor habitat. The structures were rich in species and diversity and were heavily encrusted by various biofouling organisms dominated by mussels. This encrustation included such animals as rock scallops, barnacles, and mussels and was thought to greatly add to the available fish food ([Carlisle et al., 1964](#page30)).

One of the most controversial topics in artificial reef theory, and also very important to fishery managers if artificial reefs are used as a management tool, is the question of attraction vs. production. [Bohnsack](#page30) [(1989)](#page30) first hypothesized that artificial reefs could either “provide ad-ditional critical habitat that increases the environmental carrying ca-pacity and eventually the abundance and biomass of reef fishes” (pro-duction) or “attract fishes as the result of behavioral preferences but do not significantly increase total fish biomass” (attraction). Increased production is one of the underlying rationales behind establishment of artificial reefs, but if attraction is actually the case, reef fishes could be subjected to increased catchability, thus increased fishing mortality ([Bohnsack, 1989](#page30); [Bohnsack et al., 1991](#page30)).

During the early to mid-1980s, CDFG attention was focused pri-marily on determining if an artificial reef could be productive for fisheries? The construction and multi-year study of PAR, off northern San Diego County, proved that, in time, a well-constructed artificial reef can develop the same community structure and be productive as simi-larly configured natural reefs (Bedford et al., 2000). As a bi-product of this work the qualitative and quantitative production of attached shellfishes and other invertebrate species was well documented.

Attempts to resolve the finfish “attraction vs. production” question has played an important role in the planning and installation of new artificial reefs along the southern California coast, whether for fisheries management purposes or mitigation (Polovina, 1989). Work during the late 1980s and into the present has focused on trying to quantify the productivity of artificial reefs for finfish species, and to develop reefs directed at producing more of certain species. Central to the problem of establishing productivity for fishes is knowing when and for how long different species are resident on a reef. Further, since small individuals of a given species are likely to use a reef in a different manner than larger individuals, residency as well as territoriality must be accounted for separately for each size class of fish.

With the exception of a few early studies (Carlisle et al., 1964; Bascom et al., 1976; Wolfson et al., 1979; Allen et al., 1987) a limited amount of research on the biota specifically at oil and gas platforms on the OCS off southern California was conducted until the mid-1990s. It is

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probable that the Chevron 4H decommissioning and removal project which began in 1994 prompted a re-interest in the populations of fish and invertebrates under platforms and their connections to local ecology and fisheries. At that time, the National Biological Survey (later the Biological Resources Division of the United State Geological Survey (USGS)) funded the first in a series of surveys of the fishes and in-vertebrate populations around federal structures beyond state waters. While the USGS early studies were ongoing, the California legislature, through Senator Dede Albert, requested that the University of Cali-fornia convene a “Blue Ribbon Panel” to examine the potential ecolo-gical consequences and issues surrounding the decommissioning of platforms.

The Blue Ribbon Panel, officially the “Select Scientific Advisory Committee on Decommissioning,” explored possible marine ecological implications related to the decommissioning of California's 27 offshore oil production platforms to assess the current state of knowledge and identify a research agenda to fill information gaps (Holbrook et al., [2000](#page31)). Various interests in the RtR debate participated in meetings held with the Select Committee, and included representatives of the Amer-ican Sportfishing Association, the San Diego Oceans Foundation, the Professional Association of Diving Instructors, Proteus SeaFarms Inter-national, the California Sea Grant Extension Program, a commercial fisherman, the Center for Marine Conservation, the Environmental Defense Center and the United Anglers of Southern California/Amer-ican Sportfishing Association Conservation Coordinating Committee.

The Select Committee explored the ecological consequences of five identified decommissioning options for coastal platforms including (1) leaving the intact structure in place, (2) complete removal, (3) top portion of platform removed to 20–30 m subsurface and remaining lower portion left standing in place (“topping”), (4) structure toppled over in the same location (“toppling”) and (5) structure moved to a new location and toppled. MRLA, passed in 2010, established state policy to allow, on a case-by-case basis, partial removal during decommissioning of offshore oil and gas platforms. Under the law, California will con-sider only partial removal for reefing done by severing the platform jacket and conductors at about 26 m below the sea surface.

Throughout the Select Committee discussions in 2000, attention was focused upon a number of scientific, technical and institutional issues. These included: 1) whether rigs actually enhance, or simply attract reef fishes; 2) the net ecological benefits or costs of removal and of reefing;

1. the practicality of removal and of reefing, especially involving platforms in very deep waters; 4) concerns for navigational safety; 5) interference with other ocean uses; 6) funding to support maintenance and monitoring as well as initial reefing; and 7) liability, among others. The Blue Ribbon Panel Report focused on scientific issues and provided a partial road map of unanswered questions and research topics ([Holbrook et al., 2000](#page31)).

From the Panel's perspective, one basic question was asked and not answered. What is the proportion of the total hard substratum, i.e. rocky reefs, off coastal California? There are no quantitative estimates of the extent to which platforms contribute to the total amount of “reef” habitat in the Pacific OCS region ([Carr et al., 2003](#page30)). Estimates based on the general amount of hard substratum in shallower regions of the Santa Barbara Channel, including the Santa Barbara Channel Islands, lead to the conclusion that this contribution might be very small ([Holbrook et al., 2000](#page31); [Helvey, 2002](#page31)). However, there are few rocky outcrops below about 150 ft in the areas where platforms occur and deeper-water platforms likely provide considerable hard structure below this depth. Platform Hidalgo is estimated to supply 46% of the hard surface in its local area off Point Conception (within about 2 mi of the platform) ([Love et al., 2003](#page31)). A sharply sloped pinnacle is the clo-sest natural reef structure to a platform which spans the seafloor through the sea surface. Depending on the overall intent of creating artificial reef habitat, the relative contribution varies from miniscule if the purpose is to simply contribute to the overall natural reef habitat in the region, to 100% if the interest is for the unique habitat created by

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platforms ([Dokken, 1997](#page30); [Carr et al., 2003](#page30)).

