Understanding the Ecology of Artificial Reefs: No Simple Answers[1]

Bill Lindberg and Mark Schrope[2]

Florida has one of the most active artificial reef programs in the nation. Everything from bridge rubble to specially designed concrete structures to retired naval ships has been intentionally sunk at over 2,000 locations throughout the state's waters.

Artificial reefs are created to achieve a wide range of goals—replacing natural coral reefs damaged by environmental degradation or ship groundings, breakwaters to protect beaches and coastal lands, and even as creative memorial sites for cremated human remains. Among the most popular objectives, however, are improved fishing opportunities and new scuba diving destinations. These uses boost Florida's multi-billion dollar tourism industry, especially in the local economies directly impacted by the fishermen and divers who come to take advantage of the reefs.

From the surface, it can seem as if artificial reefs are guaranteed to have positive environmental impacts and to increase the amount of fish. In reality, the situation is much more complex because an artificial reef is just a small part of a much larger ecosystem, with impacts that are often difficult to see.

New artificial reefs are indeed reliably populated in short order by many fish. However, it remains an often-asked question whether those fish are merely attracted there from other areas—concentrating them at a known location for fishermen to catch—or if artificial reefs actually lead to the production of more fish.

Bill Lindberg, a fisheries professor at the University of Florida, has been designing and studying artificial reefs for decades, and much of his work is pertinent to the "attraction- production" debate. Science writer Mark Schrope conducted this interview with him to discuss the issue.

Q. How do artificial and natural reefs compare?

A. The same ecological processes apply on natural and artificial reefs. However, with artificial reefs we do tweak the physical architecture and complexity of the structure in ways that presumably help our purposes and that can affect growth, survival, and other processes. I think it's probable that the reefs we develop, which have more nooks and crannies that fit the body sizes of fishes, allow higher concentrations of fish to occur relative to the natural reefs in a region.

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Q. Standard ecology theory would say that over time, fish will naturally adjust their densities among reefs, filling all those available nooks and crannies. Do you find that's the case?

A. In the absence of fishing we might expect fish to move in such a way that their numbers are spread out among all the available habitat, with the densities of fish at a given reef reflecting how much suitable space and food are available. Some of our results suggest that while that might be true in an unperturbed ecological system, it's not necessarily true for heavily fished reef fishes.

That's because people move around in response to catch rates, and change fishing sites faster than the fish naturally redistribute themselves. So you end up with the potential for fishermen to catch the same number of fish for a given amount of effort, even if a fish population is declining.

Q. Do fish find artificial reefs more attractive than natural ones?

A. When we build a reef, we're altering the availability of the structure fish need in proximity to their foraging grounds. So yes, they're drawn to it, and there are reasonable studies to suggest that in general, artificial reefs hold initially higher densities of fish than natural reefs. However, there is not necessarily the same biodiversity or the same community composition because the reef structures, by design, are different.

Q. If there is some tendency for fish to be attracted to artificial reefs, what's the best way to look at the question of whether artificial reefs just attract fish from other spots, or whether they actually support the production of more fish?

A. The answer is going to depend on the idiosyncrasies of the life history and ecology of what it is you're talking about. Small fishes that are highly sedentary and highly site attached, meaning they get their shelter, get their food, and complete their life cycle essentially at the same place, for them an artificial reef may very well lead to new production. That might be a situation where each increment of habitat allows for more of these kinds of critters to do their thing. But the more mobile the fish is, the more it depends on a broader footprint than just the reef for its prey and for its various life stages to play out. For those fish, such as the grouper we study and most of the economically valuable fish, it's much less likely that any individual reef is going to contribute production sufficient to offset harvest.

Q. So then what is the likely effect of artificial reefs on those economically important species?

A. When you're concentrating fish by providing them shelter, looking at it strictly at a local scale, the question becomes: is any new fish production associated with bringing that targeted fish and its shelter requirements and its forage area into proximity? In other words, is the production associated with changing the dynamics of how that fish makes its living sufficient to offset the loss of fish at that location due to fishing? If that associated fishing mortality exceeds the production of the fishes in residence during that period of time, then you're operating at a deficit. Other important questions to consider are whether, as artificial reef development continues, you change the way fishes seek shelter, avoid predation, conserve energy, and access food from areas adjacent to a reef. Those are open questions.

Q. What does all that mean for Florida?

A. Here in Florida, we have extensive artificial reef development, but compared to the naturally occurring habitat it's still a drop in the bucket. One of the arguments is that adding more habitat really isn't doing anything but changing the spatial dynamics of fish distribution—and where people fish. If anything, because of fishing success rates at artificial reefs, you may be exacerbating the problem by increasing fishing mortality. Given the fishing mortality, there's no reason to presume that building artificial reefs enhances production at the fisheries population level. But, that argument doesn't necessarily take into account spatial dynamics and the importance of the quality of habitat and their effects on growth rates and reproduction.

