Fish Movement Patterns in Virgin Islands National Park, Virgin Islands Coral Reef National Monument and Adjacent Waters

NOAA National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment

Alan M. Friedlander
Mark E. Monaco
Randy Clark
Simon J. Pittman
Jim Beets
Rafe Boulon
Russel Callender
John Christensen
Sarah Hile
Matt S. Kendall
Jeff Miller
Caroline Rogers
Kosta Starnoulis
Lisa Wedding
Kimberly Roberson




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NOAA/NOS/National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment (CCMA)
Coastal Oceanographic Assessment, Status and Trends (COAST) Branch
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United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service Holly Bamford
Rebecca Blank Deputy Secretary	Kathryn Sullivan Acting Under Secretary	Assistant Administrator

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Executive Summary

NOAA's National Centers for Coastal Ocean Science (NCCOS)-Center for Coastal Monitoring and Assessment's (CCMA) Biogeography Branch, National Park Service (NPS), US Geological Survey, and the University of Hawaii used acoustic telemetry to quantify spatial patterns and habitat affinities of reef fishes around the island of St. John, US Virgin Islands (Fig. 1). The objective of the study was to define the movements of reef fishes among habitats within and between the Virgin Islands Coral Reef National Monument (VICRNM), the Virgin Islands National Park (VIIS), and Territorial waters surrounding St. John. In order to better understand species' habitat utilization patterns among management regimes, we deployed an array of hydroacoustic receivers and acoustically tagged reef fishes. Thirty six receivers were deployed in shallow near-shore bays and across the shelf to depths of approximately 30 m. One hundred eighty four individual fishes were tagged representing 19 species from 10 different families with VEMCO V9-2L-R64K transmitters. The array provides fish movement information at fine (e.g., day-night and 100s meters within a bay) to broad spatial and temporal scales (multiple years and 1000s meters across the shelf). The long term multi-year tracking project provides direct evidence of connectivity across habitat types in the seascape and among management units. An important finding for management was that a number of individuals moved among management units (VICRNM, VINP, Territorial waters) and several snapper moved from near-shore protected areas to offshore shelf-edge spawning aggregations. However, most individuals spent the majority of their time with VIIS and VICRNM, with only a few wide-ranging species moving outside the management units.

Five species of snappers (Lutjanidae) accounted for 31% of all individuals tagged, followed by three species of grunts (Haemulidae) accounting for an additional 23% of the total. No other family had more than a single species represented in the study. Bluestripe grunt (Haemulon sciurus) comprised 22% of all individuals tagged, followed by lane snappers (Lutjanus synagris) at 21%, bar jack (Carangoides ruber) at 11%, and saucereye porgy (Calamus calamus) at 10%. The largest individual tagged was a 70 cm TL nurse shark (Ginglymostoma cirratum), followed by a 65 cm mutton snapper (Lutjanus analis), a 47 cm bar jack, and a 41 cm dog snapper (Lutjanus jocu). The smallest individuals tagged were a 19 cm blue tang (Acanthurus coeruleus) and a 19.2 cm doctorfish (Acanthurus chirurgus).

Of the 40 bluestriped grunt acoustically tagged, 73% were detected on the receiver array. The average days at large (DAL) was 249 (just over 8 months), with one individual detected for 930 days (over two and a half years). Lane snapper were the next most abundant species tagged (N = 38) with 89% detected on the array. The average days at large (DAL) was 221 with one individual detected for 351 days. Seventy-one percent of the bar jacks (N = 21) were detected on the array with the average DALs at 47 days. All of the mutton snapper (N = 12) were detected on the array with an average DAL of 273 and the longest at 784. The average maximum distance travelled (MDT) was ca. 2 km with large variations among species. Grunts, snappers, jacks, and porgies showed the greatest movements. Among all individuals across species, there was a positive and significant correlation between size of individuals and MDT and between DAL and MDT.

Overall, for all species pooled, 71% of the time was spent in VIIS, 25% in VICRNM, and only 4% in territorial waters. Based on these data and species' life history requirements, the current management boundaries appear adequate for most species, except for the most wide-ranging and transient ones. Many of the points along the south shore of St. John are hotspots for tagged fish detections and are likely used as movement reference points along migratory pathways. The patch reefs at White Cliffs appear to be an important transit point for fishes moving between the near-shore areas of VIIS and the deeper mid-shelf reef in VICRNM.

Acoustic telemetry of reef fishes has proven to be a valuable tool for examining long-term movement patterns of fishes around St. John. This cost effective approach has identified important corridors that connect habitats and management units along the south shore of St. John. It also highlights the variability among species and the importance of taking an ecosystem- based approach to ecology studies.

Figure 1. Location of US Virgin Islands in the context of the greater Caribbean.

Introduction

Virgin Islands Marine Resources

Virgin Islands National Park (VIIS) was established in 1956 with marine portions added in 1962. The park consists of 2,947 hectares of land (about 56% of the 48 km2 island) and 2,287 ha of surrounding waters. Within the park, taking of fishes or other marine life is prohibited except with rod and line or traps of 'conventional Virgin Islands design' and small seine nets. Trunk Bay (21 ha) is technically a no-take area where all fishing is prohibited. The nature of these regulations means that fishing still persists within VIIS with fisheries resources and the marine environment as a whole having shown dramatic declines in recent decades (Rogers et al. 1997, Rogers and Beets 2001, Beets and Rogers 2002, Friedlander and Beets 2008). Owing to this decline, Virgin Islands Coral Reef National Monument (VICR) was established by Presidential Proclamation #7399 in 2001. This new monument added ca. 5,142 hectares of marine habitat off the island of St. John, U.S. Virgin Islands (USVI), greatly increased the NPS jurisdiction in USVI waters (Fig. 2, Monaco et al. 2007, Boulon et al. 2009). Provisions within the Presidential Proclamation prohibit all extractive uses with the exception of fishing for a coastal pelagic species, blue runner (Caranx crysos), south of St. John and bait fishing in a small area within the Coral Bay component of VICRNM (Fig. 2). The Proclamation recognizes that the platform on

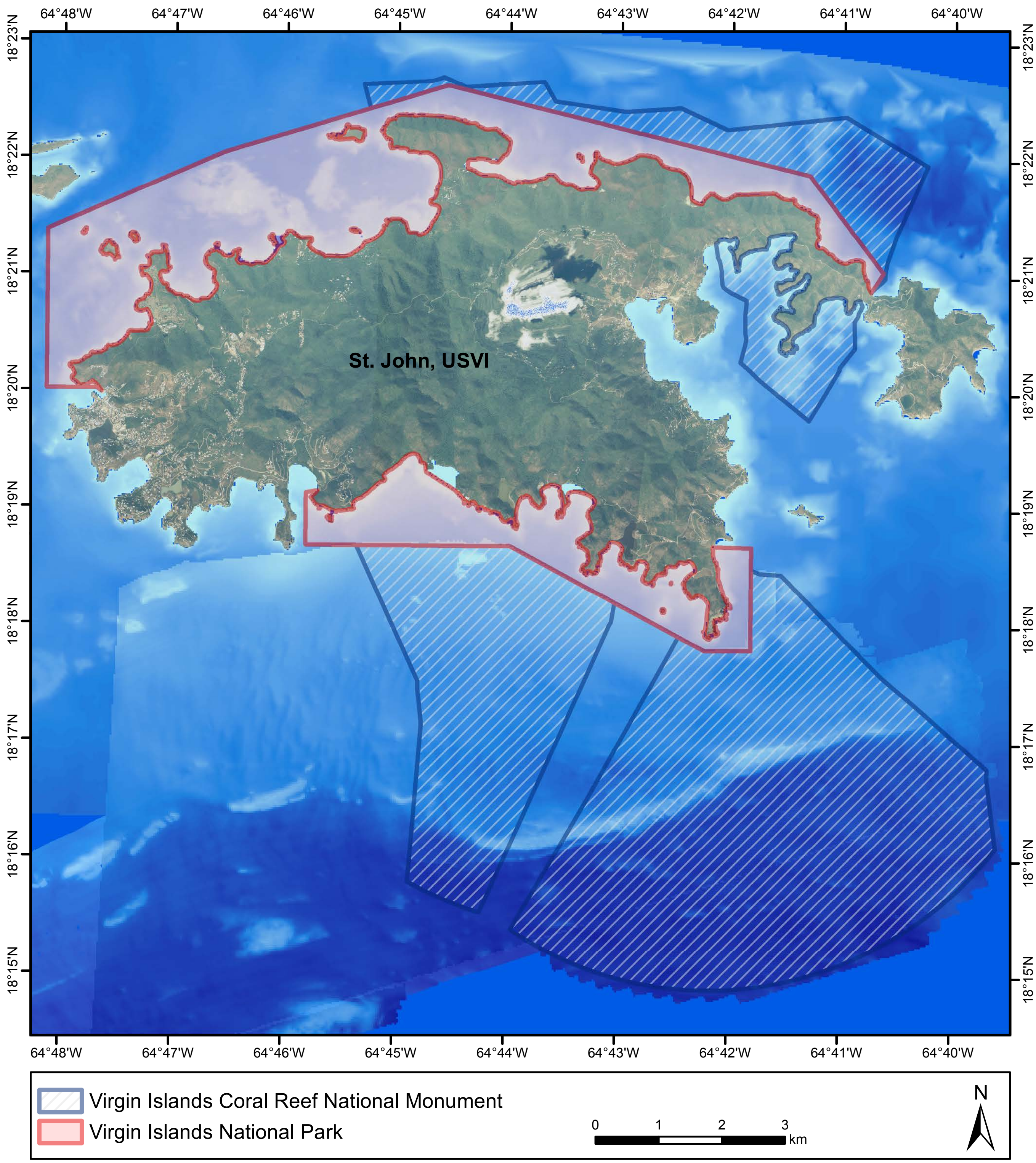

Figure 2. Location of NPS's marine protected area boundaries around the island of St. John, USVI.

which VIIS and VICRNM occurs “contains a multitude of species that exist in a delicate balance, interlinked through complex relationships that have developed over tens of thousands of years”. This project attempted to determine some of the migratory pathways and inter-habitat relationships that link VIIS with VICRNM.

Since 2001, NPS’s VIIS/VICR Resource Management Division has been working closely with NOAA, USGS, and academic partners to characterize benthic habitats to document resource utilization among habitats in VIIS and VICR (Monaco et al., 2007; Monaco et al. 2008; Boulon et al. 2008). NOAA-CCMA Biogeography Branch has completed resource maps of benthic habitats around St. John in VIIS and VICRNM (Zitello et al. 2009). Additionally, they have developed benthic habitat maps of the deeper-water portions of VICR based on remote-sensing data (e.g., multibeam sonar and underwater video) collected over the past five years on NOAA ships. In consultation with NPS, NOAA’s SE Fisheries Science Center and the University of Miami, CCMA’s Biogeography Branch led the development of a fish monitoring protocol to meet pressing NPS management needs within the VIIS, BUIS, and other NPS units in Florida and the Caribbean (Menza et al., 2006).

An important complementary component to resource characterization and monitoring is an understanding of the movement (behavior) of organisms among habitats, between VIIS and VICR, and across those boundaries into Territorial and Federal (EEZ) waters. Documentation of movement of reef fish species is extremely important to NPS resource managers, particularly the knowledge of movements of fish that appear to be residents within park boundaries and species thought to frequently move across park boundaries. Understanding reef fish habitat utilization patterns, residence time, ontogenetic and day and night movement patterns of organisms is critical to defining essential fish habitat (EFH), as well as designing and evaluating marine protected areas (MPAs) (Pittman and McAlpine 2003, Lowe and Bray 2006, Appeldoorn et al. 2009). These data are extremely important to both NPS units, so that: 1) resource data can be provided for development of the General Management Plan and other planning documents, 2) the level of protection can be adequately evaluated, 3) modification of regulations can be assessed, and 4) benefits of different levels of protection and resource enhancement may be evaluated.

Fish also move as they develop, utilizing different habitats as they grow larger (Roberts 1996). Many coral reef associated fish species show ontogenetic migrations from shallow sites; primarily seagrass and mangrove habitats as juveniles, to deeper sites further offshore (Ogden and Zieman 1977, Ogden 1977, Cocheret de la Morinière 2002; Appeldoorn et al. 2003; Christensen et al. 2003). A number of fish show regular movement patterns on a daily basis between resting and feeding areas. Examples include grunts (Ogden and Ehrlich 1977) and goatfish (Holland et al. 1993). Some species also move seasonally, including moving potentially hundreds of kilometers to aggregate at specific places to reproduce (Harding et al. 1978; Johannes et al. 1999, Kobara et al. 2013).

Identifying these ecological pathways is also relevant to EFH and MPA function. For example, the greatest biomass and abundance of fishes in seagrass habitats around St. John are large adult grunts which shelter by day on the coral reefs and make nocturnal feeding migrations into seagrass beds (Beets et al. 2003). These patterns are similar to those documented for juvenile grunts (Helfman et al. 1982). Manual acoustic tracking of bluestriped grunts and schoolmaster snapper over 24 hour periods in bays on St. John and St. Thomas revealed that young adult fish home ranges are between 163 m2 and 25,267 m2, with significantly larger activity spaces being utilized at night for foraging (Hitt et al. 2011a; Hitt et al. 2011b).These movements result in fishes transporting nutrients and biomass from one habitat to another (Parrish 1989, Meyer et al. 1983, Clark et al. 2009) and the identification of these movement patterns can help better understand how energy flows through the ecosystem. Studies in southwestern Puerto Rico using gillnet set at habitat patch boundaries over 24 hrs. found that many species of coral reef associated fishes including large cartilaginous species, undertake nocturnal migrations between coral reefs and seagrasses and between mangroves and seagrasses (Clark et al. 2009).

Underwater Acoustic Telemetry

Underwater acoustic telemetry is an effective remote sensing tool that provides detailed information on the normal spatial and temporal movements of fishes through the seascape. Information obtained from tracking fishes can help to explain questions of immigration/emigration, residence time, habitat preference, site fidelity, as well as movements relative to management strategies such as MPAs. Movement patterns can be described using acoustic tracking of animals either manually or with continuous recording data loggers (i.e., acoustic receivers). Manual tracking provides detailed movement information for limited periods of time (24 hrs. up to several weeks), but requires a large amount of field effort. Continuous receivers log presence/absence data for an individual animal and enables monitoring over a longer time frame (one year or more). Strategically placed continuous monitors can provide information on movement at broad spatial and temporal scales (Lowe and Bray 2006). Coupling benthic habitat maps with movement patterns of organisms provides a spatial framework to address questions concerning linkage among adjacent habitats, particularly how connectivity across mosaics of patches influences reef fish ecology (Lowe et al. 2003, Lowe and Bray 2006, Topping et al. 2005, 2006, Hitt et al. 2011a).

Within an ecosystem-based management context, quantifying information on the range of movements, habitat utilization patterns and ecological connectivity for key economic and ecologically important species throughout their life span is necessary to define “essential fish habitat (EFH)”. Movement patterns also have important implications for MPA size, location, and boundary placement (Clark et al. 2005; Ault et al. 2005; Heupel et al. 2006; Friedlander et al. 2007; Friedlander & Monaco 2007; Meyer et al. 2010). However, empirical data quantifying the spatial scale and patterns of movements of most coral reef fishes are scarce (Meyer et al. 2000; Meyer and Holland 2005; Sale et al. 2005). Such information is important because the long-term effectiveness of MPAs depends on resident fishes remaining within MPA boundaries where they can grow and reproduce successfully (Bohnsack 1993; DeMartini 1993; Rakitin and Kramer 1996; Nowlis and Roberts 1999; Meyer 2003; Meyer and Holland 2005). If MPAs are too small, then resident fishes will frequently roam into fished areas where they may be captured, thereby eroding longterm MPA benefits (DeMartini 1993; Rakitin and Kramer 1996; Nowlis and Roberts 1999; Meyer 2003).

Acoustic telemetry can provide valuable, quantitative data on movement patterns of coral reef fishes at MPA sites (e.g., Holland et al. 1996; Zeller and Russ 1998; Meyer et al. 2000; Meyer 2003; Meyer and Holland 2005; Popple and Hunte 2005, Meyer et al. 2010). Short-term active tracking of coral reef fishes at MPA sites has shown that a wide variety of targeted coral reef fishes are site-attached to well-defined home ranges and have predictable daily movement patterns (Holland et al. 1993, 1996; Meyer et al. 2000; Meyer 2003; Meyer and Holland 2005). These studies suggest that reef fishes are inherently well suited to protection in even relatively small (<1 km2) MPAs (Holland et al. 1993, 1996; Meyer et al. 2000; Meyer 2003; Meyer and Holland 2005). However, active tracking (using a boat to follow a fish equipped with an acoustic transmitter) can only quantify the behavior of a few individual fishes over relatively short periods of time (several weeks). Reserves must afford long-term protection to target species in order to maintain resident populations of large, highly fecund individuals (DeMartini 1993; Meyer 2003; Sale et al. 2005, Birkeland and Dayton 2005). It is important to determine whether site-attached behavior patterns observed using short-term active tracking persist over longer time-scales (months to years) and are exhibited by multiple individuals. Short-term active or passive tracking may underestimate the full extent of fish movements that will lead to underestimates of the minimum MPA size required for effective protection of targeted species. For example, although short-term active tracking revealed that bluefin trevally (Caranx melampygus) utilize 1 km of reef edge on a daily basis (Holland et al. 1996; Meyer 2003), long-term passive tracking showed that bluefin trevally moved back and forth along up to 10 km of coastline over a 9-month period (Meyer and Honebrink 2005). These results show that acoustic monitoring can provide valuable empirical data on the long-term space and habitat requirements of heavily targeted coral reef fishes, which would be of considerable value to resource managers but is currently unavailable.

Another largely untested assumption is that MPAs will provide effective refuges for multi- species assemblages of coral reef fishes. Coral reef habitats support a large number of fish species with different feeding strategies and life history characteristics. Subsequently, there are likely to be species-specific differences in space and habitat requirements, movement patterns and residence times within MPAs. Recent work has highlighted the importance of quantifying space utilization of multiple species within a single protected area (e.g., Lowe et al. 2003; Topping et al. 2006; Meyer 2003; Meyer et al. 2007a, b).

The primary objectives of this project are to: 1) Examine the movement of fish species between inshore habitats within VIIS and offshore habitats within the VICR, 2) examine the movement of fish species inside and outside of VIIS and VICR, 3) examine the habitat utilization patterns and movements of fishes over diel time periods at various spatial scales, 4) examine the habitat utilization patterns and movements of fishes over time periods ranging from weeks to months to years, and 5) define ecological linkages based on fish movements between VIIS and VICR. The linkages between VICR and VIIS and among various habitats of both units will be investigated by studying the movements of fish species in different trophic groups. This information will allow resource managers to understand the movement of fish into and out of the management units and to identify resources and movement pathways that may require management focus. Inventory and characterization of existing marine resources within VIIS has progressed during recent years and has been initiated for VICR to establish current baseline conditions of fish and macro-invertebrates (e.g., fish density) and quality of benthic habitats (e.g., percent coral cover). This investigation provides a major component of the data required for development of ecosystem management strategies for VIIS and VICR.

Materials and Methods

The VEMCOTM VR2 and VR2-W acoustic monitoring system was used to track reef fish movements around the southern side of St. John. This system consists of 36 small (340 mm long 960 mm diameter, weight in water 300 g), self-contained, single channel (69 kHz) underwater receivers, which detect and log the presence of coded-pulse acoustic transmitters (Figure 3). Each of the acoustic receivers has a nominal detection range of 300 m. Receivers were deployed approximately 1 meter from the seafloor on vinyl coated stainless steel wire attached to sand screws. These omnidirectional receivers recorded the identification number and time stamp from the coded acoustic transmitters as tagged fishes traveled within receiver range, which was determined to be ca. 300 m. (Fig. 4). To determine the movements of reef fishes, receivers were positioned along the entire south shore of St. John and portions of its eastern bays within and outside VICRNM and VIIS (both near-shore and along the mid-shelf reef, Figure 5a and b, Table 1). Based on our knowledge of the distribution of habitats using NOAA's benthic habitat maps and local reef fish ecology, receivers were placed close to coral reefs in shallow near-shore bays and across the shelf to depths of approximately 30 m.

Figure 3. Acoustic transmittters, hydroacoustic receivers, and mooring design and deployemtn.

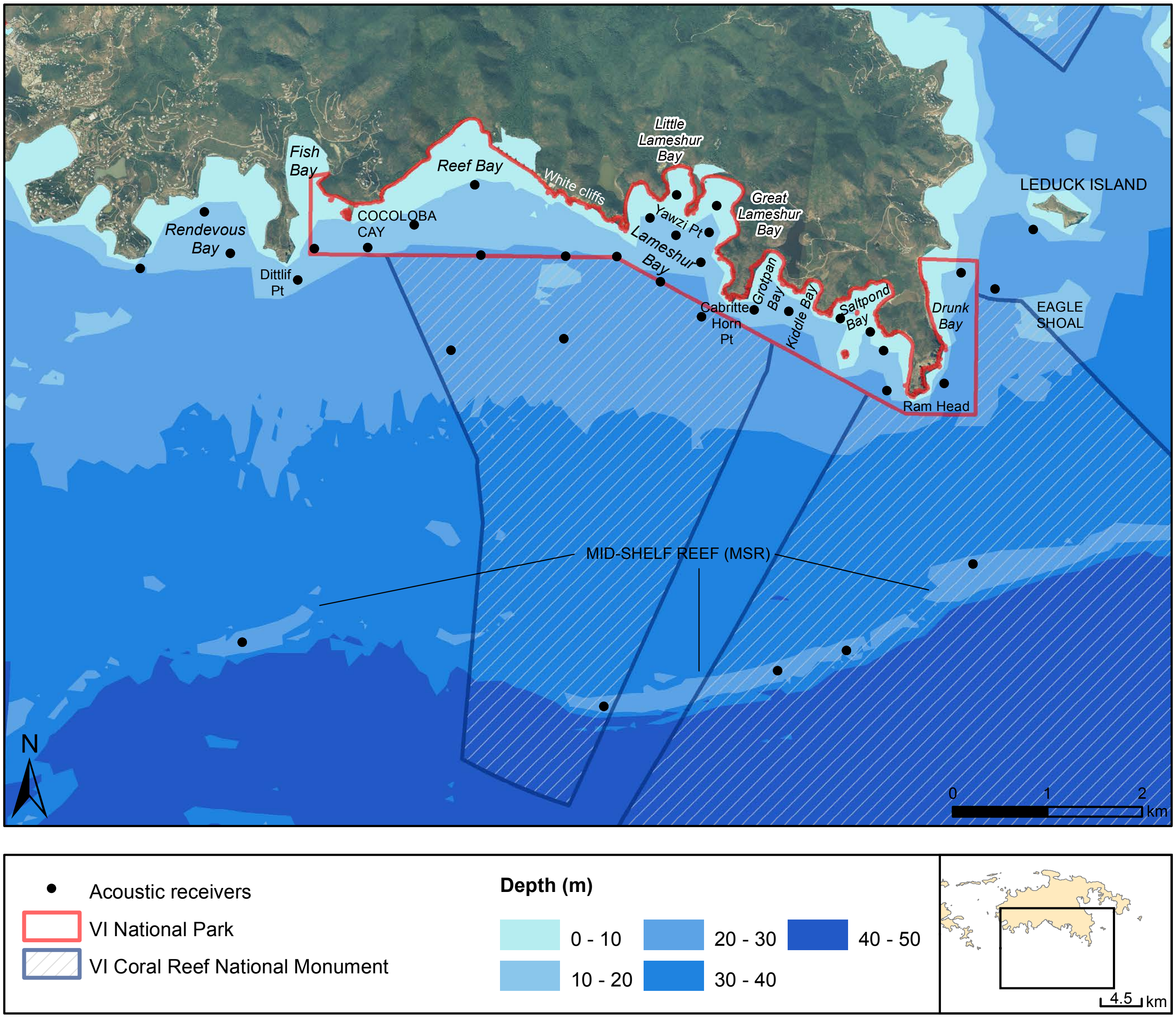

Figure 4. Locations of NOAA-CCMA acoustic receivers around St. John with place names referenced in the text.

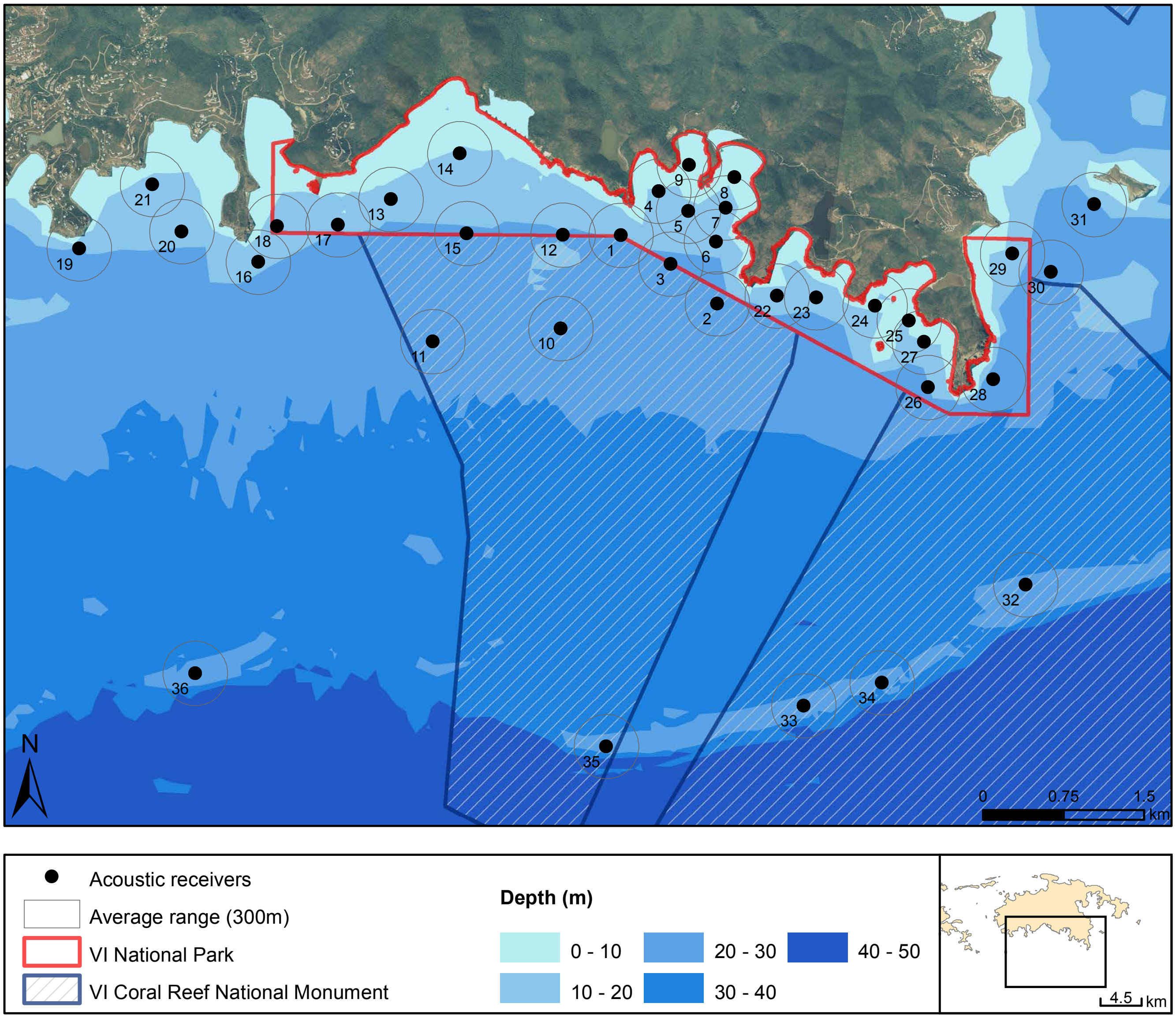

Figure 5a. Locations of NOAA-CCMA acoustic receivers around St. John. Circles around receivers show 300 radius detection ranges.

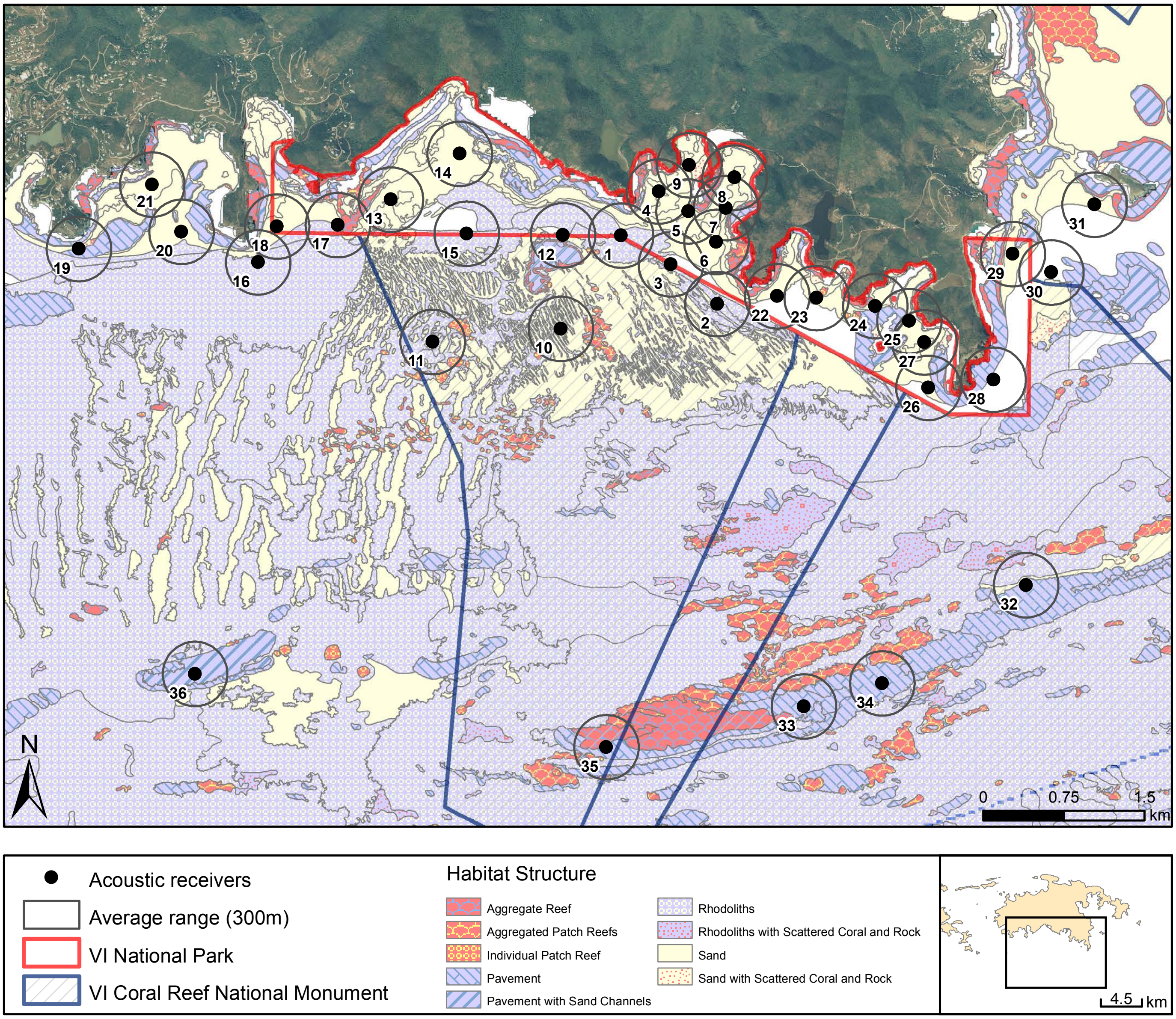

Figure 5b. Locations of NOAA-CCMA acoustic receivers around St. John. Circles around receivers show 300 radius detection range. The underlying map depicts benthic habitat structure from NOAA benthic habitat maps (Zitello et al. 2009).

Trapping fish

Fish were captured using baited fish traps and hook and line. Fish were transported in aerated tubs and hypodermic needles were used to release gas for the swim bladders of fish which showed signs of barotrauma. All fish were transported to a 450 gallon shore-based holding tank with flow-through seawater at a rate of 23 liters/minute to allow for recovery from capture and surgery to ensure that fishes were released in healthy condition (Figure 6).

Table 1. Location of VR2/2W NOAA-CCMA hydroacoustic receivers along south shore of St. John, USVI.

Station	Location	Depth(ft.)	LAT	LONG
1	Lameshur Bay	62	18.3114	-64.7328
2	Lameshur Bay	75	18.3057	-64.7242
3	Lameshur Bay	72	18.3090	-64.7284
4	Lameshur Bay	38	18.3151	-64.7295
5	Lameshur Bay	45	18.3135	-64.7269
6	Lameshur Bay	56	18.3109	-64.7244
7	Lameshur Bay	41	18.3138	-64.7236
8	Lameshur Bay	24	18.3164	-64.7228
9	Lameshur Bay	23	18.3174	-64.7268
10	White Cliffs	88	18.3035	-64.738
11	White Cliffs	92	18.3023	-64.7492
12	White Cliffs	71	18.3114	-64.7379
13	Reef Bay	50	18.3142	-64.7530
14	Reef Bay	37	18.3181	-64.7470
15	Reef Bay	71	18.3114	-64.7463
16	Cocoloba Cay	63	18.3088	-64.7647
17	Fish Bay	61	18.3120	-64.7577
18	Fish Bay	47	18.3119	-64.7630
19	Rendezvous Bay	71	18.3098	-64.7804
20	Rendezvous Bay	59	18.3113	-64.7714
21	Rendezvous Bay	39	18.3153	-64.77404
22	Grotpan Bay	55	18.3064	-64.7190
23	Kittle Bay	59	18.3063	-64.7155
24	Salt Pond	36	18.3057	-64.7104
25	Salt Pond	31	18.3044	-64.7073
26	Salt Pond	78	18.2988	-64.7056
27	Salt Pond	35	18.3026	-64.7060
28	Rams Head	89	18.2996	-64.6999
29	Drunk Bay	57	18.3101	-64.6983
30	Eagle Shoals	85	18.3086	-64.6949
31	Le Duck	77	18.3144	-64.6912
32	MSR In East 3	68	18.2823	-64.6969
33	MSR In East 1	78	18.2720	-64.7163
34	MSR In East 2	81	18.2740	-64.7094
35	MSR In West 1	84	18.2684	-64.7336
36	MSR Out West	81	18.2742	-64.7699

Figure 6. A) Fish traps used to capture fish; B) Aerated holding tank; C) Shore-based holding tank (450 gallons) at Virgin Islands Environmental Research Station, St. John; D) Tagged fish in holding tank. External transmitters and external t-bar tags evident on a few individuals; E) Crowder used to minimize handling and stress; F) Queen triggerfish (*Balistes vetula*) with external transmitter.

Acoustic Tagging

We surgically implanted VEMCO V9-2L-R64K transmitters (9 mm x 29 mm, 2.9 g in water) into the stomach cavities of captured fishes (Fig. 7). These transmitters periodically emit a 'pulse train' of closely spaced 69-kHz 'pings', which uniquely identify each fish. These pulse trains are a few seconds in length, and the transmitters were silent for a randomized period between each pulse train. Each successfully decoded pulse train is recorded as a single detection by a VR2 receiver, and is stored in the receiver memory as the unique transmitter number, date and time of detection. A 1 cm incision was made 1cm off-center from the ventral midline behind the pelvic fins and a small acoustic transmitter (22mm) was placed within the body cavity. The incision was closed with two surgical sutures and the fish were observed to ensure adequate recovery. After holding fish for 24 hours in post-surgery recovery tanks, they were released at a location in close proximity to their original capture location. Several fish species were unsuitable for surgical implantation because of body shape or size of the stomach cavity. These species were tagged externally by gluing transmitters to a small disk tags (1 cm) with steel pins and inserting the pins through the dorsal musculature or before the caudal.

Figure 7. A) VEMCO V9-2L-R64K transmitters (9 mm x 29 mm, 2.9 g in water), B) Inserting transmitter 32 cm yellow goatfish (*Mulloidichthys martinicus*), C & D) Incision and suturing 30 cm red hind (*Epinephelus guttatus*).

Data Management

Data (detections) from acoustic receivers were downloaded approximately twice a year, whereupon routine maintenance of moorings took place, faulty and outdated receivers were replaced and lithium batteries were changed where necessary. The array was composed of a mixture of VR2 and VR2W receivers. Firmware was regularly updated as recommended by VEMCO with the latest version (v2) compatible with VUE (VEMCO User Environment) software version 1.8.1. Data files were converted to MS Excel, quality checked and imported to MS Access. The final database included over 2 million detections. At conclusion of the project, we then expanded the database of detections through data sharing and integration to include data from three additional arrays in the U.S. Virgin Islands including the NMFS queen conch array (St. John near shore); UVI shelf edge arrays (Marine Conservation District, Grammanik & other shelf edge) and NOAA NMFS Apex Predator array COASTSPAN (St. John near-shore). The integrated database contains over 7.5 million hits and is now known as the U.S. Caribbean Acoustic Tracking Network (USCAN) (Pittman and Legare 2010). The benefits of combining and sharing data have included increasing the total area of detection resulting in an understanding of broader scale connectivity than would have been possible with a single array. Partnering has also been cost- effectiveness through sharing of field work, staff time and equipment and exchanges of knowledge and experience across the network. Use of multiple arrays has also helped in optimizing the design of arrays when additional receivers are deployed. The combined arrays have made the USVI network one of the most extensive acoustic arrays in the world with a total of 150+ receivers available, although not necessarily all deployed at all times. Preliminary results showing connectivity between near-shore areas and spawning aggregations that emerged from the U.S. Caribbean Acoustic Tracking Network are shown in Appendix 1.

Analyses

Bubble plots were used to illustrate overall spatial distribution of detections of each species. We first calculated the number of individuals of each species detected at each receiver location, then normalized these values by converting them to percentages (of the total number of each species tagged) and scaled bubbles according to these percentage values. We used diel scatter plots of detections to show the night vs. day variation in habitat occupancy for each tagged fish.

Minimum Distance Traveled (MDT) was calculated for each tagged individual based on the greatest water distance between two receivers for which at least one detection day was recorded. Water distance between receivers was calculated using ArcGIS 10 by first creating individual shape files for each receiver location, then using the "Cost Distance" tool to create distance rasters to each point. In addition to the individual receiver shape files, the other input to the tool was a raster of the study area for which each water cell (1m x 1m) was designated a value of 1 and each land cell was designated "NoData". Thus distances were calculated over water only. To extract the values from the distance rasters, the "Sample" tool was utilized to return distance values for each receiver. If an individual was recorded on only one receiver then MDT = 0.

To examine the relative contribution of each receiver to the total number of detections within the array, we divided the total number of detection days for each receiver by the total number of individual fish released near that receiver to account for the fact most fish were released near a limited number of receivers. Additionally, the number of detections per day for each receiverwas weighted by the distance of each receiver to the release site for each tagged fish. For each tag/receiver combination, we calculated the distance from the release site to each receiver in the array and calculated the average distance from release for all individuals combined. We then multiplied this distance weighting factor by the total number of detection days at each receiver. In this way, we accounted for the fact that the greatest number of detections should occur closest to the receiver where it was released.

Results

We tagged 184 individual fishes representing 19 common species from 10 different families encompassing a wide range of functional groups (Table 2). Five species of snappers (Lutjanidae) accounted for 31 % of all individuals tagged, followed by three species of grunts (Haemulidae), which accounting for an additional 23 % of the total. No other family had more than a single species represented in the tagging pool. Bluestripe grunt (Haemulon sciurus) comprised 22 % of all individuals tagged, followed by lane snappers (Lutjanus synagris) at 21 %, bar jack (Carangoides ruber) at 11 %, and saucereye porgy (Calamus calamus) at 10 %. The largest individual tagged was a 70 cm TL nurse shark (Ginglymostoma cirratum), followed by a 65 cm mutton snapper (Lutjanus analis), a 47 cm bar jack, and a 41 cm dog snapper (Lutjanus jocu). The smallest individuals tagged were a 19 cm blue tang (Acanthurus coeruleus) and a 19.2 cm doctorfish (Acanthurus chirurgus).

