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An Update on Florida's Artificial Reefs: Recent Research and What It Means for Florida[1]

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Abstract

As coastal managers and practitioners continue placing artificial reefs in marine waters, the scientific understanding of the effects and implications of artificial reefs is changing. It is especially important for resource managers and Extension and outreach personnel, as well as the interested public, to keep aware of these changes as they occur. One of the challenges to staying well informed is that nearly all recent scientific studies are published in peer-reviewed journals initially. Such journals may be inaccessible, either owing to jargon or paywalls. The purpose of this publication is to describe some of the most recent artificial reef studies, published 2016–2020, that are likely to be especially relevant to Florida. We categorize the studies included here into three broad groups: (1) marine ecology, (2) effects on fishers, and (3) monitoring and design. Each study included is summarized and described with respect to its potential relevance to Florida. It is critical to recognize that this publication is not a complete census or record of recent research. The studies were selected by the authors owing to their perceived relevance. This publication is best used to augment existing publications that provide a more general background of how artificial reefs function and affect Florida. These additional publications are described in the Introduction. When used as intended, this publication should help the interested public as well as managers and education/outreach personnel stay well-informed of recent developments in artificial reef science that should be considered when making decisions about artificial reefs.

Introduction

Artificial reefs are human-made or sourced materials that are placed on the sea floor (Lindberg and Seaman 2011). When deployed intentionally, their purpose is typically to increase the amount of structural habitat in a way that will benefit fish populations and humans (Becker et al. 2018). Artificial reefs have been shown to have ranges of effects on fish and other marine life, as well as recreational fishers and divers. They can even affect local economies, so they matter to resource managers and elected officials alike. One thing that separates the installation and upkeep of artificial reefs from many other fisheries-management actions is that they are semi-permanent. In reality, "undoing" or removing artificial reefs is logistically difficult, expensive, or both.

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The expense of removing them makes artificial reefs, for all intents and purposes, mostly permanent. The semi-permanence of artificial reefs combined with the important effects they can have on coastal systems makes it really important to understand the effects of artificial reefs **before** they are implemented. For this reason scientists have been studying artificial reefs for decades. There has been so much research on artificial reefs that it can be difficult to keep up with new studies. The purpose of this publication is to provide a summary of some of the most recent innovations (2016–2020) in artificial-reef-related science. It especially focuses on research taking place in or near Florida (such as the Gulf of Mexico or Southeast Atlantic), though there are some informational studies from farther away that may be especially important to Florida. The publication is intended to be used by the interested public, as well as management agencies and education/outreach professionals who seek to communicate with the public.

It is important to understand that this publication alone does not provide a full description of the scientific understanding of the effects of artificial reefs, or all of the information readers may wish to have about artificial reefs in Florida. For more background information on how artificial reefs are expected to affect fish, fishers, and fisheries systems, please see the Artificial Reef 101 EDIS series. For an update on recent artificial reef deployments in Florida, please refer to the publication, "An update on Florida's Artificial Reefs: recent deployments and trends" that summarizes reef deployments and trends from 2015–2021. Additional information on the economic effects of artificial reefs can be found in FE649; information about the ecological effects of artificial reefs on fish can be found in SG100; and an overview of how artificial reefs are created can be found in FA231. Finally, there is additional information available through the Florida Master Naturalist Program in the Marine Habitat Restoration Course. The current publication is best used as an "update" on recent discoveries and changes in the understanding of artificial reefs.

Artificial reef research covers a range of topics. This publication groups some of the recent research relevant to Florida into three categories: (1) marine ecology, (2) fishers, and (3) the monitoring and design of artificial reefs. The ecology category focuses on how artificial reefs affect marine life—mostly, but not entirely fish. The "fishers" category focuses on how artificial reefs may alter the behavior or perception of fishers, especially recreational fishers. Finally, the monitoring and design of artificial reefs describes some of the more methodological advances for understanding the effects of artificial reefs (monitoring) and how artificial reefs are physically constructed (design). The information in this publication includes research presented at the Florida Artificial Reef Summit in 2021 that has been published, along with other especially relevant studies from the broader scientific literature.

