# Preliminary Visualization of Broad-scale Movement Patterns of Great Barracuda (*Syphraena barracuda*) Around Two Caribbean Islands

# Visualizando Patrones de Movimientos de Larga Escala de la Gran Barracuda (*Syphraena barracuda*) Alrededor de Dos Islas del Caribe.

# Les Modèles de Déplacement de Grand Barracuda (*Syphraena barracuda*) à Deux Îles des Caraïbes

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## ABSTRACT

Great barracuda are top predators of tropical marine systems found in a wide range of habitats. Given their wide distribution and abundance, *S. barracuda* likely play an important ecological role in nearshore ecosystems, yet very few studies exist that quantify their spatial ecology. Tracking of movement patterns via passive acoustic telemetry is being conducted in two locations in the Caribbean with varying habitat types and management status: Culebra, Puerto Rico and Buck Island Reef National Monument in St. Croix, U.S. Virgin Islands. To date, 12 (mean length = 105.5 cm, SD = 25 cm) and 36 (mean length = 91.7 cm, SD = 16.5cm) fish are tagged in Culebra and St. Croix, respectively So far, 392,150 reliable detections spanning 24 months in Culebra and 926,676 detections for 12 months in St. Croix have been processed. Preliminary analyses using graph theory show large differences in movement patterns among individual fish. Catch-Per-Unit-Effort analyses show significant differences in population density between sites. Future analyses will examine movement patterns in relation to habitat types, prey species assemblages, fish size, population density, and ambient environmental conditions such as temperature, tide, and season.

KEY WORDS: Marine Spatial Planning (MSP), ecosystem-based management, Pedro Bank, Jamaica, Small Island Developing States (SIDS)

## INTRODUCTION

In recent decades fisheries management has shifted from stock management towards ecosystem-based approaches (Pikitch et al. 2004), with increasing emphasis on spatial frameworks such as the creation of marine protected areas (Pauly et al. 2002, Airame et al. 2003). This shift necessitates better understanding of habitat use by fish species. Quantitative assessments are needed to replace assumptions that decreasing fishing pressure in designated zones will automatically result in healthier ecosystems (Heupel et al. 2006, Farmer et al. 2011). Successfully implementing ecosystem-based management requires a nuanced understanding not just of the target area or habitat type, but also of the interrelationships between adjacent habitats and regional networks of ecosystems and meta-populations. Studies on habitat connectivity through fish populations has frequently focused on larval or juvenile stages, but fisheries management must include all phases of life history in order to provide an accurate assessment of habitat and population connectivity (Frisk et al. 2013). The inclusion of adult fish in ecosystem-based management is intuitive but requires a greater understanding of underlying trophic interrelationships (Nyunja et al. 2009, Kimirei et al. 2011), adult population dynamics (Frisk et al. 2013), and patterns of habitat use and movement.

Tracking of movements through acoustic telemetry is valuable in quantifying habitat use within and between habitat types for adult fish, allowing for long term data sets on residency and migration patterns (Heupel et al. 2006). Large predatory fish provide an interesting platform through which to assess movement patterns. Large animals are more likely to have larger home ranges, potentially encompassing multiple habitat types or management areas (Meyer et al. 2007a). Many studies verify movements of large predators across habitat boundaries (Humston et al. 2005, Meyer et al. 2007a, Meyer et al. 2007b, Clark et al. 2009, Murchie et al. 2013). Due to their size and predation rates these populations could exert strong top down influences on a broad range of fish communities (Meyer et al. 2007a). Assessing movement patterns can show spatial and temporal variation in ecological roles, and can illuminate patterns of connectivity between habitat types and management areas. Understanding how ecologically important populations associate with benthic habitat patterns and prey assemblages can improve management efforts by strengthening managers ability to make ecological inferences based on easily surveyed variables. Similarly, assessing how these patterns are dependent on population density may begin to show how different factors influencing top predator populations could impact entire communities.