Days at large - Of the 40 bluestriped grunt acoustically tagged, 80 % were detected on the receiver array (Figure 8, Table 3). The average days at large (DAL) was 237 with one individual detected for 930 days (Figure 6). Lane snapper were the next most abundant species tagged (N = 38) with 92 % detected on the array. The average days at large (DAL) was 220 with one individual detected for 722 days. All of the bar jacks (100 %, N = 21) were detected on at least one receiver in the array with the average DALs at 47 days. All of the mutton snapper (N = 12) were detected on the array with an average DAL of 273 and the longest begin 784 days.

Movement among management units – Most of the individuals were tagged in either VIIS or VICRNM and the vast majority of the individuals stayed within these two management units (Table 4). Of the 32 Lane Snapper tagged with > 7 DAL, 56 % of their time was spent in VIIS and 44 % in VICRNM. The 20 tagged bluestriped grunt with > 7 DAL spent 69 % of their time in VIIS and 31 % in VICRNM. Of the five grey snapper tagged with > 7 DAL, 57 % of time was spent in VICRNM and the remaining 43 % in VIIS. Very few individuals were detected in Territorial waters. The exceptions to this were the wide ranging, highly mobile species including bar jacks, yellowtail snapper, dog snapper, and yellow goatfish. Of the five bar jacks detected for > 7 days, 77 % of their time was spent in either VIIS or VICRNM but 23 % of their time was spent in Territorial waters. Likewise for yellowtail snapper, 81 % of their time was spent in either VIIS or VICRNM with 18% of the time spent in territorial waters. Only one yellow goatfish and one dog snappers had sufficient detections to examine residence among management units, but these results also show a modest amount of movement into territorial waters.

Distance travelled by species – The maximum distance traveled within the array varied greatly among species (Table 5). The 11 mutton snapper at large for > 7 days moved on average 4.5 km. Two of these fish were also observed at a spawning aggregation site off St. Thomas, a straight line distance of approximately 26 km. One dog snapper moved nearly 7 km over its 311 DAL within the array. The single white grunt tagged moved 4.2 km over the 332 DAL, while the single schoolmaster snapper moved ca. 3 km over 382 DAL. One yellow goatfish moved ca. 3 km but was only detected on the array for 35 days. However, this fish was detected by receivers maintained by NMFS increasing the distance traveled to 3.9 km). Not surprisingly, bar jacks showed wide ranging movement but also high variability, with some individuals moving great distances (max. MDT = 8.6 km), while others moved very little. Saucereye porgy and yellowtail snapper also showed large movement ranges and high variability among individuals. At the other end of the movement spectrum, squirrelfish, a nurse shark, queen triggerfish, and a red hind all showed average MDT at ca. 1 km or less. Among all individuals across species, there was a positive and significant correlation between size of individuals and MDT (Spearman's $\rho = 0.23$, $p = 0.014$) and between DAL and MDT (Spearman's $\rho = 0.25$, $p = 0.009$).

Hotspots within the array – By examining the total number of detections for each receiver (weighted by either distance from release site or number of tagged fish released at a receiver), we are able to identify hotspots of activity within the array that may have important ecological significance, for instance, as high quality habitat or as a location along a movement corridor. Receivers off Salt Pond (# 27, #25), Fish Bay (#17), Cocoloba Cay (# 16), Kittle Bay (# 23), and Lameshur Bay (# 2, #3) had the greatest number of detection days weighted by distance from release sites. Additionally, sites off Reef Bay (#13), Fish Bay (#18), and White Cliffs (#12) also appeared to be active locations for the tagged fishes within the array. Many of these sites are points that are likely used as movement reference points along migratory pathways. The patch reefs at White Cliffs appear to be an important transit point for fishes moving between the near-shore areas of VIIS and the deeper mid-shelf reef in VICRNM. Many fishes moved actively along the boundary between VIIS and VICRNM adjacent to Lameshur and Fish Bay. One important location not within VIIS or VICRNM was Ditleff Point, between Rendezvous and Fish Bay.

Table 2. Summary information for tagged reef fishes. Trophic levels: P = piscivore, MI = mobile invertivore, SI = sessile invertivore, H = herbivore, Z = planktivore.

Family	Scientific Name	Common name	Trophic level	Num tagged	Avg len (TL cm) (SD)	Min. len (TL cm)	Max len (TL cm)
Haemulidae	*Haemulon sciurus*	Bluestriped grunt	MI	40	27.8 (1.9)	24	30.6
Lutjanidae	*Lutjanus synagris*	Lane snapper	MI/P	38	27.5 (4.2)	20	36
Carangidae	*Caranx ruber*	Bar jack	P	21	35.7 (4.3)	29.8	47
Sparidae	*Calamus calamus*	Saucereye porgy	MI/SI	19	28.5 (3.3)	21.3	35
Lutjanidae	*Ocyurus chrysurus*	Yellowtail snapper	MI/Z	14	30.6 (4.5)	22.5	38
Lutjanidae	*Lutjanus analis*	Mutton snapper	MI	12	44.6 (9.7)	31	65
Holocentridae	*Holocentrus adscensionis*	Longjaw squirrelfish	MI	9	27.8 (0.8)	26	29
Acanthuridae	*Acanthurus coeruleus*	Blue tang	H	5	21 (2.1)	19	24
Balistidae	*Balistes vetula*	Queen triggerfish	MI	5	33.4 (4.2)	29	39
Lutjanidae	*Lutjanus griseus*	Gray snapper	MI/P	5	28.9 (4.0)	25.2	35.4
Mullidae	*Mulloidichthys martinicus*	Yellow goatfish	MI/Z	3	31.8 (0.7)	31	32.3
Acanthuridae	*Acanthurus chirurgus*	Doctorfish	H	2	21.5 (3.3)	19.2	23.9
Serranidae	*Epinephelus guttatus*	Red hind	MI/P	2	33.0 (5.0)	29.5	36.5
Ginglymostomatidae	*Ginglymostoma cirratum*	Nurse shark	MI/P	2	62.5 (10.6)	55	70
Haemulidae	*Haemulon flavolineatum*	French grunt	MI/SI	2	20.7 (1.1)	20	21.5
Haemulidae	*Haemulon plumierii*	White grunt	MI	2	28.2 (4.6)	25	31.5
Lutjanidae	*Lutjanus apodus*	Schoolmaster	MI/P	1	27.0 (-)	27	27
Lutjanidae	*Lutjanus jocu*	Dog snapper	MI/P	1	41.4 (-)	41.4	41.4
Mullidae	*Pseudupeneus maculatus*	Spotted goatfish	MI	1	27.0 (-)	27	27

Table 3. Summary of detection data for reef fishes tagged around St. John.

Scientific name	Common name	Num tagged	% detected	Total detection span (days)			Number of days detected per receiver		
				min	max	avg	min	max	avg
Haemulon sciurus	Bluestriped grunt	40	80.0	0	930	236.6	1	553	57.8
Lutjanus synagris	Lane snapper	38	92.1	0	722	220.1	1	351	57.4
Carangoides ruber	Bar jack	20	100.0	0	329	45.0	1	289	10.8
Calamus calamus	Saucereye porgy	19	89.5	0	180	79.5	1	172	11.6
Ocyurus chrysurus	Yellowtail snapper	15	93.3	0	333	61.7	1	248	13.1
Lutjanus analis	Mutton snapper	11	100.0	1	784	272.8	1	510	49.8
Holocentrus adscensionis	Longjaw Squirrelfish	9	77.8	2	348	104.9	1	287	40.3
Acanthurus coeruleus	Blue tang	5	100.0	5	106	40.2	1	75	17.6
Balistes vetula	Queen triggerfish	5	60.0	4	38	20.3	1	37	11.8
Lutjanus griseus	Gray snapper	5	80.0	0	657	328.8	1	602	140.5
Mulloidichthys martinicus	Yellow goatfish	3	100.0	2	34	12.7	1	35	6.7
Acanthurus chirurgus	Doctorfish	2	100.0	25	85	55.0	2	73	19.4
Epinephelus guttatus	Red hind	2	100.0	1	402	201.5	1	265	57.8
Ginglymostoma cirratum	Nurse shark	2	50.0	233	233	233.0	2	210	61.8
Haemulon flavolineatum	French grunt	2	50.0	1	1	1.0	2	2	2.0
Haemulon plumierii	White grunt	2	50.0	332	332	332.0	1	83	17.8
Lutjanus apodus	Schoolmaster	1	100.0	382	382	382.0	1	10	3.0
Lutjanus jocu	Dog snapper	1	100.0	311	311	311.0	2	122	29.3
Pseudupeneus maculatus	Spotted goatfish	1	0.0	0	0	0			

Table 4. Average number of detection days in each NPS management area and Territory. Individuals with DALs > 7

Species	No. indiv.	Territory	VICRNM	VIIS	% Terr	% VICRNM	% VIIS
Lutjanus griseus	5	0.00	312.33	235.67	0.00	57.00	43.00
Epinephelus guttatus	1	0 .00	43.00	285.00	0.00	13.11	86.89
Haemulon sciurus	20	0.05	90.45	198.20	0.02	31.33	68.65
Lutjanus analis	11	1.27	98.37	163.09	0.48	37.42	62.10
Lutjanus synagris	32	0.03	99.69	126.53	0.01	44.06	55.93
Ginglymostoma cirratum	1	0.00	0.00	212.00	0.00	0.00	100.00
Lutjanus jocu	1	20.00	151.00	0.00	11.70	88.30	0.00
Caranx ruber	5	29.00	1.80	92.80	23.46	1.46	75.08
Holocentrus adscensionis	5	0.00	24.80	83.80	0.00	22.84	77.16
Ocyurus chrysurus	6	20.50	28.33	59.33	18.95	26.19	54.85
Haemulon plumierii	1	0.00	0.00	90.00	0.00	0.00	100.00
Calamus calamus	10	3.20	4.50	63.30	4.51	6.34	89.15
Acanthurus chirurgus	2	0.00	1.00	49.50	0.00	1.98	98.02
Acanthurus coeruleus	4	0.00	0.25	41.25	0.00	0.60	99.40
Mulloidichthys martinicus	1	2.00	0.00	35.00	5.41	0.00	94.59
Balistes vetula	2	0.00	23.50	1.50	0.00	94.00	6.00
Lutjanus apodus	1	0.00	0.00	13.00	0.00	0.00	100.00

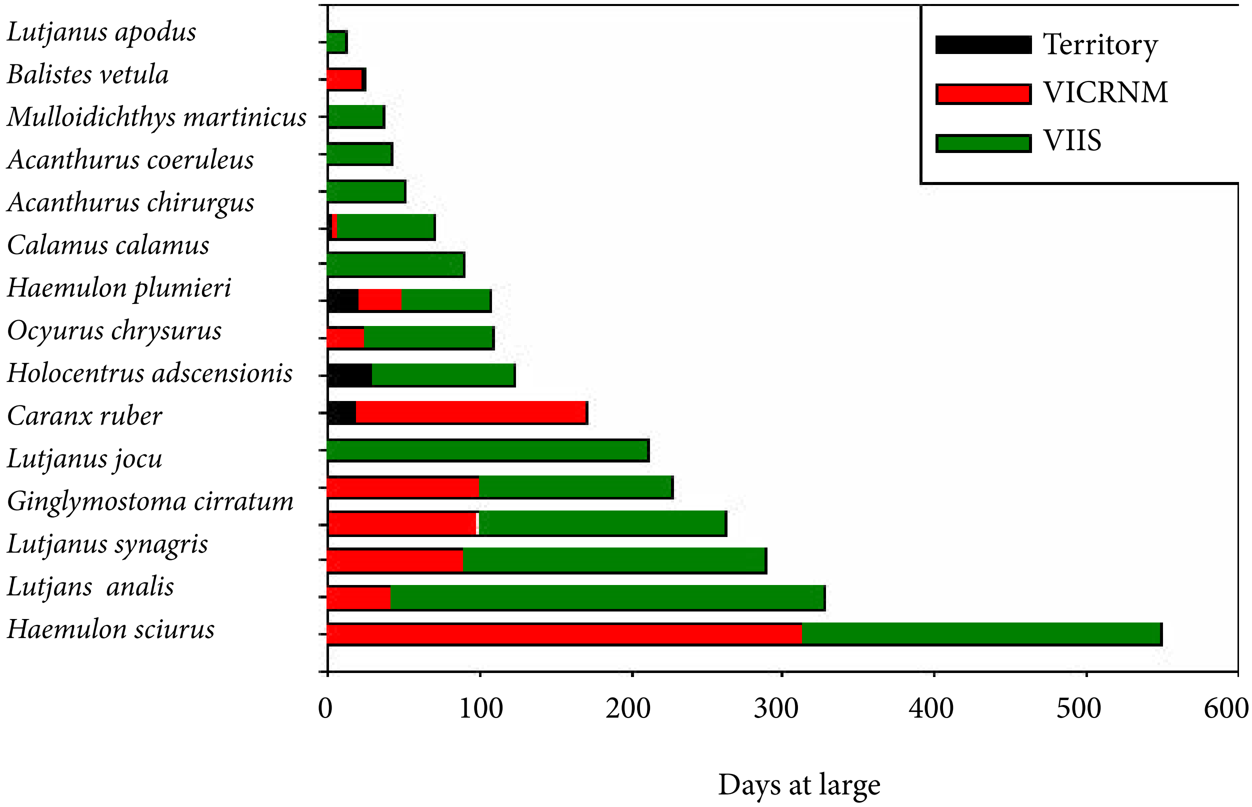

Figure 8. Average number of days at large for each species by management area. Only fishes that were at large for more than one week were considered in this analysis.

Species	N	Average MDT	Max. MDT	Min. MDT	Average DAL
Lutjanus jocu	1	6.96 (-)	6.96	6.96	311.0 (-)
Lutjanus analis	11	4.46 (2.13)	8.56	1.16	297.5 (195.7)
Haemulon plumieri	1	4.24 (-)	4.24	4.34	333.0 (-)
Mulloidichthys martinicus	1	3.09 (-)	3.09	3.09	34.0 (-)
Lutjanus apodus	1	2.93 (-)	2.93	2.93	383.0 (-)
Caranx ruber	6	2.86 (3.03)	8.58	0.08	145.3 (153.9)
Calamus calamus	10	2.33 (2.70)	9.32	0.08	133.6 (43.1)
Ocyurus chrysurus	6	2.24 (3.50)	9.35	0.57	141.8 (133.7)
Haemulon sciurus	21	1.73 (2.10)	8.52	0.36	338.9 (238.4)
Acanthurus coeruleus	4	1.55 (0.45)	1.98	1.16	49.0 (39.1)
Acanthurus chirurgus	2	1.51 (0.65)	1.98	1.05	55.0 (42.4)
Lutjanus synagris	32	1.49 (1.15)	5.31	0.08	240.6 (149.8)
Lutjanus griseus	3	1.42 (0.29)	1.76	1.34	438.3 (189.6)
Epinephelus guttatus	1	1.08 (-)	1.08	1.08	403.0 (-)
Balistes vetula	2	0.93 (0.49)	1.27	0.58	28.5 (13.4)
Ginglymostoma cirratum	1	0.69 (-)	0.69	0.69	233.0 (-)
Holocentrus adscensionis	6	0.63 (0.69)	1.28	0.08	123.0 (138.1)

Table 5. Minimum distance traveled (MDT) in km for species with > 7 days-at-large (DAL). Values in parentheses are one standard deviation of the mean. Species are ordered by the largest to smallest average MDT.

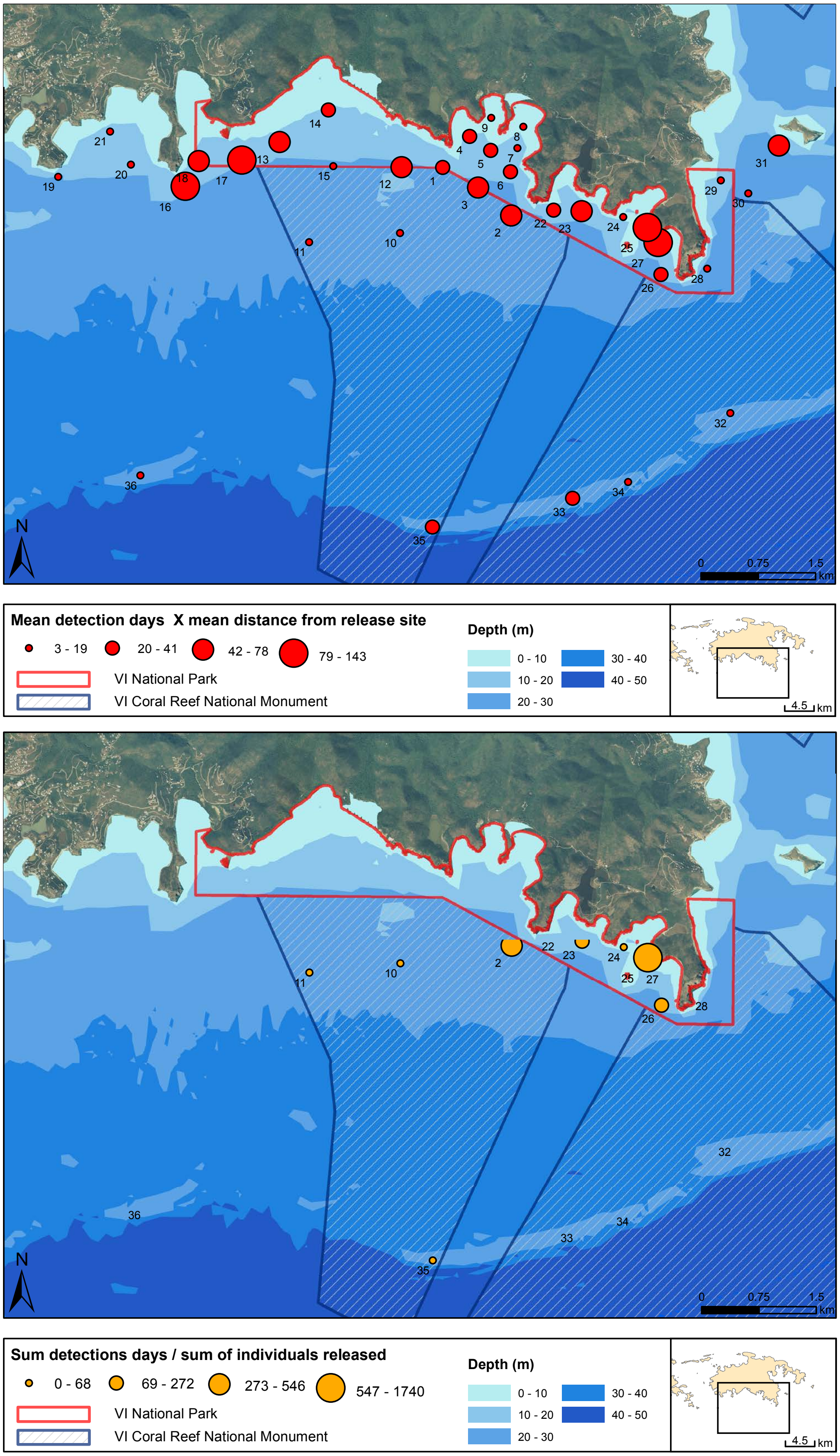

Figure 9. Weighted number of detection days by receiver. A. Total detection days weighted by the distance of each tag/receiver combination to all other receiver. B. Total detection days divided by the total number of fish released at that receiver. (see text for details)

Summary of Individual Fish Patterns

Family Ginglymostomatidae: Nurse Sharks

Ginglymostomatidae is a cosmopolitan family of carpet sharks, containing the three monotypic genera (Ginglymostoma, Nebrius, and Pseudoginglymostoma) (Nelson 1994). The combination of characters including nasoral grooves, barbels, anterior mouth, posterior portion of first dorsal fin, absence of caudal keels and precaudal pits, and asymmetrical caudal fin readily distinguishes this shark from all others (Compagno 1984). Nurse sharks are nocturnal animals and spend the day in large inactive groups or as solitary individuals.

Nurse shark: *Ginglymostoma cirratum*

This species is found on both sides of the tropical and subtropical Atlantic Ocean, as well as the Eastern Tropical Pacific (Randall 1996). Ginglymostoma is a monospecific genera. Nurse sharks are most commonly observed lying on the bottom in coral reef habitats and are the most common shark encountered on Caribbean reefs (Randall 1996). Nurse sharks feed mainly on fishes along with a wide variety of invertebrates.

We tagged two nurse sharks, but only one was detected on the acoustic array. One 70 cm nurse shark was tagged in Little Lameshur Bay and was detected on the array for 233 days. More than 98 % of all detections were recorded at station 9, which was also the release site for the shark. The vast majority of the detections on the station 9 receiver occurred during daylight hours with the shark showing a clear pattern of movement towards and away from this receiver during dawn and dusk. Movement towards the mouth of the bay at night was observed in the first few months after tagging, but no detections were recorded at these other receivers in the subsequent months. The MDT was only 0.6 km over the 233 DALs.

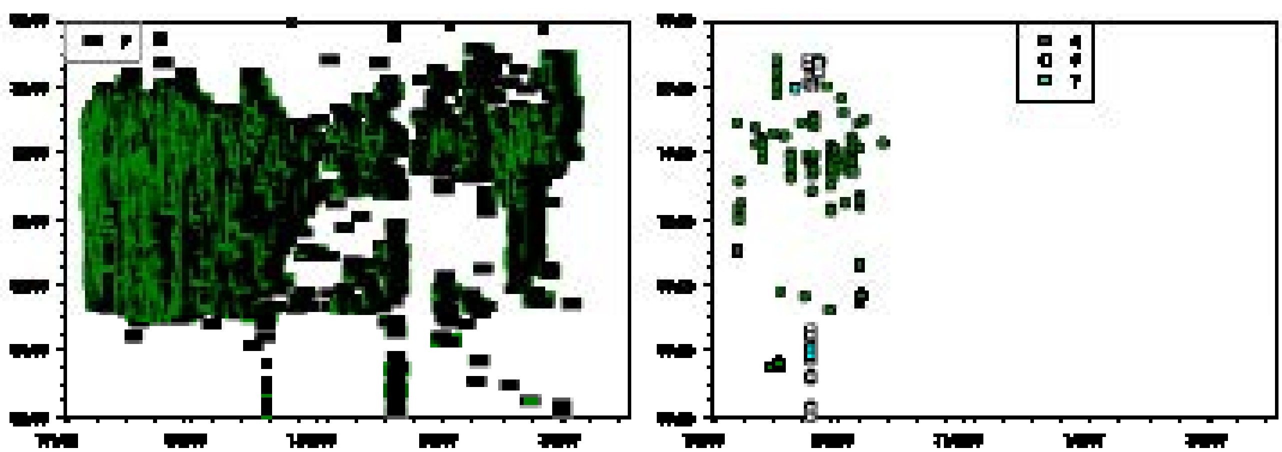

Figure 10. Day (left) and night (right) detection patterns for nurse shark – *Ginglymostoma cirratum.* Tag # 3196 (70 cm TL). Symbol and # in boxes represent the acoustic receiver station#.

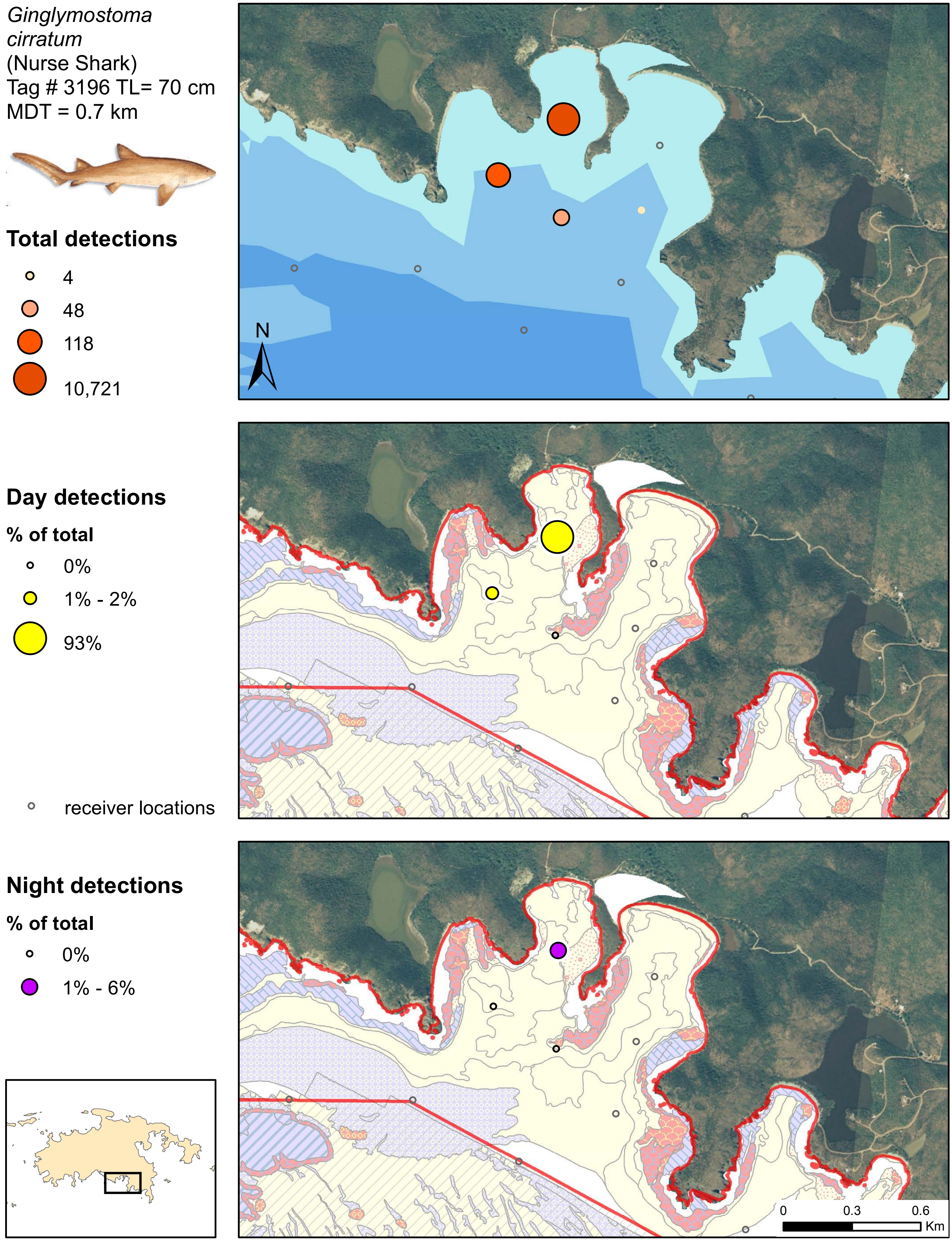

Figure 11. Day and night detections for nurse shark, *Ginglymostoma cirratum*. Tag # 3196 (70 cm TL)

Family Holocentridae: Squirrelfishes

Holocentrids are reef fishes with large eyes and red body color (Randall 1996). The subfamily Holocentrinae has a strong spine present at the angle of the preoperculum. Squirrelfishes are mostly nocturnal and usually hide in the reef during daylight hours (Nelson 1994). They feed at night, mostly on planktonic crustaceans.

Longjaw Squirrelfish, *Holocentrus adscensionis*

The longjaw squirrelfish ranges from Bermuda and New York to southern Brazil and is a common species in the Virgin Islands. It can obtain a maximum length of 35 cm and is frequently captured in the Virgin Islands trap fishery. Like most members of this family, longjaw squirrelfish are benthic carnivores that forage at night. A total of nine longjaw squirrelfish, ranging in size from 26 to 29 cm TL (mean = 27.8 ± 0.8), were tagged with acoustic transmitters during the study. Of these tagged fish, 67 % were detected on the acoustic array with an average detection span of 112 days (range = 7 to 348 days) (Figure 12).

Longjaw squirrelfish tag # 2342 (28 cm TL) was tagged off Kiddel Point, at the mouth of Salt Pond Bay. No detections occurred at the release site but did occur 0.6 km across the mouth of the bay at station 25. This fish appeared to spend most of its diurnal time around this receiver with movement to Ram Head at night. On two occasions in January 2008, the fish was detected around the eastern side of Ram Head at station 28. The MDT for this fish was 1.5 km.

Longjaw squirrelfish, tag # 3180 (27.5 cm TL) was tagged of Cabritte Horn Point, at the eastern edge of Great Lameshur Bay. Nearly 78 % of the detections occurred at station 2 off Cabritte Horn Point and there was no day and night pattern to these detections. Station 3 accounted for 22 % of the total detections for this fish, with most of these detections occurring during daylight hours (Figure 14). The fish also made a few excursions into Lameshur Bay and also rounded Cabritte Horn Point on one occasion and was detected at station 22. Total MDT for this fish was 1.2 km.

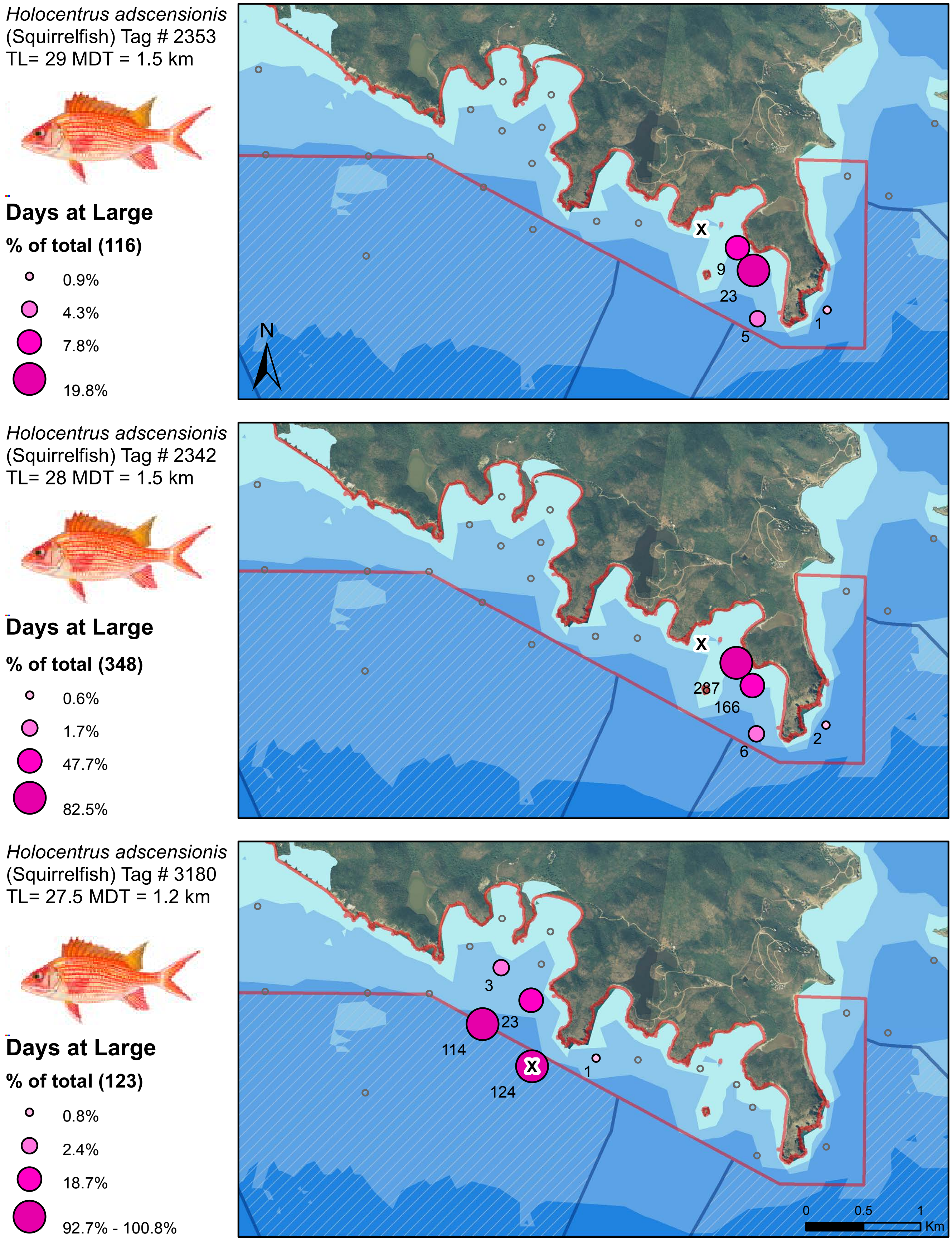

Figure 12. Day and night detections for longjaw squirrelfish, Holocentrus adscensionis. X = point of capture and release.

Figure 12. Day and night detections for longjaw squirrelfish, *Holocentrus adscensionis*. X = point of capture and release.

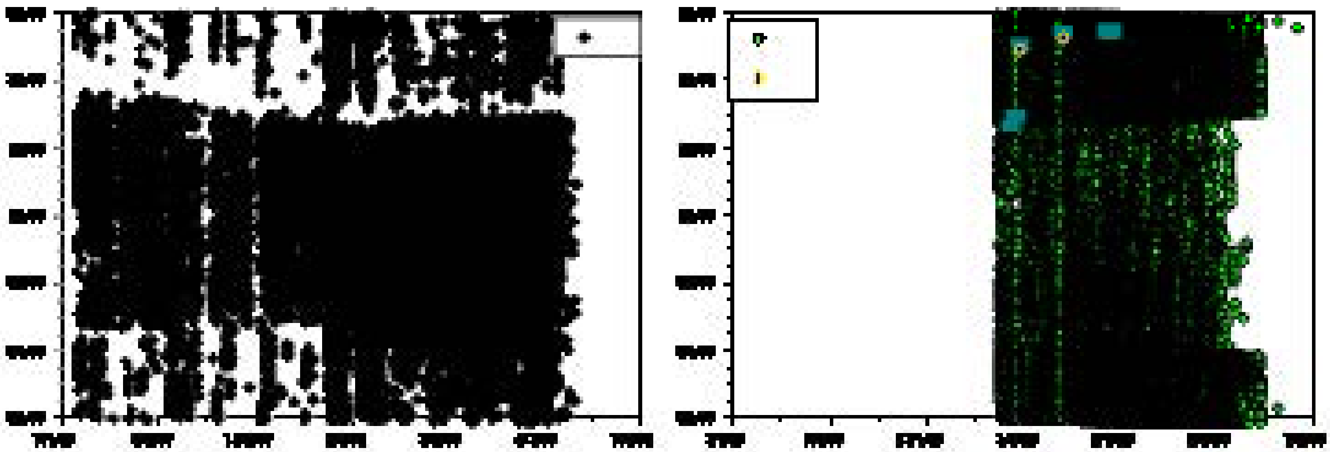

Figure 13. Day and night detection patterns for longjaw squirrelfish, *Holocentrus adscensionis*, tag # 2342 (28 cm TL). Receiver 27 malfunction from July to December 2007.

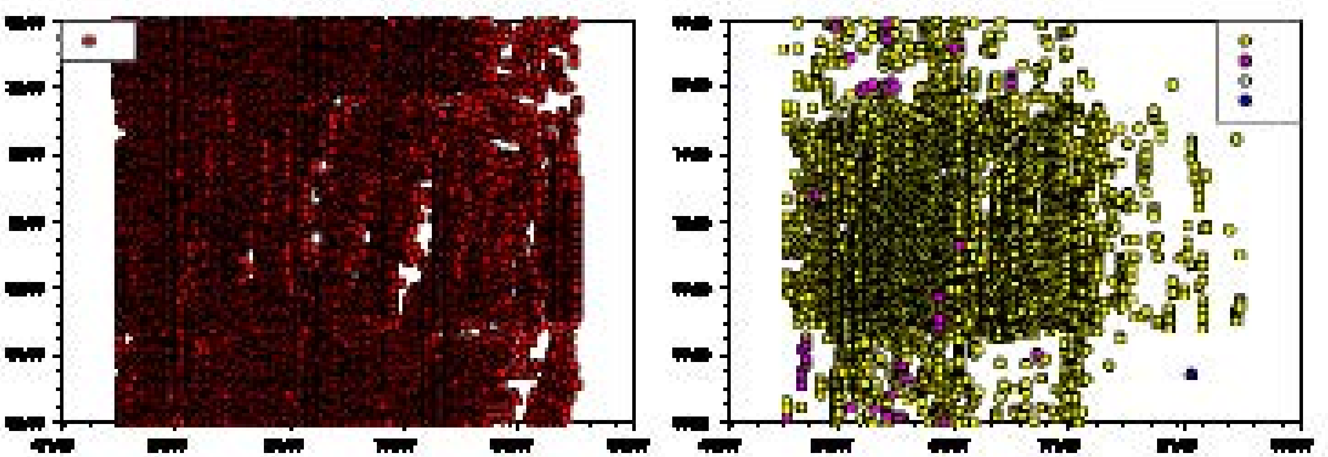

Figure 14. Day and night detection patterns for longjaw squirrelfish, *Holocentrus adscensionis*, tag # 3180 (27.5 cm TL). Symbol and # in boxes represent the acoustic receiver station #.

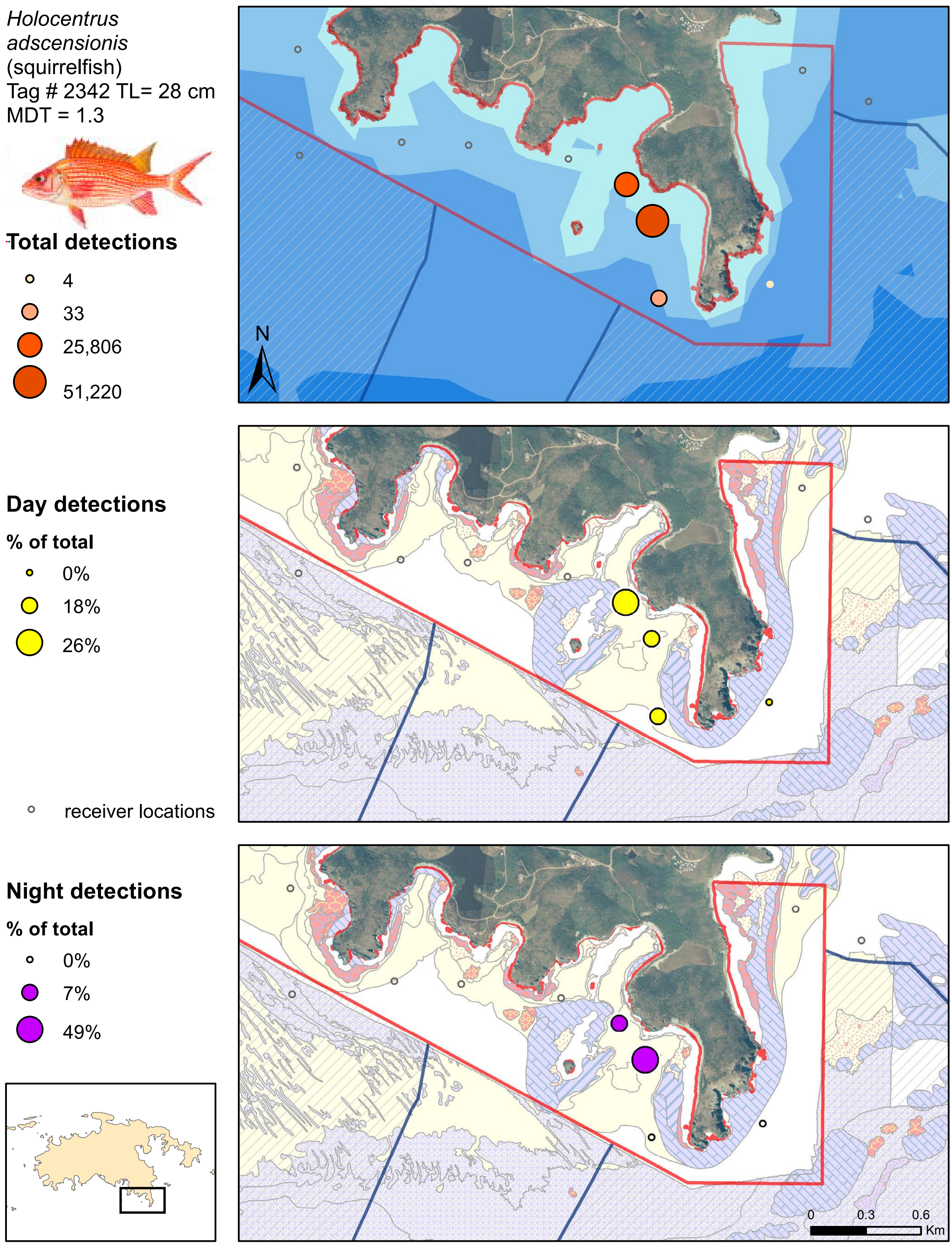

Figure 15. Day and night detections for longjaw squirrelfish, *Holocentrus adscensionis*, tag # 2342 (28 cm TL). X = point of capture and release.