In 2007, the California Natural Resources Agency (CNRA) called for additional examination of platform decommissioning in advance of possible consideration of legislation for RtR. CNRA asked the California Ocean Science Trust (OST) in 2008 to provide a study whose purpose was “to assemble and examine scientific and legal information that will frame future state policy discussion on the alternatives for decommis-sioned platforms.” OST is a nonprofit 501(c)(3) public benefit cor-poration established pursuant to the California Ocean Resources Stewardship Act of 2000 to encourage coordinated, multi-agency, multi-institution approaches to translating ocean science to manage-ment and policy. The OST provides integration of a scientific perspec-tive, data synthesis, and information for decision-making processes of California state agencies and coordinating bodies, such as the California Ocean Protection Council. The OST serves California citizens by co-ordinating expert advice and acting as liaison and bridging institution. The OST-sponsored report “Evaluating Alternatives for Decommissioning California's Offshore Oil and Gas Platforms: A Technical Analysis to Inform State Policy” was a foundational docu-ment for California in consideration of the partial removal reefing op-tion (Bernstein et al., 2010). The goal of the study was to create an analysis and a decision framework to assist decision makers and other interested parties in understanding and investigating the implications of different decommissioning options and making a choice among these. The endeavor met its goal by accomplishing its major objectives:

1. To prioritize potential decommissioning options and identify the most viable for more detailed analysis;
2. To summarize available information on these options in order to present a comparative analysis of impacts, costs, and benefits across a wide range of issues, focusing on those aspects of decom-missioning that will contribute most to a choice among options (e.g., the analysis excludes or minimizes those aspects that are the same across options); and,
3. To examine the existing legal/regulatory framework to identify mechanisms that would aid in implementing decommissioning op-tions.

In addition, the OST-sponsored report reiterated and attempted to answer the fundamental question of platform productivity. The report used data from platform monitoring surveys and conducted population dynamics modeling of fish communities on eight platforms with data adequate for the modeling analysis. However, data gaps prevented quantitative comparisons of platform productivity to that in other global communities or ecosystems in southern California, or any rig-orous estimate of the overall contribution of platform communities to the regional ecosystem (Bernstein et al., 2010). They also conducted modeling of larval dispersal patterns that suggested platforms can function both as sources and as sinks, or recruitment locations, for fish larvae in the region.

*6.2. Federally-funded research*

Continuing from the mid-1980s, through the 1990s, into 2017, and beyond, the federal government has funded decades of research to ex-amine the impact and relationship between oil and gas platforms, the marine ecosystem, and fisheries. As early as 1979, before the creation of the MMS, the Bureau of Land Management, funded an investigation of the degree to which oil and gas operations on the OCS off California conflicted with fishing activities, such as trawling. The study was a comprehensive survey of ongoing and potential space-use conflicts between offshore oil and gas development and recreational and com-mercial fishing as well as an investigation of potential conflicts over vessel and dock space within ports. That research was quickly followed by an in-depth survey of the associated fish and invertebrates at the few federal platforms that existed at the time (Allen et al., 1987). By 1986,

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as the U.S. was advocating artificial reef development to enhance fisheries, MMS asked whether there were sufficient data to determine if platforms simply attract fishes or actually increase their productivity (Allen et al., 1987). The answer was that there was no suitable quan-titative information that would allow the determination of whether platforms increase fish productivity or simply attract fishes from sur-rounding areas. Recommendations for further studies included:

1. A synoptic survey of all existing platforms in California OCS waters, to identify differences in the fish assemblages at different platforms;
2. Monitoring studies (of up to 10 years) at representative platforms with the goal of describing inter-annual changes in the fish assem-blages and populations at deep water and northern platforms;
3. Feeding studies to determine which species feed on platform-asso-ciated prey and the relative importance of this prey in their diet; and,
4. Tagging studies to determine residence time at, and movement be-tween, platforms (Allen et al., 1987).

Initial surveys funded by the USGS compared fish populations at nearby natural reefs and nine platforms in federal waters within Santa Barbara Channel and the Santa Maria Basin (north of Point Conception). These surveys culminated in a synthesis of information from detailed annual surveys performed for six consecutive years that described and compared spatial and temporal patterns of fish assem-blages around platforms and reefs (Love et al., 2003). Scuba was used to survey species in the shallow water areas and a manned submersible was used for species in depths greater than about 80–100 ft.

When adult fish populations were compared between platforms and reefs, there was a high degree of overlap in rockfish species and dif-ferences were primarily due to generally higher densities, of more species, that grow to be large-sized when mature, at the platforms. Diminutive species, in high densities, dominated natural reefs ([Love](#page31) et al., 2003). During these same surveys, estimates of young-of-the-year (YOY) fishes found a minimum of 430,000 juvenile bocaccio during observations under the studied platforms (Fig. 11). Using a conservative estimate, the research determined that the number of bocaccio YOY beneath the platforms was about 20% of the average number of juvenile bocaccio that survive annually for the geographic range of the species (Alaska to Baja California). When these juveniles became adults, it was estimated that they would contribute about one percent (0.8%) of the additional amount of fish needed to rebuild the Pacific Coast bocaccio population. During the same period of time, the recruitment of YOY bocaccio to nearshore natural nursery grounds, as determined through regional scuba surveys, was low. This research demonstrates that a relatively small amount of artificial nursery habitat may be quite va-luable in rebuilding an overfished species (Love and Schroeder, 2006) ([Fig. 11](#page23)).

Beginning with the USGS, funding for descriptions of the fish and invertebrate populations beneath platforms compared to nearby natural reefs (Love et al., 1990; [1999a](#page31),[b](#page31); [2000](#page31); [2001](#page31); [2003](#page31)), DOI, through the MMS, expanded funding to include surveys of platforms off Summer-land and Huntington Beach. Those studies also described the fish po-pulations and compared them to populations on nearby reefs and ex-panded the extent of area of investigation to include all 23 federal platforms and numerous natural reefs within offshore southern and south-central California ([Love et al., 2010](#page31), [2012](#page31)).

All these surveys revealed three distinct fish assemblages beneath each platform: midwaters, bottom, and shell mound. These assemblages did not appreciably change over the course of all years and all studies. Midwater assemblages were similar across platforms, while bottom and shell mound assemblages varied with platform bottom depth. In gen-eral, all of these assemblages differed from a lesser to greater degrees from those observed at natural sites. There tended to be higher densities of YOY fishes, particularly rockfishes, around many platforms than at most natural sites. Older juveniles and adults of economically important

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**Fig. 11.** Young-of-the-Year (YOY) bocaccio, *Sebastes paucispinis*, beneath plat-form offshore California.

species were also more likely to be found at higher densities at some platforms than at most natural sites. This latter may reflect 1) an ex-tensive and complex bottom habitat around the bottoms of some plat-forms that serve as sheltering areas for economically important species and 2) the lower fishing effort (a de facto marine reserve effect) of platforms because many of these structures are rarely fished, especially those in the Santa Barbara Channel and Santa Maria Basin (Love et al., [2003](#page31), [Love et al., 2006](#page31), [2008](#page31); [2009a](#page31)).