For this study, we examined movement patterns of great barracuda (*Syphraena barracuda*). Barracuda are highly abundant throughout most of the subtropical and tropical world (De Sylva 1963). Despite their potentially large ecological role throughout multiple habitat types, few studies have focused on this species. Adult barracuda exist very high on the trophic pyramids of coastal ecosystems and as large predators that eat indiscriminately, they may exert a significant influence on fish community structure (Blaber 1982, Kadison et al. 2010). They are known to utilize a variety of nearshore habitat types throughout their life histories, moving from inshore estuaries to reefs and open water as they mature, and are believed to spawn in offshore aggregations throughout the summer months (De Sylva 1963, Blaber 1982, Kadison et al. 2010). Adults utilize all nearshore habitats, but the specifics of habitat use remain relatively unknown (De Sylva 1963, Blaber 1982, Kadison et al. 2010). The only study to date on movement ecology for adult great barracuda shows high variability in habitat choice, residency, and site fidelity, thus highlighting the need for further research examining adult

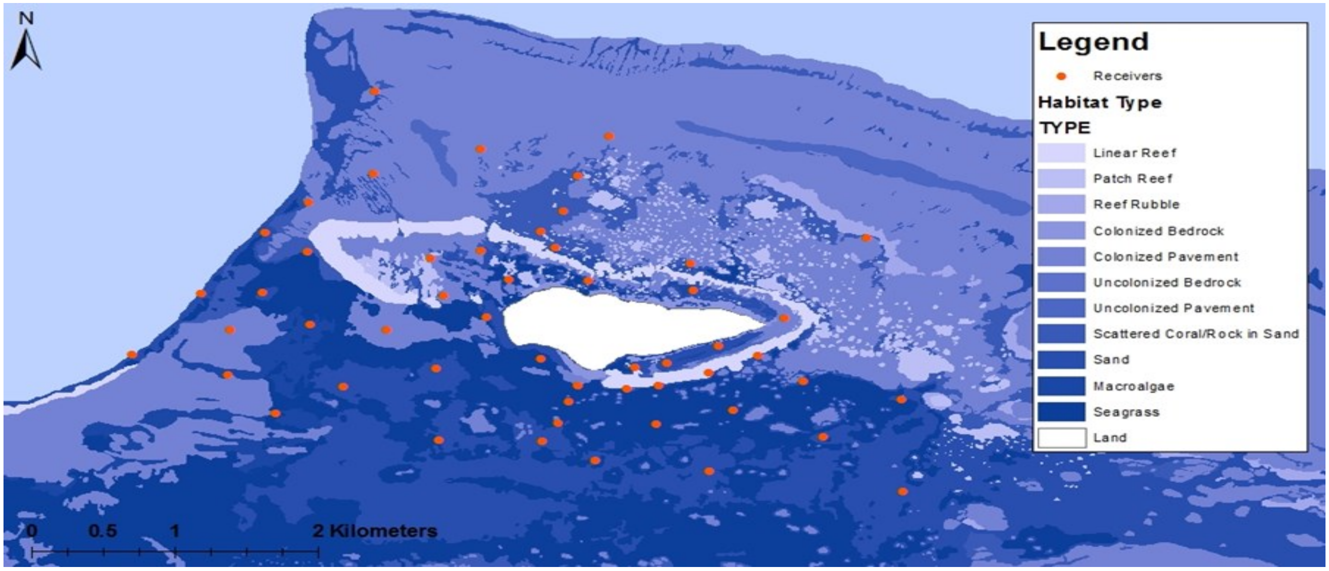


**Figure 1.** Geographic location of Jamaica and the Pedro Bank and detail of the Pedro Bank (600 m isobath) MSP area.

habitat use (O'Toole 2011).

## STUDY AREA

This study was conducted in two sites in US Caribbean territories: Buck Island Reef National Monument, St. Croix, U.S. Virgin Islands, and Culebra, Puerto Rico. Both sites contain arrays of acoustic receivers that have been used for studies focusing on turtles and sharks in St. Croix and permit, turtles, and bonefish in Culebra.

