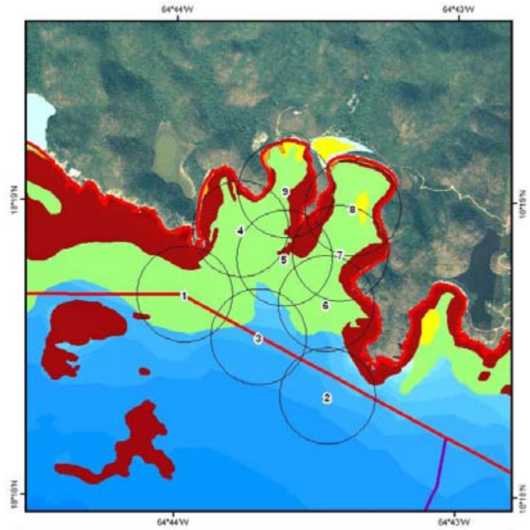
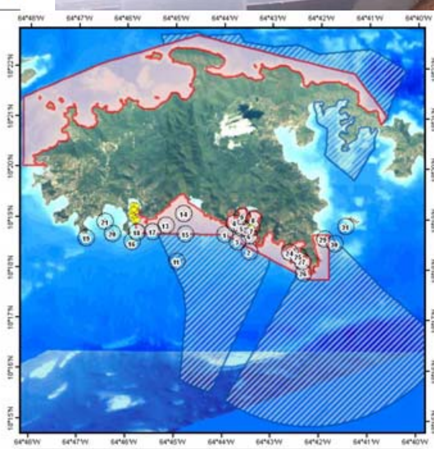
Acoustic Tracking of Reef Fishes to Elucidate Habitat Utilization Patterns and Residence Times Inside and Outside Marine Protected Areas Around the Island of St. John, USVI



Interim Project Report
October 2007

Alan M. Friedlander and Mark E. Monaco
NOAA/NOS/NCCOS/CCMA-Biogeography Branch

With contributions from: Jim Beets, Rafe Boulon, Russell Callender, John Christensen, Randy Clark, Sarah Hile, Matt Kendall, Jeff Miller, Caroline Rogers, Lisa Wedding, and KimWoody.

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Abstract

This technical memorandum describes a developing project under the direction of NOAA's Biogeography Branch in consultation with the National Park Service and US Geological Survey to understand and quantify spatial patterns and habitat affinities of reef fishes in the US Virgin Islands. The purpose of this report is to describe and disseminate the initial results from the project and to share information on the location of acoustic receivers and species electronic tag ID codes. The Virgin Islands Coral Reef National Monument (VICRNM), adjacent to Virgin Islands National Park (VIIS), was established by Executive Order in 2000, but resources within the monument are poorly documented and the degree of connectivity to VIIS is unknown. Whereas, VICRNM was established with full protection from resource exploitation, VIIS has incurred resource harvest by fishers since 1956 as allowed in its enabling legislation. Large changes in local reef communities have occurred over the past several decades, in part due to overexploitation. In order to better understand the habitat utilization patterns and movement of fishes among management regimes and areas open to fishing around St, John, an array of hydroacoustic receivers was deployed while a variety of reef fish species were acoustically tagged. In July 2006, nine receivers with a detection range of ca. 350 m were deployed in Lameshur Bay on the south shore of St. John, within VIIS. Receivers were located adjacent to reefs and in seagrass beds, inshore and offshore of these reefs. It was found that lane snappers and bluestriped grunts showed diel movement from reef habitats during daytime hours to offshore seagrass bed at night. Timing of migrations was highly predictable and coincided with changes in sunrise and sunset over the course of the year. Fish associated with reefs that did not have adjacent seagrass beds made more extensive movements than those fishes associated with reefs that had adjacent seagrass habitats. In April 2007, 21 additional receivers were deployed along much of the south shore of St. John (ca. 20 km of shoreline). This current array will address broader-scale movement among management units and examine the potential benefits of the VICRNM to provide adult "spillover" into VIIS and adjacent harvested areas. The results from this work will aid in defining fine to moderate spatial scales of reef fish habitat affinities and in designing and evaluating marine protected areas.

INTRODUCTION

Study Area and Background

Coral reefs in the US Virgin Islands and in National Park Service (NPS) units have been in decline during recent decades (Rogers et al. 1997, Rogers and Beets 2001, Beets and Rogers 2002). The establishment of the Virgin Islands Coral Reef National Monument (VICRNM) in 2000, provides approximately 5,143 hectares of marine habitat off the island of St. John, US Virgin Islands (USVI) and greatly increased the NPS jurisdiction in territorial waters. VICRNM was intended to enhance resources in the Virgin Islands National Park (VIIS), which was established by Congress in 1956 and expanded in 1962. This new monument roughly doubles the area in and around St. John now under the jurisdiction of the National Park Service (Figure 1).

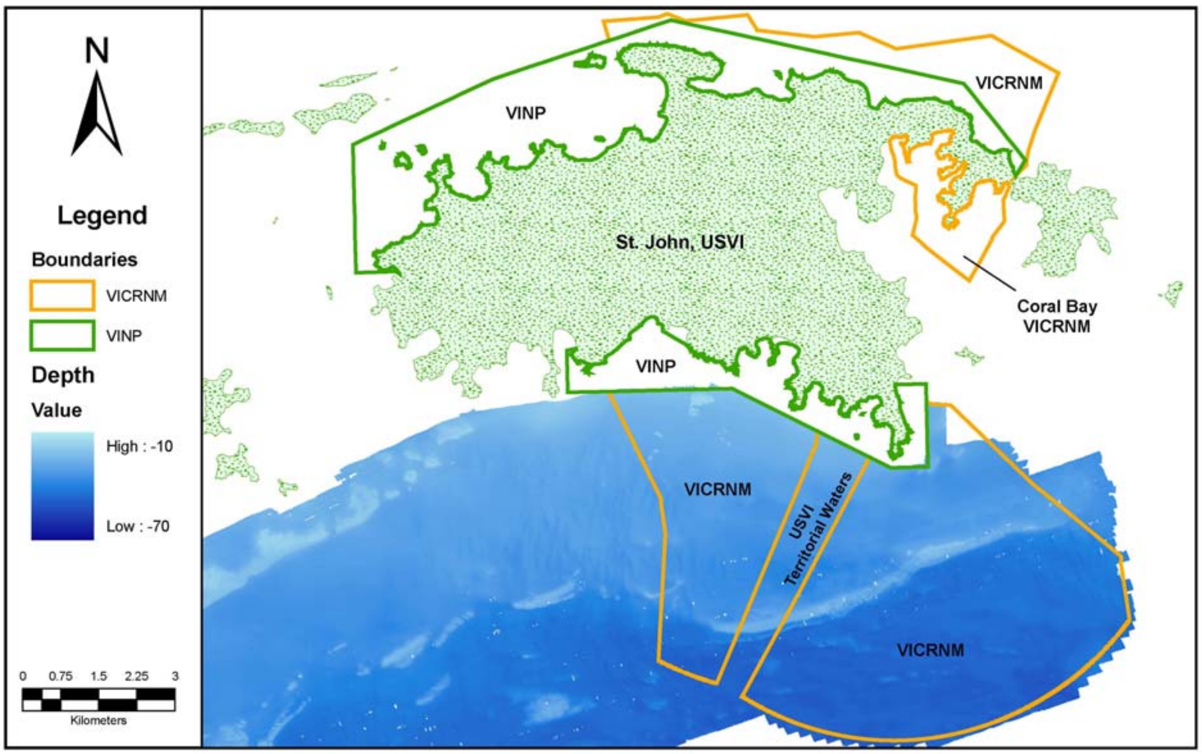

Figure 1. Location of marine protected area boundaries around the island of St. John, USVI.

Part of the impetus for the designation of VICRNM was the relatively poor condition of habitats and fish populations found throughout Virgin Islands National Park (VIIS) (Rogers and Beets 2001, Beets and Rogers 2002). Resources in VICRNM are poorly documented; therefore, there is a critical need of data for development of the Resource Management Plan for VICRNM. The initial baseline characterization of the mid-shelf region of the VICRNM was recently completed by the project partners (Monaco et al. 2007) and coral ecosystem monitoring is underway at random sites within and outside VIIS and VICRNM. To assess the long-term effectiveness of management regulations and of VICRNM as a marine protected area (MPA) it is necessary to conduct investigations that can provide data on the movement of organisms (e.g., reef fishes) across NPS boundaries and on linkages among adjacent units. Data on movement coupled with inventory and abundance data are essential if the effectiveness of full protection of reef fishes is to be evaluated. The living marine resource data are extremely important to both NPS units, so that: 1) resource data can be provided for development of the General Management Plan, 2) the level of protection can be adequately evaluated, 3) modification in regulations can be assessed, and 4) benefits of different levels of protection and resource enhancement may be evaluated.

VIIS Resource Management Division has been working closely with National Oceanic and Atmospheric Administration (NOAA), United States Geological Service (USGS), and academic partners to characterize benthic habitats to document living marine resource habitat utilization patterns in VIIS and VICRNM. NOAA-NOS Biogeography Branch has completed resource maps of benthic habitats around St. John in VIIS and VICRNM. Additionally, they are completing development of benthic maps of the significant deeper-water portions of VICRNM based on remote-sensing data collected over the past two years on the NOAA ship Nancy Foster. These maps are under development based on multibeam sonar data and remotely operated vehicle digital imagery. To conduct integrated coral reef ecosystem mapping and monitoring NOAA-NOS Biogeography Branch and the NPS, USGS, NOAA Fisheries and the University of Miami partners have developed technical guidance documents to monitor reef fishes based on addressing NPS management needs within the VIIS, BUIS, and other NPS units in Florida and the Caribbean (Menza et al. 2007). Coupling benthic habitat maps with movement patterns of organisms provide a spatial framework to address questions concerning linkage among adjacent habitats and how the mosaic of habitats connects in the seascape that structures reef fish distribution patterns.

Reef Fish Movements

An important component to resource characterization and monitoring is an understanding of the movement (behavior) of organisms among habitats, between VIIS and VICRNM, and across those boundaries into Territorial and other Federal managed waters. Documentation of movement of reef fish species is extremely important to NPS resource managers, particularly the knowledge of species movements of resident fish within park boundaries and of those species which frequently move across park boundaries. Results of this investigation will not only be important for resource management in VIIS and VICRNM, but will provide new information on reef fish distribution patterns around St. John and St. Thomas, USVI. Additionally, results on the effectiveness of management strategies and MPAs will be valuable to Federal and Territorial marine resource management agencies.

Many species of fish utilize different habitats as they grow and mature. These movement patterns vary depending on adjacent habitat, with certain habitat-types acting as barriers to dispersal (e.g., Acosta 1999). Movements can also occur on a daily basis, such as juvenile grunts in the Caribbean (Ogden and Ehrlich 1977) and goatfishes in Hawaii (Holland et al. 1993), which undergo predictable movements between daytime resting and nighttime feeding areas. Many fish species aggregate to spawn and undergo extensive spawning migrations to aggregation sites (Domeier and Colin 1997, Beets and Friedlander 1999). Long-term persistence of these aggregations at specific sites makes these species extremely susceptible to fishing pressure (Sadovy 1993). Identifying the timing and location of these aggregations is critical for better management of these species.

Understanding habitat utilization patterns, residence time, ontogenetic and diel movement patterns of organisms is critical to defining essential fish habitat (EFH), as well as designing and evaluating marine protected areas (MPAs) (Lowe & Bray 2006). Many reef fish species show ontogentic migrations from shallow sites; primarily seagrass and mangrove habitats, to deeper sites further offshore (Appeldoorn et al. 2003; Christensen et al. 2003). 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). These movements allow fishes to move nutrients from one habitat to another (Meyer et al. 1983) and the identification of these movement patterns can help better understand how energy flows through the ecosystem.

Underwater acoustic telemetry is an important tool to examine spatial and temporal time budgets of fishes in their natural environment. Information obtained from tracking fishes can help to explain questions of immigration/emigration, residence time, habitat preference, site fidelity and many other important life history traits. Movement patterns can be described using continuous 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, but enables monitoring over a longer time frame (1 year or more). Strategically placed continuous monitors can provide information on movement at large spatial and temporal scales (Lowe & Bray 2006). Coupling benthic habitat maps with movement patterns of organisms provides a spatial framework to address questions concerning linkage among adjacent habitats and how the mosaic of habitats connects in the seascape to structure the reef fish ecology (Lowe et al. 2003, Lowe & Bray 2006, Topping et al. 2005, 2006).

This technical memorandum describes a developing project conducted by NOAA's Biogeography Branch to understand and quantify spatial patterns and habitat affinities of reef fishes in the US Virgin Islands. The purpose of this report is to describe and disseminate the initial results from the project and to share information on the location of acoustic receivers and species' electronic tag ID codes. The primary objectives of this study are to: 1) examine the movement of fish species between inshore habitats within VINP and offshore habitats within the VICRNM, 2) examine the movement of fish species inside and outside of VINP and VICRNM, 3) examine the habitat utilization patterns and movements of fishes over diel time periods at small and large spatial scales, and 4) examine the habitat utilization patterns and movements of fishes over time periods ranging from weeks to months to years.

Methods

The first field mission was conducted in July 2006 and resulted in deployment of nine acoustic receivers (model VR2, VEMCO, Ltd.) in Lameshur Bay, on the south side of St. John, USVI within VIIS (Fig. 2 and Table 1). Site selection for each receiver, placed about 2 m above the seafloor, was based on providing adequate coverage to detect movement of fishes and to address the movement of fishes between habitats and management units. This resulted in acoustic receivers deployed in an array adjacent to a variety of habitats, from shallow nearshore mangroves, to shoreline boulder habitats, to seagrass beds, to coral reefs, and to deeper algal plains. 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. Receivers in Lameshur Bay were deployed to allow for maximum overlap among detection ranges. During the April 2007 mission, an additional 21 receivers were deployed along the south shore of St. John (Figures 3 & 4). Thus, a total of 30 hydroacoustic receivers (i.e., continuous data loggers) have been deployed along the south shore using sandscrews, steel cable, and submerged buoys (Figure 5).

Fish were captured using 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.

For most fish species, we surgically implanted VEMCO V9-2L-R64K transmitters into the stomach cavities of fishes caught using traps and hook and line. In a shallow seawater tub, fish were rolled over with their ventral surface facing upward. This induced tonic immobility and eliminated the need for anesthesia. A 1 cm incision was made 1 cm off-center from the ventral midline between the pelvic fins and the anus and a small acoustic transmitter (22 mm) was placed within the visceral cavity. Battery life for these transmitters ranges from 1-1.5 years, on average. Acoustic transmitters were coated in a combination of beeswax and paraffin (1:2.33) to reduce immunorejection. The incision was closed with 2 surgical sutures (Ethicon Chromic Gut 2-0) and the fish were observed to ensure adequate recovery (Lowe et al. 2003). Finally, each fish was measured (total length [TL]). 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 (Figs. 6, 7). After holding fish for post surgery recovery, they were released at a location in close proximity to the original capture location.

A total of 55 fishes, representing 11 species and 8 families, were acoustically tagged around Lameshur Bay, St. John during July 2006 (Friedlander and Monaco 2006). In April 2007, an additional 78 fishes were acoustically tagged resulting in a total of 123 total tagged individuals from 18 different species and 10 different families (Table 2).

