Title

A Review of California's Artificial Reefs: To Help Inform Future Development of a Statewide Management Plan.



Author
Hunter, Liz

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# A REVIEW OF CALIFORNIA'S ARTIFICIAL REEFS:

## To help inform future development of a statewide management plan.


**STUDENT NAME**: J. Liz Hunter

**DEGREE NAME**: Masters of Advanced Studies Marine Biodiversity and Conservation

**DEPARTMENT**: Scripps Institution of Oceanography

**INSTITUTION**: University of California San Diego


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**COMMITTEE CHAIR**: Ms. Catherine Courtier
Research and Extension Analyst- Science Integration Team
California Sea Grant

*Catherine A. Courtier*

**COMMITTEE MEMBER**: Mr. Brian Owens, Senior Marine Biologist, Specialist
Habitat Conservation Program, Marine Region
California Department of Fish and Wildlife (CDFW)

*Brian Owens*

**COMMITTEE MEMBER**: Dr. Lyall Bellquist
Fisheries Scientist, California Oceans Program
The Nature Conservancy

*Lyall Bellquist*

**COMMITTEE MEMBER**: Dr. Richard Norris
Geosciences Research Division
UCSD Professor of Paleobiology

*Richard norris*

## Abstract

The California Department of Fish and Wildlife (CDFW) has been involved in the construction of artificial reefs (ARs) since the 1950s. Then in 1985, the California Artificial Reef Program (CARP) was created by legislative statute to address declines in various southern California marine species. The CARP is managed by CDFW but no longer receives funding to manage this program. Before CDFW can support further creation of ARs we need to identify gaps in the program and know how ARs affect marine species and the marine ecosystems. This will ultimately inform a scientifically based statewide AR management plan, which CDFW needs to support in the program. The first step into making informed management decisions of the ARs is to complete a literature review of published material and to survey the type, number, and placement of ARs. The results of this survey need to be standardized and transparent in order for the CDFW to review, compare, and make informed management decisions. Some critical data to include in the surveys will be reef attributes (the quality and specific features of the reef), fish density, biomass, and the assemblage of the AR structure. Identification of gaps in the CARP and the organization and standardization of timely and regular AR assessments will then allow resource managers and stakeholders to use the best available science to make the most informed management decisions possible.

With the ocean continuing to warm and acidify and the world population continuing to increase, fish populations and marine ecosystems are at risk and face unforeseen dangers, including the reduction of fish stocks and the degradation of marine habitat. Rebuilding depleted stocks typically involves conventional fisheries management approaches, such as seasons, quotas, size limits, gear restrictions, MPAs, or even fishery closures. The concept of stock enhancement has been debated as another potential tool in the fisheries management toolbox, and may be possible with the successful implementation of CA's ARs. CDFW has been involved with the AR program for decades but currently has no statewide management plan to guide placement, development, and testing of AR effectiveness and functionality.

## Background

The CARP is mandated to include: a) the placement of ARs in state waters; b) science-based design criteria needed for ARs capable of increasing fish and invertebrate production; and c) a determination of the requirements for reef design. CDFW has management responsibilities under CARP and as a Trustee Agency the State's natural resources.

Currently there are over 30 known ARs off California. A variety of materials were used in their construction, with most containing quarry rock, and some reefs were made with concrete rubble, pier pilings, car bodies, tires, street cars, and some ships. Many of the ARs were originally constructed with the goal of enhancing species that were popular with the sport fishing community. No formal monitoring program exists to study the biological communities on and around ARs; however, there has been some informative research and studies on ARs in California and around the world. Specifically in California, there have been some independent researchers, including Vantuna Research Group (VRG) with Occidental College, who have collected data including both fish only surveys (1996 through 2006) and CRANE surveys (2004 through 2018) of 29 different sites in Southern California. CRANE surveys collect data visually by SCUBA divers that access sample sites from four different depth strata: the inner (5 meters), the middle (10 meters), the outer (15 meters), and the deep (20-25 meters). Within each depth strata two benthic sampling protocols are used: Uniform Point Contact (UPC) and Swath. See enclosure (1) for surveying history and VRG's CRANE sampling protocols.

Today, key outstanding scientific questions remain unanswered, and there is a need for a comprehensive statewide management plan for the placement of ARs in state waters. This paper and capstone project will aim to set the foundation for this plan, and will assist CDFW with the improvement of the management program by providing them with an interactive GIS Story Map, an annotated bibliography of the 41 references reviewed, a Point of Contact (POC) list, and this paper.

**Introduction**

In this paper an analysis of conclusions and recommendations will be made, which will include gaps in science relevant for the CARP. Forty-one documents and journals were reviewed and annotated to produce a 25-page annotated bibliography. See Enclosure (2). The literature and research specifically targeted California, but journals that studied locations with a similar temperate climate (i.e. Australia, Canada) were also included. The topics and questions below, drafted by CDFW, were the four focus areas of the literature review:

1. **Habitat Replacement:** What is the tradeoff for the affected communities by replacing soft bottom habitat with hard bottom habitat? Does placing hard bottom habitat in areas with expansive soft bottom habitat (i.e., islands of reefs amongst large areas of sandy bottoms) disrupt soft bottom community migration and dispersal patterns? Does placement of an AR impact sediment transport or recruitment?

2. **Contribution to the Standing Stock:** What proportion of biomass do ARs contribute to the standing stock of a given population and how large would an AR need to be to be able detect that it is contributing to the overall standing stock of a given population in a given bio-region?

3. **Management of the Reefs:** Should newly developed reefs be open or closed to fishing initially? Are there other limits that should be in place to ensure the reef maximizes its potential with limited targeted removal from fishing? Is there evidence that ARs support coastal fisheries in CA?

4. **Lessons Learned Review:** What lessons learned from all the work that has been done (synthesize this information down through a literature review), what have they learned from the construction of these, and how has the design affected reef production/attraction?

**Habitat**

Our California coastline has continued to change over the years and the rocky reef and giant kelp forest habitats have significantly decreased. Recovering these habitats and mitigating any negative risks are paramount to a healthy marine ecosystem. Historically, California ARs have been used to enhance fishing opportunities; however, ARs are being designed and constructed around the world to assist in habitat recovery. Many of these ARs are designed to mirror the habitat that is surrounding them. Ruhl et al. [24] states that since "habitat characteristics are major drivers of the structure and function of animal communities, the design of ARs should mimic that of the environment that they are intending to rebuild."

Most of California's ARs replace soft bottom habitats with hard structure. But placing hard bottom habitat in areas with expansive soft bottom habitat may disrupt soft bottom community migration and dispersal patterns; like most management tools, there are tradeoffs. For the marine communities, more published literature and research should be completed to help define what effects replacing soft bottom habitats with hard bottom habitats have on marine communities. Placement and location of an AR can also impact sediment transport or recruitment. Both of these topics need further research and review, this was an informational gap found in the review.

Many papers stated that hard substrate or structure did provide a healthy marine ecosystem. Jessee et al. [18] initially reviewed the Pendleton AR (PAR) in 1985 and thought PAR "attract fish for two reasons: physical structure and because it produces food for fish feeding from hard bottoms." There is a good quantity of literature on the San Clemente AR (SCAR) which was constructed to mitigate the anthropogenic impacts of the San Onofre Nuclear Generation Station (SONGS). The SCAR led to the eventual development and continued construction of the Wheeler North Artificial Reef (WNAR). The results from Reed et al. [33] indicated that all configurations of the SCAR experimental phases of reef material and bottom coverage tested provided suitable habitat for kelp forest fishes.

There also exists an ample amount literature on oil and gas platforms, largely with regard to the Gulf of Mexico. While oil and gas platforms were not the focus of this review, but some literature with regards to California's oil and gas platforms were reviewed due to their similarity as artificial structures. The National Oceanic and Atmospheric Administration (NOAA) [28] stated that "as potential stepping-stones for the expansion of various living resource communities […] there was an increase in rockfish at oil and gas platforms when compared to populations found nearby natural reefs which was thought may be attributed to the platform serving as a nursery, assisting with larval production and therefore juvenile growth rates."

As with any foreign object put in the body, there is a risk of infection. The ocean is no exception to this, and as such, objects should be considered carefully and risks researched before any material is placed there. Dafforn et al. [10] studied the presence of alien marine species on static (immobile) AR structures in Australia, and stated that "although there are exceptions, a large majority of marine alien species seem to be associated, at least for some of the time, with artificial structures." In California, Mineur et al. [27] found alien species on offshore platforms to include Bryozoa (*Watersipora subtorquata*), Bivalvia (byssate) (*Mytilus edulis*), and Crustacea, Amphipoda (*Caprella mutica*). Daffon et al.'s [10] study out of Port Jackson, Australia found "that non-indigenous species are less successful at occupying space on reef compared to artificial structures, and manipulations of biotic and abiotic conditions (primarily orientation and to a lesser extent biotic resistance) on experimental 'reefs' explained a large portion of this variation."

**Stock**

Understanding what proportion of biomass ARs contribute to the standing stock of a given population will assist in calculating how large an AR would need to be to be able to detect a contribution to the overall standing stock of a given population in a specific bio-region. This was not specifically discussed in any of the literature reviewed and is another informational gap that was identified.

Granneman et al. [16] detailed five of California's ARs: Topanga (Santa Monica), San Clemente/WNAR, Pendleton, Torrey Pines, and Pacific Beach. Granneman et al. [16] found that "fish species richness was not significantly different between artificial and natural reefs, but density and biomass tended to be higher on average on ARs, body size was slighter smaller, and assemblage structure differed between the two reef types." In general, the ARs reviewed by Granneman et al. consisted of larger boulders, extended higher off the seabed, supported less giant kelp, harbored more invertebrates, and had a higher rugosity. In this sense, rugosity is a measurement of the surface roughness that is evaluated as one of the physical characteristic of ARs. Granneman et al. [16] results supported that if ARs are constructed to mirror the physical characteristics of natural reefs, then they can support fish assemblages similar to those on natural reefs. This was supported by some observation by Granneman et al. [16] who found that ARs "can even be made to exceed natural reefs in some regards at the expense of other biological attributes."

Some species commonly found on or around ARs off the coast of California include kelp bass (*Paralabrax clathratus*), barred sand bass (*Paralabrax nebulifer*), California sheephead (*Semicossyphus pulcher*), barred surfperch (*Amphistichus argenteus*), redtail surfperch (*Amphistichus rhodoterus*), cabezon (*Scorpaenichthys marmoratus*), sculpin (*Scorpaena guttata*), rockfish (*Sebastes constellatus*), blacksmith (*Chromis punctipinnis*), garibaldi (*Hypsypops rubicundus*), plainfin midshipman (*Porichthys notatus*), opaleye (*Girella nigricans*), halfmoon (*Medialuna californiensis*), and invertebrates; including lobster (*Panulirus interruptus*), sea urchins (*Strongylocentrotus purpuratus*), crabs (*Loxorhynchus grandis*) and scallops (*Crassadoma gigantea*). The links supplied both in this paper and on the interactive Story Map (see Figure 1 and Deliverables section) give additional information on each species, specifically the CDFW's 2019 Enhancement Status Report.

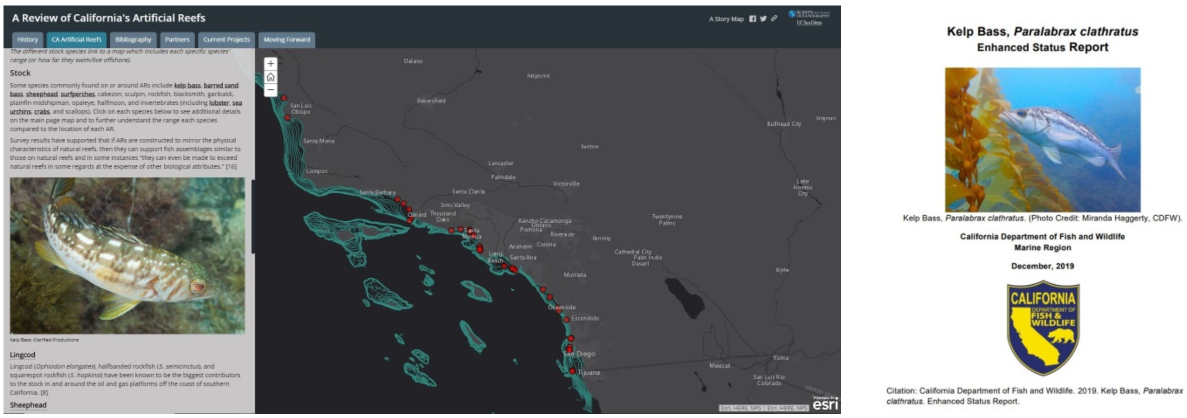

*Figure 1: Story Map associated link for the Kelp Bass to the Enhanced Status Report*

Oil and gas platform are not part of the CA AR program and were never designed to intentionally be reefs. However, some literature was reviewed with regard to these foreign structures off the California coast. In relation to stock, a study by Claisse et al. [8] that looked at secondary production of oil platforms off the coast of California. The study area included 16 platforms off the Santa Barbra and Palos Verdes coastline and seven natural reefs which were surveyed for at least five years (some up to 15 years) between 1995 and 2011. Claisse et al. [8] found that these platforms "have the second highest secondary fish production per unit area of seafloor of any marine habitat that has been studied." The increased fish production on these platforms seemed to have resulted from high levels of recruitment and growth of primarily rockfish (genus *Sebastes*). The annual secondary production or "Total Production" was calculated by summing "Somatic Production" (difference between observed biomass and the biomass predicted 1 year later) plus "Recruitment Production" (estimation of growth production of post-larval and pelagic juvenile fishes). Secondary production was studied because it incorporates multiple characterizes of a population or community of organisms (including density, body size, growth, and survivorship). In addition, Claisse et al. [8] point out that "understanding the local and regional oceanography related to larval fish delivery will be an important consideration in terms of how structure location influences fish production."

To review stock in an interesting and informative manner, I chose to incorporate three specific species important to local fisheries and their habitat into the AR Story Map. These species included Lingcod (*Ophiodon elongates*), California Sheephead (*Semicossyphus pulcher*), and White Seabass (*Atractoscion nobilis*). Claisse et al. [8] found lingcod (*Ophiodon elongates*) to be one of the bigger contributors to the stock in and around the oil and gas platforms off the coast of southern California. Interestingly, Granneman et al. [16] found small reefs to provide better habitat for ecotone specialists, such as California Sheephead, which were significantly more abundant on ARs than on natural reefs. An ecotone in this context refers to two overlapping marine communities. Logan el at. [23] studied stock on the WNAR site and then compared it to three nearby natural reefs in San Clemente, CA; San Mateo Kelp Bed, Barn Kelp Bed, and Trestles Reef. DeMartini el at. [12] found that California Sheephead was also one of two species, which compromised the majority of the tagged fish at Torrey Pines AR (TPAR) in 1994, where he found them to have relatively high growth rates and somatic production values. The White Seabass was another identified gap of knowledge, no articles or journals were found that examined this species with relation to any ARs.