Buck Island Reef National Monument (BIRNM) is a marine protected area managed by the National Park Service. BIRMN is located on the northeastern shelf of St. Croix. In 2001, management shifted from multi-use to no-take and the original park boundaries were greatly expanded to over 19,000 acres. To date, no studies have been done quantifying fish species home ranges, habitat use, and connectivity between habitat structures within and adjacent to the park. BIRNM is composed of a shelf habitat containing various shallow water habitats and deeper waters overlying a drop off towards an oceanic trench. An extensive linear reef protects the southeastern coastline. Inside these reef structures lie calm lagoons. High rugosity linear and patch reefs are interspersed with colonized hard bottom and spur and groove reef to the north and west. Sandy flats and seagrass occur to the south and west. Habitat types are highly interwoven in a patchy mosaic pattern (Figure 1).

Culebra is approximately 27 km east of Puerto Rico and is comprised of mostly mountainous terrain. There is significant terrestrial conservation land on Culebra and the surrounding islands in the form of a wildlife refuge run by the Fish and Wildlife Service, including protection of coastal terrestrial habitats. The Luis Peña Channel No-Take Natural Reserve (LPCNR), an MPA established in 1999, is located on the southwest coast of the island (Hernández-Delgado et al. 2002). The benthic habitat surrounding Culebra represents a wide range of habitat types. The area to the northeast of the island is dominated by reef, rubble, and colonized hard-bottom, and is exposed to greater wave action and currents. The southwest side of the island is more protected from currents and wave action and is dominated by seagrass beds. There are two large bays located on the east and southeast sides of the island, dominated by seagrass, sandy flats, and mangroves (Figure 2).

## METHODS

This study used passive acoustic telemetry. Previous research teams have installed fixed arrays of acoustic receivers (VR2W 69 kHz VEMCO, Inc.) semi-permanently at both sites (Figures 1 - 2). To date, 52 acoustic receivers are distributed throughout BIRNM and 59 around the coastline of Culebra. The BIRNM acoustic array is dispersed through the park's shallow water habitats. Receivers in Culebra are dispersed around the coastline of the main island, and then gathered in greater densities at the mouth of the Ensenada Honda and Puerto del Manglar bays. Only one receiver lies within the MPA, so the bulk of the array occurs in fished waters. A VEMCO Positioning System, which uses overlapping receiver coverage and sync tags to allow for triangulation of acoustic transmissions, is located on a small reef flat known as Las Pelas.

Barracuda were captured by trolling with heavy action recreational fishing gear and artificial lures (O'Toole 2011). Fishing effort data was collected by timing trolling and recording gear type and number of hooks. All capture sites were marked with a GPS waypoint. Upon capture, the fish were evaluated visually to determine if health was adequate to support a tag. Fish were placed into a 100 L cooler of seawater containing a sufficient amount of the anesthetic MS-222 to induce stage 4 anesthesia. Anesthetized fish were held in a supine position with gills submerged while an incision was cut with a scalpel along the central mid-line between the pelvic and anal fins. Disinfected acoustic tags were then surgically implanted into the