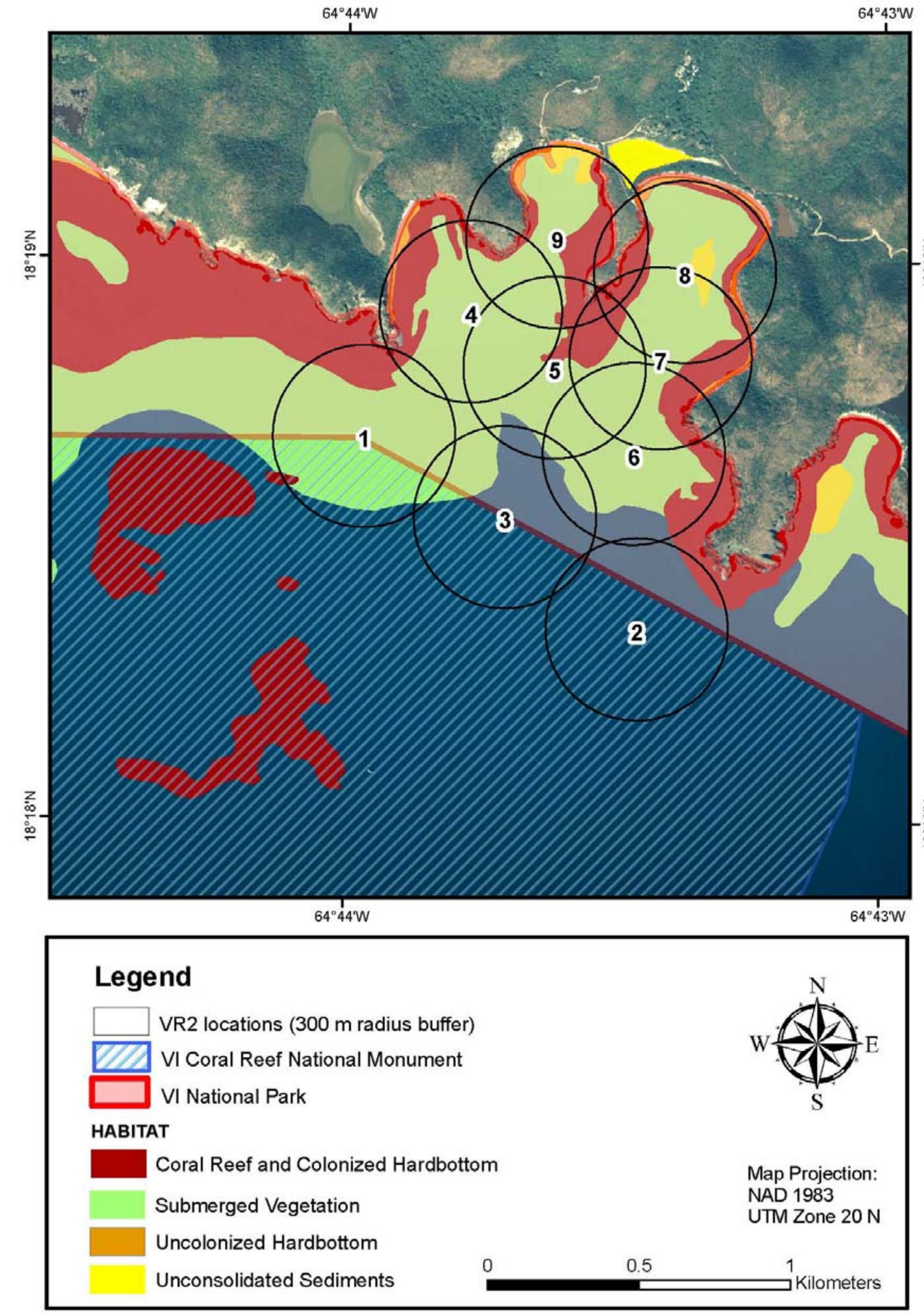

Figure 2. Location of hydroacoustic receivers deployed in Lamehsur Bay, St. John, USVI with a 300 m radius detection buffer indicated by circles.

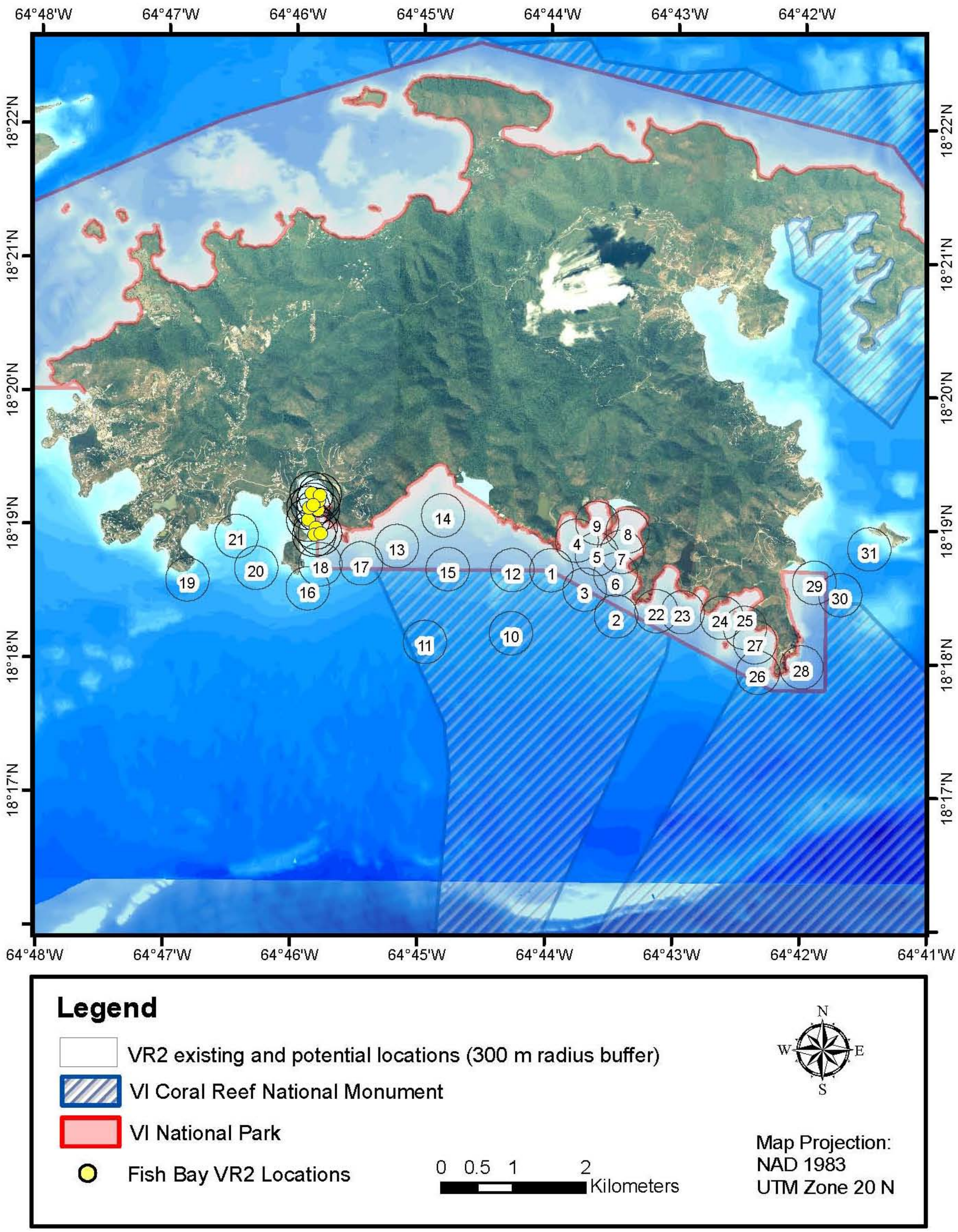

Figure 3. Location of hydroacoustic receivers deployed along south shore St. John, USVI with a 300 m radius detection buffer indicated by circles. (Note: yellow spheres represent VR2s deployed by NMFS SEFS for conch movement study.)

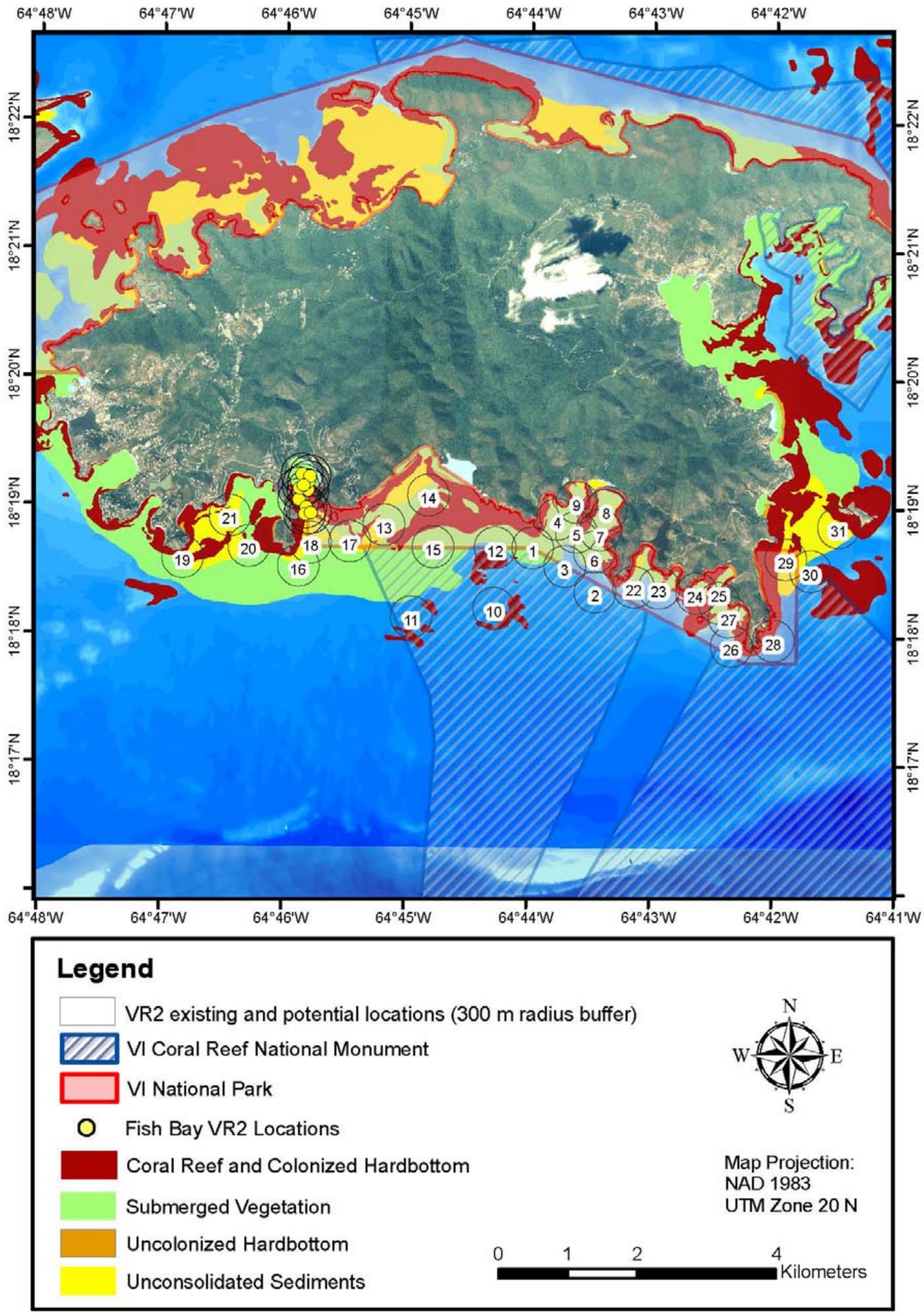

Figure 4. VR2 hydroacoustic receiver locations shown with habitat map.

Figure 5. Acoustic transmitters, hydroacoustic receivers, and mooring design and deployment.

Table 1. Location of VR2 hydroacoustic receivers along south shore of St. John, USVI.

Station	Location	Depth (m)	Depth (ft)	Lat.	Long.
1	Lameshur Bay	18.9	62	18.3114	-64.7328
2	Lameshur Bay	22.9	75	18.3057	-64.7242
3	Lameshur Bay	21.9	72	18.3090	-64.7284
4	Lameshur Bay	11.6	38	18.3151	-64.7295
5	Lameshur Bay	13.7	45	18.3135	-64.7269
6	Lameshur Bay	17.1	56	18.3109	-64.7244
7	Lameshur Bay	12.5	41	18.3138	-64.7236
8	Lameshur Bay	7.3	24	18.3164	-64.7228
9	Lameshur Bay	7.0	23	18.3174	-64.7268
10	White Cliffs	26.8	88	18.3035	-64.7380
11	White Cliffs	28.0	92	18.3023	-64.7492
12	White Cliffs	21.6	71	18.3114	-64.7379
13	Reef Bay	15.2	50	18.3142	-64.7530
14	Reef Bay	11.3	37	18.3181	-64.7470
15	Reef Bay	21.6	71	18.3114	-64.7463
16	Cocoloba Cay	19.2	63	18.3089	-64.7647
17	Fish Bay	18.6	61	18.3120	-64.7577
18	Fish Bay	14.3	47	18.3119	-64.7630
19	Rendezvous Bay	21.6	71	18.3098	-64.7804
20	Rendezvous Bay	18.0	59	18.3114	-64.7714
21	Rendezvous Bay	17.4	57	18.3153	64.7740
22	Kittle Bay	16.8	55	18.3064	-64.7190
23	Grotpan Bay	18.0	59	18.3063	-64.7155
24	Salt Pound	11.0	36	18.3057	-64.7104
25	Salt Pound	9.4	31	18.3044	-64.7073
26	Salt Pound	23.8	78	18.2988	-64.7056
27	Salt Pound	10.7	35	18.3027	-64.7060
28	Rams Head	27.1	89	18.2996	-64.6999
29	Drunk Bay	17.4	57	18.3101	-64.6983
30	Eagle Shoals	25.9	85	18.3086	-64.6949
31	Le Duc	23.5	77	18.3144	-64.6912