Q. What roles might those factors play?

A. Fish are adapted to seek out shelter, and to avoid predation. But what if the configuration of their shelter, specifically the dimensions of an artificial reef vs. a natural reef, changes the proximity of predators like grouper or red snapper to their prey, or their predators? If that's the case, then natural mortality may also be altered because the encounter rate between predator and prey has changed because of the nature of artificial reef development.

Q. How might considering such factors change understanding of the true impacts of an artificial reef?

A. For species that move and have habitat shifts, during years when the number of young fish is large, which we call a strong year class, the inner shelf may not have enough of the naturally occurring habitat structure to support maximum growth. So, we've suggested that adding new, artificial reef structure on that inner shelf may allow for better growth rates and, perhaps, better survival rates of those juveniles. The expectation is that that should ultimately lead to better reproduction. The Steinhatchee project now underway will help test that hypothesis.

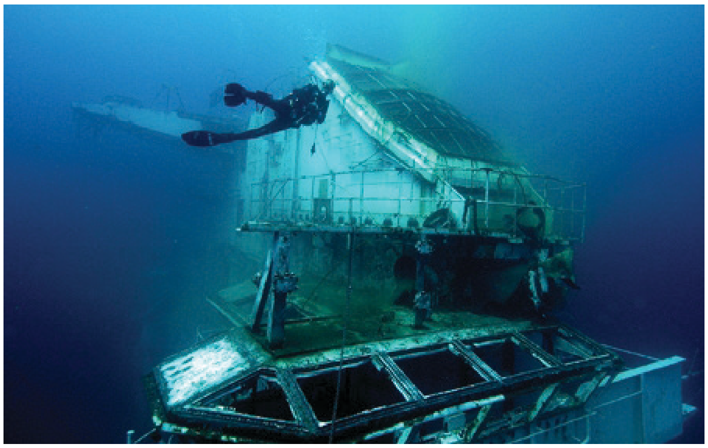

Figure 1. A diver inspects the decommissioned aircraft carrier, the USS Oriskany, shortly after its successful 2006 deployment off Pensacola by the U.S. Navy and the Florida Fish and Wildlife Conservation Commission. Improved fishing opportunities and creative new dive destinations are among the most popular objectives of artificial reef development.
Credit: Keith Mille

Q. What are the conservation implications if this bottleneck hypothesis is correct?

A. If you took a particular amount of material and built relatively few large reefs, you may enhance fishing but you would end up with fewer fish, slower growing fish, and higher fishing mortality. By taking that same investment in reef material and changing the way you deploy it, you can diminish the risk of fishing mortality, hopefully increasing survivorship and enhancing growth rates.

Q. Does that suggest that growth of some of the economically important fish populations is in fact limited by the amount of habitat that's available to them?

A. Remember, there are no simple answers here. The naturally occurring habitat may be able to adequately sustain a strong year class moving across that shelf. And, the natural mortality rates and growth rates of the individuals that constitute that strong year class may be entirely adequate and consistent with what's been historically available to sustain the population. But the question is, what's the potential of that strong year class? And this is where you really get into the issue of whether that strong year class is habitat limited. In the strict sense of how we use the term, that strong year class is not habitat limited. But, what if we were able to tweak the system in such a way that there could be an incremental gain in growth rate, or an incremental decrease in the natural mortality rate? Then, that same strong year class may represent a greater reproductive potential at some later point in time than it would have otherwise. That represents not a limitation in the classic sense, but a bottleneck in the potential reproduction versus the realized reproduction. In simplest terms, providing additional artificial habitat for juveniles may allow the fish to grow larger and healthier, leading ultimately to larger populations.

Q. How well established are the economic benefits of artificial reefs?

A. All the analyses of artificial reefs indicate some economic and societal benefit, though of course the benefits vary and they are not always well quantified. Now, what's often not been discussed is what the opportunity cost is for a reef—the value of the alternative you pass up. If you think of reefs as a public investment in a part of the economic infrastructure of a coastal community, you can look at the cost of the reef construction and the economic activity that's been generated by virtue of having those reefs in place. The other part of the decision making is answering the question of whether making that same investment in some other form of economic infrastructure would have had a greater return on investment. That's a significant public policy consideration.

Q. Since artificial reefs are, for the most part, built using public funds, and since economic benefits are mainly tied to the public being able to use a reef, do you think that the coordinates for reefs should always be made public?

A. We have made the recommendation based on experimental results that if you're building reefs for conservation purposes it would be better not to make their locations known by publishing their coordinates. Prior to that recommendation, the policy had been that the location of any reefs built with public money would be advertised for access by fishermen. That's obviously critical if a goal for a given reef is fishing enhancement. But, if the purpose is fisheries conservation, then publishing the coordinates, which in many cases increases the loss of fish from a reef, may be contrary to a conservation purpose.

