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Project Title: **Mesophotic Coral Ecosystems: Refugia for Lionfish?**
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Project Abstract from Proposal:

Invasive lionfish have caused significant changes to Atlantic coral reef structure and function due to their novel predatory impacts on ecologically important fishes. However, management solutions to control these invasive predators have been constrained by a generally limited understanding of their ecology in their new environment. For example, although recent data suggest that culling operations on some shallow Caribbean coral reefs have reduced lionfish populations, these studies have not addressed the numbers of lionfish in contiguous mesophotic coral reef habitats (~ 30-150m depth), nor have they examined the degree to which these populations migrate between mesophotic and shallow depths to feed. ***We hypothesize that lionfish are using mesophotic reefs as refugia from fishing pressure on shallow coral reefs, and undertaking diel migrations to feed on shallow reefs.*** The goals of this project are to: 1) document the size of lionfish populations in the mesophotic reefs of the USVI and Guam, and to determine whether lionfish migrate from mesophotic to shallow reefs to feed, 2) assess USVI mesophotic reef structure relative to lionfish habitat and resources (*i.e*., food), and 3) enhance awareness of the importance of invasive lionfish to the entire coral reef community through public education and outreach. Our team, which includes academic partners from multiple institutions as well as resource managers, will utilize technical diving and long-term monitoring data to address these issues for the first time. These studies will advance our understanding of the biology and ecology of lionfish over a greater depth range than prior studies, with important implications for coral reef management. This project will be based in the USVI where these issues are particularly timely and critical, as outlined in the NOAA National Marine Sanctuaries Lionfish Response Plan, as well as in Guam, within the native range of this invasive species. Lessons learned will have broad applicability to the US Coral Reef Conservation Program Goals and Objectives for US coral reefs, as well as for international coral reef management plans within the invaded range of the western Atlantic basin, including the Caribbean Sea and the Gulf of Mexico.

Actions Completed During This Research Project:

This project was transferred from the Flower Garden Banks National Marine Sanctuary due to scheduling conflicts with the NOAA R/V Manta, which was requisite for travel to/from the FGBNMS, following Hurricane Harvey (17 August 2017); thus our first field season occurred on St. Croix, USVI (29 July to 12 August 2018). Twelve lionfish were acoustically tagged, and migration patterns were documented throughout Fall 2018 and Spring 2019. We returned to the USVI (June 2019) to assess the lionfish ~1 yr later. We also surveyed lionfish populations in Guam (February 2020) to compare patterns of lionfish distribution and behavior in their invaded (USVI) and native ranges (Guam). Progress to date on the four objectives described in the proposal is described below.

Objective 1: ***Document the size of lionfish populations in the mesophotic reefs of USVI and determine whether lionfish migrate from mesophotic to shallow reefs to feed.***

We surgically implanted acoustic tags in 12 lionfish at mesophotic depths near the Buck Island Reef National Monument (BIRNM). To minimize adverse effects of transporting lionfish to the surface, surgeries were performed *in situ* in August 2018. BIRNM was chosen because it already hosted an extensive acoustic receiver array (~100 receivers) in the nearby shallow patch reefs (~20-60 ft), that provide a mechanism to "observe" tagged lionfish movement from deep to shallow reefs. We also positioned nine new receivers across ~1 km of mesophotic reef in the area where our 12 lionfish were tagged, to observe lionfish movement patterns. Data from all receivers were downloaded in November 2018 to document habitat use by these lionfish through time. These lionfish data were analyzed in January-February 2019 and demonstrated a high degree of site-attachment relative to the lionfish release sites. Specifically, movement of the 12 tagged lionfish averaged between ~10,000 and ~40,000 m^2 over a 3 month period, and they did not leave the vicinity of a bank of receivers covering about 1 km of mesophotic reef (Figure 1). Contemporaneous visual observations of an additional 47 floy-tagged lionfish throughout the BIRNM indicate these individuals move very little during the colder months of the year (as previously described by Kimball *et al*. [2004] Mar. Ecol. Prog. Ser. 283:269). We were also able to download data from the acoustic receivers in Spring/Summer 2019. An unexpected result from this subsequent receiver data was that the lionfish exhibited active and distant migration strategies (~100-1000m ranges per day) in Spring/Summer relative to the Fall/Winter period, when the lionfish exhibited site fidelity (~1-10m ranges per day). While we were not able to track lionfish acoustically in the Indo-Pacific (*i.e.*, Guam), visual censuses of individual lionfish indicated that they exhibited significant site fidelity. These data suggest that location-specific biotic and/or abiotic differences between the native and invasive ranges impacts the migratory behavior of lionfish.