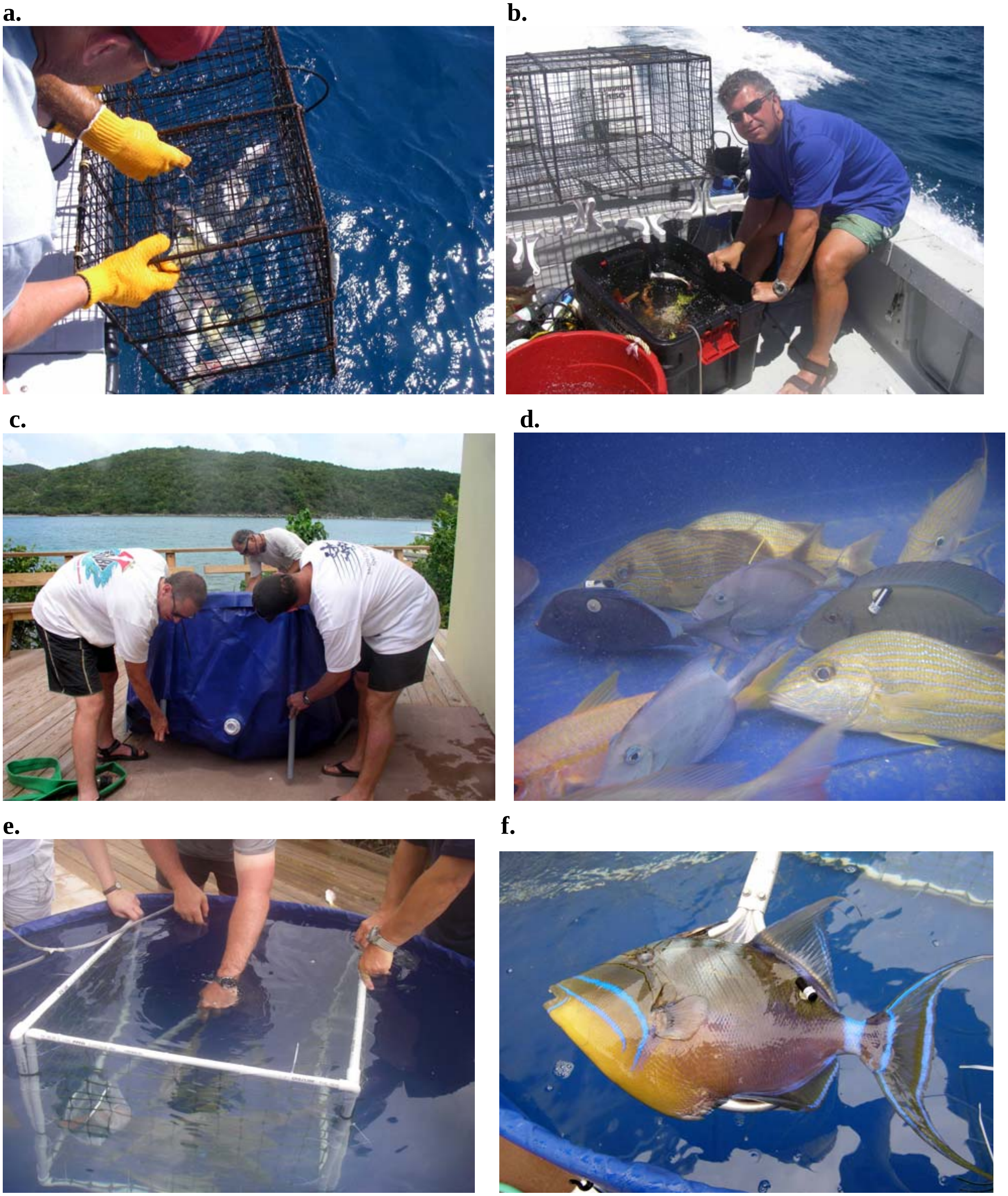

Figure 6. a) Fish traps used to capture fish; b) Aerated holding tank; c) Shore-based holding tank (450 gallons) at Virgin Islands Environmental Research Station, St. John; d) Tagged fish in holding tank. External transmitters and external t-bar tags evident on a few individuals; e) Crowder used to minimize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

Figure 7. Surgical procedures used for implanting acoustic transmitters in fishes.

Table 2. Species composition, number, and sizes of fishes acoustically tagged throughout the study area.

Scientific name	Common name	Family	N	Mean total length (cm)	Standard Deviation of TL	Max of TL	Min of TL
Lutjanus synagris	lane snapper	Lutjanidae	32	26.49	4.07	36.0	20.0
Haemulon sciurus	bluestriped grunt	Haemulidae	32	27.65	1.86	30.5	24.0
Ocyurus chrysurus	yellowtail snapper	Lutjanidae	13	30.14	4.92	38.0	22.5
Calamus calamus	saucereye porgy	Sparidae	8	27.75	4.68	35.0	21.3
Holocentrus adscensionis	longjaw squirrelfish	Holocentridae	8	28.08	0.58	29.0	27.5
Lutjanus analis	mutton snapper	Lutjanidae	6	38.12	5.85	45.0	31.0
Acanthurus coeruleus	blue tang	Acanthuridae	5	21.00	2.12	24.0	19.0
Lutjanus griseus	grey snapper	Lutjanidae	4	28.87	4.65	35.4	25.2
Balistes vetula	queen triggerfish	Balistidae	3	32.83	5.39	39.0	29.0
Acanthurus chirurgus	doctorfish	Acanthuridae	2	21.55	3.32	23.9	19.2
Haemulon plumieri	white grunt	Haemulidae	2	28.25	4.60	31.5	25.0
Ginglymostoma cirratum	nurse shark	Rhincodontidae	2	62.50	10.61	70.0	55.0
Epinephelus guttatus	red hind	Serranidae	1	29.50		29.5	29.5
Caranx ruber	bar jack	Carangidae	1	47.00		47.0	47.0
Haemulon flavolineatum	french grunt	Haemulidae	1	20.00		20.0	20.0
Lutjanus apodus	schoolmaster snapper	Lutjanidae	1	27.00		27.0	27.0
Mulloidichthys martinicus	yellow goatfish	Mullidae	1	31.00		31.0	31.0
Pseudupeneus maculatus	spotted goatfish	Mullidae	1	27.00		27.0	27.0
			123				

Initial Results & Discussion

This section of the report provides a summary on the results from the download of the acoustic tag data for 55 fishes tagged in July 2006 and subsequent data retrieval in April of 2007. An overview describing the habitat and release sites is provided for the nine Lameshur Bay, St John sites. Example results for five species are provided, followed by summary information on Lameshur Bay-wide species' habitat utilization and diel movement patterns. The 24 hour movement patterns are defined as: night = 12:00-04:00 and 20:00-24:00; crepuscular = 04:00-08:00 and 16:00-20:00; and daytime = 08:00-16:00.

Table 3 provides information on the habitat at and surrounding the nine Lameshur Bay stations as classified in Kendall et al. 2001. In addition, information is provided on the distance from hard bottom coral reef locations and distance from mid-bay receiver station numbers 4, 5, and 6 (Fig 8).

Table 3. Habitat descriptions and distance from release sites for acoustic receivers deployed in Lameshur Bay, St. John.

Station	Lat.	Long.	Zone	Type	Cover	% Cover	Depth (m)	Depth (ft.)	Dist. from Hard bottom (m)	Release sites Dist. from Station 4 (m)	Release sites Dist. from Station 5 (m)	Release sites Dist. from Station 6 (m)
1	18.3114	-64.7328	Bank/Shelf	Macroalgae	Patchy	(50-<90%)	-18.9	-62.15	149	540	666	889
2	18.3057	-64.7242	Bank/Shelf	Macroalgae	Patchy	(50-<90%)	-22.8	-74.95	248	1,180	903	578
3	18.3090	-64.7284	Bank/Shelf	Macroalgae	Patchy	(50-<90%)	-21.8	-71.58	522	687	519	472
4	18.3151	-64.7295	Bank/Shelf	Seagrass	Patchy	(50-<70%)	-11.6	-38.12	139	0	332	712
5	18.3135	-64.7269	Bank/Shelf	Seagrass	Patchy	(50-<70%)	-14.3	-46.78	15	332	0	385
6	18.3109	-64.7244	Bank/Shelf	Seagrass	Patchy	(50-<70%)	-17.0	-55.64	141	712	385	0
7	18.3138	-64.7236	Bank/Shelf	Seagrass	Patchy	(50-<70%)	-12.5	-41.01	73	643	351	327
8	18.3163	-64.7228	Bank/Shelf	Seagrass	Patchy	(50-<70%)	-7.4	-24.30	118	716	532	622
9	18.3173	-64.7268	Bank/Shelf	Seagrass	Continuous		-7.0	-23.11	21	374	429	756

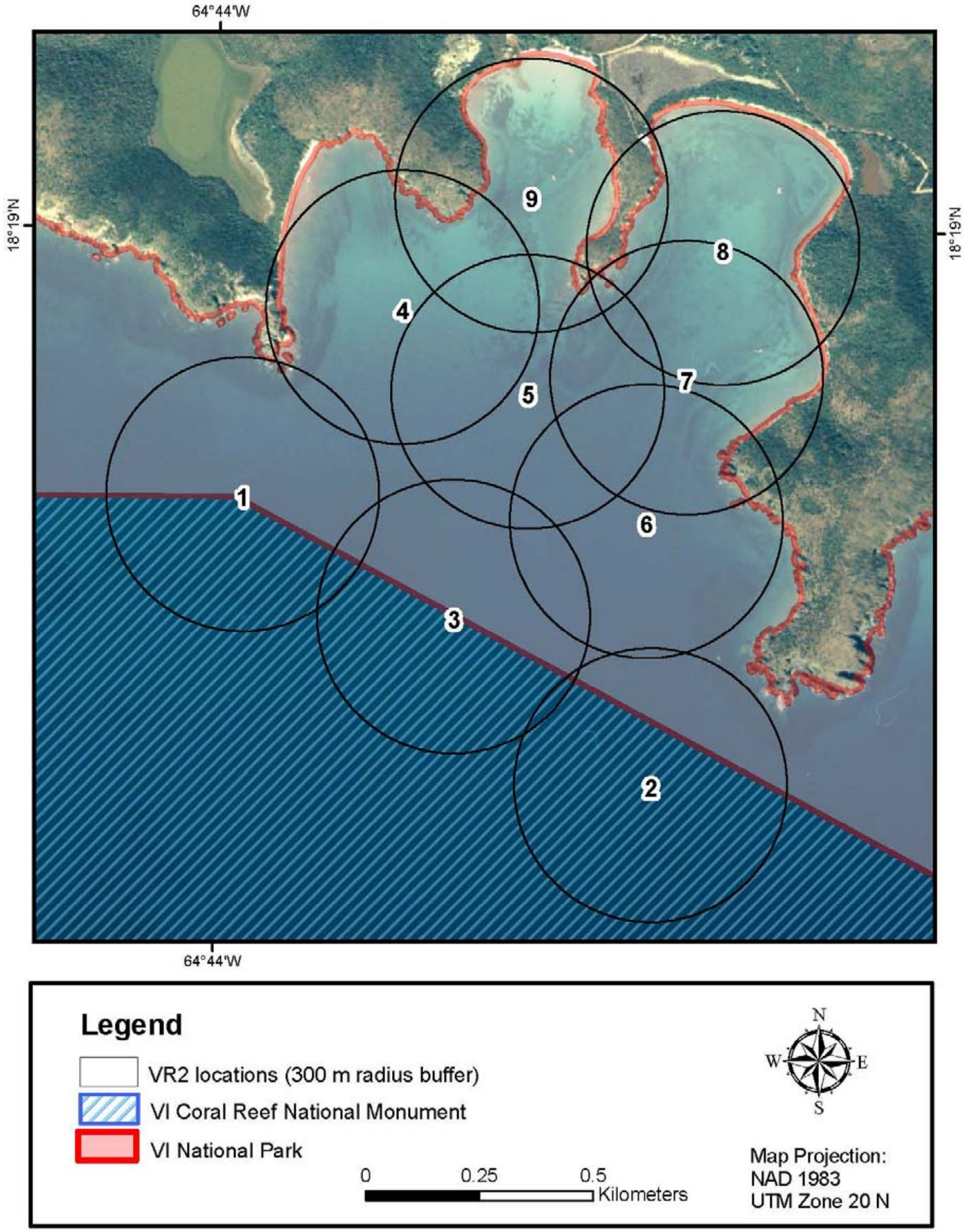

Figure 8. Locations of nine receivers in Lameshur Bay showing 300 m radius detection buffer and station detection overlap.

Station 1

Station 1 was located in sand covered with patchy macroalgae, at a depth of 18.9 m and 149 m from the nearest hard bottom habitat (Table 3). Nine different tag fish were detected by this receiver, but the most persistent fish was #3183. This 31.0 cm lane snapper (*Lutjanus synagris*) was detected at this receiver from July 13, 2006 until December 4, 2006. The release site for this fish was station 5, which is 666 m away. More than 66% of the total detections occurred at night, with 31% occurring during crepuscular time periods, and 14% during daytime hours.

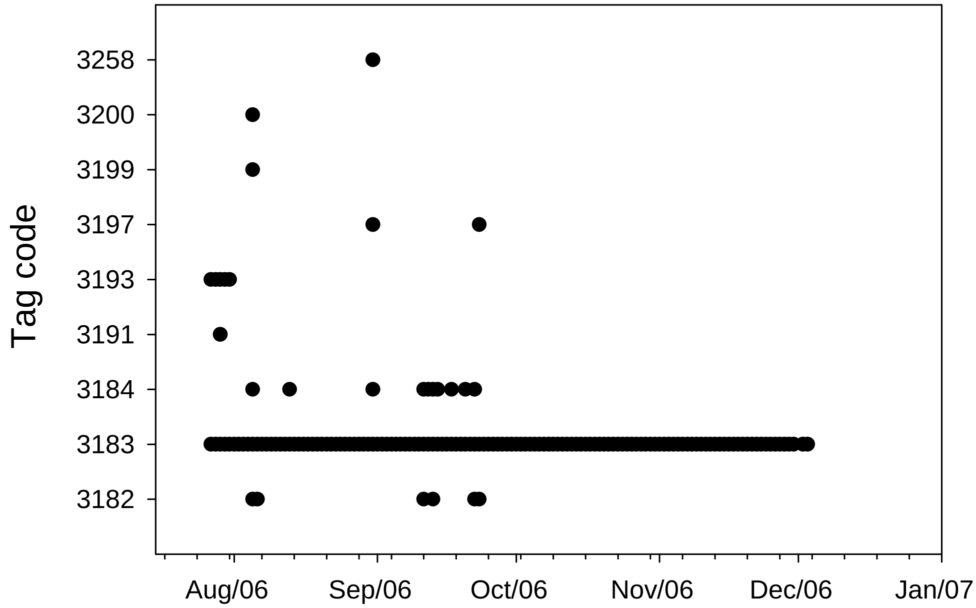

Figure 9. Detection of acoustically tagged fish by VR2 receiver at Station 1. Black circles indicate tag detection.

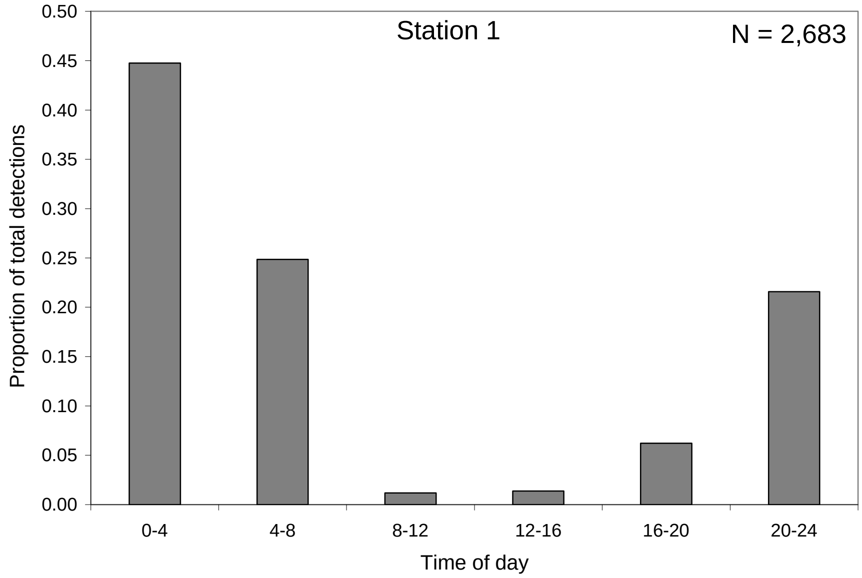

Figure 10. Proportion of total detections by time of day for station 1.

Station 2.

Station 2 was located in sand covered with patchy macroalgae, at a depth of 22.9 m and 248 m from the nearest hard bottom habitat (Table 3). Sixteen different tag fish were detected by this receiver. Five fish were detected from July 06 to April 07. All were lane snappers between 23-29 cm and all were released at station 6 (Tektite Reef), a distance of 578 m away. A majority (59%) of the detections occurred during the daytime and crepuscular (35%) time periods, and these fish were likely detected while still on the reef. Only 7% of all detections were recorded during night.

