Bonefish nursery habitats: Marine spatial planning for the next generation

Hábitats de cría de macabí: Planificación espacial marina para la próxima generación

Habitats de nurserie de bonefish: planification de l'espace marin pour la prochaine generation

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EXTENDED ABSTRACT

Bonefish, *Albula vulpes*, are an ecologically, culturally, and economically important sportfish found throughout the flats habitats of The Bahamas. The economic importance of bonefish to The Bahamas—$169 million (USD) estimated annual economic impact (Smith et al. 2023)—and their *near threatened* conservation status (Adams et al. 2014) have made the species a focal point for conservation efforts. Bonefish use of coastal flats and mangrove-lined tidal creeks for foraging and movement corridors, and nearshore inner-reef habitats for pre-spawning aggregations, positions most of bonefish life history in sensitive locations that are vulnerable to anthropogenic impacts, such as coastal development and dredging of channels and marinas. The need to protect essential spawning and foraging habitats has aided in the establishment of five national parks, and expansion of one, on Abaco and Grand Bahama Island. Previous tagging studies have also been referenced to evaluate the effectiveness of current park boundaries, confirming the sufficiency of these boundaries for adults (Adams et al. 2021). However, nursery habitats have yet to be taken into consideration in this process. Bonefish nursery habitats are predominately low energy, unstructured, inter-tidal sand and mud-bottom shorelines (Haak et al. 2019). Here, we distill the work of Lombardo et al. (2022) to provide a framework for evaluating a marine protected area network's capacity for protecting settled larvae from a known spawning area using biophysical larval dispersal models of observed spawning events.

Spawning observations of bonefish were made in Abaco, The Bahamas, in 2013, 2018, and 2019 using active acoustic telemetry. Fish were surgically implanted with continuous acoustic telemetry tags with pressure sensors (V9P-2H, 9 mm diameter, 21 mm in length, 1.6 g in air, 2000 ms transmission period; V9TP, 9 mm diameter, 31 mm long, 4.9 h in air, period 1000 ms; Innovasea Systems Inc., Massachusetts), allowing for offshore movements to be tracked using a boat-mounted directional hydrophone. Horizontal and vertical movements and time were logged as the fish moved offshore to spawn, and spawning behavior was identified by rapid vertical ascent (Lombardo et al. 2019). The four-dimensional data were the foundation for creating biophysical larval dispersal models in the software program Ichthyop. The US Navy NCOM AmSeas hydrodynamic model was converted to a ROMS-style grid using MATLAB, and input into the Ichthyop program for the time periods matching the observed spawning events. Additional biological parameters were set to account for larval growth and migration to the surface upon settlement competency between 41 d and 71 d post-spawn. Settlement zones, locations where larvae could settle upon competency, were programmed along the shorelines of all islands within the Bahamian Archipelago. Each simulation was run 100 times, using 10000 particles. Kernel density estimates were made for each of the spawning years, highlighting clusters of settled larvae, and allowing for the evaluation of core settlement zones vs established park boundaries.

The current boundaries of the marine protected area network within the Bahamas, comprised of 77 protected areas, provides substantial protection of vulnerable nearshore habitats. Many of the simulated larvae that successfully settled did so within park boundaries. Others settled in locations that did not contain suitable nursery habitat and thus were not considered in evaluating the park boundaries. Core kernel densities and peripheral locations with high larval densities could be found distant and adjacent to already established parks. Centered around protecting bonefish nurseries, we put forth the suggestion of three new parks and three park expansions. New parks include (Figure 1): (1) Moore's Island (Abaco), (2) East Central Berry Islands, and (3) North Eleuthera. Park expansions are suggested for: (4) Marls of Abaco National Park to Cross Harbor National Park, (5) Northshore/The Gap National Park to the West End MPA (Grand Bahama), and (6) Joulter Cays National Park (Andros).