The shell mounds surrounding California platforms are a unique feature of these structures and are composed primarily of living and dead mussels and associated marine life. They form an extensive web of low, but complex, seafloor. The relatively small crevices created by mussel shells prevent large numbers of many high-relief species from venturing onto these areas. Rather, most shell mound species are either the juveniles of larger species, whose juvenile stages require small sheltering sites, or somewhat generalist species that live over 1) soft seafloors, 2) the ecotones between soft and low-relief hard bottom, and

1. low-relief reefs. Reefs in the deeper waters of California tend to be low relief and thus more like shell mounds ([Love et al., 2009b](#page31)).

In the mid-2000s, research turned to consideration of the ecological performance of platforms as habitat, the survival and fate of larval rockfish that were attracted to the platforms, the contamination and body burden of pollutants in platform fishes compared to California coastal fishes, and the site-fidelity and home range to platforms by adult rockfish. Using existing data from the surveys, a study comparing the ecological performance of platforms and natural reefs found that plat-forms tended to have higher abundances of large fishes, particularly of those preferred by recreational and commercial fishers such as cowcod, bocaccio, and lingcod, than did most or all natural reefs. It is likely that this was due to the relatively low fishing effort around most platforms in southern California, again alluding to the de facto marine preserve effect. The study compared densities of all rockfishes (of all sizes), all rockfishes greater than or equal to 12 in, and adult bocaccio and cowcod that were observed at platforms and at natural outcrops. In most instances, fishes 12 in or larger were less abundant, or sometimes absent, from many natural reefs compared to most platforms ([Love and](#page31) [Schroeder, 2006](#page31); [Love et al., 2007](#page31)). Calculations of potential larval output from two important fisheries species, bocaccio and cowcod, found that the total removal of a single platform, Platform Gail (whose footprint is 1.3 acres), would be the equivalent of removing 30.6 acres of average-producing natural habitat in southern California for cowcod, or equivalent to removing 72.3 acres of average-producing natural habitat in southern California for bocaccio ([Love et al., 2005](#page31), [2006](#page31); [Scarborough Bull et al., 2008](#page33)).

Comparing the growth rates of fishes living around platforms with those on natural reefs is one method of contrasting the overall health

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and potential survival of these animals. Daily growth rates of YOY blue rockfish living around three platforms and three natural outcrops were compared. The results of these comparisons found that the rockfish at platforms grew as quickly and as well as those from natural reefs, and may, in some instances, grow faster at platforms (Love and Schroeder, [2006](#page31); [Love et al., 2007](#page31)).

The level of contamination from 21 elements, including heavy me-tals and other elements that can be found in drilling fluids, were compared between three fish species from five platforms and 10 natural sites well away from platforms (Love et al., 2013). Statistical compar-isons of these elements in fish indicated that none consistently ex-hibited higher concentrations at oil platforms than at natural areas. Another study looked at reproductive conditions. If significant con-tamination is occurring at platforms, it would be expected to impair the reproductive abilities of impacted fishes. One form of reproductive impairment is called atresia, the abnormal reabsorption of developing fish eggs that were destined to be spawned. Atresia has been widely used as an indicator of pollutant-related reproductive impairment in fishes. This study examined the occurrence of reabsorbed eggs in Pacific sanddab, a resident species, collected at two offshore platforms in the Santa Barbara Channel and at two natural reference sites away from the platforms. 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. In general, there is no evi-dence of conspicuous reproductive impairment in Pacific sanddab from either platforms or natural sites on the coast of southern California ([Love and Goldberg, 2009](#page31)).

Densities of YOY rockfishes around platforms are usually far higher than those at nearby natural reefs (Love et al., 2003). Research into links between water currents and transport of very young rockfishes to and from coastal areas examined whether the platforms merely act as sinks for larval rockfishes and reduce recruitment to nearshore natural reefs and kelp beds by functioning as diversion catchments for pelagic juvenile rockfishes. Observations of ocean water movement were used to estimate dispersal pathways for YOY bocaccio in the vicinity of Platform Irene north of Point Conception. The Platform Irene location was used because there was excellent high-frequency radar data for ocean currents in that area. Results clearly showed that most of the hundreds of thousands of YOY bocaccio settling at Platform Irene would not survive to settle on nearshore reefs in the absence of the platform. Instead, prevailing currents would transport them offshore where they would have a very low probability of survival. Although it is possible that some individuals would have encountered acceptable nursery ha-bitat on offshore banks or islands, it is likely that most would have perished as these features are not in the vicinity, nor in the mid-plat-forms water depths, of Platform Irene. The presence of Platform Irene almost certainly increased the survival of young bocaccio in the Point Conception–Point Arguello region (Nishimoto and Washburn, 2002; [Emery et al., 2006](#page30)).

Fish site-fidelity and habitat utilization of platforms have been de-liberated and discussed by California citizens and scientists since the 1980s (Holbrook et al., 2000). These same subjects were studied in the mid-2000s during an investigation that acoustically tagged rockfish and lingcod at two platforms in the Santa Barbara Channel and followed their 24/7 movements using radio receivers over a 2-year period. In addition, some tagged fishes from the platforms were successfully transplanted to a new Marine Protected Area, across the Channel at Anacapa Island (where it was assumed they would take up residence in these designated no-take locations) to determine whether fishes from offshore oil platforms in the Santa Barbara Channel would home back to their platforms of capture (Anthony et al., 2013). The findings from this study were surprising. Twenty-five percent of all tagged fishes that were transplanted to a natural reef, returned relatively quickly, tra-veling long distances,7–10 + mi, back to their home platform in under 20 h. Those that did not home took up residency at Anacapa Island, moved to Santa Cruz Island, or moved out of the range of detection.

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Those rockfishes and lingcod tagged but not translocated showed a high probability of being detected at the same platforms over a 2-year period. A few tagged individuals moved between platforms and/or natural habitat, although a majority moved from a platform in shal-lower water to a platform located in a deeper water over time. Observed movements of fishes between platforms and natural reef habitats in-dicate that they can navigate between these habitats and that platform habitat, despite having higher densities of rockfishes, may be preferred, and (in an unknown manner) of higher quality to some individuals than natural reefs ([Lowe et al., 2009](#page31)).

