Food web modeling to assess interactions between artificial reefs and natural reefs

Modelo de redes tróficas para evaluar las interacciones entre arrecifes artificiales y naturales

Modélisation du réseau trophique enfin d'évaluer les interactions entre les récifs artificiels et les récifs naturels

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EXTENDED ABSTRACT

Coral reefs cover only one percent of the seafloor; however, they are disproportionally important for the biodiversity and the economics of many coastal communities, including Florida (Coral Reef Alliance, 2020). While these coral reefs are the core of this tropical marine ecosystem, there are many stressors that threaten their health. Marine biodiversity can be impacted directly and indirectly by pollution, destruction of habitats, climate change, and changes in water quality/ chemistry (Worm et al., 2006). Unfortunately, coral reefs have degraded significantly in the past few decades. In a time of coral reef degradation and overfishing, artificial reefs are advertised as beneficial due to fishermen and divers taking advantage of these structures instead of the natural reefs (Leeworthy et al., 2006).

Artificial reefs are deployed worldwide to provide additional habitat for fishes (Rilov & Benayahu, 2000); enhancing diving and fishing (Ambrose & Swarbrick, 1989). These manufactured structures differ in size, material, and vertical relief from each other as well as the natural reef, making them difficult to study and generalize findings one to the next. Previous studies show that artificial reefs attract an abundance of reef associated fish (Arena et al., 2007). Artificial reefs often have higher densities of predators that could affect nearby natural reefs (Paxton et al., 2019), but there are few quantitative studies on how these reefs interact, and is a significant lack of comprehensive information related to regulation, long-term management goals, and environmental assessment (Baine, 2001) including how they impact the underwater communities they are deployed in. We wanted to investigate how artificial reefs may interact with the surrounding community, knowing that these structures do not exist in a bubble.

We looked at an artificial reef in the Florida Keys called Aquarius Reef Base and a number of natural reef sites radiating around it. Aquarius Reef Base (ARB) is a small artificial reef surrounded by Conch Reef, a spur and groove reef formation. ARB is an ideal site for this study. It is located in a Research Only Area and adjacent to a Sanctuary Preservation Area within the Florida Keys National Marine Sanctuary. There is no commercial or recreational fishing allowing in these areas which makes this a perfect baseline study size and allows for future work to include these types of extractive practices.

Fish surveys were performed at ARB using a visual census and at 14 natural reef sites spanning 4 habitat types at varying distances from ARB along the reef track using transects. The change in methods from the natural reefs to the artificial reef was due to the difficulty of deploying transects on the artificial structure. Species, size, and abundance was recorded for each fish observed in the surveys; from this, biomass was calculated using allometric growth curve. This information was separated into functional groups considering size, diet, morphometric information, and feeding behavior. This was input into Ecopath with supporting data from previous research for other inputs. Using this program, we were able to visualize the food webs of the study sites and generalize the population structure (Pauly, 2000).

Ecotrophic efficiency was used to analyze the results. Ecotrophic efficiency (EE) is the amount of energy that moves through the food web into higher trophic levels. An EE of closer to zero shows that more energy leaves the system through emigration, fishing, or natural mortality. An EE closer to one shows that more energy is moving up the food web through consumption. An EE above 1 shows that the predatory fish require more of the prey functional group than is available; this is designated as overexploited.

More fish in total, more pelagic fish, and bigger schools were observed on the artificial reef. Through modeling, we show that there is not enough food on Aquarius, shown by the high EEs in Table 1, and that predatory fish that reside there must forage off of the artificial reef and onto nearby natural reefs where the predator/prey ratio is smaller. Next, we mapped the seascape of the surrounding natural reefs, identifying the major reef types and introduced the artificial reef food web to equivalent areas of biomass from each seascape. None of the habitat types could provide enough food, or enough variety of food, to satisfy the population at the artificial reef. Lastly, we introduced the habitats in the proportions they are available. By looking at ecotrophic efficiencies which can represent overexploitation, we were able to show that the population that shows residency on Aquarius requires over 3 and upwards of 6 square kilometers of the surrounding seascape to access enough quantity and variety of prey (Figure 1). These findings were supported by acoustic tracking of a couple species of predatory fish which showed residency on Aquarius with consistent utilization of the closest natural reef sites.

This is the first study that we know of that uses this methodology to investigate the spatial subsidy of artificial reefs by natural reefs, and the tool allows for easy inclusion of spatial and temporal mapping, and extractive practices such as fisheries. Additional supporting research is also needed. Many of the studies from which the other Ecopath parameters where calculated are older and may not be appropriate in today's ecosystem. Other parameters had to be calculated from

