Office of National Marine Sanctuaries Review of Artificial Reefs
DRAFT
Kathy Broughton (NOAA Office of National Marine Sanctuaries)
May 23, 2012

Reviewers and Affiliations

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The document that follows is a copy of the **DRAFT** *Office of National Marine Sanctuaries Review of Artificial Reefs* that was disseminated to three individuals who served as peer reviewers. In December 2004, the White House Office of Management and Budget (OMB) issued a Final Information Quality Bulletin for Peer Review (OMB Bulletin) establishing peer review standards that would enhance the quality and credibility of the federal government's scientific information. Among other information, these standards apply to Influential Scientific Information (ISI), which is information that can reasonably be determined to have a "clear and substantial impact on important public policies or private sector decisions." This report is considered to be Influential Scientific Information. For this reason, it is subject to the review requirements of both the Information Quality Act and the OMB Bulletin guidelines. Therefore, following the completion of this report it was reviewed by a team of three individuals who are considered to be experts in the field, were not involved in the development of the report, and are not Office of National Marine Sanctuaries employees. Following the External Peer Review the comments and recommendations of the reviewers were considered by the author and incorporated, as appropriate, into a final draft document. The comments and suggested edits that were received from the reviewers are listed below and embedded in the draft itself that follows. The final report may be downloaded from: http://sanctuaries.noaa.gov.

Reviewer 1:
I have completed my review of the reference paper, and included comments as track changes and "comment bubble". Please see the attached Word document. Following this email I will provide the many additional references mentioned in my comments. I signed and faxed the conflict of interest form to the NOAA fax number 301-713-4306.

Overall, the paper is a good review of the many historical reference documents that exist on artificial reefs, although there seems to be an over-emphasis on materials which have long been prohibited and no longer used as artificial reef materials (such as automobiles and tires), or practices which are no longer permitted (such as placement within seagrass beds). This may be a result of the many references dating back to the 1980s and 1990s, that may be addressed by providing reference to more current peer reviewed articles (there are comparatively few references from the 2000s or 2010s). In general there is a need to update the review to provide a more accurate reflection on current activities, or at the very least make a distinction between historical practices and current practices. There were many 'lessons learned' from the early days of artificial reefing which were used to help establish today's standards, but it is equally important make a distinction between the past practices as a historical perspective and present the current practices based upon the latest research objectives.

Another general recommendation throughout should be a discussion describing regulatory oversight. Artificial reef deployments in the U.S. today are carefully regulated and monitored to ensure compliance with permit conditions. It is through the regulatory process that compliance with thresholds and standards ensure environmental protection. Citations to relevant regulatory guidance documents would be appropriate. For example, I was surprised to see that reference to the FKNMS Policy paper on artificial reefs was not included (NOAA, 2003. Policy Statement of the National Marine Sanctuary Program: Artificial Reef Permitting Guidelines. Silver Spring, Maryland, U.S. Department of Commerce: iii, 1-20, Appendix A-C.)

From a document layout perspective, consider improving the flow in some section by grouping discussions into logical sections such as marine fisheries considerations, coral and coral reef protection considerations, economic considerations, etc.

Personally, I would also like to see a discussion somewhere in the document talking about the role National Marine Sanctuaries may be able to play in artificial reef research and habitat enhancement. Artificial reefs are designated as EFH by the SAFMC for the grouper-snapper complex, and the Gulf Council is currently considering designating artificial reefs as EFH in the Gulf of Mexico. What opportunities are there within the NMS system to construct high quality EFH artificial reefs for fish and coral species of concern? For example, while the majority of the discussion about attraction-production is essentially predicated on the effect of fishing pressure, by looking at establishment of artificial reefs within MPAs (areas closes closed to fishing), fishing pressure would essentially not be a factor, and opportunities to resolve bottlenecks in marine fisheries management could become a viable possibility for targeted reef fish populations.

Most of my comments are contained directly in the document, however I provide some additional other broad comments as follows:

Pages 1 and 2. I think there needs to be real distinction between what materials are currently used and allowed now; and what was used before permitting restrictions were put into place around 1990 (21 years ago). Most of the materials section seems to be in present tense, when much of it should be historical. A discussion of permits and their restrictions would be useful here also. It almost sounds like it is still an unregulated activity.

On page 4 the paper seems to make the point than artificial reef fish populations do mimic natural reefs and then goes on to make the arguments as if artificial reef do not mimic natural reefs, which point are they trying to make?

Page 4 and 5 and 7. The contribution of artificial reef to total fish abundance may be trivial in California with only 27 rigs, few artificial reefs and a lot of natural reef habitats, but this may not be the case for 7,000 rigs in the northern Gulf of Mexico. Also if fish abundances are trivial on ARs, then the entire attraction/production issue would be moot, particularly the attraction, overfishing argument.

Page 7 and 8. Active oil rigs do not seem to meet the definition of an artificial reef used on page 1, yet are discussed later as if they are.

Page 13. No reference was made to the USEPA/MARAD Best Management Practices document and it should be included in the ships discussion.

Page 14. Any discussion of the Oriskany fish sampling results should include the fact that the USEPA issued a risk based disposal permit for known quantities of PCBs that were purposely left on the ship. This is in great contrast to newer and future vessel deployments, where all PCBs and other pollutants will be removed.

Page 14. Discussion of bottom paint and other chemicals should include with the fact that these materials become less toxic with age. The tone of some of that discussion almost implies that these materials are deployed new, when in fact they are as old as the ship or structure being used.

Thank you for the opportunity to comment, and please keep me informed of the progress in drafting the final report. I remain available to assist as needed, and very much look forward to the final report.

Sections to consider adding:

Reef Research
Consider adding a section: Reef Research. Artificial reefs provide a unique and important opportunity to conduct standardized reef research. This section could discuss and describe the value of standardized module designs, such as Lindberg's Steinhatchee Fisheries Management Area. Efforts to use reef research to integrate artificial reef development with marine fisheries management should also be emphasized.

For example, see

Seaman et al (2011). Artificial reefs as unifying and anergizing factors in future research and management of fisheries and ecoysystems. In: Artificial Reefs In Fisheries Management. S. A. Bortone, F. P. Brandini, G. Fabi and S. Otake. Boca Raton, FL, CRC Press: 7-30.

Structural Reconstruction of Natural Reefs from Boat Groundings

Consider adding a section: Structural Reconstruction of Natural Reefs from Boat Groundings. Perhaps the highest level of scrutiny in the use on man-made materials as artificial reefs is for the re-construction of natural coral reefs following damage by ship groundings. Consider including a section describing and discussing the construction techniques and results of long-term monitoring of sites such as Molasses Reef, Looe Key, the use of in-water cement practices, fiberglass rebar, etc to stabilize the natural reef structure. See:

Bright, T. J., S. R. Gittings, et al. (1987). Coral Recovery Following the Grounding of the Freighter M/V Wellwood on Molasses Reef, Key Largo National Marine Sanctuary. College Station, TX, College of Geosciences, Texas A&M Research Foundation: 1-182, Photographs 1-40.

Bodge, K. R. (1996). Structural Restoration of Coral Reefs Damaged by Vessel Groudings. Proceedings, 25th International Conference on Coastal Engineering, American Society of Civil Engineers (ASCE): 1-13.

Gittings, S. (2002). Pre-Construction Coral Survey of the M-V Wellwood Grounding Site. Silver Spring, Maryland, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Marine Sanctuaries Division: iii, 1-16.

Gittings, S. R. (1991). Coral Reef Destruction at the M/V ALEC OWEN MAITLAND Grounding Site, Key Largo National Marine Sanctuary: i-v, 1-28.

Gittings, S. R. (1991). Mitigation & Recovery Enhancement at the Grounding Site of the Freighter M/V ELPIS, Key Largo National Marine Sanctuary: i-iii, 1-11.

Gittings, S. R. (1991). Mitigation & Recovery Enhancement at the Grounding Site of the M/V Alec Owen Maitland, Key Largo National Marine Sanctuary, Submitted to: United States Department of Justice: i-ii, 1-14.

Gittings, S. R. (1991). Reef Coral Destruction at the M/V ELPIS Grounding Site, Key Largo National Marine Sanctuary, Submitted to: United States Department of Justice: i-v, 1-17, 28.

Hudson, H. J. and E. C. Franklin (2005). Structural Reef Restoration and Coral Transplantation to the R/V Columbus Iselin Grounding Site in the Florida Keys
National Marine Sanctuary. OCEANS 2005 Proceedings of MTS/IEEE. 1: (1-4) 207-210.

Hudson, J. H., J. Schittone, et al. (2008). M/V Alec Owen Maitland Coral Reef Restoration Monitoring Report, Monitoring Events 2004-2007. Marine Sanctuaries Conservation Series

NMSP-08-01 Silver Spring, MD, Florida Keys National Marine Sanctuary vi, 1-34.

Hudson, J. H., J. Schittone, et al. (2008). M/V Elpis Coral Reef Restoration Monitoring Report, Monitoring Events 2004-2007. Marine Sanctuaries Conservation Series NMSP-08-03. Silver Spring, MD, Florida Keys National Marine Sanctuary v, 1-37.

Reef Environmental Education Foundation (2007). Fish Assemblage Monitoring at the M-V Wellwood Grounding Restoration May 2002 - August 2007: 1-21.

Schmahl, G. P., D. R. Deis, et al. (2006). Cooperative Natural Resource Damage Assessment and Coral Reef Restoration at the Container Ship Houston Grounding in the FL Keys National Marine Sanctuary. Coral Reef Restoration Handbook. W. F. Precht, Taylor & Francis: 235-256.

Coral Nurseries

Consider adding a section: Coral nurseries. Concrete and limestone materials have been successfully used as substrate for coral recruitment, growth, and transplantation. Consider inserting a section to discuss such practices. Examples include artificial reefs as nursery areas to recover corals fragmented from ship groundings and other anthropgenic activities such as jetty reconstruction, beach nourishment, cable crossings, and dredge projects. References: Koenig oculina project, NOVA nurseries, etc.

Climate Change

Consider adding a section on climate change. Serious attention has been placed on climate change in recent years. Consider inserting a chapter contemplating the contributions artificial reefs might be able to provide towards experimenting with construction of new hardbottom habitat to help protect and preserve corals and coral reefs as related to sea level rise, ocean acidification, and sea temperature rise.

Red Tide

Consider including a section discussing the contribution artificial reefs provided towards reef community recovery following environmental phenomenon such as the 2005 red tide event in SW Florida. High profile artificial reefs, with upper sections that were unaffected by the red tide's 2-4 ft layer above the seafloor, were hypothesized to help accelerate the recolonization and recovery process following the red tide event.

Trawl Deterrents

Consider adding a section on the artificial reefs as trawl deterrents. In some nations, such as in the IndoPacific, large concrete artificial reefs are used as trawl deterrents to prevent damage to natural coral reefs, by creating an effective barrier preventing trawls from damaging fragile natural coral reef habitat. Such a concept was considered as one additional tool to protect the Oculina Banks HAPC off of Cape Canaveral, FL (see http://www.artificialreefs.org/ScientificReports/Experimental%20Oculina%20Research%20Reserve.htm). Some hypothesis consider the defacto anti-trawl effect of artificial reef construction on marine fisheries such a red snapper. For example, see

Cowan Jr., J. H. (2011). "Red Snapper in the Gulf of Mexico and U.S. South Atlantic: Data, Doubt, and Debate." Fisheries 36(7): 319-331.

and for anti-trawl reefs in other nations, see:

http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8253476

Oyster Reef Enhancement Projects

Consider adding a section discussing artificial reefs for oyster reef enhancement. Concrete artificial reef Modules, and oyster shell projects have successfully been used in a variety of oyster reef restoration projects. For example, see http://www.tampabaywatch.org/index.cfm?fuseaction=content.home&pageID=21

Wave Attenuation and Shoreline Habitat Enhancement Projects

Consider inserting a section discussing the use of artificial reefs for wave attenuation. Artificial reefs have successfully been used to provide wave attenuation for eroding shorelines in estuaries and restore salt marsh habitat. For example, see: http://www.dep.state.fl.us/northwest/ecosys/section/greenshores.htm

Historical Resources

Consider inserting a section discussing artificial reefs as historical resources. Artificial Reef steel vessels, and old bridge spans are increasingly gaining recognition as historical resources. For example, the Florida Keys NMS, three of the nine steel vessels that comprise the FKNMS Shipwreck trail were intentionally deployed artificial reefs: see http://floridakeys.noaa.gov/shipwrecktrail/welcome.html

Sculptures and Novelty Reefs

Consider inserting a section discussing sculptures and novelty reefs. A classic example if the ‘Christ of the Abyss’ statue located in the FKNMS. Since 2009 large scale underwater sculpture efforts have been made internationally by artist Jason de Caires Taylor see: http://www.underwatersculpture.com/.