The question of attraction versus production, for oil and gas plat-forms, has been discussed as part of the artificial reef debate in the Gulf of Mexico as well as offshore California. Initially, artificial structures placed in the ocean attract fishes, biofouling invertebrates, and mobile invertebrates. What happens after 30–50 years, if a structure is not fished, or otherwise disrupted, on a regular basis? What does an eco-system, albeit man-made, resemble after decades, and how does it in-fluence regional fisheries? Is there significant larval export? The answer to such questions requires long-term, repetitious field monitoring that is difficult, labor intensive, and expensive. By the end of the 18 years of intensive scuba, submersible, and/or ROV surveys at federal platforms and numerous natural reefs off California, enough data had been ob-tained and analyzed to attempt to resolve the question of production from these structures as artificial reefs.

Secondary production is the formation of new animal biomass from growth for all individuals in a given area during some period of time. This production is an important pathway of energy flow through an ecosystem as it makes energy available to consumers, including hu-mans. It is a powerful tool for evaluating ecosystem function and ser-vices because it incorporates multiple characteristics of a community of organisms such as density, body size, growth, and survivorship into a single metric. Claisse et al. (2014) published in the Proceedings of the National Academy of Sciences, found that oil and gas platforms off the coast of California have the highest fish production per square meter (about 10 sq. ft) area of seafloor of any marine habitat that has been studied, about 10 times higher than fish communities from other marine ecosystems. Most previous estimates have come from estuarine environments, generally regarded as one of the most productive eco-systems globally. High rates of fish production on these platforms ul-timately result from high levels of recruitment and the subsequent growth of young rockfishes to the substantial amount of complex hardscape habitat created by the platform structure distributed throughout the water column. The platforms have a high ratio of structural surface area to seafloor surface area, resulting in large amounts of habitat for juvenile and adult demersal fishes over a rela-tively small footprint of seafloor ([Love et al., 2003](#page31); [Claisse et al., 2014](#page30)).

Annual Total Production (standing biomass, existing fish plus growth) per square meter (about 3 sq. ft) of seafloor for complete platforms was significantly greater than, and 27.4 times more, than fish produced per square meter on natural rocky reefs located at similar depths offshore southern California. When platforms were evaluated individually, their average annual total production tended to be about ten times higher than that of fish communities in other marine eco-systems where similar types of measurements have been made ([Claisse](#page30) [et al., 2014](#page30)).

The midwater sections of these structures are important nursery grounds for YOY rockfishes that settle to the platforms as larvae or pelagic juveniles (Love et al., 2003; Love and Schroeder, 2006; [Love](#page31) et al., 2006). Recruitment production per square meter of midwater platform habitat (i.e., not scaled to per square meter of seafloor) was 3.7 times as much as that on natural reefs. With hard substrate located throughout the water column, platform mid-water habitat is likely more readily accessible than natural reefs to the settling fishes that tend to be found in the upper 300 ft of the water column during their pelagic stage (Moser and Boehlert, 1991). Partial removal would likely severe the subsea portion of the platforms at about 85 feet below sea surface. The

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extent of loss of YOY recruits from the mid-waters and input to the shell mound community, as a consequence from partial removal, was also tested by Claisse et al. in a subsequent study (Claisse et al., 2015). This follow-up study examined the effect that the partial removal would have on recruitment of juvenile rockfish to platforms and the effect that the loss of the shallow water biofouling growth would have on the shell mounds.

While complete removal would likely eliminate the existing fish and invertebrate biomass and associated secondary production, the poten-tial impacts of partial removal would likely be insignificant on all but one platform off the coast of California. On average 80% of total 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. Platform Edith, located in the southern end of the geographical range of platforms off California is estimated to retain only about 20% of production ([Claisse et al., 2015](#page30)).

Partial removal would likely result in the loss of fish biomass and production for species typically found residing in the shallowest por-tions of the platform structure. However, these fishes generally re-present a small proportion of the fishes associated with these platforms.

Further, partially removed platforms would still have some of the highest production values (when scaled to per square meter of seafloor) of any marine habitat globally (Claisse et al., 2015). Many of the rockfishes that make up a substantial proportion of the biomass and production on platforms are important to recreational and commercial fisheries, and two, bocaccio and widow rockfish are currently managed under federal rebuilding plans (PFMC, 2008). These results suggest that partially removed platforms will still remain viable habitats for these important species.

The vertical distribution of rockfish larval settlement, or recruit-ment, is an important factor in evaluating the impacts of the partial removal option because this option likely involves removing the upper 85 ft of the platform. Past discussions of this option have commonly assumed that the bulk of larval fish recruitment to platforms occurs in the upper ten meters (approximately) of the water column and that larval settlement would therefore be significantly reduced under the partial removal option. This assumption is not borne out by recent evidence. While Love et al. (2003) reported some YOY bocaccio in the upper 100 ft of the platform, they also confirmed (Love et al., 2006) that few of these juveniles were found above 85 ft. This result was extended to all rockfish by Nishimoto et al. (2008) who confirmed that YOY rockfish are found almost exclusively below 85 ft water depth. Thus, these studies demonstrate that partial platform removal to a water depth of 85 ft would most likely not eliminate the potential nursery function of these structures for rockfishes (Love et al., 2012; [Claisse et al., 2015](#page30)).

Recruitment of most species of larval and pelagic juvenile rockfishes to platform habitat, the ultimate driver of both the somatic and re-cruitment components of total production, appears unlikely to be im-pacted substantially by partial removal and that recruitment of rock-fishes does not appear dependent upon the platform structure extending up to the surface (Love et al., 2012; Claisse et al., 2015). The YOY fish assemblages on the platform structures at depths that would remain after partial removal were similar to those observed on deeper pinnacle reefs and shipwrecks (structures not reaching the surface). Carr et al. [(2003)](#page30) also found that YOY rockfish were observed primarily at the midwater depths with relatively few above 85 ft.

Partial removal will likely result in a reduction over time in the thickness and complexity of shell mound habitats surrounding plat-forms and in the food subsidy associated with falling invertebrates, including a possible complete loss of this habitat (Bomkamp et al., [2004](#page30)). Shell mounds are biogenic reefs that surround some of these platforms resulting from an accumulation of mollusk shells that have fallen from the shallow areas of the platforms mostly above the depth of partial removal. Claisse et al. (2015) found that shell mounds are moderately productive fish habitats, similar to or greater than natural

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rocky reefs in the region at comparable depths. Partial removal would eliminate litter-fall of shells. While the ultimate fate of shell mound habitats after partial removal is currently unknown, Claisse et al. [(2015)](#page30) determined what additional reductions in fish production would occur if shell mounds were lost completely. The platforms with the largest relative areas of shell mounds could loose from 13 to 24% of production. The platforms with the smallest and most dispersed shell mounds could loose from 0.3 to 0.5% of production.