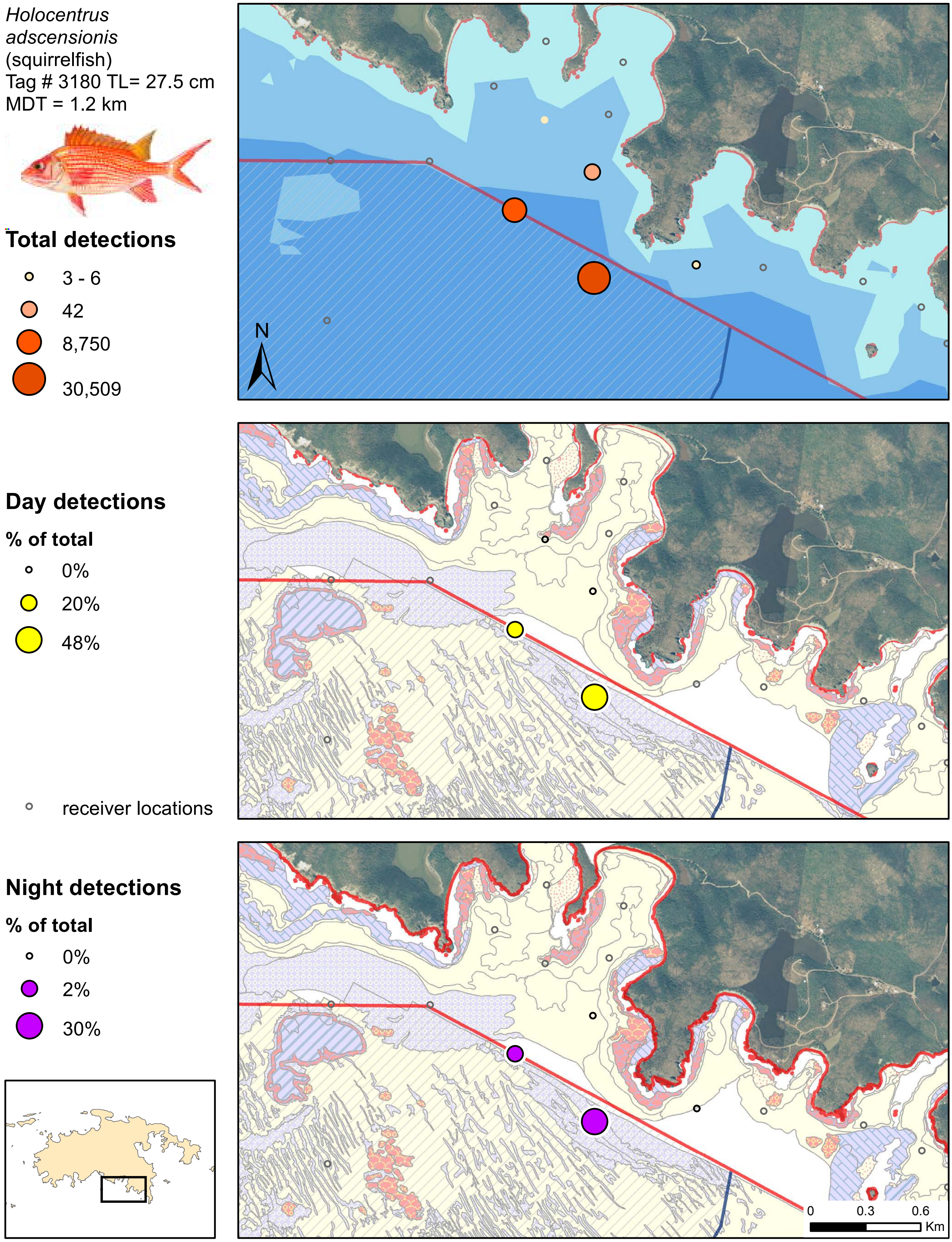

Figure 16. Day and night detections for longjaw squirrelfish Holocentrus adscensionis, tag #3180 (27.5 cm TL).

Family Serranidae: Groupers and Seabasses

The serranids are a monophyletic family and are one of the least specialized families of perciform fishes (Randall 1996, Nelson 1994). All serranids are carnivorous and feed mainly on fishes and crustaceans. Many groupers and sea basses are hermaphroditic and some, particularly the large-bodied groupers, form large spawning aggregations at predictable times and locations, making them vulnerable to overexploitation.

Red Hind, *Epinephelus guttatus*

The red hind ranges from North Carolina Bermuda North Carolina to Paraíba, Brazil. It is the most common species of Epinephelus in the West Indies and can obtain a maximum length of 76 cm. They are found in shallow reefs and rocky bottoms and are usually solitary and territorial. They feed mainly on crabs and other crustaceans (alpheid shrimps and scyllarid lobsters), fishes, and octopus. Red hind form spawning aggregations during the winter month in the Virgin Islands that were heavily targeted by fishermen prior to the establishment of a marine reserve designated to protect this and other aggregating species (Beets and Friedlander 1997, Nemeth 2005).

Two red hind, ranging in size from 29.5 to 36.5 cm TL (mean = 33.0 ± 5.0), were tagged with acoustic transmitters during the study. One was only detected on the array for a single day while the other fish (tag # 3258) was at large for 402 days (Fig. 18). The fish moved very little and spent most of the time off Yawzi Point in between Great and Little Lameshur Bays remaining within the VIIS. Total MDT for this fish was 1.0 km. More than 99 % of all detections occurred at station 5 despite several gaps in the data at this station due to equipment malfunction. The fish was detected on six other receivers in the Lameshur Bay complex and appeared more active during the first three months after tagging. No detections occurred on other receivers in the broader USCAN array.

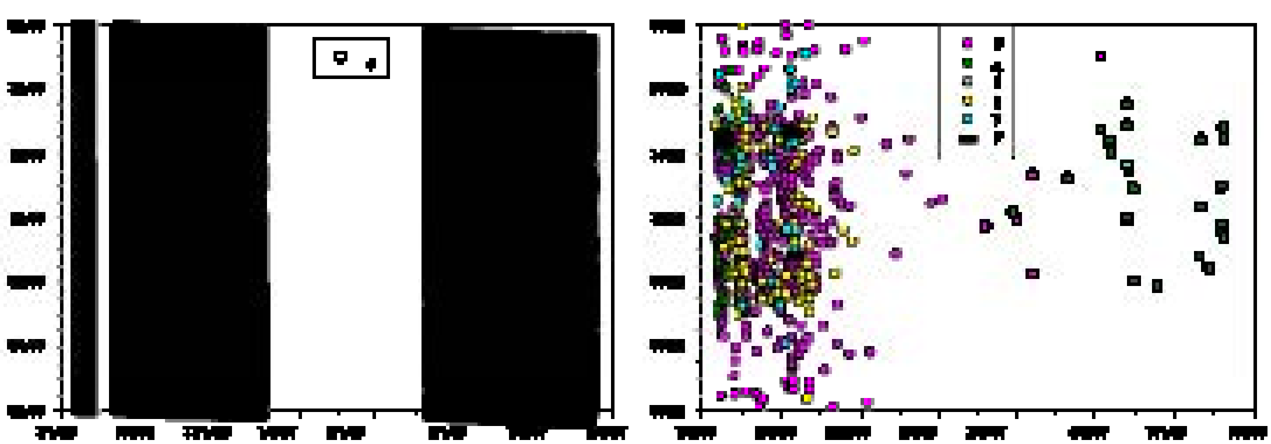

Figure 17. Day and night detection patterns for red hind – Epinephelus guttatus. Tag # 3258 (29.5 cm TL).

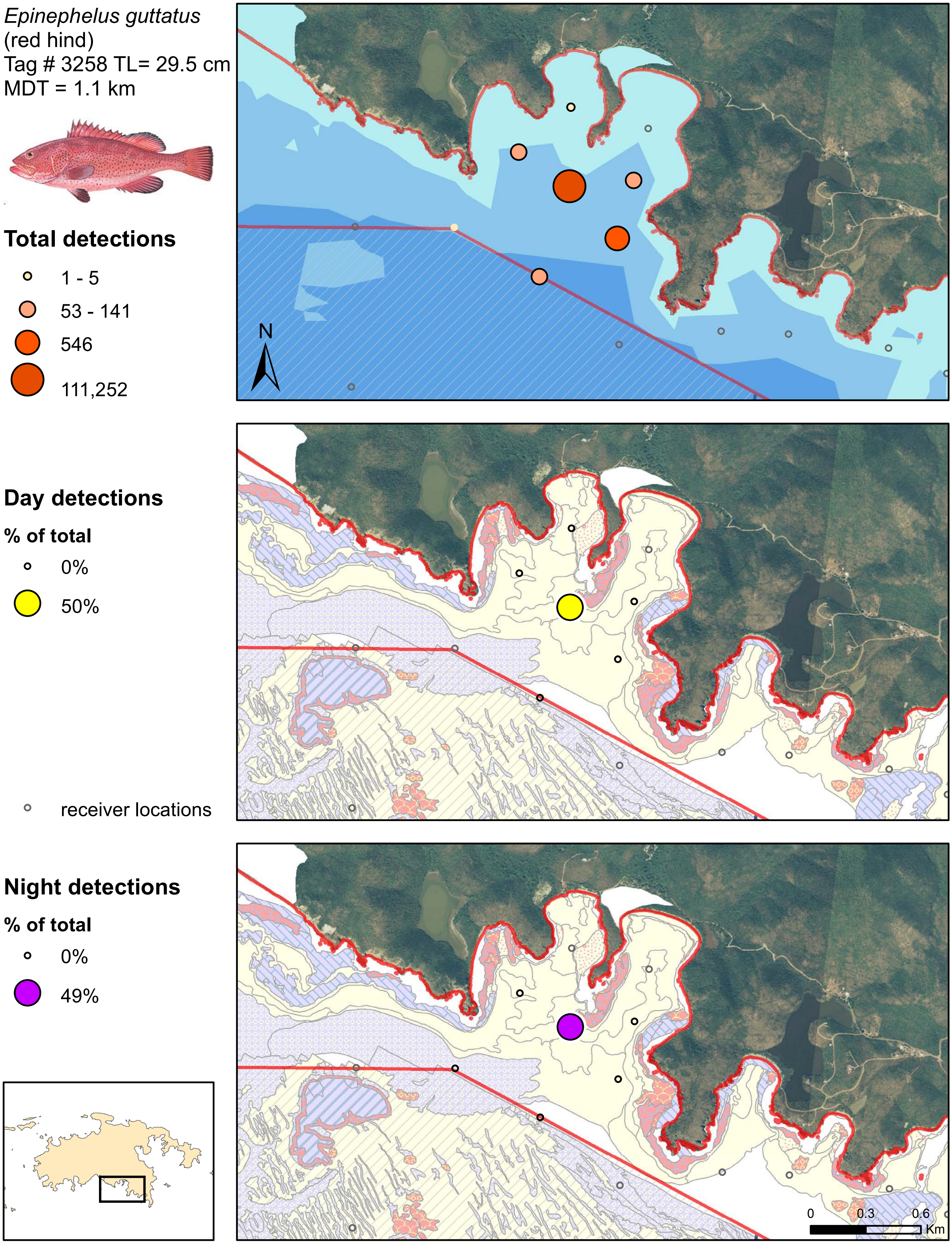

Figure 18. Day and night detections for red hind (Epinephelus guttatus). Tag # 3298 (29.5 cm TL).

Family Carangidae: Jacks

Jacks are a large family of 32 genera and 140 species (Nelson 1994). The body is generally compressed and silver in color. They are strong-swimming roving predators and many of the species are popular food and recreational species. A number of other species within the family have been implicated in ciguatera poisoning and this is certainly true within the Virgin Islands.

Bar jack, *Carangoides ruber*

Bar jack range from New Jersey to northern Brazil and is the most common jack observed on Virgin Island reefs. They grow to a recorded maximum of 65 cm and a weight of 6.8 kg and are a minor fisheries target although they have been implicated in ciguatera poisoning. The species inhabits clear shallow waters, often over coral reefs where it lives either solitarily or in large schools, taking various fishes, crustaceans and cephalopods as prey.

We tagged 21 bar jacks (mean = 35.7 ± 4.3 cm TL) during the course of the study with over 71% of these detected on the acoustic array. Although one fish was detected on the array for 329 days, the average duration of detections was only 47 days. Fish tag # 6033 was tagged in Reef Bay and was at large for 327 days and had a MDT of 8.1 km. This fish spent most of the daytime hours in Reef Bay between stations 14 and 16. There was a strong diurnal signal to the detections at these stations. It was detected on 14 other receivers along the south shore from as far west as Ditliff Point and as far east as Drunk Bay, a distance of 8.1 km, but there were typically short excursions with the fish returning to Reef Bay in all cases. Bar jack tag # 53781 (35.3 cm TL) was released on the east side of Cabritte Horn and moved along the mouth of the Lameshur Bay complex for ca. one week before it left the array. It was briefly detected at station 5 off of Yawzi Point two months later and then briefly again that the same station nine months later. Three fish (#53784, #6731 and #6033) were also detected on a USCAN collaborator's receiver in Fish Bay.

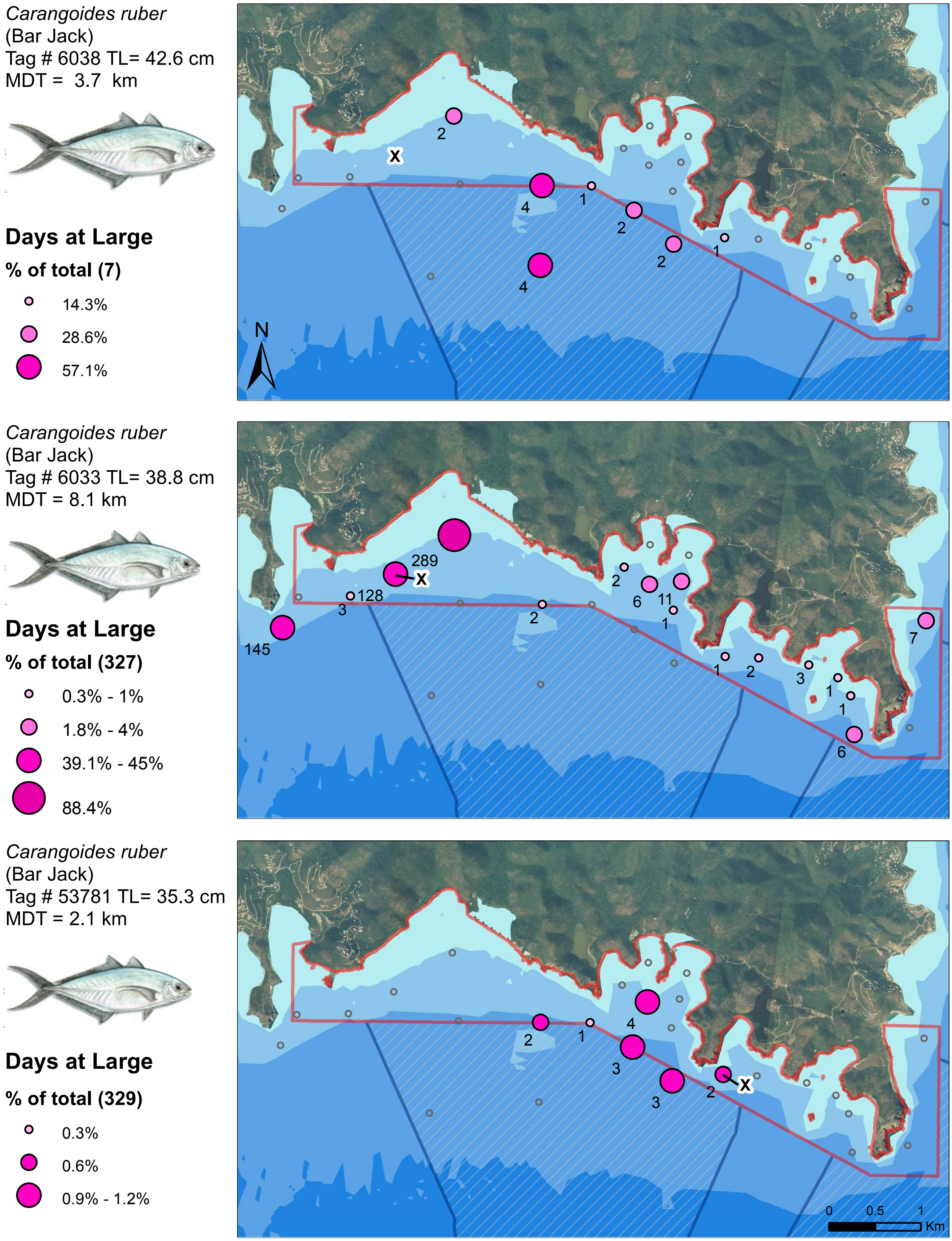

Figure 19. Number of detections of Bar jack (*Carangoides ruber)* at each receiver and bubble plot represent relative % proportion of detections.

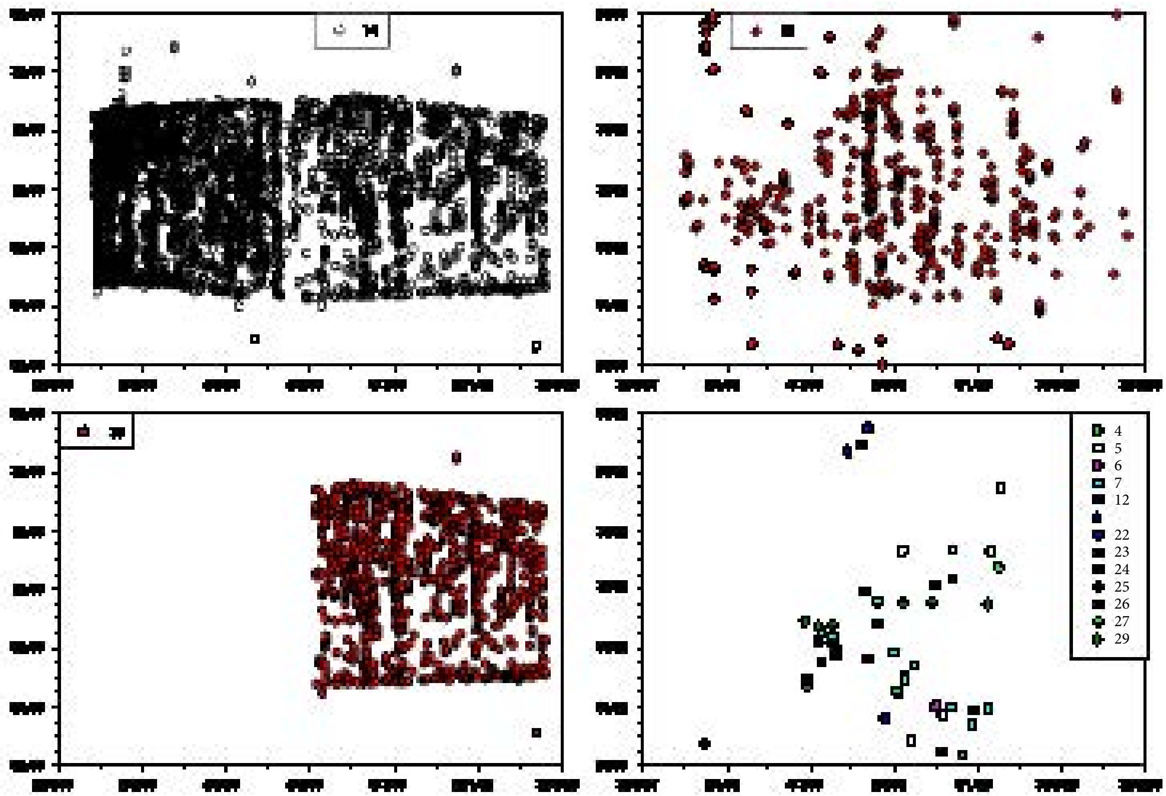

Figure 20. Day and night detection patterns for Bar jack, *Carangoides ruber*.
Tag # 6033 (38.8 cm TL).

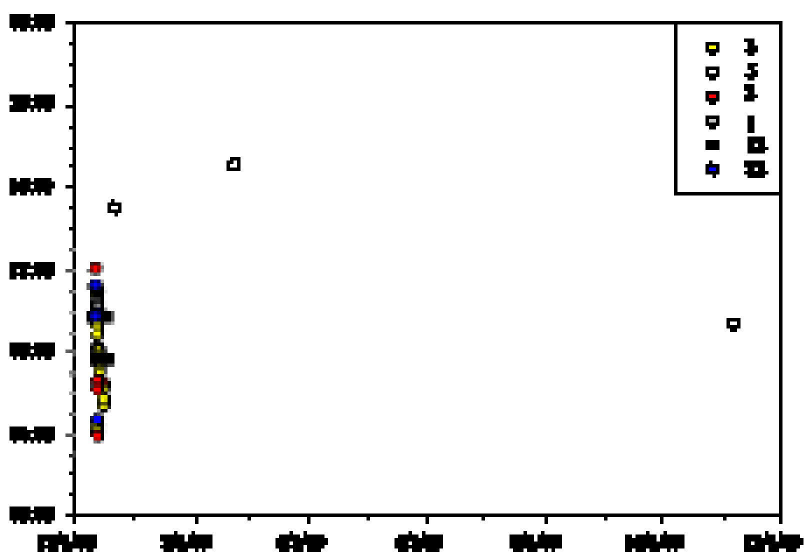

Figure 21. Day and night detection patterns for Bar jack,
Carangoides ruber. Tag # 53781 (35.3 cm TL).

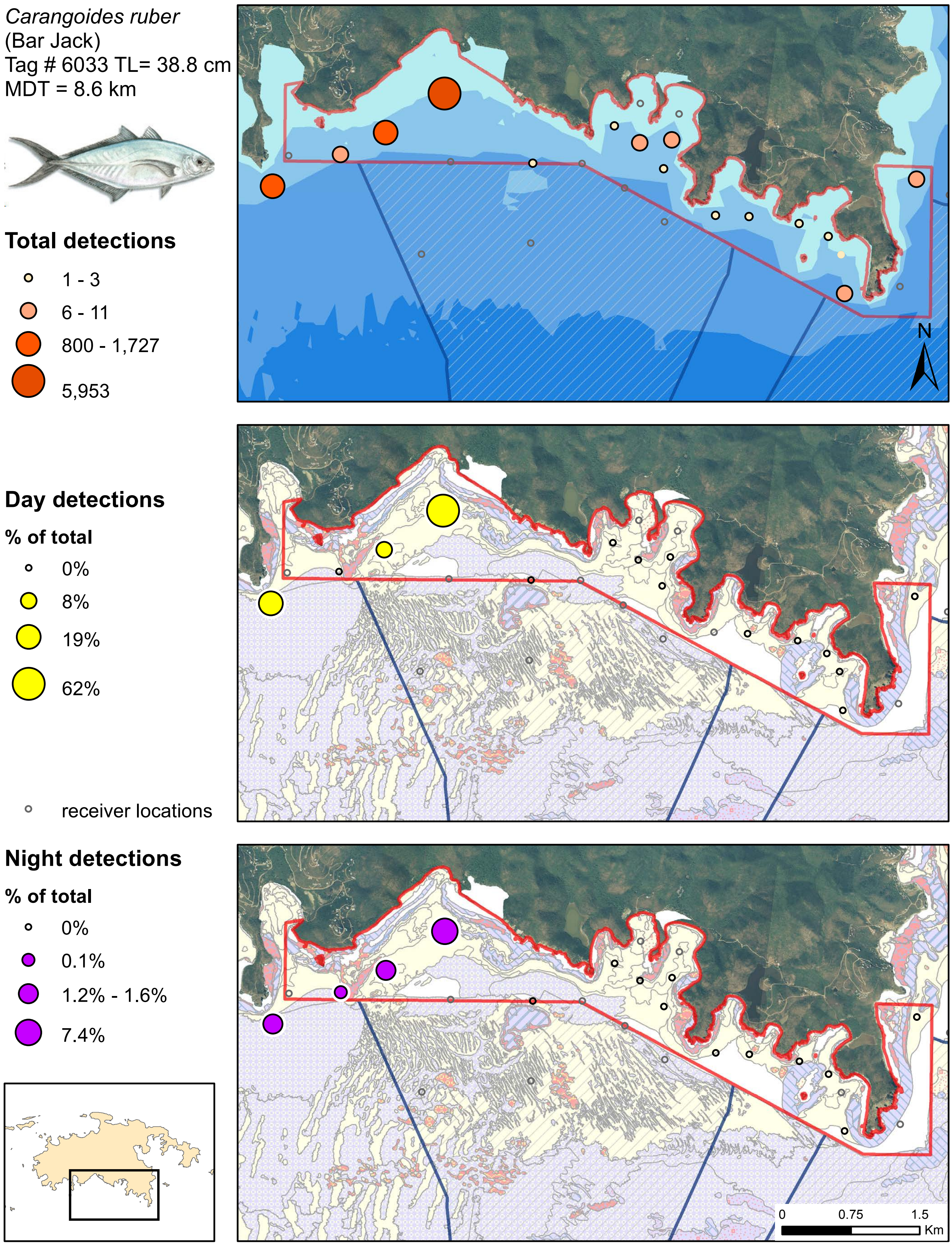

Figure 22. Day and night detections for bar jack, *Carangoides ruber* tag # 6033 (38.8 cm TL).

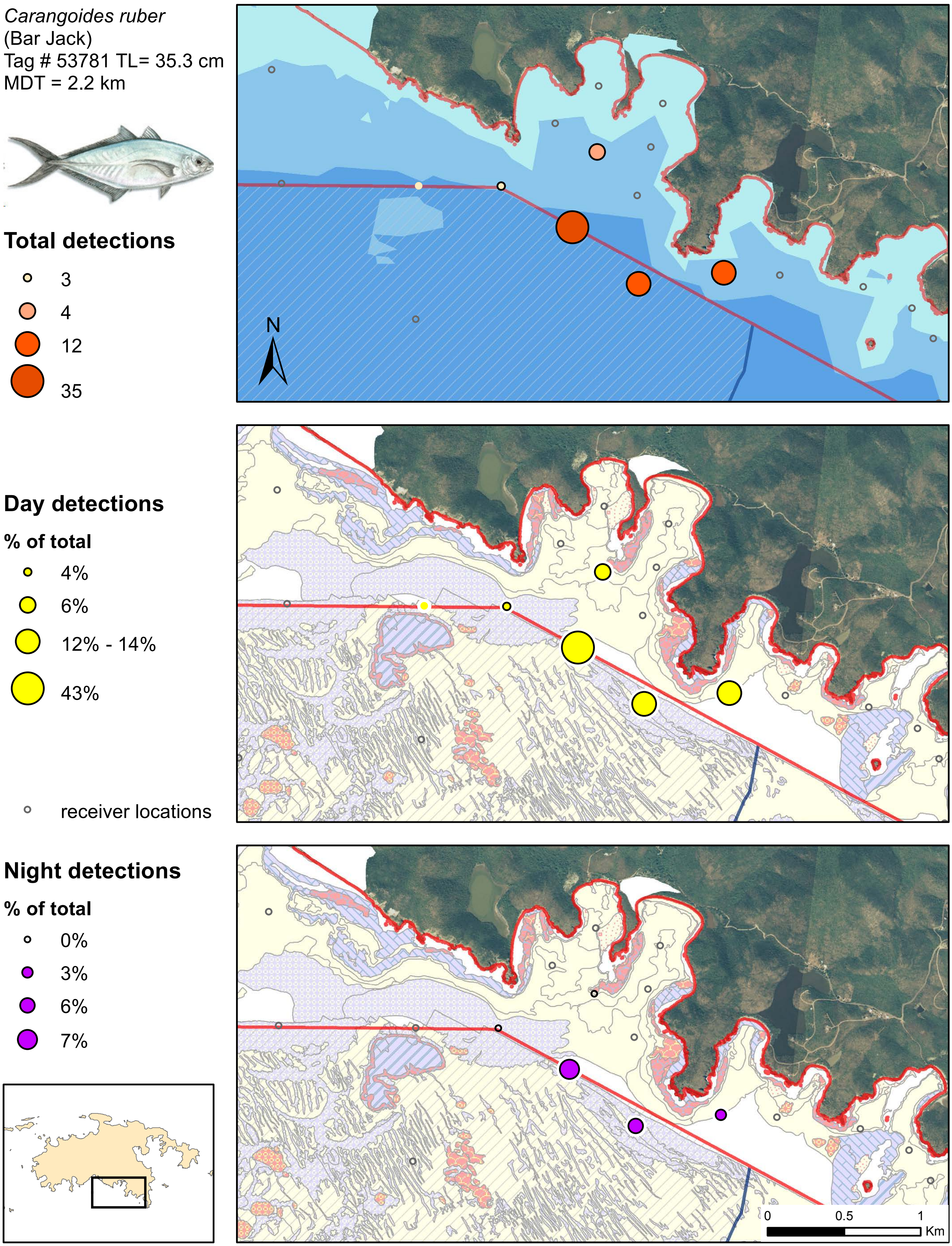

Figure 23. Day and night detections for bar jack - *Carangoides ruber* tag # 53781 (35.3cm TL).

Family Lutjanidae: Snappers

Snappers are a diverse family that consists of 21 genera and 125 species recognized in five subfamilies (Nelson 1994). Lutjanids are generally benthic carnivores although some species are planktivorous. Larger species and individuals tend to be primarily piscivorous, while smaller snappers feed more on crustaceans. They are an important food fish family, but some species in the Caribbean (e.g., Lutjanus jocu and L. cyanopterus) have been implicated in ciguatera poisoning.

Schoolmaster snapper, *Lutjanus apodus*

Schoolmaster snapper are known to reach over 67 cm TL, sometimes form large resting aggregations during the day and feed on fishes, shrimps, crabs, worms, gastropods and cephalopods. Based on SEAMAP-C fisheries-independent trapping data, their rank abundance around St. John declined from 11th overall in 1992-93 to 32nd in 1999-2000.

Only one schoolmaster snapper was acoustically tagged during the study. This 27.0 cm TL fish (tag # 2330) was tagged in Lameshur Bay and was detected on receivers 5,6, and 8 within the bay for two days and then was not detected for more than two months, when it appeared at station 22, just to the east of Cabritte Horn Point (Fig. 22a, 22b, and 23). The fish was intermittently detected on this receiver for two weeks and was absent from the array for ca. 10 months when it briefly was observed at station 27, just to the east of Salt Pond Bay. MDT on the array was 2.8 km but this fish left the array for extended periods of time. This fish was not detected by any other receivers in the broader USCAN array.

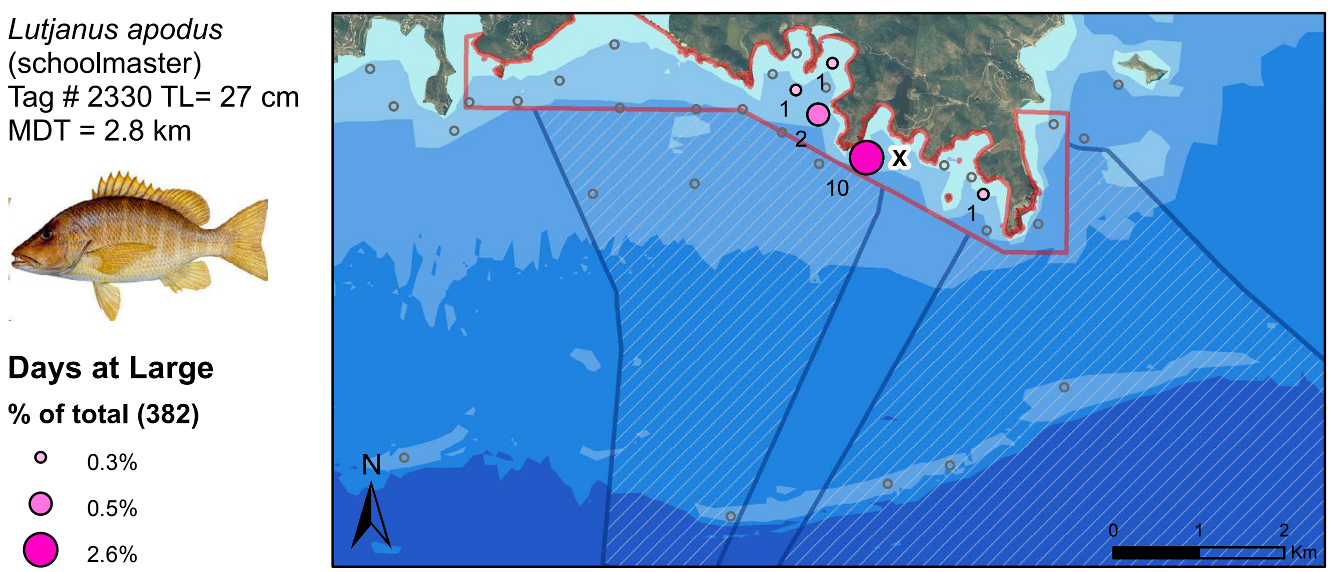

Figure 24a. Detections for schoolmaster snapper, *Lutjanus apodus* tag # 2330 (27.0 cm TL). X = location of capture and release.

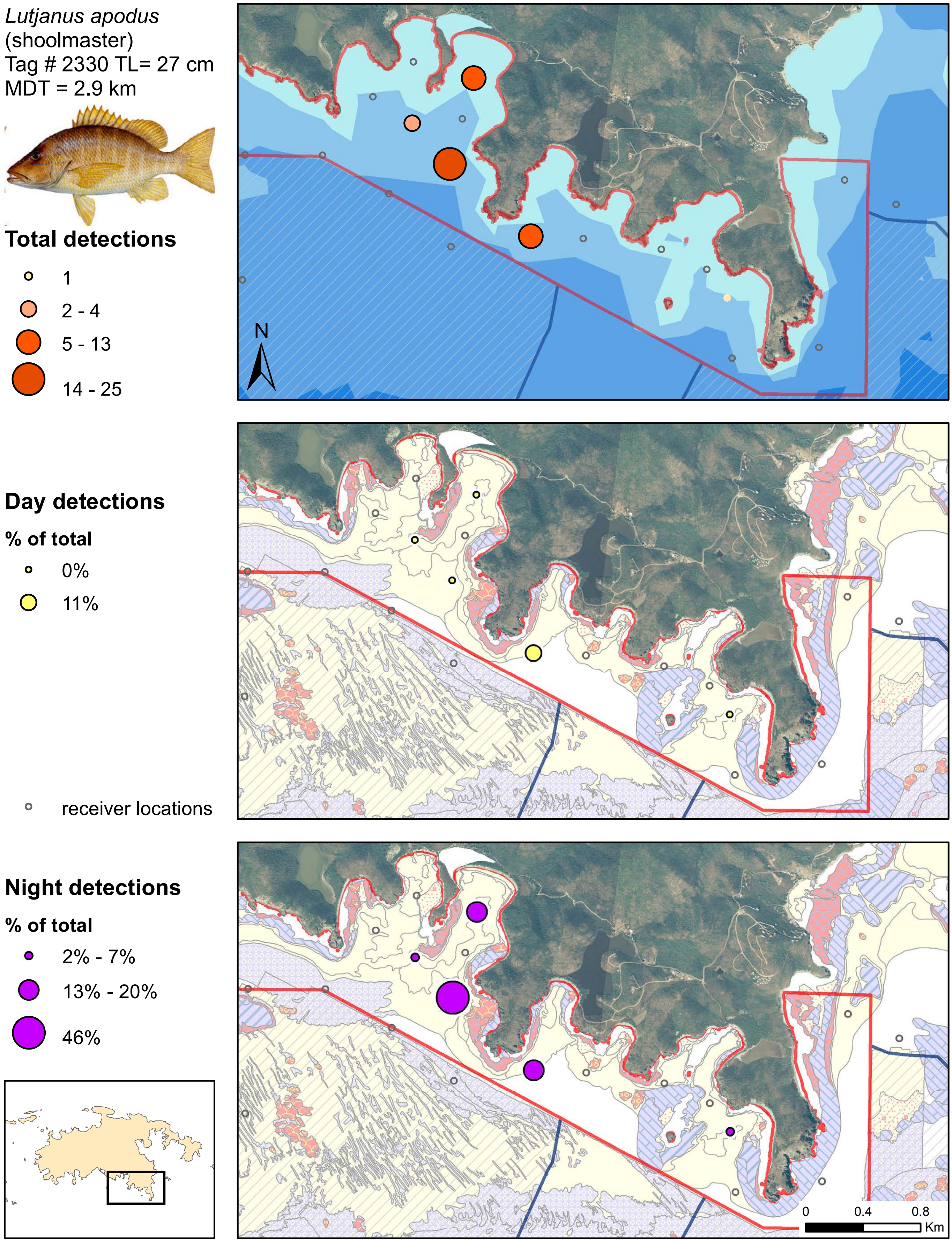

Figure 24b. Day and night detections for schoolmaster snapper, *Lutjanus apodus* tag # 2330 (27.0 cm TL).

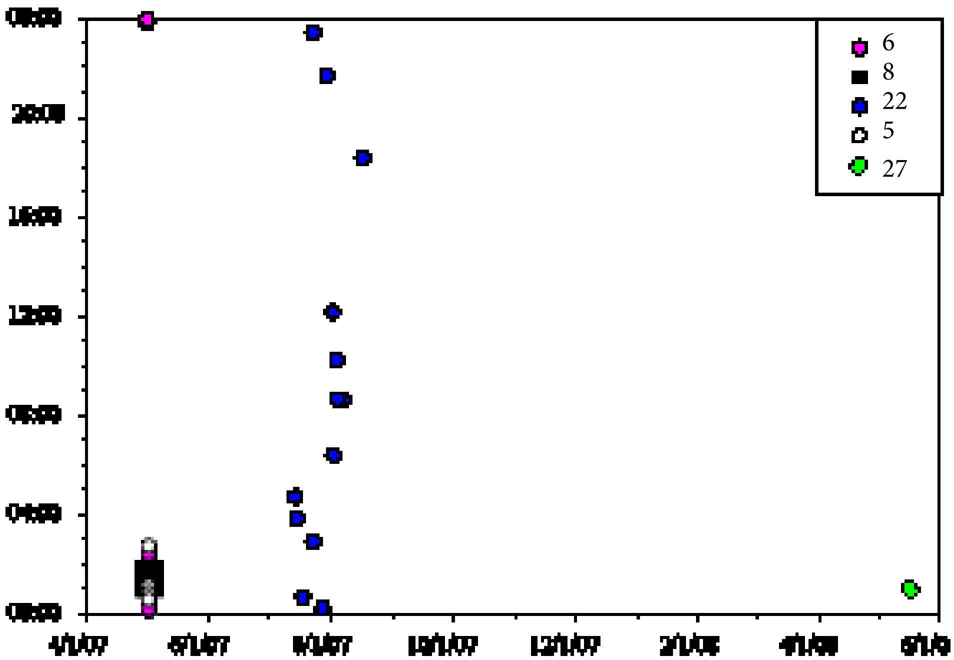

Figure 25. Day and night detection patterns for schoolmaster snapper, *Lutjanus apodus* tag # 2330 (27.0 cm TL).

Mutton snapper, *Lutjanus analis*

Mutton snapper range from Massachusetts to southeast Brazil, including the Caribbean and the Gulf of Mexico. They occur in continental shelf areas, as well as clear waters around islands. Large adults are usually found among rocks and coral while juveniles occur over sandy, vegetated bottoms (usually Thalassia seagrasses). Mutton snappers form small aggregations which disband during the night (Allen 1985). They feed both day and night on fishes, shrimps, crabs, cephalopods, and gastropods.