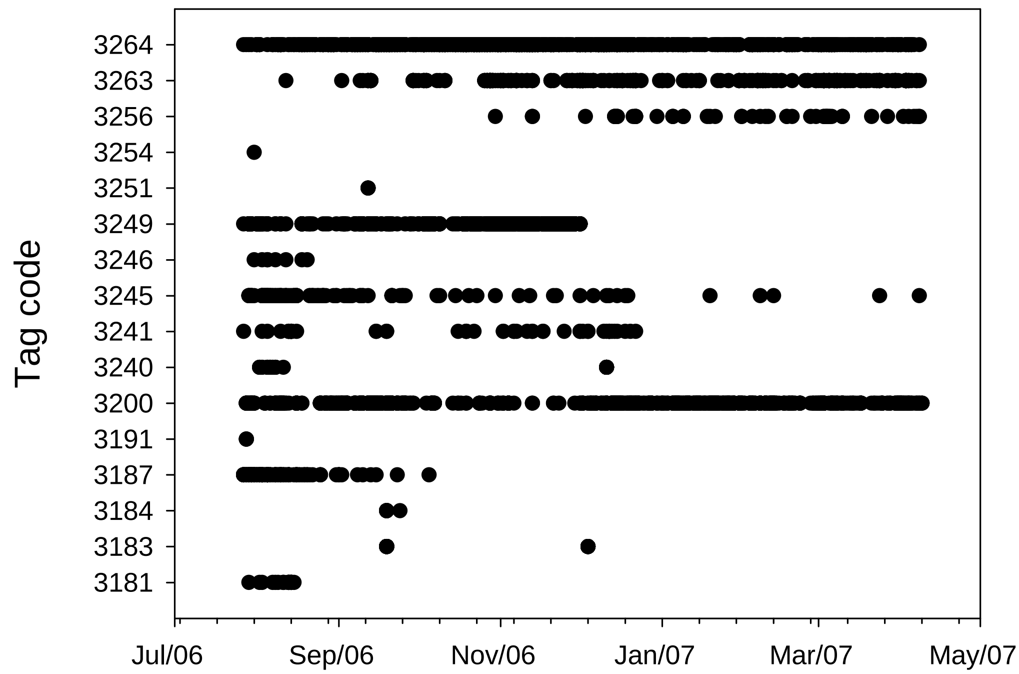

Figure 11. Detection of acoustically tagged fish by VR2 receiver at Station 2.

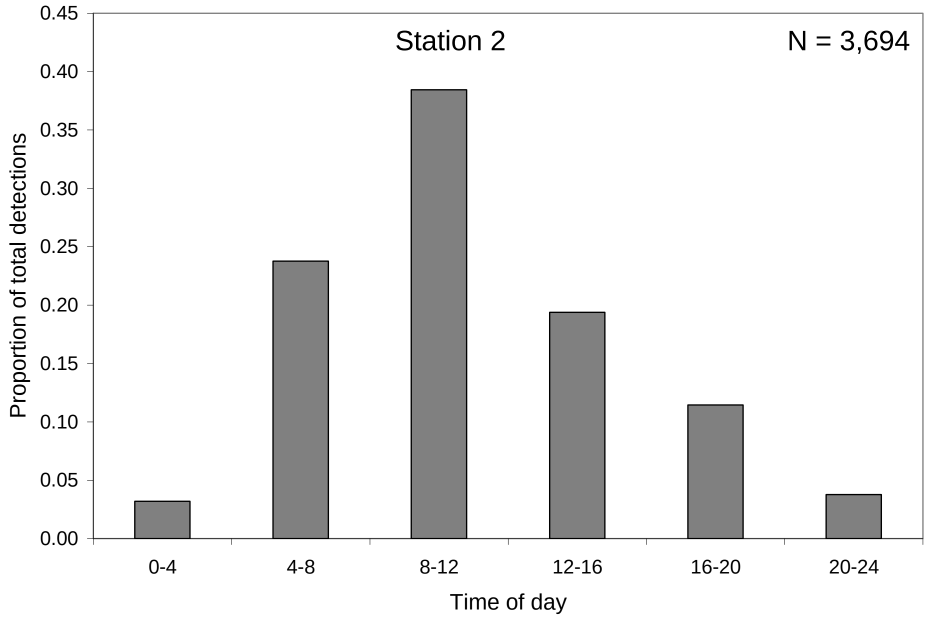

Figure 12. Proportion of total detections by time of day for station 2.

Station 3.

Station 3 was located in sand covered with patchy macroalgae at a depth of 21.9 m. It was located in the center of the bay and 522 m from the nearest hard bottom habitat (Table 3). A total of 31 tagged fishes were detected on this receiver between July 2006 and April 2007. Seven fish were consistently present at this receiver over this time period. All were lane snappers ranging in size from 23 to 36 cm. Four of these fish were originally released at Station 6 (Tektite), a distance of 472 m away. The remaining three fish were released at Station 5 (Yawzi Pt.), which was 519 m away. The night time period accounted for 55% of all detections, followed by the crepuscular period with 31%, and 14% during daytime.

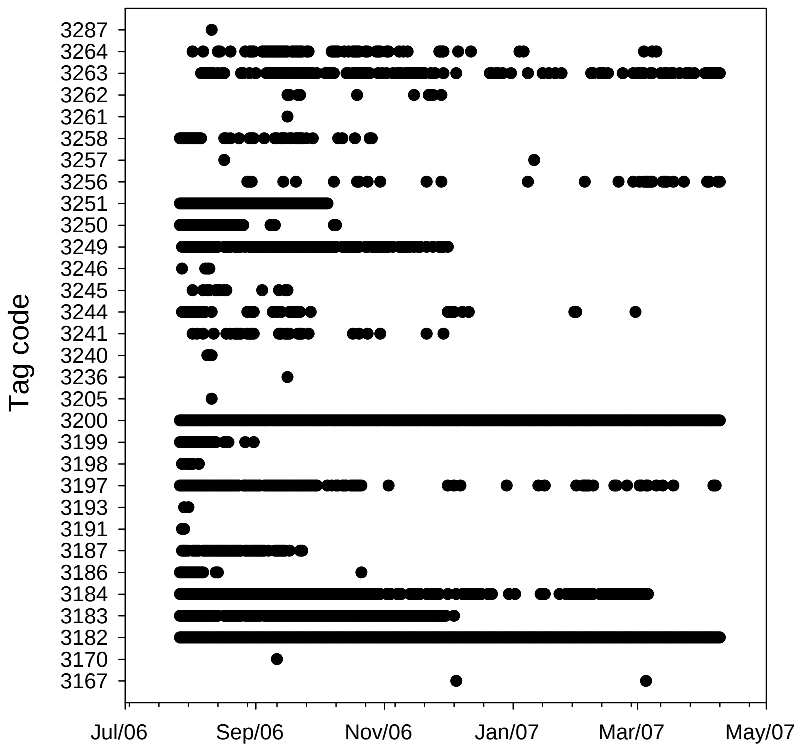

Figure 13. Detection of acoustically tagged fish by VR2 receiver at Station 3.

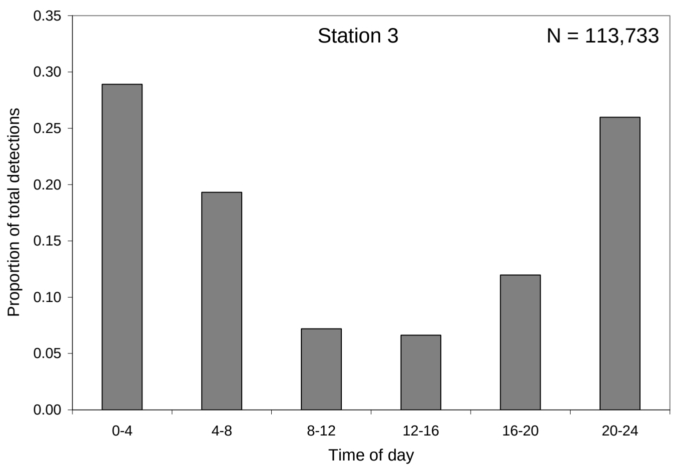

Figure 14. Proportion of total detections by time of day for station 3.

Station 4.

Station 4 is located in a patchy seagrass bed in 11.6 m of water. It is 139 m from the nearest hard bottom. A total of 18 tag fishes were detected at Station 4 (Table 3). Of these, seven fish shows persistence over the full time period. Five were lane snappers, along with one 25 cm bluestriped grunt (*Haemulon sciurus*), and one 28 cm saucereye porgy (*Calamus calamus*). The bluestriped grunt and one of the lane snappers were released at Station 4. Three lanes and the saucereye porgy were originally released at Station 5, 332 m away. One 27 cm lane snapper was detected for an extended period of time at Station 4 but was originally released at Station 6 (712 m away). The vast majority of the detections occurred during night (63%) and crepuscular (28% time periods). Only 9% occurred during the day.

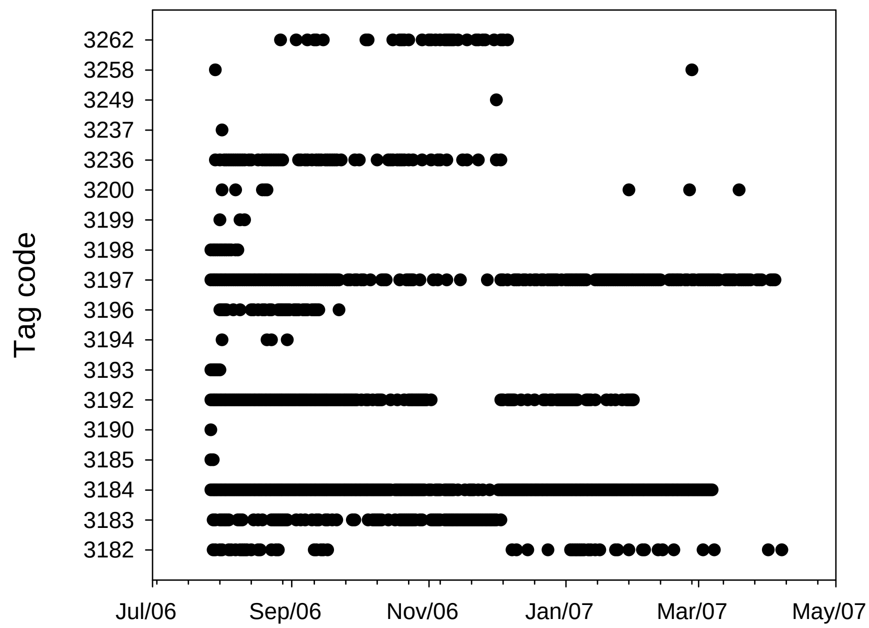

Figure 15. Detection of acoustically tagged fish by VR2 receiver at Station 4.

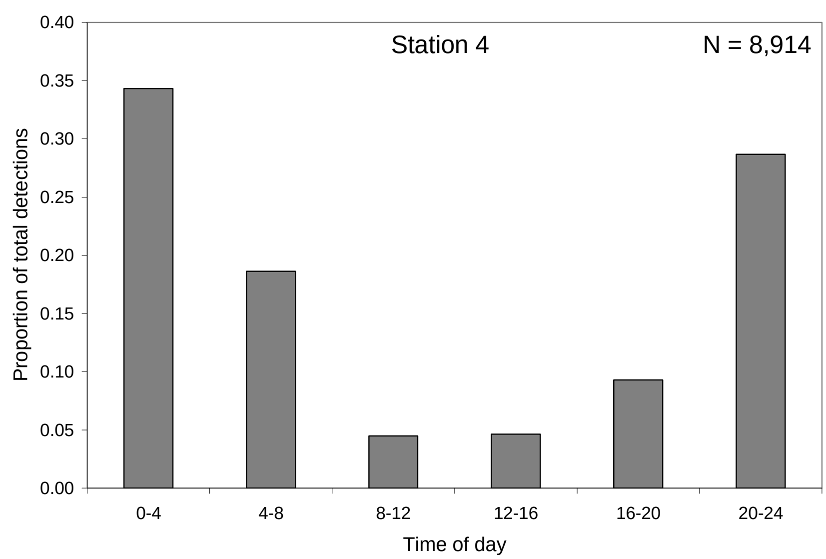

Figure 16. Proportion of total detections by time of day for station 4.

Station 5.

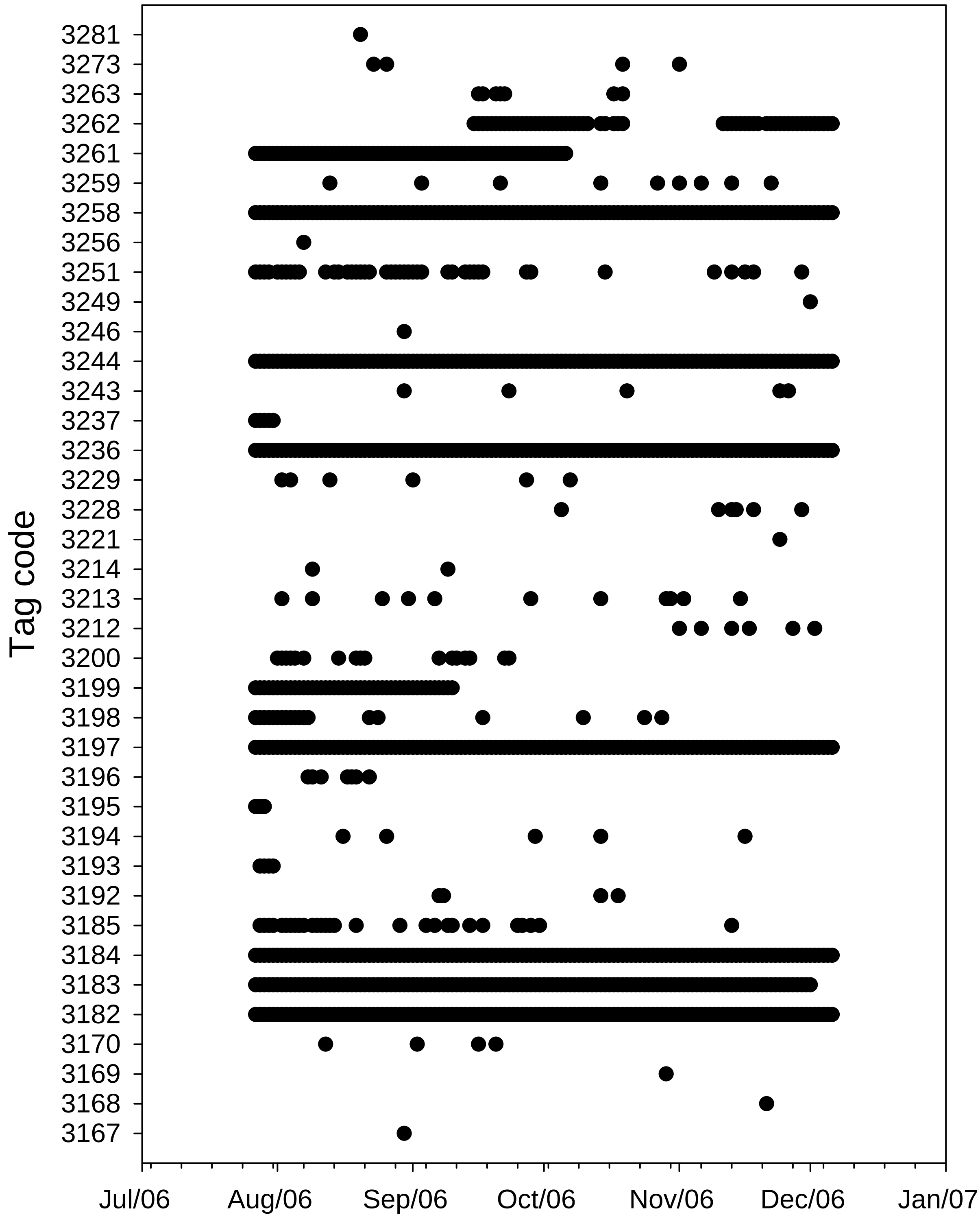

Figure 17. Detection of acoustically tagged fish by VR2 receiver at Station 5.