## Management

Parnell [29] recommended that for enhancement of fish production in southern California utilizing ARs to be effective, a staged process should be used. After completing this literature review I believe a topic worth discussion and further review would be the initial opening or closure of newly developed ARs to fishing, both commercially and recreational. Wilson et al. [40] found that a timeline of five to ten years is usually observed to achieve equilibrium of ARs. Wilson et al. [40] defines equilibrium in this context as when a “natural situation is attained and the plant and animal populations on man-made reefs exhibit fluctuations typical of 'natural' reef ecosystems.”

Becker et al. [3] recommended setting clear, specific, and quantitative goals to include biological, social, and economic strategies and believed that this could fuel the broader application of ARs in fisheries management. Becker et al. [3] reviewed 270 articles to determine if current monitoring methods met the AR goals and found only 62% of these studies clearly defined the initial goals of the reef. An aquaculture-based fisheries framework was then recommended to quantitatively monitor AR performance and can be summarized below into six steps:

1. Use science (before establishing an artificial & in the mgmt. of our current ones).
2. Establish clear and quantifiable goals (for each reef).
3. Implement a consistent monitoring method (this way data can be compared and the ARs can be evaluated to understand if it has meet its original goal).
4. Mitigate any negative impacts (to both the current marine life and environment).
5. Complement other fisheries management measures (including Marine Protected Areas and seasonal closures).
6. Manage adaptively (review this process every five years to ensure its still working, ensure process is repeatable and transparent both to managers and the public)

With regards to Step 1, Davis et al. [11] examined a site in Port Stephens, Australia and recommended a detailed understanding of seabed structures for management purposes, and offered the solution of using sonar technologies to map out the site before any construction. The planning stage of any marine parks and/or ARs where protection of fish biodiversity is an objective or goal is critical. In Claisse’s et al. [8] paper, it was suggested that if oil and gas platforms (or other types of ARs) are designated as no-take areas, then the attraction versus production debate may cease to be evident. Step six will most likely prove to be the most challenging step since most monitoring programs only have funding for one to three years, when the reality is that a ten to 15- year duration is truly needed to understand the full picture of how the marine environment has been affected by the AR.

Wilson et al. [41] stated that the “success of habitat enhancement operations and, particularly, reef construction and study program depends upon the cooperation and support of governmental agencies, the legislature, academic institutions, industry, fisherman, and general public. Through team effort, [CDFW] can undertake a program of sufficient magnitude to contribute, meaningfully, to the maintenance and replenishment of California’s nearshore living marine resources.”

Another gap identified is lack of evidence that ARs support coastal fisheries in CA. As in many environmental situations, the cost of the construction of an AR is easier to quantify than the benefits of an AR. Unforeseen and intangible externalities, or consequences, of an AR could include both positive and negative effects on other marine communities. The cost of ARs was defined originally with the first ten large quarry rock reefs, beginning with PAR. Lewis et al. [22] stated that these ARs, which had been built from San Luis Obispo to San Diego, cost an average of $275,000 (in 1980) for the construction of each (estimated at approximately $906,000 today). However, can we quantify the benefits in the same monetary manner with regard to the fishing community or marine habitats? A cost-benefit analysis was completed for San Diego's YUKON AR with regard to recreational diving quantifiable metrics. Pendleton [30] stated that the San Diego Oceans foundation estimated that 10,000 divers made 26,000 visits to the Yukon AR site between August 2002 and August 2003. Pendleton [30] also stated that the Yukon generated anywhere from $600,000 to over $2 million in local expenditures annually. In California, McGinnis et al. (2001) calculated that the average per person-day expenditures of divers visiting oil rigs was $64, with a total annual value of $10,700. The Yukon cost more than $400,000 to acquire, prepare and sink and costs more than $1,000 annually for basic maintenance. Moving forward research for a full cost-benefit analysis could assist in the management of California's ARs and is currently a gap in knowledge based on this literature review. An accurate cost-benefit analysis of ARs could be weighed and considered in conscious decision making about policy and management of an AR statewide management program.

**Lessons Learned**

Japan has used ARs for over 500 years. In the U.S., ARs have only been used for a fraction of the time, approximately 170 years. Throughout history, ARs have seemingly always been recognized for attracting fish; however, fish production on and around ARs is still not clearly understood. Lewis et al. [22] stated that "Japanese scientists found that fish attraction was generally greatest in those reefs with the highest profile to water depth ratio." These early Japanese ARs were built tall and open with prefabricated reef structures; the structures provided high relief and little surface area. Similarly, Lewis et al. [22] stated that "California species are also attracted to high volume, low surface area reefs. To overcome this potential problem, DFG biologists design reefs which will not only attract fishes, but will provide them with adequate habitat for shelter, forage, growth, and reproduction, thereby, increasing fish production." Moving forward, both biologists and the whole design team (architect, engineer, research team, etc.) should communicate and design in a way that provides habitat and allows the AR to meet its end goal, being aware of a suite of considerations that need to be taken into account such as the appropriate profile depth ratio and adequate habitat criteria.

Wilson et al. [41] looked at AR restoration efforts in Hong Kong and stated that "successful implementation of the 'no-take' zones should be established with representatives from the fishing community, the government, and academia." These restoration efforts included choosing specific locations to place ARs and then established those locations as 'no-take' zones to assist in fisheries restoration. Wilson et al. [41] explains that "modeling results indicate that AR deployment, utilizing 10-20% of local waters managed predominately as no-take zones, could arrest the current decline in fisheries yield and produce significant improvements within ten years." The ten year timeline is not complete, but preliminary results are trending in the right direction.

There was some literature which recommended the use of Reefball® modules. Reef Balls are AR modules that are designed to create an aquatic habitat and the organization strives to achieve this in an environmentally compatible way. In particular, Folpp et al. [15] examined fish assemblages on estuarine ARs at three locations in Australia including Lake MacQuarie (a source of cooling of three power stations) Botany Bay, and St. George's Basin. The performance at each location was evaluated using a baited remote underwater video (BRUV) and were assessed 18 months after the ARs were established. Folpp et al. [15] stated that the Reef Ball® modules had been successfully used in other parts of the country as well in Victoria, Queensland, and Western Australia. Mills et al. [26] also discussed the use of Reef Ball® modules in Phillip Bay in south-eastern Australia, another temperate ecosystem. They conducted a before-after-control-impact experiment of a small-scale AR and the data was compared to three control sites with no reef and three different control sites with natural reefs. BRUVs were again used as well as underwater visual census (UVC) a methods to monitor and detect fish assemblages that can be adapted to recognize fish abundance, body-size, and behavior), and surveys were conducted six months before the ARs were constructed and then again 22 months after the AR deployment. In this study, two to five Reef Balls® used were arranged in a regular array to increase their footprint and increase the sediment to reef edge ratio. This type of design was used because it was considered a suitable habitat for their targeted species the snapper (*Chrysophrys auratus*) as they prefer both sediment and reef habitat. Overall, Mills et al. [26] found that "the deployment of patchwork ARs increased species diversity and abundance of fish, and did not impact existing sediment fish assemblages." Reviewing literature on Reef Balls® was done to understand the differing options available and the variance in reef complexity and doesn't represent a stance on the appropriateness of using these artificial structures in California waters.

The use of 3-D printing was used in the development on ARs in the South Pacific Ocean, on the island of Fiji. Ruhl et al. [34] "demonstrated that complexity plays an important role in determining habitat associations and subsequent behavior of the coral-associated damselfish, *Pomacentrus moluccensis*." Ruhl et al. also stated that "habitat characteristics are major drivers of the structure and function of animal communities, [thus] the design of ARs should mimic that of the environment that they are intending to rebuild."

Learning about the history of California's ARs highlighted the biggest lesson learned of all, as Wilson et al. [40] recognized 30 years ago there is a definite need to "develop a comprehensive long-term reef program for fisheries [habitat] enhancement." It is my hope that this capstone stone project and its deliverables can help assist with the foundation of a long-term California statewide management plan.

**Current artificial reef projects:**

<u>Wheeler North Artificial Reef (WNAR)</u>:

WNAR was originally built in 2008 as a mitigation effort related to the San Onofre Nuclear Generating Station to help increase the number of residential fish in the area. Today, the reef covers 174.5 acres and supports an average of about 14 tons of residential fish. That, however, is short of the 28 tons per year set by the California Coastal Commission, the governmental body overseeing the mitigation project. The expansion project started in 2018 to expand the reef by 374 acres. Physical work to expand the reef began in July 2019.

<u>Palos Verdes (PV2)</u>:

Palos Verdes Reef Restoration project's goal is to restore rocky-reef habitats and associated marine species on the Palos Verdes Shelf that were impacted by contamination in the sediments from the discharge of DDT and PCBs from the Joint Water Pollution Control Plant's Whites Point Outfall and sedimentation. This restoration project will fulfill the objective of the NOAA Montrose Settlements Restoration Program (MSRP).

**Conclusion: Recommendations for a successful way forward**

In summary the knowledge gaps identified included: what effects replacing soft bottom habitats with hard bottom habitats have on marine communities, how the location of an AR can impact sediment transport or recruitment, a further understanding of what proportion of biomass ARs contribute to the standing stock and how large an AR would need to be in order to detect contribution, and what if any affect do ARs have on the White Seabass population. In addition, a full cost-benefit analysis of the implementation of any ARs could assist in a more informed decision making process.

Unfortunately due to extenuating circumstances, the planned site visits to AR sites were limited and the timeline did not all for use of a Remote Operating Vehicle (ROV) or scientific dive surveys. A recommendation moving forward would be to complete site visits with, at a minimum, an ROV. Scripps Institution of Oceanography has this capability available through rent. It costs $150/day for the ROV equipment and $50/day for a qualified operator. The POC for the ROV is Brett Pickering. In addition, scientific divers and a boat can be rented for $30/hour plus fuel costs. Ideally, the ROV capability would be used to survey any sites 60 feet or deeper, while scientific divers would be used to complete sites less than 60 feet. Christian McDonald is the POC for scientific divers. Additionally, for semi-regular surveys of TPAR, contact Christian McDonald to use the Scientific Diver Course as a platform to gather information and visit Torrey Pines AR1 and AR2. Another option would be to contact and use The U.S. Coast Guard Blue Technology Center of Expertise (BTCOE) to form a relationship with local Coast Guard divers, whom also have ROV capability and possible training opportunities. The Coast Guard divers in San Diego are part of the Marine Safety Response Team (MSRT) West and are currently located in National City.

Data of each AR should include reef attributes (the quality and specific features of the reef), fish density, biomass, and the assemblage of the AR structure in addition to any current photographs or videos of ARs are also of assistance to confirm the current placement and condition of any AR. Any photographs or videography submitted to CDFW should include, at minimum, the location (latitude and longitude), the depth the AR was found at, any marine life (different types of species and number of each) that was observed, the temperature of the water, the date visited, and an approximate distance of visibility. As initial information is collected, a more formal survey criterion can be established and published appropriately. The results of this survey need to be standardized and transparent in order for the CDFW to review, compare, and make informed management decisions.

**Deliverables:**

In addition to this paper and its' enclosures, an interactive GIS Story Map was created using UC San Diego's account with ERSI software, and can be found: https://arcg.is/1De1a8. This Story Map includes a table of CA ARs with year built, size (acreage), type of material, depth of water, and location (latitude and longitude coordinates), see Figure 2. This visualization tools helps summarize the results of my research for the various stakeholders involved in ARs, any invested policy makers, and is informative for the general public.

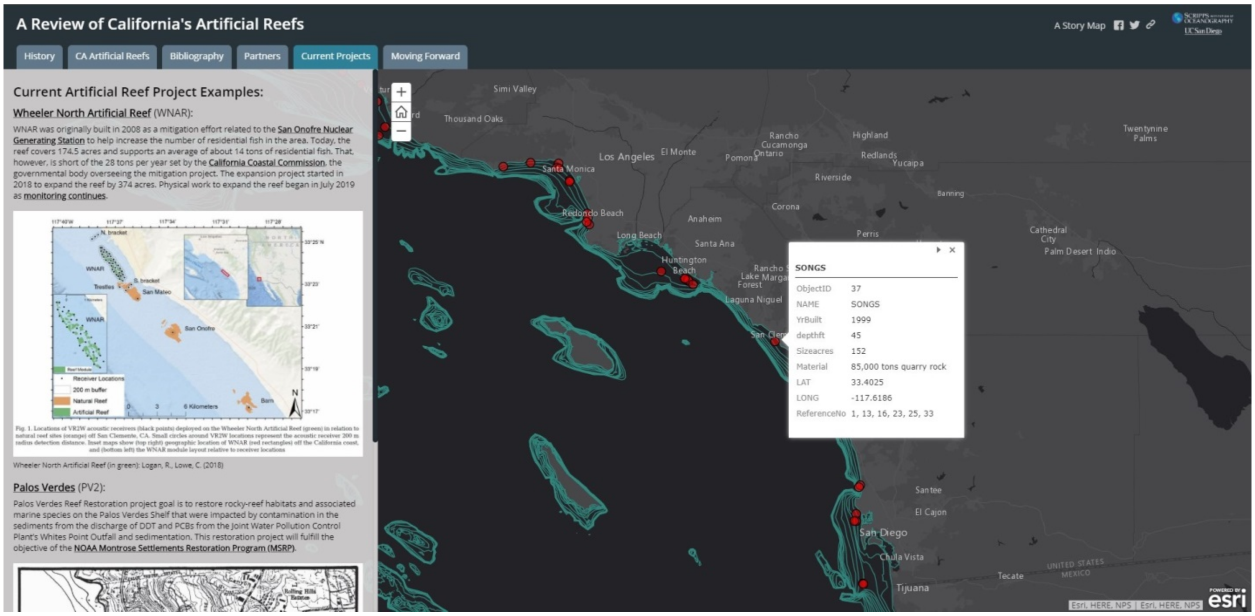


*Figure 2: Current Projects tab of the Story Map developed, displaying the basic information for an AR.*

In addition to the Story Map, this capstone project will be presented at a California AR Workshop in the summer of 2020, location and details TBD. Key stakeholders will participate in a working group meeting for the summer of 2020; due to the unforeseen COVID-19 circumstance this workshop will have to be held remotely. An in-person meeting is planned to take place during the summer of 2021. Enclosure 3 can assist in identifying any key stakeholders or invested researchers. Establishing relationships with local entities will be essential to a repeatable and sustainable management scheme. This group of stakeholders should also establish a technical advisory team to assist in future management decisions. Long term options for data collection and storage/sharing should be discussed. The workshop will be the first step in establishing an AR Scientific Advisory Group who, going forward will consider the science questions and baseline assessment through the lens of how they interact with California fisheries and the populations that sustain them. Addressing these can help narrate core components of the statewide management plan. The goal of this meeting is to leave with clear science guidelines from which CDFW can direct future work.