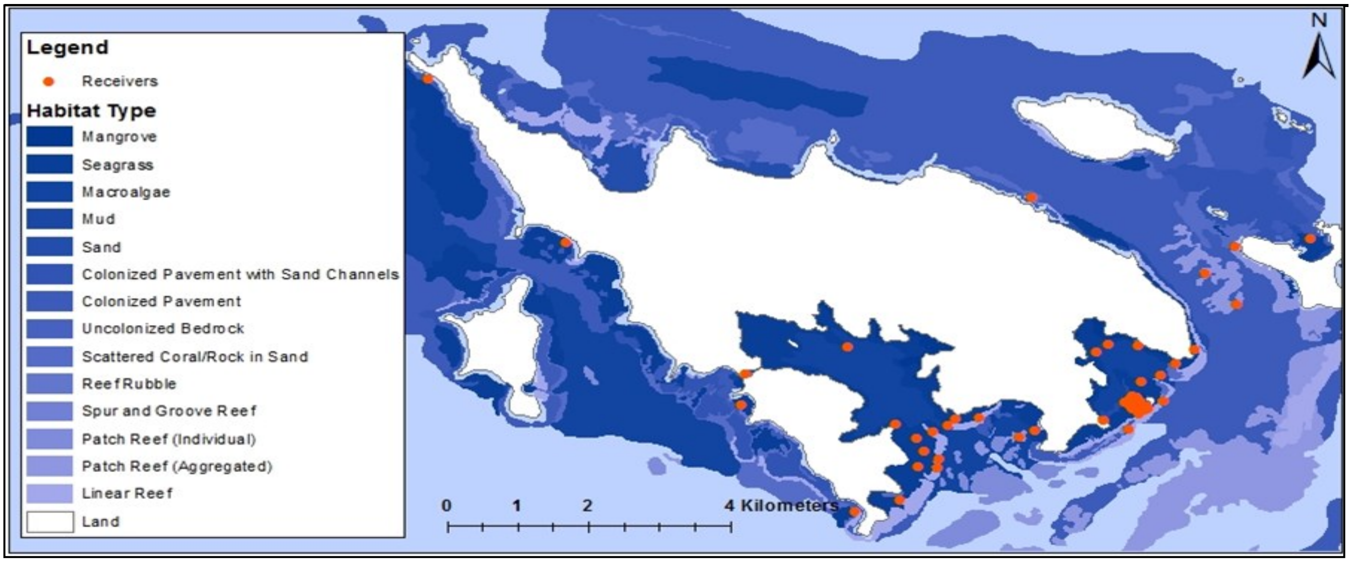


**Figure 2.** Culebra habitat types and acoustic array.

body cavity. Barracuda were tagged with transmitters (coded ID transmitter 69 kHz, VEMCO, Inc) programmed to ping randomly between 60 - 180 seconds for the duration of the battery life. Random ping rates reduce the risk of tag collisions among project partners. Thirty-six adult and sub-adult barracuda are tagged in BIRNM and 12 in Culebra. In BIRNM, three of these fish are being tracked with V13AP VEMCO accelerometer tags, which track acceleration rates and pressure, while the remaining 45 at both sites are tagged with a combination of V16 and V13 standard VEMCO acoustic transmitters. Incisions were closed with 2 - 3 simple interrupted sutures. Halfway through the surgery, fresh seawater was added to the cooler to dilute the anesthetic and begin the recovery process. Total length and fork length was recorded. Time and length of procedure was recorded for all aspects of the capture and surgery. Fish were allowed to recover and monitored in ambient seawater until normal swimming patterns are observed before being released back into the study area from which they were captured (Friedlander and Monaco 2007, O'Toole 2011). No more than four fish from a given capture site were tagged on a single tagging trip to ensure adequate distribution of tagged animals throughout the array and across habitat types and to avoid tag collisions.

In order to compare between the barracuda population densities at Culebra and Buck Island, we calculated a standardized CPUE rate based on randomized surveys throughout both study sites. Trolling surveys were conducted using the same gear as for capture, but with lures modified by removing the hooks. Straight line transects with start points and direction of travel randomized using random number generators in ArcGIS were conducted, running for 15 minutes or until an obstacle was encountered. Transects were timed, number of strikes were counted, and waypoints were taken to quantify rate and location of capture.

Preliminary visualizations of spatial patterns have been conducted using network analysis, to-from movement matrices, and raw cumulative detections maps. Bipartite graphs that display similarities in individual fish's detection histories were plotted to identify overlap and variation in spatial patterns at each sites. Raw detections were mapped by receiver to show spatial displays of areas of high and low barracuda detection rates at each site. Individual fish detection histories were converted into to-from movement matrices, and these were used to spatially plot movements of fish from one receiver to another, in order to coarsely approximate fish movements. Finally, mean CPUE by minute trolling were calculated for each site. A one-tailed randomization test without replacement with 1,000 repetitions was conducted to assess whether the two sites have statistically significant differences in population density based on the difference in mean CPUE values. These visualizations are a preliminary first step in viewing patterns in our data. This will serve as an initial data exploration step that we will be following up on in the coming years with more thorough quantitative analysis and modeling.