Reviewer 2:
The document is very well written and overall presents an excellent review of available literature. To call it a summary of current scientific literature (top of page 2) is somewhat of a misnomer. The document certainly reflects a real attempt to update the original manuscript begun in 1998 and does include recent studies on aspects of artificial reefs with regard to structural integrity, range expansion, invasive species, and toxicological impacts.
However, the document does not include discussion of a number of important recent papers on attraction versus production and attributes of ecosystem change.

For example, discussion of larval transport and placement of artificial reefs on pages 4 and 5 should include the paper from Fishery Bulletin 104:391-400 (2006) by Emery et al. "Do oil and gas platforms off California reduce recruitment of bocaccio (Sebastes paucispinis) to natural habitat? An analysis based on trajectories derived from high-frequency radar," (See: http://www.lovelab.id.ucsb.edu/Emery_et_al._2006.pdf,). Results from this oceanic current study indicate that most of the young-of-the-year (YOY) bocaccio that settled around offshore Platform Irene during two separate years would not have survived in the absence of the platform. Instead, prevailing currents would likely advect the YOY's offshore where they have a very low probability of survival. Although it is possible that some individuals would encounter acceptable nursery habitat on offshore banks or islands, it is likely that most would perish. The presence of Platform Irene almost certainly increases the survival of YOY bocaccio in the Point Conception–Point Arguello region off California. The study shows that knowledge of regional ocean circulation patterns is essential for evaluating the effects of oil production platforms or other artificial habitats on dispersal pathways. Location of artificial habitat, oceanographic current patterns and presence/absence of suitable natural habitat and its distribution determine the balance between settlement on an artificial reef and settlement on natural habitat.

Increasing survival by settlement of YOY bocaccio on artificial habitat, know to support growth to adulthood of that same species (Love et al. 2006, cited in manuscript), greatly increases potential local production of bocaccio, which is a designated species of concern by the National Marine Fisheries Service (see: http://www.nmfs.noaa.gov/pr/pdfs/species/bocaccio_detailed.pdf) and a fishery stock determined to be depleted and overfished by the Pacific Fishery Management Council (see: http://www.pcouncil.org/groundfish/fishery-management-plan/fmp-amendment-16-4/).

Additionally, page 4 contains discussion of Carr and Hixon's (1997) conclusion that "attraction would occur in the case where intercepted larvae grew less productively on the artificial reef than they would have on a natural reef, and production would occur in the case where intercepted larvae grew more productively on the artificial reef than they would have on a natural reef." A study by Love et al., "Ecological performance of young-of -the-year blue rockfish (Sebastes mystinus) associated with oil platforms and natural reefs in California as measured by daily growth rates," in Bulletin of Marine Science 80(1): 147–157, 2007, examined that very premise, (See http://www.lovelab.id.ucsb.edu/Love%20et%20al.%20daily%20growh%202007.pdf). Their examination of daily growth rates of YOY blue rockfish, through parings from natural and artificial reefs, demonstrated that juvenile blue rockfish living at the artificial habitat of oil and gas production platforms grew at least as well as those at natural reefs and in one case grew more productively than those at natural reefs. By Carr and Hixon's definition, production is occurring from these artificial habitats and the results further imply that some artificial reefs may benefit regional fish populations.

As the manuscript points out, there has been a longstanding scientific debate as to whether artificial reefs actually increase biological production of fish species or simply attract and/or aggregate species away from natural areas. This issue has been explored extensively in relation to the conversion of decommissioned offshore oil and gas platforms into designated artificial reefs in both the Gulf of Mexico and offshore southern California. The discussion of Rigs-to-Reefs on page 7 should include a paper by Scarborough-Bull et al. 2008, entitled "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, Proceedings of the 4th World Fishery Congress, Vancouver, Canada, pp. 587-603. (See: reprint provided with this review). This paper noted that offshore platforms, as artificial habitat, play very different roles in the two ecosystems.

Platforms in the Gulf of Mexico are concentrated in the north-central and northwestern regions where few natural reefs exist; they harbor unique communities bearing little resemblance to those in the natural surrounding habitat. There is evidence that the artificial habitat supplied by platforms in the Gulf of Mexico has increased the regional carrying capacity for economically important reef fish species such as red snapper (Lutjanus campechanus). Platforms in the Gulf of Mexico are customary destinations for both commercial and recreational fishing. When the number of offshore platforms increased over decades, the production of reef fish also increased within the system and commercial fisheries for red snapper (L. campechanus) relocated to coincide with the geographic patterns of platform installation. Recreational fisheries increased concomitantly with the increasing number of platforms. Contrary to the Gulf of Mexico experience, California platforms are concentrated in the Santa Barbara Channel area among natural reefs and offshore islands and they harbor fish assemblages that resemble those found in nearby habitats. Off southern California, increased production of rockfish at platforms when compared to populations found on nearby natural reefs may be attributed, in part, to platform nursery function, larval production (Love et al. 2006 cited in manuscript), juvenile growth rates (see above) and light to non-existent fishing efforts at platforms. Observations at natural reefs and platforms off California found that platforms have become harvest refugia for increasingly rare and overfished species, which is thought to be a direct result of continual fishing pressure at natural reefs and a lack of fishing pressure at platforms. Significant differences in fishing pressure on natural versus artificial sites causes southern California platforms to act as de facto "no-take" marine protected areas. Thus, there is a continuum along the full spectrum with attraction at one end and production at the other end for any artificial reef or reef system and Rigs-to-Reefs are thought to increase and/or maintain production for a number of reef-related species in the Gulf of Mexico and in the southern California bight on local to regional scales.

For inclusion in discussion of the cost of offshore platform removal on page 8, an independent cost estimate for removal of the 24 federal platforms off California was completed for the Department of the Interior, by Proserve Offshore in 2010 entitled "Decommissioning Cost Update for Removing Pacific OCS Region Offshore Oil and Gas Facilities." The update estimated that it would cost approximately $1.3 billion to remove the 24 platforms in federal waters alone, (see: http://www.boemre.gov/omm/pacific/lease/Decommissioning/2010-

Decommissioning-Cost-Report-Update.pdf). In addition, the update shows that, in most cases, the cost of decommissioning continues to increase over time.

Invasive species are well discussed on page 9; however, the proliferation of invasive species on artificial habitat can also complicate issues when those species, as prey items, provide positive production environments for higher trophic levels. Page et al. 2007, examined the positive and negatives effects when invasive lower trophic level prey species are more common on artificial reefs versus natural reefs in a paper published in Marine Ecology Progress Series, 2007, Vol. 344: 245–256, entitled "Trophic links and condition of a temperate reef fish: comparisons among offshore oil platform and natural reef habitats," (See: http://www.lovelab.id.ucsb.edu/Page%20et%20al.%202007.pdf). The results fit a scenario described for some marine systems of water movement where exotic amphipod species proliferate in artificial habitats. In this case, a reef-resident fish, present in both natural and artificial habitats, harvested the exotic species from the artificial reefs with positive effects on fish condition. The authors conclude that the potential negative effects of the exotic species on the native amphipod assemblage contrasted with a positive effect on the condition of a higher level consumer. Their findings suggest that trophic pathways on other types of artificial structures colonized by exotic species likely differ from those of the natural reef habitat and support the manuscript's further discussion into this topic on page 10.

On page 16, the discussion of the possibility for contaminate exposure to humans through consumption of contaminated fish due to oil and gas platform discharges cites a single paper from 1983. The discussion should include a report by Love et al. 2009, entitled "Reproductive Ecology and Body Burden of Resident Fish Prior to Decommissioning." (See: http://www.lovelab.id.ucsb.edu/Love.Nishimoto.Sakai_2009Reproductive_Ecology.pdf). The contaminant load in platform fishes as well as any fishes from natural or artificial reefs must be seen against the background levels of fishes in the region. The study examined elemental metal concentrations both in platform-dwelling fishes and those same species from natural sites, focusing on a large suite of elements likely to be released during platform operations. The natural reefs, which served as reference sites, were located far enough away from or at geographic locations to be uninfluenced by contaminants originating from platforms. Although there was substantial variability in concentrations of a number of heavy metal elements among fishes, there was no consistent pattern of higher concentrations of any element at either platforms or natural sites. In addition, the study characterized the reproductive capabilities of Pacific sanddabs, a species of limited home range that remains in close proximity to its reefal structure, living around platforms and on natural sites to assess for possible indirect effects of the hypothesized contaminants from platforms on reproduction. The study found no consistent pattern of significantly higher levels of severely atretic eggs among sanddabs from either platform or natural sites. Atresia has been widely used as an indicator of pollutant-related reproductive impairment in fishes.

Manuscript Editorial Comments:

Harland and Brown 1989, cited in the second full paragraph on page 15 is not in the Cited Literature section.

The Cited Literature section is incorrectly alphabetized in at least two instances.

There is a duplicate punctuation mark at the end of the final sentence in the first paragraph on page 8.

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DRAFT
Kathy Broughton (NOAA Office of National Marine Sanctuaries)
April 11, 2012

Table of Contents

Overview

Artificial reefs are human-made structures that are deliberately submerged underwater, usually with the purpose of mimicking some characteristics of a natural reef. Artificial reefs alter local habitat by providing hard substrate and complex vertical relief where typically none previously existed (Bohnsack and Sutherland 1985, Sheehy and Vik 1992, Sheehy and Vik 2010). They may be created from a variety of sources and materials including intentional sinking of ships and barges, decommissioned oil and gas platforms, rubble and concrete, rocks, stone, boulders, steel, and metal, etc. (Baine 2001). These various materials have benefits and drawbacks when used in artificial reef construction (see Table 1 for examples).

The establishment of an artificial structure influences the surrounding underwater ecosystem by creating new habitat that can potentially change the abundance and distribution of living resources. Artificial structures can provide many of the same ecological functions as natural habitat, including developing epibiotic communities that create microhabitat for motile species, locally concentrate planktonic and pelagic food resources, alter current flows to provide sheltered areas, provide visual reference points, and create spawning sites (Bohnsack and Sutherland 1985, Sheehy and Vik 2010). Because of their ability to create habitat for a variety of marine life they are often popular destinations for divers, snorkelers, and fishermen. Therefore, their creation can also alter human use by shifting recreational diving and fishing patterns (Leeworthy et al. 2006, Leeworthy 2011).

General agreement exists in the scientific community that artificial reefs can be effectively accumulate fish and other organisms (Bohnsack and Sutherland 1985). Somewhat less understood are the effects of artificial reefs on living resource production, their ability to act as stepping-stones that facilitate native and non-native species dispersal, how they affect disease frequency in fish and invertebrates, toxicological impacts, their long-term structural integrity,

Comment [A1]: Reviewer 1: Consider including some descriptors in the title if possible to state the overall geographical, ecological, and timeline context of this review paper. (e.g., Review of Marine(?) artificial reefs: in the United States? Atlantic, Gulf of Mexico, Pacific? Globally? In association with National Marine Sanctuaries only? Estuarine, nearshore, inshore, offshore habitats? Since the 1960s? Through 2000?)

Comment [A2]: Reviewer 1: Many of these items may not be used as artificial reef material – they have been prohibited per regulatory permits for at least the past 20 years in the US.

Comment [A3]: Reviewer 1: Sentence one defines artificial reefs as "deliberately submerged." - contradictory to including unintentional materials as part of the primary definition of artificial reefs. Yes, unintentional materials (such as shipwrecks), and structures built for other purposes (such as breakwaters, jetties, bridges, offshore lighthouses, airforce towers, navigational aids, marine data buoys, active oil rigs, etc) provide marine habitat, but a distinction needs to be made between artificial reefs intentionally deployed for marine habitat enhancement, versus unintentional structures or structures constructed for some other primary purpose. Suggest inserting a paragraph describing unintentional deployments and other structures, and contrast with intentionally deployed artificial reefs. For example, shipwrecks are often located on top of coral reef habitat (often the same reefs that caused the ship to wreck), without any additional ballast, and sunk as-is. Versus ships intentionally sunk as artificial reefs are cleaned in accordance with EPA standards and carefully planned and deployed at specified planned location away from natural reefs.

Deleted: both the unintentional and

Deleted: gravel, plastic and PVC, wood,

Deleted: rope and netting, automobiles and train cars,

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Deleted: attractants

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and changes to the socioeconomic conditions of adjacent coastal communities. The purpose of this paper is to summarize the current scientific literature and findings on these subjects.

Table 1. Comparison of various materials that have been used in the development of underwater artificial reefs in the United States (*Source: modified from AGSMFC 2004*).