Station 5 was located in patchy seagrass at a depth of 14.3 m, and only 4.6 m away from the Yawzi Point reef. Thirty-eight different tagged fishes were detected at this station between July 2006 and Dec 15, 2006, when the memory in the receiver became full. A number of fish were consistently detected at Station 5 over the study period. Most were lane snappers released at Station 5 but several were released at Station 4 (332 m away) and Station 6 (385 m away). Fish # 3258 was a red hind (*Epinephelus guttatus*) that spent most of the time at Station 5 (>98% of all detections), although some detections occurred on other receivers. Similarly, a saucereye porgy, fish #3236, was also resident with more than 99% of all detections at Station 5. Fifty percent of the detections at Station 5 occurred during daytime hours, followed by the crepuscular time period (34%), and 16% at night.

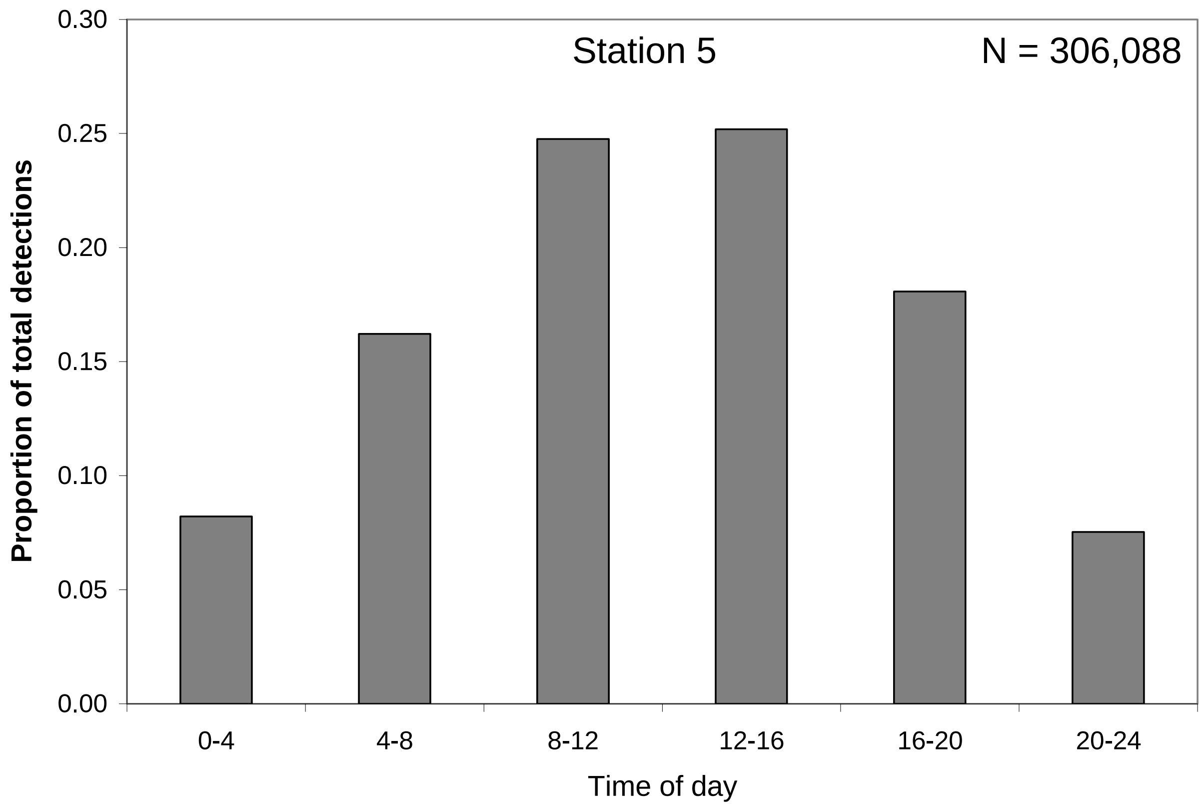

Figure 18. Proportion of total detections by time of day for station 5.

Station 6.

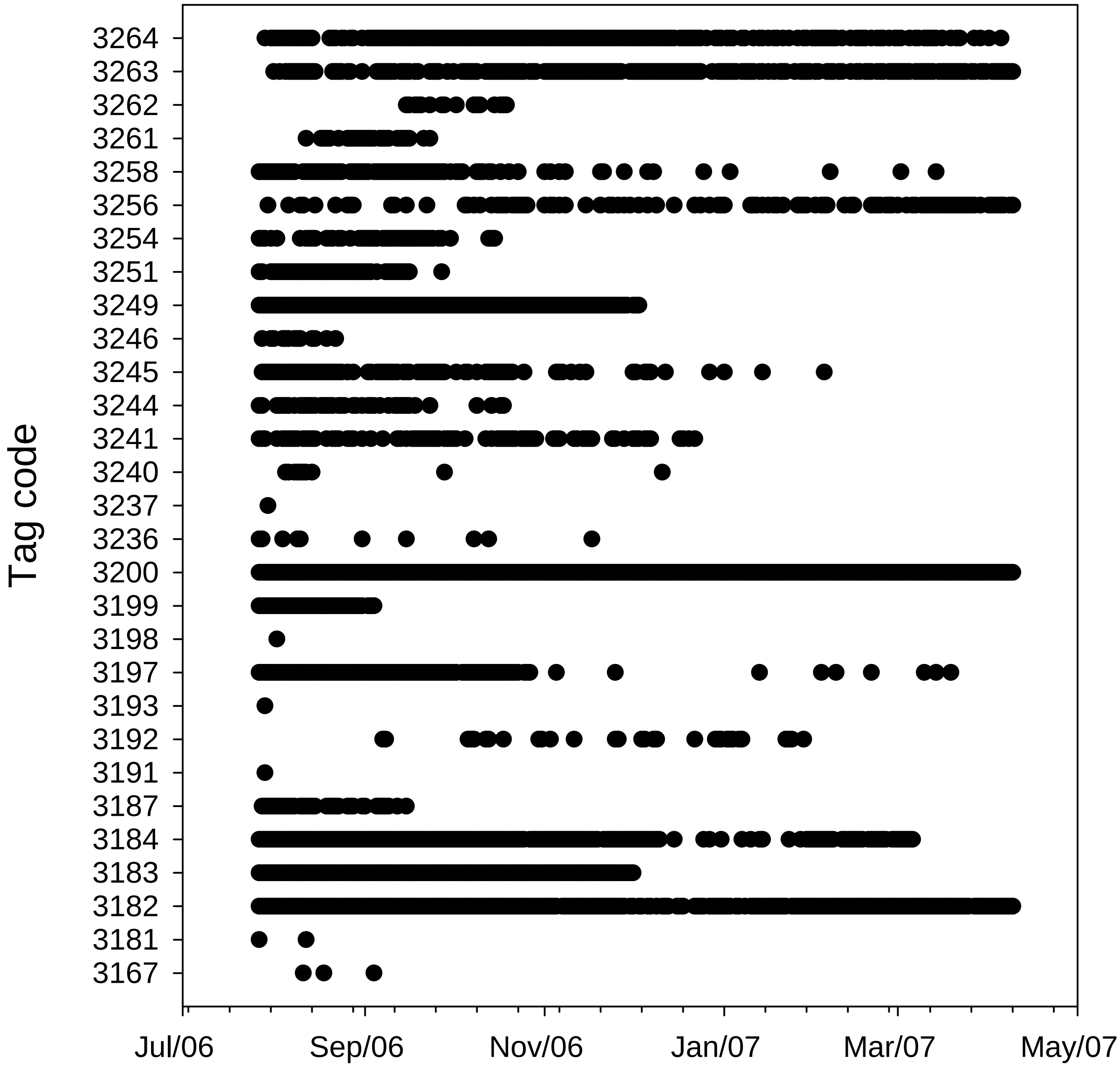

Figure 19. Detection of acoustically tagged fish by VR2 receiver at Station 6.

Station 6 was located in patchy seagrass in 17 m of water, 141 m away from Tektite Reef on the eastern portion of Greater Lameshur Bay. A total of 29 individuals were detected at Station 6 between July 2006 and April 2007. Most of the fish that persisted over this time period were lane snappers released at either Station 6 or Station 5 (384 m away). Fish were most commonly detected at this station during the daytime period (42%), followed by crepuscular (34%), and night (24%).

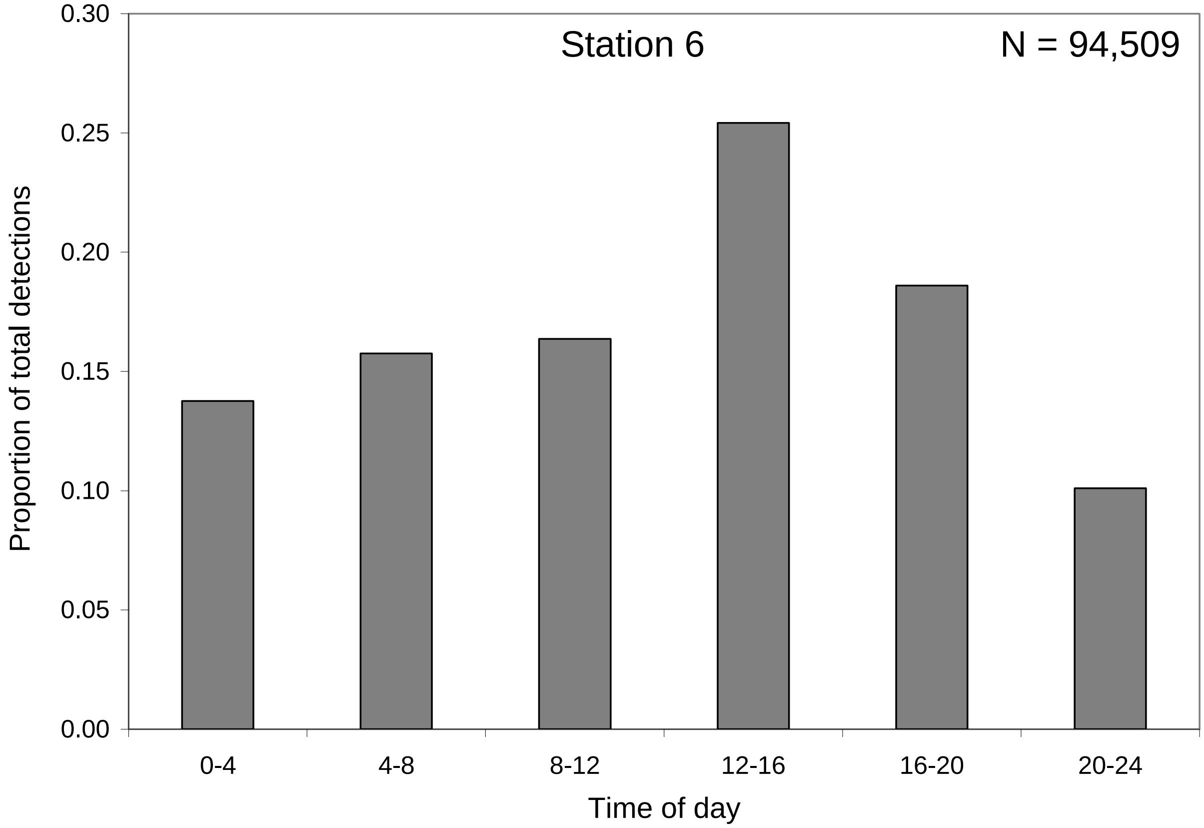

Figure 20. Proportion of total detections by time of day for station 6.

Station 7.

Station 7 was located in Greater Lameshur Bay between Stations 5 and 6 in patchy seagrass in 12.5 m. Sixteen different individuals were detected at this receiver with only a few fish present over the entire time period. These again were lane snappers. Fish #3200 was a lane snapper released at Station 6 (327 m away). Fish #3182 also was a lane snapper released at Station 5 (351 m away). Over 93% of all detection occurred during the day (56%) or during the crepuscular changeover (37%). Only 7% of the detections occurred at night.

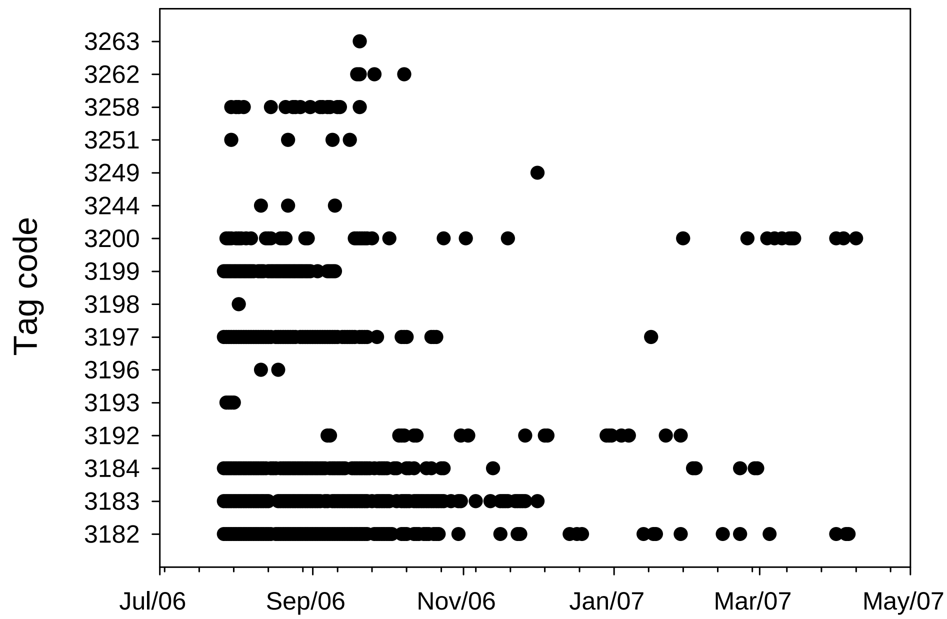

Figure 21. Detection of acoustically tagged fish by VR2 receiver at Station 7.