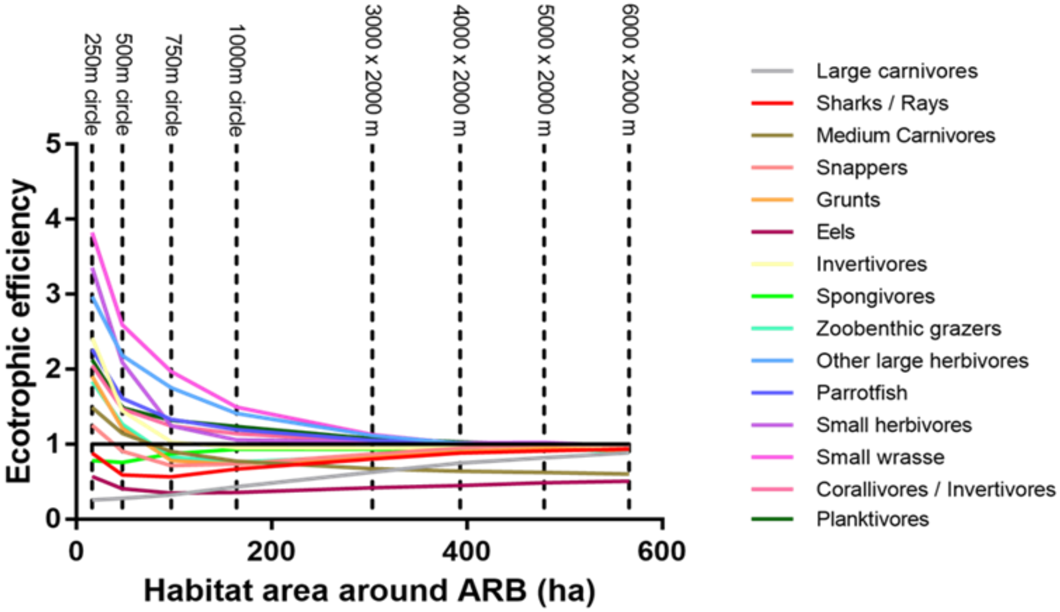

Figure 1. Ecotrophic efficiencies of functional groups with increasing area around ARB**.**

generic databases which did not have species specific information for each species observed in our study. There is significant scope for model improvement by having more detail for Florida-specific diets and consumption rates, and species-specific aspect ratios and productivity. More recent research is also needed for food web inputs such as invertebrates, plankton, and benthic producers which were not directly measured in this study, and current research is not known to the authors.

Future studies on other artificial reefs need to be done; these would include structure variables such as footprint size, vertical relief, and distance from natural reefs. Future studies should also include other variables such as extractive practices like fishing or aquarium collecting. This has important ecological and management implications for future deployments of artificial reefs which should be purpose driven as to balance ecological and economical drivers. It is particularly important in this moment as the Florida Keys National Marine Sanctuary is undergoing a 7-year process to update its Restoration Blueprint which would change zoning and other regulations. With the known decline of live coral cover, the Restoration Blueprint is focusing on ecosystem connectivity and reef restoration. Interactions between artificial natural reefs should be taken into consideration for current artificial reefs, and if the deployment of new artificial reefs within the Sanctuary is to continue.

KEYWORDS: artificial reef, food web, modeling, coral reef, Ecopath

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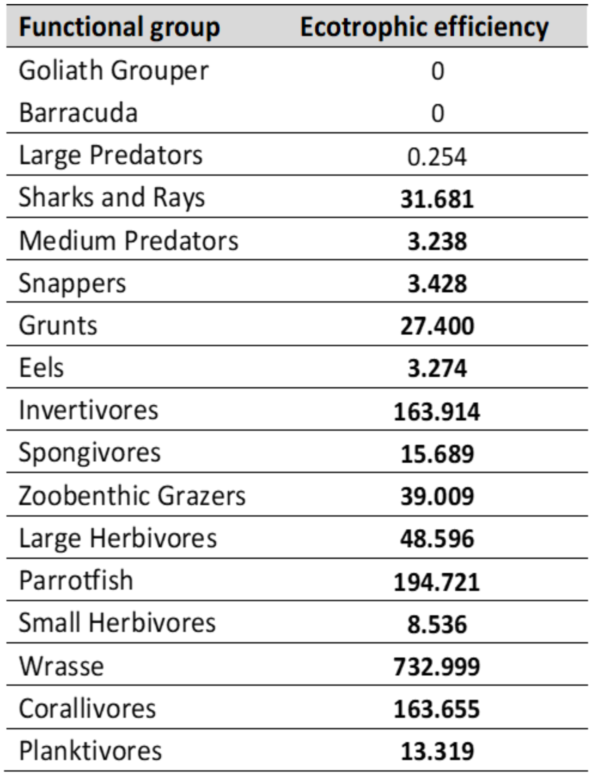
Table 1. The ecotrophic efficiencies of the functional groups observed on Aquarius Reef Base.



Functional group	Ecotrophic efficiency
Goliath Grouper	0
Barracuda	0
Large Predators	0.254
Sharks and Rays	**31.681**
Medium Predators	**3.238**
Snappers	**3.428**
Grunts	**27.400**
Eels	**3.274**
Invertivores	**163.914**
Spongivores	**15.689**
Zoobenthic Grazers	**39.009**
Large Herbivores	**48.596**
Parrotfish	**194.721**
Small Herbivores	**8.536**
Wrasse	**732.999**
Corallivores	**163.655**
Planktivores	**13.319**