## RESULTS

CPUE randomization tests showed a statistically significant difference between our two sites, with a p-value of 0.005. Detection distribution maps showed a large variation in the number of detections heard at each receiver for our tagged barracuda. In St. Croix raw detection numbers ranged from 9 – 154,704, with linear reef and seagrass patches having the highest numbers of raw detections, indicating heavy use of these areas. In Culebra raw detections ranged from 0 – 41,552, with linear reef and protected bays as most heavily used habitats, with evidence of crossing deep channels to access nearshore habitats of nearby islands (Figures 4 - 5). Spatial plots created for each individual fish displayed distinct, but overlapping ranges and showed repeating patterns of movement from one receiver to another, potentially indicating targeted use of specific areas (Figure 4-5).

Bipartite graphs, which demonstrate strength of association between fish and receivers by creating a non-spatially referenced plot in which like fish are clumped with like fish, and where distinct groups can be identified by similarity in spatial use patterns. At both BIRNM and Culebra, graphs show central groups displaying more detections and similar spatial use patterns along with fringe groups with fewer detections and dissimilar patterns (Figure 3). These results potentially indicate spatial separation of home ranges (fewer detections showing ranges on the edge of the array) or populations of resident and transient fish.

## DISCUSSION AND FUTURE WORK

These preliminary results are the first pass of exploration and visualization of the data that will be further analyzed for my master's thesis. The coarse patterns that we have seen here will form the baseline and guidance for future analysis. In future work, I will elaborate on the current preliminary exploration by describing barracuda spatial ecology through statistically evaluating variation in spatial patterns in relation to benthic habitat, prey base assemblages, and population density. I will conduct a broad scale site comparison between BIRNM and Culebra, assessing variation between the two sites in home range size, site fidelity, and temporal patterns in relation to benthic habitat variables, population density, and fish size. I will focus on BIRNM data and create finer scale movement models to examine spatial and temporal patterns within this array. These models will be validated with limited accelerometer data. Comparisons will be made between barracuda spatial patterns, benthic habitat, and prey base distributions. Results from these analyses will be discussed in the context of known ecology of the species and future spatial management. In particular, I will address the management implications of my findings and assess my various methods of spatial analysis for their pros and cons as management tools in different settings.

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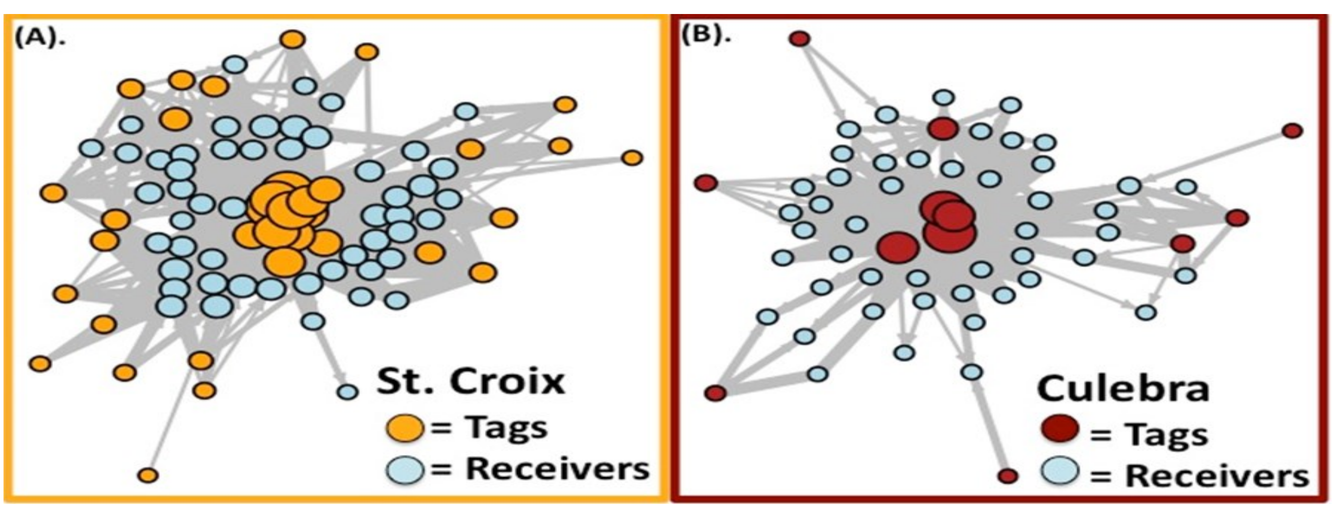