Material Type	Benefits	Drawbacks
Concrete, secondary use materials (culverts, stormwater junction boxes, etc.)	Cost effective; material is compatible with marine environment; material is highly durable and stable; readily available; can be cast into many forms; provides surfaces for settlement and growth of encrusting organisms.	Heavy weight; higher cost needed for deployment. Waterfront staging area is needed for long term accumulation of donated materials.
Steel Hulled Vessels	Make for interesting diving locations and as such can generate economic contributions to coastal communities; durable at certain depths; attract both pelagic and demersal fishes; provide surface area for epibenthic colonization.	Stability during hurricanes is variable; durability can be compromised due to salvage; removal of hazardous materials is expensive.
Oil and Gas Platforms	Provide habitat for a variety of species otherwise only associated with coral reefs; compatible with marine environment; durable and stable; readily available.	Could pose obstructions to navigation; expensive to move or remove structures.
Automobiles (prohibited per current permit conditions, based on past negative performance)	Readily available; easy to handle.	Require a great deal of preparation prior to deployment; not durable or stable.
Tires (prohibited per current permit conditions, based on past negative performance)	Easy to handle; readily available; low cost; long life-span.	Leaching of petrochemical or heavy metal toxicants is possible; un-ballasted tires are unstable; properly ballasted tired are more expensive and difficult to handle.
Concrete designed structures	Can be engineered to address specific goals and objectives of an artificial reef program; standardized modules provide valuable opportunities for	Can be limiting due to lack of funding and module manufacturers; deployment can be more expensive in comparison to secondary use

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Comment [A4]: Reviewer 1: past?

Comment [A5]: Reviewer 1: Need to segregate current materials with historical materials. Automobiles, tires, wood have been prohibited by the USACOE permits since at least 1990 (22 years ago!).

Deleted: vessels could be contaminated with pollutants and

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Comment [A6]: Reviewer 1: The potential to increase fishing pressure could be said for every artificial reef deployment. Whether or not this is a drawback depends on a variety of factors: existing fishing regulations, enforcement, the presence of an MPA or fishing restrictions, as well as the type of fishing opportunities created and whether or not those fishing opportunities might offer a local shift to more well-managed species, reducing pressure on other overfished species or reducing fishing pressure on undersized fish.

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Comment [A7]: Reviewer 1: change to prohibited

Comment [A8]: Reviewer 1: change to prohibited

Comment [A9]: Reviewer 1: concrete modules (properly designed and sited) are very popular with the public in Florida.

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	research monitoring; can be readily available if vendors are local; long-term stability.	materails.
Natural materials (e.g., rock, shell)	Can be readily available; minimal risk to navigation and fishing practices.	Excavation of natural materials may have terrestrial environmental trade-offs.
Consider inserting a row dedicated for concrete bridge materials. Concrete and/or steel bridge materials are a subset of secondary use concrete materials, but bridges have some unique benefits and drawbacks		

Policy of the Office of National Marine Sanctuaries

Deleted: usually

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Comment [A12]: Reviewer 1: Not necessarily " readily available". Depends on location, and material desired: For example, due to high levels of mitigation reef construction for burial of natural hardbottom during beach nourishment projects during the 1990s and 2000s, Florida is currently experiencing a shortage of natural limestone boulders.

Comment [A15]: Reviewer 1: Natural boulders can be extremely stable. Natural materials do not contain toxic compounds!

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Deleted: Short-term stability and life span

Deleted: ; can be relocated due to light weight; could contain toxic compounds.

Comment [A10]: Wood is prohibited

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Comment [A13]: Reviewer 1: Prey species for what? For example, prey species for red snapper are primarily found in adjacent sand habitat (McCawley and Cowan 2010). Also, "Providing refuge space" can be said for every artificial reef and for both predators and prey, etc.

Deleted: provides refuge space for prey species

Deleted: ; breakdown of wood attracts large concentrations of fish;

Comment [A11]: Reviewer 1: Shell is used, but primarily for inshore estuarine oyster reef construction. Is oyster reef construction considered in this report?

Comment [A14]: Reviewer 1: Depends on the depth and location in which the material is placed. "Minimal risk to navigation" should be said for every properly designed and sited artificial reef – that is the purpose of regulatory review and approval from the USCG.

Comment [A16]: Reviewer 1 suggested insertion of new section.

What is the policy of the ONMS, and what is the purpose of this review document? How is the 2003 NMS Policy document on artificial reef permitting guidelines relate to this document? See:

NOAA, 2003. Policy Statement of the National Marine Sanctuary Program: Artificial Reef Permitting Guidelines. Silver Spring, Maryland, U.S. Department of Commerce: iii, 1-20, Appendix A-C.

Attraction Versus Production

Artificial reefs have been purposely deployed in coastal and offshore habitats, including some national marine sanctuaries, to enhance the production of reef-associated species (e.g., macroalgae, invertebrates, and fish). Often, this increased production has historically been aimed to mitigate the losses from overfishing and other anthropogenic pressures (e.g., pollution, habitat destruction, etc.). For example, in Thunder Bay within Lake Huron artificial reefs have been established to mitigate aquatic habitat degradation and loss that has resulted from cement kiln dust deposition (a waste by-product of cement production) by creating approximately two acres of new habitat for reef-spawning fishes. Artificial reefs are also created to enhance the convenience and efficiency of fishing for reef-associated species (Ambrose 1994, Carr and Hixon 1997). More recently, efforts towards reducing fishing pressure through constructing unpublished reefs, engineering more difficult to detect small low-profile reefs, and developing reefs to reduce fishing pressure at natural sites have been implemented with greater emphasis to integrate artificial reef construction with fisheries management objectives. Today, critical questions during the planning process include contemplation of the impacts that artificial structures have on living resource production. For example, perhaps the most commonly asked question with regards to artificial reef development is if they primarily increase fish production or aggregate fish. The production hypothesis suggests that reef habitat is a limiting factor and that artificial reefs increase fish production by providing a habitat that would otherwise not be present. The attraction hypothesis proposes that fish are simple attracted to artificial reefs, and questions whether fishes that recruit to artificial reefs could have instead recruited to natural reefs. If so, do artificial reefs impact growth, mortality, and emigration (Carr and Hixon 1997)?

Attraction is the net movement of individual organisms from natural to artificial habitats (Carr and Hixon 1997). Production, somewhat more difficult to observe, is best quantified as a change in biomass through time. It reflects births, immigration, growth, death, and emigration (Carr and Hixon 1997). Several scientists and research managers have addressed the attraction-production issue in research and literature, but the relative levels of each, and the factors affecting them, have yet to be unequivocally resolved (Bohnsack and Sutherland 1985, Bohnsack 1989, Bohnsack et al. 1991, Bohnsack et al. 1997, Lindberg 1997, Herrnkind et al. 1997, Grossman et al. 1997). As a result, today it is widely acknowledged that artificial reefs function both in attraction and production. Some findings suggest that artificial reefs allow for secondary biomass production through increased survival and growth of new individuals by providing additional food sources; shelter from predation and shelf currents; a point of physical orientation; increased recruitment habitat for settling individuals that would otherwise be lost to the population; and vacated space in the natural environment that allows replacement from outside the system (Randall 1963, Bohnsack and Sutherland 1985, Bohnsack 1989, Meier et al. 1989, Carr and Hixon 1997, Love et al. 2006, Otake and Oshitani 2006). Other study results suggest that by aggregating existing scattered individuals, artificial reefs can have deleterious effects on exploited populations by making remaining fish too easy to catch, especially if overfishing is a problem (Bohnsack 1989, Meier et al. 1989, Grossman et al. 1997). Concentrated fishing effort and catch at artificial reefs can increase the potential for over exploitation. Thus, artificial reef design and fisheries management on artificial reefs, both under the authority of resource managers, may influence the levels of attraction and production (Pickering and Whitmarsh 1996).

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In the FKNMS, fish assessment studies documented that 6 out of 7 nearby reference natural reefs had higher species richness after the ship went down than before (see figure 3, REEF, 2007)

Recent analysis of natural mortality and fishing mortality estimates show the overwhelming influence fishing pressure has on fish stocks, regardless of the presence of artificial reefs (Patterson et al. 2009). One component of mortality related to fishing is a result of release mortality caused by barotrauma and/or hook injuries. Recent efforts towards reducing release mortality include implementation of de-hooking and venting tools, recompression devices, and circle hooks. Artificial reefs could potentially play a role towards the effort to reduce release mortality by giving consideration towards placement of artificial reefs intended for fishing opportunities at depth locations to minimize barotraumas injuries.

Studies have shown that the materials and design of artificial reefs impact their relative value as a fisheries enhancement tool. Historically, most artificial reefs consist of manufactued materials (see Table 1), such as metal or concrete. Studies have shown higher species abundance with increasing structural volume and complexity of artificial reefs (Potts and Hulbert 1994, Spieler et al. 2001, Quinn 2009) with larger, more structurally complex reefs (e.g., structures with holes, overhangs, and shadows) providing more opportunity for animals to recruit and thus may lead to a higher local biological diversity (Menge 1976). Brock and Norris (1989) compared four artificial reef designs and found that reefs composed of haphazardly dumped scrap materials (automobile shells and surplus concrete pipe) provided the poorest enhancement, while reefs composed of modules of scrap automobile tires set in concrete bases and dumped haphazardly showed moderate enhancement that varied with the degree of module dispersion. Significantly greater enhancement effects (e,g., mean standing crop, mean size per fish and mean number of species) were attained on an artificial reef constructed in an open framework of concrete cube modules that were arranged to provide maximum refuge space for fishes. Their data suggest that haphazard deployment of materials provided significantly poorer enhancement relative to a reef constructed of designed modules assembled into a specific configuration.

Carr and Hixon (1997) suggested that placement of artificial reefs also largely determines how much attraction and/or production occur. They presented three possible scenarios that were tested in field studies. In the first, they concluded that a management area with only an artificial reef would increase regional production. In the second scenario, a management area included an artificial reef located offshore from a natural reef with a strong long shore current present. They concluded that the current would preclude larval or migratory transport between the natural reef and the artificial reef and that if the artificial reef did not exist, the larvae that settled on it would be lost from the management area. That artificial reef, therefore, would increase production in the management area. In the final scenario, an artificial reef was located up current from a natural reef in a management area. They concluded that attraction dominated in this case because intercepted larvae grew less well on the artificial reef than they would have on a natural reef. Total growth and production would have been higher if the larvae intercepted by the artificial reef could have settled on a natural reef.

Further complicating the attraction-production issue is the question of whether the communities that form at artificial reef sites mimic natural reef communities. Many studies have shown that artificial reefs have a higher abundance and biomass than randomly selected bottom control

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Reference, REEF 2007.

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Artificial Reefs Deployed on the Northwest Florida Shelf (FWC-06120): 2005-08
Modeling Report. Pensacola, FL, University of West Florida: 1-53.

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areas, however, natural and artificial reefs generally have similar community structure (see Bohnsack and Sutherland 1985). As an example, a study by Walton (1982) found that the density of fish on artificial reefs was eight times greater in comparison to natural reefs. It has been found that the structural complexity provided by artificial reefs contributes to the greater density of fishes on artificial reefs in comparison to natural reefs (Smith et al. 1979, Bohnsack et al. 1994, Eklund 1996). However, it should be noted that although fish density is usually higher on artificial reefs than natural reefs, the actual total abundance of fishes on artificial reefs is trivial compared to natural reefs because most artificial reefs cover a much smaller total area. Therefore, the contribution of artificial reefs to total fish abundance is trivial (DeMartini et al. 1989).

~~If artificial reef communities do not mimic natural systems but do attract life from natural reefs, then what are the potential ramifications to the natural balance of the ecosystem? The answer to this question depends, in part, on whether the organisms attracted to the artificial reef would have recruited to a natural reef or would have been lost (died) had an artificial reef not been present. If organisms would have otherwise been lost, it would appear that recruitment to an artificial reef would not upset the balance on natural reefs.~~ A key issue is habitat limitation and whether or not artificial reefs provide critical habitat for increased production that would not otherwise be possible. Reef fish abundance has traditionally been considered limited by habitat or space partly because reefs are a patchy resource, limited in geographical coverage and separated from other reefs (Bohnsack 1989). Habitat can be limiting primarily by the availability of food or shelter from predation (Bohnsack 1989). However, some fishery scientists argue that habitat is not limiting (Lindberg 1997). They reason that before reef fishes were heavily exploited, the existing natural habitat supported an abundance of reef fish, presumably at or near carrying capacity. Fishing mortality later reduced stocks, yet the amount of natural habitat remained the same. With fish stocks substantially below carrying capacity, they reason that the amount of habitat could not be the factor that limits population size. An alternative is that instead most adult reef fish populations are limited by recruitment variability (Doherty and Williams 1998, Doherty and Fowler 1994, Booth and Brosnan 1995). In the cases of heavily exploited species with depleted populations, a lack of spawning adult may limit recruitment success and population replenishment. Some scientists note that some species are habitat-limited while others are recruitment-limited (Bohnsack et al. 1991).