Twelve mutton snapper were tagged. Days at large are mapped for three individuals (Figure 26) and summaries of day and night movements, as well as longer cross-shelf movements for three individuals are provided here.

The majority of detections for individual #3273 (43 cm TL) occurred at station 27 near Salt Pond Bay, but there was a clear difference between day and night activity. Station 27 was occupied almost exclusively at night except for the initial period after tagging and then in September 2007 and September 2008 for brief periods of time (Fig. 27 and 28). Daytime movements appeared wide-ranging with a MDT of 3.5 km.

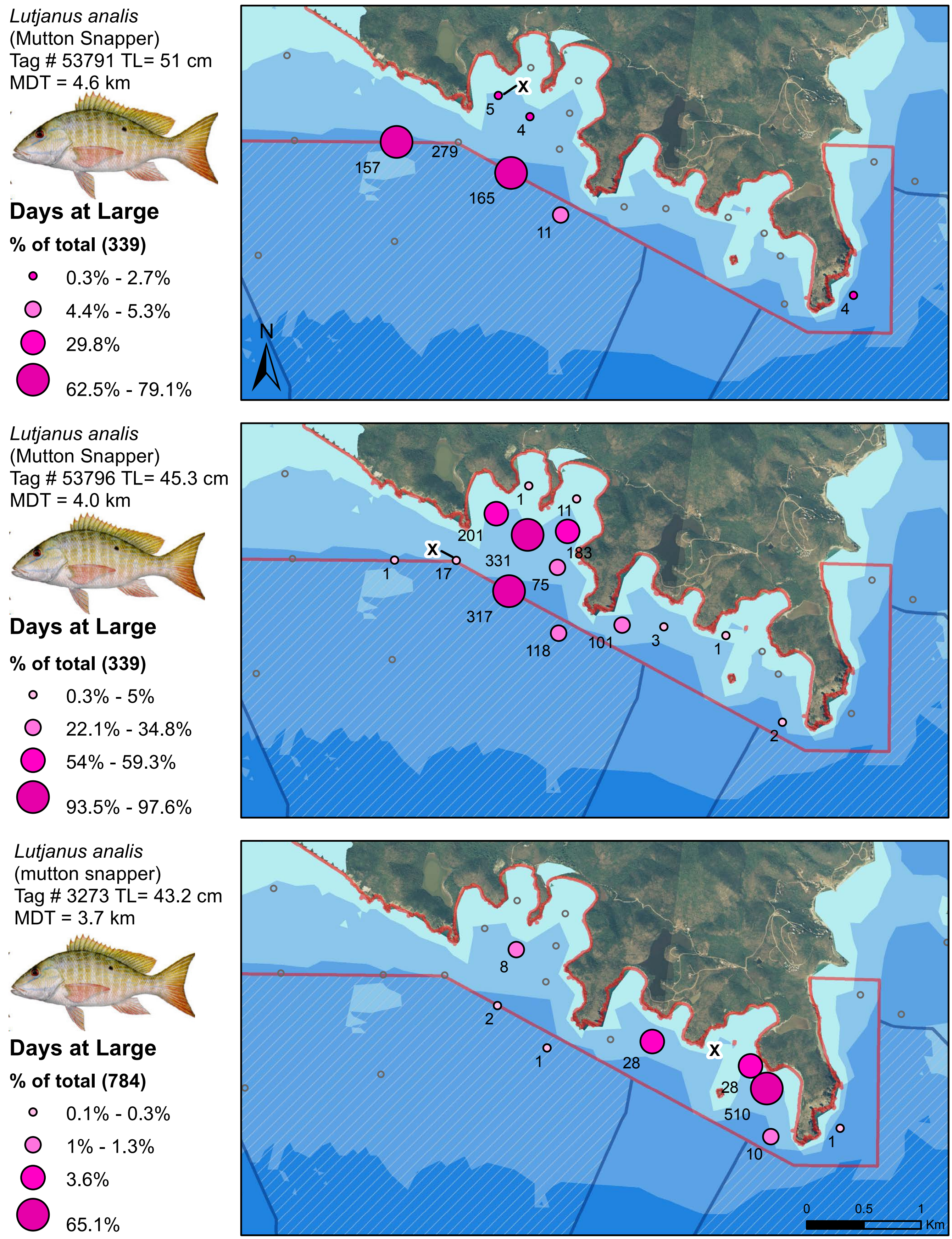

Figure 26. Detections for mutton snapper *Lutjanus analis.* X = location of capture and release.

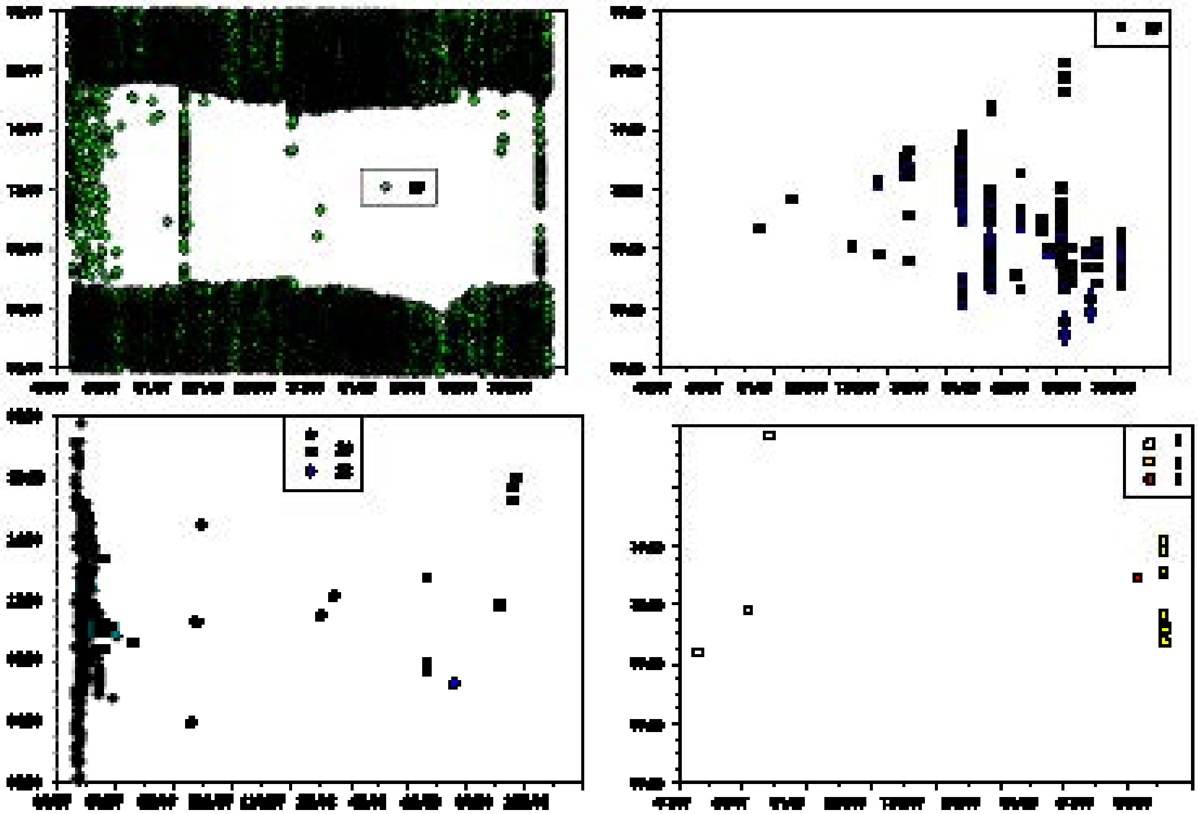

Figure 27. Day and night detections for mutton snapper – *Lutjanus analis* tag # 3273 (43.0 cm TL).

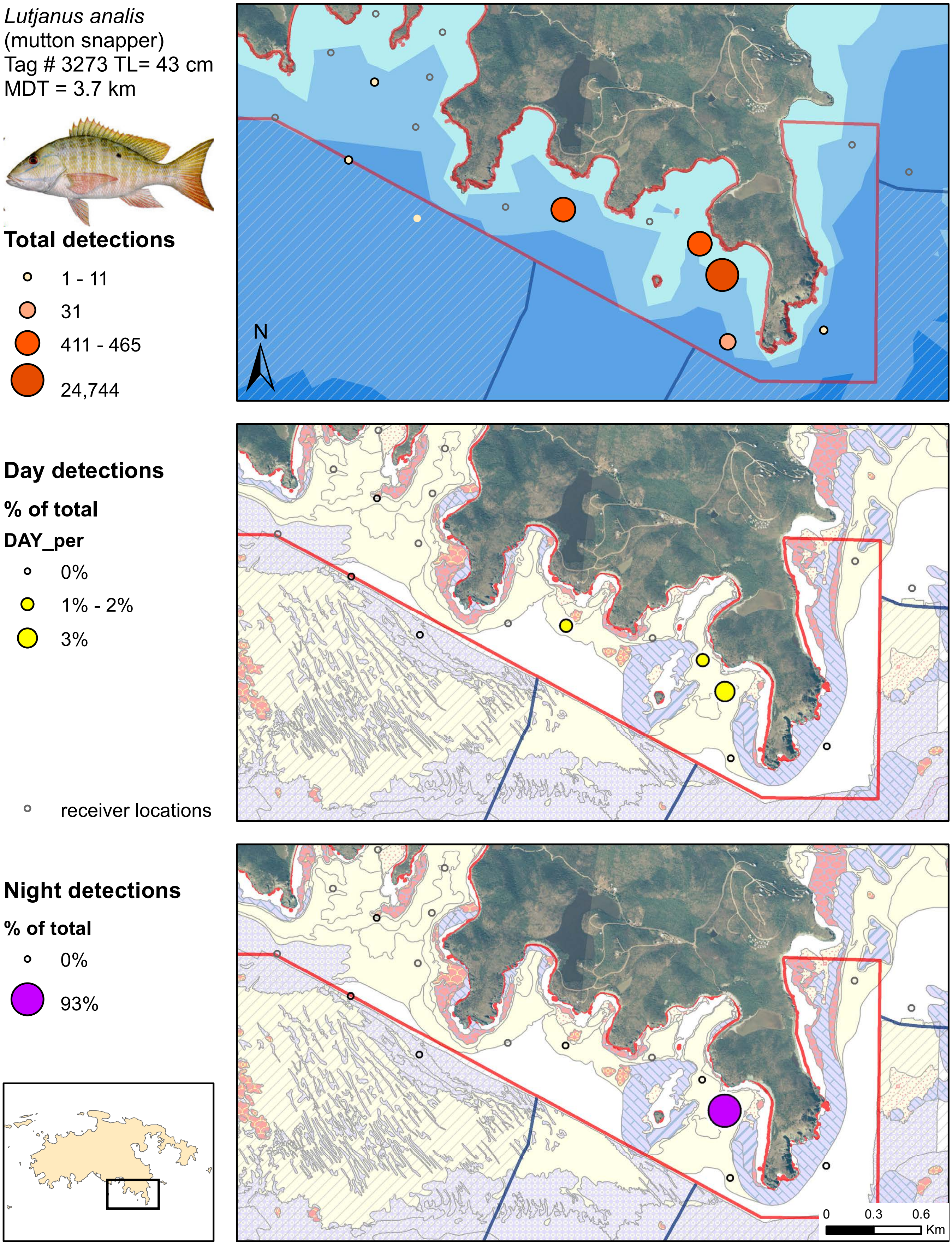

Figure 28. Day and night detections for mutton snapper *Lutjanus analis* tag # 3273 (43.0 cm TL).

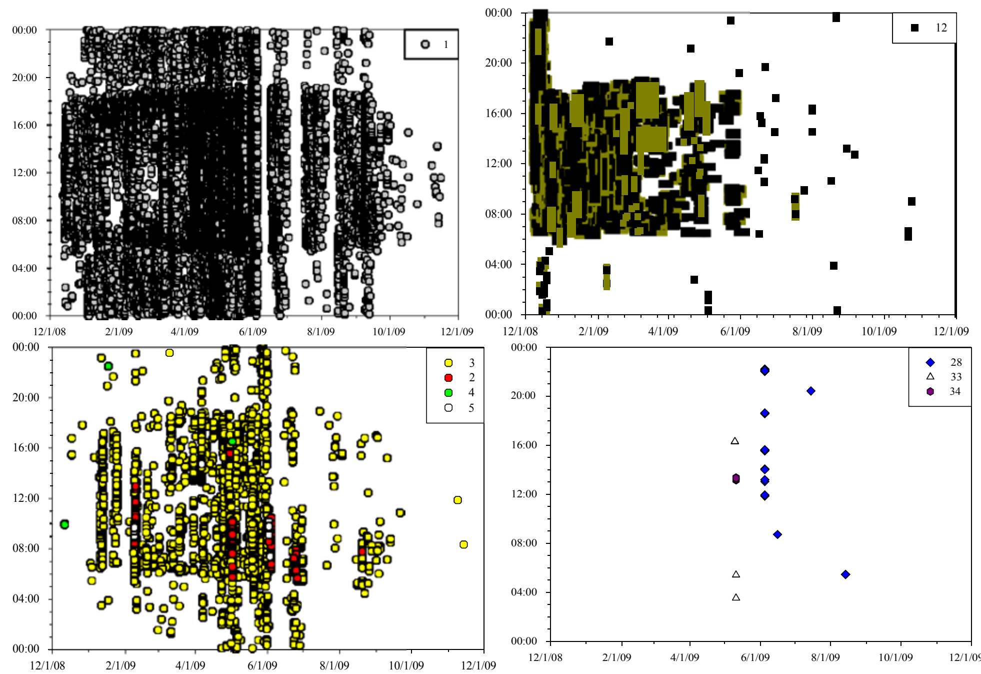

Figure 29. Day and night movement patterns for mutton snapper tag # 53791 (51 cm TL).

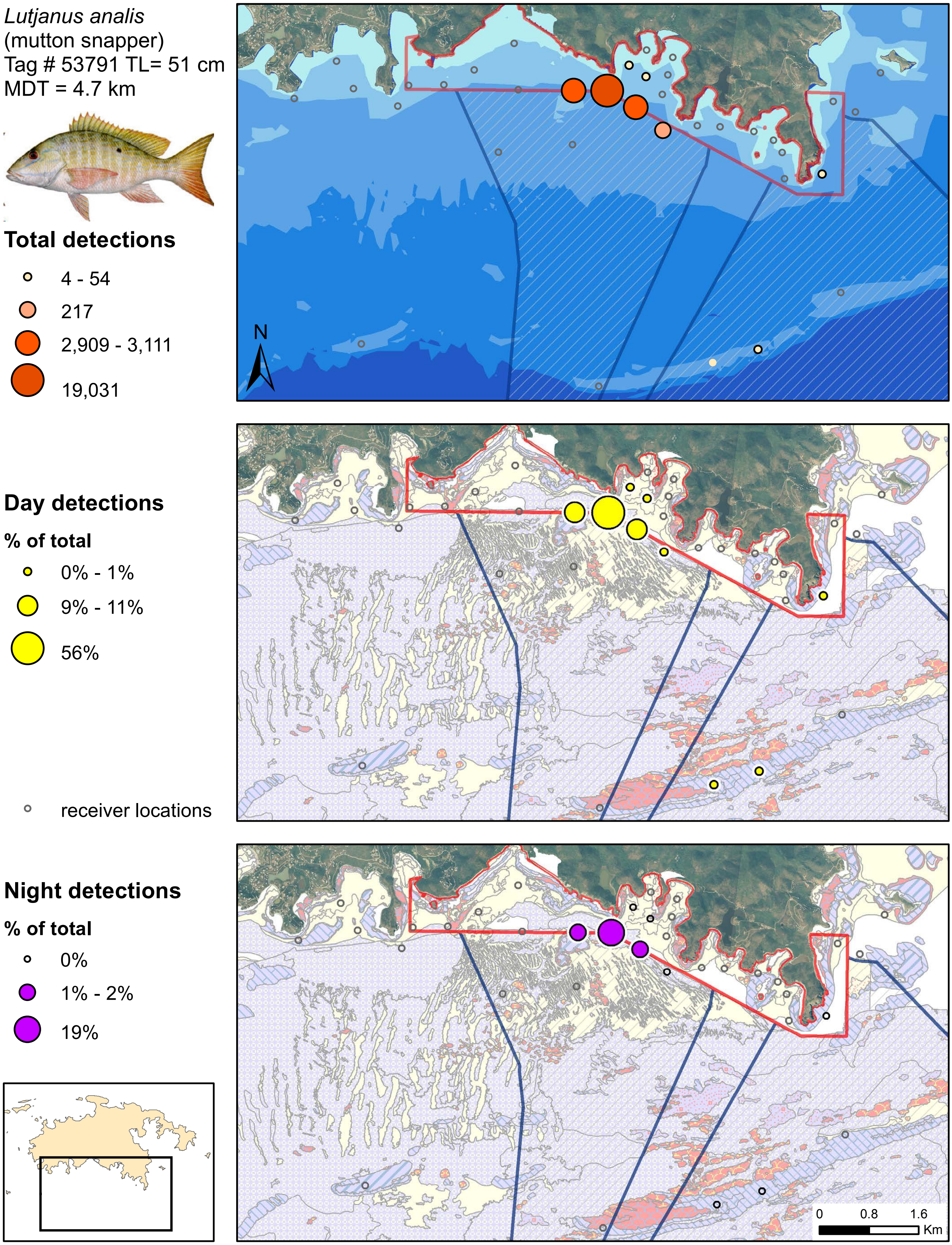

Figure 30. Day and night detections for mutton snapper tag # 53791 (51 cm TL).

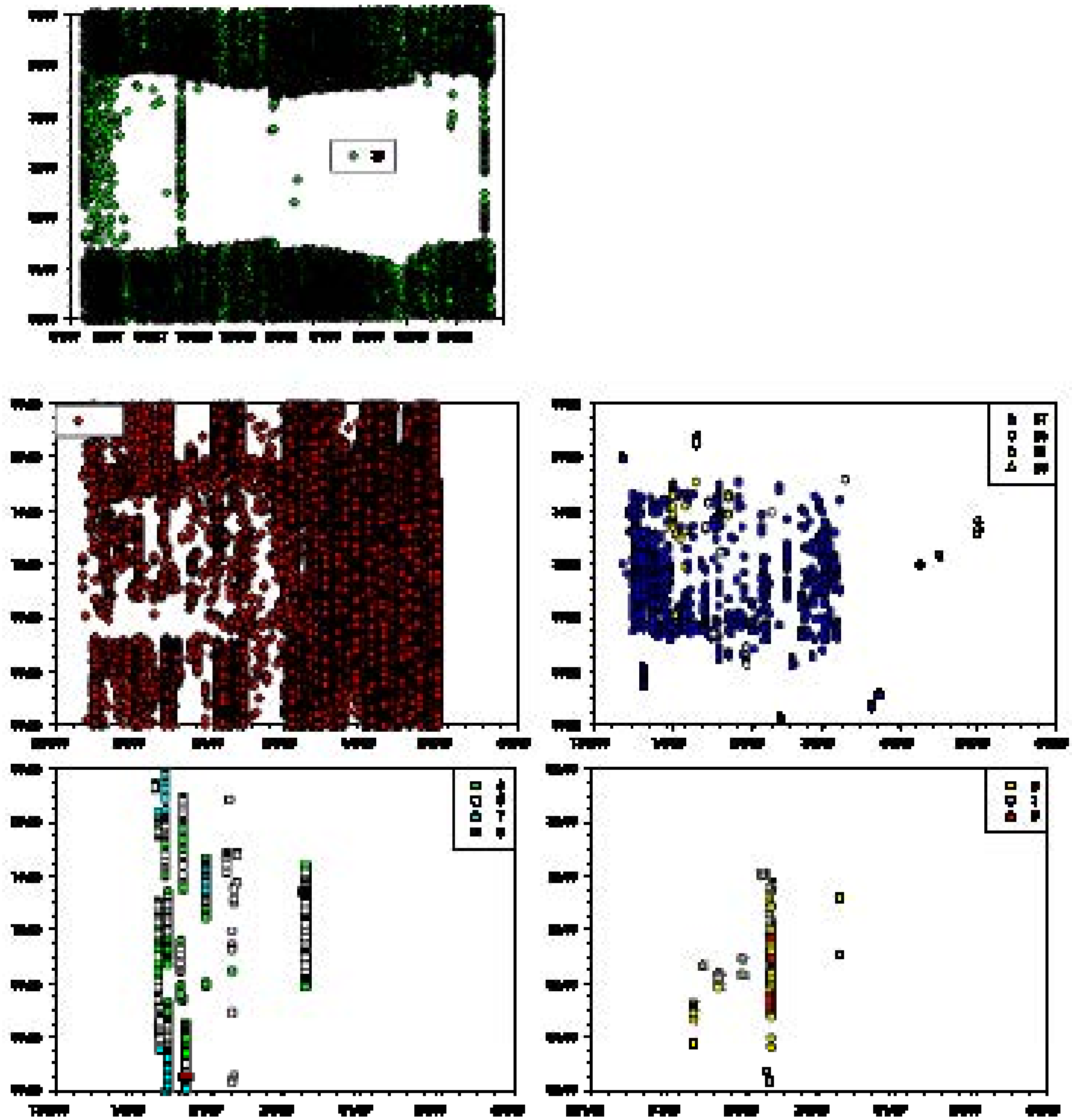

Figure 31. Day and night detection patterns for mutton snapper tag #53798 (65 cm TL).

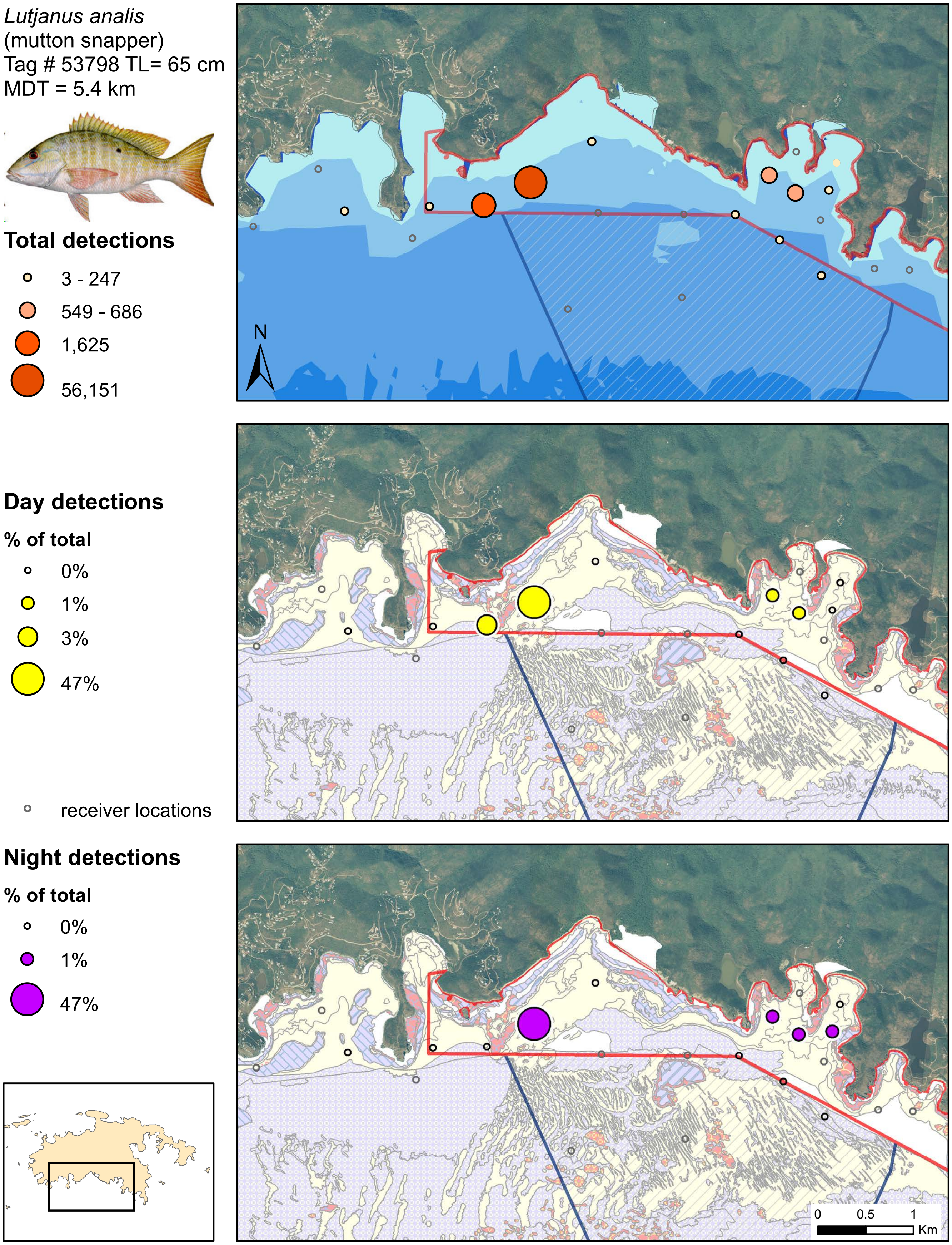

Figure 32. Day and night detections for mutton snapper, *Lutjanus analis,* tag #53798 (65 cm).

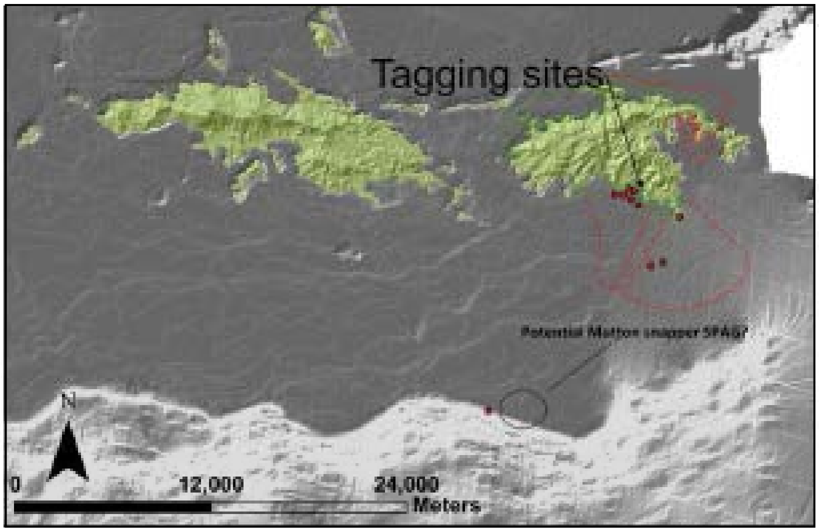

Figure 33. Migration of mutton snapper, *Lutjanus analis,* tag # 53791 from near shore St. John to shelf-edge at spawning time.

For mutton snapper #53791 (45.2 cm), the majority of detections occurred at station 1 with an obvious diurnal cycle (Fig. 29 & 30). Most of the detections on the adjacent stations (12 and 3) occurred during daylight hours. Monthly movements across Lameshur Bay were detected in the months of February, May, June, and July (Figure 29). This fish was also detected at Ram Head and at midshelf reef stations 33 and 34 during the May, June, and July movements. MDT within the array was 4.3 km. However, this fish was also detected on a shelf edge receiver maintained by University of the Virgin Islands (Pittman & Legare 2010). The fish moved widely across the south shore St. John National Park and National Monument and at spawning time was detected at a suspected spawning aggregation on the shelf-edge south of St. John (Figure 33).

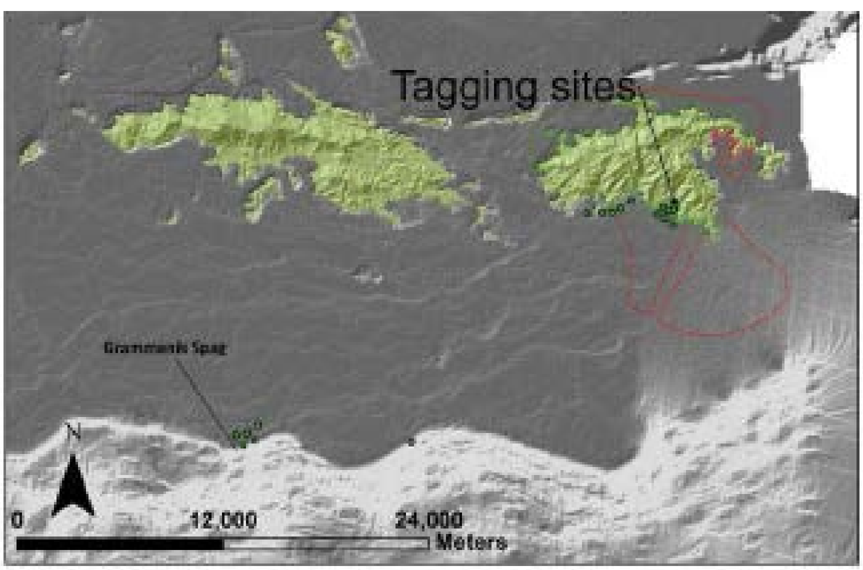

Figure 34. Migration of mutton snapper, *Lutjanus analis,* tag # 53798 (65 cm TL) from near shore St. John to shelf- edge at spawning time.

The majority of the detections for mutton snapper tag # 53798 (51 cm TL) were at station 13, near the western end of Reef Bay (Fig. 31 and 32). Daytime activity space also included the adjacent receiver near Cocoloba Cay (station 17) and inside Reef Bay (station 14) (Fig. 32). This mutton snapper was detected on the receivers inside Lameshur Bay (stations 4, 5, 7, 8) on regular intervals, ca. one month apart. It was briefly detected to the west of Reef Bay at stations 18 and 20 before leaving the array. This fish was also detected on a shelf edge receiver maintained by University of the Virgin Islands (Pittman & Legare 2010). It had moved widely inside and outside of the VI Park and Monument and visited the Grammanik Bank spawning aggregation at spawning time (Figure 34).

Gray snapper, *Lutjanus griseus*

Gray snapper, sometimes called mangrove snapper, are found throughout the tropical Atlantic (Randall 1996). Gray snapper often form large aggregations and feed mainly at night on small fishes, shrimps, crabs, gastropods, cephalopods and some planktonic items. They can reach 89 cm TL and obtain sexual maturity at 26 cm FL in Cuba (García-Cagide et al. 1994). They are an important food fish in many parts of the Atlantic and Caribbean, but are not well represented in the catch around St. John.

Five gray snapper ranging in size from 25 to 35 cm TL (mean = 28.9 ± 4.0 cm TL) were tagged during the study. The mean number of detection days was 329, with a maximum of 657 days at large. Results of three individuals are found in Figure 35.

For gray snapper #53787, most detections occurred on the boundary between VIIS and VICRNM off of Lameshur Bay. Station 1 and 2 received most of the detections with station12 detections occurring primarily in the day, while at night the fish moved inshore inside the bay. MDT for this individual was 1.2 km. Gray snapper #2333 was detected primarily around station 25 just outside Salt Pond Bay. This and the adjacent station 27 were occupied primarily during the day, while at night the fish was much more active and was detected on the major points between Ram Head and Cabritte Horn (Figure 38 and 39). The MDT was 1.6 km. Gray snapper #3169 occupied the space around Cabritte Horn Point and into Lameshure Bay with daytime occupancy closer to shore, while moving out into VICRNM at night (Fig 40 and 41). These fish were not detected at any other receivers within the broader USCAN array.

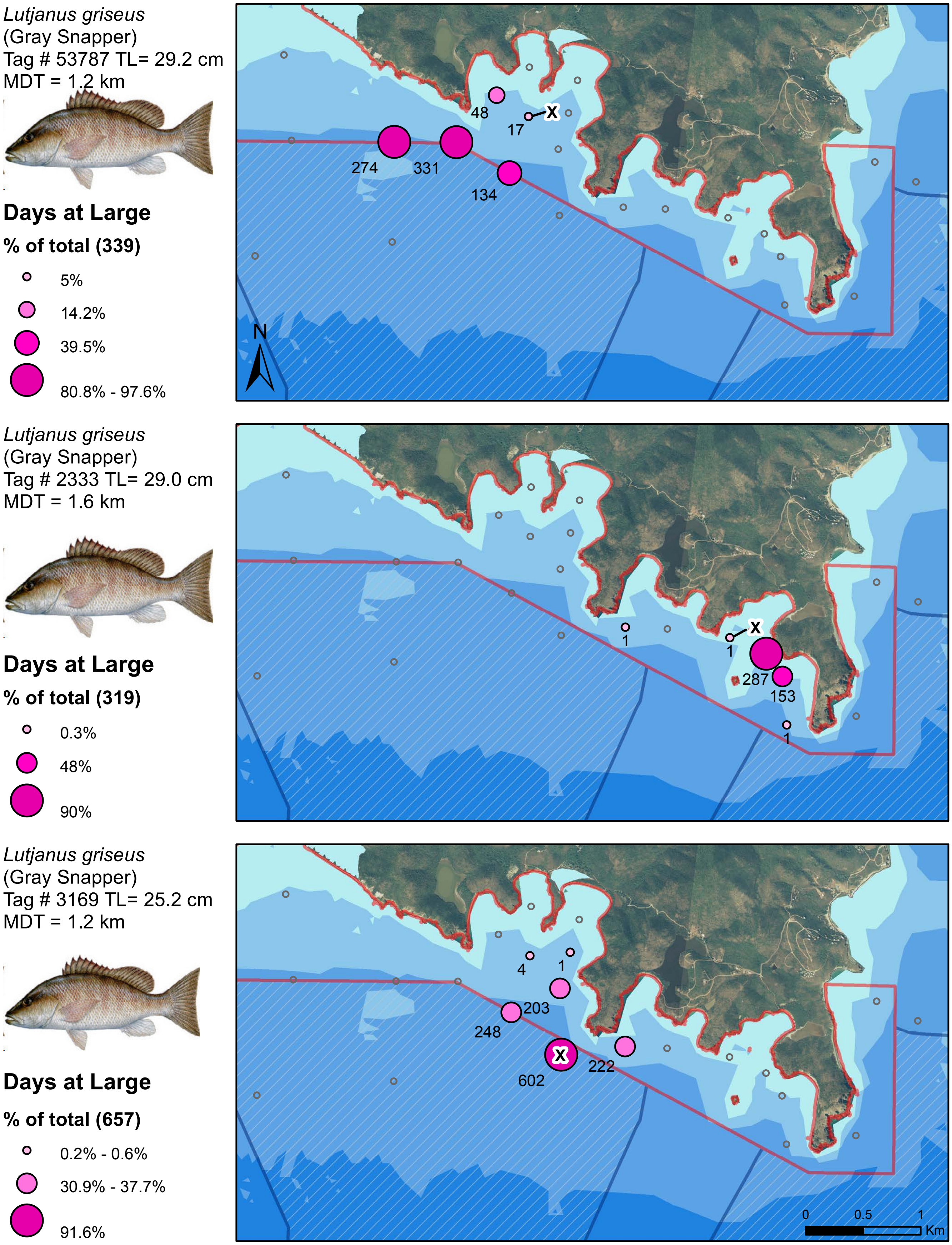

Figure 35. Detections for gray snapper, *Lutjanus griseus*. X = location of capture and release.