Potential exists to enhance or augment the habitat on the seafloor around the base of partially removed platforms in order to provide additional litter and compensate for loss of shell-fall. Larger and older rockfishes of many species tend to move deeper as they grow ([Carr](#page30) et al., 2003; Love et al., 2009b). Those on platforms are able to take refuge in complex sheltering habitats created by the large horizontal beams typically at or near the seafloor at the base of a platform ([Love](#page31) and York, 2005, [2006](#page31)). Given that in California the platform base ha-bitat (bottom 2 m) has the highest production rate of any platform sub-habitat type per unit area (Claisse et al., 2014), adding additional structure at the seafloor will likely have positive impacts on production. Seafloor habitats can be augmented by placing the partially removed platform superstructure or some other additional habitat enrichment material, e.g., mixed sizes of quarry rock or pieces of concrete, adjacent to the platform base (Love et al., 2003; Schroeder and Love, 2004; Macreadie et al., 2011). Habitat augmentation by placing the partially removed platform superstructure or some other additional habitat en-richment material on the seafloor adjacent to the base of partially re-moved platforms provides additional options to enhance fish produc-tion, potentially mitigating reductions in shell mound habitat.

CDFW recommends quarry rock or surplus concrete as both cost effective and beneficial materials for artificial reefs (Lewis and McKee, [1989](#page31)). In the Lewis and McKee study of 1989, quarry rock, at half the cost of pre-fabricated concrete boxes proved to be the most cost-effec-tive material for California's artificial reef program. Rock and concrete materials both have potential for colonization by, and production of, food organisms and are acceptable artificial reef materials. Placing a variety of smaller sizes and shapes of rock and/or concrete around the base of a partially removed platform could provide some mitigation for the loss of shell and would likely remain stable over time.

Artificial reefs are known to be aggregators of marine life and are popular fishing and diving locations because of the large numbers of fish and invertebrates attracted to the structures for habitat and food. Because of the popularity of these sites for anglers, fish mortality could increase in the vicinity of newly constructed reefs. Thus, before a reef is constructed at a given site, appropriate steps need to be taken to ensure that reef design, size, placement, and long-term management will ac-commodate the anticipated increases in fishing and other uses of the reef site (Bernstein et al., 2010).

*6.3. How and why platforms work as productive habitat*

Offshore platforms maintain highly diverse communities of fish and invertebrates, with the fish community dominated by rockfish species. These communities are similar to those on natural reefs but have greater densities of fishes, and larger individual sizes for many species, particularly mussels, sea stars, and rockfish (Love and Schroeder, 2006; Scarborough Bull et al., 2008). Platform foodwebs have not been well studied; however, because most rockfish are piscivores they are less dependent on invertebrate food sources, including those on shell mounds. The fall of organic material from the upper portion of the platform structure to the bottom helps to support shell mound com-munities. The platform structure includes habitats for both settlement and growth. Rockfish appear to settle predominantly below 85 feet and move deeper as they age (Love et al., 2003). Platforms' overall regional contribution to hard substrate is likely to be small, depending on how this is calculated, but they constitute a larger amount of the hard substrate below a depth of 150 ft (Love et al., 2003; Schroeder and

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Love, 2004). Modeling of larval dispersal suggests that platforms pro-vide an important opportunity for recruitment of fish larvae and that many larvae from the platforms would not settle elsewhere in the re-gion (Love et al., 2006). Studies of bocaccio indicate that recruitment of bocaccio to platforms constitute 20% of the average yearly, and 40% of the median, value for the entire species ([Bernstein et al., 2010](#page30)).

The two alternatives of attraction versus production are not mu-tually exclusive. It is more likely that both mechanisms are operating simultaneously along a spectrum, which may favor one over another or be in a general equilibrium, depending on the species. Hence the the-ories must be stated more specifically, especially as regards particular species, before they can be adequately tested. An issue related to evaluating the utility of platforms as habitat under the partial removal option, is the degree to which they are merely Fish Attracting Devices (FAD), a widely used role for artificial structures throughout the world, as opposed to production reefs, i.e., the attraction versus production controversy (Osenberg et al., 2002; Bernstein et al., 2010). Some spe-cies may be merely attracted to the platforms but other species may benefit from increased secondary production at platforms. The sum of the use of the platforms by the major species in the assemblage would then determine the overall relative importance of the platforms as at-tractors or producers.

At Platform Hazel schools of small pelagic fishes (Pacific sardines, jack mackerel and Pacific chub mackerel) were observed milling under the structure. Upon leaving the “shelter” of the platform, these species were frequently preyed upon by larger, pelagic predators such as yel-lowtail or Pacific bonito (Carlisle et al., 1964). It is likely that the prey species involved were primarily attracted to the structure for its phy-sical presence (shade, the added vertical dimension, or simply as a point of reference) and not because of the presence of added productivity; this is because the fishes observed feed largely on planktonic and pe-lagic prey that are not associated with the platforms. The predators, however, clearly benefitted from the fact that these species were at-tracted to the platform.

If platforms act only as FADs, then when fished they will likely decrease nearshore resources because fishing is more efficient on a concentrated population. Evidence of rockfish recruitment to the plat-forms, the presence of a range of size classes, the fact that adult rock-fishes in the bottom stratum tend to be larger than rockfishes on natural reefs (Love et al., 2003; Love et al., 2007), and the evidence of biolo-gical production on the platforms (Claisse et al., 2014, [2015](#page30)) suggest that the platforms support resident populations in substantial numbers. No doubt some species of fishes are transient and attracted to platforms for short periods of time (as they are to natural outcrops) (Carr et al., [2003](#page30); Love et al., 2003; Love et al., 2007). Studies of site fidelity of lingcod and rockfish species (Lowe et al., 2009) show there is some movement among habitats but that migration by adult rockfish is lim-ited. Hartmann (1987) showed that young bocaccio individuals tagged at several platforms in the Santa Barbara Channel were recovered on natural reefs as adults several years later, as much as 90 miles away from their original tagging site (Bernstein et al., 2010). However, there are no quantitative estimates of immigration and emigration rates that could be applied to either platform and reef communities across the region.