Marine Ecology

One of oldest subjects of artificial reef research is also one with recent research updates relevant to Florida: how species compositions of artificial reefs compare to those of natural reefs. Some recent and especially relevant publications on this topic include:

- **Gardner et al. 2019: Effect of reef morphology and depth on fish community and trophic structure in the northcentral Gulf of Mexico.** This study examined differences in reef fish community and trophic structure between natural and artificial reefs. The authors also tested the effect of depth (shallow vs deep), relief (low vs high), and complexity (low vs high) on fish diversity, community structure, and trophic guild and species-specific densities. They conducted remotely operated vehicle surveys at 47 reef sites (23 artificial reefs, 24 natural reefs) off of the Panhandle of Florida. They found that relief and complexity played a strong role in influencing the reef communities. They observed higher mean densities of several reef fishes like Lutjanids (snappers), Carangids (jacks), and some Serranids (groupers), at artificial reefs compared to natural ones, suggesting that artificial reefs attract and concentrate some biomass. The complex natural reefs with high relief supported high densities of planktivorous fishery species but greatly increased densities of small, demersal (bottom-associated), non-fishery species that use the structure for refuge. This study identified specific habitat characteristics that affect community and trophic structure which can be used to facilitate species-specific vulnerability assessments to environmental threats. A main implication of this study for Florida's artificial reef program is that the types of reefs implemented should affect the fish they attract.
- **Paxton et al. 2020: Meta-analysis reveals artificial reefs can be effective tools for fish community enhancement but are not one-size-fits-all.** This study was not Florida-specific, but instead was a meta-analysis—a study of other studies. It sought to describe broad trends in how artificial reefs compared to natural reefs by summarizing and analyzing the findings of 39 small studies. What it showed was that, in general, artificial reefs were quite similar to natural reefs. Specifically, the authors found similar amounts of fish density, biomass, richness (number of

species) and diversity (which describes the proportion of all fish made up by different species). While artificial and natural reefs were similar when looking at all the studies, there were some statistically significant differences when comparing artificial versus natural for certain regions, oceans, or types of reef. For example, density of artificial and natural reefs was similar between reef types for subtropical waters (much of Florida waters), but diversity at artificial reefs appeared lower. These findings may be seen as a mixed bag for Florida—similar density is promising for artificial reefs being used by many fish, but lower diversity is not ideal and may require additional work to understand which specific species are more or less benefited by artificial reefs. An important take-home message from this paper for artificial reef work in Florida is that the effects of artificial reefs will likely differ across systems, potentially varying with the materials used to construct the reefs. This emphasizes the need for continued monitoring of artificial reefs.

- **Paxton et al. 2020: Artificial habitats host elevated densities of large reef-associated predators.** This study specifically assessed how densities of larger, more transient predators like sharks, mackerel, jacks, and barracuda differed between natural and artificial reefs. The authors compared thirty artificial and natural reefs off the coast of North Carolina. They generally found greater densi-ties of these large predators on artificial reefs. This was especially true when the artificial reefs were composed of larger, more vertical structures like sunken ships. One implication this has for Florida is the potential to create artificial reefs that are tailored for specific fisheries, such as the "reef darts" that are being implemented in southeast Florida. See the publication, "An update on Florida's Artificial Reefs: Recent Deployments and Trends."

Understandably, the majority of artificial fish ecology research has focused on how artificial reefs affect reef fish—fish that spend most or a lot of their life near benthic structure. The most obvious examples are popular sportfish snappers and groupers, and specifically there is an abundance of literature describing effects of artificial reefs on red snapper. However, some more recent research is describing observations and potential effects of artificial reefs on more migratory species. Some of these studies include:

- **Ajemian et al. 2020 Movement patterns and habitat use of tiger sharks (*Galeocerdo cuvier*) across ontogeny in the Gulf of Mexico.** The authors tagged tiger sharks from Texas to Florida and analyzed their movement patterns. They specifically attempted to assess if sharks seemed to use or frequent oil platforms (which generally function as and are often used by fishers as artificial reefs). Like most movement studies, the results differ between individuals (including by size), but most sharks seemed to relate to shelf breaks (major changes in the water depth) more so than artificial structures. This does not mean sharks did not use the structures, just that it was difficult to see a preference for them. The main implication of this work for Florida is that artificial reefs may well be used by some of the largest and most charismatic predators, but the manner in which they are used is unclear. This gap in our understanding emphasizes the importance of additional monitoring of reefs, especially beyond traditional, more benthic-oriented reef species.
- **Snodgrass et al. 2020 Potential impacts of oil production platforms and their function as fish aggregating devices on the biology of highly migratory species.** This research provides a very helpful summary of much of the past and recent scientific work completed by describing how highly migratory species may relate to artificial structures, specifically oil platforms. Highly migratory species include sought-after commercial and recreational species like billfish, tunas, mackerels, and sharks. This work focused on the area of the Gulf of Mexico with a great density of oil platforms. The authors describe and discuss the evidence for how these oil platforms may change how these species move or gather. One of the most notable concepts is that these platforms could serve as de facto "fish aggregation devices." Fish aggregation devices (commonly known as FADs) are common in many countries with smaller scale or artisanal fisheries. If artificial reefs (purpose-built ones or oil platforms) do in fact aggregate some of these highly migratory species, it could result in greater catch rates for some fishers. Greater catch rates may be enjoyable in the short term, but could eventually lead to greater harvest. Still, the authors caution that these effects are more likely at local or regional scales, since artificial structures still represent very small amounts of total habitat in the Gulf of Mexico, and the aggregation of these highly migratory species does not seem as strong as some reef species, like red snapper. The study should be of particular interest to Florida, which recently implemented some purposeful FADs in the northwest (Panhandle) region (see "An update on Florida's Artificial Reefs: Recent Deployments and Trends" for details). This study may also have implications for other areas of Florida with shallower coastal waters where the largest pelagics (e.g., tunas, billfish) may not venture in areas with actual artificial reefs (as opposed to, for example, oil platforms that may function as reefs to fish and fishers). It is possible that FADs placed in these waters may augment recreational angler catches of other species such as cobia, tripletail, and mackerel.

Fisher Behaviors

Arguably one of the most important trends in the last decade or so of research on artificial reefs has been the increasing understanding of the way that these structures affect not just fish, but also people. Artificial reefs may affect fisher behavior (like how many fishing trips are made) or they may alter the effect of fishers' actions, for instance, by increasing the catchability (how many fish a unit of fishing effort catches). More detailed information about the effects of artificial reefs on fishers can be found in the third publication in the Artificial Reefs 101 series, "Effects on Fishers and Divers." While the effects of artificial reefs on fishers are important, they have also been difficult to study. A couple of recent studies with particular importance for Florida are described below:

- **Simard et al. 2016: Quantification of boat visitation rates at artificial and natural reefs in the eastern Gulf of Mexico using acoustic recorders.** Some fisheries scientists have hypothesized that artificial reefs may be visited more frequently by anglers than natural reefs or hardbottom, either because artificial reefs are easier to locate, because they are thought to have more fish around them, or both. This study tested the question by placing acoustic recorders that collected sound data. The data could be analyzed to identify and then quantify boat engines. The analyses revealed that visitation rates were much greater at artificial reefs than natural hardbottom. The research took place near Tampa Bay and suggests that artificial reefs at least have the potential of increasing fishing effort. More work is needed, though, because it is not easy to figure out whether those visiting artificial reefs would not have fished without the reefs, or whether they simply would have fished elsewhere.
- **Schuett et al. 2016: Examining the behavior, management preferences, and sociodemographics of artificial reef users in the Gulf of Mexico offshore from Texas.** There are not many studies that actually report on the types of anglers using artificial reefs and what they say they want. This lack of information can lead to assumptions about these important factors, and untested assumptions can sometimes lead to management mistakes. This study actually surveyed (mail and online) anglers who used artificial reefs off the coast of Texas. They found most users were white males over 55 years old and with relatively high incomes. Overall, anglers stated they enjoyed fishing oil rigs, and believed these structures were important for presence of fish and fishing. They generally stated they would like to see more artificial reefs and to be able to place their own reefs. The results of this study are largely unsurprising, but it is quite valuable to have some peer-reviewed studies to be cited. Another implication for Florida is that it might be worth comparing the attitudes and behaviors of reef anglers along Florida's Atlantic and Gulf coasts, where there are fewer oil platforms. Understanding if or how attitudes differed when different types of structures are functioning as reefs would improve information for making management decisions.
- **Karnauskas et al. 2017: Red snapper distribution on natural habitats and artificial structures in the northern Gulf of Mexico.** By now it is well-known that red snapper often aggregate around artificial reefs, and that fishers often target them there. These two things make it possible that fishers' catchability is greater around artificial reefs, but this has been difficult to prove. This study analyzed data collected from an expansive, multi-gear survey in the Gulf of Mexico. A multi-gear survey means multiple types of scientific gear were used to sample fish—for example, a trawled net along with a long-line. The results showed particular areas of the coast, from Texas to Florida, where red snapper seem to aggregate more than at other areas. One of the most notable findings in the study was that catch rates on artificial structures, including oil platforms, were about 20 times greater than on natural reefs. Catch rates (fish caught per unit time) should basically scale with catchability, so this study has been widely cited as potential evidence that catchability may in fact be much greater on artificial reefs, at least for red snapper. This has implications everywhere red snapper are caught, including Florida. If catchability is consistently that much greater on artificial reefs, even if they make up a small amount of the total habitat, increasing artificial reefs may lead to local or regional increase in harvest rates. More discussion of these potential unintended consequences of artificial reefs is provided throughout the Artificial Reefs 101 series, especially in the third and fourth parts of the series, "Effects on Fishers and Divers" and "Effects on Fisheries."