While the detailed agenda for the workshop is being finalized, the following is a draft list of topics to be discussed:

1. Presentation by Scripps Institution of Oceanography Masters of Advanced Studies in Marine Biodiversity and Conservation student on her Capstone project
2. Feedback and discussion of CDFW's core science questions
3. Results from the analysis of CDFW's recreational angling and diving community survey on how these recreational groups use and perceive ARs
4. Definition of a successful and/or functioning AR, from both a biological standpoint and to test against the stated purpose of the reef's development.
5. Strategies for carrying out a baseline assessment of existing reefs to look at both the physical and biological components.
    a. Data needed to evaluate that success;
    b. Data analysis methods that would best suit this evaluation; and
    c. Implications for the MPA Network when siting an AR.

**Enclosures:**

(1) VRG's surveying history and CRANE sampling protocols
(2) Annotated bibliography
(3) POC list

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## VANTUNA RESEARCH GROUP SURVEYING HISTORY

| | | | Fish Surveys Only | | | CRANE Surveys | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Latitude | Longitude | 1997-2002 | 2002-2003 | 2006 | 2004 | 2007 | 2008 | 2009 | 2011 | 2012 | 2013 | 2015 | 2016 | 2017 | 2018 |
| Cabrillo Breakwater | 33.70630 | -118.27444 | | X | | | | X | | | | | | | | |
| Cabrillo Jetty | 33.70625 | -118.27867 | | | | | | X | | | | | | | | |
| Hermosa Beach AR - AC | 33.85387 | -118.41372 | | | | | | | | | | | X | | | |
| Hermosa Beach AR - Boxes | 33.85279 | -118.41301 | | | | | | | | | | | X | | | |
| Hermosa Beach AR - Giants | 33.85370 | -118.41297 | | | | | | | | | | | X | X | X | X |
| Hermosa Beach AR - NW | 33.85420 | -118.41479 | | | | | | | | | | | X | | | |
| Hermosa Beach AR - Pier Pilings | 33.85291 | -118.41430 | | | | | | | | | | | X | | | |
| KH - Bend | 33.84338 | -118.39866 | | | | | | X | | | | | | | | |
| KH - East Jetty | 33.84195 | -118.39365 | | | | | X | | | | | | | | | |
| KH - Point | 33.84170 | -118.39595 | | | | | X | | | | | | | | | |
| KH - Portofino | 33.84471 | -118.39719 | | | | | X | X | X | X | X | X | | | | |
| KH - West Breakwater | 33.84133 | -118.39625 | | | | X | | X | | | | | | | | |
| LACSD 120 Inch Outfall | 33.70935 | -118.32350 | | | | | | | | | | | X | | | |
| LACSD 90 Inch Outfall | 33.71274 | -118.32742 | | | | | | | | | | | X | | | |
| Marina Del Rey AR - F | 33.96755 | -118.48666 | | | | | | | | | | | X | X | X | X |
| Marina Del Rey AR - I | 33.96851 | -118.48578 | | | | | | | | | | | X | X | X | X |
| Marina Del Rey AR - K | 33.96887 | -118.48758 | | | | | | | | | | | X | X | X | X |
| POLA - Angels Gate East | 33.71125 | -118.24373 | | | | | | X | | | | | | | | |
| POLA - Angels Gate West | 33.70726 | -118.25458 | | X | X | | | X | | | | | | | | |
| POLA - Middle Breakwall | 33.71245 | -118.23866 | | X | | | | | | | | | | | | |
| POLA - Pier 400 | 33.71755 | -118.25809 | | | | | | X | | | | | | | | |
| POLA - Shallow Water Habitat | 33.71180 | -118.26562 | | | | | | X | | | | | | | | |
| Redondo Beach AR - C | 33.83813 | -118.40978 | | | | | | | | | | | X | | | |
| Santa Monica AR - A | 34.00956 | -118.53043 | | | | | | | | | | | X | X | X | X |
| Santa Monica AR - B | 34.00916 | -118.53118 | | | | | | | | | | | X | X | X | X |
| Santa Monica AR - C | 34.00891 | -118.53071 | | | | | | | | | | | X | X | X | X |
| Star of Scotland | 33.99688 | -118.52038 | | | | | | | | | | | X | | | |
| Wreck of the Avalon | 33.78961 | -118.42813 | | | | | | | | | | | X | | | |
| Zuniga Jetty | 32.66584 | -117.22316 | X | | | | | | | | | | | | | |

## CURRENT (2020) VRG SAMPLING PROTOCOL

**Sampling Unit** – Data are collected visually by teams of SCUBA divers that access sample sites from a research vessel. A single site consists of at least 250m of reef habitat. Within each site four depth strata (if present) are sampled and geo-referenced. These strata are the inner (~5 m), middle (~10 m), outer (~15 m) and deep (~20-25 m) portions of a natural reef. Within each depth strata two benthic sampling protocols are completed, Uniform Point Contact (UPC) and Swath. In addition, urchins and other economically important or emerging fisheries species are measured in each zone at each site (ISC - Invertebrate Size Class). For Fishes, four benthic, mid-depth and canopy (when present) transects are completed in each depth zone. If kelp reaches the surface, then the canopy transects are completed. Therefore, the maximum sampling effort for a site includes 16 benthic fish transects, 16 midwater fish transects, 16 canopy fish transects, 8 UPC and 8 Swath transects. All transects are 30 m; swath and fish transects are 30 m x 2 m x 2 m belt transects.

**UPC** – Substrate type, substrate relief and benthic cover are recorded at each meter mark along the 30 m transect tape to estimate percent cover. Substrate type is defined as: bedrock (> 1 m), boulder (1 m), cobble (<10 cm), or sand. Substrate relief is defined as the maximum relief (0-0.1 m, 0.1-1 m, 1-2 m or > 2 m) within a rectangle centered on the point that is 0.5 m along the tape and 1 m wide. To contact benthic organisms, the line is pushed down and the species under the tape is recorded. If the line does not contact the substrate, the diver's finger is used to mark the spot. Epiphytes, epizooids and mobile organisms are not recorded. If the contact point is on a blade of macroalgae, brittlestars or the sea cucumber *Pachythione rubra*, the organism under the point is recorded as a 'superlayer' which notes that the point is underneath one of these organisms. Benthic cover is recorded by species or taxonomic group, or as the following types of abiotic cover: rock, sand, shell debris, and mud/sediment.

**Swath** – The purpose of the swath sampling is to estimate the density of conspicuous, solitary invertebrates as well as specific macroalgae. The number of stipes for each *Macrocystis* holdfast is also quantified. Individual invertebrates (larger than 2.5 cm) and select macroalgae are counted along the entire 30 m x 2 m transect. Transects are completed even if sand is encountered, but when there is sand for more than 5 continuous meters, the direction of the transect is changed to the minimum necessary to remain on rocky habitat. Divers slowly swim along the transect counting invertebrates and macroalgae. Cracks and crevices are searched and understory algae pushed aside. Any organism with more than half of its body inside the swath area is counted. The following minimum size criteria are also applied when counting macroalgal species:

- *Macrocystis* taller than 1 m; number of stipes counted at 1 m above the substrate; *Macrocystis* is not subsampled
- *Nereocystis, Pelagophycus, Pterygophora*, *Egregia menziesii*, *Laminaria setchellii* and *Eisenia arborea* taller than 30 cm
- *Laminaria farlowii* and *Agarum fimbriatum* greater than 10 cm wide
- *Stephanocystis* spp. greater than 6 cm wide

Transects are divided into three 10-meter segments. Species that occurred in high densities (e.g., purple urchins) may be subsampled if greater than 30 individuals occurred within any of the three 10-m segments on a transect. When species are subsampled, the diver records the meter mark at which the threshold abundance is reached and then stops counting that species for the remainder of that segment. The species continues to be counted at the start of each following segment and the same threshold abundance rule was applied. The subsampled abundances are then extrapolated per segment to calculate an estimated total abundance per transect.

**ISC** – In order to gain a more accurate estimate of the size frequency distribution of species of economic importance or emerging fisheries, specimens are collected and measured at each depth zone in the areas on and around each transect. The following species are measured:

- *Strongylocentrotus purpuratus, S. franciscanus, Megathura crenulata, Megastraea undosa, Kelletia kelletii*: up to 100 individuals of each species are collected and returned to the surface for measurement to the nearest millimeter on the research vessel, then returned to the reef. Individuals are collected from multiple areas of each depth zone, if possible. To avoid bias in size measurements, all emergent individuals are collected from each patch unless the patch is very large, in which case only a portion of the patch is completely collected.
- *Haliotis rufescens, H. corrugata, H. fulgens, H. sorenseni, H. kamtschatkana, H. kamtschatkana assimilis, H. cracherodii*: Any abalone encountered is identified and measured to the nearest centimeter without removing the animal from the substrate.
- *Panulirus interruptus*: Carapace length is estimated to the nearest centimeter for each lobster encountered without disturbing the individual.

**<u>Fishes</u>** – The purpose of the fish sampling is to estimate fish density and length frequency distributions by species at each site. A minimum of 3 m of horizontal visibility is the acceptability cutoff.  Divers swim in the pre-arranged compass direction for a distance of 30 m while counting and estimating the sizes of the fish along an isobath. All conspicuous fishes encountered along the transects are recorded. Divers count and estimated total length (TL) of all fishes to the nearest cm. Sex of *Bodianus pulcher* is also recorded. The observer censuses fishes within the boundaries of an imaginary observation "box" slightly ahead of them as they swim along, sometimes stopping, scanning and searching within discrete areas of the "box" that is delimited by the 2-m transect width and natural features such as kelp plants or large boulders. If there is an intervening obstacle, the transect continues over it so long as the depth change is less than 2.5 m. If the obstacle is greater than 2.5 m in height, the transect circumvents it. Transects are completed even if sand is encountered. When there is sand for more than five continuous meters and it appears that the habitat continued primarily as sand, the transect direction is changed to the minimum necessary to remain on rocky habitat. Physical data collected on each transect includes observation depth (m), water temperature ($C^o$), horizontal visibility (m), surge (0-4 relative scale), and kelp canopy cover (%). Transects are completed in 3-6 minutes depending on the number of fishes and the complexity of the habitat. Upon completing a transect, the divers then swim to the starting point of their next replicate transect within the same zone by choosing a haphazard direction along a similar depth contour. The preferred distance between transects is at least 10 m.

# Annotated Bibliography

1. Anderson, T. W., Reed, D. C., & Schroeter, S. C. (2004, October 8). Fisheries Habitat: Recruitment, Growth, and Survival of Coastal Fishes on an Experimental Artificial Reef. Retrieved May 29, 2020, from https://escholarship.org/uc/item/0qz1k6j4 Habitat SONGS/SCAR

One approach to anthropogenic impacts, over-fishing, and habitat degradation is habitat enhancement and specifically the use of ARs. The goal of this paper is to quantify recruitment (input of young-of-year fish), growth, and survival of near-shore fish populations. With this information, resource managers could better assess the role of habitat in management of fisheries and possibly replicate on a larger-scale AR. Two main studies of focus: (1) recruitment success of reef fishes that settle to the experimental reef and (2) production of reef fishes. Three tasks: (1) quantify recruitment success of several reef fishes among treatments of habitat structure, (2) estimate fish production on the experimental reef as a function of habitat structure, and (3) determine the degree of correspondence in spatial variation using an index of settlement and recruitment of the kelp bass. In order to do this, surveys were conducted from 2001 to 2004 to record the densities of YOY fish at SCAR. Using SCUBA and fixed transect lines, YOY recruits and their major predators (the kelp bass and the barred sand bass) were counted and their size estimated visually. Kelp bass were found only in reasonable numbers in 2001 and few or no kelp bass in 2002 and 2003. "In interacting with other reef fish ecologists who were monitoring settlement of kelp bass and rockfishes in southern and central California over this period, they also found poor or no recruitment of their target species. This apparent recruitment failure may have been widespread, and there may be a note on this phenomenon in collaboration with other researchers."

2. Artificial Reef Meetings- Public Comments and Questions Received Summarized by Department of Fish and Wildlife (CDFW) June 26, 2017. (2017). CDFW: Sacramento, Los Alamitos, Oxnard. MGMT

This Meeting Summary from CDFW (2017) recommended the digitization of all historical reef survey data in a useful format, a follow-up with Dr. Dan Pondella (Occidental College) regarding his work between natural (NR) and artificial reefs (AR). Public comments also recommended to develop a process to gather information and data from stakeholders regarding ARs and reducing the timeline to less than six months for completion of the baseline survey of an AR. The question of appropriate depth range of any future reefs came up, with the literature I've read a depth of 37-50' is usually used. A baseline assessment of existing reefs is needed and "CDFW is exploring development options with partners such as the Ocean Protection Council's Science Advisory Team, the Ocean Science Trust, and other state and federal agencies." "One of the protocols to be developed will include a process for exploring both informal and formal ways for volunteers to participate and assist. Additionally, data and file sharing options investigated to determine the best way for CDFW and the public to share data."

My capstone in particular should meet the recommendation of "develop a web-based system to compile past literature and current survey efforts."

3. Becker, A., Taylor, M. D., Folpp, H., & Lowry, M. B. (2018). Managing the development of artificial reef systems: The need for quantitative goals. Fish and Fisheries, 19(4), 740–752. doi: 10.1111/faf.12288 Mgmt → "In reviewing research on artificial reefs,"

This journal reviewed 270 research articles to determine whether ARs met their pre-deployment goals. Interestingly, only 62% of studies even articulated the goal of the AR with the rest not stating at all what the initial goal was. It is often hard to find out if goals were met due to the short duration of monitoring programs and funding. "Goals were qualitative, and most studies were conducted over insufficient time frames to allow for ecological and communities to stabilize and mature." The paper recommends setting clear and explicit quantitative goals to include biological, social, and economic strategies and offers lessons learned from the aquaculture community. The aquaculture framework can be summarized in six steps: (1) use research [before establishing an AR], (2) monitor and assess program/AR to ensure goals are met, (3) have quantifiable goals, (4) and impacts controlled, (5) [AR] should complement other fisheries management measures, and (6) should be able to be managed adaptively on an ongoing basis/repeatable process. Most monitoring programs only have funding for 1-3 years, reality is that a 10-15 year duration is needed to appropriately assess. Unfortunately, that is usually not possible financially. "Thus, a compromise is required to capture both short-term variability and long-term successional processes." Cites Bortone's (2011b) 'logic model' approach (1) what is the goal (2) why is an AR/location the correct solution, and (3) how and for how long (duration) should we monitor. For an effective monitoring program, resource managers must work with science to establish quantitative goals which can then help government agencies establish informed regulations. "As artificial reef deployments usually fall under multiple layers of legislation and associated permitting requirements, we encourage government agencies to work with researchers to explore additional funding opportunities through policy to extend monitoring programs" (aka if incorporated with MPAs, a longer duration of assessment may be possible).