The workflow executed in this effort can be applied to other regions throughout the Caribbean with relative ease. The NCOM Amseas hydrodynamic model encompasses the entire Caribbean, allowing for broad and repeatable application, though computer programming ability is likely to be the largest barrier to adoption. The first step of observing spawning events can be accomplished using acoustic telemetry, biologging, or diver surveys. The second step is understanding the

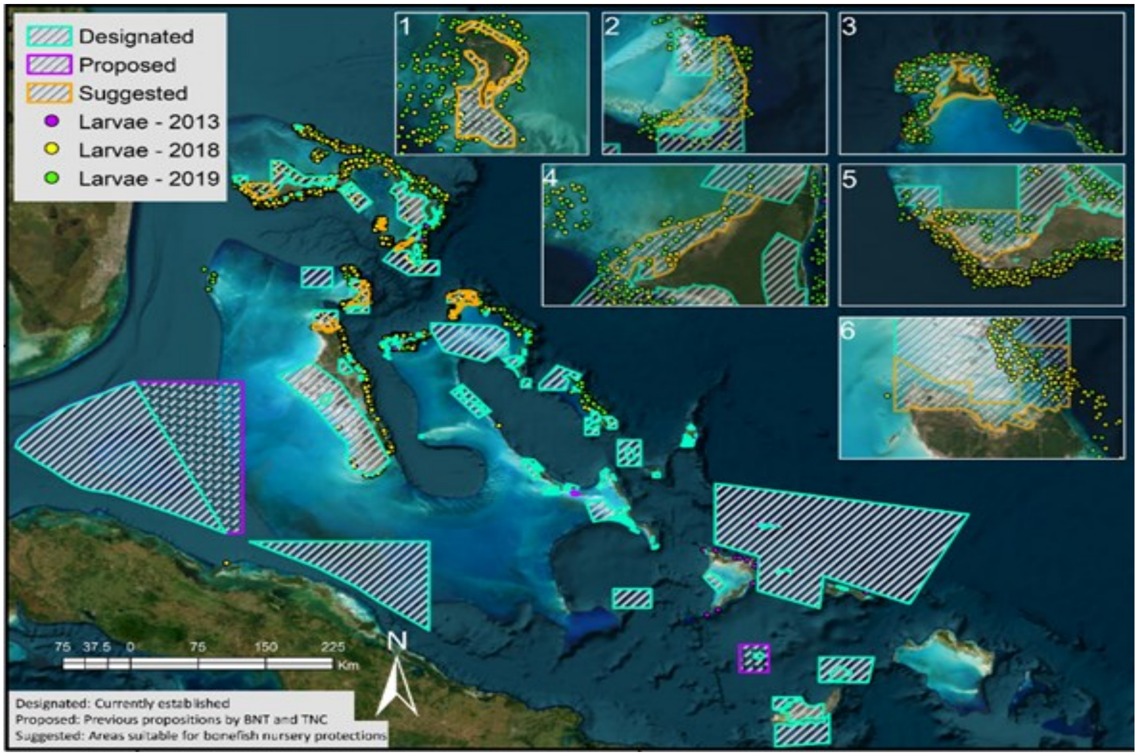

Figure 1. Figure modified from Lombardo et al. (2022). Successfully settled simulation larvae from the observed spawning events are denoted in points: purple (2013), yellow (2018), and green (2019). Current designated marine protected area park boundaries are denoted in teal boarders with solid thatching, current propositions for park boundaries by Bahamas National Trust and The Nature Conservancy are denoted in violet boarders with dashed thatching. Core larval settlement zones as identified by kernel density estimates have led to this study suggesting three new parks and thew park expansions denoted in orange boarders with dashed and dotted thatching.

early life history of the focal species, in particular the pelagic larval duration, time of settlement competency, and development rates and behaviors. Identifying the distribution of potential nursery habitats also helps to refine the biophysical larval dispersal model process. Third, one must access and modify the NCOM AmSeas model and translate the data into a ROMS-style grid. Alternate hydrodynamic models can be used, however, NCOM AmSeas has the highest resolution of the maintained oceanic models (1/36° or 1/30° at 3-hour time steps) and is less complicated than initializing a ROMS model. Finally, the results of the biophysical larval dispersal model can be interpreted in relation to the boundaries of parks within existing marine protected area networks, using kernel density estimates in R and/or GIS.

KEYWORDS: Marine Spatial Planning, Bonefish, Nursery Habitat, Habitat Management

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