Finally, although it is likely that artificial reefs both attract and produce fish to some extent, the discussions surrounding artificial reefs need to evolve from the single issue of attraction versus production to an evaluation of the overall ecological performance of fishes at natural versus artificial reefs (Love et al. 2006), and how these dynamics change over time. Comparisons of natural versus artificial reefs should examine: 1) survival rate of young fishes at the two habitat types, 2) the density of recruiting juveniles at an artificial reef versus surrounding natural reefs, 3) the possibility that an artificial reef is attracting fishes from nearby natural reefs, and 4) the source of fishes found on an artificial reef (Love et al. 2006).

The above questions on the performance of artificial reefs are complex; one cannot be answered without considering the others.

Marine Protected Areas

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Shipp, R. L. and S. A. Bortone (2009). "A perspective of the Importance of Artificial Habitat on the Management of Red Snapper in the Gulf of Mexico." Reviews in Fisheries Science 17(1): 41-47.

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Lindberg, W. J., T. K. Frazer, et al. (2006). "Density-dependent Habitat Selection and ...

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Range Expansion

Artificial structures may provide habitat that can directly or indirectly support recruitment and range expansion for various organisms including sponges, bryozoans, barnacles, hydroids, corals, and associated fish communities (Shinn 1974, Rooker et al. 1997, Sammarco et al. 2004, Atchison 2005, Love and York 2005, Sheehy and Vik 2010). Artificial structures provide hard substrate, which may increase the supply of prey, shelter, and spawning sites that could alter the local distributions of species and potentially contribute to range expansions (Rooker et al. 1997, Casell et al. 2002). Studies have shown that algae, invertebrates, and fishes are capable of colonizing new reef structures rapidly (Fager 1971, Bohnsack and Talbot 1980, Bohnsack and Sutherland 1985). 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. It should be noted that the majority of fish and invertebrate species that are observed on both artificial and natural reefs do not spend their entire life in these habitats. Different stages of development may have different habitat requirements and population limitations. For these reasons, organisms observed on an artificial structure are ecologically part of a number of interconnected populations. Therefore, an artificial structure can affect other populations across regions and habitats (Schroeder and Love 2004).

Numerous studies have examined recruitment and succession on artificial reefs. Oil and gas platforms have been shown to support the expansion and growth of sessile invertebrate communities (Shinn 1974, Sammarco et al. 2004, Atchison 2005, Sheehy and Vik 2010). The northern Gulf of Mexico region is predominantly characterized by sandy mud with little habitat diversity, thus making it unavailable to sessile, epibenthic hard bottom organisms. When oil and gas platforms were introduced in the Gulf of Mexico in the 1940s they represented one of the few shallow-water, hard substrates capable of supporting coral communities. Since the 1940s approximately 7,000 oil and gas platforms have been installed in the Gulf of Mexico. Today there are approximately 3,300 active oil and gas platforms in federal waters in the Gulf of Mexico (D. Peter, Louisiana Dept. of Wildlife and Fisheries Artificial Reef Program, pers. comm., 2011)[1]. Studies have shown that these platforms act as hard substrate upon which many reef organisms can recruit and grow, including sessile algae, barnacles, mussels, anemones, sponges, corals, and other attached organisms (Shinn 1974, Sammarco et al. 2004, Atchison 2005). Genetic analyses conducted by Atchison (2005) showed that oil and gas platforms facilitate the spread of coral larvae by acting as stepping stones where larvae that have been dispersed from the Flower Garden Banks or other natural reefs can settle and eventually spawn, thus dispersing corals further to additional platforms. Sammarco et al. (2004) found that oil and gas platforms are capable of supporting coral growth in areas where none previously existed, suggesting that they can extend species ranges. Their studies also show that many coral community variables are correlated with platform age, demonstrating that as the platforms age, coral abundance, species diversity, and colony size increase. As a result of these findings, the researchers determined that the oil and gas platforms in the Gulf of Mexico have a beneficial

[1] In the past, most decommissioned oil and gas platforms in the Gulf of Mexico have been removed and recycled. However, forty percent of these structures were single pile caissons, and not considered substantial structures for artificial reef use. Approximately 10% of all platforms have been "reefed" in designated artificial reef sites (see *Rigs-to-Reef* section). Occasionally platforms have been reinstalled and reused in other offshore locations and continue as petroleum production facilities.

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environmental value with respect to corals, which increases over in otherwise barren locations (Sammarco et al. 2004, Atchison 2005).

Artificial structures have also been shown to allow some species to increase their ranges into areas where they did not previously exist — a form of range extension referred to as "island hopping" (MacArthur and Wilson 1967, Pattengill 1998). Various environmental factors contribute to fish attraction to artificial reefs, including visual cues of size, shape, color, and light; sound; touch; and pressure (Bohnsack and Sutherland 1985). In addition, species type, fish age, season, and artificial reef age, structural characteristics, and location also influence recruitment rates (Bohnsack and Sutherland 1985). Pattengill (1998) proposed that the introduction of sergeant major (*Abudefduf saxatilis*) to the Flower Garden Banks was the result of "island hopping." Sergeant major, a species known to require shallow habitat for settlement, historically was absent from the Flower Garden Banks. However, she found that with the introduction of artificial shallow habitat (mooring lines and nearby oil and gas platforms), juvenile recruits were seen near the surface on these structures, and subsequently populations eventually became established. Rooker et al. (1997) also found reef fish expansion to have occurred at an oil platform in the Flower Garden Banks National Marine Sanctuary (HI-A389A, located in 125 m of water, and approximately 2 km and 22 km from the high diversity reef zones of East and West Banks, respectively). He found a similar faunal composition at the platform as on adjacent natural communities on East and West Flower Garden Banks, although higher numbers of species were observed on the natural reefs than on platforms due to greater habitat area available on the natural reefs.

Love and York (2005) conducted a study in southern California that compared fish assemblages of a platform and associated pipeline with that of the adjacent, natural seafloor. Their research strongly suggests that platforms, and their adjacent shell mounds, provide considerable hard substrate that can allow for fish range expansion by providing important habitat and nursery grounds for a variety of juvenile and diminutive fish species, particularly rockfishes (*Sebastes* spp.) and lingcod (*Ophiodon elongatus*). They found that many of the species that were found on the pipelines, particularly rockfish, were absent from the seafloor. They also found that the fish assemblages found on the pipelines were similar to those that occupy low-relief habitats such as cobble, small boulders, and shell mounds. The pipeline they studied appeared to also act as a nursery for a number of fishes, some of which (e.g., blackgill, flag, greenspotted, and splitnose rockfishes) recruit directly to the pipeline as young-of-the-year.

Rigs-to-Reefs

The oil and gas industry is faced with hundreds of aging platforms that are approaching the end of their production capability. Estimates are that one thousand rigs in the Gulf of Mexico will be retired over the next decade (Salcido 2005) and 27 will be decommissioned in California's state tidelands and off the outer continental shelf (OST 2010). Federal legislation requires that all oil and gas platforms in U.S. waters must be removed within five years after they are considered to be no longer useful for operations (BOEM 2010). Cost estimates for the removal of a platform range from $50,000 for short platforms in very shallow waters to $15 million for tall platforms in the deepest waters (Salcido 2005). From 2000 to 2010 approximately 150 platforms were decommissioned each year (D. Peter, Louisiana Dept. of Wildlife and Fisheries Artificial Reef Program, pers. comm., 2011), thus causing the loss of hard substrate, which could reduce fish

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populations and encrusting organisms that depend on the hard substrate for survival. It has been suggested if these platforms were to instead remain undisturbed, or only be partially removed that their expected life-span could be as great as 300 years (Quigel and Thornton 1989) and their associated communities would be permitted to develop fully (Atchison 2005, OST 2010). In addition, it has been suggested that retired platforms would also provide recreational diving and fishing opportunities, and to a lesser extent, benefits to the commercial fishing community as well (OST 2010). For this reason, the Rigs-to-Reefs program, administered by the Bureau of Ocean Energy Management (BOEM, formerly part of the Minerals Management Service), was developed to permit platforms scheduled for decommissioning to either remain either on site or be brought to another site to be used as artificial reefs (Sammarco et al. 2004, Atchison 2005). The ownership and responsibility of the platform is then transferred to a public agency, which accepts title and responsibility for the structure as a permanent reef. Initially established in the 1980s, the program is funded by cost savings from this less expensive disposal option. Rigs-to-Reefs projects avoid some of the more costly decommissioning activities such as transportation, onshore dismantling, and payment of disposal fees (Salcido 2005). To date, 378 platforms in federal waters of the Gulf of Mexico have been reefed since 1973 (D. Peter, Louisiana Dept. of Wildlife and Fisheries Artificial Reef Program, pers. comm., 2011). Because a substantial number of the Gulf of Mexico platforms are scheduled to be decommissioned in the near future and 166 platforms and/or rigs were damaged or destroyed during hurricanes Rita and Katrina, there has been a recent increase in Rigs-to-Reefs applications (Sammarco et al. 2004, Sheehy and Vik 2010). The oil industry is a common proponent of the Rigs-to-Reefs program, simply because such a program reduces operating costs. Recreational fishermen and divers are also strong supporters of Rigs-to-Reefs because they believe artificial reefs provide fishing and diving opportunities. Both groups also argue that decommissioning offshore platforms can have detrimental environmental impacts through air, water, and land pollution. In addition, habitat and marine life in the vicinity of the platforms is often lost to due to impacts from the large equipment and explosives that are required for their removal (OST 2010).

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Conflicting opinions exist about the value of artificial reefs and the possible benefit that a Rigs-to-Reefs program could have on the marine environment. Critics argue that the goals of Rigs-to-Reef projects are more to subsidize oil production than improve fisheries, and as such, they reject these projects as ocean dumping rather than as an approach to enhance marine resources (Salcido 2005). It is also argued that artificial reef science is insufficiently developed and significant scientific uncertainty still remains in the attraction-versus-production debate, thus calling into question the value of converting a rig to a reef and having such a program be endorsed at a policy level. Groups such as the Ocean Conservancy and the Natural Resources Defense Council suggest considerably more evaluation of artificial reefs is necessary, and they point out that little restoration of failing marine health can be achieved by recreational use of artificial reefs (Salcido 2005). In addition, opponents also suggest that Rigs-to-Reefs programs also perpetuate the practice of ocean dumping of wastes. Some even go as far as to state that "these projects are nothing more than legally-approved garbage dumping that attracts fish away from valuable fisheries habitat" (Salcido 2005).

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In California the government and industry are planning to decommission 27 offshore platforms (Salcido 2005, OST 2010) at an estimated cost of $1.09 billion for their complete removal (OST 2010). A Rigs-to-Reefs program was instituted in California in September 2010. The law (AB

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2503) allows for the partial removal of a decommissioned oil platform as an alternative to complete removal, but only if the conversion would result in a net benefit to the marine environment. The bill also created the California Endowment for Marine Preservation, which receives the cost savings and uses it to fund marine protection projects and programs in perpetuity. Compared to the Gulf States, California has limited experience and infrastructure in decommissioning obsolete oil production facilities, and unlike the Gulf of Mexico, California stakeholder views are highly polarized. Therefore, it will be critical to define the social and ecological goals of these decommissioned platforms as artificial reefs. Studies by Schroeder and Love (2004) demonstrated that a pipeline in southern California (the Gail-Grace pipeline) is an important habitat and nursery ground for a number of juvenile and diminutive fish species, including some exploited species, such as cowcod, blackgill, and vermilion rockfishes. The extent of this significance as habitat will play an important role in determining preferred options in future decommissioning activities once oil production ceases (Schroeder and Love 2004).

Invasive Species

Non-indigenous species are recognized worldwide as a major threat to ecosystem integrity if they become invasive. Non-indigenous species in the marine environment can alter community composition by competing with native species for food and space, reducing the abundance and diversity of native marine species, interfering with ecosystem function, introducing diseases, altering habitats, disrupting commercial and recreational activities, and in some instances causing extinction of indigenous plants and animals (Olden et al. 2004, Clavero and Garcia-Berthou 2005, Ruiz-Carus et al. 2006). Local extinction of native species can occur either via non-indigenous species preying on them directly or by out-competing them for food or space. Once established, non-indigenous species can be difficult, if not impossible, to control or eradicate.