4. Bedford, D., Kashiwada, J., Walls, G. (1995). Biological Surveys of Five Southern California Artificial Reefs: Oceanside #1, Oceanside #2, Carlsbad, Pacific Beach, and Mission Bay Park. California Department Fish & Game. STOCK Oceanside #1 (OAR1), Oceanside #2 (OAR2), Carlsbad AR (CAR), PB AR, and MB Park AR (RUBY E).

OAR1 is the oldest reef of the five and was constructed of 2,000 tons of quarry rock in 1964, augmented with concrete floating docks in 1987. OAR2 and PBAR were constructed of 10,000 tons of quarry rock in 1987. MBAR consists of a 165' USCGC rumrunner blockade vessel built in 1934, the Ruby E, that was placed as an AR in 1989. CAR was built in 1991 out of 10,000 tons of quarry rock. OAR1 and MBAR were created to primarily develop recreational fishing opportunities and OAR2, PBAR, and CAR were created as "experimental reefs". In the late fall (October, November, and December) of 1994, all five reefs were surveyed by divers to assess how closely the communities were to a stable "equilibrium" community. This paper details the methods and results.

OAR1 was not much different in 1994 compared to 1985, providing habitat for sheephead, sculpin, blacksmith, and bass; it is thought that "OAR1 probably reached a community equilibrium state many years ago" (1994). The number of species on OAR2 has increased over time, in addition to the number of juvenile and young-of-the-year (YOY) fish. Sheephead, senorita, kelp bass, black croaker, jack mackerel, barred sand bass, black surfperch, pile surfperch, sculpin, rock wrasse, and white surfperch were all found with juveniles on OAR2. Serving as a new nursery habitat, OAR2 was thought to "be nearing a community of equilibrium condition." CAR also had an increase in juvenile species, but change was more prominent in the turf, macroalgal, and invertebrate communities; kelp continued to increase on CAR and will be monitored to see if a kelp-dominated equilibrium will be reached. PBAR had one of the least diverse turf invertebrate communities; however had the highest incidence of lobsters (as high as 1.74 per square meter). PBAR was thought to "still be a few years away from having a stable community." MBAR was the only AR not constructed of quarry rock and had 31 feet of relief (the other ARs had no more than 11 feet). Made of a steel hull from USCGC RUBY E, larger schools of jack mackerel and sardines were found, but the macroinvertebrate community was not as developed. MBAR had similar species numbers as to CAR and OAR2, and fewer than OAR1 and PBAR. Although sunken vessels are viewed by CDG as less useful than other reef materials, they serve as popular dive and angler sites. "In a sense, these artificial reefs are becoming less artificial over time."

5. Belhassen, Y., Rousseau, M., Tynyakov, J., & Shashar, N. (2017). Evaluating the attractiveness and effectiveness of artificial coral reefs as a recreational ecosystem service. Journal of Environmental Management, 203, 448–456. doi: 10.1016/j.jenvman.2017.08.020 MGMT

This journal examined coral reefs as a recreational ecosystem services in Israel at a resort city, Eilat, located on the shores of the Red Sea. Monitoring diver behaviors around the Tamar AR and comparing to the two adjacent natural reefs, the findings showed that the diver density at the AR was higher than the two nearby natural reefs. Therefore they concluded that the AR effectively diverts divers from natural reefs thus taking stress away from the natural reefs (which also has economic benefit). The AR in Eilat was intentionally designed near an MPA and was made of concrete with drilled holes, allowing for corals to be planted. "It was developed by the Israel Nature and Parks Authority, Ocean Bricks Systems, and academics from Ben-Gurion University at Eilat, the Inter-University Institute for Marine Sciences, the Hebrew University of Jerusalem, and the Marine Science Station in Aqaba, Jordan." "The Tamar Reef serves as a diving attraction that can be paralleled to petting areas in aquariums and zoos that are often used to energize curiosity by educating visitors about natural life and conservation."

6. Boule, M., & Dybdahl, M. (1980). Humboldt Bay Wetlands Review & Baylands Analysis. Seattle, WA: U.S. Army Corps of Engineers. Lessons learned

Under subsection "Jetties and Reefs": The final habitat type to be considered, these are man-made structures constructed from impermeable material. Concrete and rocks have been used in the construction of jetties and sea walls; tires were used to construct the artificial reef in South Bay. Although they do not support flowering plants, these structures provide substrate for a large and diverse algal community. Red, green and brown algae are usually distributed over much of the subtidal and intertidal portions of the substrate. In addition, an even wider variety of invertebrate fauna occupy this habitat type.

7. Bulger, D. (2019). Evaluating British Columbia's Artificial Reefs in a Conservation Context. University of Victoria. Lessons Learned (good formatting example for Capstone Project)- Victoria BC

This is a thesis submitted for a Masters of Science at the University of Victoria evaluating BC ARs in a conservation context. It recommended that ARs should be deeper in water column and within boundaries of a conservation area. Factors of reef rugosity, slope, and surface areas were found to be most important to AR success. "Reef type, depth, and relief were significant variables in explaining species richness patterns." However, "to truly differentiate between abundance and productivity, analyses considering total biomass, fish movement, and mortality should be included." This is especially complicated in temperature areas because optimal methods such as photography/videography used in tropical environments are less practical due to the regular low light and variable visibility conditions that exist in temperate environments. This particular study focused on rockfish on ARs, both density and variance. Although the density on ARs was greater, the variance and groundfish species richness was greater on natural reefs in the area. "Unexpectedly, rockfish were more abundant on ARs and NRs if they were farther from the nearest conservation area (RCS)." Unfortunately, "analyses were not robust enough to measure productivity."

8. Claisse, J. T., Pondella, D. J., Love, M., Zahn, L. A., Williams, C. M., Williams, J. P., & Bull, A. S. (2014). Oil platforms off California are among the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences, 111(43), 15462–15467. doi: 10.1073/pnas.1411477111 Stock- Santa Barbra and PV Oil Rig platforms (IRENE, HIDALGO, HARVEST, HERMOSA, HOLLY, A, B, HILLHOUSE, HABITAT, GRACE, GILDA, GAIL, EDITH, ELLY, ELLEN, EUREKA

This study looked at secondary production of oil platforms off the coast of California and found that they "have the second highest secondary fish production per unit area of seafloor of any marine habitat that has been studied […] high rates of fish production on these platforms ultimately result from high levels of recruitment and the subsequent growth of primarily rockfish (genus *Sebastes*) larvae and pelagic juveniles to the substantial amount of complex hardscape habitat created by the platform structure throughout the water column." The annual secondary production or "Total Production" was calculated by summing "Somatic Production" (difference between observed biomass and the biomass predicted 1 year later) plus "Recruitment Production" (estimation of growth production of postlarval and pelagic juvenile fishes). Secondary production was chosen as the tool to measure because it incorporates multiple characterizes of a population or community of organisms (including density, body size, growth, and survivorship). The study area included 16 platforms off the Santa Barbra and Palos Verdes coastline and seven natural reefs which were surveyed for at least five years (some up to 15 years) between 1995 and 2011. Two specific types of platform habitat consist of the "platform base habitat", the bottom 2 meters of the structure and the "platform midwater habitat", the structure from the water's surface to 2 meters above the bottom. The platform base habitat functions as complex "sheltering habitats" consisting of the large horizontal beams and often buried with fallen mussel shells.

Lingcod (*Ophiodon elongates*), halfbanded rockfish (*S. semicinctus*), and squarespot rockfish (*S. hopkinsi*) were the biggest contributors to the habitat. A conservative feature of their model was that they applied the mortality at the start of the time interval. The paper suggested that if ARs are designated as no-take areas then the attraction versus production debate may cease to be evident. In addition, it points out that "understanding the local and regional oceanography related to larval fish delivery will be an important consideration in terms of how structure location influences fish production."

9. Claisse, J. T., Pondella, D. J., Love, M., Zahn, L. A., Williams, C. M., & Bull, A. S. (2015). Impacts from Partial Removal of Decommissioned Oil and Gas Platforms on Fish Biomass and Production on the Remaining Platform Structure and Surrounding Shell Mounds. Plos One, 10(9). doi: 10.1371/journal.pone.0135812 Stock- CA O&G platforms

This journal examines the potential impacts of partial removal of 16 O&G platforms off the coastline of California, including the areas of Santa Barbra and Long Beach. The study conducted surveys of all 16 platforms for at least up to 5 years (up to 15 years) between 1995 and 2011. They found that "the potential impacts of partial removal would likely be limited on all but one platform." "Platform Edith, located in the southern end of the geographical range of platforms in our study, was the lone exception retaining only 18.7% of SSB (standing stock biomass) and 20.1% of Total Production (sum of Somatic Production and Recruitment Production). It was also an exception in that Blacksmith, *Chromis punctipinnis*, a primarily planktivorous damselfish was the top contributor of Platform Edith, providing 53.8% of SSB and 63.9% of Total Production)." "Relatively few taxa, largely rockfishes and Lingcod, *Ophiodon elongatus*, contributed the majority of SSB and Total Production on any given platform." "Lingcod was one of the top two contributors to Total Production at the shell mounds surrounding all but two of the twelve platforms where shell mounds were surveyed." "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, *Sebastes paucispinis*, and Widow Rockfish, *S. entomelas*, are currently managed under federal rebuilding plans. These results suggest that partially removed platforms will still remain viable habitats for these important species." Transects were divided into three subsets: (1) platform shallow habitat (water's surface to 26 meters below), (2) platform midwater habitat (26 meters below surface to 2 meters above bottom), and (3) platform base habitat (bottom 2 meters). "[Their] approach is thought to be conservative with respect to not underestimating the impact of partial removal on these northernmost platforms."

Article defines the four alternatives for O&G platforms that have to be decommissioned: (1) complete removal, (2) tow-and-place, (3) partial removal or "topping", and (4) toppling. This is a critical consideration of California's ARs with the passage of AB 2503 The California Marine Resources Legacy Act in 2010. This allows California to consider the partial removal of decommissioned offshore oil platforms as a viable option as an alternative for complete removal provided that the "net benefit" to the environment is greater. Since most of California's O&G platforms are in deeper water and there is a good quantity of biological information now available, "California has an opportunity to serve as a model for decommissioning elsewhere."

10. Dafforn, K. A., Glasby, T. M., & Johnston, E. L. (2012). Comparing the Invasibility of Experimental "Reefs" with Field Observations of Natural Reefs and Artificial Structures. PLoS ONE, 7(5). doi: 10.1371/journal.pone.0038124  Port Jackson, Australia

As natural marine systems are being increasingly modified by the development of ARs, there is concern that ARs may facilitate invasion.  Thus, "it is important to investigate potential factors that reduce or enhance invisibility."  This paper uses study sites in Port Jackson, Australia to survey and compare the "distribution of non-indigenous and native invertebrates and algae between artificial habitats and natural reefs in a marine subtidal system."  In addition, they "deployed sandstone plates as experimental 'reefs' and manipulated the orientation, starting assemblage and degree of shading."  "Non-indigenous invertebrates are less successful than native invertebrates on horizontal reefs despite functional similarities.  Manipulative experiments revealed that even when non-indigenous invertebrates invade vertical "reefs", they are unlikely to gain a foothold and never exceed covers of native invertebrates (regardless of space availability)."  Their "findings suggest that non-indigenous species are less successful at occupying space on reef compared to artificial structures, and manipulations of biotic and abiotic conditions (primarily orientation and to a lesser extent biotic resistance) on experimental "reefs" explained a large portion of this variation, however they could not fully explain the magnitude of differences."

11. Davis, T. R., & Smith, S. D. (2017). Proximity effects of natural and artificial reef walls on fish assemblages. Regional Studies in Marine Science, 9, 17–23. doi: 10.1016/j.rsma.2016.10.007 Habitat- Port Stephens, New South Wales, Australia

This journal examines a temperate small (10s M) AR structures at a study site in Port Stephens, New South Wales, Australia (an estuary).  They assessed the effects of proximity to natural and artificial vertical walls on patterns of fish assemblages, at a scale relevant to fish survey transects.  "Walls appear[ed] to act as localized biodiversity 'hotspots' and consideration should be given to inclusion of areas containing such features with marine reserves."  Assemblages changed in the immediate vicinity of both natural and artificial walls.  The size of the effect was proportional to the size of the wall.  "Vertical walls were found to support denser and more diverse fish assemblages than surrounding flat or gently sloping reef areas."  Differences between natural and artificial walls were detected but were not consistent. "The planktivore, *Atypichthys strigatus*, was a large contributor to the differences between walls and surrounding areas."  The results supported their initial hypotheses but did not unequivocally support that fish species richness and abundance are higher at natural walls than at artificial walls, further work would still be required to isolate differences in fish assemblages between wall types.  Recommendations for management included a detailed understanding of seabed structures using sonar technologies should be mapped and considered during the planning stage of any marine parks/ARs where protection of fish biodiversity is an objective.

12. DeMartini, E. E., Barnett, A. M., Johnson, T. D., & Ambrose, R. F. (1994). Growth and Production Estimates for Biomass-Dominant Fishes on a Southern California Artificial Reef. Bulletin of Marine Science, 55(2-3), 484–500. Stock- TPAR (Torrey Pines AR #2)

This bulletin examines somatic growth/production and gonadal production that was estimated in May-November 1989 for six different species. TPAR was a 14-year old AR at the time, made of quarry rock off La Jolla, California. "On average, the per capita growth rates of taxa dominated by immature stages were faster than those dominated by large adults […] our observations suggests that the elaboration of tissue unrelated to yield is nontrivial and represents a major component of energy flow through the fishes in this reef system and perhaps others."

"Kelp bass and California sheephead, two species in which immature-sized individuals compromised the majority of the tagged fish (and represented large fractions of stock biomass at TPAR), had relatively high growth rates and somatic production values. Conversely, most of the tagged garibaldi, like those in the TPAR populations, were large adults with relatively slow growth and low per capita somatic production values."

"This study is among the first to conclusively demonstrate that fishes present on a shallow marine artificial reef in the temperate zone produce tissue, through both growth and reproduction, that is a substantial fraction of their standing stock biomass […] a large fraction of the fish tagged were resident on TPAR for the half-year duration of the study. This fact, plus the observation that most of the fishes fed on or immediately near TPAR, indicates that the majority of the fish production we measured was attributable to the study reef."