Design and Monitoring

Both the design and monitoring of artificial reefs are critically important. As some of the earlier-mentioned research shows, what artificial reefs are constructed out of and their general shape may well affect the fish communities that use them (Paxton et al. 2020a, 2020b). But the only way we are learning how fish, as well as fishers are affected by artificial reefs is through monitoring of some form, as is well illustrated by the Karnauskas et al. (2017) study that suggests artificial structures may allow for much greater catchabilities of red snapper.

Scientists have evaluated the way artificial reefs have been constructed and designed for nearly as long as artificial reefs have become common as a management tool (Sheehy 1985; Bell et al. 1989). One of the challenges in assessing the effects of artificial reef design is that there are so many. For example, Paxton et al. (2020a) simply grouped artificial reefs by material type (e.g., rock, concrete, vessel, etc.). Even within a single material, however, especially when that material is concrete, there are myriad different ways reefs might be constructed, and the specifics of construction may well affect not only the fish communities, but even overall production, or the hydrodynamics which could influence things like coastal erosion. A couple of recent notable studies include:

- **Lemoine et al. 2019: Selecting the optimal artificial reefs to achieve fish habitat enhancement goals:** The authors evaluated the ecological performance of four types of marine artificial reefs (metal ships, concrete pipes, reef balls®, and Atlantic pods) and compared them to each other and to a nearby rocky reef. This study was conducted off the shores of North Carolina and sampled 23 reefs (both artificial and natural reefs). The concrete modules (pipes, reef balls®, and Atlantic pods) all had fish abundance, biomass, and community composition similar to those of the rocky reef, but the metal ships had the highest fish abundance and biomass compared to the concrete modules and the rocky reefs. They also had significantly different community composition. These fish community patterns were consistent with previous findings in the study area and Florida (Arena et al. 2007). These results showed that structural complexity may drive patterns in fish communities. Specifically, increased complexity was correlated with higher fish abundance—the complexity of the ship is greater than that of the concrete modules and the rocky reefs. The authors recommend deploying concrete modules if the objective is to mimic natural habitats and suggest that deploying ships as artificial reefs may actually create habitats that surpass natural reefs in fish abundance and biomass and that will differ in species composition. That artificial reefs may increase abundance, biomass, and species diversity is encouraging, as a large number of Florida's recent artificial reef additions have been these pre-constructed concrete reefs (Camp et al. 2021) (Figure 1). As some of the following studies show, however, not all pre-fabricated concrete reefs are the same.
- **Rouse et al. 2020: Artificial reef design affects benthic secondary productivity and provision of functional habitat.** This study looked at benthic secondary productivity. (Secondary production is biomass produced by organisms that don't make their own food—e.g., fish, crustaceans, and virtually all living things that are not plants.) The rate of secondary productivity is important to our understanding of energy flow in ecosystems, basically because almost all of the marine life humans pay attention to relies on secondary production for most of its food. The study looked at a bryozoan (bryozoa are simple aquatic invertebrates that live in colonies) and assessed how its production differed when it lived on simple artificial reef blocks with lesser surface area versus when it lived on more complex reef blocks with greater surface area. They found production was 2.4 times greater on the complex blocks. This information is especially important because of the long and ongoing discussions about artificial reef production and attraction. This discussion (sometimes called a debate, though scientists increasingly understand that both production and attraction are likely occurring at some levels with most reefs; Lindberg and Seaman 2011) is critical because for artificial reefs to truly augment ecosystems, they need to produce. This research suggests that how much production occurs may well depend on the design of the reef construction. The study should be especially relevant to Florida, where the majority of recently implemented artificial reefs are modules constructed out of (mostly) concrete.