Artificial structures may facilitate invasive species introductions and establishment by transporting attached fouling communities, providing new unoccupied habitat for establishment, ~~attracting recreational users,~~ and creating corridors for further dispersal and expansion (Glasby et al. 2007, Sheehy and Vik 2010, Figure 1). Invasions by non-indigenous aquatic species are increasingly common worldwide due to shipping traffic, world trade, and intentional or accidental releases of aquarium animal and plants. Though the most significant global mechanism for the introduction of aquatic species is ship ballast water, biofouling communities on ships or oil and gas platforms and the placement of human-made structures that provide new habitat are also identified as probable vectors for the spread of invasive species (Wasson et al. 2005, Glasby et al. 2007, Tyrrell and Byers 2007, Sheehy and Vik 2010). Artificial reefs with extensive vertical hard substrate provide large amounts of surface area, creating habitat for marine organisms, including invasive species. Because artificial reefs are often located in areas that lack hard bottom habitat, they typically provide unoccupied or novel substrate for colonization (Wasson et al. 2005, Tyrrell and Byers 2007, Sheehy and Vik 2010).

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Artificial structures may facilitate invasive species introductions and establishment by transferring attached fouling communities, providing new unoccupied habitat for establishment, ~~attracting recreational users,~~ and creating corridors for further dispersal and expansion (Glasby et al. 2007, Sheehy and Vik 2010, Figure 1).¶
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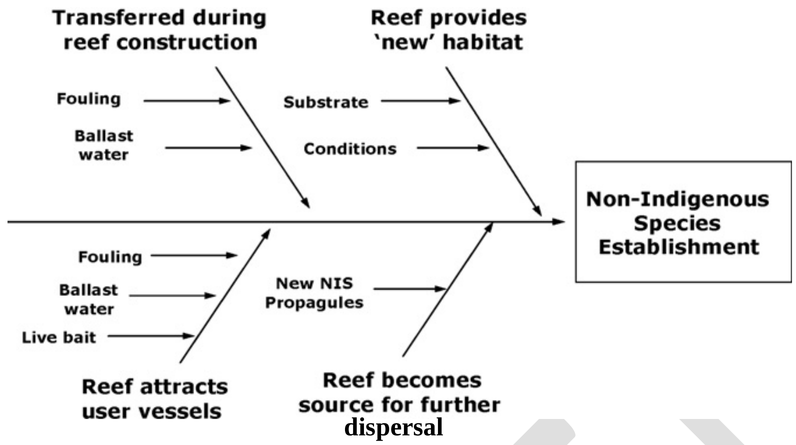

Figure 1. Cause and effect diagram illustrating how constructing reefs may result in the establishment of non-indigenous species (*Source: Sheehy and Vik 2010*).

Most studies on the role of artificial structures in facilitating marine invasions involve attached fouling organisms or invertebrates with relatively limited dispersal ability. Studies in Elkhorn Slough, an estuary in the Monterey Bay National Marine Sanctuary in Central California, have demonstrated that novel, hard artificial structures (e.g., pilings, gravel bars, jetties, rip-rap, docks) are much more heavily fouled by marine invertebrate invasive species in comparison to soft substrate (Wasson et al. 2005). Additional studies (Glasby et al. 2007, Tyrrell and Byers 2007) found greater numbers of nonindigenous epibiotic species than native species on artificial structures than on natural reefs. An explanation for the propensity for artificial, hard structures to attract invasive species in estuaries is that estuaries are typically dominated by soft sediments with the exception of oyster beds and driftwood. As such, there are few competitive, native, estuarine, sessile hard substratum species (Wasson et al. 2005). Also, because these structures are novel, there is no evolutionary history for native species on such surfaces (Wasson et al. 2005, Tyrrell and Byers 2007, Glasby et al. 2007).

In the Gulf of Mexico, invasive invertebrate species have been reported on artificial reefs and oil and gas platforms (Sammarco et al. 2004). They include the expansion of coral communities (e.g., orange cup coral *Tubastraea coccinea*), the introduction of two species of mussel (the brown mussel *Perna perna* and the green mussel *P. viridis*), the white crust tunicate (*Didemnum perlucidum*), and the Australian spotted jellyfish (*Phyllorhiza punctata*).

As a case study, the orange cup coral (*Tubastraea coccinea*) expanded its range into the Caribbean from the Indo-Pacific (Cairns 2000, Fenner and Banks 2004). Likely introduced in the 1940s, it has now invaded the Gulf of Mexico, Brazil, and Florida (Fenner and Banks 2004, Ferry 2009, Shearer 2010). Observations in the Caribbean and the Gulf of Mexico show that this species can cause tissue necrosis and partial mortality of native corals (Creed 2006). It primarily appears on artificial substrates such as submerged steel wrecks and oil and gas platforms (Fenner

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and Banks 2004, Ferry 2009, Shearer 2010). It is suspected that in addition to dispersal vectors such as attachment to boats and drifting in currents, these artificial structures play a major role in the spread of this species (Fenner and Banks 2004). By 1999, *Tubastrea* sp. was commonly observed on Gulf of Mexico oil and gas platforms, located in federal waters off the coast of Texas (J. Embesi, FGBNMS, pers. comm., 2011). In 2002 the species was first documented on natural substrate at the East Flower Garden Bank, suggesting it had begun to invade the sanctuary, most likely from nearby oil and gas platforms (e.g., an active gas platform, HIA389A, located one mile from the reef cap of East Flower Garden Bank, has extensive colonies of orange cup corals) (Hickerson and Schmahl 2005). In 2011, orange cup coral was identified for the first time at the West Flower Garden Bank during monitoring surveys (E. Hickerson, FGBNMS, pers. comm., 2011). It has also been documented to be well established on Geyer and Sonnier Banks located in the northwestern Gulf of Mexico (Schmahl et al. 2008). A study by Ferry (2009) indicates that orange cup coral has not yet become established in the lower Florida Keys, but it is present in high abundance on the surfaces of the Aquarius underwater habitat off Key Largo in the upper Florida Keys. The potential for this species to impact reef communities in this region is high due to a lack of natural predators, high proliferation rates, and the ability to out-compete native species for limited available substrate.

Structural habitat is an important resource for mobile taxa like reef fishes as it provides refuge from predation, and reproduction and foraging sites. Few studies have examined whether artificial reef availability facilitates the introduction and establishment of invasive reef fishes. It has been suggested that artificial structures contribute to the dispersal and establishment of the lionfish (*Pterois* spp.). Lionfish, native to the western Pacific, Red Sea, and eastern Indian oceans, were first reported in the 1980s along south Florida and are now well established in the Caribbean and along the Southeast U.S., including the Florida Keys National Marine Sanctuary (Ruiz-Carus et al. 2006, Morris et al. 2009). In July 2011, lionfish were observed for the first time in the Flower Garden Banks National Marine Sanctuary. Lionfish have been observed on eight oil and gas platforms in the Northwestern Gulf of Mexico region. One of these sightings was made on a platform within 2 nautical miles of the East Flower Garden Bank boundary. The remaining platforms in which lionfish were observed are located 125-230 nautical miles east of the sanctuary. In addition, six lionfish have been observed on the *Texas Clipper*, a shipwreck approximately 200 nautical miles southwest of the sanctuary.

The increasing abundance and wider distribution of lionfish in the South Atlantic Bight, Bermuda, Florida, and the Bahamas indicates that lionfish are the first marine fish species in recent times to successfully establish a breeding population in the tropical western Atlantic. Lionfish are ambush predators, and can threaten local ecosystems by altering the structure of native reef fish communities by out-competing local species and reducing forage fish biomass (Morris and Whitfield 2009). Impacts from lionfish could include direct competition with groupers and other carnivores for food, and increased predation on reef fish and crustaceans (Ruiz-Carus et al. 2006, Albins and Hixon 2008, Morris and Akins 2009). Also, lionfish pose a danger to divers and fishermen – stings from the venomous spines of the fish may result in pain, swelling, numbness and sometimes more severe effects including paralysis and systemic effects.

Smith (2006) suggests from research conducted in the Bahamas that lionfish are capable of invading natural patch reefs in the absence of artificial structures, but the presence of artificial

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Comment [A33]: Reviewer 1: Citation? On the contrary, observations by Dr. Jim Morris, NOAA, show lionfish dispersed equally across natural bottom, and that the additional of artificial structure did not increase lionfish density on natural hardbottoms.

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reefs facilitates colonization of marginal habitats like sand-seagrass and to a lesser extent, hard bottoms. This pattern suggests that artificial structures represent a resource subsidy to lionfish. Sand-seagrass is marginal habitat for lionfish due to the lack of suitable substrate, but adding artificial structures facilitates lionfish dispersal, thus allowing it to support similar abundances as those found in more structurally complex, higher-quality natural habitats such as on coral reefs and hard bottoms. This pattern has implications for lionfish local persistence and rates of regional spread. Sand-seagrass may naturally function as sink habitats for lionfish in which local populations are maintained by continued migration from more productive sources such as coral reefs. Adding artificial structures may promote a transition from a sink to a source habitat in which the formation of self-sustaining populations allows for the net export of individuals or larvae to new areas.

Smith (2006) also demonstrated that lionfish are slow to colonize artificial reefs, especially in comparison to most native Atlantic fishes, thus suggesting that the rapid range expansion of lionfish in the Atlantic is not due to superior colonizing ability. Therefore, removing or preventing the placement of artificial structures may slow the spread of lionfish, particularly in marginal habitats; however, it is unlikely to prevent their expansion. Instead, their rapid invasion may more likely be linked to their novel predation strategies, unique reproduction, lack of predators, ability to maintain fine-scale positioning in the water column, and superior defense mechanisms.

In order to avoid and/or slow the introduction, establishment, and proliferation of invasive species it has been suggested that resource managers should consider removing or minimizing the addition of submerged artificial structures in coastal and estuarine habitats since they will likely increase the biomass and perhaps the diversity of invasives in these systems (Wasson et al. 2005, Smith 2006, Glasby et al. 2007, Tyrrell and Byers 2007, Sheehy and Vik 2010). If artificial reefs must be deployed, then Sheehy and Vik (2010) recommend the following key precautions when determining the placement of constructed reefs:

- The placement of materials with intact fouling communities should be limited to areas close to the source of these communities,
- Estuarine to marine transfers should be restricted,
- The construction of large contiguous reefs (e.g., the proposed Texas Great Barrier Reef Project) should be carefully evaluated to avoid creating a ready corridor for the expansion of invasive species, and
- Reef site selections should be made in the context of the system or network composed of constructed and natural reef/hard bottom, oil and gas platforms rather than on a reef-by-reef basis.

Comment [A35]: Reviewer 1: It may be important to note that for artificial reefs which are popular dive attractions (regularly visited by dive operators), some dive operators have been taking the approach of 'adopting' the reef where dive masters have been regularly removing lionfish. For example, the Vandenberg artificial reef off of Key West Florida is visited by multiple dive boats each day and lionfish are regularly removed. As a result, the density of lionfish on the Vandenberg reef is significantly lower than on the adjacent natural reefs. One dive master from Dive Key West, Inc. (http://www.divekeywest.com/) stated that during the lionfish derbies they specifically avoid the public artificial reefs to collect lionfish as time is better spent over natural reefs where lionfish densities are greater. This may be one example of an artificial reef (the Vandenberg) acting essentially as a 'sink' for the local lionfish densities.

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Comment [A36]: Reviewer 1: Artificial reefs in Florida have been prohibited from being deployed in seagrass habitat since the 1970s.

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Comment [A37]: Reviewer 1: Agreed

Comment [A38]: Reviewer 1: Why? Citations? This statement doesn't seem to be supported in the document. Did I miss something?

Comment [A39]: Reviewer 1: Need to solve the conflicts this recommendation presents with information provided earlier in the document. This recommendation may be good to minimize the expansion of invasive species, but limiting size doesn't seem to be good for total fish abundance based on the information presented previously (bottom of page 4) as follows:

"However, it should be noted that although fish density on artificial reefs is usually higher in comparison to natural reefs, the actual abundance of fishes is trivial compared to the number of fishes on natural reefs, most likely due to the small size of most artificial reefs. Therefore, although high densities of fish exist on artificial reefs, the relative small area of these manmade structures, in comparison to natural reefs, makes their contributions to total fish abundance trivial (DeMartini et al. 1989)."

Comment [A40]: Reviewer 1: Consider rewording this sentence. It is not clear what the author is trying to say with this - maybe it isn't worded right?