13. Deysher, L., Dean, T. A., Grove, R. S., & Jahn, A. (2002). Design considerations for an artificial reef to grow giant kelp (Macrocystis pyrifera) in Southern California. ICES Journal of Marine Science, 59, S201–S207. doi: 10.1006/jmsc.2002.1187 Habitat- SONGS- Torrey Pines, Pendleton, Pitas Point, Oceanside, Pacific Beach, Carlsbad +*CA AR history*

This paper looks at the results of surveys that led to the design specifications for the SONGS AR that consists of 56 modules with eight different designs. They looked at six different reefs that are at an appropriate depth range for giant kelp: (1) Torrey Pines, (2) Pendleton, (3) Pitas Point, (4) Oceanside, (5) Pacific Beach, and (6) Carlsbad. Looking at published literature and previous surveys low relief reef was the most favorable configuration to support kelp populations. "Ariel surveys of the kelp canopies between Newport Beach and the Mexican Border were made at least four times per year during the period of greatest canopy cover each year from 1975 to 1991." Kelp persistence maps were then formed using a GIS database. Their findings "suggest that giant kelp is a moderately opportunistic species that does best under conditions of intermediate disturbance" and this "hypothesis is supported by the relationship between kelp density and rock size."

"Artificial reef construction in Southern California has a long history (Lewis and McKee, 1989). The first reefs were built in 1958 at Paradise Cove in Malibu and at Redondo Beach. The Paradise Cove reef was constructed from 20 old automobile bodies and the Redondo Beach reef consisted of six wooden streetcars that were sunk by the Navy. Both reefs were placed in 18m of water. Since that time (article written in 2002), a total of 22 reefs have been built in Southern California. Because they were built to support sport fisheries, most were constructed in water too deep for kelp growth." Figure 1: Kelp persistence map of the San Clemente region (just north of SONGS) used to select high-persistence and low-persistence (having less than five years of canopy persistence) kelp sites for use in the comparisons of substrate types. Figure 2: Summary of the history (presence/absence) of kelp populations on shallow-water artificial reefs in Southern California. The Torrey Pines Reef was not successful at establishing a long-term kelp population due to the grazing of sea urchins and the Pendleton Reef was not able to sustain a kelp population due to intense fish grazing. Both the winter of 1983-1984 and 1984-1985 had increased storm activity. The experiment also investigated both quarry rock and recycled concrete for construction. Quarry rock has proven to be environmentally acceptable and is obtained from Catalina Island that is then abled to be towed to the appropriate construction type with little footprint. Concrete was being used when it was primarily being disposed of at landfills but now much of the concrete is used to make gravel, making the economics of this material not ideal.

14. Florisson, J. H., Tweedley, J. R., Walker, T. H., & Chaplin, J. A. (2018). Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs. Fisheries Research, 206, 296–308. doi: 10.1016/j.fishres.2018.05.006 Mgmt

This journal explored a citizen science program, Reef vision, to monitor the fish fauna of an AR in south-western Australia, the Bunbury and Dunsborough ARs in Geograhpe Bay. They contributed their successful results with proper and targeted recruitment (and training) of knowledgeable, motivated, and competent citizens. The citizens were volunteers and collected video samples using a Baited Remote Underwater Video (ROV) system which was then analyzed and interpreted by professional scientists. The soak time for the ROV was determined to be 45 minutes, which was sufficient to capture more than 95% of the "number of species, abundance, diversity, and composition of fish fauna. This citizen science was used for a cost-effective monitoring approach and achieved community outreach, education, and ownership. Both the U.S. and Australia have a large recreational fishing industry and similar Mediterranean climate (hot, dry summers and cool, wet winters). A cost comparison of Reef Vision to a Science equivalent monitoring system found it to be about half the cost; Reef Vision coming in at a $28K cost and the Science equivalent with a $55K cost

15. Folpp, H., Lowry, M., Gregson, M., & Suthers, I. M. (2013). Fish Assemblages on Estuarine Artificial Reefs: Natural Rocky-Reef Mimics or Discrete Assemblages? PLoS ONE, 8(6), 1–14. doi: 10.1371/journal.pone.0063505 temperate SE Australia habitat-Lake MacQuarie

This journal examines AR temperate habitats in southeast Australia. The ARs were constructed from 2005 to 2007 and have 6 reefs at each location. The three locations are Lake MacQuarie (LM) which is a source of cooling of three power stations, Botany Bay (BB), and St. George's Basin (SGB). The performance was evaluated using a baited remote underwater video (BRUV) and were assessed 18 months after the ARs were established. The ARs are made out of ReefBall® modules and have successfully been used in other parts of the country as well including Victoria, Queensland, and Western Australia. The paper "concluded that estuarine AR assemblages are likely to differ significantly from adjacent rocky-reef, potentially as a result of physical factors such as reef isolation, coupled with species specific behavioral traits such as the ability of some species to traverse large sand flats in order to locate reef structure, and feeding preferences. Artificial reefs should not be viewed as direct surrogates for natural reef. The assemblages are likely to remain distinct from naturally occurring habitat comprised of species that reside on a range of adjacent natural habitats."

The goals of the study were to (1) identify dominant species and family groups and (2) to investigate the ability of an AR to support an assemblage comparable to those identified on the natural rocky-reef. Samples were taken randomly six times per season. A total of 53 species were identified over 6,853 individual fish over the three locations. BB had the greatest number of species (43) while LM (22) and SGB (16) were similar.

16. Granneman, J. E., & Steele, M. A. (2015). Effects of reef attributes on fish assemblage similarity between artificial and natural reefs. ICES Journal of Marine Science, 72(8), 2385–2397. doi: 10.1093/icesjms/fsv094 Stock **5 CA reefs- Topanga (Santa Monica), San Clemente/SONGS, Pendleton, Torrey Pines, Pacific Beach

Using five pairs of ARs that are located in the Southern Californian Bight (spanning 225 km), this paper evaluated fish assemblage and compared results to corresponding natural reefs. Using visual transects, fish were quantified by species richness, density, size structure, rugosity (small-scale variations of amplitude in the height of a surface), giant kelp density, and invertebrate density. Each AR evaluated had a neighboring natural reef 7.4km (~4.5 miles) or less away. The AR locations were Topanga, San Clemente, Pendleton, Torrey Pines, and Pacific Beach. "Fish species richness was not significantly different between artificial and natural reefs, but density and biomass tended to be higher on average on artificial reefs, body size was slighter smaller, and assemblage structure differed between the two reef types." In general, ARs consisted of larger boulders, extended higher off the seabed, supported less giant kelp, harbored more invertebrates, and had a higher rugosity. Results supported that if ARs are constructed to mirror the physical characteristics of natural reefs, than they can support fish assemblages similar to those on natural reefs and in some instances they can even be made to exceed natural reefs in some regards at the expense of other biological attributes.

The ARs chosen (ranging in age from 10 to 34 years) were because they were the only ones in the SCB that were relatively large, similar in physical structure to nearby natural reefs, and thus likely to be influenced by similar oceanic conditions (i.e. temperature, surge, and turbidity). The goal of all five ARs was to mitigate impacts to neighboring NRs by providing new fishing opportunities. On both reef types, only rocky habitat was sampled. Table 1 details the estimated year established, depth, height, number of modules, length, width, spacing, and total reef area of each AR and NR. "On average, artificial reefs were composed of larger rocks than were on natural reefs, but the San Clemente and Topanga ARs were more similar in substrate composition to NRs than the other three ARs […] these results strongly suggest that the physical structure of these two reefs is what made their fish assemblages most similar to those on NRs." Unfortunately, most ARs in this particular study never supported a persistent kelp bed, despite initiatives of transplant experiments with kelp. Interestingly, fish density decreased with reef area, "indicating that smaller reefs supported greater density of fish […] the greater perimeter to surface area relationships of small reefs may attract fish from a proportionately greater area, and this would result in greater densities on small reefs. Moreover, small reefs may provide better habitat for ecotone specialists such as blackeye gobies and California sheephead, which were both significantly more abundant on ARs than on NRs."

Recommendation: "Designing ARs, so they incorporate a variety of physical features (e.g. high relief and low relief areas), may enable them to support unusually high densities of desirable species (e.g. some ecologically and economically important reef fish) while ensuring that other key species (e.g. giant kelp and associated fauna) are supported."

17. Helvey, M. (2002). Are southern California oil and gas platforms essential fish habitat? ICES Journal of Marine Science, 59, S266–S271. doi: 10.1006/jmsc.2002.1226 Habitat – O&G Platforms

This journal discusses the question of if oil and gas platforms can be considered Essential Fish Habitat (EFH). EFH was included into the 1998 provision of the Pacific Groundfish Fishery Management Plan that was written by the Pacific Fishery Management Council with recommendations from the National Marine Fisheries Service (NMFS). EFHs are defined as either a necessity to support a sustainable fishery or a contribution to a healthy ecosystem. This journal's goal is to "present the outcome of a review of the scientific literature pertaining to the ecological structure and function of southern California platforms relating to Pacific Groundfish FMP species." Three relevant studies were found and compared: Love et all. (1999a) using the SCUBA method, Love et al. (2001) using the submersible method, and Love and Westphal (1990) using the hook and line method. "The only parameter common to all studies was species richness and results revealed that the two habitat types do not generally differ in cumulative number of species. Juvenile rockfish, sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and jack mackerel (*Trachurus symmetricus*) were found to be common to O&G platforms. Literature indicated that community metrics at platforms do not consistently exceed those at natural reefs. The data is insufficient to definitely conclude that O&G platforms serve as an EFH under the definition as defined by the statute. The journal recommends continuation of O&G platform research. With recreational and commercial fisheries declining the "removal of any existing habitat may exacerbate further stock collapses, especially because platforms may be one of the few remaining habitats yet to be fully exploited owing to their inherent risk of ensnaring fishing gear."

18. Jessee, W. N., Carpenter, A. L., & Carter, J. W. (1985). Distribution Patterns and Density Estimates of Fishes on a Southern California Artificial Reef with Comparisons to Natural Kelp-Reef Habitats. Bulletin of Marine Science , 37(1), 214–226. Stock- PAR

"In this paper we provide evidence for habitat partitioning on Pendleton Artificial Reef (PAR) and attempt to assess its mitigative capacity by answering the following questions: (1) What are the distribution and abundance patterns of eight species on PAR with respect to strata and modules based upon 1981-1983 data? and (2) Are densities of six species on PAR similar to those at a kelp forest site predicted to be impacted by power plant operations (San Onofre Kelp Forest, SOK) and a natural reef (Las Pulgas Reef, LPR) located nearby?"

The species included: halfmoon (*Medialuna californiensis*), opaleye (*Girella nigricans*), kelp bass (*Paralabrax clathratus*), barred sand bass (*Paralabrax nebulifer*), blacksmith (*Chromis punctipinnis*), black perch (*Embiotoca jacksoni*), garibaldi (*Hypsypops rubicundus*), and

California sheephead (*Semicossyphus pulcher*). They compared findings with a nearby kelp forest, San Onofre Kelp Forest (SOK) and a natural reef, Las Pulgas Reef (LPR).
(1) "Stratum differences in densities were well defined for six of the eight species considered. Blacksmith, halfmoon, and garibaldi densities suggested that these species preferred the crest stratum […] Barred sand bass, California sheaphead, and black perch densities suggested that these species preferred the bottom stratum." (2) "Halfmoon, opaleye, and black perch densities were significantly greater on PAR relative to SOK and LPR. Kelp bass and barred sand bass densities suggest that APR also supports greater numbers of these two species relative to SOK and LPR; however, we were unable to obtain a clearly defined statistical difference between sites because site variances were highly heteroscedastic. Our results overall, however, are consistent with observations made on natural and artificial reefs elsewhere (Randall, 1963; Turner et al., 1969, Walton, 1979); namely, artificial reefs tend to support significantly greater fish densities relative to natural reefs and kelp forests."

The paper states that they believe PAR attracts fish for two reasons: physical structure and because it produces food for fish feeding from hard bottoms. Two additional factors they stated may impact fish density was an optimal "area to perimeter ratio" and proximity to neighboring reefs. Offering design recommendations of 600 m (~2,000 ft) if goal of AR is to attract and hold independent fish; and 0-50m (~160 ft) if goal of AR is to replace or enlarge portions of natural communities. Interesting fact: As far back as the 1980s, ARs have been "evaluated for their mitigative potential in nearshore marine habitats potentially impacted by operations of power plants, offshore petroleum exploration activities and municipal sewage outfalls (Aquabio, 1981)."

19. Kashiwada, J. (1997). Biological Surveys of Four Southern California Artificial Reefs: Oceanside #2, Carlsbad, Pacific Beach, and Mission Bay Park. California Department Fish & Game. STOCK Oceanside #2 (OAR2), Carlsbad AR (CAR), PB AR, and MB Park AR.

During December 1996 (MBPAS) and March 1997 (OAR2, CAR, and PBAR), these four reefs "were surveyed by Department divers to assess how closely their biological communities have progressed towards a stable 'equilibrium' community." OAR2, PBAR, and CAR were created as experimental reefs while MBPAR was created to enhance opportunities for recreational fisheries; this reef was of particular interest due to its giant kelp lasting longer than any other reef. Nearshore Sport Fish Habitat Enhancement Program (NSFHEP) biologist-divers were used to survey the assemblage of fishes, macroinvertebrates, turf communities, and macroalgae.

"The four artificial reefs surveyed this year continue to undergo successional changes. Fish and macroinvertebrate communities appear to be fluctuating with environmental conditions, but based on this past surveys, will remain similar to the current structure. The algal and invertebrate turf communities will likely increase in number of species and percent coverage. Future changes in turf communities will probably not be dramatic; the most likely changes will be increasing coverage by the dominant species. While biological communities on artificial reefs continue to show changes, the rates of these changes appear to slow with time. The biological communities of OAR2 and PBAR are probably stable enough to begin studies to compare performance in reef-design variables."

20. Keller, K., Steffe, A. S., Lowry, M. B., Murphy, J. J., Smith, J. A., & Suthers, I. M. (2017). Estimating the recreational harvest of fish from a nearshore designed artificial reef using a pragmatic approach. Fisheries Research, 187, 158–167. doi: 10.1016/j.fishres.2016.11.022 MGMT

This journal brought to light the challenges with harvest estimations. This team took a pragmatic approach to estimate the harvest at an AR off Sydney, Australia. Fishing effort was taken from June 2013 to May 2014 (acquired from digital images and confirmed by observation), while an existing data set from March 2007 to February 2009 had to be used for harvest rates. The use of previous data to represent current conditions is subject to bias, however cost-effective. Though, all sampling methods can be subject to bias. This journal cited table from Pollock et al. (1994), that included the following methods: fisher logbooks, smartphone fishing application, web-based data, scientific fishing (standardized gear), telephone survey (off-site), mail survey (off-site), roving survey (on-site), and access point survey (on-site).
The journal recognizes that the attraction v. production is an ongoing debate. ARs in the area have been deployed for the primary purpose of recreational fishing enhancement, designed purposefully with voids and towers (i.e. vertical walls). The harvest at the AR by quantity and weight was relatively small, but relatively high when considered with per unit area. The journal ended with a recommendation that future studies estimate harvest at AR with an integrated methodology that uses both existing datasets and cost-effective sampling methods.