Oil platforms also support a wide variety of invertebrate species, both on the jacket structure and on the surrounding shell mound ([Sea](#page33) Surveyor, 2003). The attached invertebrate community varies in thickness with depth, with the thickest portion at shallower depths (Wolfson et al., 1979; CSA, 2005). This encrusting layer, which is dominated by mussels in shallow water and other bivalves, contributes to the formation of a shell mound on the seafloor bottom beneath the platform (Fig. 12). Some commercially important crab species are found in extraordinary numbers at the base of platforms and on the shell mounds (Page and Dugan, 1999). The composition, diversity, and coverage of the invertebrate community vary among platforms and with depth on individual platforms (Page and Hubbard, 1987; [Page](#page32)

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**Fig. 12.** Shell mound with economically important spot prawn, *Pandalus pla-tyceros*, and red rock crab, *Cancer productus.*



**Fig. 13.** Sea stars, *Pisaster gigantean*, feeding on mussels growing on platform leg offshore California.



**Fig. 14.** Platform Holly in state waters located about 1.5 miles west of Goleta.

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**Fig. 15.** Platforms Grace and Gail in federal waters within the Santa Barbara Channel.

et al., 2006, [2008](#page32)). Individuals on the platforms can have higher growth rates than those on natural habitats. As an example, on at least some platforms mussels and sea stars that feed on them reach sizes near their upper known limits (Fig. 13) (Page and Hubbard, 1987). Less is known about invertebrate recruitment to platforms than for fishes, al-though recruitment patterns appear to reflect prevailing oceanographic gradients ([Page and Dugan, 2000](#page32); [Page et al., 2008](#page32)).

Fish and invertebrate communities on platforms are somewhat si-milar to those on nearby natural reefs, though with some important differences in species composition and relative abundance (Carr et al., [2003](#page30)). Platforms do not support macroalgae (e.g., kelps) or many of the fish and invertebrate species associated with them (Carr et al., 2003). Platforms, particularly those located in deeper water and/or further from shore, are also underrepresented in fishes with limited larval dispersal, such as surf perches (Carr et al., 2003). In contrast, in-dividuals of several species are larger and occur at higher densities on platforms compared to natural reefs, possibly because of lower fishing pressure on platform populations (Love et al., 2003; Love et al., 2007). For example, YOY blue rockfish at Platform Holly had higher growth rates than individuals at a nearby natural reef (Love et al., 2007) and YOY of all rockfishes occurred at higher densities over a five-year period at Platform Hidalgo than at North Reef (Love et al., 2003). [Love](#page31) et al. (2003) attribute the larger sizes of adults to the fact that platforms act as de facto marine preserves that are mostly free from fishing pressure. In addition, the extraordinary abundance of YOY fishes is likely a result of the fact that platforms occupy a large portion of the midwater (> 85 ft) where pre-settlement juveniles of many rockfish species are most likely to be encountered and of the fact that there are few predators associated with the midwater portions of platforms.

The amount of connectivity in fish larval dispersal between an off-shore platform and other platforms and/or natural reefs is difficult to assess. Recruitment of YOY fish to both platforms and natural reefs varies greatly from year to year (Love et al., 2007). Because platform midwaters support a higher density of YOY rockfishes than natural reefs nearby (Love et al., 1999b; Carr et al., 2003; Love et al., 2003), it is likely that a platform's structural complexity and high vertical profile provide juvenile pelagic rockfishes (and larvae of other species) with a strong stimulus to trigger settlement (Carr et al., 2003). In addition, Love et al. (2007) showed through an analysis of fish birth dates that fish recruiting to platform habitats were most likely from the same group as those that recruited to a natural reef inshore. An indication of the potential value of offshore platform habitat to the regional eco-system is the finding that juvenile bocaccio (and likely other species of *Sebastes* spp.) settling on a platform would otherwise have been trans-ported offshore and perished, as opposed to finding a natural reef (Emery et al., 2006). Because the majority of rockfish settlement on the platforms appears to take place below 85 ft (Love et al., 2003, [2006](#page31); Nishimoto et al., 2008), the partial removal decommissioning option would not greatly affect platforms' function as a potential settlement habitat of last resort. On the other hand, limited data on regional re-cruitment make it impossible to estimate what proportion of total re-cruitment in the region this represents.

*6.4. Conservation of fisheries*

Platforms on the OCS off California will soon end their services as hydrocarbon producers and it is possible that many could be removed within a relatively short time frame (McGinnis et al., 2001). Relatively little research has been conducted on the effect of platform removal on fish populations not living on the effected platform. As noted pre-viously, rockfishes of many species are a major component of the Ca-lifornia platform fish assemblages. Therefore, what might be the effect from these removals on rockfish populations? This question exists against a background of intense overfishing of many rockfish species in the 1980s and 1990s. Examples of the severity of this overfishing in-clude the Pacific Fishery Management Council (PFMC) describing both bocaccio and cowcod as historically overexploited (MacCall, 2003; [Love](#page31) and Yoklavich, 2008). In January 2001, NOAA Fisheries received a petition to consider listing bocaccio under the Endangered Species Act (Act) and although not listed under the Act, bocaccio, cowcod, and other rockfish species have been listed as species of special concern (NOAA, 2004). In 2002, the PFMC and the State of California began to restrict targeted fishing for these and other rockfish species. In addition, the State of California banned the trawl fishery for spot prawn in April 2003, in order to eliminate bycatch of bocaccio.

Although PFMC has not recognized Pacific offshore platforms as Essential Fish Habitat (EFH) for any fish, they have recognized existing platforms as important habitat for some rockfishes and began to con-sider the creation of artificial reefs from platforms at their March 2004 meeting (Helvey, 2002; PFMC, 2004). The PFMC considered the des-ignation 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 des-ignation 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. It is possible that this lack of support derived from a reluctance by NOAA to designate artificial, man-made structures as part of EFH, even for overfished species under re-building restrictions from NOAA itself.

Several studies have focused directly on the greater role that California platforms might play as rockfish habitat. Perhaps the most important of these is (Love et al., 2006). This study examined the effect on the bocaccio stock of the estimate 430,000 YOY bocaccio observed around eight platforms in the Santa Barbara Channel in 2003. It was determined that 1) these YOYs represented about 20% of the average number of bocaccio that survive annually for the full geographic range of the species and that 2) with average survivorship, these juveniles would add nearly 1% to the total number of adults needed to rebuild the species' population.