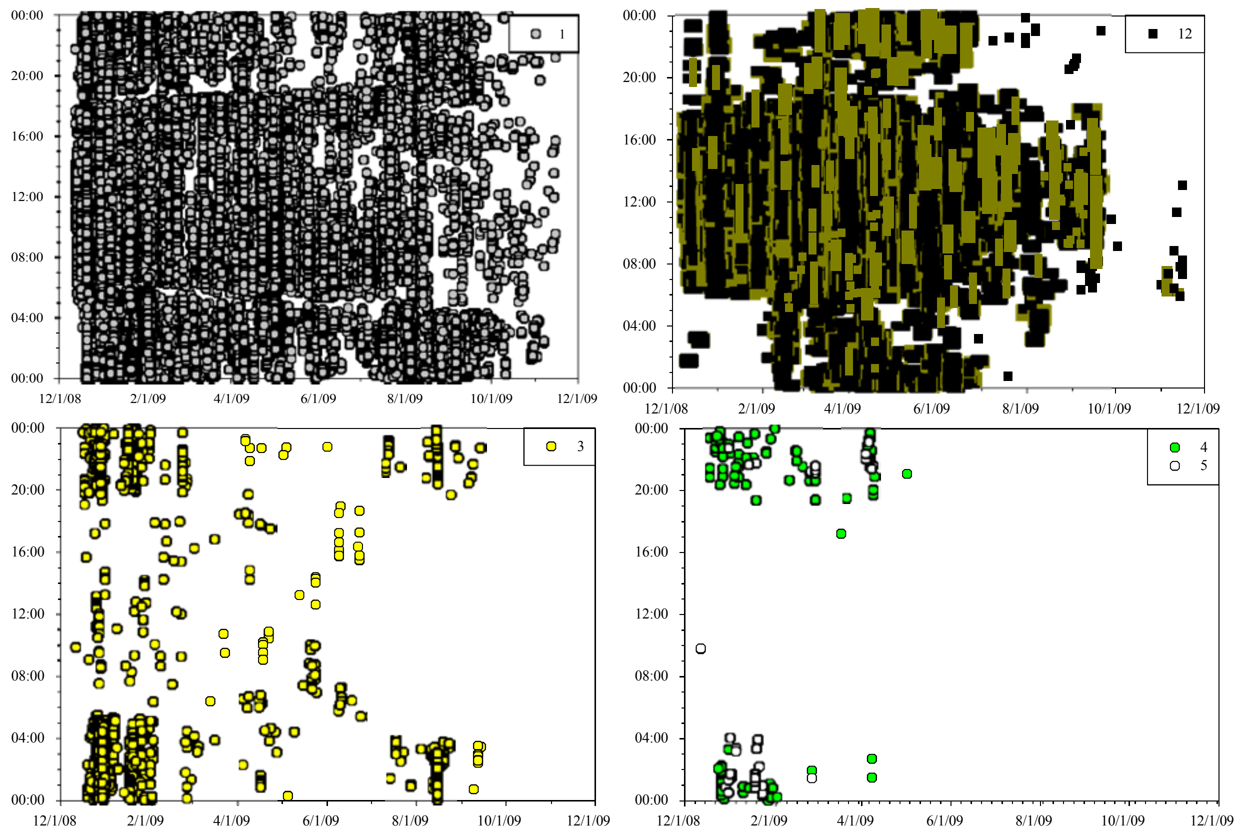

Figure 36. Day and night detections for gray snapper, *Lutjanus griseus,* tag # 53787 (29.2 cm TL)

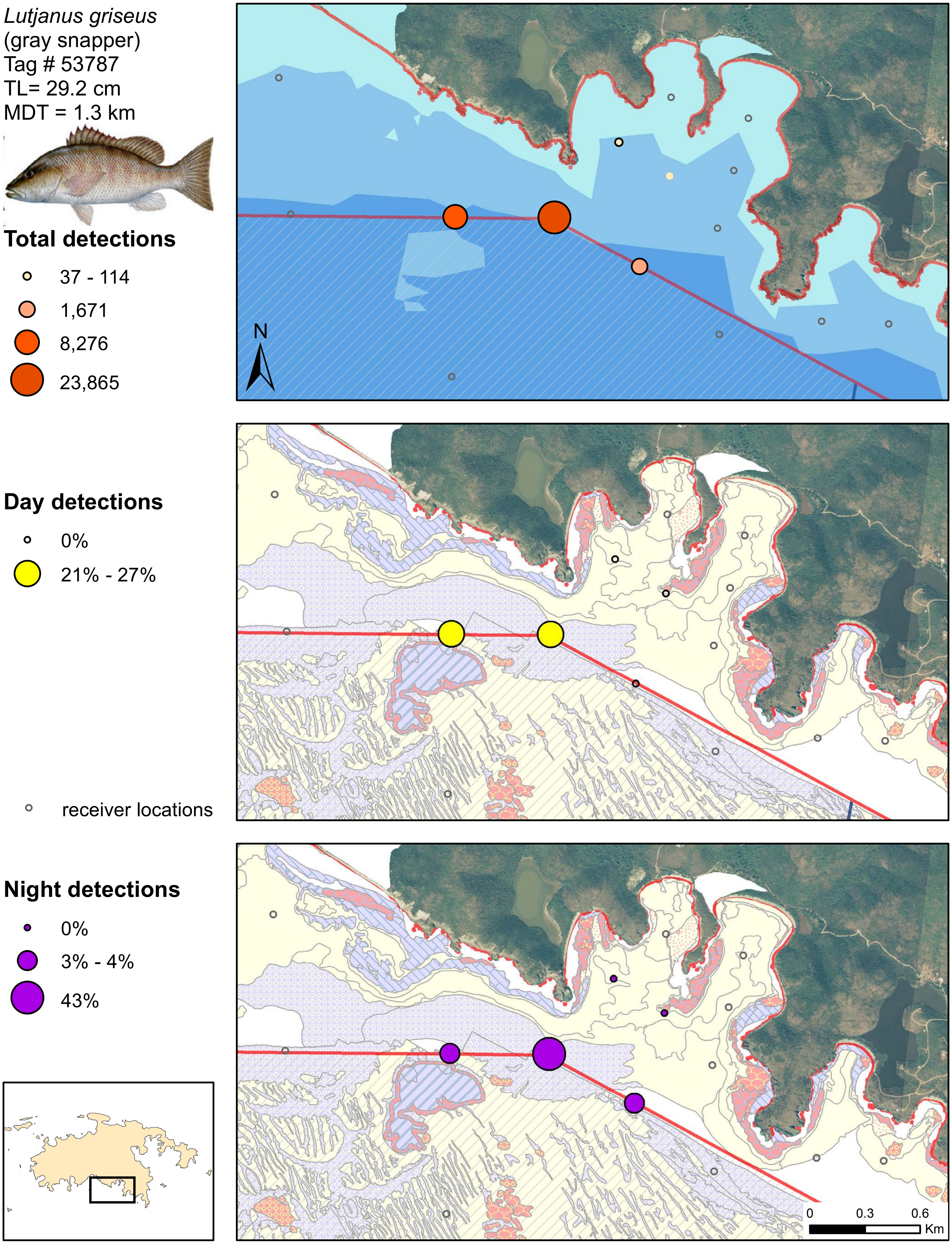

Figure 37. Day and night detections for gray snapper, *Lutjanus griseus,* tag # 53787 (29.2 cm TL)

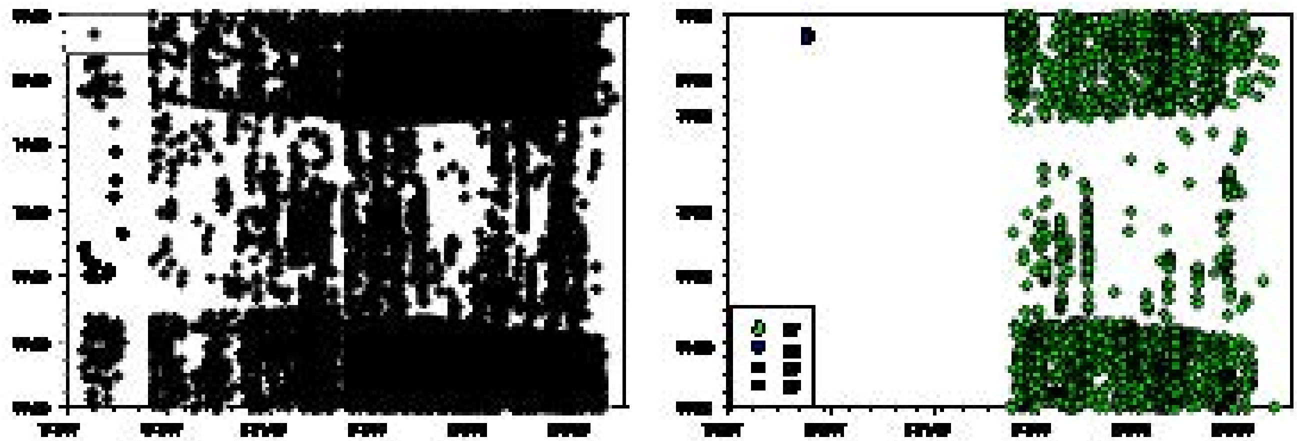

Figure 38. Day and night detections for gray snapper, *Lutjanus griseus,* tag # 2333 (29.0 cm TL)

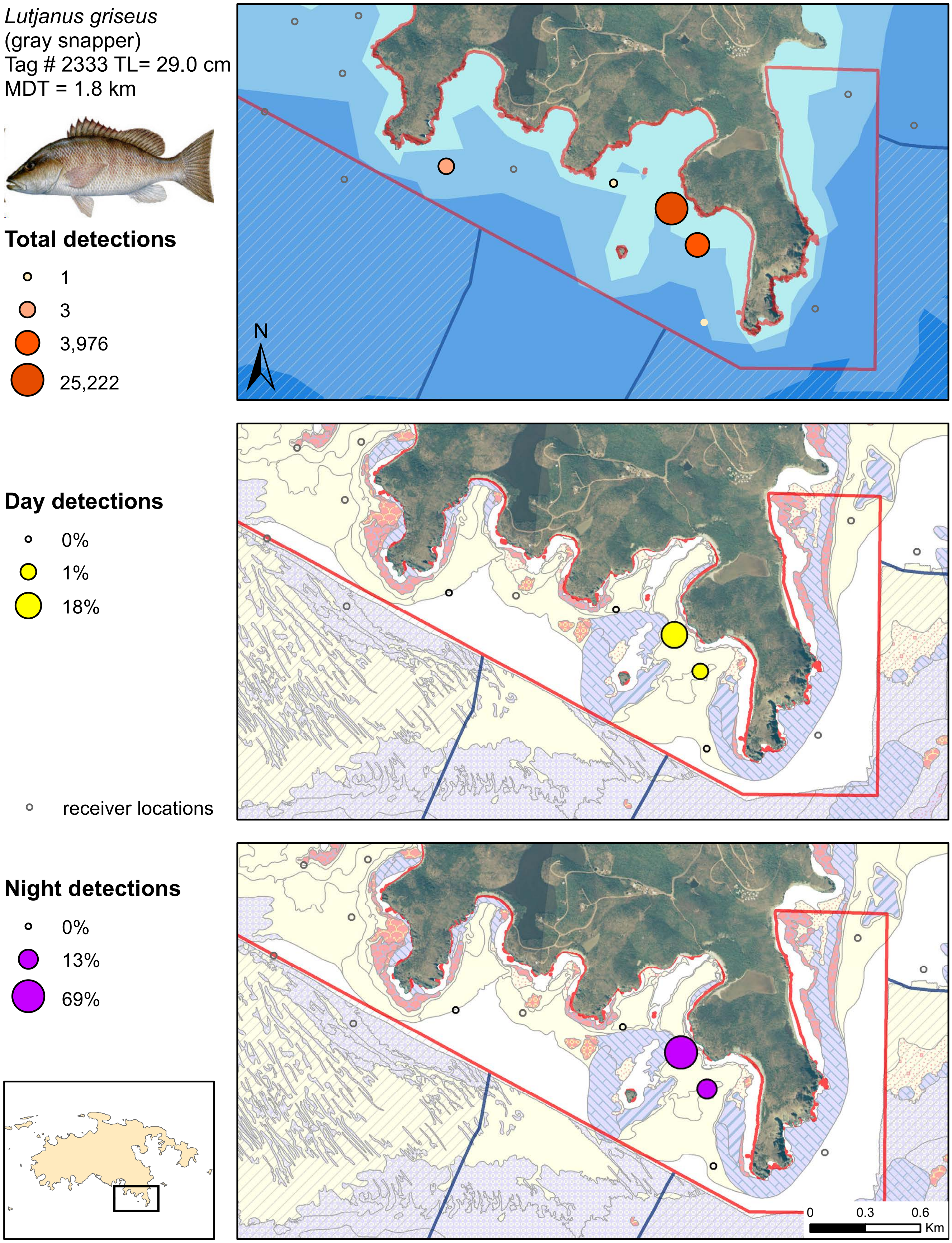

Figure 39. Day and night detections for gray snapper, *Lutjanus griseus,* tag # 2333 (29.0 cm TL)

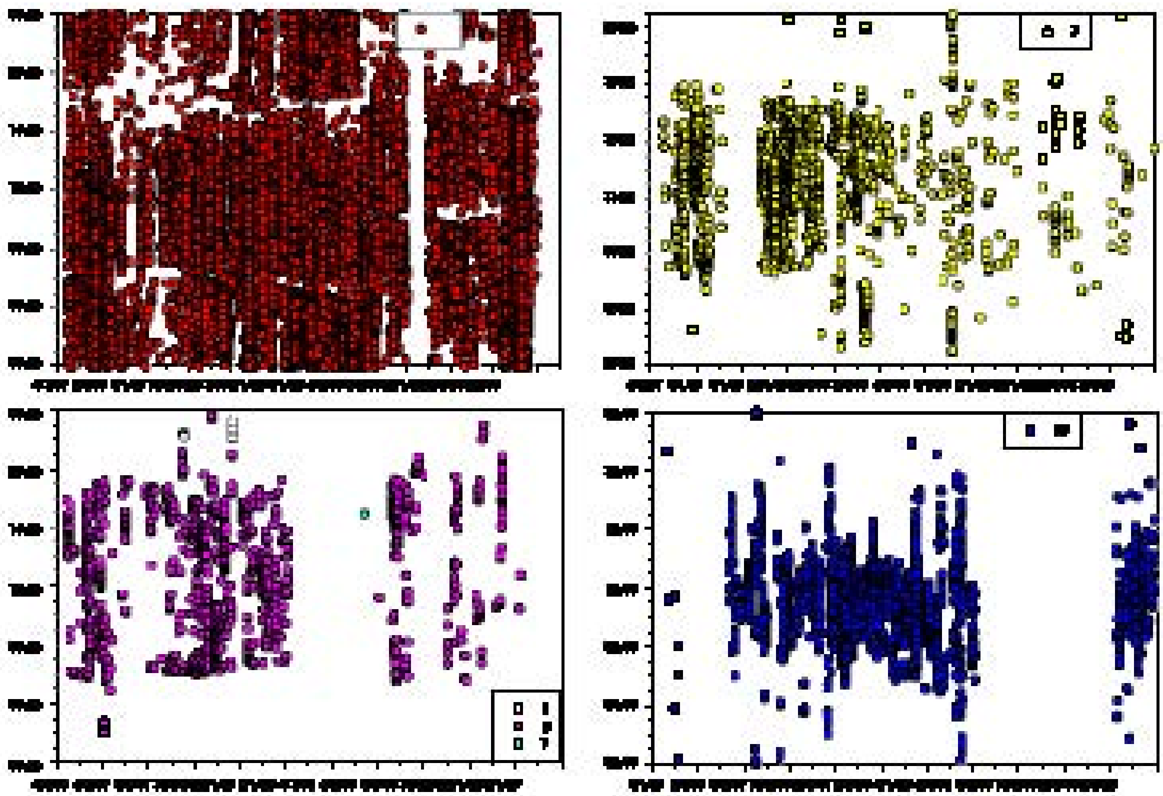

Figure 40. Day and night detections for gray snapper, *Lutjanus griseus*, tag # 3169 (25.2 cm TL)

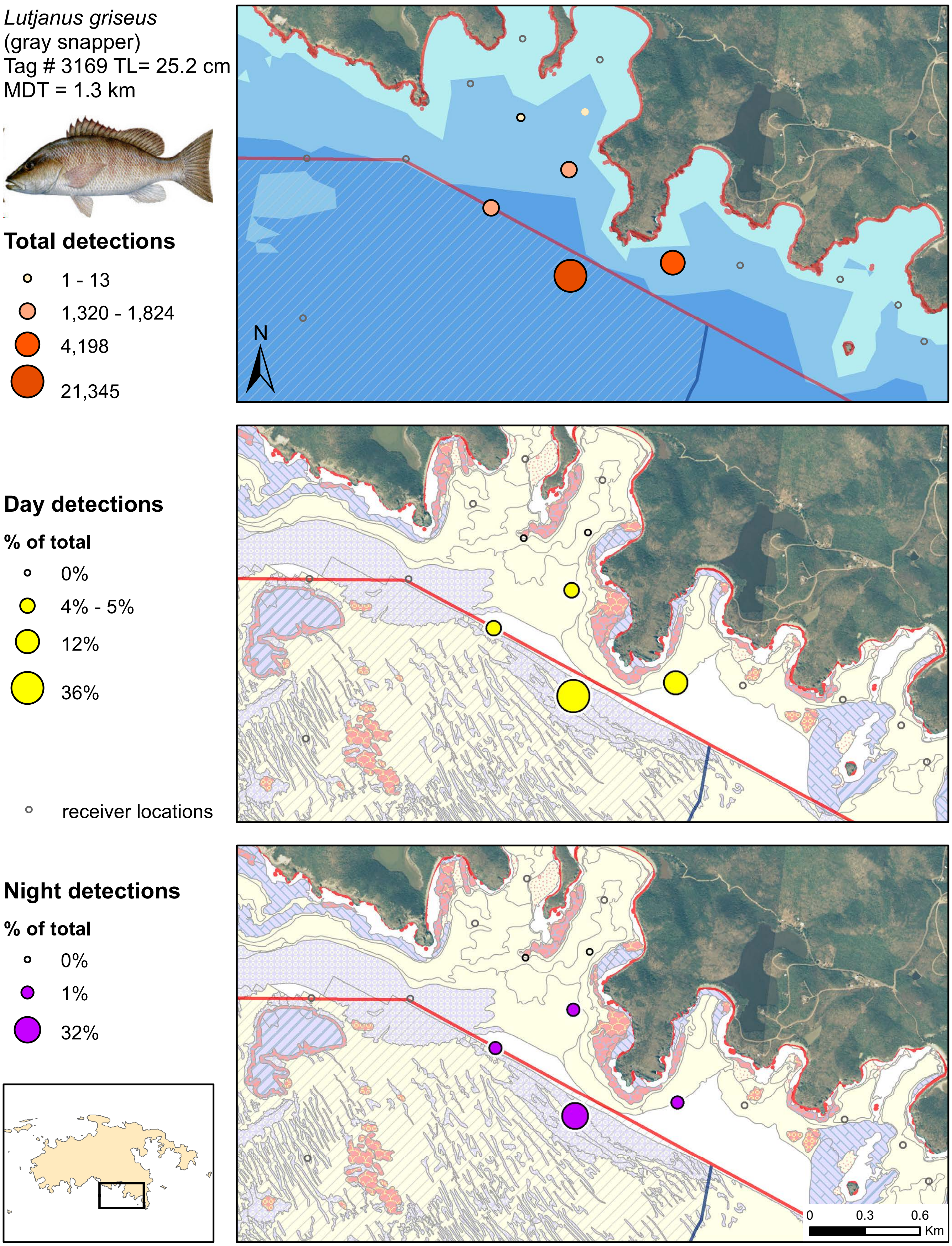

Figure 41. Day and night detections for gray snapper, *Lutjanus griseus,* tag # 3169 (25.2 cm TL).

Dog snapper, *Lutjanus jocu*

Dog snappers have a broad distribution and range from Massachusetts to São Paulo, Brazil (Floeter et al. 2003), including the Gulf of Mexico and the Caribbean Sea (Randall 1996). They have also been reported in the eastern Atlantic at St. Paul's Rocks and Ascension Island, as well as Tinhosa Grande, south of Príncipe Island (Lubbock and Edwards 1981). Adults are common around rocky or coral reefs, while young are found in estuaries and occasionally enter rivers. They feed mainly on fishes and benthic invertebrates, including shrimps, crabs, gastropods and cephalopods. The largest recorded dog snapper is 128 cm TL with a maximum published weight of 28.6 kg.

We tagged a single 41.4 cm TL dog snapper that was at large for 311 days and had a MDT of 6.8 km. This fish was tagged off station 12 and was detected on this receiver primarily at night between December 2007 and April 2008. After that, it moved out to the midshelf reef, a distance of 5.6 km. It was also detected at station 31 off LeDuc Island, which is 6.2 km away and located outside of any protected areas. This fish made a number of migrations between these two locations between May and September 2008. Overall activity was much higher during the night. This fish was not detected elsewhere on the USCAN array.

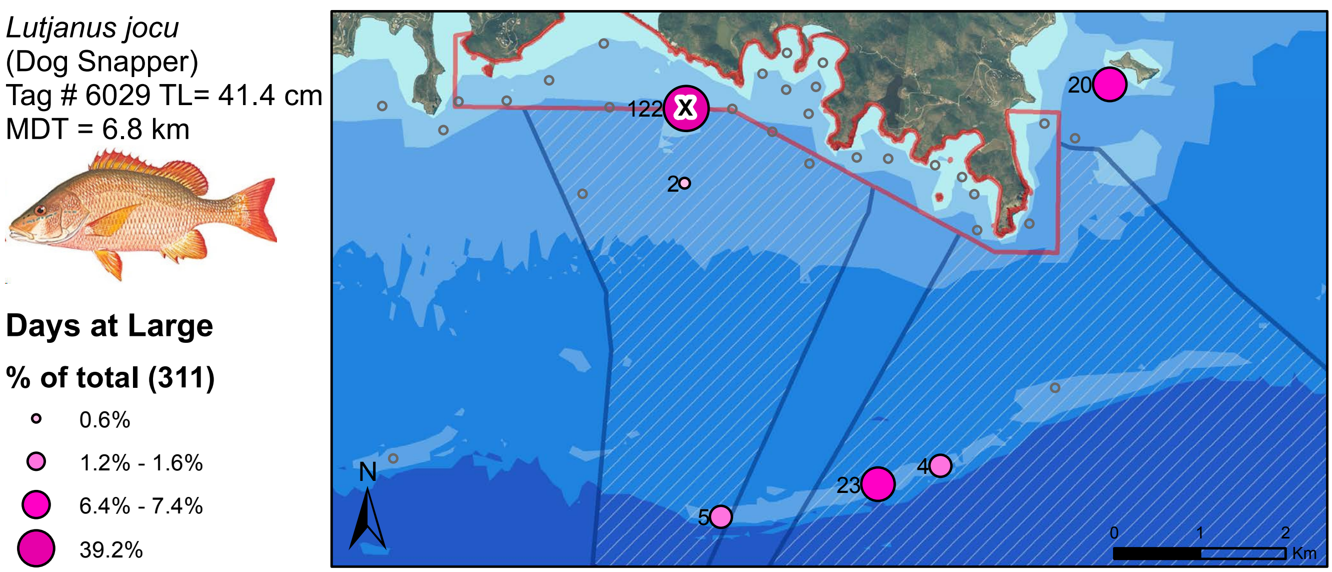

Figure 42. Receiver detections for dog snapper, *Lutjanus jocu,* tag # 6029 (41.4 cm TL). X = location of capture and release.

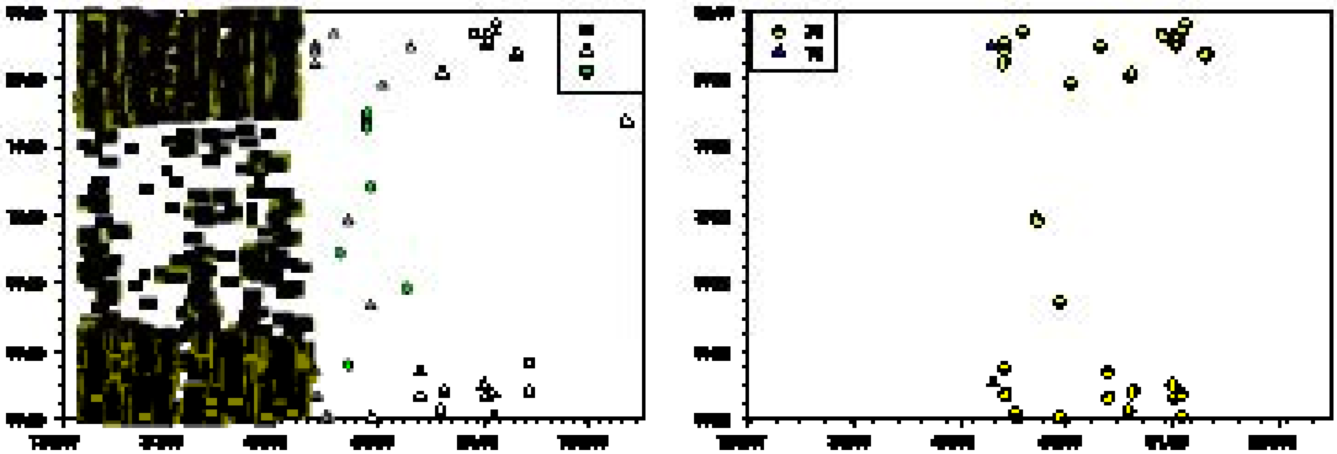

Figure 43. Day and night detections for dog snapper tag # 6029 (41.4 cm TL)

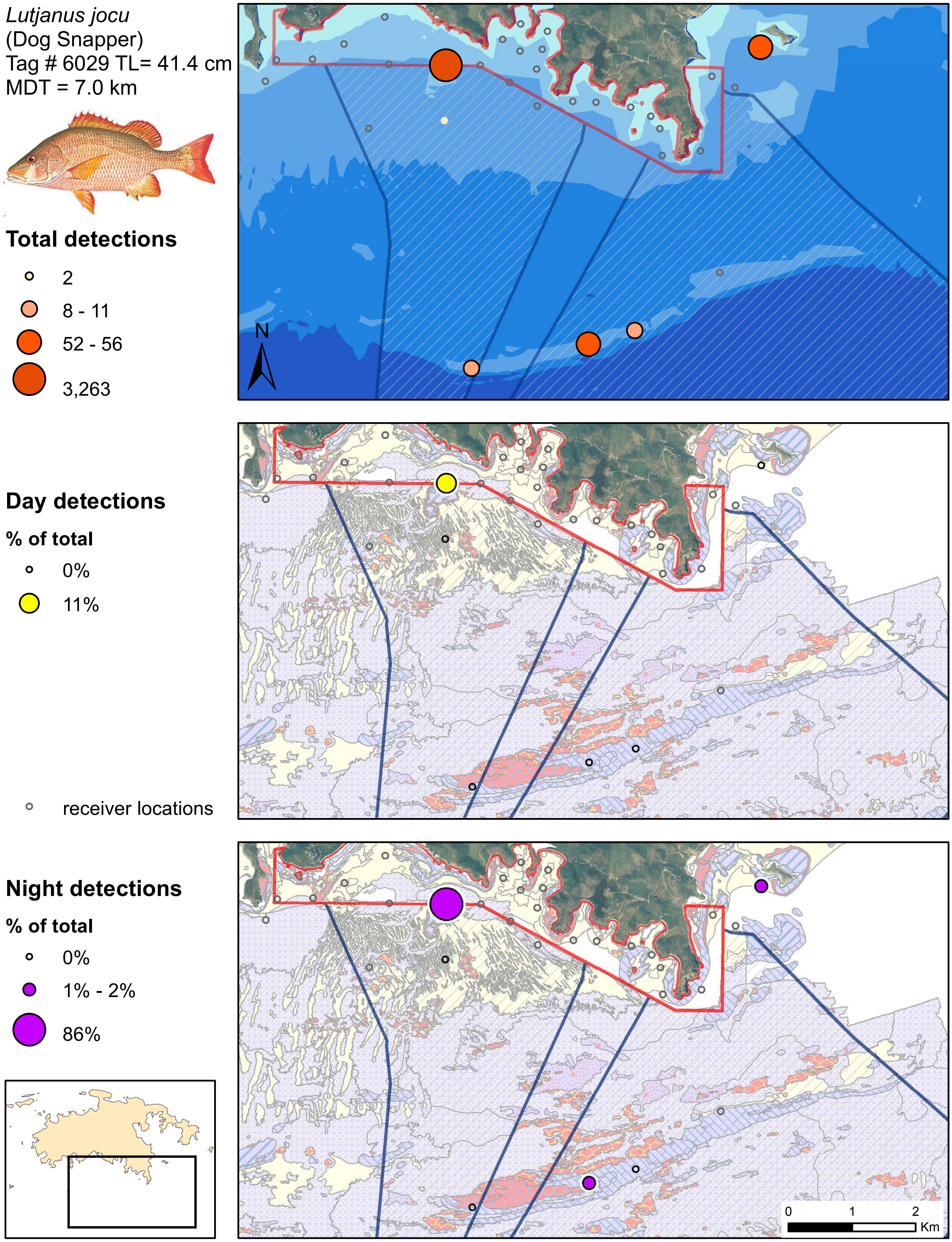

Figure 44. Day and night detections for dog snapper tag # 6029 (41.4 cm TL)

Lane snapper, *Lutjanus synagris*

Lane snapper range from North Carolina to Brazil and in shallow water to depths of over 400 m (Randall 1996). They are found in clear coral reef waters, as well as turbid, muddy areas. Lane snappers are known to reach 60 cm TL and often form large aggregations, especially during the breeding season. They feed at night on small fishes, bottom-living crabs, shrimps, worms, gastropods and cephalopods. They were the 2nd most common snapper observed in traps around St. John, accounting for 31% of the total (Garrison et al. 2004, Friedlander and Monaco 2007). Previous acoustically tagged Lane snapper around St. John showed strong site fidelity to daytime resting areas and regular departures at sunset to nocturnal foraging areas with a return at sunrise (Monaco et al. 2009a) Results from the movement of three lane snappers is found in Figure 43.

Lane snapper # 3197 (32.0 cm) had a MDT of 1.2 km and was active during the day both in Lameshur Bay and in the adjacent seagrass offshore at night. Most of the detections were outside the bay in VICRNM or just at the mouth of the bay to the west (Fig. 46 and 47). Lane snapper # 3245 (27.0 cm) was at large for 722 and had a MDT of 1.0 km. It spent most of its time around Cabritte Horn Point during the day, while at night it passed by station 2 offshore but seemed to go further offshore since it was only detected on the receiver at dawn and dusk while leaving and returning to the bay (Fig 48 and 49). One fish (#3255) was also detected on a NMFS receiver in Fish Bay.

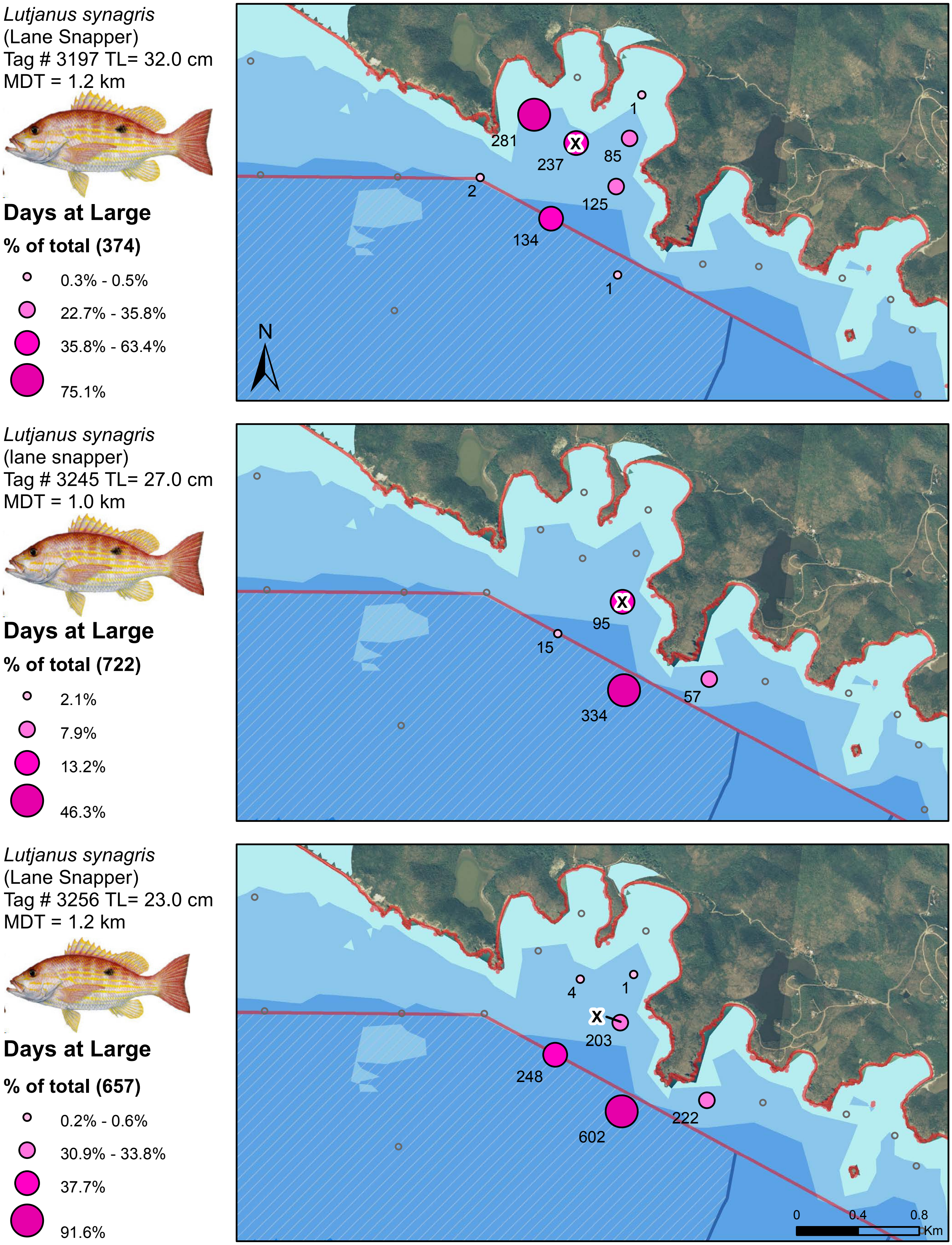

Figure 45. Receiver detections for lane snapper, *Lutjanus synagris*. X = location of capture and release.

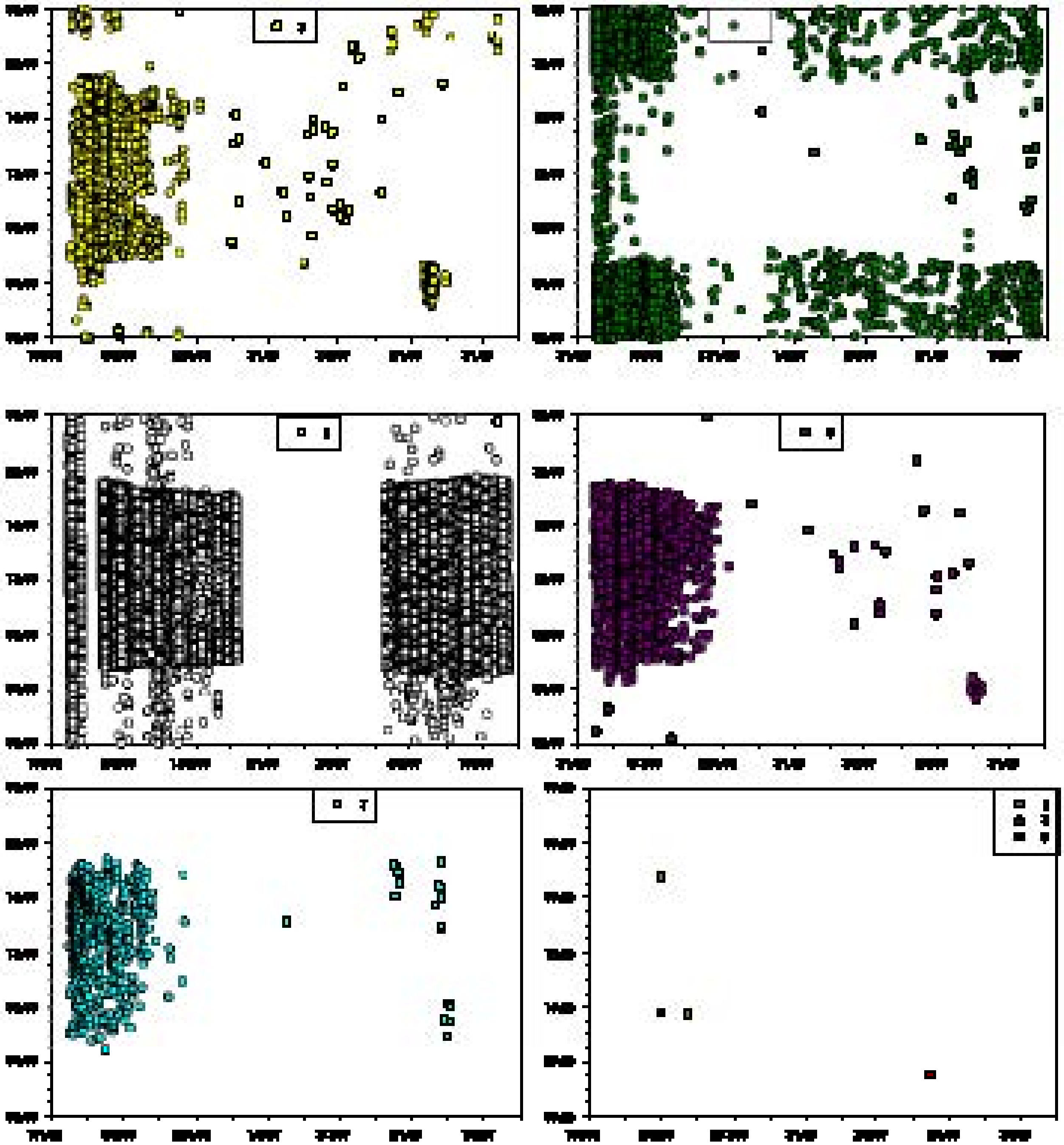

Figure 46. Day and night detection patterns for lane snapper, *Lutjanus synagris*, tag # 3197 (32 cm TL). Days at large = 374, minimum distance travelled = 1.2 km.

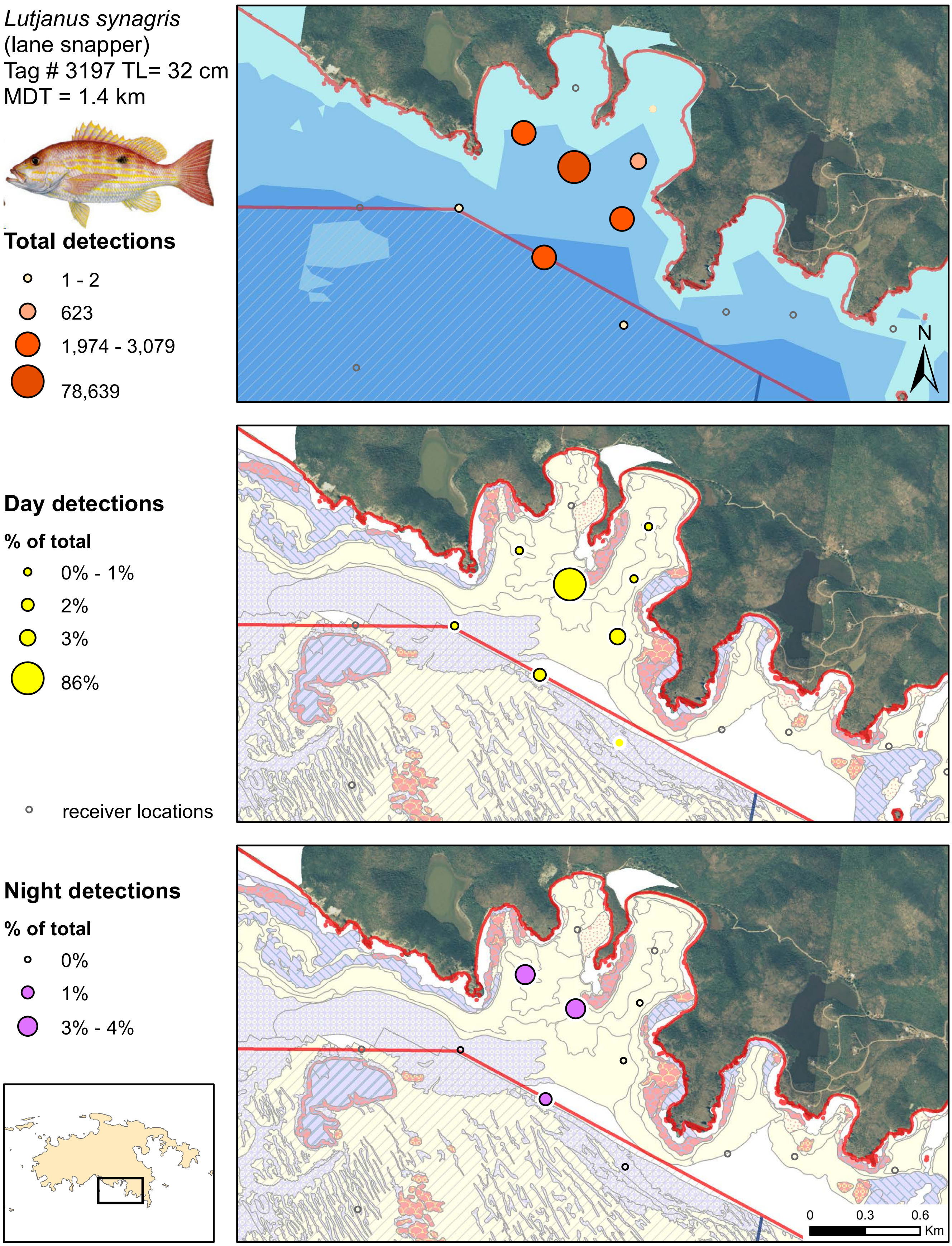

Figure 47. Day and night detections for lane snapper, *Lutjanus synagris*, tag # 3197 (32 cm TL).

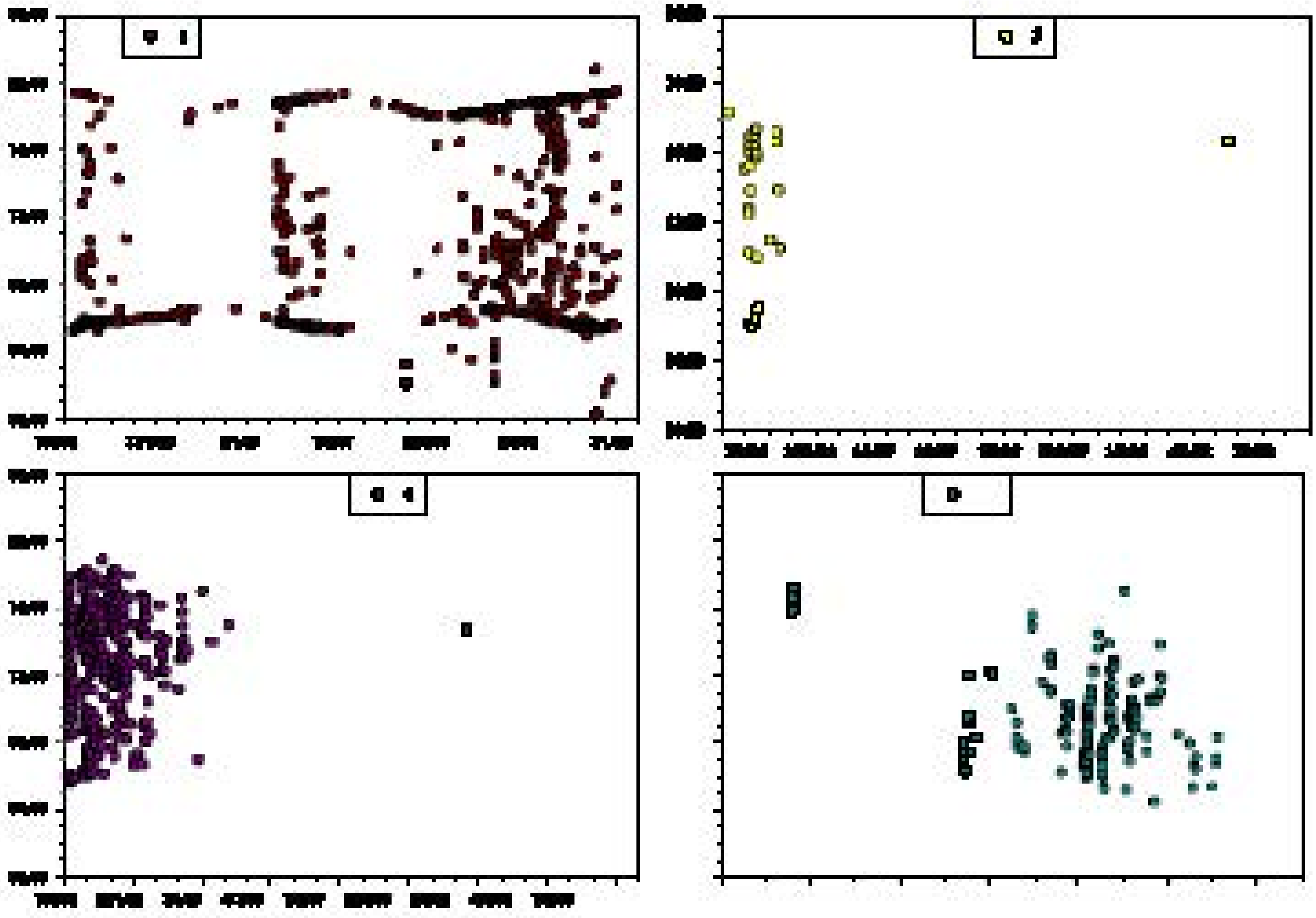

Figure 48. Day and night detection patterns for Lane snapper, *Lutjanus synagris*, tag # 3245 (27 cm TL). Days at large = 722, minimum distance travelled = 1.0 km.