21. Lee, M. O., Otake, S., & Kim, J. K. (2018). Transition of artificial reefs (ARs) research and its prospects. Ocean & Coastal Management, 154, 55–65. doi: 10.1016/j.ocecoaman.2018.01.010 Lessons Learned- O&G platforms

This is a literature review of 160 studies worldwide, they examined the transition of AR research and described future prospects of AR development and management of different geographic regions. They compared and provided graphics looking at how the number of studies has increased over the years and how the objectives for AR deployment have changed. In particular AR objectives have shifted from improving fisheries as a resource to rehabilitating marine ecosystems. The future of ARs in the U.S. is expected to increase with the recycling of O&G development rigs and the number of studies has increased using ROV and acoustic tomography and observing economic keystone fish behavior.

“The first record of ARs being used by humans is in Japan. Ogawa (1968) described a warrior who had made a fishing ground at sea using stones from a mountain in Kochi Prefecture in the 1640s.” “The first record of AR use in the USA appears to be in the 1880s, when anglers used long huts sunken off the coast of South Carolina as a fishing reef.” “In 1958, California Department of Fish and Game started a pilot study monitoring ARs off the coast of Southern California.”

They divided the AR research into three different phases: (1) 1987-1997, (2) 1998-2007, and (3) 2008-2017. Comparing materials, substrates, flow field and stability, performance, fisheries production, ecological functions, community structure, and fish behavior, this article showed “that the theme of AR research has changed over time to become more divers and implies that socio-economic demand has changed in accordance with advances in scientific technology for ARs."

22. Lewis, R. D., & McKee, K. K. (1989). A guide to the artificial reefs of Southern California. Sacramento, CA: State of California, Resources Agency, Dept. of Fish and Game. MGMT

This booklet was a group effort of the Nearshore Sportfish Habitat Enhancement Program staff. It describes the latitude and longitude coordinates of southern California's artificial reefs and the materials of construction. It offers some history of the early reefs that were designed to attract fish, proving to be successful. "Surfperches, sargos, kelp bass, and small California halibut were among the first fishes attracted to the reef, followed closely by sheephead and opaleye. Later, rockfish and sand bass appeared." Some relocating and mapping operations were conducted by Ecosystems Management Associates, Inc., under contract with CDFW. John J. Grant wrote the original 1989 text, most of which remains intact in the 2001 update. Relocation of reefs and recording with differentially corrected GPS was done with the assistance of Greg Walls, Juan Hernandez and Jerry Kashiwada, all members of the NSHEP staff.

Lessons learned: "Japanese scientists found that fish attraction was generally greatest in those reefs with the highest profile to water depth ratio. They built tall, open, prefabricated reef structures that provided little surface area, but considerable high relief." "California species are also attracted to high volume, low surface area reefs. To overcome this potential problem, DFG biologists design reefs which will not only attract fishes, but will provide them with adequate habitat for shelter, forage, growth, and reproduction, thereby, increasing fish production. Cattlemen and ecologists use the term 'carrying capacity' […] To increase carrying capacity, we attempt to mimic those areas that naturally produce and maintain greater numbers of fish and good fishing success."

"Since 1980, beginning with Pendleton Artificial Reef, ten large quarry rock reefs have been built from San Luis Obispo to San Diego at an average cost of $275,000."

23. Logan, R., & Lowe, C. (2018). Residency and inter-reef connectivity of three gamefishes between natural reefs and a large mitigation artificial reef. Marine Ecology Progress Series, 593, 111–126. doi: 10.3354/meps12527 Stock- SONGS

"The results of this study suggest that fish remain resident to a single reef, and are not consistently attracted to WNAR. Therefore, in its current community state, WNAR is functioning and producing fish similarly to surrounding natural reef habitat." This journal targeted three gamefish on or near the Wheeler North Artificial Reef (WNAR) site and compared their findings to three nearby natural reefs in San Clemente, CA; San Mateo Kelp Bed (SMK), Barn Kelp Bed (BK), and lastly Trestles Reef (TR). The three gamefish species included kelp bass, *Paralabrax clathratus* (KB), barred sand bass, *P. nebulifer* (BSB), and California sheephead, *Semicossyphus pulcher* (SH).

It mentioned that after the National Fishing Enhancement Act of 1984, that the majority of ARs implemented in CA focused on enhancing fishery resources and fishing opportunities (Stone

1985). It goes on to suggest that the future of CA AR management should implement low relief modules that are ideal for giant kelp attachment, citing Reed et al. 2006. During this study, most likely due in part to the El Nino year that occurred over the course of the study from 2015-2016, there was a significant decrease in the abundance of giant kelp. In addition, the length of the study was only about 6 months, starting in September 2015 and ending in March 2015. However, similar findings were observed by Lowry et al. (2017) where yellowfin bream *Acanthopagrus australis* were observed to be highly resident to AR habitat. ["In contrast, Keller et al. (2017) noted significant connectivity (>5km) between natural and ARs where individuals of 3 species of benthic fish and elasmobranch were often detected at up to 6 different reef sites.]

24. Matthews, K. R. (1985). Species Similarity and Movement of Fishes on Natural and Artificial Reefs in Monterey Bay, California. Bulletin of Marine Science, 37(1), 252–270. Stock- (Soquel Cove constructed in Aug 1981 near Santa Cruz)

This study investigated the fish interactions between a new AR and nearby NRs in Monterey Bay. Using underwater transects, it was found that after one year the species composition on the AR and NR was similar. The new AR consisted of adult and subadult rockfishes, surfperches, greenlings, and cabezon. "Large amounts of fishing pressure suggest that ARs could have detrimental effects on NR fish populations. Although it is impossible to know what proportion of colonizers came from nearby NRs, the location of the NRs may be an important consideration when planning the placement of future ARs." The bulletin offers a management recommendation of have new ARs be MPAs for 1-3 years, then opening them in a step process: spearfishers, recreation fishing, and then commercial fishing.

"Since temperature ARs do attract reef fishes, this could suggest that fishes are moving from nearby NRs […] another source of recruitment onto ARs may be rocky-reef fishes that have not been able to establish territories on reefs and are roving about on sandy areas." The goal of this study was to be able to answer: "1) Is the fish assemblage on the Capitola artificial reef similar to those of nearby natural reefs, and does this similarity change over time? 2) How does the amount of fishing pressure compare on the natural and artificial reefs? 3) How much movement of fishes occurs between the natural and artificial reefs and does this amount of movement change with time?" The four natural reefs that were compared were Surfer Reef (habitat supports giant kelp), Rockfish reef (no giant kelp), Adams Reef (flat rocks, no giant kelp), and Tankhouse Rock ("lush stand of kelp"). "Very few small rockfish were observed during the summer of 1983 after the winter storms destroyed the kelp canopy." "Marked ARs receive greater amounts of fishing pressure than most natural reefs […] at least 11.4% of the fishes tagged on nearby NRs eventually moved to the AR, where they were caught (which could represent 48% of the AR fish population)."

25. McKinney, J. (2013). Capstone Project: Reef Mitigation: A Policy Framework for California. University of Washington- Bothell, Summer 2013. SONGS, PAR

This is a capstone project from a graduate student at the University of Washington – Bothell, studying Policy Studies. There are two case studies in Appendix 1 with detail about SONGS/PAR and Boston Harbor Reef (2004). Formatted well, document has a useful list of acronyms and abbreviations. Recognized the uncertainty of the attraction v. production debate, but did not offer opinion. Cited the Southern California Coastal Water Research Project (Pondella et. Al., 2011) its organization of Southern California Bight (SCB) reefs into six categories:  low relief and cobble, flat reefs, middle relief, high relief, wall reefs, and pinnacles. Mentioned a "recent" development in regards to the Port of LA and the potential use of an AR citing Anchor QEA (2012), however did not offer any further information. The paper points out that there is no uncertainty with regard to the economic benefits of ARs throughout U.S.  The paper also stated that site selection and biological measures such as substrate type should be assessed when deciding the location of any future ARs.  Has a good paragraph on page 12 about why kelp is important and essential for ecological function.  Stressors of California reefs include both natural (El Nino, landslides, sea urchins) and anthropogenic factors (turbidity, river plumes, sedimentation, overfishing, pollution, dredging, coastal power plants, desalinization plants). Other rocky reef mitigation projects have occurred in AK, WA, CA, MA, & DE (both pilot projects and experiments).  In particular Massachusetts, found that ARs have an overall greater abundance of organisms versus natural reefs, but with less species diversity.  The paper stated that fish population can't be the only measure of success, ecological functions must be considered as well.  This paper defined Federal: Clean Water Act, Rivers and Harbor Act of 1899, Coastal Zone Management Act of 1972 (CZMA), Endangered Special Act of 1973 (ESA), Magnuson-Stevens Fishery Conservations and Management Act (MSFCMA), National Artificial Reef Program of 1984 (NARP)//State: California Coastal Act (CCA), California Marine Life Protection Act (MLPA).

26. Mills, K., Hamer, P., & Quinn, G. (2017). Artificial reefs create distinct fish assemblages. Marine Ecology Progress Series, 585, 155–173. doi: 10.3354/meps12390 Port Philip Bay, AUS

This journal conducted a before-after-control-impact (BACI) experiment of a small-scale AR in a temperate bay in south-eastern Australia.  The bay was Port Phillip Bay and the data was compared to three control sites with no reef and three control sites of natural reef.  Baited remote underwater video (BRUV) and underwater visual census (UVC) were used six months before the ARs were constructed and then 22 months after the AR deployment.  The critical recreational species snapper *Chrysophrys auratus* was recorded more often on the AR and NR than the sediment. Overall, this study found that "the deployment of patchwork ARs increased species diversity and abundance of fish, and did not impact existing sediment fish assemblages."

In this study, two to five Reef Balls® were used arranged in a regular array to increase footprint and increase the sediment to reef edge ratio.  The BACI design is a rare approach and was chosen with sediment control and natural reef comparison sites to "(1) determine the impact of small-scale artificial reef deployments on existing fish assemblages, (2) identify fish species that characterize community differences between artificial reef, sediment controls and reference natural reef habitats, and (3) identify changes in the abundance of key species, including fishery species, in response to artificial patch reef deployment.  The outcomes provide baseline information that can inform consideration of a broader program of artificial reef creation."  A total of 56 species were recorded on NRs, 53 on ARs, and 29 on sediments.  Species richness at ARs was lower than NRs at all times except during winter.

27. Mineur, F., Cook, E., Minchin, D., Bohn, K., Macleod, A., & Maggs, C. (2012). Changing coasts: Marine Aliens and Artificial Structures. Oceanography and Marine Biology Oceanography and Marine Biology - An Annual Review, 50, 189–234. doi: 10.1201/b12157-5

“Marine aliens are non-native species that have been transported across major geographic barriers by human activity.” In this paper, they “examine the presence of alien marine species on static (immobile) artificial reef structures”. “Although there are exceptions, a large majority of marine alien species seem to be associated, at least for some of the time, with artificial structures.” “The red alga *Pikea californica* survived out of water on a yacht rail for several hours, leading to speculation that it may have been introduced from California to the Isles of Scilly, England, by flying boat (Maggs & Ward 1996).” Other alien species found on offshore in California include: Bryozoa *Watersipora subtorquata*, Bivalvia (byssate) *Mytilus edulis*, and Crustacea, Amphipoda *Caprella mutica*.

“The economically important edible kelp *Undaria pinnatifida* (brown seaweed), commonly known as wakame, is native to Japan and Korea (Voisin et al. 2005). It has a wide non-native range, including Argentina, California, South Australia and Tasmania, New Zealand, the Atlantic coasts of Europe and Mediterranean lagoons (Voisin et al. 2005), and is ranked third in the top five high-risk invasive algae (Nyberg & Wallentinus 2005). In its native range, *Undaria pinnatifida* (Figure 5B) occurs naturally subtidally on cobbles, coralline algal turf and bedrock. It is grown extensively in aquaculture installations in Japan and Korea, with a world crop value in 2008 of about US$750 million (FAO 2010).”

28. National Oceanic and Atmospheric Administration. (2012). Office of National Marine Sanctuaries Science Review of Artificial Reefs.

This reports aim was to summarize the scientific literature on ARs. It stated that “today it is widely acknowledged that artificial reefs function both in attraction and production” and provided examples of both. They defined attraction as the “the net movement of individual organisms from natural to artificial habitats; and defined production as “best quantified as a change in biomass through time [reflecting] births, immigration, growth, death, and emigration”. Both materials and placement of reef can attribute to whether the reef is more attraction or production. “As such, artificial structures, particularly offshore oil and gas platforms, have been described as potential stepping-stones for the expansion of various living resource communities.” This document went in detail about oil rigs in the Gulf of Mexico and ARs off the coast of Florida. It cited Love and York’s (2005) study in southern California that compared fish assemblages with a specific pipeline, finding that fish assemblages were similar to those that occupy low-relief habitats such as cobble or small boulders. It also cited Love et al. (2006), which found that there was an increase in rockfish at oil and gas platforms when compared to populations found nearby natural reefs which was thought may be attributed to the platform serving as a nursery, assisting with larval production and therefore juvenile growth rates. This document includes oil and gas statistics and the establishment of the Rigs to Reef Program. It noted that the knowledge of regional ocean circulation patterns is essential for evaluating ARs, therefore it is also critical to consider this when designing ARs in particular to protect larval and transport larval successfully. NOAA also discusses the risk that ARs bring to the table in regards to invasive or non-indigenous species, such as the lion fish. The report also includes a material chart color coded with materials that used to be used in AR construction and more recently which materials have proven to be successful and less harmful to the marine environment. It then goes on to define toxicological impacts specifically of PCBs, heavy metals, oil and fuel residues, and other toxic chemicals (i.e. asbestos, antifouling paint, copper and tributyltin (TBT), lead, mercury, cadmium, iron). However, "adverse effects will not occur unless the chemicals are present at or above their effective concentrations". In additional, it offers recommendations about management and placement in particular of shipwrecks, stating "the long axis of a wreck, when oriented perpendicular to the prevailing current, typically exhibits areas of higher velocity and energy and lower sedimentation rates, in comparison to midship."

Florida has the largest number of permitted artificial reef sites in the US (Mostkoff 1992) and also has a regular hurricane season that has been growing with intensity. As such, Florida developed own software to predict the long term stability of artificial reefs under given storm conditions which allows "administrators in coastal counties to determine the deployment water depth, orientation, and reef material weight" for ARs.