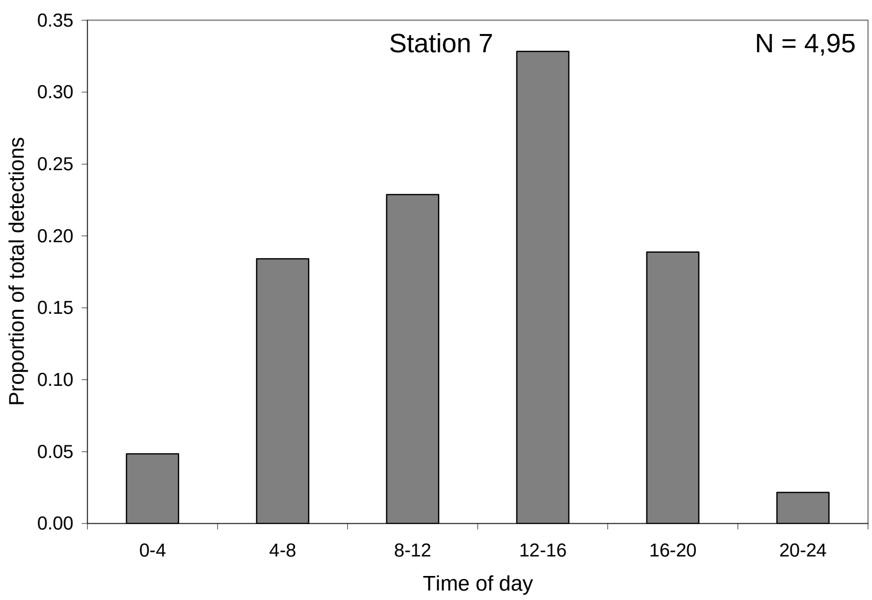

Figure 22. Proportion of total detections by time of day for station 7.

Station 8.

Station 8 is located in the shallow portion (7.3 m) of Greater Lamehsur Bay in a dense seagrass bed. Detections were only recorded in July and August of 2006. The receiver may have malfunctioned. There were only three fish and 15 detections recorded on this receiver so the examination of time of day is not valid or useful.

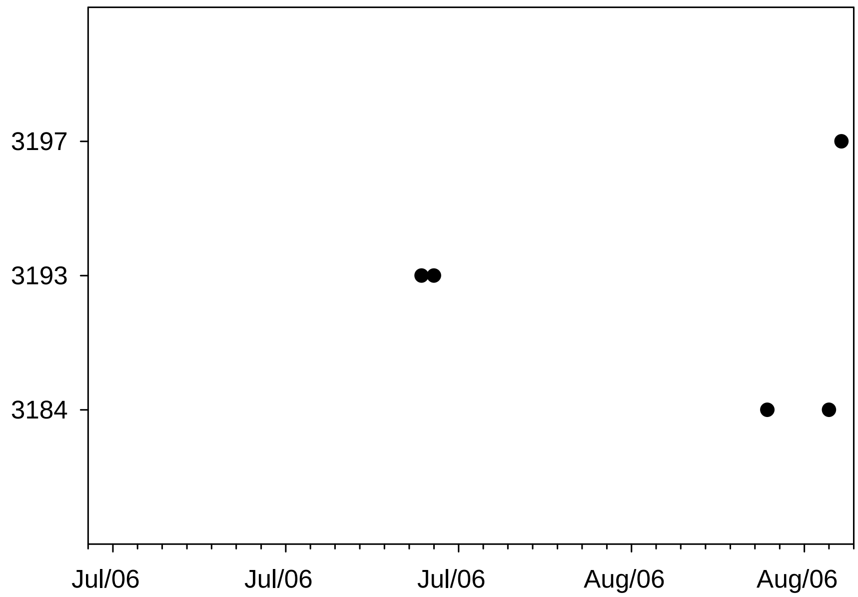

Figure 23. Detection of acoustically tagged fish by VR2 receiver at Station 8.

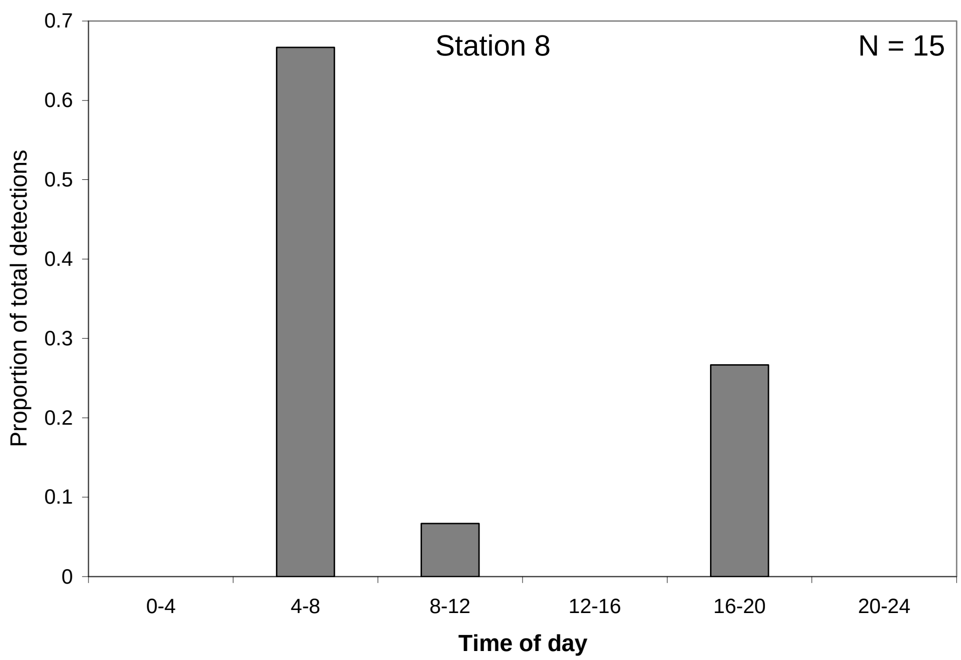

Figure 24. Proportion of total detections by time of day for station 8.

Station 9.

Station 9 is located in the shallow portion of Little Lameshur Bay in 7 m of water. It is 21 m away for the nearest hard bottom habitat in a dense seagrass bed. Fifteen different tagged fish were detected at this receiver. The most persistent fish at this station was a 70 cm nurse shark that was resident at this site. There were no strong apparent patterns in time of day.

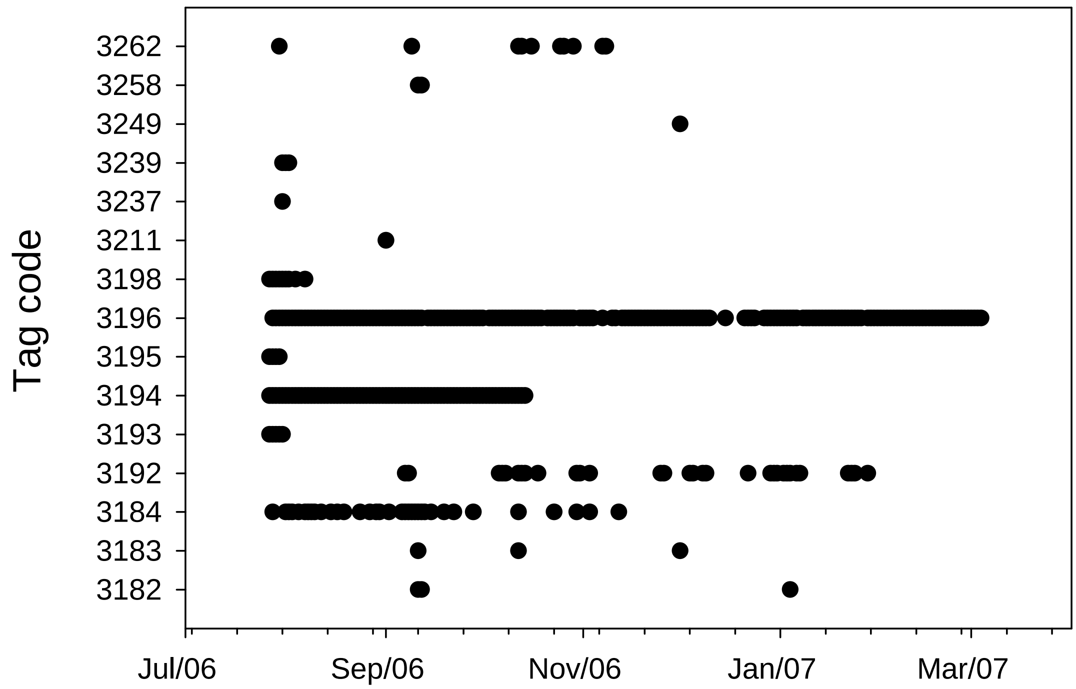

Figure 25. Detection of acoustically tagged fish by VR2 receiver at Station 9.

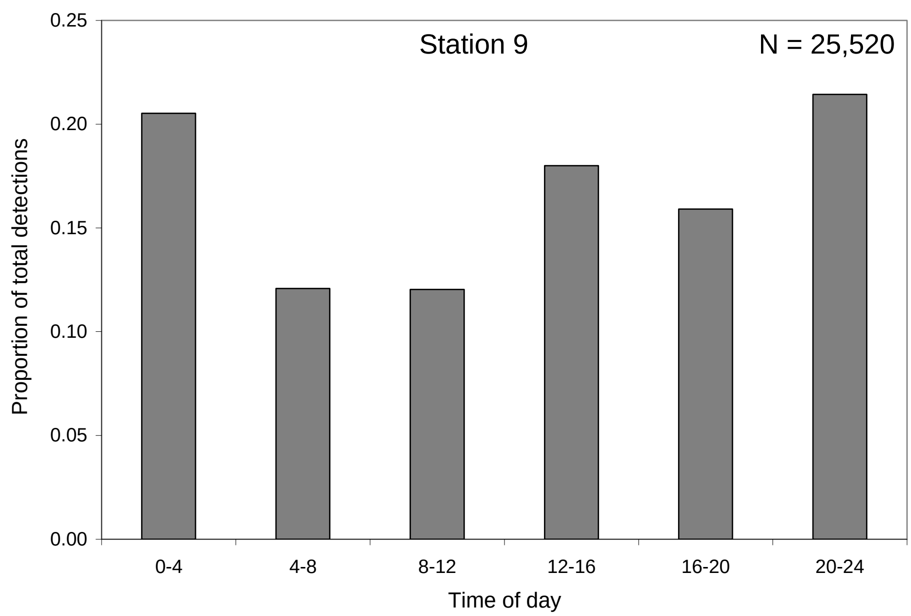

Figure 26. Proportion of total detections by time of day for station 9.

Species

Fish # 3264 – lane snapper
A 29 cm lane snapper was captured in a fish trap at Tektite Reef (Station 6) on July 10, 2006, and released at approximately the same location on July 11th. During daylight hours this fish was observed at Station 6, the release site, as well as Station 2, which is 578 m away at the southeast end of the bay. It was also observed at Station 3 during daylight hours, which is 472 m away in the center of the bay. At approximately sunrise and sunset this fish was detected at Station 2 and was likely leaving the bay since it was not observed on any other receivers at that time. Presumably, this fish migrated offshore into deeper water to forage and returned back to Tektite Reef at sunrise each day at very predictable times.

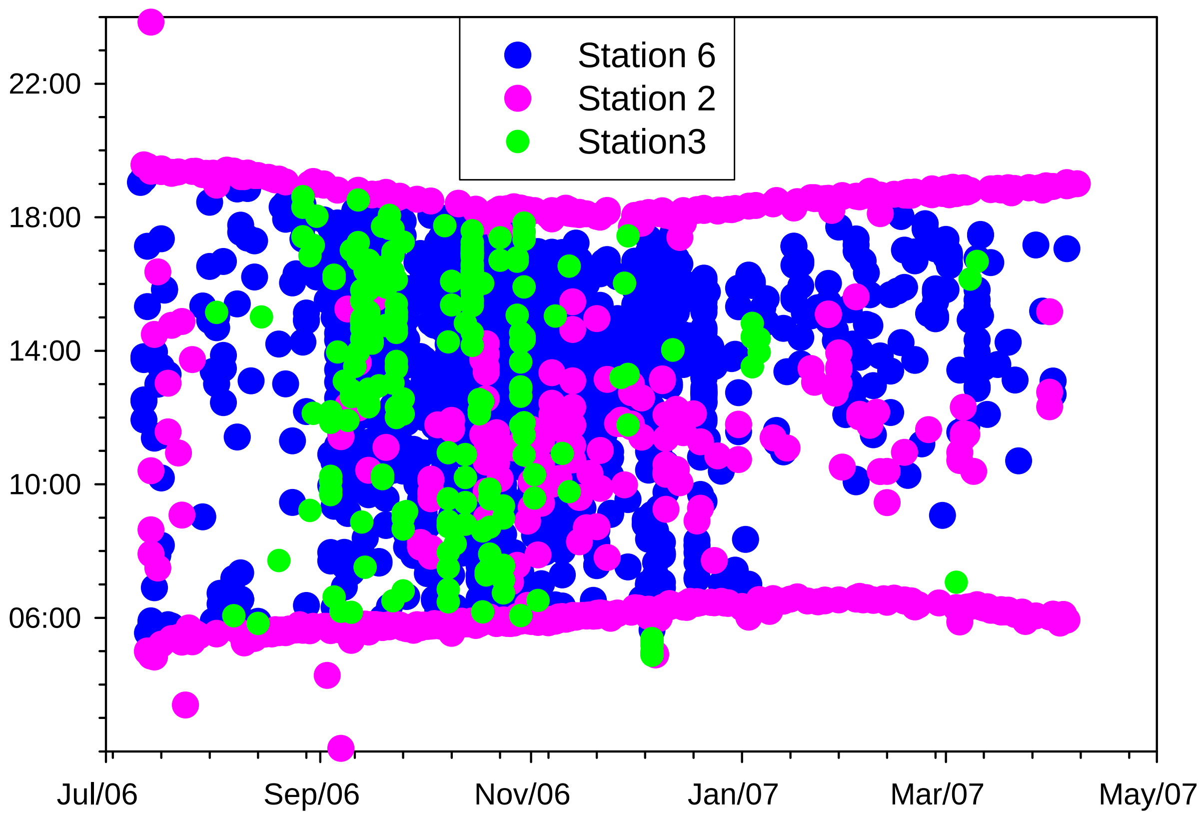

Figure 27. Detection patterns for fish #3264, a 29 cm TL lane snapper released at Tektite Reef (Station 6) on July 11, 2007.