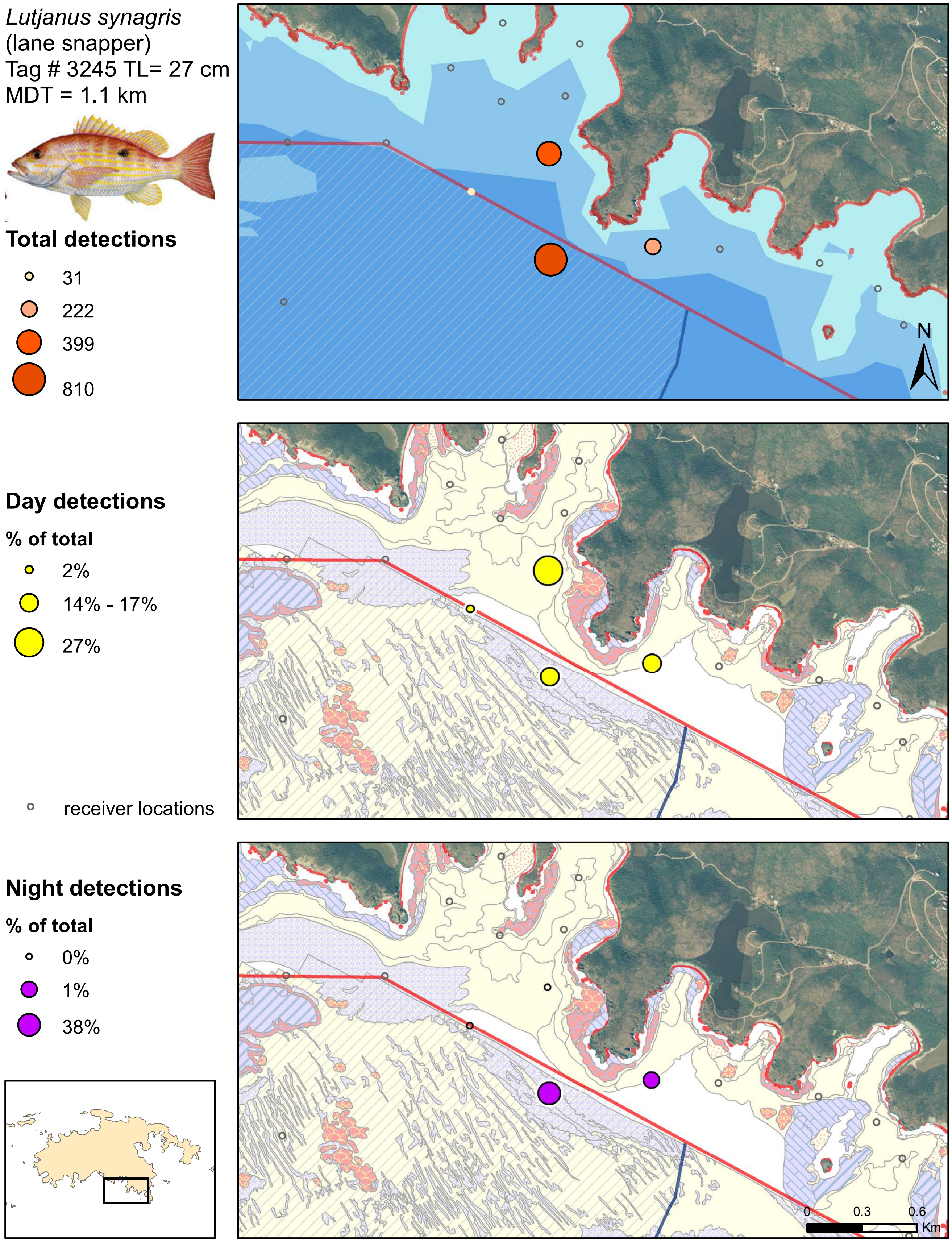

Figure 49. Receiver detections for lane snapper (*Lutjanus synagris*) tag # 3245 (27.0 cm TL).

Yellowtail snapper, *Ocyurus chrysurus*

Yellowtail snapper reach over 86 cm TL and feed mainly at night on a combination of plankton and benthic animals including fishes, crustaceans, worms, gastropods and cephalopods. Juveniles feed primarily on plankton. They are an important fisheries resource throughout the region and were the 4th most abundant species captured around St. John in the SEAMAP-C fisheries-independent sampling in 1999-2000. Garrison et al. (2004) found yellowtail snapper to be the most common snapper observed in traps around St. John, accounting for 59% of the total.

Yellowtail snapper showed considerable movement around St. John (Fig. 50). While some fish were present on the array for a large portion of their DALs, others moved in and out of the array. Yellowtail snapper # 3257 (23 cm) was at large for 286 days but was only present on the array for a limited amount of time. Yellowtail snapper #6043 (34 cm) was at large for 333 days and had a MDT of 9 km. It moved extensively around the south shore of St. John and was detected on nearly every receiver, but spent the majority of the time at stations 14, 15, and 16. Activity did not seem to differ substantially between day and night. Movement was detected between St. John and the MSR with monthly movements from Salt Pond to the MSR. These fish were not detected at any other receivers within the broader USCAN array.

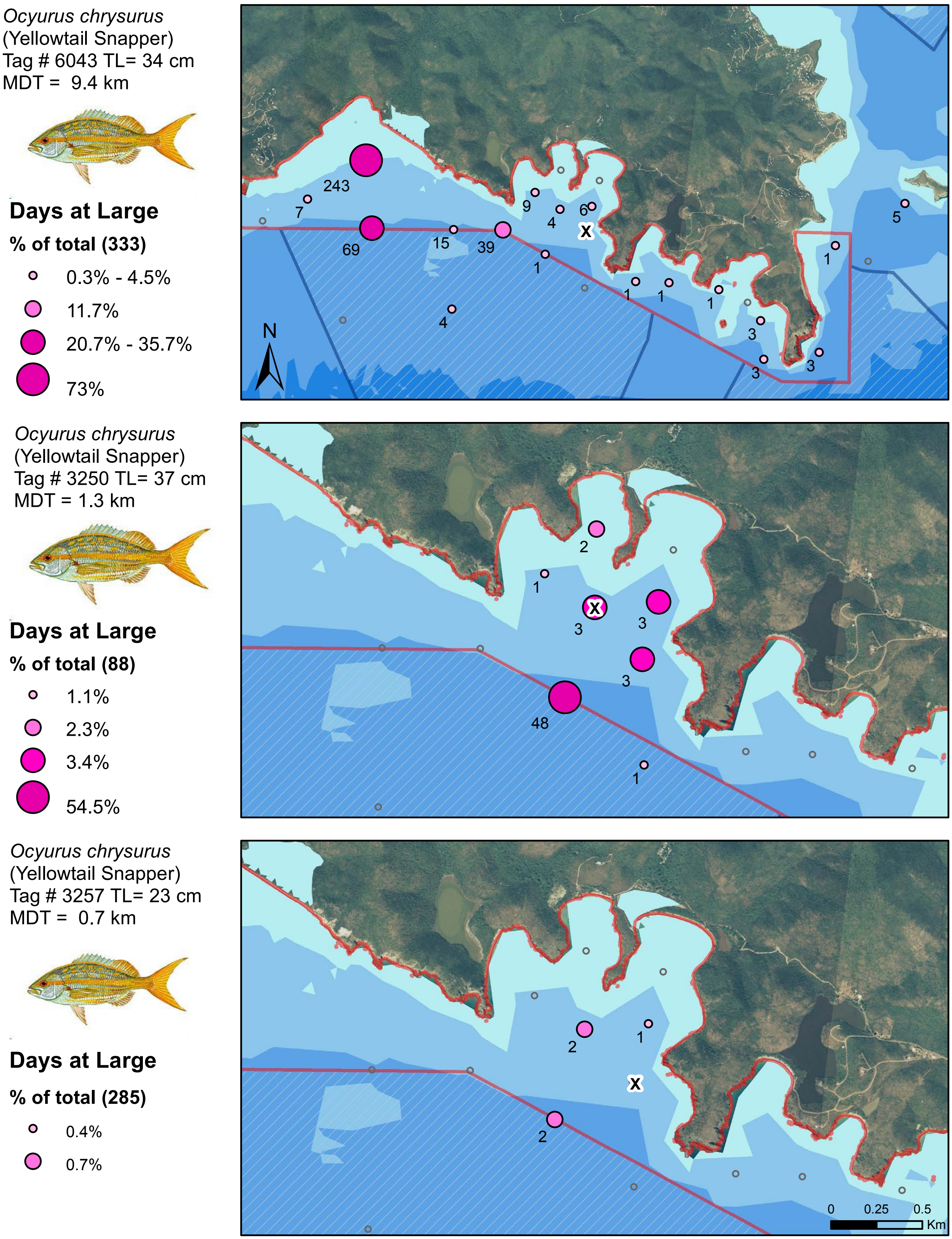

Figure 50. Detections for yellowtail snapper *Ocyurus chrysurus*. X = location of capture and release.

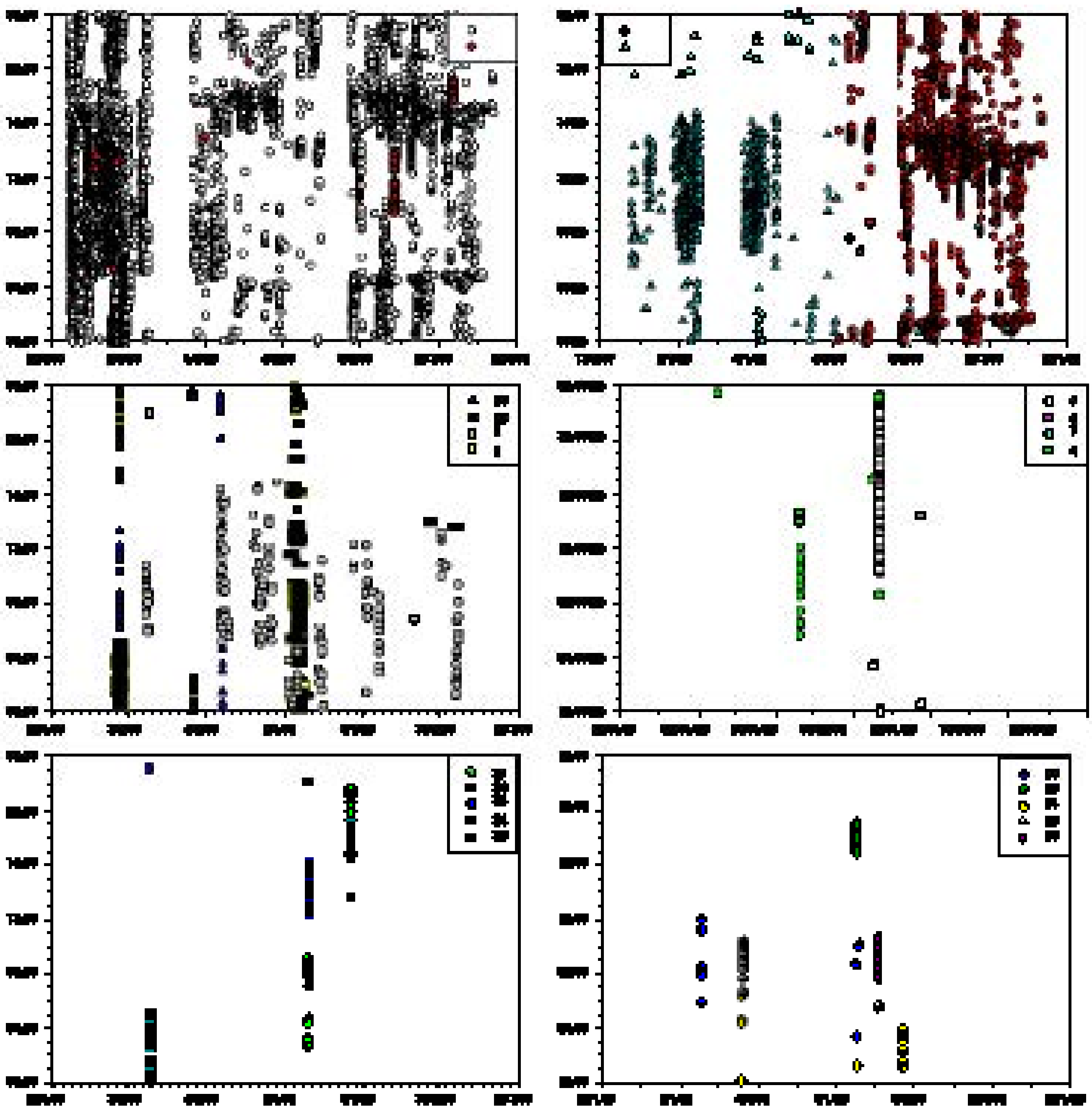

Figure 51. Day and night detections for yellowtail snapper, *Ocyurus chrysurus*, tag # 6043 (34 cm TL).

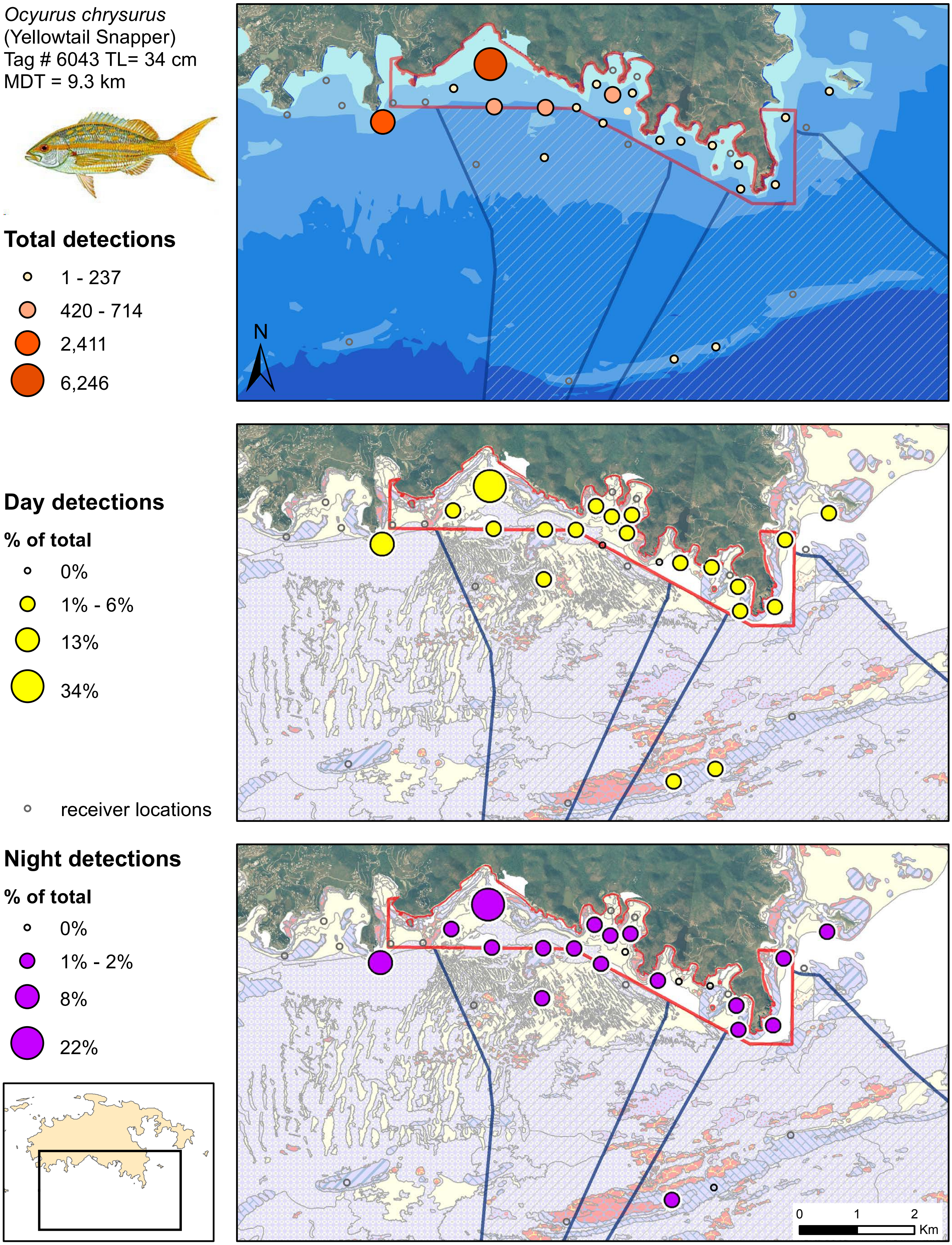

Figure 52. Day and night detections for yellowtail snapper, *Ocyurus chrysurus*, tag # 6043 (34 cm TL).

Family Haemulidae: Grunts

Haemulids are widely distributed in Atlantic, Indian and Pacific Oceans. Primarily marine environments, but some occur in brackish and rarely in freshwater. They form an important food fish throughout their range and are often caught in fish traps. Adults are thought to be less active during daylight hours when they shelter near or under ledges.They disperse to feed on benthic invertebrates at night. The maximum recorded length for a Haemulid is 60 cm..

Bluestriped grunt, *Haemulon sciurus*

Bluestriped grunts reach a maximum size of 46 cm TL and are found in small groups over coral and rocky reefs and drop-offs. They feed on crustaceans, bivalves, and occasionally on small fishes. Large bluestriped grunts showed high site fidelity to nocturnal foraging sites in seagrass beds around St. John (Beets et al. 2003). Tracking fish closely over 24 hour periods in St. John and St. Thomas revealed that fish have very varied and individualistic home range movements with some fish more active than others during the day, but overall night time activity spaces were bigger than daytime spaces (Hitt et al. 2011). (Fig. 52).

Bluestriped grunt #3175 (26.0 cm) was at large for 930 days and had a MDT of 1.9 km. The fish spent daytime around Cabritte Horn Point and moved offshore to station 3 at night. Several daytime forays were made from Cabritte Horn Point to the patch reefs off White Cliffs, a distance of ca. 1.5 km (Fig. 54 and 55). Bluestriped grunt #3189 (24.0 cm) was at large for 486 days and had a MDT of 1.5 km. This fish also showed a strong daytime fidelity to Lameshur Bay, but showed a much greater level of movement at night, both inside and outside the bay (Fig. 56 and 57). Three fish (#3166, #3281 & #6039) were also detected in Fish Bay on NMFS receivers.

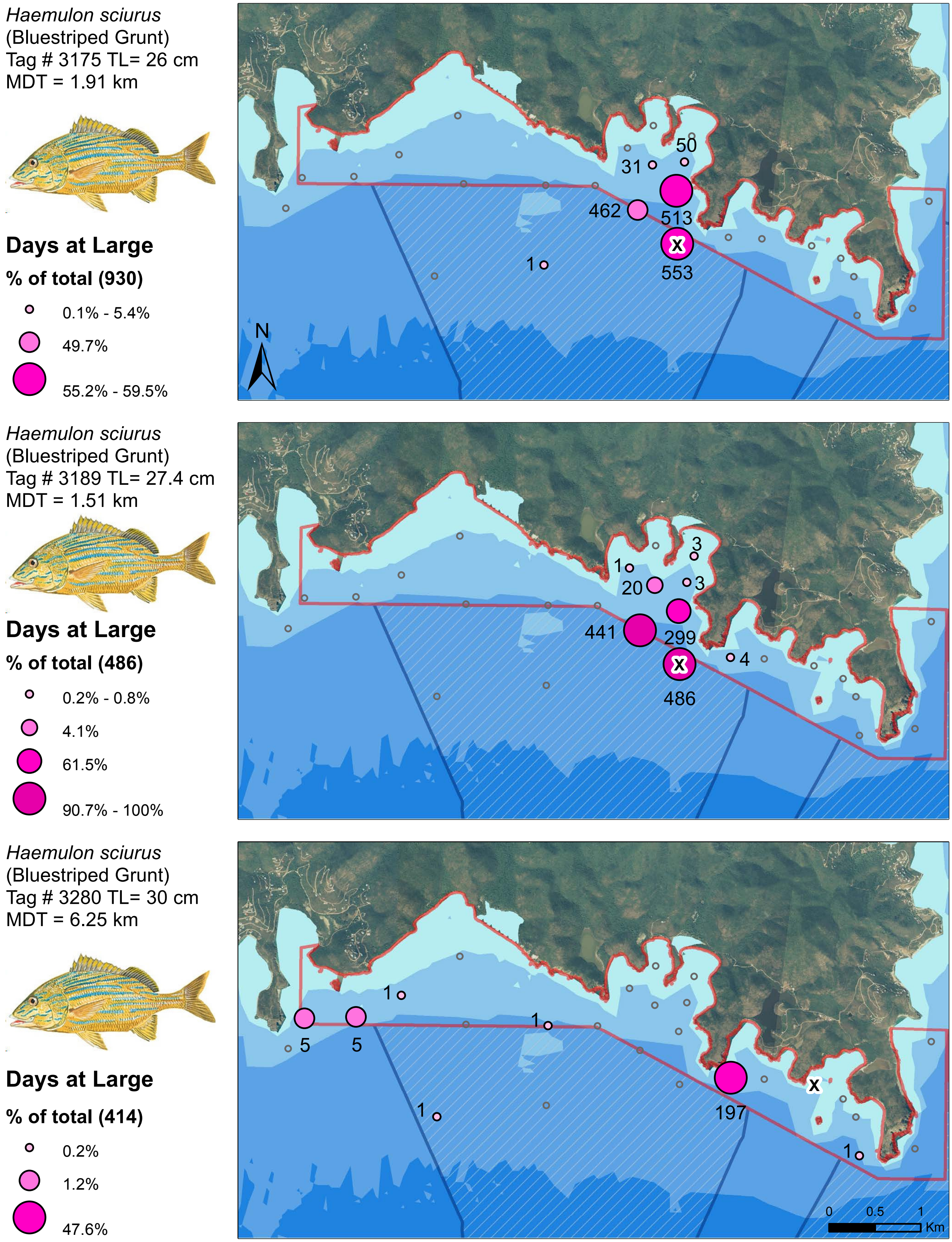

Figure 53. Days at large for three bluestriped grunt, *Haemulon sciurus*, around receiver array. The x denotes the location of release for the tagged individual. Numbers denote number of days the individual was detected at each receiver.

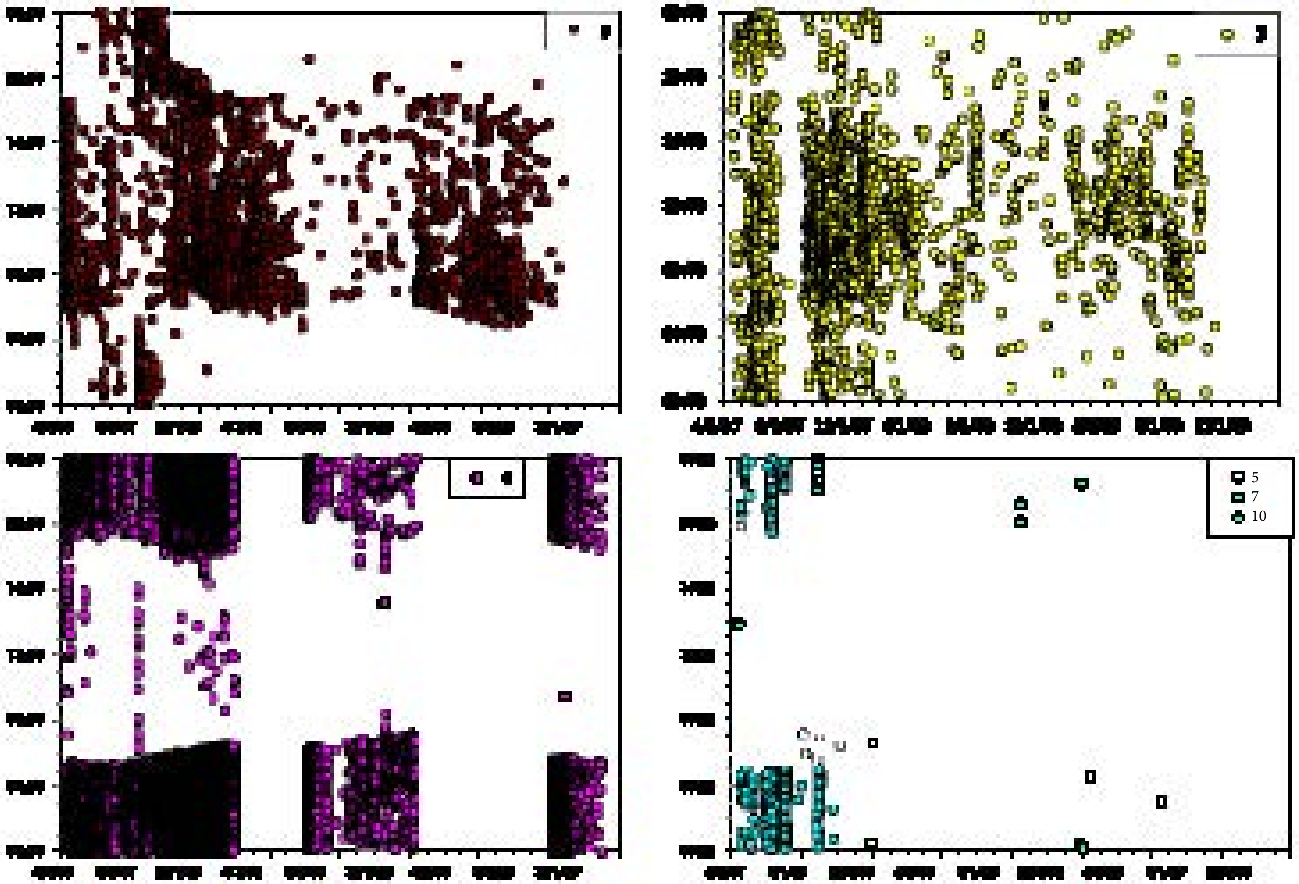

Figure 54. Day and night detection patterns for bluestriped grunt, *Haemulon sciurus*, tag # 3175 (26 cm TL).

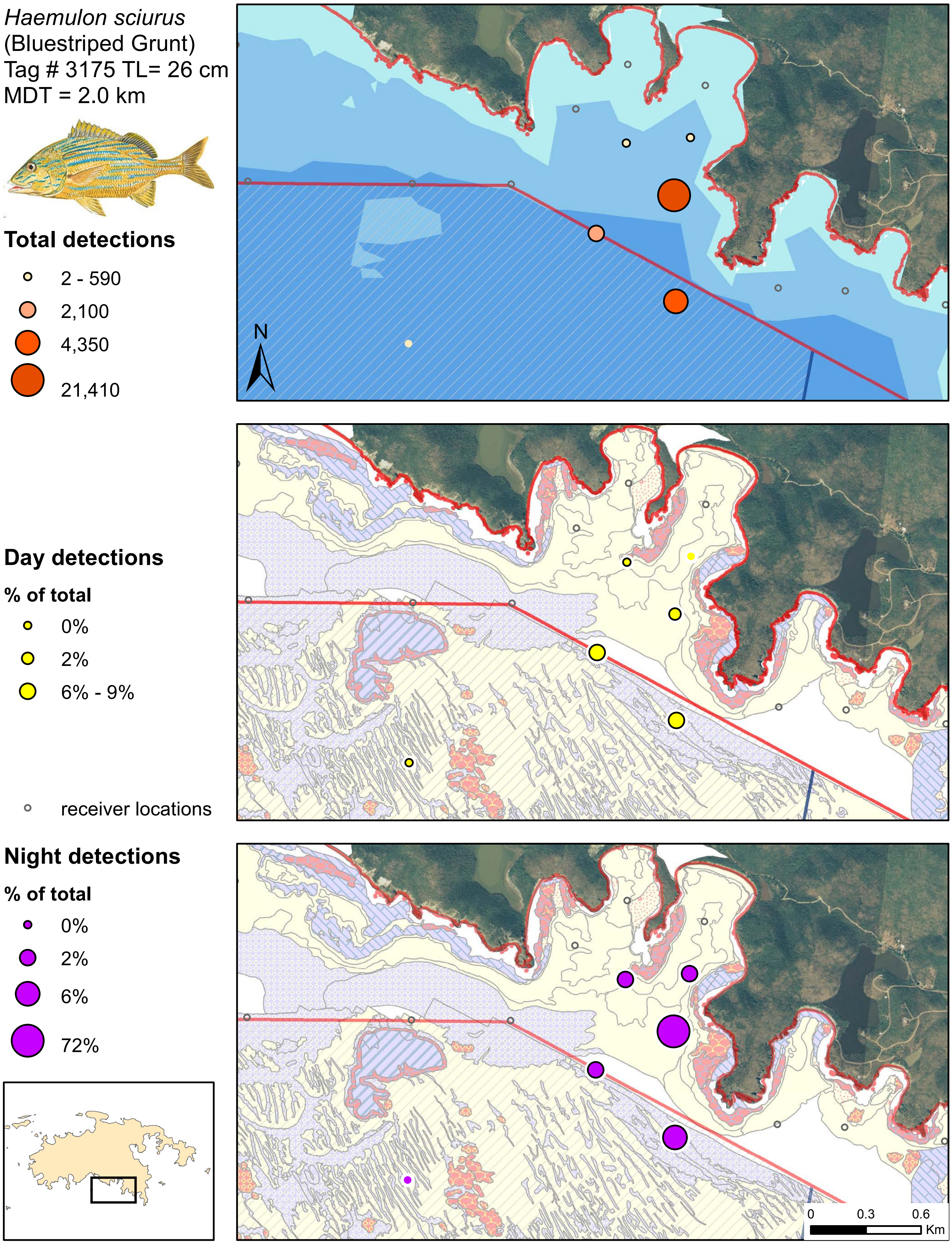

Figure 55. Detections for bluestriped grunt, *Haemulon sciurus*, tag # 3175 (26 cm TL).

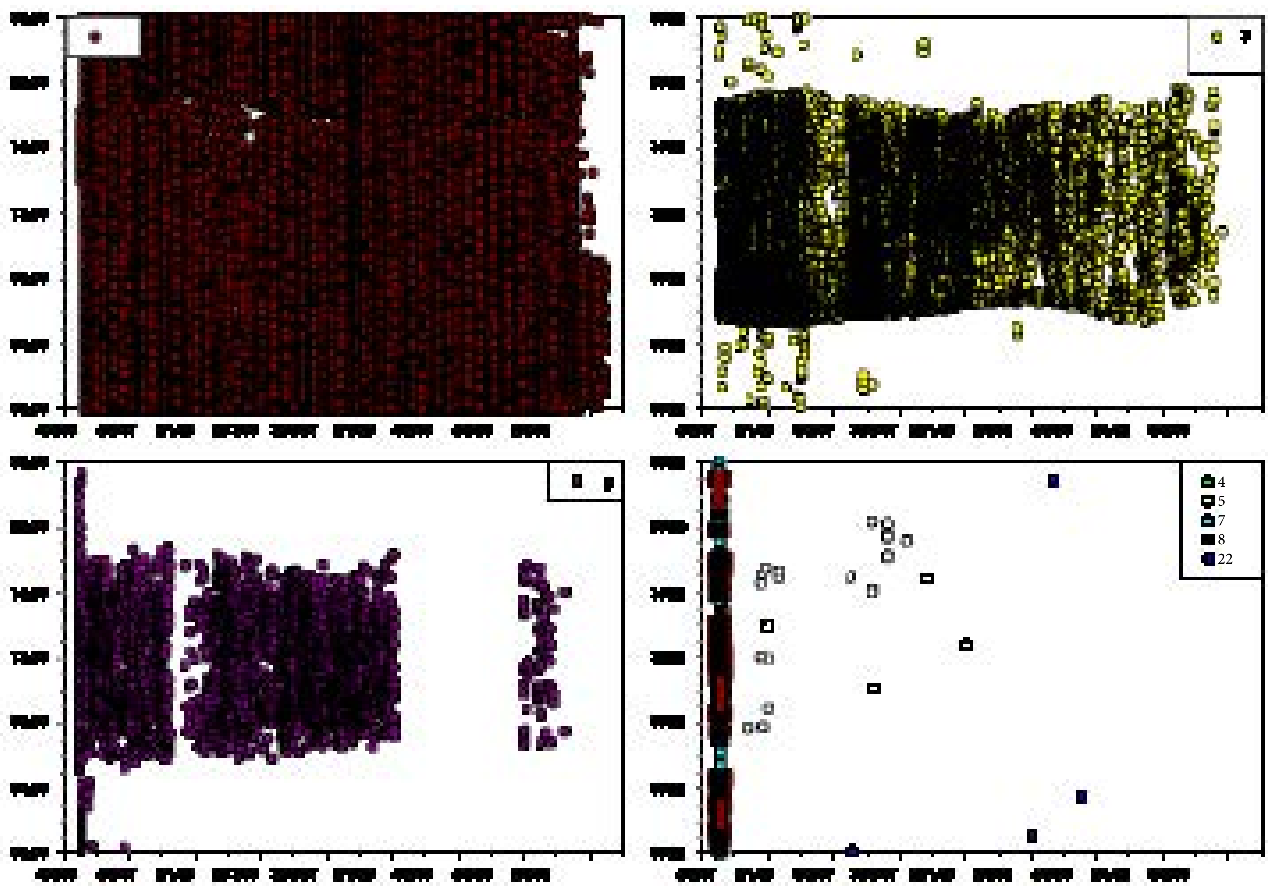

Figure 56. Day and night detection patterns for bluestriped grunt, *Haemulon sciurus*, tag # 3189 (27 cm TL). Days at large = 486, minimum distance travelled = 1.9 km.

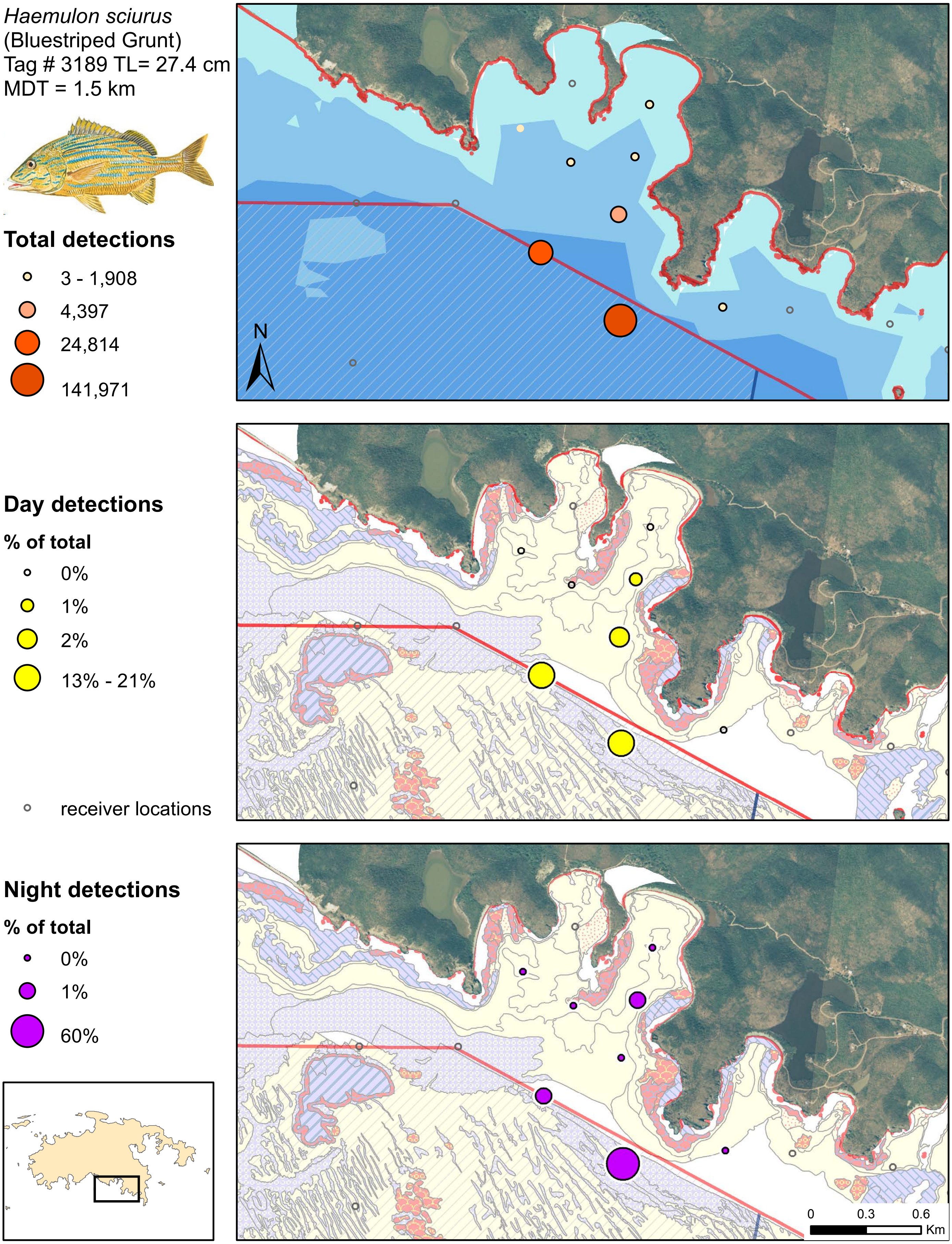

Figure 57. Day and night detections for bluestriped grunt *Haemulon sciurus*. Tag # 3189 (27 cm TL).

White grunt, *Haemulon plumierii*

White grunt are found in large aggregation on reefs during the day and feed primarily on crustaceans, small mollusks, and small fishes. They are distributed from the West Atlantic from Chesapeake Bay to the Gulf of Mexico, the Caribbean, and south to Brazil. White grunt #3194 (25 cm) was at large for 332 days and had a MDT of 4.2 km. It spent >99.8 % of time at station 9 and then moved to station 4 and 5. It left station 5 on November 16, 2006 and was briefly detected 209 days later at stations 17 and 18, off Ditliff Point and Fish Bay. All detections were at receivers within VIIS. This fish was not detected elsewhere on the USCAN array.