29. Parnell, E. (2005). Ecological Assessment of the HMCS Yukon Artificial Reef off San Diego, CA (USA). Scripps Institution of Oceanography, Integrative Oceanography Division, University of California. MGMT- HMCS Yukon & Mission Bay AR (Wreck Alley), MB, San Diego

This unpublished report gives an intricate history and ecological assessment of the AR HMCS Yukon off the coast of Mission Beach, San Diego and ecological assessment of the AR. The San Diego Oceans Foundation (SDOF) sank the ship in 2000 and then formed a volunteer based monitoring program. SDOF established a training program through PADI, 'Yukon Research Diver', that ensured volunteers were adequately trained and qualified. The REEF fish survey project, http://www.reef.org/data/surveyproject.htm, is an example of a volunteer observer program in marine ecology. However, for the YUKON monitoring program the web-based data entry, htttp://www.sdoceans.org/forms/armp_diverform.php was used to report data as well as a closed Facebook page to facilitate discussion. Unfortunately, monitoring did not began until 11 months after the Yukon sank therefore missing the critical baseline data survey and details. Barred sand bass, sculpin, and cabezon were the first observed near the Yukon and there was a secondary attraction of kelp bass, rockfish, and lingcod. "The most abundant fish were (in order of abundance) white surfperch, blacksmith, black surfperch, boccacio, vermillion rockfish, other rockfish, pile surfperch, black eyed gobies, barred sand bass, painted greenling, senorita, snubnose sculpin, and sheephead." There was a strong seasonal component with more fish observed in the summer and fall. There was twice the amount of fish diversity in the kelp forest than on the Yukon. However, vermillion rockfish and boccacio are very rarely seen in kelp forests and appeared to have a suitable habitat on the Yukon. The Yukon successfully served as an education and public outreach program in important components of the Foundation's mission. In the algal community, the Yukon appeared to be disturbed with high mortality due to fouling by hyroids and bryozoans; larger kelps did not appear to be able to attach firmly to the hull. "The oldest giant kelp plants (*Macrocystis pyrifera*) observed on the Yukon were in the 4-stipe stage and therefore less than six months old." *Pelagophycus porra* (the other canopy forming kelp in Southern California) did not appear to stay attached beyond a couple of meters.

The paper discussed the attraction versus production controversy and 'kill zones', but only offered that more "comprehensive studies of this artificial reef network are needed to determine whether these reefs are beneficial or harmful to natural populations." Offered management recommendations: "effective enhancement of fish production in southern California utilizing artificial habitats is still in its infancy and should be approached using a staged process."

30. Pendleton, L. H. (2004). Creating Underwater Value: The Economic Value of Artificial Reefs for Recreational Diving. Los Angeles, California: University of California. Lessons Learned- Yukon AR

This paper provides a cost-benefit analysis of artificial reefs, focusing and comparing values of recreational diving on sunken ships such as the Yukon AR off San Diego. As of 2004, San Diego only had 10 ships placed as ARs intended for recreational diving, comparatively to FL (380), NJ (129), SC (100), and NY (65). The cost of an AR (specifically a sunken ship) can range from $46K to $2M. However, the benefits are of course harder to predict since an argument can be made there are many non-market benefits. "Economic expenditures (per person-day) by recreational divers range from $64 in Southern California to $119 for rigs in the Gulf of Mexico. Hess et al. (2001) found that ARs "generate an average of $3.4 million in gross revenues annually." Specifically, "the San Diego Oceans foundation estimates that 10,000 divers made 26,000 visits to the Yukon artificial reef site between August 2002 and August 2003 […] expect the Yukon to generate anywhere from $600,000 to over $2 million in local expenditures annually." "In California, McGinnis et al. (2001) calculate[d that] the average per person-day expenditures of divers visiting oil rigs to be $64, with a total annual value of $10,700." "The Yukon cost more than $400,000 to acquire, prepare and sink and costs more than $1,000 annually for basic maintenance."

31. Pondella, D. J., Allen, L. G., Craig, M. T., & Gintert, B. (2006). Evaluation of Eelgrass Mitigation and Fishery Enhancement Structures in San Diego Bay, California. Bulletin of Marine Science, 78(1), 115–131. Habitat- San Diego Bay/Eelgrass & ARs/mitigation efforts

This bulletin discusses the mitigation effort to offset eelgrass habitat loss in San Diego Bay that occurred in 1997. The effort consisted of transplanting eelgrass, *Zostera marina L.*, in the western portion of the bay and the addition of four ARs either made of quarry rock or concrete rubble. The goal was to further enhance fishery stocks and the San Diego Bay's marine ecosystem and was examined during a 5 year pilot program. It was found that neither reef material influenced fish utilization and but that both the ARs and eelgrass transplantation achieved the enhancement and mitigation goals. Starting in September 1997, "immediately following reef construction and eelgrass planting, the fish enhancement structures, eelgrass transplant area, and surrounding soft bottom habitats were monitored regularly for 5 years by SCUBA divers. Concomitant with this monitoring, two reference sites, the closest naturally occurring eelgrass bed and the nearest rocky-reef, were also surveyed." The four ARs were quickly colonized by *Laminaria farlowii* Setch (Phaeophyta), *Sargassum muticum* Yendo, (Phaeophyta), and *Macrocystis pyriferai* Agardh, (Linnaeus). Lobsters, *Panulirus interruptus* were the most prevalent macroinvertebrates observed in high densities on reefs and also in eelgrass habitat. "Results demonstrated that, in addition to creating a vibrant and complex enhancement fish habitat, enhancement reefs increased localized fishery production in terms of both eelgrass restoration and production of targeted species."

32. Pondella, D. J., Williams, J. P., & Williams, C. M. (2018). Restoring a Nearshore Rocky Reef Ecosystem in the Challenge of an Urban Setting. American Fisheries Society Symposium, 86, 165–186. Habitat- Palos Verdes Peninsula (natural reef habitat)

This paper focused on the Palos Verdes Peninsula in LA County that is subject to multiple anthropogenic impacts in particular large landslides that results in sedimentation and reef burial thus significantly decreasing the rocky reef habitat of the coastline. As they intensively mapped and surveyed the shoreline they began to better understand the extensive rocky reef habitat with established kelp forests. "Notable among all survey locations is a relatively high-relief (~5m) area of reef within the sediment impacted area that consistently has the highest fish biomass density among anywhere on the peninsula." "Their primary objective was to use the 63,500 metric tons of quarry rock the budget would allow us to create the most productive habitat by restoring the natural reef environment while balancing scientific study design considerations with maximizing the potential for an effective restoration effort across the range of important species and overall kelp forest diversity."

Using biological performance and informed by scientific literature of NRs and ARs reef surveys in the region, the proposed sample design "attempted to maximize high relief components, [void spaces], surface to volume ratio, perimeter, ecotones, and small-scale current flow features and nutrient flux. In addition, "placement and spacing of individual reef blocks included space for sand channels between blocks to permit sediment transport and create sand/rock ecotone habitats while remaining close enough to each other and existing natural reefs to maintain biological connectivity." In addition to the appropriate and ideal design of a specific AR this paper also highly recommended detailed planning and implementation of a pre- and post- construction monitoring program to inform future reef restoration. BACIPS- a before-after control-impact paired series sampling design was deemed most appropriate to assess changes in biomass due to fish movements (relocation from nearby reefs). Used CRANE (Cooperative Research and Assessment of Nearshore Ecosystems) protocol. Considered recreational components including impacts on surfing opportunities. Reef construction was planned for the fall of 2018.

33. Reed, D. C., Schroeter, S. C., Huang, D., Anderson, T. W., & Ambrose, R. F. (2006). Quantitative Assessment of Different Artificial Reef Designs in Mitigating Losses to Kelp Forest Fishes. Bulletin of Marine Science, 78(1), 133–150. Mgmt- SONGS

This literature focused on the giant kelp *Macrocystis pyrifera* (Linnaeus) habitat that had been degraded from the operations of SONGS. In particular, they focused on the response of the kelp forest fish with relation to AR material (recycled concrete rubble vs. quarry rock) and bottom coverage by conducting a 5 year experiment (phase 1) on small scale (~9 ha). Their results indicated that all configurations of the experimental phases of reef material and bottom coverage tested provided suitable habitat for kelp forest fishes. "Reef-associated fishes > 1-yr old rapidly colonized the bottom 2 m of the AR modules and by summer of 2000 all six reef designs displayed densities of resident fishes that were similar to or greater than those observed on the nearby reference reefs (San Mateo and Barn)." "Importantly, none of the AR designs had mean values of either resident or YOY fishes that were below the performance standards." "Our results show that fish standing stock, density, species richness, and recruitment on all the AR designs were either similar to or greater than that observed at the nearby natural reefs at San Mateo and Barn. These findings are consistent with those of previous studies that found the numerical and biomass densities of fishes to be higher on ARs compared to natural reefs in southern California." However, SONGS mitigation reef was intended to compensate for the loss of an entire community of algae, invertebrates and fishes, thus "its ultimate design will need to be 'tuned' to meet the overall objective of producing a balanced kelp forest community that has the appropriate representation of all trophic elements."

The California Coastal Commission (CCC) uses four performance standards: (1) resident fish assemblage, (2) total density and number of species of YOY fish (and compare with natural reefs in the area), (3) fish reproduction rates (also compare with natural reefs), and (4) fish production (somatic + gondal mass). This study did not use standards (3) and (4) as criteria for their experiment and focused on (1) and (2). The experimental phase of the San Clemente Artificial Reef (SCAR) was constructed in August and September 1999 and consisted of eight module types (ARs) at seven locations evenly spaced along the coastline at approximately 3.5 km (2 mi). Each artificial reef module was about 40 x 40m (~130') and the 56 modules covered approximately 9 hectares (22 acres) of the sea floor and mimicked low-lying reefs (<1 m tall).

34. Ruhl, E. J., & Dixson, D. L. (2018). Thesis: Understanding the Importance of Habitat Complexity for Juvenile Fish and the Application of 3D Printed Corals for Reef Restoration. University of Delaware, Summer 2018. Habitat- Fiji ARs

This thesis for a Master of Science in Marine Studies from the University of Delaware isolated and replicated the physical structure of a common Indo-Pacific reef in Fiji through 3-D printed models. "Several dozen models (PLA/PHA) of A. Formosa coral colonies were placed on the protected reef on Tavewa Island, Yasawas, Fiji from February 6, 2018 to October 15, 2018." "Coral settlement was observed using 3D printed settlement tiles made of different filaments placed on Fijian reef." "This thesis demonstrated that complexity plays an important role in determining habitat associations and subsequent behavior of the coral-associated damselfish, *P. moluccensis*." "As habitat characteristics are major drivers of the structure and function of animal communities, the design of artificial reefs should mimic that of the environment that they are intending to rebuild."

35. Scarborough-Bull, A., Love, M. S., & Schroeder, D. M. (2008). Artificial Reefs as Fishery Conservation Tools: Contrasting the Roles of Offshore Structures Between the Gulf of Mexico and the Southern California Bight. American Fisheries Society Symposium, 49, 899–915. Mgmt- O&G platforms

This paper recognized the importance of management decisions with regard to California's O&G platforms and compares details to the Gulf of Mexico's platforms. As of 2008, there were 23 structures in the Southern California Bight (SCB) and over 4,000 platforms in the Gulf of Mexico. California's marine habitat consists of natural reefs and offshore islands, concentrated in the Santa Barbra Channel area, while the Gulf of Mexico has few natural reefs and is mostly a soft bottom type. This paper's studies showed that the bocacio *Sebates paucispinis*, cowcod *S.*

*levis*, vermilion rockfish *S. miniatus*, lingcod *Ophiodon elongates*, and cabezon *Scorpaenichthys marmoratus* were found in high densities on Southern California Bight platforms. It also discusses how fish assemblages are characterized in three different categories: (1) midwater, (2) base, and (3) shell mound. Rockfish dominate the habitat in density and species richness, totaling 42 species. "Shellmounds may rise 7m or more above the seafloor and cover over 6 sq km in area […] together, standing platforms and their shell mounds support large and viable fish communities." "Off California, it is difficult to commercially fish for rockfish and other species around the base of platforms because of strong currents and constant gear loss due to the complex submerged platform structure." It was found on the platforms that both allowed fishing and had the highest densities of rockfish, that the assemblage was dominated by dwarf species (much below the size of an ordinary adult). California is "likely to be the first region where large deepwater platforms will be decommissioned." "The offshore structures located in the Southern California Bight act as de facto marine protected areas and provide ecological benefits for severely overfished species, including a higher potential larval production when compared to nearby natural areas […] the removal of these structures will almost certainly have ecological and economic impacts."

36. Schroeter, S. C., Reed, D. C., & Raimondi, P. T. (2015). Effects of reef physical structure on development of benthic reef community: a large-scale artificial reef experiment. Marine Ecology Progress Series 540, 43–55. Habitat- SONGS

This journal focused on the realistic scalability of the small-scale SCAR/SONGS five-year experiment artificial reef off southern California. Their findings included that the "abundance and richness of colonizing algae were significantly related to location (i.e. proximity to the nearest natural reef), while that of sessile invertebrates was not." In addition, the "findings suggest that physical attributes of reef structure may play a key role in structuring reef communities following a disturbance, but their importance diminishes over time as ecological interactions involving established reef organisms become increasingly important." Initial colonization is considered the first year and during that time findings showed variations by physical factors of AR. However, five years is the average period required to establish populations of sessile invertebrates and macroalgae who are then capable of 'new recruits,' this is where the physical attributes importance start to diminish.

"Unlike calcium carbonate reefs formed in the tropics by hermatypic corals, reefs in temperate seas typically consist of non-living geomorphic materials that vary in composition." The physical location has to be considered as well incorporating wave exposure, currents, proximity to other natural reefs, and specific knowledge of the local marine ecosystem are essential elements to consider for the successful design of an AR.

37. Seaman, W. (Ed.). (2000). Artificial Reef Evaluation: with application to natural marine habitats. Boca Raton: CRC PRESS. Habitat

A hard copy of this book is available at the UC San Diego Library. This book discusses the need for standardization across the globe as we continue to modify aquatic ecosystems in coastal waters with AR. The central question of if ARs are achieving their goals can only be answered with evaluations of those ARs. Therefore if technology is to be applied successfully and responsibly procedures of study methods should be shared, databases established, and standardization implemented for accurate data comparison. The goal of the book was to increase scope of research for the AR field and highlight the need for reliable data and global information exchange. Responsible reef planning can only be achieved through thorough and effective AR evaluations.

Chapter 3, Physical Characteristics and Engineering a Reef Sites, offered a classification of three different types of assessments (1) Basic Reef Descriptions, (2) Analyses and Comparisons, and (3) Interactions and Predictions. Chapter 6, Social and Economic Evaluation Methods, there was a helpful Potential Benefits of an Artificial Reef Project, Table 6.3 (p. 178). Chapter 7, Integrating Evaluation into Reef Project Planning, offered Table 7.1 Objectives for ARs including both economic benefits and to enhancing living marine resources (LMR). Diverse interests groups included commercial fishing, habitat restoration, recreational diving, submarine tour operators, sport fishing, artisanal fishing (Figure 7.3).