Disease Introduction or Acceleration

Artificial structures may also affect ecosystem function by increasing disease frequency in fish and invertebrates. The normal soft muddy sand bottom of the Gulf of Mexico is considered poor habitat for the dinoflagellate (*Gambierdiscus toxicus*) that causes ciguatera fish poisoning in humans. However, the elevated hard substrate provided by constructed reefs or platforms supports corals and other components that do provide appropriate substrate. Villareal et al. (2007) reported that the increased availability of hard substrate provided by the oil and gas industry in the Gulf of Mexico has contributed to the proliferation of *G. toxicus*. Constructed reefs are actively used by fishers, providing a connection between fish consumers and potentially toxic fish (Villareal et al. 2007). Although a clear linkage between oil and gas platforms or artificial reefs and ciguatera has not yet been demonstrated, these findings suggest that the provision of reef hard substrate in areas commonly devoid of this habitat may have unintended consequences for human health.

In the Florida Keys National Marine Sanctuary, researchers have proposed that illegally-deployed artificial substrates may increase transmission of a known viral condition (PaV1) of the Caribbean spiny lobster (*Panulirus argus*). The artificial structures, known as "casitas," are deployed to aggregate lobsters, making them easier to catch. Casitas may act as an "ecological trap" by attracting small lobsters, where their mortality, growth, and condition may be compromised and exposure to disease increased. Research on the effects of aggregated lobsters has just begun so it is too early to estimate the effects of artificial substrates on this important commercial and recreational fishery in Florida.

Lobster trap reduction efforts

Toxicological Impacts

Deployment of artificial reefs containing PCBs, heavy metals, oil and fuel residues, and other toxic chemicals could pose a potential risk of contamination to the underwater environment, especially in sensitive coastal ecosystems. Therefore, prior to deployment, structures are typically stripped of potentially hazardous materials in order to make them environmentally safe in accordance with the EPA Best Management Practices for preparing vessels intended to create artificial reefs (EPA 2006). The removal of petroleum products, hazardous materials, paint cans, batteries, plastics, oil and fuel is specified on the U.S. Coast Guard's Ocean Disposal/Artificial Reef Inspection form. Additionally, under the Toxic Substances Control Act (TSCA), the Environmental Protection Agency (EPA) has the authority to gather data on and regulate chemical substances and mixtures imminently hazardous or presenting an unreasonable risk of injury to public health or the environment. Still some materials of concern below EPA thresholds may potentially remain on vessels permitted to be scuttled as artificial reefs. Such materials include asbestos, polychlorinated biphenyls (PCBs), iron, lead paint, and antifouling paint. As such, biological communities associated with artificial reefs are potentially exposed to pollutants emanating from these structures; therefore, resource managers should consider the risks associated with materials remaining on vessels to be used as artificial reefs (Boland et al. 1983).

Asbestos is the name given to six naturally occurring minerals that are effective as insulators and fire retardants. Its fibers are resistant to heat and chemicals and do not dissolve in water.

Comment [A41]: Reviewer 1: citations?

Comment [A42]: Reviewer 1: what about use of lobster shorts as bait in traps?

Comment [A43]: Reviewer 1: From the perspective of protection of natural coral reef structure, and minimizing damage to natural coral reef outcrops, some could argue that avoiding damage to natural coral reefs and 'making easier to catch' could be a positive step towards coral reef protection by reducing/eliminating diver impact during the process of collecting lobsters from natural coral reefs, as well as reducing impacts caused by traps and traps lines.

Comment [A44]: Reviewer 1: Preliminary research by Hunt et al does not support this statement. See slide 13 from Hunt 2011 http://myfwc.com/media/1583198/51_SpinyLobster_presentation.pdf

Comment [A45]: Reviewer 1: see research by Hunt et al.

Comment [A46]: Reviewer 1: Consider inserting a section discussing the lobster trap reduction debate. Discuss impacts to natural reefs caused by lobster trap industry and the potential benefit properly planned, designed, permitted, constructed, and enforced stable artificial reef modules might have towards reducing industry reliance on the deleterious trap industry.

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Asbestos was used in spray-on insulation, ceiling tiles, floor tiles, and fire doors among other things until it was banned in 1989. Friable asbestos, that which is easily crumbled, releasing fibers, is the most hazardous. Sprayed on asbestos is an example of highly friable asbestos. Floor tiles containing asbestos are not highly friable and will release asbestos fibers only when damaged or disturbed. Several studies have investigated the effects of friable asbestos on fish (Batterman and Cook 1981, Belanger et al. 1990, Belanger et al. 1986, Woodhead et al. 1983). Findings indicate that asbestos concentrations on the order of 10^6 to 10^8 fibers/L may cause epidermal lesions, epithelial hypertrophy, kidney damage, decreased orientation and swimming ability, degradation of the lateral line, reduced growth, and mortality in fish. Asbestos has also been found to decrease the survival rate of the brine shrimp *Artemia salina* (Stewart and Schurr 1980). Friable asbestos is required to be properly removed and disposed of during the process of preparing an artificial reef. Scientific studies utilizing non-friable asbestos plates and cement to investigate successional patterns of fouling communities and collection of oyster spat, respectively, illustrate the relative harmlessness of undisturbed, non-friable asbestos (Montoya et al. 1985, Garcia and Salzwedel 1995).

PCBs have been used in water-tight gaskets, cable insulations, paints, transformers, capacitors and other components of ex-Navy vessels (Eisler and Belisle 1996). They are lipophilic, highly persistent chemicals. PCBs have been implicated in: reduced primary productivity in phytoplankton; reduced hatchability of contaminated fish and bird eggs; reproductive failure in seals; altered steroid levels and subsequent reproductive impairment in fish and sea stars; reduced fertilization efficiency in sea urchins; and reduced plasma retinol and thyroid hormone levels potentially leading to increased susceptibility to microbial infections, reproductive disorders and other pathological alterations in seals and other marine mammals (Adams and Slaughter-Williams 1988, Brouwer et al. 1989, Clark 1992, den Besten et al. 1991). The Florida Fish and Wildlife Conservation Commission sampled reef fish at Oriskany Reef, a decommissioned former aircraft carrier that was deployed by the U.S. Navy as an artificial reef in May 2006 in the Gulf of Mexico, southeast of Pensacola, FL. The Navy applied for and received a PCB risk-based disposal permit from the EPA (reference) to allow certain PCB materials to remain onboard based on the results of leachate and toxicological monitoring studies and the conclusions of an independent science advisory board panel (references). The results of the first five years of post-deployment monitoring of reef fish from the Oriskany found a declining trend in PCB levels for sampled reef fish. Initially, and of concern, the mean PCB levels for sampled fish within the first two years of deployment exceeded both the Florida Department of Health (FDOH) and EPA screening values. Between years two and three the PCB level measured decreased to below the FDOH value and slightly above the EPA value. After three years, the mean PCB levels were below both the FDOH and EPA thresholds (Dodrill et al. 2011).

Vessel hulls are typically painted with antifouling paints. Copper and tributyltin (TBT) are the two most common active ingredients in antifouling paints, and typically have an effective life span of five years or less. TBT has been found to be toxic to non-target, non-fouling organisms at ng/L levels and efforts to establish a world-wide ban have been made by the International Maritime Organization since 1998, and TBT is banned in many nations and was banned in the U.S. in 19xx. Its most marked effects have been the induction of shell thickening and growth anomalies in oysters and imposex (development of sexual organs of the opposite sex) in the

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Significant Risk-based disposal reviews were conducted prior to EPA issuance of the permit:

http://yosemite.epa.gov/sab/sabproduct.nsf/0/b8403da96273abfe85256fee0052d1a3!OpenDocument&TableRow=2.0#2.

See:

Pape, T. L. (2006). Polychlorinated biphenyls (PCB) Source Term Estimates for ex-ORISKANY (CVA-34). Fairfax, Virginia, Program Executive Office (Ships); CACI International Inc and Subsidary Companies: 1-21.

SPARWAR Systems Center San Diego (2006). Artificial Reefing: Ex-ORISKANY Artificial Reef Project - Prospective Risk Assessment Model (PRAM) Version 1.4C. San Diego, California. (Prepared for: Program Executiv Office Ships (PMS 333)), Navy Environmental Health Center, URS Corporation, SPARWAR Systems Center, : Sections 1-2, Tables 1-11, Figures 1-15, Appendicies A-K.

SPARWAR Systems Center San Diego (2006). Ex-Oriskany Artificial Reef Project: Human Health Risk Assessment. [Prepared for: Program Executive Office Ships (PMS 333)]: x, Sections 1-11, Appendicies A-K.

SPARWAR Systems Center San Diego (2006). Ex-Oriskany Project: Time Dynamic Model Documentation (TDM), [Prepared for: Program Executive Office Ships (PMS 333)]: Section 1, Appendicies A-D.

SPARWAR Systems Center San Diego, R. D. George, et al. (2006). Ex-Oriskany Project: Investigation of Polychlorinated Biphenyl (PCB) Release-Rates From Selected Shipboard Materials Under Laboratory-Simulated Shallow Ocean (Artificial Reef) Environments: xvii, 1-219, Appendices pp. 1-836.

Johnston, R. K., R. D. George, et al. (2006). Artificial Reefing: Ex-ORISKANY Artificial Reef Project, Ecological Risk Assessment. San Diego, California 92152-6326, Marine Environmental Support Office, Environmental Sciences and Applied Systems Branch, SPARWAR Systems Center. (Prepared for: Program Executive Office Ships (PMS 333): xxi, Sections 1-10, Tables 1-30, Figures 1-49, Appendicies A-E.
Johnston, R. K., H. Halkola, et al. (2005). The Ecological Risk of Using Former Navy Vessels to Construct Artificial Reefs: An Initial and Advanced Screening Level Ecorisk Assessment. Marine Environmental Support Office, Space and Naval ...

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dogwhelk (*Nucella lapillus*) potentially leading to sterility. Sterility in *N. lapillus* has been noted at concentrations as low as 3-5 ng Sn/L (approximately 7.5-10.5 ng TBT/L) (Gibbs et al. 1988). Oysters exposed to TBT concentrations >2 ng/L have displayed progressive increases in chambering and at levels above 100 ng TBT/L severely abnormal shell morphology (Laughlin 1996). At higher concentrations (0.5-1.8 g TBT oxide/L), TBT-based paint leachate has been found to elicit polyp retraction, pigmentation loss, and death in corals. The discovery of the highly toxic nature of TBT-based paints has led many countries to ban the use of these paints for non-aluminum hulled vessels less than 25 meters in length. In the case of large steel vessels proposed as artificial reefs, typically by the time artificial reefing is considered as an option the vessels have effectively exceeded their life expectancy and the active ingredients in antifouling paint are no longer effective. Furthermore, the target upright deployment of steel vessels results in deployment with the hull being located underneath the ship, and not exposed for epibenthic colonization.

Heavy metals can be divided into nonessential elements (lead, mercury, and probably cadmium) and essential elements with relatively well-defined roles and functions (copper, iron, selenium, and zinc) (Thompson 1990). In the case of essential metals, body concentrations of metabolically available metal must obtain a minimum concentration (Rainbow 1990). The accumulation of metal in organisms will depend on mechanisms of accumulation and methods of detoxification.

Copper, though an effective antifoulant, has not shown the extensive effects on non-target organisms. At low concentrations, copper is a minor nutrient for both plants and animals involved in biological processes such as oxygen transport and enzyme activity. When present in high concentrations, however, copper can be toxic to aquatic life. In fish, it has been found to cause histological alterations, reduced egg production, abnormalities in newly hatched fry and reduced survival of young (Sorensen 1991). Excessive mucus production, distension of tentacles, and a progressive loss of zooxanthellae have been seen in anemones exposed to copper concentrations of 50 and 200 g/L (Harland and Nganro 1990).

Comment [A48]: Reviewer 1: What situations have copper at these levels? What concentration is copper in antifouling paint? What is the effective life of copper anti-fouling paint, and what is the concentration of copper at the time of deployment as an artificial reef?