In addition, the fact that platforms often have higher densities of large rockfishes than do nearby natural reefs (M. Love, unpub. data) implies that larval export from platforms, on a per area basis, may be more important at the structures compared to many natural sites. [Love](#page31) et al. (2005), calculated the potential egg output from adult bocaccio and cowcod at the base of five platforms offshore California, which

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includes only the bottom and less than 15 ft of the water column above, and the density and potential egg output of adults of the same species at 25 reefs in the Santa Barbara Channel region. The natural reefs were equivalent to a platform base in general location, depth, and vertical relief, but were larger in area. At each site, adult densities and size frequencies were calculated. Using known length-fecundity relation-ship, the potential egg output per individual was estimated. Comparing densities and egg output per individual, the study computed the total egg production and potential larval production per square meter at each site. For both bocaccio and cowcod, the mean potential larval produc-tion was significantly greater at the platforms (Love and Schroeder, [2006](#page31)).

That possibility becomes even more important when considering that rockfishes are live bearers whose fecundity increases with age (Love et al., 2002). There is evidence that older, larger female rock-fishes produce larvae that withstand starvation longer and grow faster than the offspring of younger fish (Berkeley et al., 2005). The higher densities of large, reproductively mature rockfishes (e.g., bocaccio and cowcod) at the base of some Pacific platforms compared to the reduced densities of these at many natural reefs indicates that those rockfish adults at platforms may produce more fit larvae that would have an effect on local and perhaps regional populations (Love et al., 1999b, [2001](#page31); [2003](#page31); [Butler et al., 2003](#page30)).

Thus, although their influence on the conservation of rockfishes (and perhaps other species) has been unintentional, without the op-portunity to reef at least some Pacific platforms using partial removal (no explosives), there may be important ecological results from the total removal of platforms off California. Perhaps the most important con-sequence may be a change in local and regional fish production (the biomass of fish accrued per year) and the composition (i.e. relative abundance) of the regional fish assemblages, both of which may in turn influence yields to fisheries (Carr et al., 2003). Parenthetically, [Polunin](#page33) and Roberts (1993) note that the total reproductive output of relatively small habitats harboring larger females could possibly be as or more productive than much larger areas harboring more but smaller females.

**7. Discussion and considerations**

To date, Louisiana, Texas, and Mississippi have successfully ad-ministered state artificial reef plans that include RtR. The artificial reef coordinators assess the interest of their respective states in acquiring oil or gas structures offered for artificial reef development, work with the structure operator (or agent) in securing any permit required under statutes administered by the USACE (including Section 10 of the Rivers and Harbors Act), negotiate an agreement for a structure donation, and accept title and responsibility on behalf of the state for the structure as a permanent state-approved artificial reef. The CDFW has an artificial reef program that began in the 1960s that is mostly inactive now, and the state enacted the MRLA in 2010 that allows consideration of RtR for decommissioned platforms. No platforms have been decommissioned, removed, or reefed since the state legislation of 2010.

The artificial reef complexes created from offshore structures in the Gulf of Mexico and the Southern California Bight are useful as fisheries conservation tools, but in different ways. The extensive array of nearly 3000 Gulf of Mexico structures raises the carrying capacity of fish species that associate with hard substrate. The offshore structures lo-cated in the Southern California Bight are rarely fished and therefore act as de facto Marine Protected Areas and provide ecological benefits for severely overfished species including a higher potential larval pro-duction when compared to nearby natural areas that are fished. Compared to the Gulf States, California has limited experience and limited industry infrastructure to decommission obsolete platforms, especially in deeper water. However, it is likely to be the first region where large deepwater platforms will be decommissioned, and unlike the Gulf of Mexico, California stakeholder views are highly contentious and divided (see Manago and Williamson, 1998; McGinnis et al., 2001).

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There are two different decommissioning options, total or partial, for California platforms and each will result in an array of environ-mental and socioeconomic impacts, some positive and some negative. These impacts, and their costs and benefits, will be perceived and va-lued differently by stakeholders with differing perspectives. For ex-ample, some will see the need to decommission platforms that have reached the end of their useful production lifetime as an opportunity to fulfill operators' original lease obligations and remove these large structures from the ocean, thereby restoring the seabed to its original, natural state. That is the existing state and federal regulation, although this requirement is obviously suspended for the reefing option. Decommissioning can also be viewed as an opportunity to provide a chance to preserve a large part of the biological communities that in-habit offshore platforms, thus conserving an ecological resource that contributes to biological production locally and regionally. Finally, decommissioning may be an opportunity for the state to achieve fi-nancial benefit through its share of avoided decommissioning costs, thus increasing resources available to support efforts that produce en-vironmental and socioeconomic benefits ([Bernstein et al., 2010](#page30)).

Research by Love et al. (2005, [2006](#page31)) also found evidence that, in general, platforms harbored higher densities of YOY rockfishes than did nearby natural outcrops or, indeed, most other outcrops surveyed in central and southern California. The studies pointed out that platforms occupy more of the water column than do most outcrops, and pre-set-tlement pelagic juvenile rockfishes are much more likely to encounter these tall structures than the relatively low-lying natural reefs. The researchers also observed that many of the major predators of young rockfishes are species that live and stay close to the bottom and that, in general, these species do not ascend the platform jacket up into the water column and are generally absent from the midwaters occupied by the YOY recruits.

High rates of fish production per unit area of seafloor for the com-plete platforms are achieved because the platform jacket (horizontal crossbeams and vertical pilings) and oil and gas conductors create a complex structure that provides a large underwater surface area of hard substrate throughout the water column (see Figs. 1 and 2). A high ratio of platform structural surface area to seafloor surface area creates large amounts of habitat available to juvenile and adult demersal fishes over a relatively small footprint of seafloor. Additionally, if artificial struc-tures are designated as no-take areas, then the attraction–production issue may cease to be relevant. This is because attraction draws fish from the surrounding areas and may make it easier to exploit them. Protected reefs serve to export biomass through spillover and larval export (Polovina, 1989). Many operational offshore structures asso-ciated with energy production, including some of the platforms in Ca-lifornia, currently function as “de facto marine reserves” due to the difficulties of fishing them or security regulations that limit some fishing vessel access all together ([Claisse et al., 2014](#page30)).