Anti-trawling reefs should (1) be lasting, but not polluting, (2) be heavy and strong, so as not to be broken or moved by large otter trawls, (3) have as many different-sized holes as possible, maintaining structural integrity, (4) have some surfaces protected against siltation or sedimentation, (5) have links for ropes or chains useful for additional mariculture operation (such as mussels or oysters hung in special cages) or for mooring boats.

"Any tool used properly does good, but it has the potential to be misused, or used for its intended purpose but still do unintentional harm. The possibility of harm is increased by ignorance and reduced by knowledge."

38. Simon, T., Pinheiro, H. T., & Joyeux, J.-C. (2011). Target fishes on artificial reefs: Evidences of impacts over nearby natural environments. Science of The Total Environment, 409(21), 4579–4584. doi: 10.1016/j.scitotenv.2011.07.057 Stock- Brazil ARs

This paper evaluates target fish on two ARs in SE Brazil off Guarapari, the Bellucia and the Victory 8B shipwrecks and aims to verify if the fishes are being attracted or produced on artificial reefs. The two control sites were nearby natural rocky reefs, Rasa and Escalvada islands. The four targeted fish were jacks, snappers, groupers, and while grunts. Length frequency, mean biomass, and frequency of occurrence were compared between the ARs and NRs. "Results were inconclusive for the pelagic predators *Cranx* sup. The attraction that artificial reefs exert over large demersal predators can negatively affect nearby natural areas through shifts in predation, competition or nutrient input."

"Although no conclusion for this pattern was drawn by the authors, it is probable that nearshore natural environments are not obligatory nursery areas, as previously assumed. Presumably, deep artificial reefs offer conditions not encountered in deep natural reefs, conditions that would involve post-settlement ecological processes such as predation, competition or food and quality and quantity. In the present study, the differences in depth range and slope between artificial and natural reefs can actually cause the differences in tomtate recruitment patterns, but a temporal assessment of the population is required for testing." This article also mentioned that "artificial reefs have higher rugosity than natural reefs: (unpubl. data). "Artificial reefs will at the same time support an increase in biomass for some fishes (such as grunts) and attract others (such as snappers and groupers) from nearby areas."

39. Southern California Marine Institute, Vantuna Research Group (2020). Initial Construction Audit (submitted to California Coastal Commission) Palos Verdes Reef. Retrieved May 29, 2020, from https://www.oxy.edu/academics/vantuna-research-group/palos-verdes-reef MGMT Palos Verdes

This document serves as the initial construction audit of Module 2A of the Palos Verdes AR. Construction of Module 2A commenced on 08 May 2020 and was completed on 11 May 2020. The visual survey performed by both SONAR and divers was done on 12 May 2020. Following the perimeter, divers surveyed the size and shape of the submodules, noting that very few quarry rocks were outside of the main pile. No natural reefs appeared to be impacted and several fish were seen along the perimeter: Kelp Bass, Barred Sand Bass, California Sheephead, and Blacksmith. In addition, Norris's topsnail, bat stars, and wavy turban snail were all seen. Comparing the bathymetry to a module footprint from 17 Oct 2019, "each of the six submodules is distinct and the entire structure is placed nearly perfect within the planned footprint." Bravo Zulu to Connolly Pacific and the construction crew, no need to modify construction plans or method(s) at this time.

40. Wilson, K. C., Lewis, R. D., & Togstad, H. A. (1990). Artificial reef plan for sport fish enhancement. Sacramento, CA: CDFW. PAR- and all other CA ARs **Have plans and diagrams for most socal ARs, scan and see if can incorporate into Story Map.**

This document sets forth the plan for CDFW for "the construction of ARs" and includes an outline to establish a system of fisheries habitat enhancement areas. Since 1958, CDFW has constructed 31 ARs off southern California and maps of these reefs were published in 1989 titled "A Guide to the Artificial Reefs of Southern California." Seven were constructed from 1978-1987 to "improve habitat for sport fishes and associated fauna and to evaluate the enhancement characteristics of reefs related to geographic location, depth, height, rock size, and reef spacing." This document includes the evaluation of the Pendleton Artificial Reef (PAR, 1980-1986) as an example of the reef building and study process. This plan was primarily written for resource managers and aimed to "develop a comprehensive long-term reef program for fisheries enhancement."

ARs have long been recognized for attracting fish, such reefs have been used in Japan for over 500 years and in the US for over 170 years, however fish production is still not clearly understood. CDFW is authorized by the State of California "…to encourage the conservation, maintenance, and utilization of the living marine resources of the ocean… for the benefit of all the citizens of the state…" (Fish and Game Code, Sections 1700-1701 [Appendix 1]). "An objective of the Artificial Reef Plan is to investigate the relationship of sport fishes to associated reef communities." Due to anthropologic impacts, CDFG began a pilot study with three experimental reefs: (1) Paradise Cove, Los Angeles County, (2) Redondo Beach, Los Angeles County, and (3) Rincon Point, Santa Barbra County. These ARs were built with automobile bodies and streetcars, and other materials of "opportunity." Based on the pilot study, three more

ARs were constructed in 1960 in Santa Monica Bay: (4) near the city of Malibu, (5) Santa Monica, and (6) Hermosa Beach. Each of these "multiple component replication reefs" had four sub-reefs or modules of equal volume and used the same cost effective material as the first three ARs. Concrete was found to work best at first but then would get buried with sedimentation. Automobile bodies and street cars deteriorated quickly and tires would move with large swells (in addition to being toxic- polybutadienes and zinc). These ARs were considered a success and an additional 15 recreational fishing reefs (in addition to augmenting 13 existing ARs) were constructed between 1962 and 1979 (Figure 2); these low-relief modules were 2-4' high, spaced 60' apart, and located between depths of 60' and 72'. In addition, seven quarry rock reefs were also constructed adjacent to fishing piers from Venice to Oceanside. After deterioration of kelp forests in LA and SD counties in the 1960s, CDFG redirected its habitat enhancement efforts in the 1970s to Palos Verdes Peninsula. In 1979, Southern California Edison (SCE) funded a "state of the art" AR to study and test the acceptability of using an AR to facilitate kelp forest enhancement/replacement. Thus, the Pendleton AR (PAR) was constructed in the fall of 1980. To carry out the PAR agreement, CDFG formed the Nearshore Sport Fish Habitat Enhancement Program (NSHEP). NSHEP categorized reefs into three categories: (1) developmental reefs, (2) production reefs, and (3) fish attracting devices (FADs). "Developmental reefs are intended to develop better techniques for increasing production of living marine resources through scientific investigations of reef design and function." The Pitas Point AR (PPAR) and the Marina del Rey AR (MDRAR) were constructed in 1984 and 1985 respectively as such. In addition, PAR, Santa Monica Bay AR (SMBAR), Topanga AR (TAR), and three similar reefs (Santa Barbra, Oceanside, and Pacific Beach) were all constructed as developmental reefs. The Carlsbad AR (CAR) had been scheduled to be built as a future developmental reef. "Production reefs are primarily intended to enhance the production of living marine resources and fishing opportunity" (discussed more in the 'Artificial Reef Plan'). "FADs, in contrast, are constructed to attract sport fishes and increase the catch without necessarily contributing to an increase in standing crop."

In the Artificial Reef Plan five purposes are defined: (1) Sport Fish Habitat Enhancement, (2) Sport Fish Catch Enhancement, (3) Reef Study, (4) Multi-purpose, and (5) Mitigation. Pre-construction steps then include (1) define the purpose, (2) information gathering (physical, biological, and anthropologic), (3) site selection, (4) reef plans, (5) project narrative, (6) permits/approvals (CEQA, CCC, etc.). The construction phase then includes (1) funding, (2) contractor selection, (3) plan confirmation, (4) scheduling, (5) verification, (6) reef mapping, and (7) reef studies. Quantitative surveys were to be conducted semi-annually for four years (1998-2002). Equilibrium was found to be different for every reef, but estimated at 5-10 years.

Artificial reef location and mapping. Since 1958, 31 ARs were built the last being Topanga AR (Nov 1987); nine were completely lost due to (1) deterioration (i.e. wooden streetcars, automobile bodies, (2) sediment burial, (3) movement (i.e. tires), and (4) loss of surface marking buoys/changes in landmarks (aka lost). To update this information, "CDFG located and mapped thirteen of the largest and most frequently fished reefs from Santa Monica Bay to San Diego […] an informational booklet describing the location and configuration of important reefs was published in 1989 by Lewis and McKee, A Guide to the Artificial Reefs of Southern California.

STOCK: Important sport fish to track according to this study included kelp bass, barred sand bass, sheephead, surfperches, cabezon, sculpin, and rockfish. Blacksmith, garibaldi, plainfin midshipman, and invertebrates (including lobster, sea urchins, crabs, and scallops) often occur on man-made reefs. Kelp on man-made reefs provide additional habitat attracting sport fishes to include opaleye, halfmoon, and many invertebrates as well.

This document defined AR success primarily around sport fishing, but did recognize that each reef had “a different secondary purpose”. “The precise location and structure of future reefs, statewide, will be prioritized by local sport fishing needs and by biological and physical conditions.”

MITIGATION- “California Department of Fish and Game believes that artificial reefs, when properly constructed, can be used as mitigation for impacts on rocky habitat, and, in certain cases, for damage to giant kelp.” […] “ However, the extent to which artificial reefs benefit fishery stocks, has not yet been fully investigated. Until this question is satisfactorily addressed, the usefulness of artificial reefs as mitigation must be carefully considered on a case-by-case basis.”

CONCLUSION- “The success of habitat enhancement operations and, particularly, reef construction and study program depends upon the cooperation and support of governmental agencies, the legislature, academic institutions, industry, fisherman, and general public. Through team effort, CDFG can undertake a program of sufficient magnitude to contribute, meaningfully, to the maintenance and replenishment of California’s nearshore living marine resources.”

41. Wilson, K. D., Leung, A. W., & Kennish, R. (2002, February 1). Restoration of Hong Kong fisheries through deployment of artificial reefs in marine protected areas. Retrieved April 8, 2020, from https://academic.oup.com/icesjms/article/59/suppl/S157/617914 Lessons Learned- Hong Kong

This paper provides details on a restoration effort in Hong Kong’s marine ecosystems and fisheries through the development of ARs within marine parks and fishery-protected areas (FPA). It was conducted in two phases, the first being implementation of ARs into the marine parks and the second being the “establishment of FPA selected specifically for their suitability for AR deployment and fisheries restoration.” Successful implementation of the ‘no-take’ zones should be established with representatives from the fishing community, the government, and academia. The Agriculture, Fisheries, and Conservation Department (AFCD)’s “main initiative is the five-year Artificial Reef (AR) Programme, which started on 01 July 1996 with US$13 million in funding.” “Preliminary results from monitoring of the first phase and the ambit, findings and recommendations of an AR Deployment Study are presented [in this paper]. Hong Kong has a large prawn-trawl fishery and the physical presence of AR will prevent bottom trawling. “The regional problem caused by excessive trawling is recognized by fishery managers within the People’s Republic of China (PRC).” “Modeling results indicate that AR deployment, utilizing 10-20% of local waters managed predominately as no-take zones, could arrest the current decline in fisheries yield and produce significant improvements within ten years.” “If combined with reductions in the fishing fleet, it has the potential to arrest the current fisheries decline and bring about a sustained improvement over a 30-year period.”

# CA Artificial Reef- Points of Contacts

**Vantuna Research Group:**
Dan Pondella
Office: (323) 259-2955, Cell: (310) 519-3172
pondella@oxy.edu;

Jonathan Williams
jonwilliams@oxy.edu

Jeremy Claisse
Associate Professor, Biological Sciences Department
Cal Poly Pmona
Office: (909) 979-6487
jtclaisse@cpp.edu

**California State University, Long Beach (CSULB)**
Chris Lowe
Office: (562) 985-4918
chris.lowe@csulb.edu

**Reef Check**
Jan Friedweld
jfreiwald@reefcheck.org

Tom Raftican (has some expertise on fishing and CA artificial reefs)
Cell: (805) 895-3000
refish@earthlink.net

**UC Santa Barbara/Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO):**
Dr. Jennifer Caselle
University of California Santa Barbara
Marine Science Institute & National Center for Ecological Analysis and Synthesis
Office: (805) 893-5144
caselle@ucsb.edu

John Richards
Marine Advisor Emeritus
Sea Grant Extension Program
Marine Science Institute, UCSB
Cell: 805-453-5977
j_richar@lifesci.ucsb.edu

Deborah McArdle, Marine Advisor
California Sea Grant Cooperative Extension,
University of California
305 Camino del Remedio, Santa Barbara, CA 93110
Office: (805) 448-5405
damcardle@ucdavis.edu

Milton Love
Research Biologist, Marine Science Institute (https://www.youtube.com/watch?v=ouljzQHfObg&t=1s)
love@lifesci.ucsb.edu
Work:  805-893-2935

**Blue Latitudes, LLC**
Amber & Emily, Co-Presidents
Amber Sparks (Jackson)
amberleajackson@gmail.com
Emily Callahan
eadcallahan@gmail.com
Contacted on website:  https://www.bluelatitudesfoundation.org/

**SONGS**
Steve Schroeter
Office:  (760) 438-5953
schroete@ucsb.edu

**UC Santa Cruz**
Mark Carr
Office:  (831) 459-3958
carr@biology.ucsc.edu

**Other:**
Jeff Maassen
"The Urchin Hunter"/ https://vimeo.com/412342027
(805) 450-8488
unidiversb@gmail.com

David Kushner
National Park Service, Head Marine Biologist
Office:  (805) 658-5773
Cell:  (805) 259-0806

Donna Schroeder
Marine Ecologist
Bureau of Ocean Energy- Management (Greater LA area)
https://www.linkedin.com/in/donna-schroeder-507ba24

Mary Nishimoto
UCSB Marine Science Institute (MSI) Staff Research Associate
O:  (805) 893-3835
mary.nishimoto@lifesci.ucsb.edu

Chris Dewees
Marine Advisor/City of Ventura
cmdewees@cal.net

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**UC San Diego:**
Ed Parnell
Scripps Scientist/Author of the YUKON AR Ecological Assessment
eparnell@ucsd.edu
**Scripps- Small boat/Site Visit Plan**:

Brett Pickering- ROV brett@ucsd.edu

Christian McDonald; cmcdonald@ucsd.edu - Dive/Boating Policy
ROV- $150/day and $50/hr for operator (>60')
Divers- with scientific divers $30/hr for boat + fuel (<60')