Steel hulls on vessels scuttled as artificial reefs potentially contribute iron to the marine environment. Iron is an essential component of electron transport in almost all living organisms (Ferreira and Straus 1994). As an essential element, iron levels will tend to be closely regulated by organisms, and thus, it is unlikely that any pollution-derived effects will be observed except in severe and localized cases (Thompson 1990). Corals living in seawater with high concentrations of iron have been found to incorporate the metal into their skeletons (Brown et al. 1991). Elevated iron concentrations have also been found to lead to a loss of zooxanthellae from coral tissues (Harland and Brown 1989). This response is diminished in corals regularly exposed to iron, suggesting corals can alter their accumulation and detoxification pathways to adapt to iron exposure. However, it has also been documented that the unnatural presence of an iron source to an ecosystem can lead to a phase shift in species composition of coral reef ecosystems. For example, the steel hull of a shipwreck in 1991 at the remote Palmyra Atoll in the central Pacific Ocean is believed to be the primary driver behind a phase shift from coral to corallimorpharians (Work et al. 2008). Phase shifts such as this can have long-term negative impacts on coral reefs, and eradication of the organisms responsible for phase shifts in marine ecosystems can be difficult. Therefore, the researchers of this study ultimately suggest that shipwrecks in coral reef ecosystems be immediately removed to mitigate the potential of reef overgrowth by invasives (Work et al. 2008). Studies on phytoplankton and macroalgae indicate that in areas where plant nutrients such as nitrate and phosphate are abundant the availability of iron is actually a limiting factor in growth and biomass (Matsunaga et al. 1994, Wells et al. 1995 Coale et al. 1996, Frost 1996, Takeda 1998). The addition of iron has been seen to increase primary productivity and shift nutrient ratios in such areas. Hence, the concern of unnatural iron inputs from artificial reefs seems not to center on the occurrence of adverse toxicological effects in marine organisms but rather on the alteration of the composition of natural assemblages of algae and species that compete with algae.

The interiors of vessels have in some cases been painted with lead paints. Lead has no biological function and, therefore, is not metabolized and can accumulate in organisms (Thompson 1990). Corals have been found to incorporate lead into their skeletons (Dodge and Gilbert 1984). In general, marine fish, mammals, and birds exhibit low levels of lead, although bird bones have been shown to concentrate lead compared to other tissues (Thompson 1990). Unicellular algae and sea urchins seem to be the most sensitive marine organisms (Bernhard 1980). Growth inhibition has been observed in the algae species *Thalassiosira pseudonana* and *Porphyridium marinum* exposed to 200 g Pb/L. Sea urchins are sensitive at similar levels.

Comment [A49]: Reviewer 1: What are lead levels of paint on ships? Has lead been banned in paint? If so, when?

Oil and gas reserves are frequently located near natural reefs and the reef fish associated with the oil and gas platforms support a significant commercial fishery. The fish can be directly exposed to contaminants from the platform discharges, and therefore, the possibility also exists for contaminant exposure to humans through consumption of the contaminated fish (Boland et al. 1983).

Comment [A50]: Reviewer 1: What “discharges”? Aren’t the rigs regulated by international and federal ocean dumping laws?

Despite the potential toxicological effects of the chemicals discussed above, adverse effects will not occur unless the chemicals are present at or above their effective concentrations. The South Carolina Department of Natural Resources in 1998 assessed the levels of PCBs and heavy metals in biota found on ex-military ships used as artificial reefs. They collected over 100 samples of reef materials, resident invertebrates, and resident finfish from several locations along the South Carolina coast including permitted artificial reefs and naturally occurring hard bottom reefs. The artificial reef structures selected for the study were primarily ex-military vessels that had been submerged for 3 to 17 years. Three of seven vessels from which biological samples were collected were found to have materials onboard containing PCBs. The PCBs found were in gaskets and cable insulation with concentrations ranging from 1.3 to 24.5 ppm. Of the 80 tissue samples analyzed for PCBs, only 19 (4 finfish, 14 mollusks, and 1 echinoderm) were found above detectable limits. All were well below the U.S. Food and Drug Administration’s alert action level of 2.0 ppm wet weight. No significant differences were detected for PCB concentrations in the tissues of organisms collected from vessels found to contain PCB-laden materials, vessels where the presence of PCBs in onboard components was possible but not confirmed, and natural hard bottom control sites. The same tissue samples were also analyzed for metals. Although some individual tissue samples were moderately high in a particular metal, no clear correlation of high metal levels and a particular type of sample site (control versus ship reef) was found. Much higher levels of lead were found in some gastropods removed from artificial reefs when compared to low numbers for bivalves and fish off the same site. The investigators felt the high levels were likely attributable to gastropods grazing directly on the

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painted surfaces of ships and ingesting minute quantities of lead-rich paint. No indication of bioaccumulation of lead in higher trophic levels was seen. It was concluded that the PCB and metal levels detected in the study did not indicate increased hazards around military ships used as artificial reefs. (Martore et al. 1998)

Impacts to the Physical and Chemical Attributes of the Ecosystem

Deployment of an artificial reef can also affect the physical and chemical attributes of the ecosystem, which in turn, impacts the living resources of the system. Just as in the ecological dynamics of a natural hardbottom reef community, parameters such as circulation, currents, wave force, and sedimentation affect the diversity and density of living resources that colonize and utilize the hardbottom structure of artificial reefs. Strong circulation and currents are important in carrying nutrients and organic matter to living resources on artificial reefs. Sedimentation can be harmful to sessile benthic organisms because sediment particles can smother reef organisms, can clog pores of sponges, inhibit polyp feeding, reduce light available for photosynthesis, and inhibits the exchange of dissolved nutrients and gases. It has been shown that areas of high velocity flow and strong current and low sedimentation correspond to regions of high sessile benthic cover and species diversity, while areas of decelerated flow and increased sedimentation correspond to regions of less cover and lower species diversity. In regards to shipwrecks, 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. As such, these portions of shipwrecks are typically more productive since many of the sessile invertebrates found on these reefs are suspension feeders and obtain nutrients from organic particles and planktonic organisms in the water column (Baynes and Szmant 1989).

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Comment [A51]: Reviewer 1: Sebellarid worm reefs are examples of a species that require some level of sedimention. See:

Sloan, N. J. B. (2005). Burial Tolerances of Reef-Building Sabellariid Worms from the East Coast of Florida. Department of Marine and Environmental Systems. Melbourne, Florida, Florida Institute of Technology. M.S. Thesis: i-xiii, 1-59, Appx. A-B.

Additionally, nearshore algae domininated hardbottom communities required some level of scouring to maintain the diversity of algae dominated communities preferred for juvenile green turtle foraging for example. See:

Dynamac Corporation (2005). Abundance and Foraging Activity of Marine Turtles Using Nearshore Rock Resources along the Mid Reach of Brevard, County, Florida. Cape Canaveral, Florida (Submitted to: Olsen Associates Inc., Jacksonville, Florida): 1-45.

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The Bureau of Ocean Energy Management (BOEM, formerly part of the Minerals Management Service) has sponsored a series of ecosystem investigations and monitoring studies to better predict, assess, and manage the effect of outer continental shelf oil and gas development activities on marine environments. Their studies assist with understanding the impacts that artificial reefs, in the form of oil and gas platforms, have on the physical and chemical attributes of the ecosystem. They have documented that the presence of a platform or platform group had little effect on ambient water properties (Kennicutt 1995). They did find, however, that alteration of the benthic environment adjacent to offshore platforms resulted from the presence of the platforms, materials discharged from the platforms, and the oceanographic setting. Sediments close to the platforms were highly enriched in sand-sized materials derived primarily from discharged cuttings. Hydrocarbon concentrations at platforms were low, especially when compared to coastal sediment levels. In addition, PAH concentrations were below levels known to induce biological responses. Also, no enhanced bioaccumulation of contaminants in fish or invertebrates was detected near platforms.

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Longevity and Structural Integrity

The structural integrity, long-term stability and deployment location of artificial reefs can be compromised by environmental impacts such as storm and hurricane damage, waves and high surf, and other harsh environmental conditions. Impacts to artificial reefs can vary greatly and largely depend on the structural design, materials used, age of the artificial reef, geographic location, orientation, and water depth of the artificial reef. As such, impacts from environmental factors can range from no disturbance at all, to some movement, to partial or total structural modification (Blair et al. 1994). The published literature regarding the general longevity and structural integrity of artificial reefs provides the greatest scrutiny as a result of monitoring reports of mitigation artificial reefs, which document long-term stability and longevity of large concrete and limestone boulders and modules over time (CSA 2006, CPE 2007, Sathe et al. 2010). This is likely due to the fact that funding for restoration projects is short-term and there is usually little funding available to monitor and evaluate the long-term success of artificial reefs (E. Marsden, UVM, pers. comm., 2012).

Stability and wave attenuation analyses have been conducted on various models of materials to be used for artificial reefs, including all-concrete, concrete with rubber tire chips, limerock boulders, and Reef Ball™ artificial reef units (Zadikoff et al. 1996). All-concrete and limerock boulders were found to be the most stable as individual units and in mound structures. Experimental concrete structures with rubber tire chips were the least stable units.

Brock and Norris (1989) compared the design of four artificial reefs to determine their long-term stability. They found that reefs composed of haphazardly dumped scrap materials (e.g., automobile shells and surplus concrete pipe) were highly unstable and exhibited low life expectancies. Due to their high mass to volume ratio, reefs composed of modules of scrap automobile tires set in concrete bases and dumped haphazardly were relatively stable, but the design precluded effective stacking, resulting in low relief structures. Finally, an artificial reef constructed in an open framework of concrete cube modules had a long life expectancy and stability in high energy environments.

Studies have shown that artificial reefs constructed of high-density, heavily ballasted tires with strong bases show stronger stability in comparison to unballasted tires, which often fail (Myatt et al. 1989, Morley 2009). In 1967 approximately two million unballasted tires were deployed in bundles approximately 1.8 kilometers (km) offshore of Broward County, Florida in 21 meters (m) of water on sandy substrate. Within a few years (some, almost immediately), the bindings on the tire bundles failed and they became mobile with normal currents, and especially during high energy storms. As a result of these observations, tire deployments in Florida were ended by the 1980s. The tires have since moved extensively, travelling kilometers from their original location to beaches and deeper waters offshore. Many of the loose tires have also physically damaged benthic reef fauna on natural reefs. A large-scale removal plan of the tires was initiated in 2001 (Morely 2009). Interestingly, as a result of their continued movement, it has also been shown that tires have the least amount of living resource recruitment in comparison to other materials used for artificial reef construction (Fitzhardinge and Bailey-Brock 1989).

Hurricane Impacts
Many studies have examined the impacts severe storms and hurricanes have had on artificial reefs. Hurricane damage to artificial reefs can range from none to moderate to severe and the variance in damage is the result of the size and speed of storms, the frequency of storms, associated wave surges and heights, and local bathymetry and topography.

A study by Bell and Hall (1994) examined the impacts that Hurricane Hugo (Category 4, September 1989) had on a system of nearshore and offshore artificial reefs off the coast of South

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Comment [A53]: Reviewer 1: See Sathe, M. P., S. E. Thanner, et al. Bal Harbour Mitigation: Artificial Reef Monitoring Program, Year 10, Progress Report and Summary. Miami, FL: 1-39., etc

Comment [A54]: Reviewer 1: I believe this quote is in regard to long-term biological communities, not necessarily long-term physical stability.

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Comment [A56]: Reviewer 1: Morley, D. M. (2009). Environmental Enhancement Gone Awry: Characterization of an Artificial Reef Constructed From Waste Vehicle Tires. Marine Biology and Coastal Zone Management. Ft. Lauderdale, Florida, Nova Southeastern University Oceanographic Center. Master of Science: 1-70.

Carolina. Studies were conducted over a two year period following the storm to assess structural damage, movement of reef materials, environmental effects, and biological impacts. Their results showed that movement of and damage to artificial reef materials was minimal, as only four out of 19 artificial reefs showed major impacts in the form of reef material movement (some movement of small reef structures to a distance of 1.9 km was observed), structural damage, burial or severe subsidence of reef materials. Vessels and PVC reefs showed the greatest impacts. Effects of the storm on artificial reef fish communities as well as resident epibenthic invertebrates were minimal and short term in nature, with no quantifiable detrimental impacts observed. However, water turbidity in the vicinity of many of the nearshore and offshore artificial reefs was dramatically increased for over a year following the storm due to the input of large quantities of estuarine mud into coastal waters.