Q. What happens if you don't publish the coordinates?

A. We've found that artificial reefs stand some likelihood of being discovered whether their coordinates are published or not. Another consideration is that the configuration of the artificial reefs affects the rate at which they are discovered. That's part of why we recommend for conservation purposes using small, widely scattered reefs that are randomly distributed. That way, if you discover one, it's a needle in a haystack. You won't necessarily find another. This is the basis for the design and the plans for the Steinhatchee Fisheries Management Area, a long-term project now underway and authorized specifically for conservation purposes, though one section will be intended for fishing with published coordinates. It will cover a hundred square miles in the Big Bend region. We've already built reefs to serve as monitoring stations offshore.

A. Studies at those reefs will allow us to evaluate the output of fish from the larger management area closer to shore. Many of the fish of recreational and commercial interest move to different habitat areas as they grow older. We call these habitat changes, which occur as fish transition from one life history stage to the next, ontogenic shifts. For example, gag larvae first settle in shallow nursery habitats like seagrass beds then gradually make their way across the continental shelf, which forms their foraging grounds, to the outer shelf where they spawn. The monitoring reefs I'm describing are located mid-shelf and are occupied by gag transiting toward the spawning grounds.

Q. What are the implications of recognizing that fish are going to be impacted by all these other factors and areas besides the artificial reef?

A. I've gotten to the point of being a proponent of understanding the spatial dynamics as best we can, being as informed as possible about the broader landscape, and then asking what we know about a species we're targeting for enhancement, or conservation, or fishing at several scales. What would make the most sense to achieve some likelihood of enhancement? There's no guarantee it will happen, but that's quite a different approach than saying, 'Well, here's the place that's most convenient to us as people, and here's the material that's most convenient for us to accumulate, and let's put it all here.'

Q. Should the human dimension still be considered?

A. When the primary objective for reef development is to enhance fishing, then yes, proximity, location, user conflicts, as well as reef configuration, are very important and legitimate considerations.

Q. How do you use artificial reefs for your research program?

A. One of the advantages of artificial reefs is they give us the opportunity to do manipulative field experiments. You can modify characteristics of the habitat or the environment by constructing reefs in a controlled and replicated experimental design. So, we've done that in our research with reef fish, in particular gag, so that we can understand patterns and underlying processes, and more definitively answer questions about the roles that habitat plays in the life cycle, the behavior, the ecology, and the demographics of managed fish species.

Q. What are some of the conservation implications of your research?

A. Our scientific advice to management agencies and the State in particular in how they guide reef development focuses on what's likely to enhance the biological performance of any given species, because we've come to realize that one size does not fit all. What works for gag, isn't necessarily going to be the same strategy or reef design that would work for red grouper or red snapper, or amberjack, or Goliath grouper. Take your pick. So it really is important when designing reefs for conservation objectives to consider what we know about a particular population. Another clear implication of our research program and others is that an artificial reef is not a self-contained system. The fact of the matter is that the larger the animal, the more mobile it is, and the more economically valuable it is either recreationally or commercially. Such mobility means you really have to think of a reef as a node in a broader landscape, because a particular reef is only one of many areas where these fish will spend part of their life. And it's that broader landscape that's really affecting the overall ecology and performance of a fish population.

Q. You've compared the complexities of artificial reefs to different groups looking at the colors lined up on a single side of a Rubik's Cube not realizing, or even ignoring, that there are four or five other sides out of alignment. What is the result of that kind of limited perspective?

A. I do think everybody wants the best for the system, they just have different understandings.

What we end up with is a broader community that's viewing the truth from one or perhaps two vantage points, and missing the implications of assumptions or gaps in knowledge. Does it mean that one perspective is entirely true and the other is entirely false? Not necessarily. What it means is that our understanding of the truth is incomplete and inadequate. As we consider the questions associated with artificial reefs along scales of increasing complexity, the simple answers quickly dissolve.

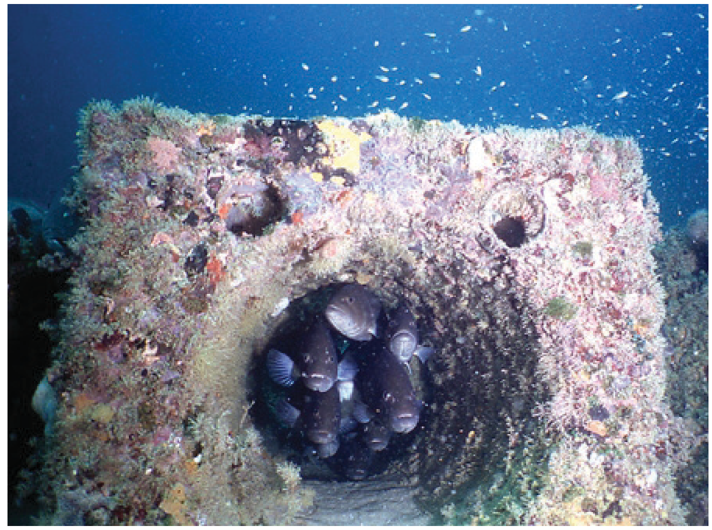

Figure 2. Gag grouper pack into reef cubes when disturbed. (Bill Lindberg photo)