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Convergence of fish community structure between a newly deployed and an established artificial reef along a five-month trajectory

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A B S T R A C T

Numbers of human-made reefs in the world's oceans are increasing, yet questions remain about patterns and speed of fish colonization of these artificial reefs. Here, we tested 1) whether the fish community on a newly deployed artificial reef converged with the fish community on an adjacent, established artificial reef over time and 2) whether fish colonization of the new artificial reef occurred sequentially. To answer these questions, we simultaneously collected time-lapse videos of fishes colonizing a new (2 wks old) artificial reef and those inhabiting a nearby (438 m away) established (> 20 yrs old) artificial reef. We found that fish community composition on the new artificial reef converged with the fish community composition on the established artificial reef over five months. Community development on the new reef followed a trajectory: schooling, planktivorous fishes initially colonized the reef in high numbers, whereas demersal fishes exhibited delayed colonization. These findings suggest that fishes may colonize human-made reefs along a specific trajectory of pelagic fishes followed by demersal fishes and that community convergence between reefs can occur over relatively short temporal scales given similar environmental conditions. When deploying additional structures, including human-engineered habitats, in the marine environment, our findings on fish colonization of artificial reefs are important to consider because they provide new insight into how artificial structures can be utilized to enhance particular fishes over different temporal scales.

1. Introduction

Numbers of artificial structures in coastal oceans are increasing. An estimated three million or more shipwrecks rest on the seafloor worldwide (UNESCO, 2017) along with 7500 oil platforms that extend throughout the water column (Macreadie et al., 2011; Parente et al., 2006). Humans deploy additional artificial structures for a variety of purposes, including to protect shorelines, harness energy resources, create and restore habitat, and foster tourism (Baine, 2001; Bulleri and Chapman, 2010; Dugan et al., 2012). For example, artificial reefs, ranging from concrete materials to decommissioned vessels, continue to be deployed to enhance fish habitat and provide fishing and diving sites (NOAA, 2007; Seaman, 2000; UNEP, 2009). Installation of artificial structures can drive ecological changes in communities (Bulleri and Chapman, 2010), warranting an understanding of how species utilize human-made structures and what processes regulate the associated community structure.

In general, ecological communities exposed to similar environmental conditions often develop similar community structures over time (Samuels and Drake, 1997). Yet, whether communities exposed to similar environmental conditions but occupying individual human-constructed habitats converge with or diverge from each other over time is debated. Some human-engineered habitats, such as reservoirs, can become more similar to each other over time (Gido et al., 2009), likely due to similarities in local scale habitat characteristics and species interactions among the unnatural habitats. Others, including artificial reefs, can diverge from each other given high frequency of physical disturbance (Cummings, 1994) and/or differing physical features (Thanner et al., 2006). Despite growing numbers of unnatural habitats, there remain unanswered questions about how colonization proceeds

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on these novel structures.

Submerged human-made structures intentionally deployed in the marine environment as artificial reefs present an opportunity to test how colonization proceeds on unnatural habitats. These marine artificial reefs are often part of government-managed artificial reef programs where structures, ranging from ships and concrete pipes to boxcars and bridges, are purposely deployed on the ocean floor to enhance fisheries and provide fishing and diving opportunities (NOAA, 2007). Marine artificial reefs often lie in close proximity (m's to km's) to one another, forming dense arrays of hard-bottom habitat. Networks of marine artificial reefs, with varied proximity to one another and different dates of deployment, allow empirical tests of how habitat provision afforded by artificial reefs changes over time.

Artificial reefs provide habitat for a diversity of species, including macroalgae, benthic invertebrates, and fishes. Macroalgae and benthic invertebrates often exhibit distinct colonization sequences on artificial reefs (Fitzhardinge and Bailey-Brock, 1989; Perkol-Finkel and Benayahu, 2005; Thanner et al., 2006). For example, fouling organisms, including bryozoans and hydrozoans, colonize hard surfaces of artificial reefs first, often followed by more persistent invertebrates, such as octocorals (Carter and Prekel, 2008). Whether mobile species, such as fishes, colonize artificial habitats in sequential patterns is not well understood. Most studies examine whether fish communities on artificial reefs converge with fish communities on natural reefs that they are intended to mimic (Becker et al., 2017; Koeck et al., 2014). Few examine whether adjacent artificial reefs support similar fish communities to each other and how fish community development progresses with time since reef deployment. Those studies that examined fish community change on artificial structures discovered that communities diverged because of differing environmental conditions (Oricchio et al., 2016), and likely because of physical differences in reef structures (Thanner et al., 2006). Fish colonization on new structures occurs rapidly, often within hours of deployment (Clark and Edwards, 1999; Cummings, 1994), but the colonization sequence varies. In some systems, pelagic species colonize first (Dance et al., 2011; Golani and Diamant, 1999), whereas in others demersal fishes or a combination of demersal and pelagic species initially dominate reefs (Alevizon and Gorham, 1989; Dance et al., 2011).