**Figure 3.** Bipartite social network plots for **(A).**St. Croix and **(B).** Culebra.

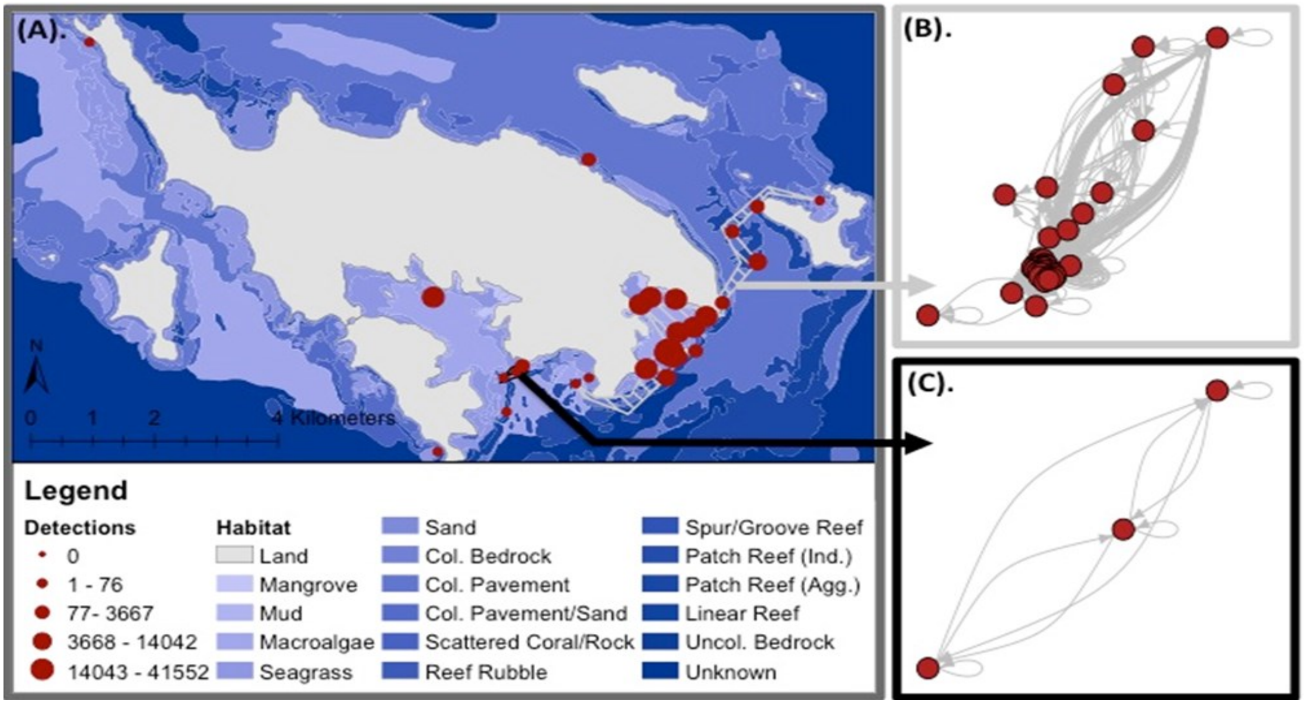


**Figure 4.** BIRNM detection maps and spatial plots: **(A).** Distribution of raw detections by receiver. Grey polygon indicates detection area for fish 26791. Black polygon indicates detection area for fish 26801. **(B).** Tag 26791 movement plot. Nodes align with receivers in (A). **(C).** Tag 26801 movement plot. Nodes align with receivers in (A).