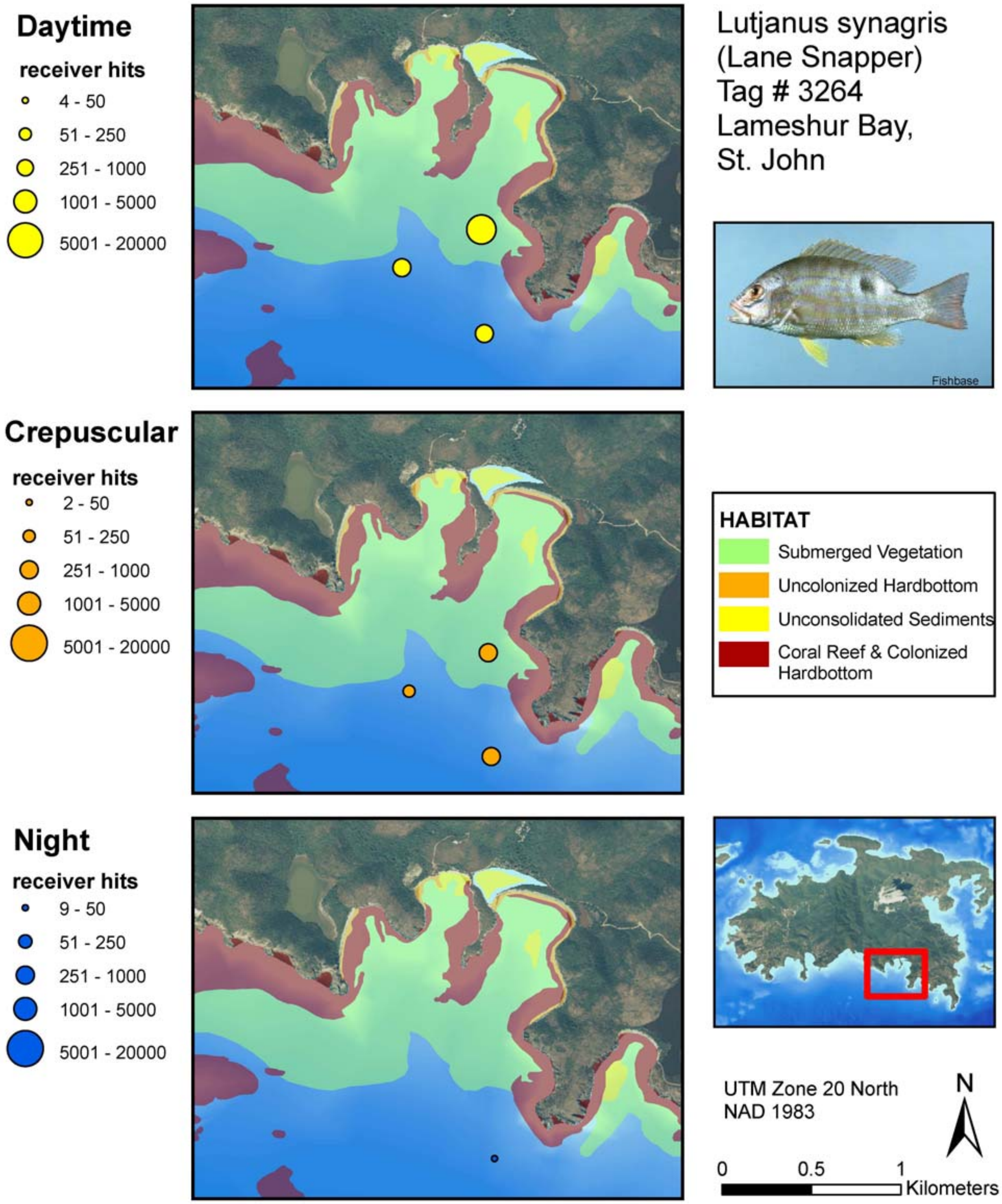

Figure 28. Detection patterns for fish #3264 by time period (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Fish # 3192 – bluestriped grunt

This 25 cm TL bluestriped grunt was captured at Europa Bay on the western side of Lameshur Bay, near Station 4 on July 22, 2007 and released at approximately the same location on July 24, 2007. It spent nearly all the daytime hours and most of July and the beginning of August near Station 4. By September it showed predictable movement patterns at around sunset from Station 4, north to Station 6, and across Yawzi Point reef to Stations 6 and 7. Since the number of detections at Station 5 were small (< 1% of total detections), it is likely that this fish moved inshore along the reef and was not detected by the receiver off the reef edge.

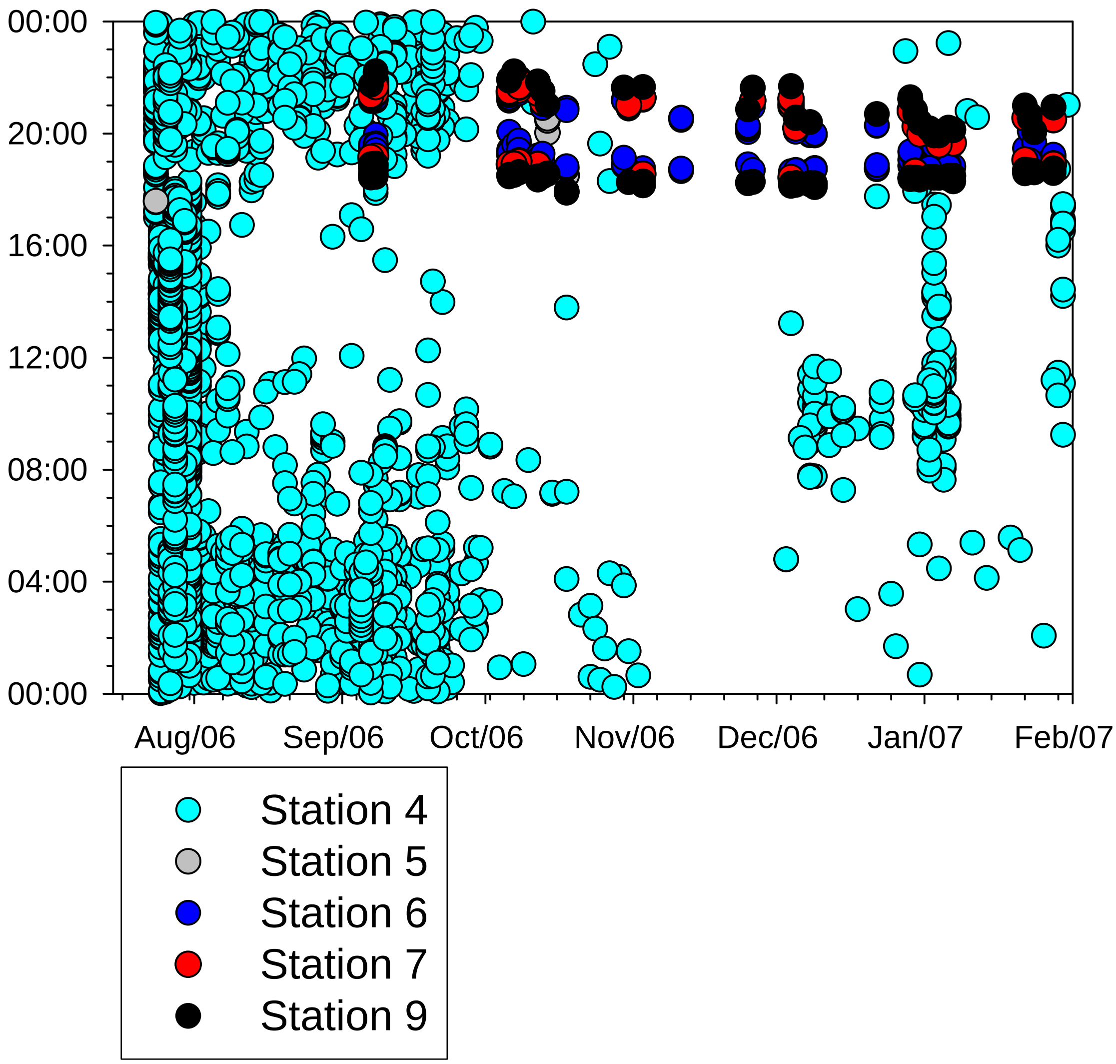

Figure 29. Detection patterns for fish #3192, a 25 cm TL blue grunt released at Eupora Bay (Station 4) on July 24, 2007.

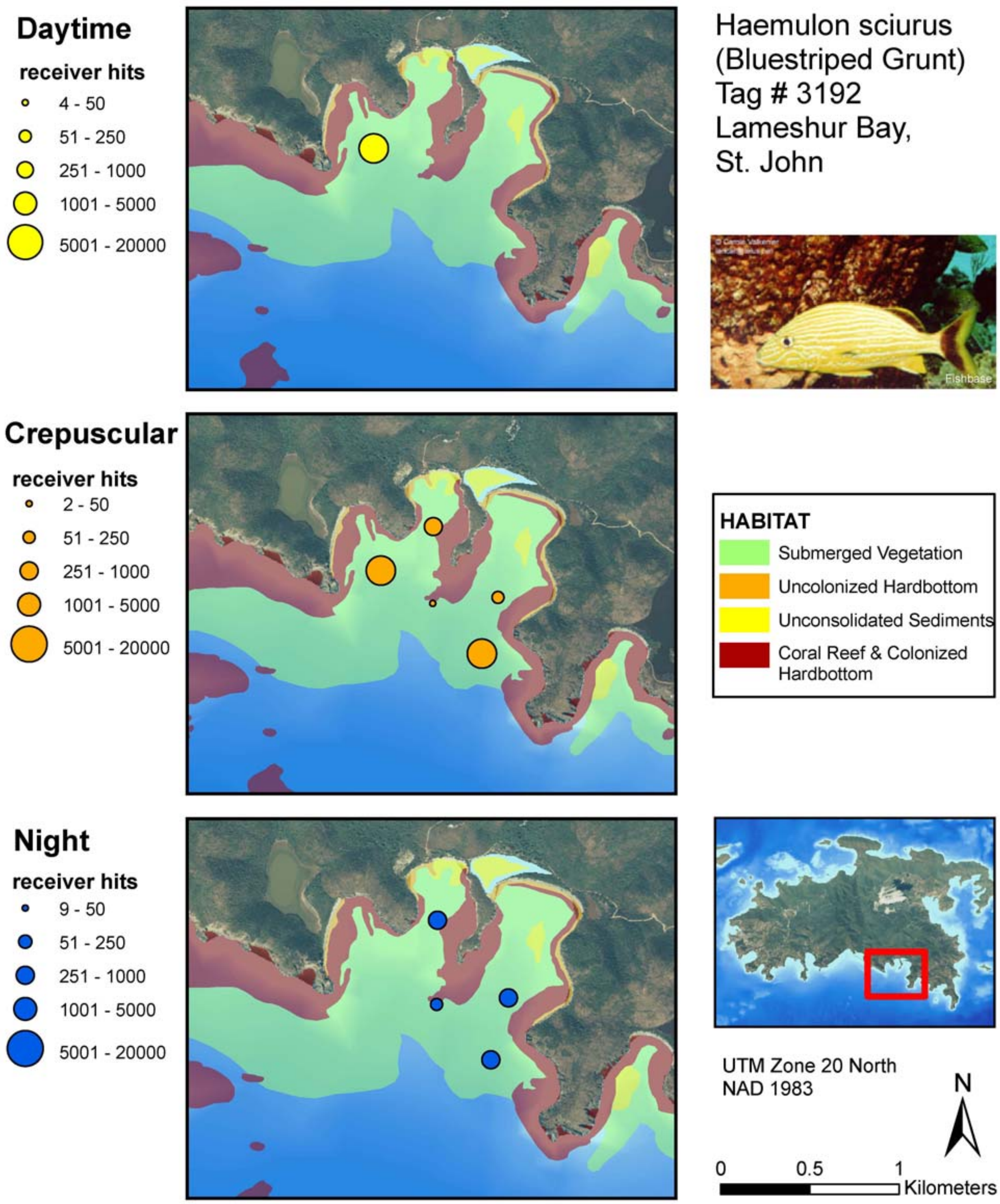

Figure 30. Detection patterns for fish #3192 by time period (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Fish # 3197 – lane snapper

This 32 cm TL lane snapper was captured at Yawzi Point (Station 5) on 13 July, 2006 and released on July 15, 2006 at approximately the same location. During daylight hours, this fish was detected primarily at Station 5, as well as Stations 6 and 7. This would imply activity along the eastern edge of the reef off Yawzi Point. There was predictable crepuscular movement off the reef and into the adjacent seagrass beds. Nighttime activity was detected at Station 4 and 5 along the western edge of Yawzi Point, near Europa Bay.

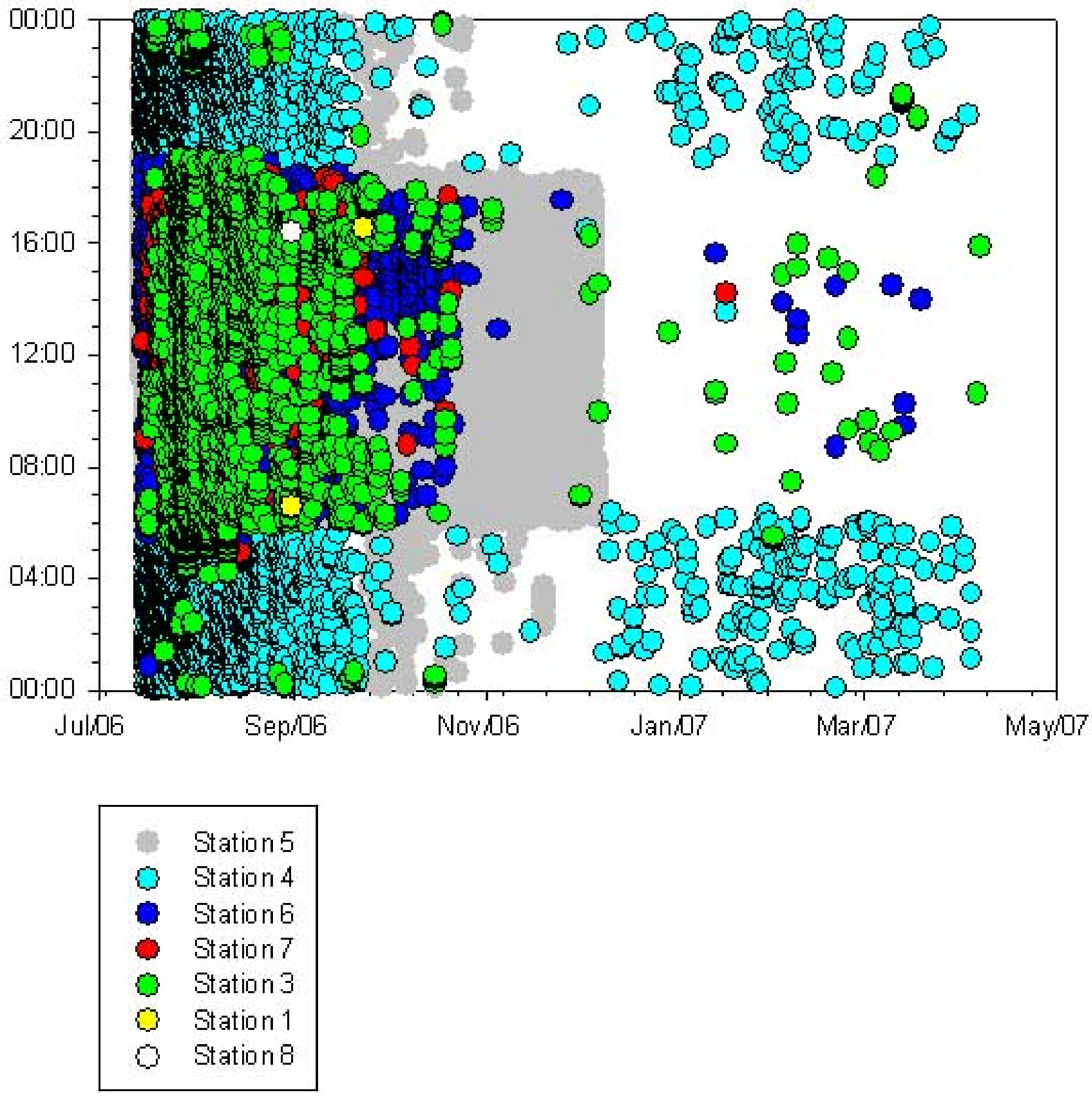

Figure 31. Detection patterns for fish #3197, a 32 cm TL lane snapper released at Yawzi Point (Station 5) on July 15, 2007. The memory capacity on the receiver at Station 5 was exceeded on December 6, 2006.