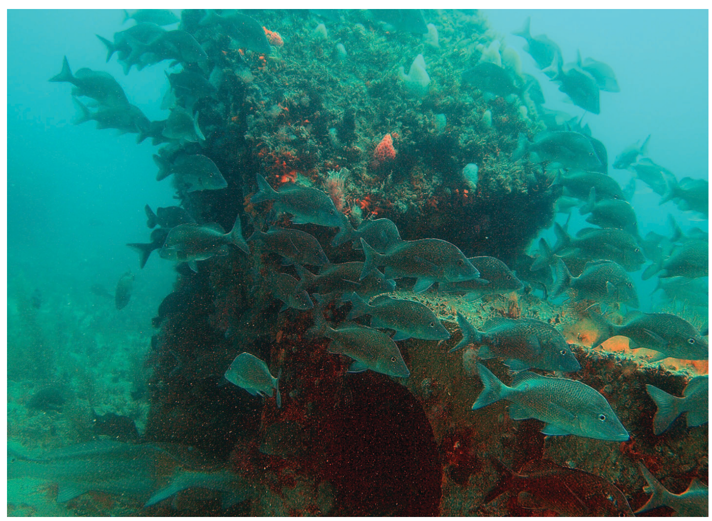

Figure 1. Example of fish around a pre-fabricated concrete artificial reef structure.
Credits: Michael Dickson, UF/IFAS

- **Hylkema et al. 2020: Fish assemblages of three common artificial reef designs during early colonization.** This study is a recent and thorough assessment of a simple question—how does the style of an artificial reef affect abundance and biomass of fish? The study compares the familiar reef balls® to both concrete "layered cakes" and simple rock. While all the structures wound up with more fish than bare sand/substrate, they found the layered cakes had 3.8 times more fish and 4.6 times more biomass than the reef balls®, and rock had values between the two. The results were from one year of colonization. While the study took place in the Caribbean off the coasts of Saba and St. Eustatius, it again should have clear relevance to Florida. Reef balls® (and similar constructed modules) have been popular and relatively easy (logistically) to obtain. If this study's results were mirrored in Florida, relatively small changes in construction could yield substantial increases in fish using the reefs.

The biggest issue with artificial reef monitoring is that it actually must occur (Lindberg and Seaman 2011; Becker et al. 2018; Hylkema et al. 2021). Monitoring reefs has been challenging, in large part because it is expensive and logistically challenging to either dive reefs or to operate larger vessels for any type of more physical sampling (whether traditional hook and line/vertical gear or remote sensing/acoustic approaches). Further, there is a need to monitor not only the fish response to reefs, but fishers (or divers) as well. Here we describe a couple of recent studies that highlight novel approaches to these issues:

- **Streich et al. 2017: A comparison of fish community structure at mesophotic artificial reefs and natural banks in the western Gulf of Mexico.** In this study, the authors used remotely operated vehicle (ROV) surveys to assess fish community structure. They compared "Rigs to Reefs" artificial reefs to the natural banks and estimated red snapper densities in each. This study took place along the Texas shelf in the western Gulf of Mexico. The ROV was equipped with cameras that made real-time observations with a live-feed video. They obtained 22.2 hours of footage and information on species richness and diversity, water temperature, salinity, species-specific MinCounts (the minimum number of fish that could be seen at any one time), and red snapper density estimates. This study showed the merits of using concurrent surveys of artificial and natural habitats to gain an understanding of the role of artificial reefs as habitat. Although the authors recommended a better survey design and effort especially for more transient species that occur higher in the water column, ROV surveys are used frequently across Florida and studies have shown merits of their use. This study emphasizes the need to have an efficient survey design in terms of placement, replication, and coverage to gain better insight into the effects of artificial reefs and species-specific traits.
- **Florisson et al. 2018: Reef vision: A citizen science program for monitoring the fish faunas of artificial reefs.** In this study, researchers sought to enlist recreational fishers' help in monitoring artificial reefs. Volunteers were trained to operate a Baited Remote Underwater Video (BRUV) system to take video of artificial reefs. The video was then analyzed to assess fish community response to artificial reefs. Benefits of this system included lower monitoring costs, as well as public engagement. One reason this study may have application to Florida is that remote operated cameras similar to BRUVs have been used to evaluate natural and artificial reefs throughout the Gulf of Mexico and Southeast Atlantic (Ajemian et al. 2015). There are several citizen science reef fish monitoring programs already operating in Florida. Probably the longest-running is the Great Goliath Grouper Count, which is not focused specifically on artificial reefs. More recently, UF/IFAS Florida Sea Grant Extension agents in the Big Bend region of Florida have begun citizen science artificial reef monitoring efforts as well. Further developing these and other efforts may help learn more about reefs while engaging more stakeholders with the science of artificial reefs.
- **Becker et al. 2020: Application of a long-range camera to monitor fishing effort on an offshore artificial reef.** In an effort to monitor the fisher response to near-shore artificial reefs (which the authors defined as those <9km from shore), the authors developed and tested a long-range camera that not only could photograph vessels at great distances, but could be calibrated to assess if vessels were fishing over the artificial reefs or not. The camera was automated (taking pictures every 15 minutes) rather than triggered or manually operated, and used a 12 v system charged by solar panels. The study showed that at least for near-shore reefs, remote camera monitoring of fishing responses was feasible. While the study took place in Australia, its results are especially notable for Florida, where more near-shore artificial reefs are being implemented. These reefs are often designed either to be used by different fish species (e.g., not necessarily larger grouper and snapper, but perhaps smaller snapper, porgy, or grunt species), or to actually be accessible by shore.

Conclusions

Our understanding of how artificial reefs affect marine systems and human communities alike has been rapidly advancing. We continue to learn how artificial reefs are often but not always functioning similarly to natural reefs, in terms of the fish communities that use them. This new knowledge has led to the understanding that it is not just reef fish using artificial reefs, but often larger pelagic or migratory species as well, and that artificial reefs may have influences on the fisheries for larger pelagic and migratory species. Two of the potential changes in fisheries that have been suggested by recent studies are that artificial reefs may increase fishing effort (or at least be visited more than natural reefs), and that the catch rates on artificial reefs may be much, much greater (at least for red snapper). This finding emphasizes how important it is to continue to understand greater details about how artificial reef design may mediate the effects on fish—and potentially fishers! Understanding the differences between reefs requires monitoring. Given the myriad possibilities for design and the relatively high cost of on-the-water monitoring, there is a need to develop innovative monitoring approaches. Two possibilities include remote sensing (whether camera or other options), which may be especially useful for monitoring fisheries, and citizen science, which could allow for fisheries-independent monitoring of the fish communities using artificial reefs.

From all the work described here, as well as the process involved in identifying these studies, two main points emerge. The first is that it still seems that most of the recent research on artificial reefs focuses on marine ecology, and specifically how reefs attract and/or enhance fish populations. This conclusion is supported by a systematic assessment of trends in artificial reefs research by Lima et al. (2019) and is even represented here in the number of studies reviewed in each of the categories described—there were many more marine ecology studies than studies either of effects on fishers or of reef monitoring and design. The other point worth making is that some of the most interesting and relevant artificial reef work is taking place far from Florida. While artificial reef research is obviously global (Lima et al. 2019), some of the work most relevant to Florida is taking place in Australia right now. This may be because the reasons for implementation (mostly to augment recreational fishing) are especially similar between these two locations. Finally, it must be emphasized again that a great many more studies have been recently completed than are described here. Nonetheless, this publication provides an idea of some of the newer things scientists are learning about artificial reefs that likely have special implications for Florida.

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