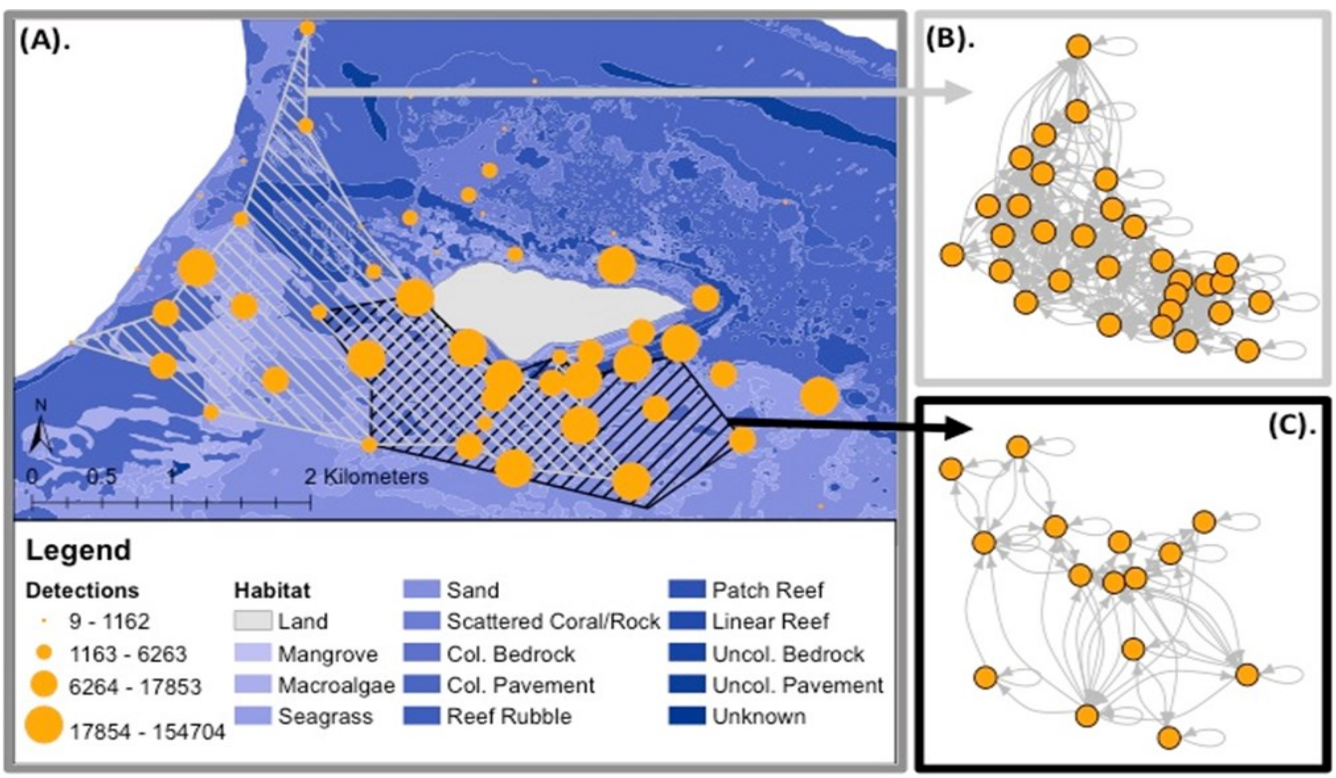


**Figure 5.** Culebra detection maps:**(A).** Distribution of raw detections by receiver. Grey polygon indicates detection area for fish 28755. Black polygon indicates detection area for fish 30393. **(B).** Tag 28755 movement plot. Nodes align with receivers in (A). **(C).** Tag 30393 movement plot. Nodes align with receivers in (A).

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