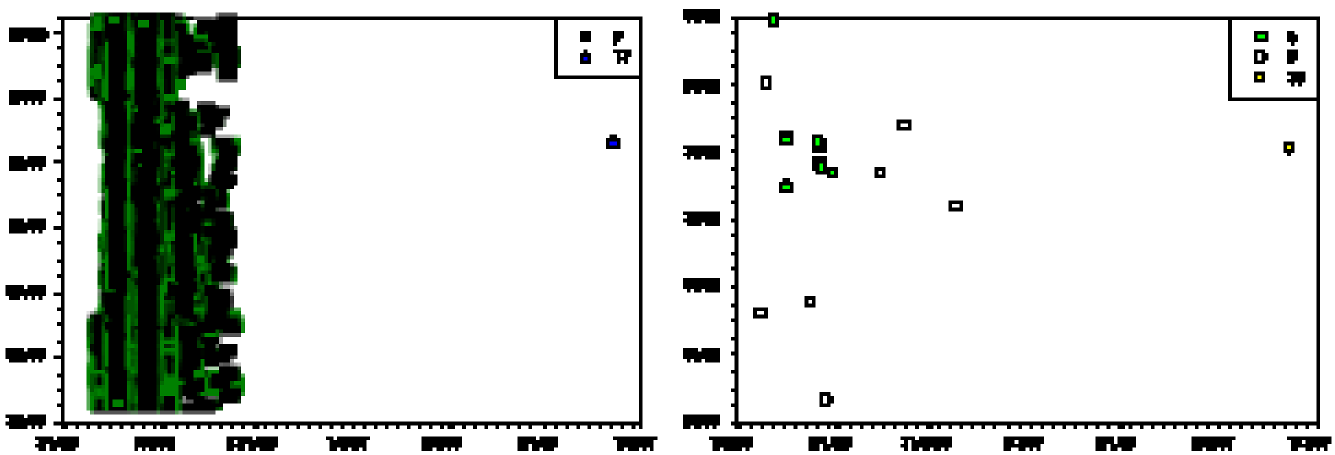

Figure 58. Day and night detections for white grunt, *Haemulon plumierii*, #3194 (25 cm).

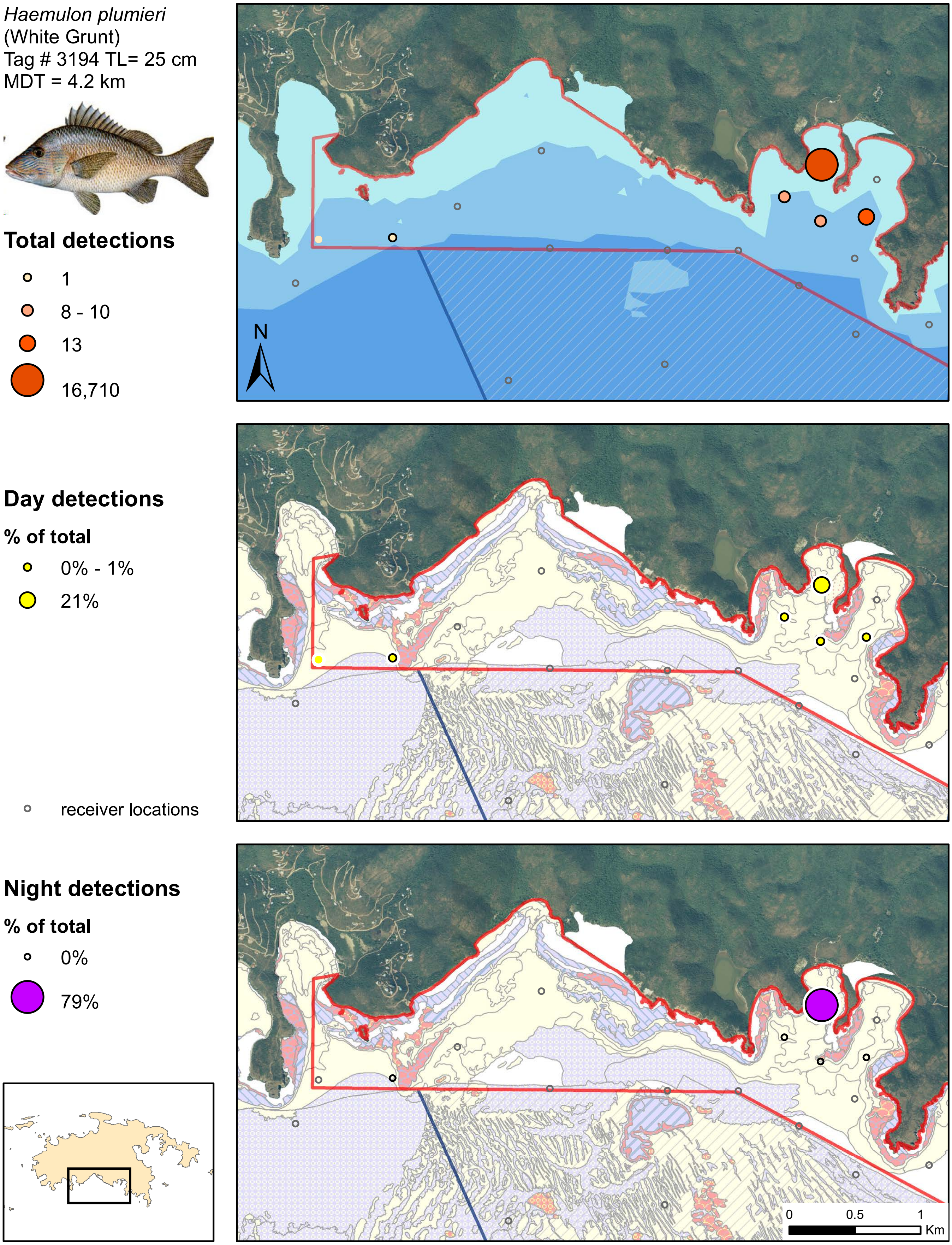

Figure 59. Day/night detections for white grunt, *Haemulon plumierii,* tag # 3194 (25 cm TL).

Family Sparidae: Porgies

Sparids are a widely distributed fish family in both tropical and temperate Atlantic and Indo-Pacific marine and rarely found in brackish and freshwater environments. They are carnivores of hard-shelled benthic invertebrates. Many species have been found to be hermaphroditic. Sparids are highly valued as food and as game fishes. A few species have been implicated in cases of ciguatera (Ref. 4537). (Nelson, J.S. 1994)

Saucereye porgy, *Calamus calamus*

Saucereye porgy are distributed throughout the Western Atlantic from North Carolina, USA south to Brazil and east to Bermuda. Saucereye porgy (Calamus calamus) - Max length : 56.0 cm TL male/unsexed; (Claro, 1994); common length : 30.0 cm TL male/unsexed; (Randall and Vergara, 1978); max. published weight: 680 g (IGFA, 2001). Western Atlantic: North Carolina, USA and Bermuda to Brazil. Adults are frequently found in coral areas, while the young prefer vegetated (e.g. Thalassia), sandy bottoms. Feeds mainly on mollusks, worms, brittle stars, hermit crabs, crabs and sea urchins (Robinsand Ray 1986).

Saucereye porgy # 3178 (28.2 cm) was at large for 180 days and had a MDT of 3.2 km. Detections of three Calamus calamus with DAL > 144 are shown in Fig. 60. This fish was released at station 6 and moved considerably over the next three weeks, going as far to the west as Ditliff Point and Cocoloba Cay (stations 17 and 18) and to the east around Ram Head where it was detected at station 30. It then left the array for more than 4.5 months (135 days) before it was again detected at station 6 where it remained for 26 days. Seven fish (# 6033, 6739, 6026, 6032, 6045, 6728 & 6732) were also recorded on NMFS receivers in Fish Bay. One entered Fish Bay (#6732), but the others were detected only a receiver located at the mouth of the bay. Calamus calamus #3236 was at-large for 145 days but moved very little from its general location near station 5 in Lameshur Bay (Fig 63, 64).

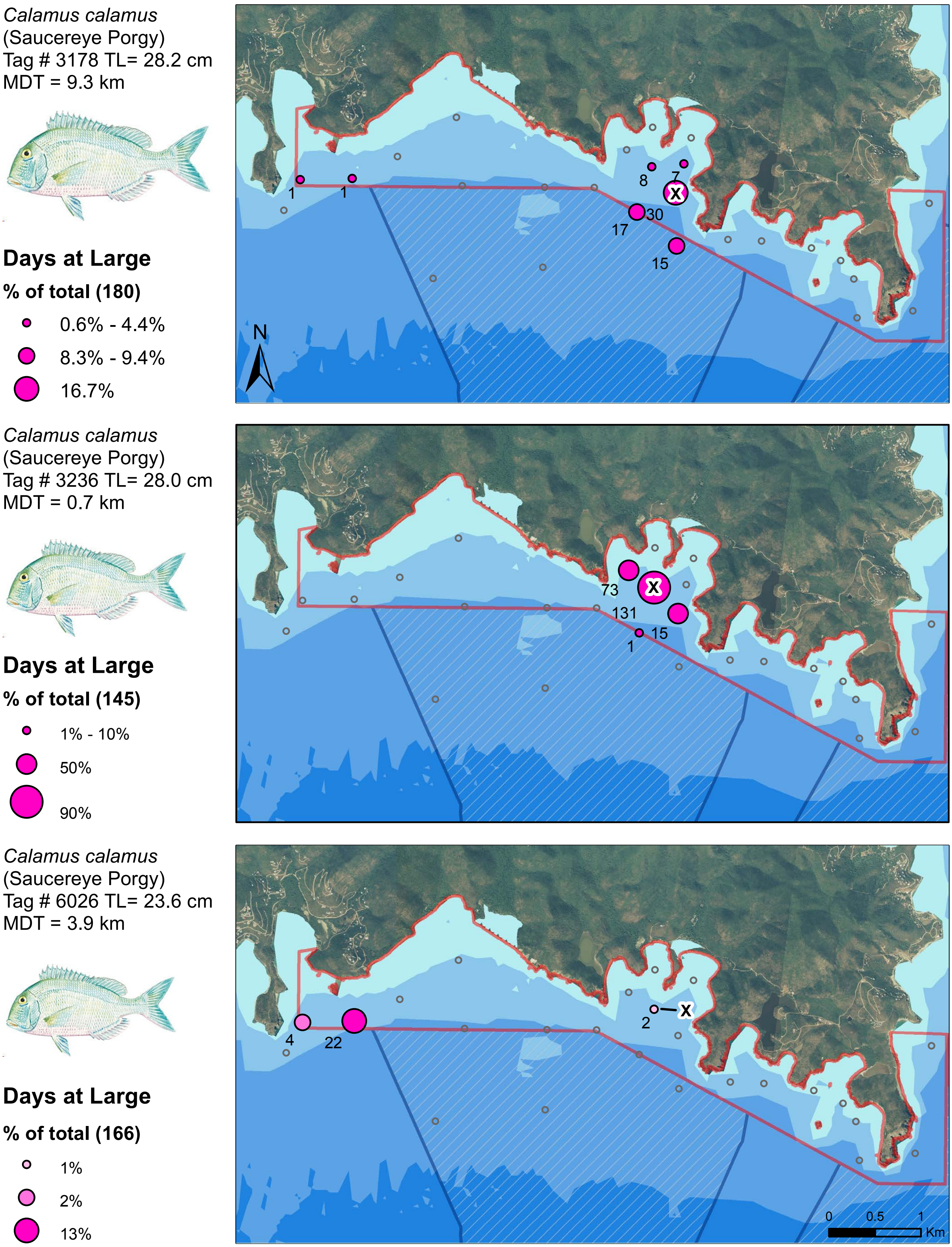

Figure 60. Detections for saucereye porgy, *Calamus calamus*. X = location of capture and release.

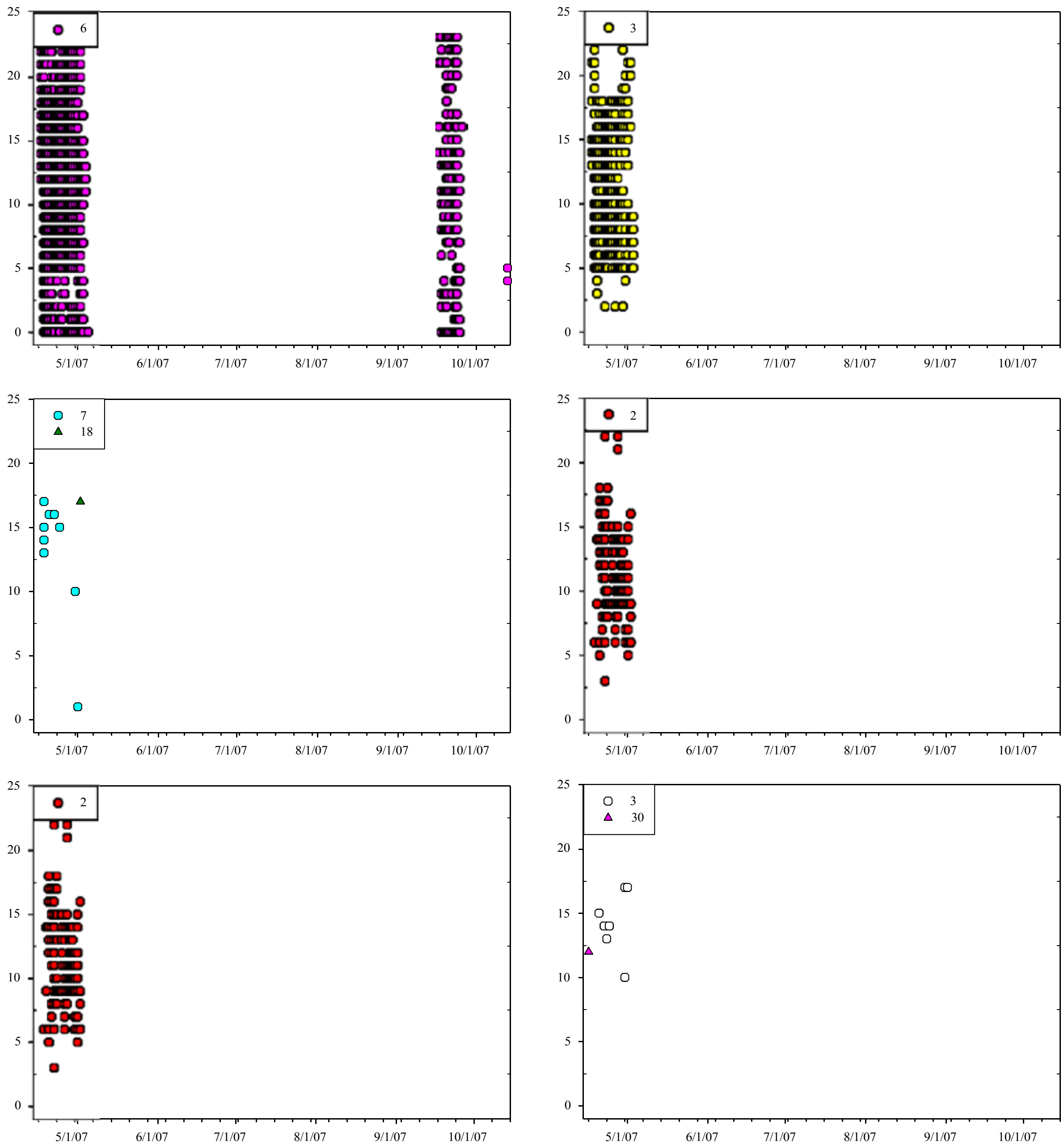

Figure 61. Day and night detections for *Calamus calamus* #3178.

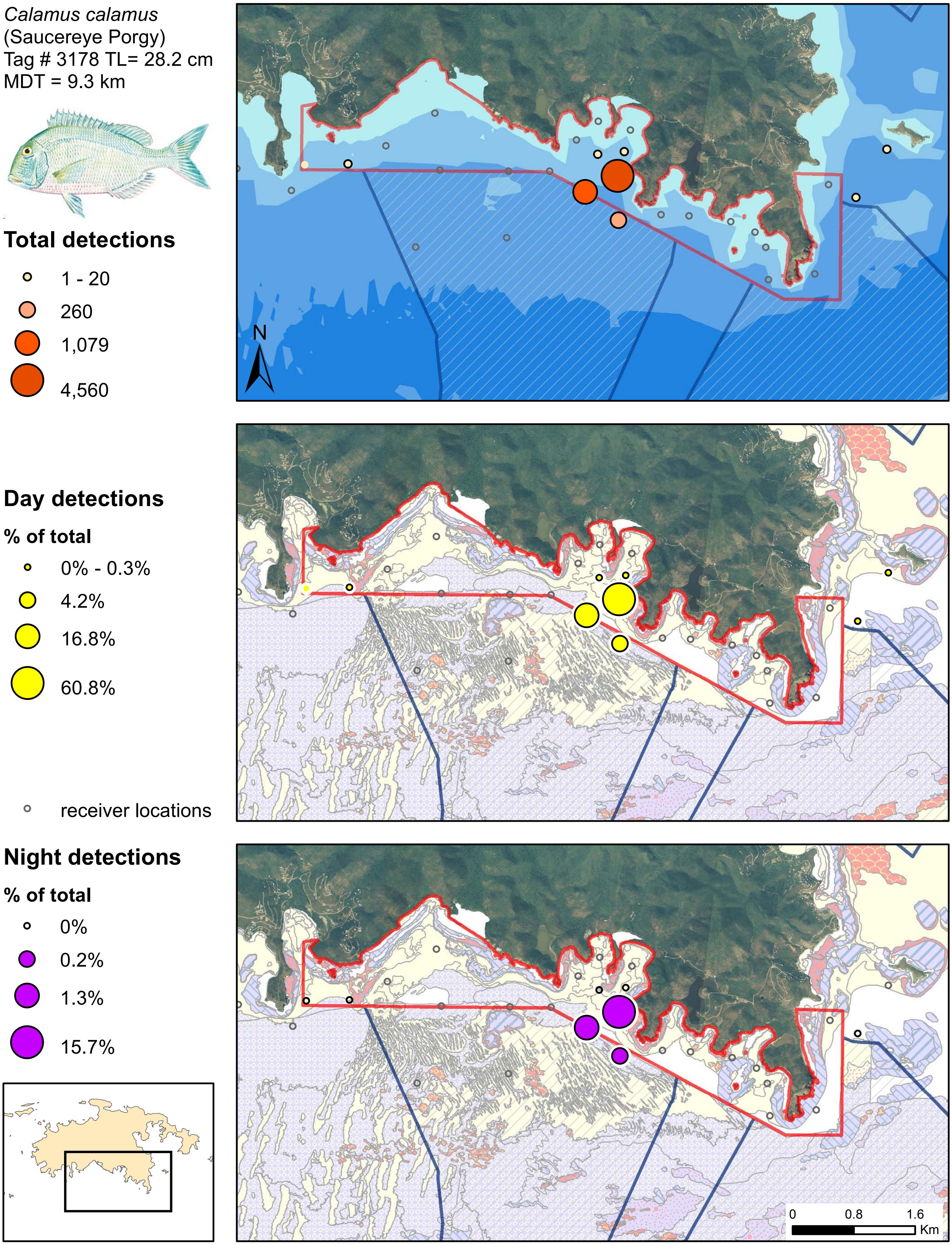

Figure 62. Day/night detections for saucereye porgy, *Calamus calamus*, tag # 3178 (28 cm TL).

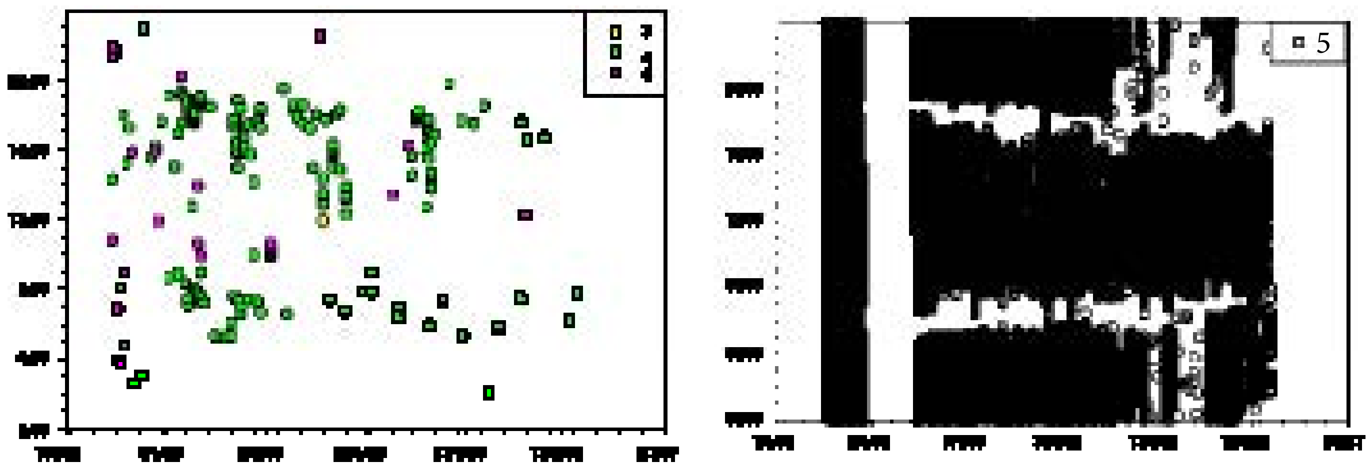

Figure 63. Day and night detections for *Calamus calamus* #3236

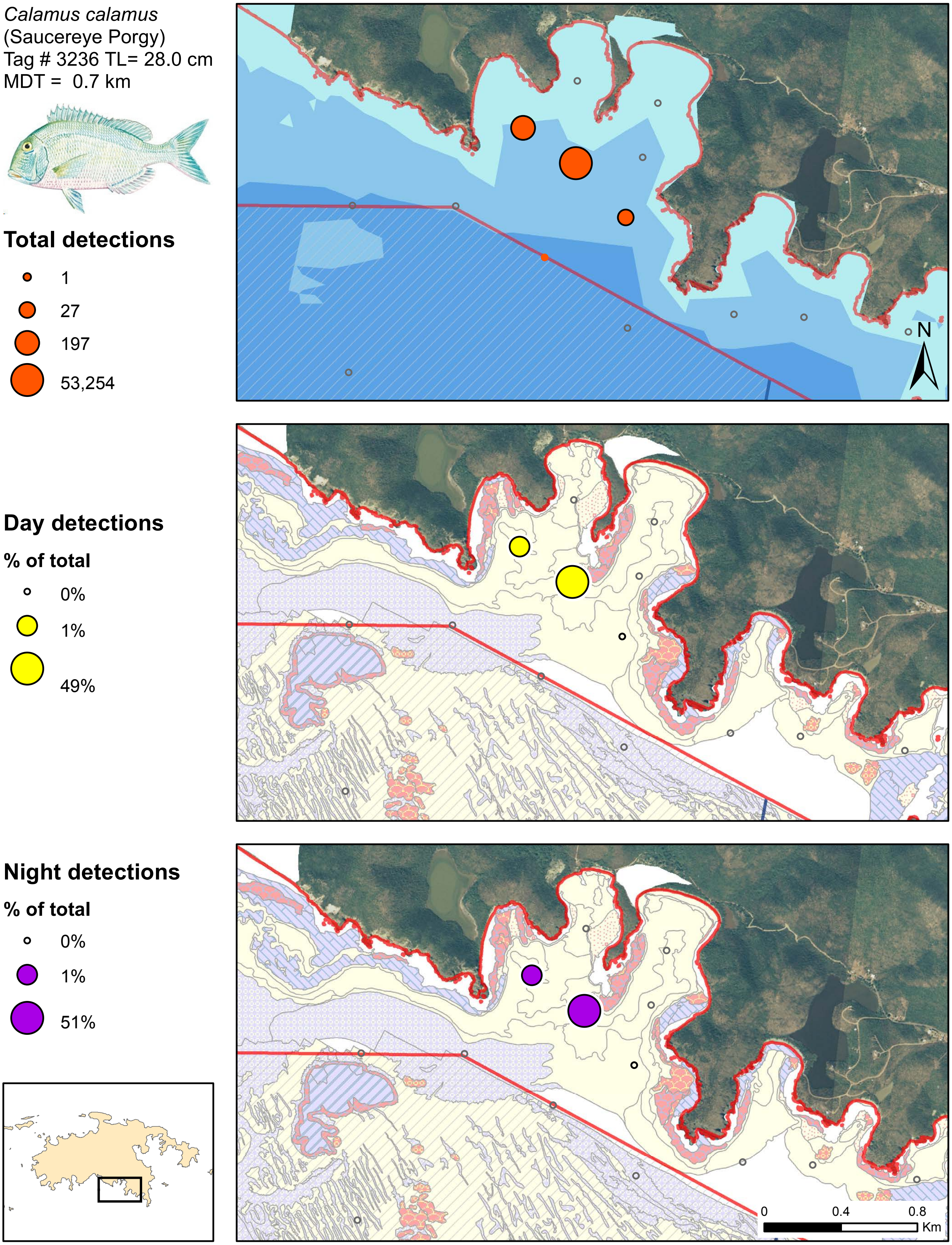

Figure 64. Day and night detections for saucereye porgy, *Calamus calamus*, tag #3236

Family Mullidae: Goatfishes

Yellow goatfish, *Mulloidichthys martinicus*

Mullids are distributed throughout the shallow waters of the Atlantic and Indo-Pacific, rarely in brackish waters. The maximum recorded size is 60cm. They are valued as a food fish. Goatfish are named because of their two long barbels under the mouth, which contain chemosensory organs and are used to probe the sand and holes in the reef for benthic invertebrates and small fish. They are pelagic spawners.

Yellow goatfish (*Mulloidichthys martinicus*) (Cuvier, 1829) – Western Atlantic: Bermuda and Florida to Brazil, including the Gulf of Mexico and the Caribbean Sea (Cervigon, 1993). Also reported from São Tomé Island (Alfonso et al., 1999). Found over sandy areas of lagoon and seaward reefs (Lieske and Myers, 1994). Often in schools (Smith, 1997).

Three yellow goatfish were tagged during the study and two of these were only detected for two days each (Fig. 65). Yellow goatfish #3283 (32.3 cm) was at large for 32 days and had a MDT of 7.5 km. This fish was released at station 24 Salt Pond at 10:00am on April 18, 2007 and was detected one hour later at station 17, a distance of 4.7 km. The majority of the detections were at stations 17 and 18 in Reef Bay until May 22nd, when the fish was observed in Rendezvous Bay (stations 19, 20, 21), before it left the array (Fig. 66 and 67). No noctural detections were recorded on the array except for a few detections off Ditliff Point as the fish was leaving the array. One fish (#3283) was detected on a NMFS receiver in Fish Bay.

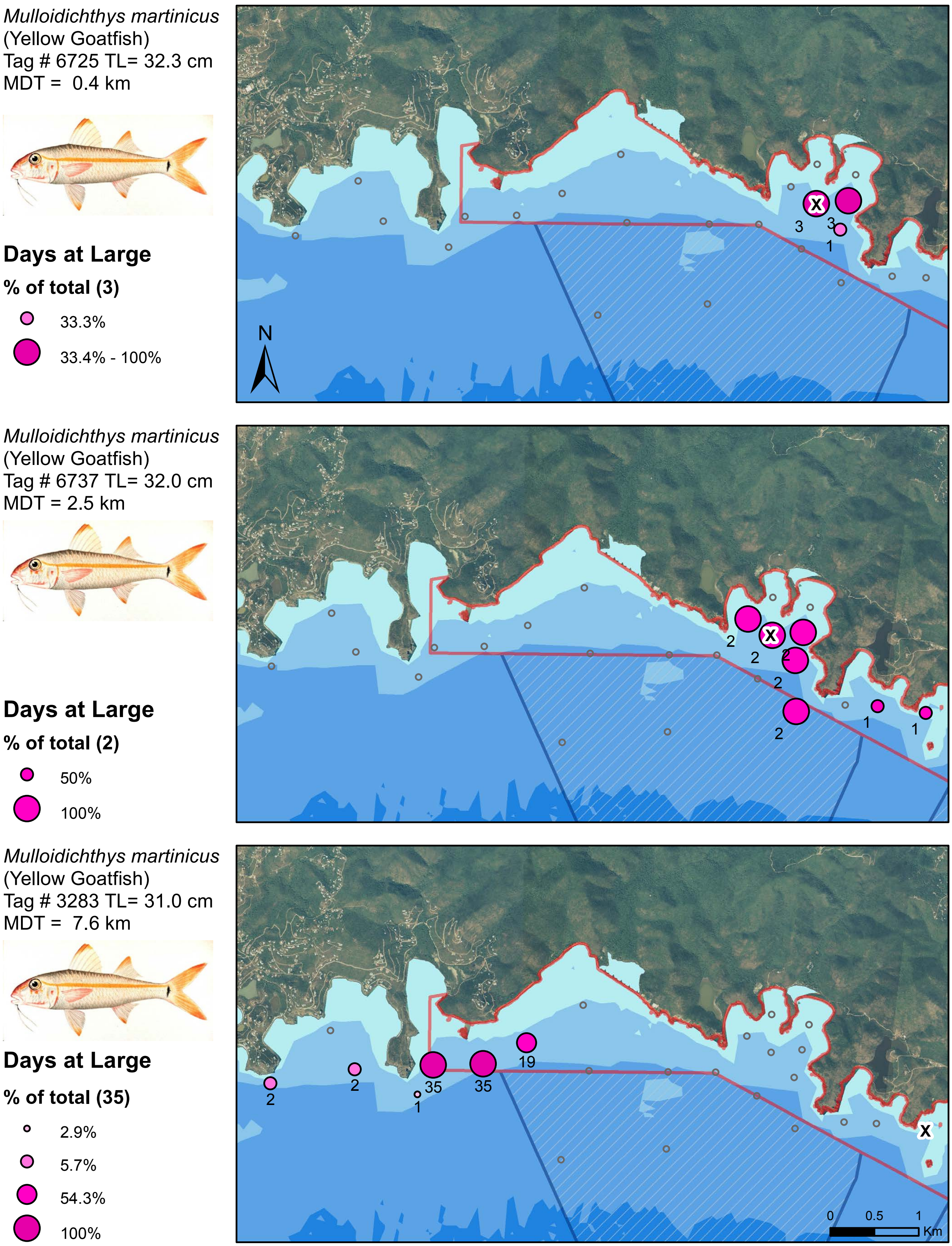

Figure 65. Detections for yellow goatfish, *Mulloidichthys martinicus*. X = point of capture and release.

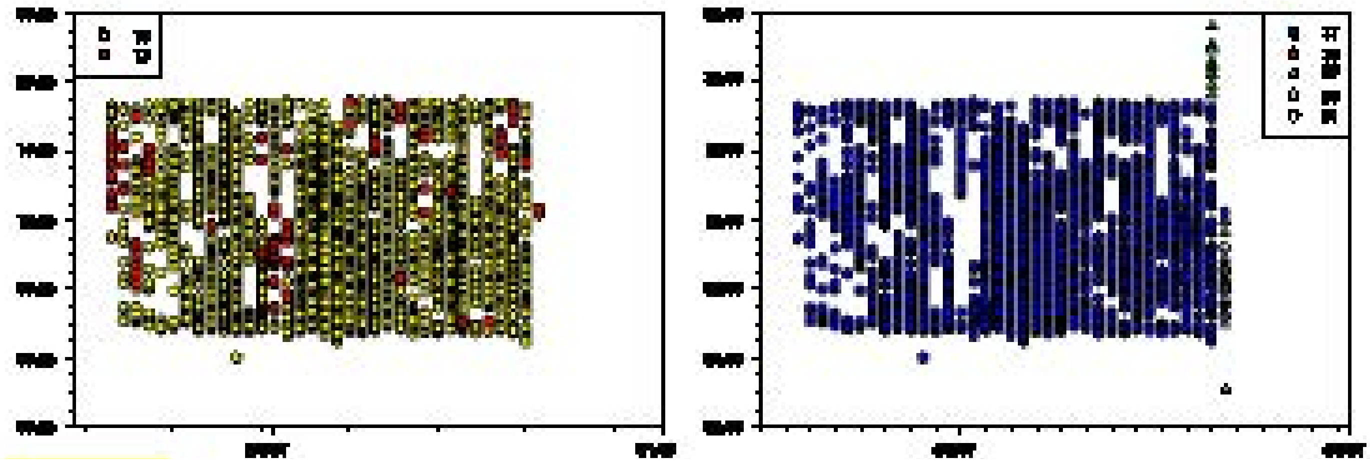

Figure 66. Yellow goatfish, *Mulloidichthys martinicus,* #3283 (32.3 cm) was at large for 32 days and had a MDT of 7.5 km.

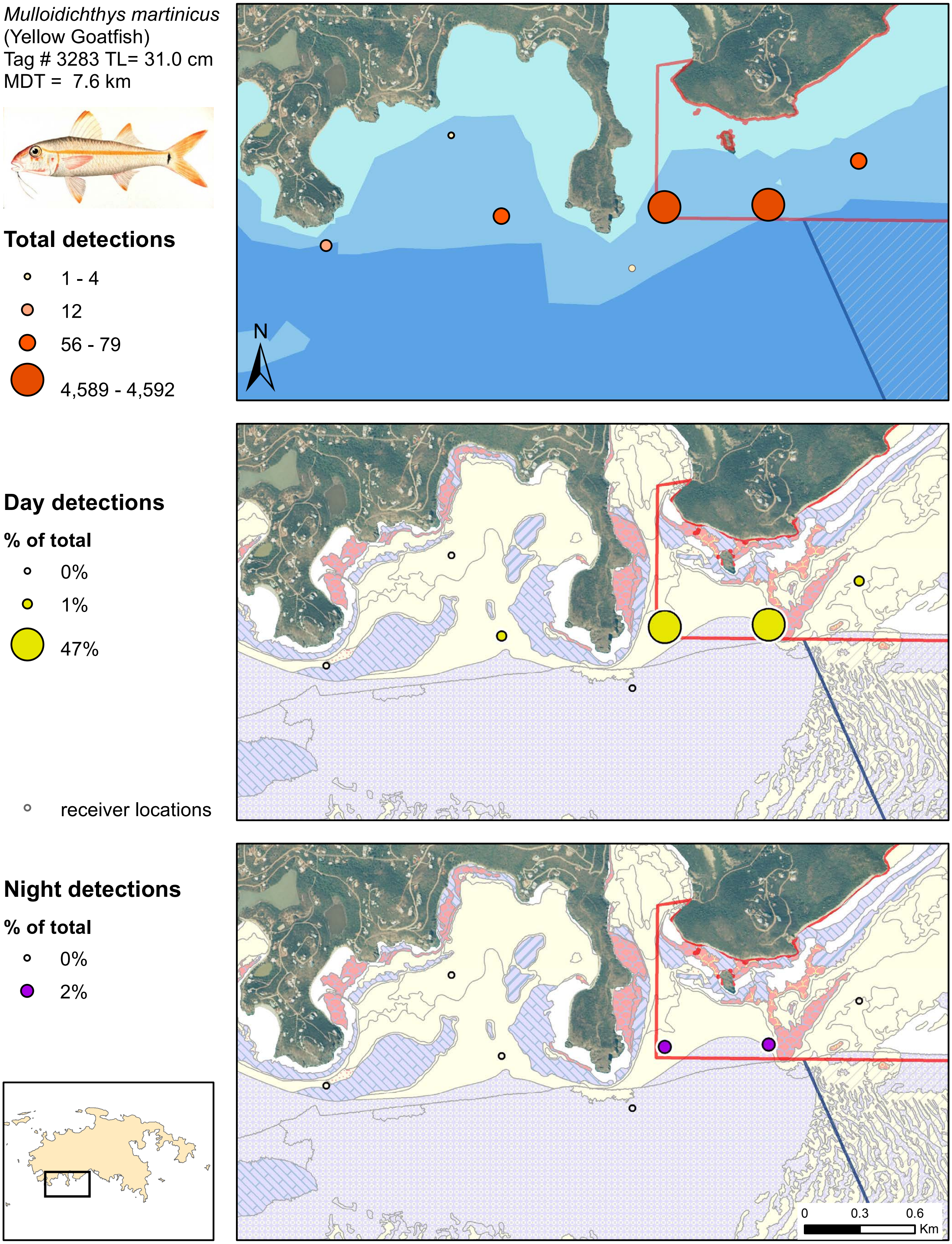

Figure 67. Day/night detections for yellow goatfish, *Mulloidichthys martinicus,* tag # 3283 (31 cm TL)

Family Acanthuridae: Surgeonfishes

A widespread fish family commonly associated with coral reef ecosystems around the world. There are six genera with only one known from the Atlantic. Surgeonfishes are readily distinguished by the possession of one or more spine or tubercles along the side of the caudal peduncle, which they use to ward off intruders (Randall 1996). These fishes are high bodied and compressed with small scales. Surgeonfishes are important herbivores and may form feeding aggregations, often mixing with more than one species. In the Caribbean they are an important food fish

Doctorfish tang, *Acanthurus chirurgus*

This species is found in the Western Atlantic from Massachusetts (USA), to Bermuda, and the northern Gulf of Mexico south to São Paulo, Brazil. Maximum recorded length is 39 cm. It is also reported from Senegal off the coast of West Africa. Doctorfish inhabit shallow reefs or rocky areas and are typically observed in aggregations. It is mainly diurnal and ingests sand when feeding on algae. The spine on both sides of the caudal peduncle may inflict painful wounds.

Doctorfish # 31274 (19.2 cm) was at large for 85 days and had a MDT of 1.0 km. It spent the vast majority of that time in Lameshur Bay around station 5 where it was released (Fig. 68, 69, 70). In contrast, doctorfish # 3290 (23.9 cm) was released off of Salt Pond Bay and quickly moved west towards Fish Bay near the VIIS boundary, a distance of 5.6 km. It left the array after 26 days and was not detected again. Neither of the two tagged fish were detected elsewhere on the USCAN array.

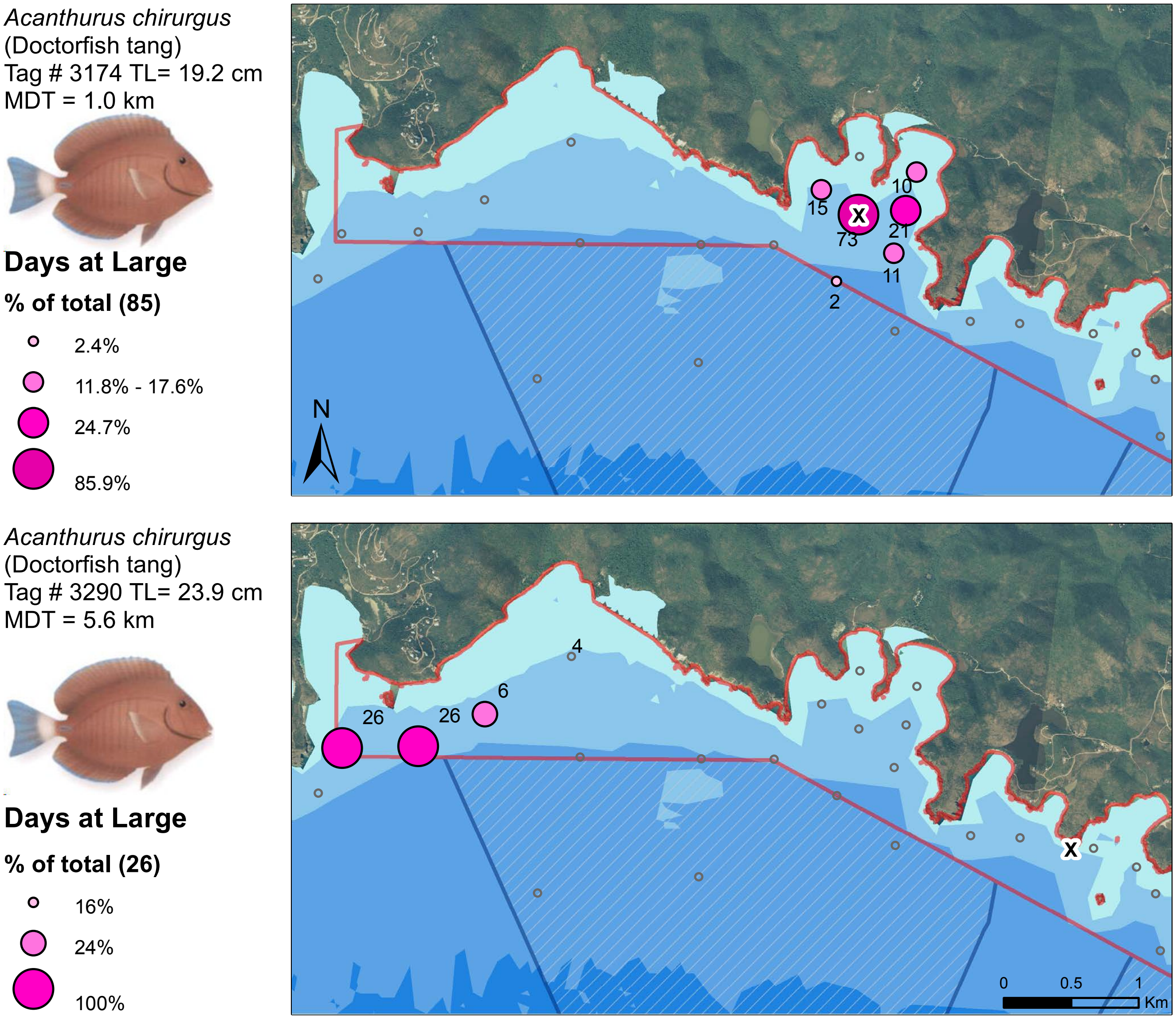

Figure 68. Detections for doctorfish tang, *Acanthurus chirurgus*. X = point of capture and release.