Damage to artificial reefs in southeastern Florida resulting from Hurricane Andrew (Category 4, August 1992) has also been assessed. Studies have shown that reefs deeper than 43 m were not significantly damaged, however, shallower artificial reefs from 12 – 30 m deep showed a 50% damage rate. The data indicated that the damage was likely the result of wave height and secondarily from storm surge (Coastal Tech 1993). Another study by Blair et al. (1994) assessed the damage resulting from Hurricane Andrew to eleven artificial reefs offshore of Miami-Dade County, Florida. Steel ships, tugs and barges represented 70% of the artificial reefs studied, with 82% of these placed seaward of the outer reef. The remaining 30% of the artificial reefs were composed of other materials including wooden vessels, steel tanks, prefabricated steel tetrahedrons and oil platforms. Blair et al. showed that following Hurricane Andrew 65% of the artificial reefs exhibited some degree of alteration, either via movement, burial, scouring or structural degradation. Alteration to ships, tugs, and barges included movement (from only a few meters up to 457 meters); overturning, bending, cracking and splitting of the vessel; and in some instances, complete loss of structural integrity. In addition, most encrusting organisms (soft corals, sponges, hard corals) were scoured from the surfaces of the artificial structures. Reefs composed of concrete materials had a similar range of alterations. The artificial reefs located within and to the north of the storm's core experienced the greatest structural changes; however, impacts did not exhibit a consistent pattern. One of the five oil platforms in the region was also impacted and suffered numerous broken weld joints, causing the platform to list to the west at a 35 degree angle. Interestingly, numerous instances were noted where a reef was severely modified or moved while an adjacent reef of similar material (e.g., ships of approximately the same size and relief) remained on location or was structurally unchanged. Despite the reefs' new or altered structural configurations, all artificial reef materials remained suitable for recolonization by benthic organisms, and in some instances may have actually improved habitat quality. Another study by Bortone (1992) examined the effects that Hurricane Andrew had on automobiles that had been deployed as artificial reefs off the coast of Pensacola, FL in the northern Gulf of Mexico. Their findings showed that the hurricane resulted in little shifting or movement of the automobiles. Regardless, by 1990, automobiles were prohibited as artificial reef material in Florida.

Studies have demonstrated that some artificial reef materials are more durable and stable when faced with a hurricane. For example, researchers examined the impacts that Hurricanes Erin (Category 2, August 1995) and Opal (Category 3, October 1995) had on over forty artificial reefs located in the northern Gulf of Mexico (Bortone and Turpin 1997, Turpin and Bortone 2002).

Materials of higher density were least affected by wave surge, while lighter weight materials were moved distances of at least 1,000 m. Automobiles and steel shipping boxes experienced the most movement as a result of the hurricanes, radio tower sections experienced some movement (anywhere from 90 – 1,000 m), while concrete pilings, pipes, prefabricated reef modules, steel oil rigs, and steel tugboats and barges were found to be the most stable and durable materials. Interestingly, their results also showed that because some artificial reefs were displaced, fishing pressure was greatly reduced for at least one year. As a result of these studies of materials deployed in the 1960s, 70s, and 80s, automobiles, steel shipping boxes, and other lightweight materials have not been deployed in Florida since the 1990s.

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Impacts of Hurricane Charley (Category 4, August 2004) to artificial reefs located in Southwest Florida were also examined (Maher 2006). Overall, relatively low levels of impacts to the artificial reef materials were observed on most of the reefs surveyed. However, there was a consistently high level of removal of the majority of invertebrates that had encrusted the structures. It was speculated that the lack of major structural impacts was the result of the very narrow wind swath of the hurricane, as well as the fact that the storm moved very rapidly over the area. Storm-related impacts did vary based on the materials used to construct the reefs and their location. For example, a structural weak steel barge exhibited significant damage, while a stronger steel car ferry did not appear to have been impacted.

Artificial reef structural damage caused by Hurricane Ivan off the coast of Escambia County, FL (Category 3, September 2004) has also been examined. Four materials were studied – fish havens (hollow, floorless concrete three sided units reinforced with metal re-bar), modules designed as "walter modules" (10' x 10' base hollow concrete tetrahedron with metal panels attached to the three sides), Goliath Reef Ball™ (reef balls constructed of granite rock); and hollow concrete Reef Ball™. Following the hurricane, half of the fish havens had collapsed and all that remained were loose piles of irregular concrete pieces. Several of the Walter Modules were damaged with about half showing the steel plate walls torn from the concrete frames. Only one of twenty Goliath Reef Ball™ was broken as a result of the hurricane, while 11% of the standard Reef Ball™ had been damaged due to the hurricane, though it was unknown if the reef balls were previously damaged during the deployment process (Horn and Reviewer 1 2004).

Florida Keys National Marine Sanctuary

In the Florida Keys National Marine Sanctuary stability issues have arisen on two artificial reefs. In 1998 Hurricane Georges (Category 4, September 1998) broke the sunken vessel *Eagle* in half (J. Delaney, FKNMS, pers. comm., 2012). The U.S.S. *Spiegel Grove*, which was scuttled as an artificial reef in 2002, sank prematurely and settled inverted on the bottom with its bow 11 meters in the air. The vessel remained lying on the her side for nearly three years until Hurricane Dennis (Category 4, July 2005) tipped the vessel to the upright position into the 20 ft scour hole that had developed beneath the keel as a result of scouring from currents over the previous three years (Farrell and Wood 2009). Interestingly, the resulting upright position of the vessel maintains the same coordinates as prior to Hurricane Dennis at a depth approximately 20 ft deeper in a scour hole, which presumably provides improved long-term stability.

Comment [A57]: Reviewer 1: Tropical Storm Dennis

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Considering that Florida has the largest number of permitted artificial reef sites in the United States (Mostkoff 1992) it is understandable that the state has contracted the development of software to predict the long term stability of artificial reefs. In 2000, the Florida Fish and Wildlife Commission contracted Paul Lin & Associates, Inc. to develop an Artificial Reef Stability Analysis Software to examine the stability of deployed artificial reef materials under given storm conditions throughout the state (Paul Lin & Associates, Inc. 2000). The software provides models that would allow artificial reef administrators in coastal counties to determine the deployment water depth, orientation, and reef material weight for a proposed artificial reef program. Similarly, in 2001 the Miami-Dade County Department of Environmental Resources Management tasked Coastal Systems International, Inc. with developing computer software that analyzes the behavior of objects that are proposed to be used to create artificial reefs under complex ocean conditions. The software uses historic wave condition data for the entire coast of Florida to predict the forces on and the stability of the proposed reef (DERM 2001). As a result of using these software stability analysis programs, and through evaluation of performance of existing artificial reefs over time, artificial reef deployments since 2000 undergo more scrutiny than the experimental materials of the 1960s-1990s.

Flower Garden Banks National Marine Sanctuary

The shipwreck *Texas Clipper* was intentionally placed in an artificial reef site off the lower Texas coast, approximately 200 nautical miles southwest of the sanctuary, in November 2007. It was substantially damaged by Hurricane Ike (Category 4, September 2008) ten months later. Although the site did not take a direct hit from the storm, a large crack was produced and the stern section of the ship fell to the seafloor. The hurricane made landfall on the upper Texas coast and hurricane strength winds (greater than 74 mph) were not recorded within 150 nautical miles of the *Texas Clipper* reef site.

Human Use and Economic Impacts

Advocates of the economic benefits of artificial reef development hypothesize that sinking an artificial structure in the vicinity of a natural reef environment can reduce human use pressure on the surrounding natural reefs, increases businesses to local dive operators, and increases economic impact on the local economy (Leeworthy 2011). Socioeconomic studies conducted at the U.S.S. *Spiegel Grove* and the U.S.S. *Vandenberg*, both submerged vessels in the Florida Keys National Marine Sanctuary, have tested these hypotheses and have demonstrated that the dive charter industry and the local economies benefit from the introduction of decommissioned ships as artificial reefs. Study results at the U.S.S. *Spiegel Grove*, a 510-foot retired navy ship that was intentionally sunk in the waters off of Key Largo, Florida in June 2002, showed that after deployment recreational use of the surrounding natural reefs decreased, while local dive charter business increased, and the greater local economy grew in terms of both income and employment (Leeworthy et al. 2006). However, results from a similar study conducted at the U.S.S. *Vandenberg*, a 520-foot retired air force missile tracking ship intentionally sunk in the waters off of Key West, Florida in May 2009, did not support the hypothesis that introducing an artificial reef would reduce use on the surrounding natural reefs. However, the hypotheses that diver operator business would increase as would impacts on the local economy were supported (Leeworthy 2011). It is important to note that the results of both studies depend heavily upon the attributes of the local economy and existing dive business structure and the marine ecosystem and the artificial reef itself; therefore, the conclusions of these studies may only apply to other locations that have similar attributes. Both studies support the idea that decommissioned ships

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converted to artificial reefs can be successful in promoting economic development and tourism and also yield a net return on investment.

The following provides background information on the socioeconomic effects of artificial reefs in the Florida Keys:

Socioeconomic information from 'Johns et al 2001'

For the year 2000, artificial reefs accounted for $117.6 million dollars in expenditures for the Monroe county economy. Artificial reef related expenditures accounted for 24% of the economic contribution of all reefs including natural reefs in the county. This study was done before the deployment of the two most highly visited artificial reefs in the Keys, the *Spiegel Grove* in 2002 and the *Vandenberg* in 2009. Artificial reefs accounted for $32.5 million dollars in income and 2,319 jobs for the local economy in 2000. (Table 6.3.2-1)

Annual use values for maintaining existing artificial reefs from June 2000 to May of 2001 was $9.4 million dollars while use value for new artificial reefs was $2.1 million per year. In general the use value is the maximum amount of money that reef users are willing to pay to maintain the reefs in their existing condition and to add more artificial reefs to the reef system. According to this paper, there appears to be a very high public demand for artificial reefs in the keys. (Table 6.3.3-1 and Table 6.3.3-2).

Socioeconomic information from 'Leeworthy 2005'

After the deployment of the *Spiegel Grove* off Key Largo on May 17, 2002 there was a net increase in the number of scuba dives with paying customers of 6,776, or a 3.7% increase in dive business locally. This confirms that the sinking of the *Spiegel Grove* yielded benefits for local dive charter operations.

Overall, local income increased by $961.8 thousand, and local employment increased by 68 jobs following the sinking of the *Spiegel Grove*. Also there was an associated increase of $2.6 million dollars in total recreational expenditures and $2.7 million increase in sales/output for the local economy following the deployment. These results confirm that the creation of the *Spiegel Grove* artificial reef resulted in net benefits for the local economy.

Socioeconomic information from 'Leeworthy 2011'

The *Hoyt Vandenberg*, a 520 ft long ship, was deployed of Key West on May 27, 2009 primarily as a new dive destination in Monroe County. The net changes in total recreational expenditures from the pre- to post-deployment period indicated that there was an increase of $6.5 million in total recreational expenditures, which generated a total impact on sales/output of $7.29 million, about $3.2 million in income, and the creation of 105 new jobs (Table 3).

For the scuba and snorkel dive businesses of Key West , there was an increase of 49,073 in the number of dives with paying customers, or a 188.9% increase in business in total from the pre-deploy to post deployment time frames. There was a 442% increase (34,394 dives) in the share of recreational SCUBA diving occurring on artificial reefs off Key West in 2009-2010, primarily due to the creation of the *Vandenberg* artificial reef (Table 2).

Comment [A59]: Reviewer 1: It might be worth discussing the benefits and drawbacks of non consumptive use of artificial reefs in this section, and discussing observations of divers and coral reefs, the value of maintaining mooring ball systems to prevent anchor damage, etc. For example, see:

Anderson, L. E. and D. K. Loomis (2011). "SCUBA Diver Specialization and Behavior Norms at Coral Reefs." Coastal Management 39: 478-491.

and

http://coralreef.noaa.gov/education/educators/resourcecd/guides/resources/mooring_buoy_g.pdf

Comment [A60]: Suggest inserting reference to Johns et al 2001 paper which includes a chapter on Monroe County.

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Acknowledgements
Thanks is given to Paula (Souik) Bizot who, in 1998, drafted a white paper for the NOAA Sanctuaries and Reserve Division titled *Considerations for Artificial Reef Development*. Portions of that document were used during the drafting stages of this updated report on the same topic.

This report also benefited significantly from the following individuals who either provided a preliminary review of the report or contributed comments, content, or literature: Greg Boland (Bureau of Ocean Energy Management), Erica Burton (NOAA MBNMS), Thomas Coon (Michigan State University), Natalie Dingledine (DLZ Michigan), Jon Dodrill (FFWCC), Scott Donahue (NOAA FKNMS), Steve Gittings (NOAA ONMS), Kaitlin Graiff (NOAA CBNMS), Russ Green (NOAA TBNMS), Lauren Heesemann (NOAA MNMS), Emma Hickerson (NOAA FGBNMS), Michelle Johnston (NOAA FGBNMS), Irina Kogan (NOAA GFNMS), Vernon R. Leeworthy (NOAA ONMS), Ellen Marsden (University of Vermont), Keith Mille (FFWCC), Michael Murphy (California Coastkeeper Alliance), Steve Rohmann (NOAA ONMS), Jan Roletto (NOAA GFNMS), and Vicki Wedell (NOAA ONMS).

Special thanks is also given to Joanne Delaney (NOAA FKNMS), John Embesi (NOAA FGBNMS), and Dale Roberts (NOAA CBNMS) who were particularly helpful in providing references and generating content and text for this report.

Finally, sincere thanks is also extended to the peer reviewers of this document: ***.