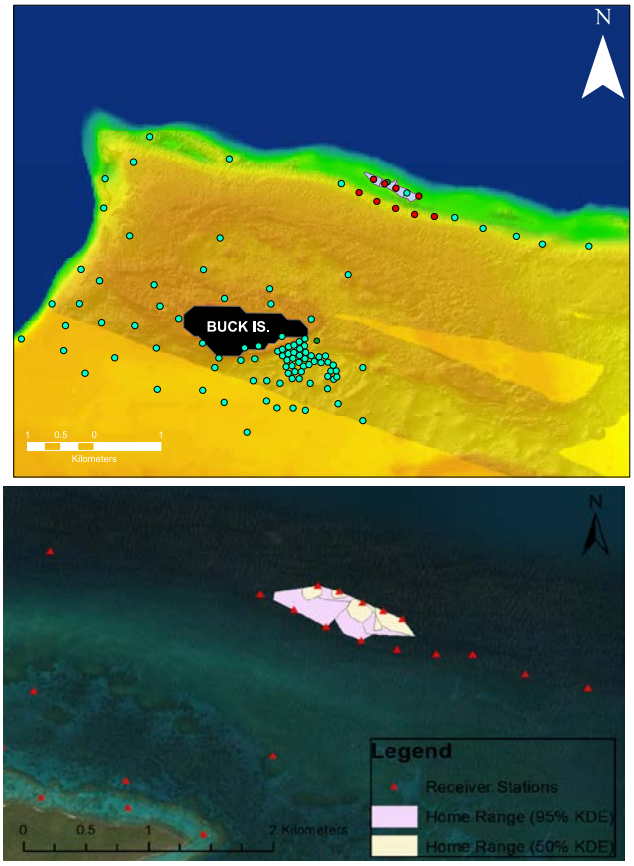

Figure 1: Buck Island Reef National Monument acoustic receiver array (upper picture). Red triangles indicate new receivers positioned during this project and location of mesophotic lionfish tagging. Pink and yellow areas (lower picture) represent the 95% and 50% KDE lionfish home ranges, respectively, demonstrating site-fidelity in August-November 2018.

Objective 2: ***Assess ontogenetic changes in habitat and resource utilization by lionfish.***

The average size of the tagged lionfish in St. Croix was 26.8 ± 0.9 cm (mean ± 1SE), but they ranged in size from 22 – 34 cm (see Fig 2). Data downloaded from the acoustic receivers also addressed the issue of habitat fidelity of different size fish. Tagged fish fell into two size classes (22 – 26.5 cm [n=6 fish], and 27 – 34 cm [n=6 fish]) representing cohorts of approximately one and two years of age. We asked whether smaller fish stay at mesophotic depths while larger fish migrate between mesophotic and shallow reefs. While our receiver data indicate that larger lionfish do not migrate to shallow reefs between August and November, they do provide some important insights on ontogenetic differences in lionfish movement patterns. Specifically, the larger lionfish exhibited significantly greater home range sizes than the smaller lionfish (~79,000 m^2 *vs.* ~6,000 m^2). During the Spring/Summer period, the ontogenetic changes tended to breakdown with both size classes exhibiting significant migrations (*i.e.*, ~100-1000 m per day), often from the deep reefs into shallow, prey-rich habitat. One notable difference: 83% of lionfish observed in Guam occurred in low-light habitats (*e.g.*, within crevices, under overhangs, or out during crepuscular hours), compared to only 28% of St. Croix lionfish (*i.e.*, most were out on the open reef during daylight). These results further support our contention that location-specific biotic &/or abiotic differences between the native and invasive ranges impacts the behavior of lionfish, in particular relative to their phototropic responses.

Figure 2: Divers surgically implanting acoustic tags into the body cavity of a 28mm lionfish (Summer 2018).

Objective 3: ***Assess changes to the USVI mesophotic reef structure and function relative to the lionfish invasion.***

Lionfish have been documented in St Croix since the earliest years of the Caribbean invasion (*i.e.*, 2012). Assuming the migration to deeper reefs occurred about two years later (as the PI documented in the Bahamas: Lesser & Slattery [2011] Biol Invasions 13:1855), the St. Croix mesophotic reefs have likely had lionfish present for a decade. That said, the BIRNM mesophotic reef was surprisingly healthy in August 2018 (Fig 3). Coral cover at mesophotic depths averaged 28.3 ± 4.1%, while sponge and algal cover averaged 14.2 ± 3.3% and 7.6 ± 2.6%, respectively. Since the Virgin Islands Territorial Coral Reef Monitoring Program (VI TCRMP) monitors a shallow (15 m) site at Buck Island, we used their data for comparison, and the mesophotic reef at Buck Island was in much better condition than the shallow site (Ennis & Smith, unpubl. data). The mesophotic fish community included at least 37 species, representing several important trophic links (*i.e.*, planktivores, herbivores, spongivores, corallivores, and meso-piscivores). An analysis of the USVI reefs in June 2019 indicated that lionfish have not caused significant changes to the