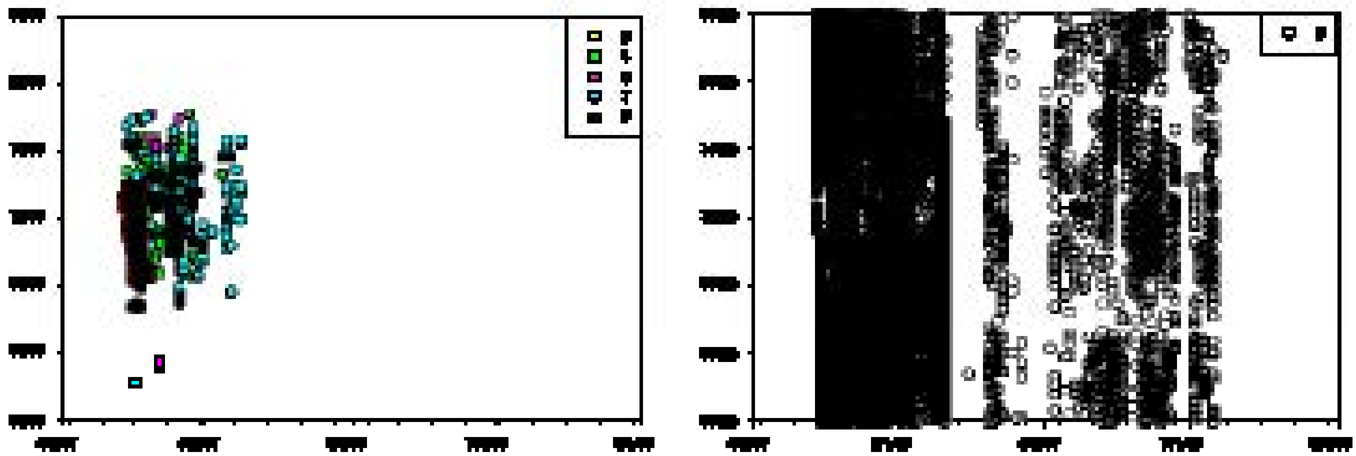

Figure 69. Doctorfish, *Acanthurus chirurgus*., tag # 3174 (19.2 cm) was at large for 85 days and had a MDT of 1.0 km.

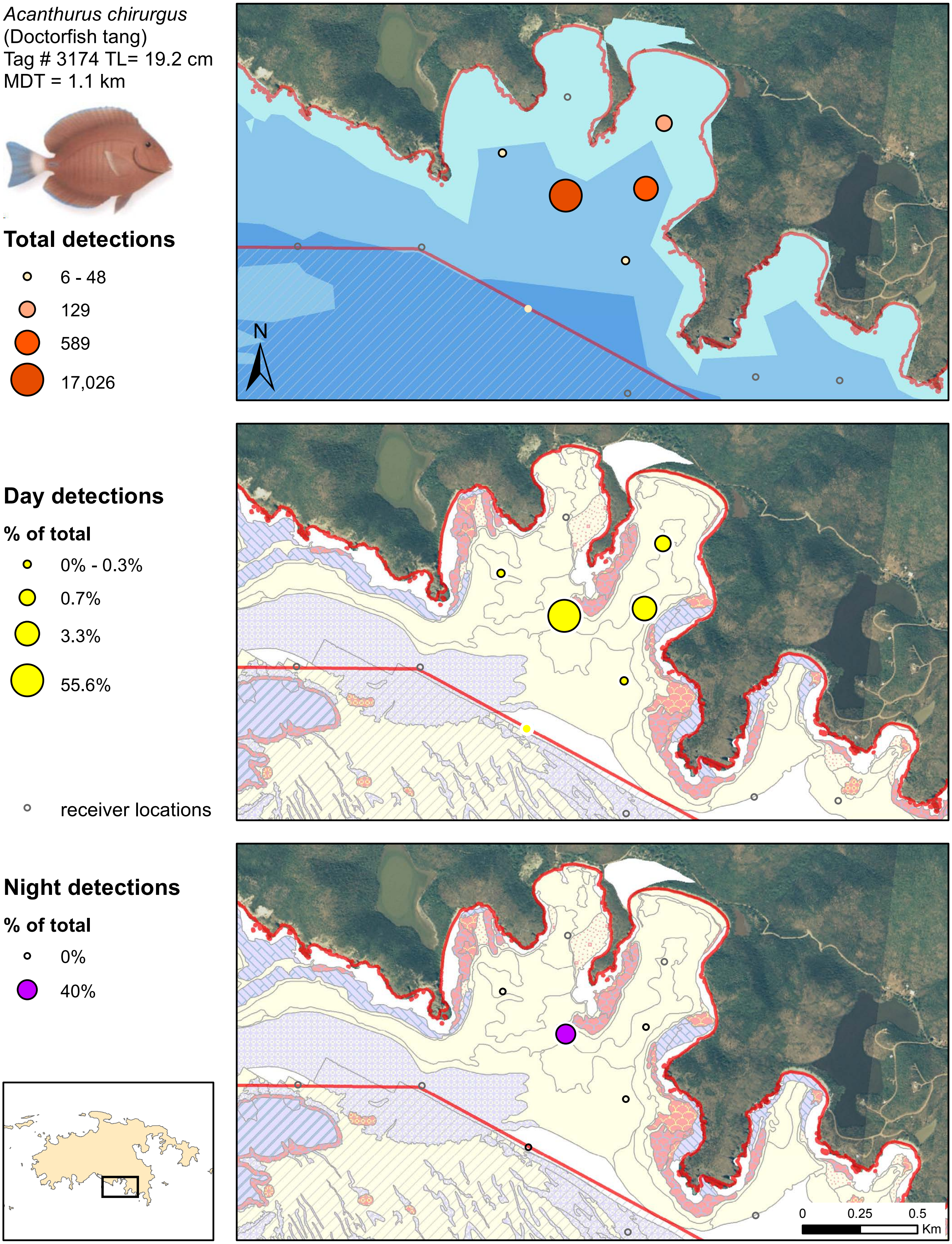

Figure 70. Detections for doctorfish, *Acanthurus chirurgus,* tag # 3174 (19.2 cm) was at large for 85 days and had a MDT of 1.0 km.

Blue tang, *Acanthurus coeruleus*

Blue tang inhabit shallow reef areas where they can be observed in mixed schools with other surgeon fishes. They feed primarily on algae and obtain a maximum size of 39 cm TL. Based on trap surveys conducted by Garrison et al. (2004), blue tang accounted for 15% of the total abundance and 75% of the surgeonfish abundance in traps around St. John.

Because of their body shape, transmitters were applied externally to blue tang. This likely resulted in stress on the individuals and few fish were detected for long periods of time (Fig. 71). One relatively large (26.0 cm) blue tang # 3172 was detected for 106 days on the array and had a MDT of 5.6 km during that time (Fig. 72, 73). This fish was released off of Salt Pond but was detected at stations 13, 17, and 18 off of Fish Bay and Cocoloba Cay after a few hours, a distance of ca. 5 km. It stayed in this general area for ca. two months before it left the array. It reappeared off station 17 one month later, where it was detected for ca. two weeks. Three fish (#3172, #3267 & #3272) were also detected on NMFS receivers in Fish Bay.

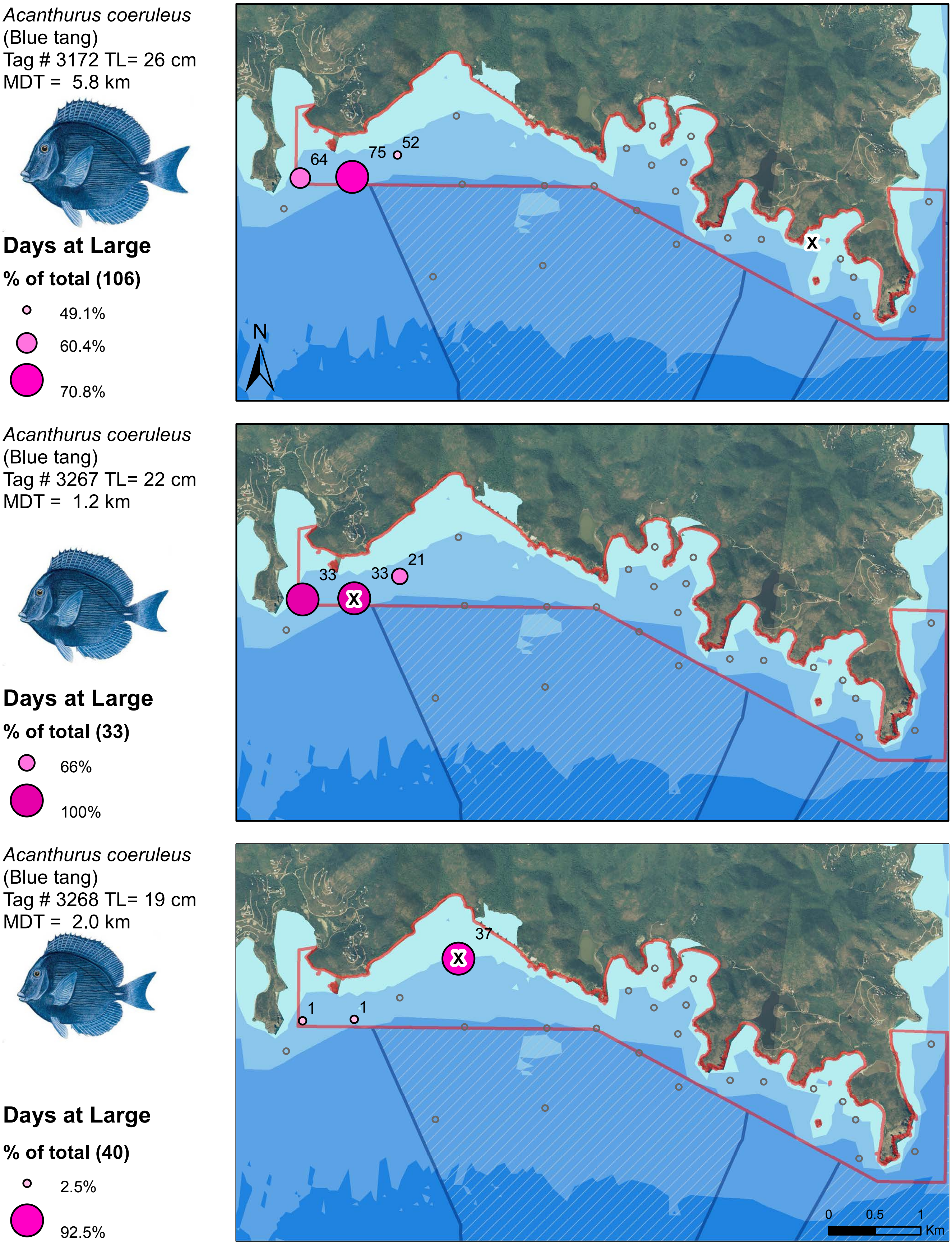

Figure 71. Detections for blue tang, *Acanthurus coeruleus*. X = point of capture and release.

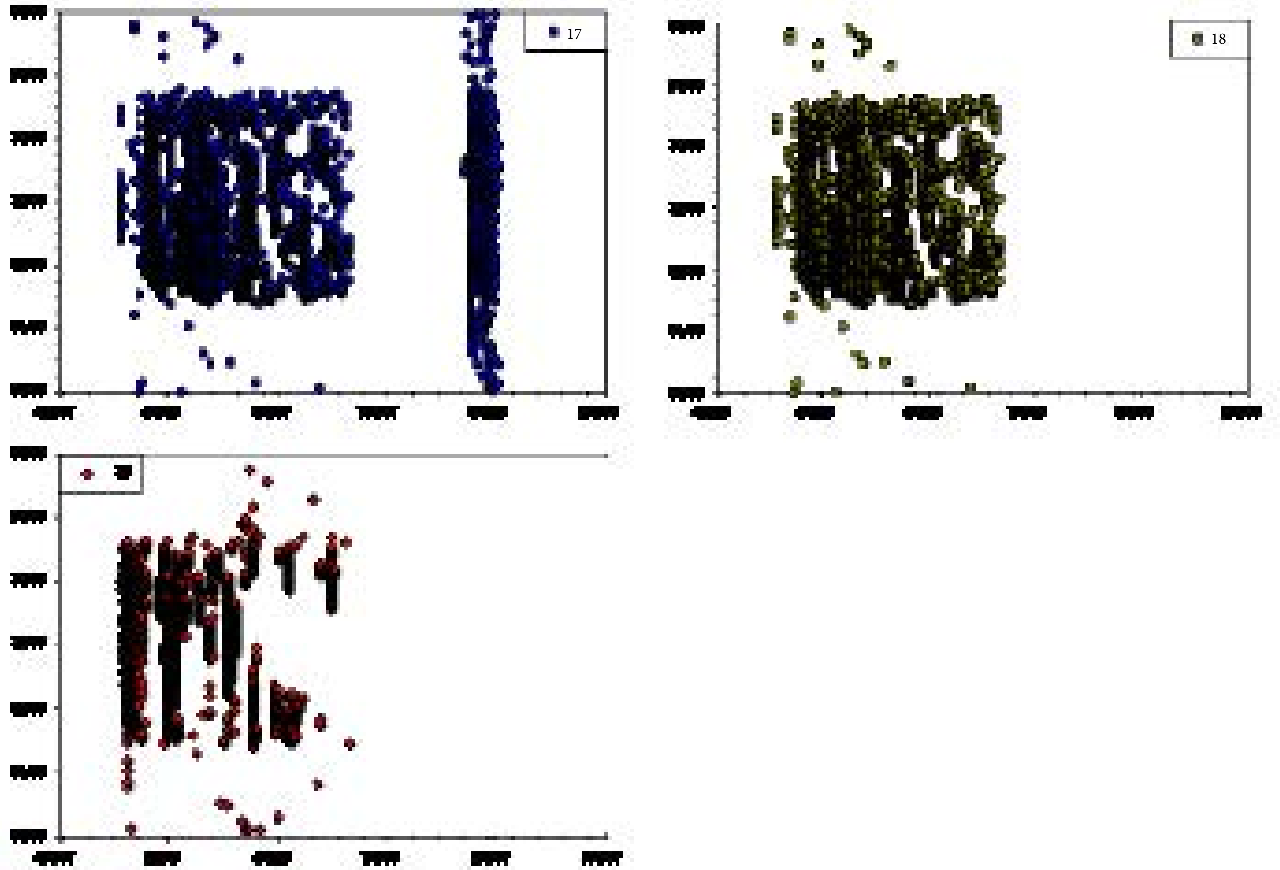

Figure 72. Day and night detection patterns for blue tang, *Acanthurus coeruleus*, tag # 3172 (26 cm TL). Days at large = 106, minimum distance travelled = 5.6 km.

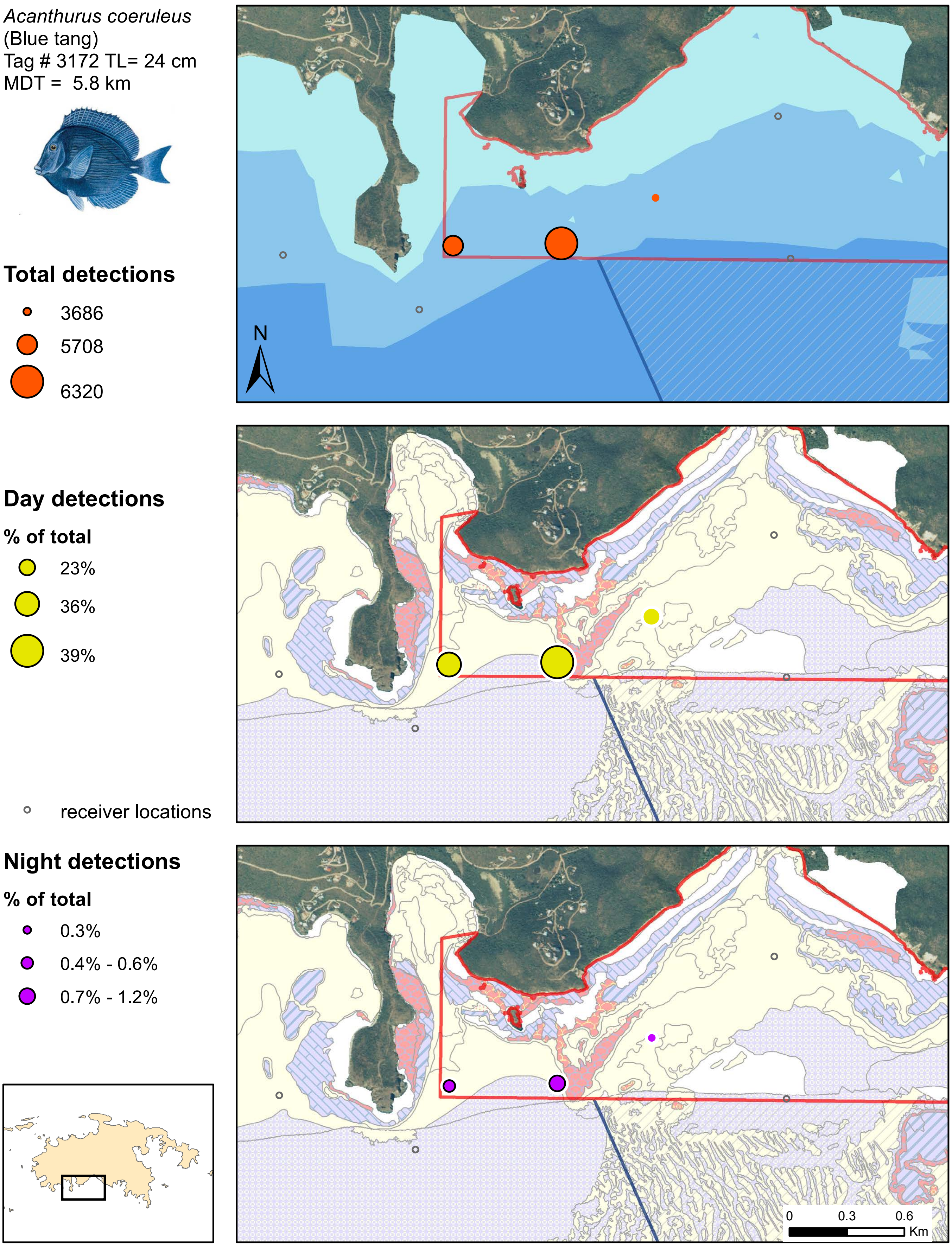

Figure 73. Map Blue tang, *Acanthurus coeruleus*, tag # 3172 (26.0 cm) DAL = 106, MDT = 5.6 km.

Family Balistidae: Triggerfish

Balistids inhabit tropical and subtropical oceans throughout the world. Most are found in relatively shallow, coastal habitats, especially over coral reefs, but a few are pelagic.

Queen triggerfish, *Balistes vetula*

Queen triggerfish are found over rocky or coral areas. They may rarely form schools, and are sometimes solitary over sand and grassy areas. Queen triggerfish feed mainly on benthic invertebrates (primarily sea urchins). They were the most abundant species caught in fish traps around St. John in 1999-2000 based on fisheries-independent SEAMAP-C data.

Queen triggerfish #6726 (32 cm) was at large for 38 days and had a MDT of 1.2 km (Fig. 74, 75, 76). This fish was caught and released at station 12 off of White Cliffs and briefly moved to station 14 in Reef Bay, a distance of 1.2 km before returning to White Cliffs for the remainder of the 38 days at large. Detections on this receiver were predominately in the daytime with far fewer nighttime detections. None of the triggerfish were detected on receivers elsewhere in the USCAN array.

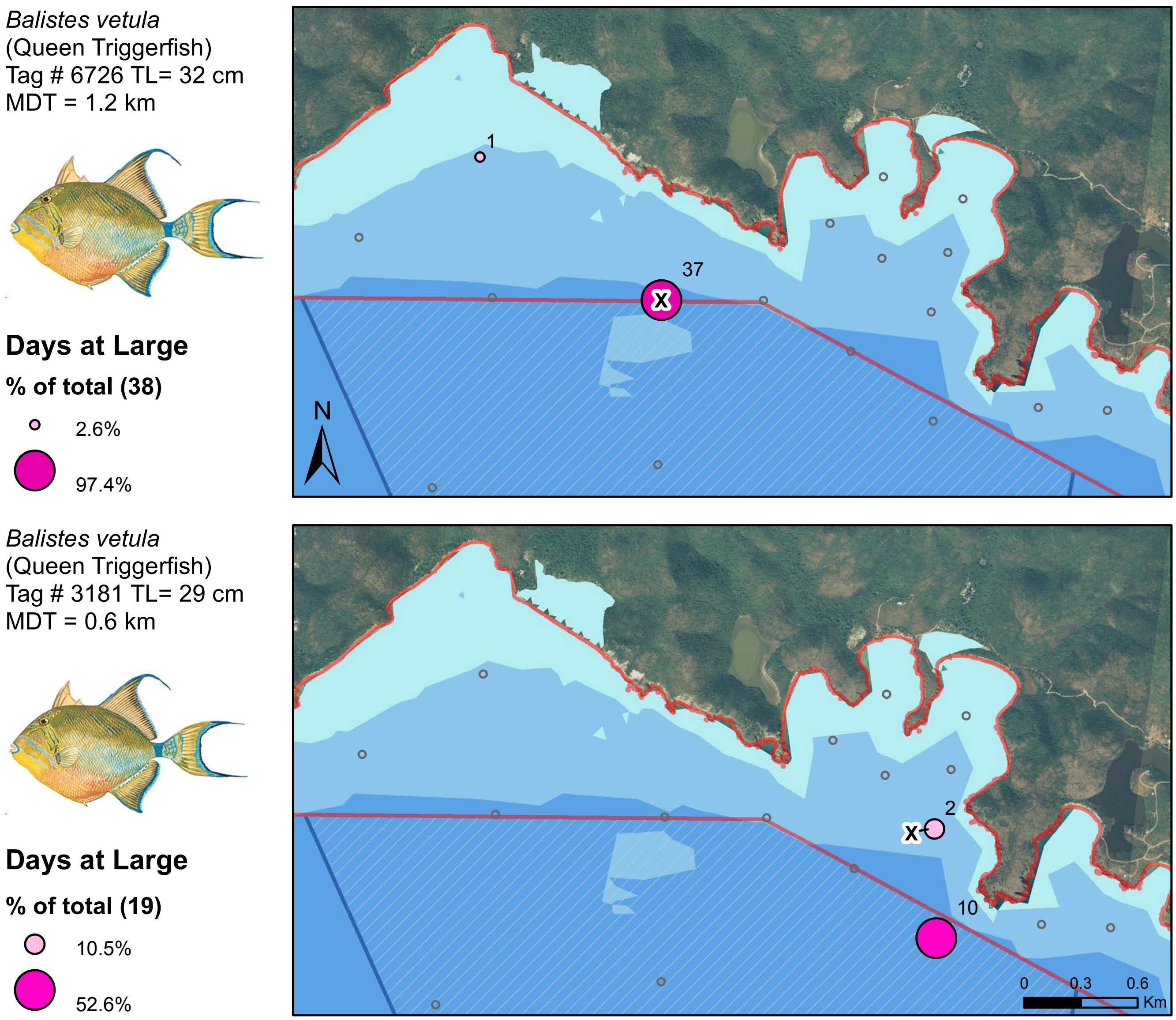

Figure 74. Detections for queen triggerfish, *Balistes vetula.* X = point of capture and release.

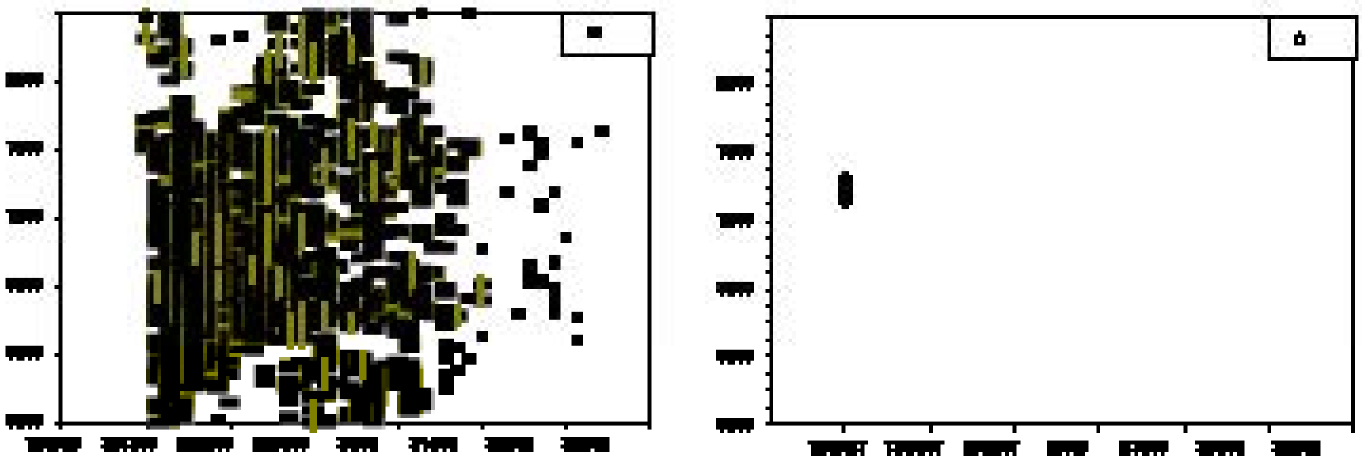

Figure 75. Queen triggerfish, *Balistes vetula*, tag # 6726 (32 cm TL).

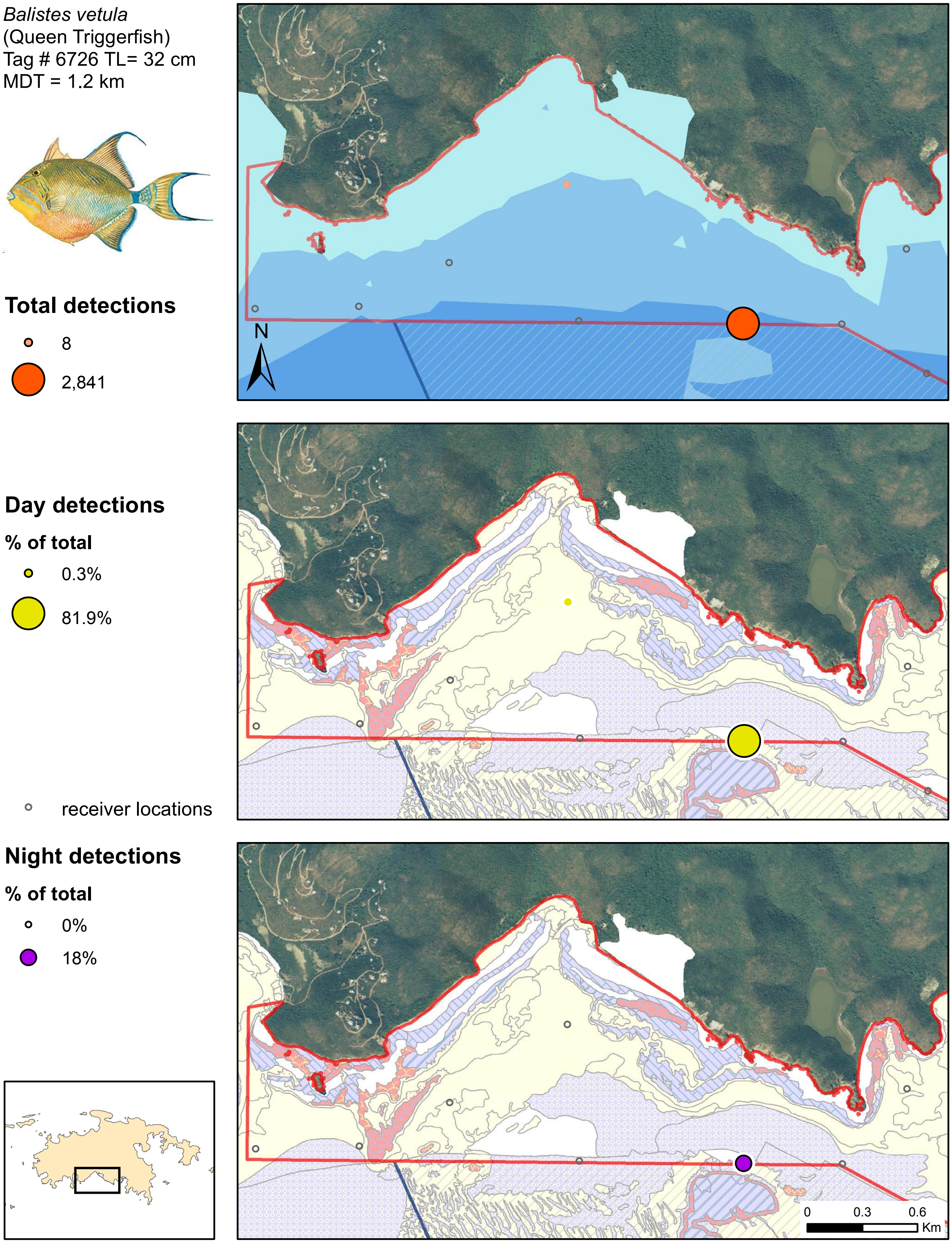

Figure 76. Day/night detections for queen triggerfish, *Balistes vetula*, tag # 6726 (32 cm TL)

Discussion

The objective of the study was to define the movements of selected reef fishes among habitats within and between the Virgin Islands Coral Reef National Monument (VICRNM), the Virgin Islands National Park (VIIS), and Territorial waters surrounding St. John. By deploying an array of 36 acoustic receivers across a broad range of habitats around St. John we have developed a better understanding of movement among management units and habitats. The array provides fish movement information at fine (e.g., day-night and 100s meters within a bay) to broad spatial and temporal scales (multiple years and 1000s meters across the shelf). The long term multi-year tracking project provides direct evidence of connectivity across habitat types in the seascape and among management units.

Many of the species showed highly predictable movement patterns with daytime spent in and around hard bottom reef habitat with minimal movement and nighttime movement to offshore areas of soft sediment and seagrass beds where movement was greater. These patterns have been recognized for a few species in the past and are likely associated with nighttime foraging and daytime resting. However, this is the first time that such a wide range of species has been tracked at one time, allowing us to better understand multi-species movement dynamics across a large are of seascape.

An important finding for management was that a number of individuals moved among management units (VICRNM, VINP, territorial waters) and several snapper moved from near- shore protected areas to off-shore shelf-edge spawning aggregations. However, most individuals spent the majority of their time with VIIS and VICRNM with only a few wide-ranging species moving outside the management units.

Overall for all species pooled, 71% of the time was spent in VIIS, 25% in VICRNM, and only 4% in territorial waters. Based on these data influenced by the specific life history patterns of the fishes tagged, the current management boundaries appear adequate for most species except for the most wide-ranging and transient ones.

The average maximum distance travelled (MDT) was ca. 2 km with large variations among species. Grunts, snappers, jacks, and porgies showed the greatest movements. Among all individuals across species, there was a positive and significant correlation between size of individuals and MDT and between DAL and MDT. When the MDT was calculated using detections from the brooder array (USCAN), average MDT was 3.8 km, with 75% of fish making long-range movements, greater than 1 km (Pittman et al. 2013).

Many of the points along the south shore of St. John are hotspots for tagged fish detections and are likely used as movement reference points along migratory pathways. The patch reefs at White Cliffs appear to be an important transit point for fishes moving between the near-shore areas of VIIS and the deeper mid-shelf reef in VICRNM.

The movements of relatively few species have been studied. Therefore this study has greatly increased our knowledge of reef fish movement patterns and habitat use for the Caribbean region. As we learn more about how far fish move, particularly as movements relate to habitats and seasons, we will gain valuable tools for creating better marine reserve design and ecosystem- based management.

During the current study, no parrotfish were tagged. Parrotfish are an important top-down controller of algae on coral reefs, yet very little is known about their movements. Studies are now underway on St. John to quantify the space use patterns of parrotfish as well as movements inside and outside the Virgin Islands Coral Reef National Monument.

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Appendix 1

U.S. Caribbean Acoustic Tracking Network (USCAN): A data sharing partnership for acoustic tracking and movement ecology of marine animals in the Caribbean Sea

Existing Data Integration - We have recently exchanged and integrated into a single database tag detections for conch, teleost and elasmobranch fish from four separately maintained arrays in the U.S. Virgin Islands including the NMFS queen conch array (St. John near shore), NOAA/NCCOSBiogeography Branch array (St. John near shore & midshelf reef); UVI shelf edge arrays (Marine Conservation District, Grammanik & other shelf edge); NOAA NMFS Apex Predator array COASTSPAN (St. John near shore). The integrated database has over 7.5 million hits. Data is shared only with consent of partners and full acknowledgements. Thus, the summary of integrated data here uses data from NOAA and UVI arrays under a cooperative agreement.

The benefits of combining and sharing data have included increasing the total area of detection resulting in an understanding of broader scale connectivity than would have been possible with a single array. Partnering has also been cost-effectiveness through sharing of field work, staff time and equipment and exchanges of knowledge and experience across the network. Use of multiple arrays has also helped in optimizing the design of arrays when additional receivers are deployed. The combined arrays have made the USVI network one of the most extensive acoustic arrays in the world with a total of 150+ receivers available, although not necessarily all deployed at all times. Currently, two UVI graduate student projects are using acoustic array data.
Some summary info:

- 8000+ conch hits from NMFS tagged queen conch were received on the NOAA Biogeography Branch array and the NMFS Apex Predator array on St. John. This data was compiled by UVI graduate student Bryan Legare and shared with Ron Hill & Jennifer Doerr
- 22 Biogeography Branch tagged fish (7 species) were detected by the NMFS Galveston array and the NMFS Apex Predators array combined including *Acanthurus coeruleus* (3 individuals), *Calamus calamus* (7), *Caranx ruber* (3), *Haemulon sciurus* (3), *Lutjanus analis* (4) *Lutjanus synagris* (1), and *Mulloidichthys martinicus* (1)
- 11 grouper (3 species) tagged by UVI were detected by NMFS Galveston & NOS Biogeography Branch arrays including *Epinephleus stratius* (7 individuals), *Epinephleus guttatus* (1), and *Mycteroperca venenosa* (2)
- 9 adult sharks tagged by URI were detected by NMFS Galveston & NOS Biogeography Branch arrays, including 2 lemon sharks and 7 tiger sharks
- 2 Lutjanus analis tagged by Biogeography Branch were detected on the UVI array
- 4 juvenile sharks were detected on the UVI array and 17 juvenile sharks including black tip and lemon sharks were detected on the Biogeography Branch array
- Several species of large-bodied grouper and snapper movements connect the VI National Park to the shelf-edge spawning aggregations at the MCD and Grammanik Bank.
- One yellowfin grouper and one red hind tagged at the shelf-edge spawning aggregations were detected on the near shore St. John array.
- Two mutton snapper tagged inside the VI National Park were detected at the shelf edge at spawning time (Figure 3). Furthermore, a Nassau grouper travelled from near shore St. Thomas to the MCD spawning aggregations.

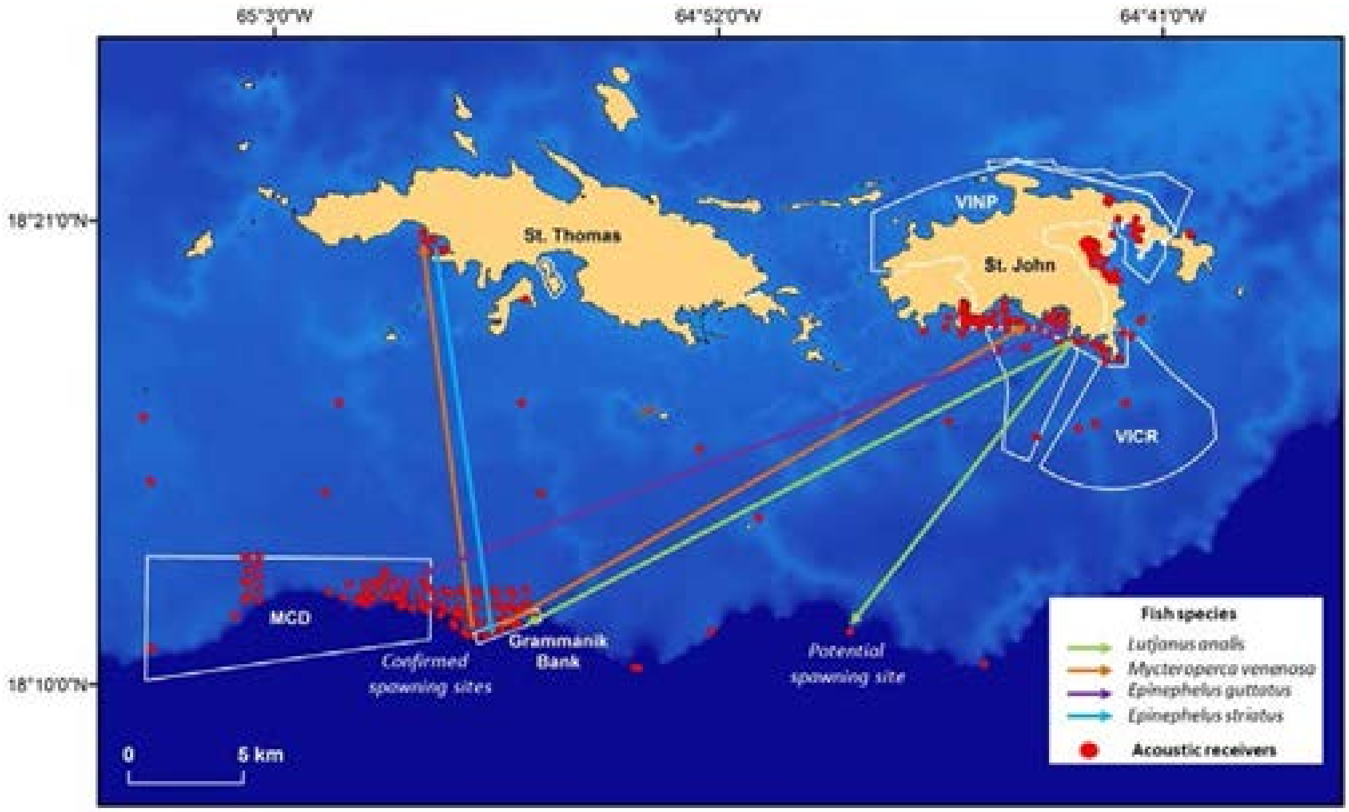

Figure A1. Long range movements of grouper and snapper from near shore areas to offshore, shelf edge spawning aggregations providing direct evidence of connectivity between VIIS managed by National Park Service and fishery closure MPAs managed by NOAA Caribbean Fishery Management Council. Red dots are receiver locations that existed within the USCAN array between 2006 and 2010.

U.S. Department of Commerce
Rebecca Blank, *Deputy Secretary*

National Oceanic and Atmospheric Administration
Kathryn Sullivan, *Acting Under Secretary for Oceans and Atmosphere*

National Ocean Service
Holly Bamford, *Assistant Administrator for Ocean Service and Coastal Zone Management*

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