If a Fishery Management Council designates, with NOAA approval, an oil and gas structure (or other artificial structures) as EFH HAPC, NOAA and the Council are required to consider actions to minimize the adverse impacts of fishing activities on such EFH. Additionally, a fed-eral agency would be required to consult with NOAA if that federal agency proposes to authorize, fund, or undertake an activity that may adversely affect the designated EFH. If a federal agency proposes to remove an oil and gas structure which had been designated as EFH, NOAA is required to provide recommendations to the federal action agency (in this case, DOI) to conserve the EFH, minimize the adverse impacts of the proposed removal, and/or compensate for any adverse impacts of the removal. NOAA's EFH conservation recommendations are advisory in nature and do not displace the jurisdiction, responsi-bilities, and regulatory oversight roles of BOEM, BSEE or the USACE which apply to these structures. In 2006, the PFMC recommended that 13 of the 23 offshore platforms in federal waters be designated as Habitat Areas of Particular Concern (PFMC, 2006); however, NOAA did not approve the designation. The 13 platforms were the most surveyed

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at the time and were in water depths greater than 300 ft located off-shore San Luis Obispo, Santa Barbara, and Ventura Counties.

Platforms converted to artificial reefs could be subject to fishing pressure that would reduce the fish populations that remained after partial removal. While CDFW could restrict fishing by California re-gistered vessels on state-owned reefs in federal waters, it is likely that such restrictions would not apply to out-of-state vessels ([Bernstein](#page30) et al., 2010). In addition, any specific restrictions must not conflict with provisions of the federal Magnuson-Stevens Fishery Conservation and Management Act or regulations established by the PFMC. PFMC has not designated platforms as EFH HAPC or focused fishery regulations spe-cifically on platforms. Restrictions on fishing activity on the artificial reefs might be seen to conflict with the intent of the NFEA, which provides the legal mechanism for transferring platform ownership to the state (or other entities) for the purposes of creating artificial reefs to improve fishing. Despite these potential legal issues, sportfishing groups in southern California have publicly confirmed on several occasions their willingness to accept certain fishing restrictions that would maintain the biological productivity of the platforms and protect po-pulations of overfished species ([Bernstein et al., 2010](#page30)).

A major question related to the partial removal option is the amount of biological production associated with platform communities. Using data from platform monitoring surveys, Claisse et al. (2014) conducted population dynamics modeling of fish communities on eight platforms with data adequate for the modeling analysis. While this analysis re-sulted in quantitative estimates of production, data gaps prevented quantitative comparisons of platform production to that in other com-munities and ecosystems in southern California, or any rigorous esti-mate of the overall contribution of platform communities to the re-gional ecosystem. Nishimoto and Washburn (2002) also conducted modeling of larval dispersal patterns that suggested platforms can function both as sources and as sinks, or recruitment locations, for fish larvae in the region.

With the passage of the MRLA in 2010, 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. One of these criteria is a finding that conversion to a man-made reef would provide a “net benefit” to the environment as com-pared to removal of the facility (MRLA, 2010). The determination of what constitutes a “net benefit” is still under consideration, and therefore there is a critical need to understand the biological pro-ductivity of these structures and how partial removal may impact as-sociated processes. Fowler et al. (2014) evaluated one of the platforms off the coast of California (Platform Grace) as a case-study of their proposed “multi-criteria decision approach” to determine a preferred decommissioning option. During this process, ‘production of exploitable biomass’ and ‘provision of reef habitat’ were ranked by expert opinion as the most important criteria in the decision for this platform. There-fore, 1) given the quantity of biological information now available for platforms in California (Love et al., 1999a; Love et al., 2003; [Schroeder](#page33) and Love, 2004; Love et al., 2006; Scarborough Bull et al., 2008) and 2) the likelihood that the Pacific may be the first region where platforms in deeper water are going to be decommissioned (Schroeder and Love, [2004](#page33)), the process in California has an opportunity to serve as a model for decommissioning elsewhere globally.

Complete platform removal will destroy all sessile invertebrates, kill cryptic fish and most invertebrate species, and the majority of all fishes associated with the platform. Should fish not die from explosives and/ or mechanical removal of habitat, they would have to disperse widely to seek another reef habitat (Scarborough Bull et al., 2008). Likely during dispersal, larger fish, if they can find and settle at a suitable reef, may face additional competition for resources. Whether displaced fishes would then suffer higher recreational or commercial fishing mortality in comparison to the platform would depend on the existing fishing pressure on the natural reef and whether it is within a pre-existing Marine Protected Area that precludes fishing.

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The ultimate outcome of the partial removal option is less certain. Monitoring data at many of the platforms show that fish communities on the platforms, particularly of rockfishes, are at higher densities and contain larger individuals than seen on natural reefs. In addition, stu-dies have shown that YOY rockfishes are also present in much higher densities on some platforms than on natural reefs. Partial removal will leave intact much of the fish community, particularly rockfishes, al-though organisms attached to the upper portion of the platform would be lost. Recent data also show that YOY rockfishes recruit almost ex-clusively below the 85 ft cutoff depth envisioned for the partial removal option. As a result, this option would most likely not eliminate plat-forms' function as a nursery area for juvenile fishes, particularly rock-fishes ([Bernstein et al., 2010](#page30)).

Because 85 feet is the most probable depth at which the platform would be cut off under the partial removal option, and most rockfish settlement appears to occur at and below this depth, partial platform removal would not eliminate the platforms' potential nursery function (Claisse et al., 2015). Partial platform removal would destroy sessile invertebrates on the upper section of the platform, while fishes in this portion of the structure would have to move down the platform or possibly disperse to inshore shallow habitats. Whether or not these fishes would survive, is questionable. These fishes would also likely face increased competition for resources. Partial removal would retain the existing community below 85 feet with production reduced sub-stantially only for the shallower platforms or if unrestricted recreational fishing occurred.

The removal of oil and gas platforms offshore California is im-minent. Consideration of whether to completely removal a platform or cut it off at some depth below the sea surface and retain the jacket as a reef is no longer a decision for California citizens that will occur in the distant future. Among the platforms off California, Platform Holly > (Fig. 14) in state waters, and Platforms Grace and Gail (Fig. 15) in federal waters, are undergoing the initial steps for decommissioning now. The decommissioning process is expensive, complex, and lengthy. Due to the intricate planning and complex technical challenges that are involved, it is probable that more platforms will soon be considered for decommissioning, likely Hildago, Harvest, and Hermosa in the Santa Maria Basin, while removal equipment, engineers, and infrastructure are underway for Holly, Grace, and Gail in the Santa Barbara Channel.

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