Figure 3: Excellent sponge and coral cover on BIRNM mesophotic reef.

aforementioned benthic community cover, or the trophic clades. Indo-Pacific reefs are notable for their greater coral cover relative to their Caribbean counterparts. However, Guam reefs are heavily impacted from natural and anthropogenic factors (Slattery & Gochfeld 2016 Mar. Biol. 163:246) similar to those affecting Caribbean reefs. Surveys of topographically similar reefs at mesophotic depths in Guam exhibited comparable benthic cover to those in St. Croix: coral cover averaged 21.2 $\pm$ 5.4%, while algae and soft corals (the functional "equivalent" of sponges within the Caribbean) averaged 30.2 $\pm$ 7.3% and 10.1 $\pm$ 4.8%, respectively. The fish communities (100+ species, representative of all aforementioned trophic links), including many individuals of lionfish gape-appropriate sizes, appeared to be diverse and healthy. While our time-point observations limit interpretations relative to lionfish as the cause of Guam reef declines (*e.g.*, Burdick *et al*. [2008] Status of the Coral Reef Ecosystems of Guam, Guam Coastal Management Program, 76pp), their relative scarcity, smaller sizes, and more cryptic nature leave the impression that lionfish do not fill the "foundation species" role in the Indo-Pacific that they do in the Caribbean.

Objective 4: ***Enhance awareness of the importance of invasive lionfish to the entire coral reef community through public education and outreach.***

We worked closely with the National Park Service that oversees the BIRNM for permitting and to keep them apprised of our research goals and early results, and we provided them with a report relative to our research progress. Likewise, we have communicated with scientists in Guam's Department of Agriculture (that provides permits for the reefs we assessed) and the National Park Service (War in the Pacific National Historic Park) to apprise them of our results. We also discussed our research findings with representatives from the recreational dive industry in St. Croix, where lionfish represent a major topic of interest to them and their clients. Following our first research mission, we uploaded a social media post to the American Academy of Underwater Sciences for distribution to thousands of followers: https://www.facebook.com/AmericanAcademyofUnderwaterSciences/posts/2101831236518251. Further discussions, of the completed project, with scientists and stakeholders have been hampered by COVID.

Significance and Outcomes:

Results from this study indicate that lionfish, in St. Croix, utilize mesophotic reefs exclusively during the Fall/Winter. However, these same individuals undergo much more extensive vertical migrations to shallow reefs, during the Spring/Summer. Lionfish apparently utilize shallow reef prey resources during these migrations, although after 10 years of residence on USVI reefs, their numbers, and consequently impact, on prey resources has diminished (see for example of ecosystem cascades: Lesser & Slattery [2011] Biol Invasions 13:1855). When compared to Indo-Pacific reefs, it seems likely that Caribbean reefs are reaching an equilibrium with the invasive lionfish.

Presentations. To date, portions of the St. Croix datasets were used in the following presentations (asterisks indicate students).

- M Slattery, MP Lesser, *JH Laverick, *KJ Macartney, TC Bridge, E Kintzing (2019) Worldwide patterns on mesophotic coral reefs indicate a community break at 60m. 48th Annual Benthic Ecology Meeting, St. Johns, Newfoundland, Canada

- *J Laverick, S Piango, *DA Andradi-Brown, DA Exton, P Bongaerts, TC Bridge, MP Lesser, RL Pyle, M Slattery, D Wagner, AD Rogers (2018) To what extent do mesophotic coral ecosystems and shallow reefs share species of conservation interest? A meta-analysis. Gordon Research Conference on Mesophotic Coral Ecosystems, Lewiston, Maine

Human Resources. Eleven marine scientists from multiple universities (University of Mississippi, University of the Virgin Islands (St. Croix and St. Thomas campuses), University of New Hampshire) contributed to this project, including: 5 graduate students (3 women), 2 post-docs (both women, one hispanic), and 4 faculty members (2 women, including the coPI). One of the graduate students (Elizabeth Smith, University of the Virgin Islands) is completing a master's thesis on the movement patterns of lionfish within Buck Island Reef National Monument, and a publication that will include some of these data is anticipated. One post-doc (Dr. Andia Chaves-Fonnegra) has received a faculty position at Florida Atlantic University/Harbor Branch Oceanographic Institution, and she remains committed to Caribbean coral reef conservation issues.