The objective of this study was to document colonization of fish communities on a newly deployed artificial reef at several time intervals since reef creation. We explicitly tested hypotheses that: 1) the fish community on a newly deployed artificial reef (2 wks old) will converge with the community on an established (> 20 yrs old) artificial reef, and 2) fishes that rely on the physical structure of artificial reefs will initially colonize the new reef, whereas fishes that rely on benthic biota associated with the artificial reef structure will exhibit delayed colonization. This research is important for understanding dynamics of how human-made structures may function to enhance fisheries over time and provide added ecosystem services.

2. Materials and methods

We selected two artificial reefs of similar structure: 1) a newly deployed artificial reef and 2) an established artificial reef (Fig. 1a). The new artificial reef, a 33-m long U.S. Army tugboat renamed the *James J. Francesconi*, was scuttled on 7 May 2016 (34.5634 N × 76.8552 W). The established artificial reef, a 100-m long landing craft repair vessel USS *Indra,* was deployed in 1992 (34.5623 N × 76.8515 W). Given its deployment over two decades ago, the USS *Indra* was assumed to have reached an established biological community (climax community within context of ocean reef succession). Both vessels are made of steel and located within a state-designated artificial reef site (AR-330) within Onslow Bay, North Carolina (NC). These two intentionally sunk vessels lie 438 m from each other on a sandy seafloor at a depth of 20 m, so both are exposed to similar environmental conditions. We documented fish communities on the new and established artificial reefs during three sampling periods over five months in 2016. The three sampling periods were: 1) May 17 – 26 (10 days); 2) July 21 – August 5 (16 days); 3) September 13 – 19 (7 days). As the new artificial reef was deployed on 7 May 2016, these sampling periods occurred one, three, and five months, after the sinking of the *James J. Francesconi* as a new artificial reef.

During each of the three sampling periods, we used time-lapse videography to simultaneously document fish communities on the new and established artificial reefs (Videos S1–S4). On each reef, divers deployed a GoPro Hero 3+ Black video camera (GoPro, USA) housed inside of a cylindrical aluminum housing (Sexton Co., USA), which included an acrylic dome port with lens optically centered, an internal battery and programmable intervalometer, and an external light (Fig. 1b). We programmed the intervalometer to interface with the video camera and light to collect videos on a set schedule during both the day and night. Video cameras recorded 20-s long videos every 20 min. The external white LED light remained off for the first 10 s of every video and then turned on during the final 10 s. Each video-camera unit was mounted on a secured, conical metal frame (0.5 m high with 0.3 m diameter base). Each frame was positioned by scientific divers on the horizontally-oriented deck of the artificial reefs with the lens of each video camera facing areas of superstructure. These units were deployed in identical locations during all three sampling periods. At the end of each sampling period, divers retrieved the video cameras and offloaded videos.

Each video was processed by an analyst who identified and counted the maximum number (maxN) of fishes in a given frame to the lowest taxonomic level possible. For each reef during each of the three sampling periods, 150 videos were randomly selected and processed. We chose to process 150 videos per reef and sampling period based on species accumulation curves. Only the last 10 s of each video were processed because this was the period during both day and night videos when the LED light was on. The area illuminated in night videos was much smaller than the visible area from the daytime videos. Because of differences in field of view between night and day videos, we chose not to analyze results from night videos. Rather, we analyzed videos from only the daytime hours of 0700 to 1900 local time, resulting in 453 total videos.

To determine whether the trajectory of fish community development on the new artificial reef converged with the fish community on the established artificial reef and whether a pattern of fish colonization occurred, we analyzed data from processed videos using R version 3.2.0 (R Development Core Team, 2015). Because we utilized a repeated observation design where we sampled the same reefs during three time periods, we employed linear mixed effects models fit with a random intercept and random slope to determine whether community metrics (abundance, species richness, Pielou's evenness) differed among the repeated observations (sampling periods) on each of the two reefs using the 'nlme' package (Pinheiro et al., 2013). The random intercept allowed for the possibility that the two different reefs initially supported different numbers of fishes, whereas the random slope component allowed for the possibility that the two reefs had a different temporal response over which changes in community metrics could occur. We found that there was no effect of the repeated observations design (e.g., multiple videos from each sampling period; factor sampling period $P > 0.05$) on community metrics with this random slope and random intercept model. Since the repeated observations component (factor sampling period) was not significant, we were able to proceed to a two-way analysis of variance (ANOVA) that tested for differences in mean community metrics (abundance, species richness, Pielou's evenness) between reefs, between sampling periods, and the interaction of these two factors and did not explicitly incorporate effects of repeated observations. We followed the two-way ANOVAs with post-hoc Tukey HSD tests. The assumption of normality was violated; however, the *P*-values indicated that observed differences in mean community metrics were significant. Given the very low *P*-values, the amount of error