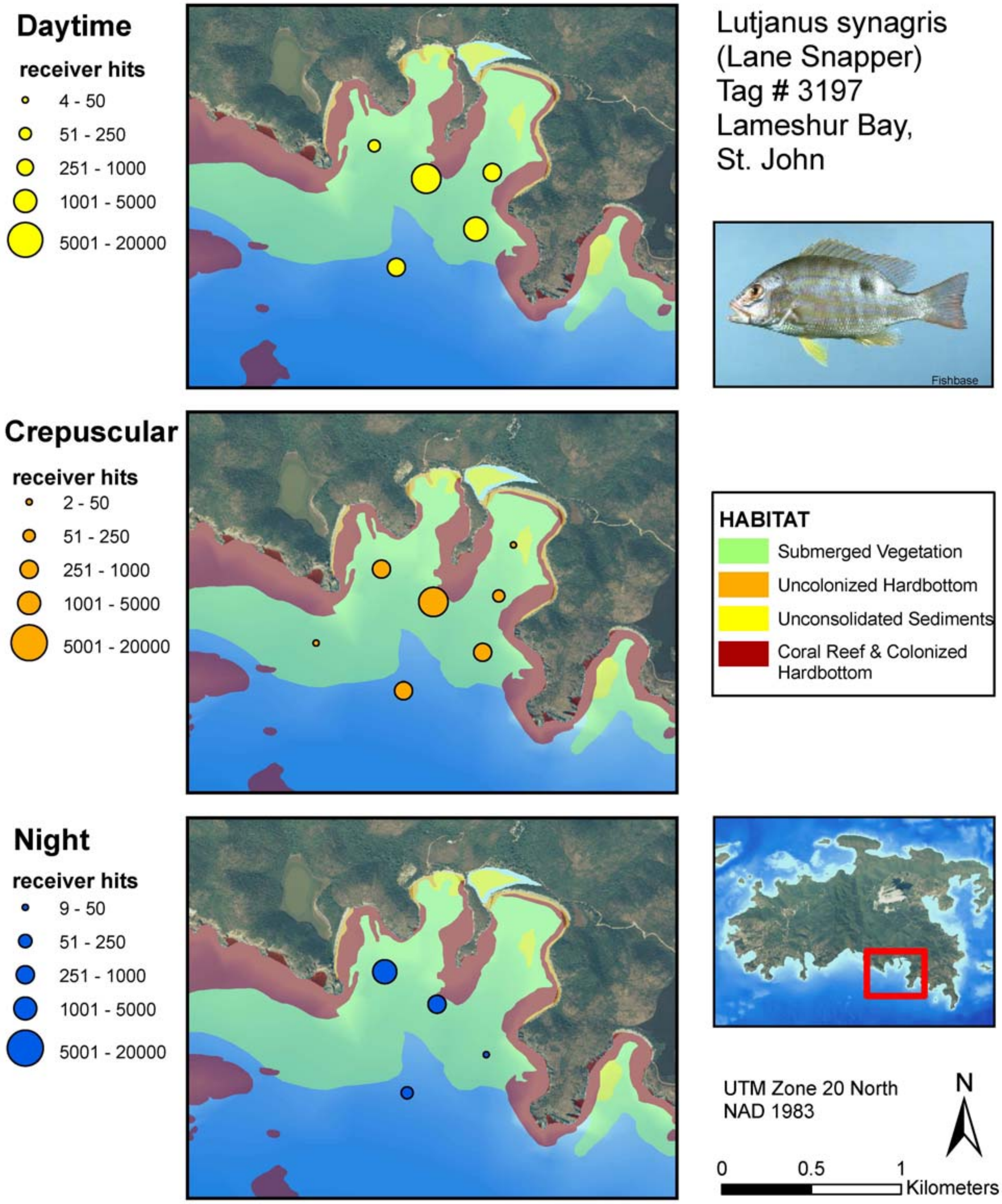

Figure 32. Detection patterns for fish #3197 by time period (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Fish # 3184 – lane snapper

A larger lane snapper (36 cm TL) was captured at Station 5 on July 13, 2006 and released back onto the adjacent reef (Yawzi Point) on July 15, 2006. Over 78% of all detections occurred at Stations 5 (68%) and Station 6 (10%) and most of these took place during daytime. The fish appears to move off the reef at dusk and was not detected by any receivers during the late evening after November. It regularly appears at Station 4 between 12:00 and 1:00 consistently over the study period.

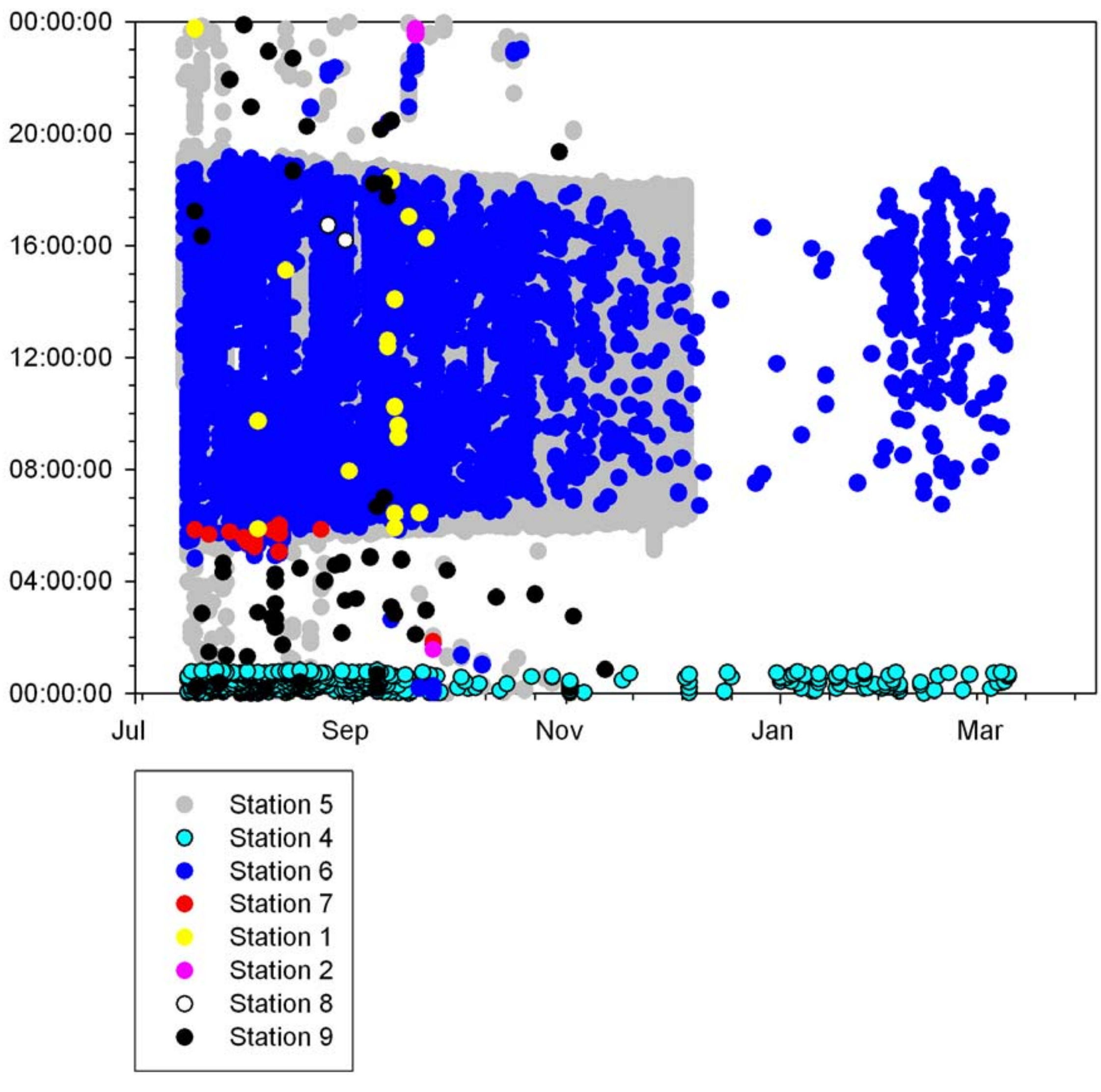

Figure 33. Detection patterns for fish #3184, a 36 cm TL lane snapper released at Yawzi Point (Station 5) on July 15, 2007. The memory capacity on the receiver at Station 5 was exceeded on December 6, 2006.

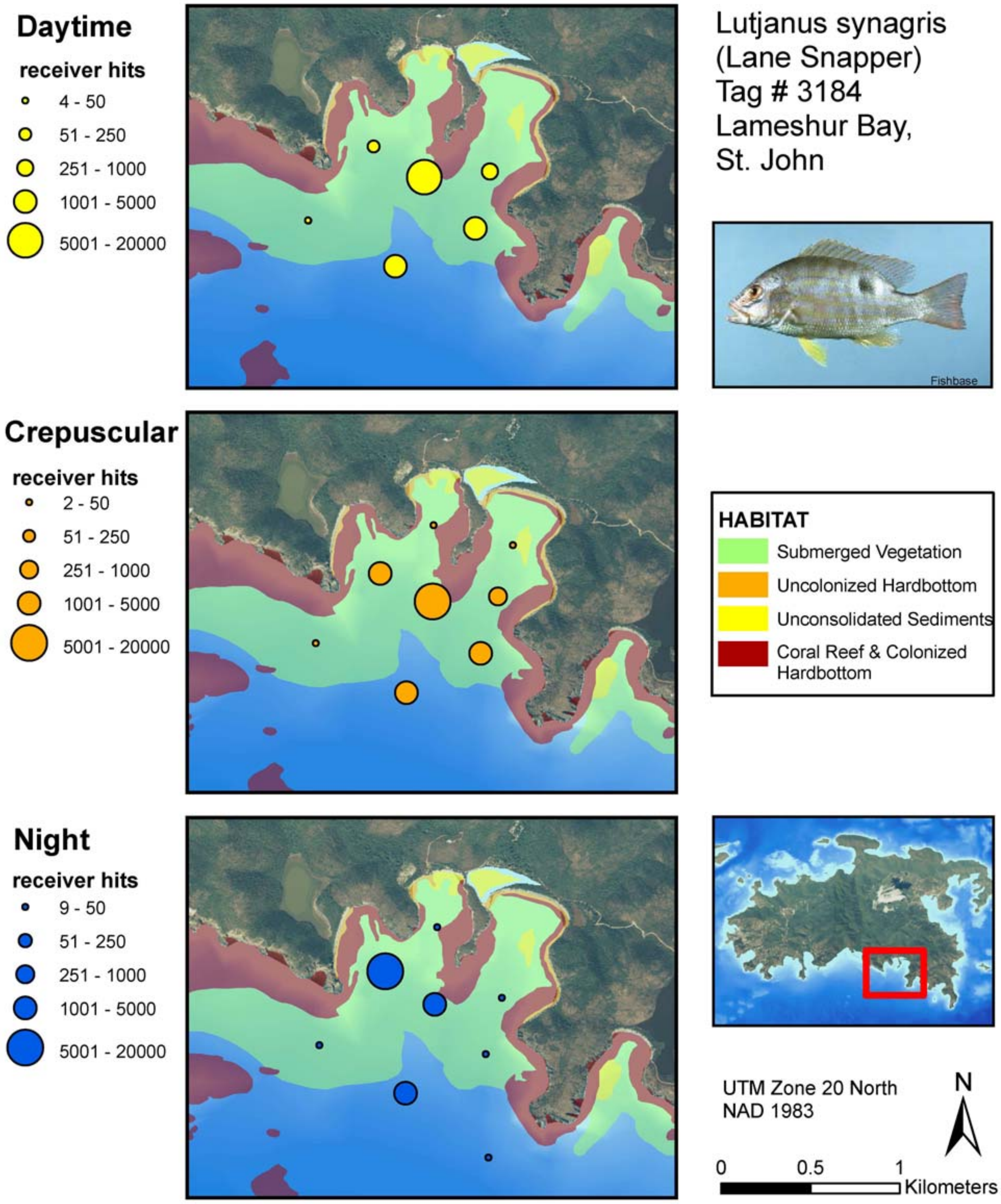

Figure 34. Detection patterns for fish #3184 by time period (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Fish 3196 - nurse shark

A 70 cm TL nurse shark was captured at Eupora Bay (Station 4) on July 14, 2006 and released on the same day, at the same general location. The fish spent the majority of its time (> 98 %) at Station 9, 374 m inshore and to the north of Station 4. The number of detections declined during the evening, between sunset and sunrise, and the fish may have been sleeping in the reef and out of detection range.

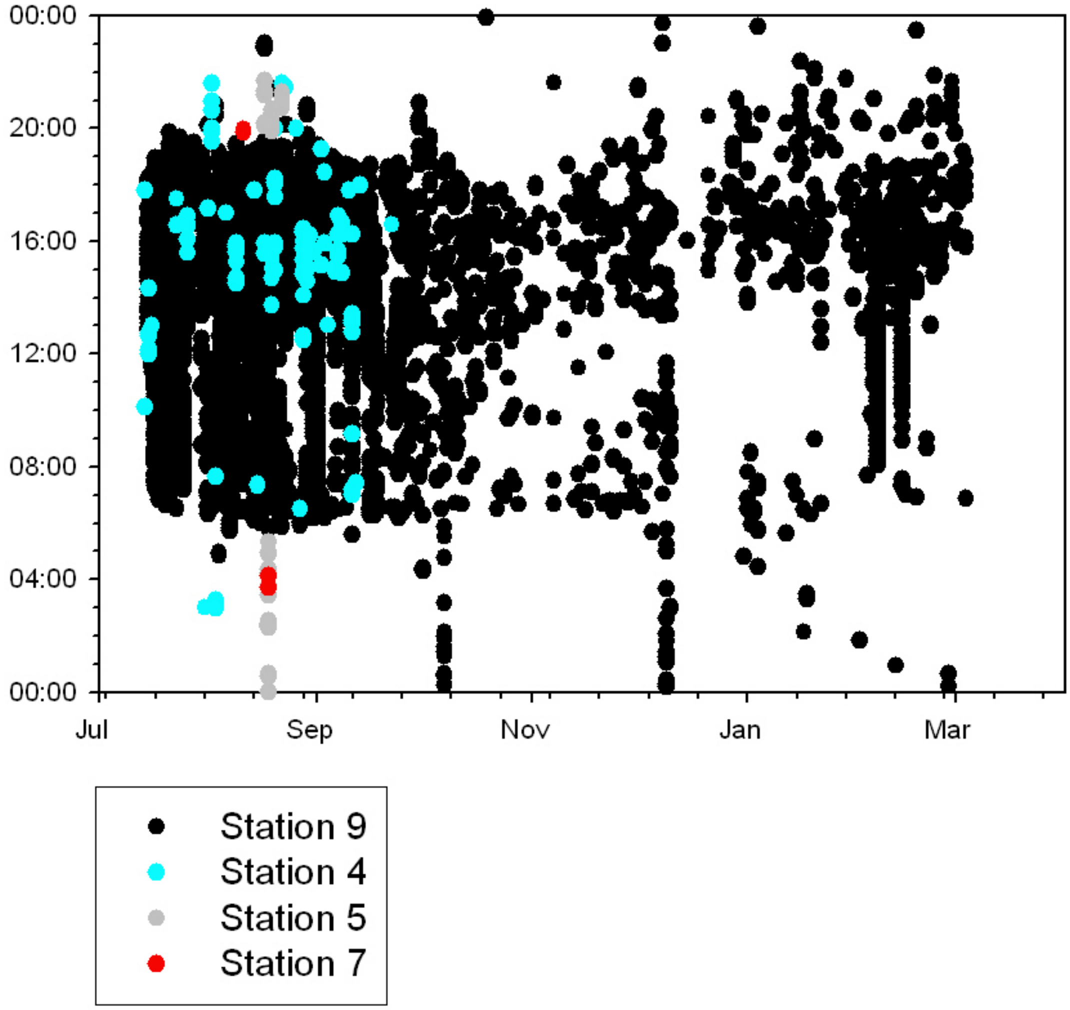

Figure 35. Detection patterns for fish #3196, a 70 cm TL nurse shark released at Europa Bay (Station 4) on July 14, 2007.

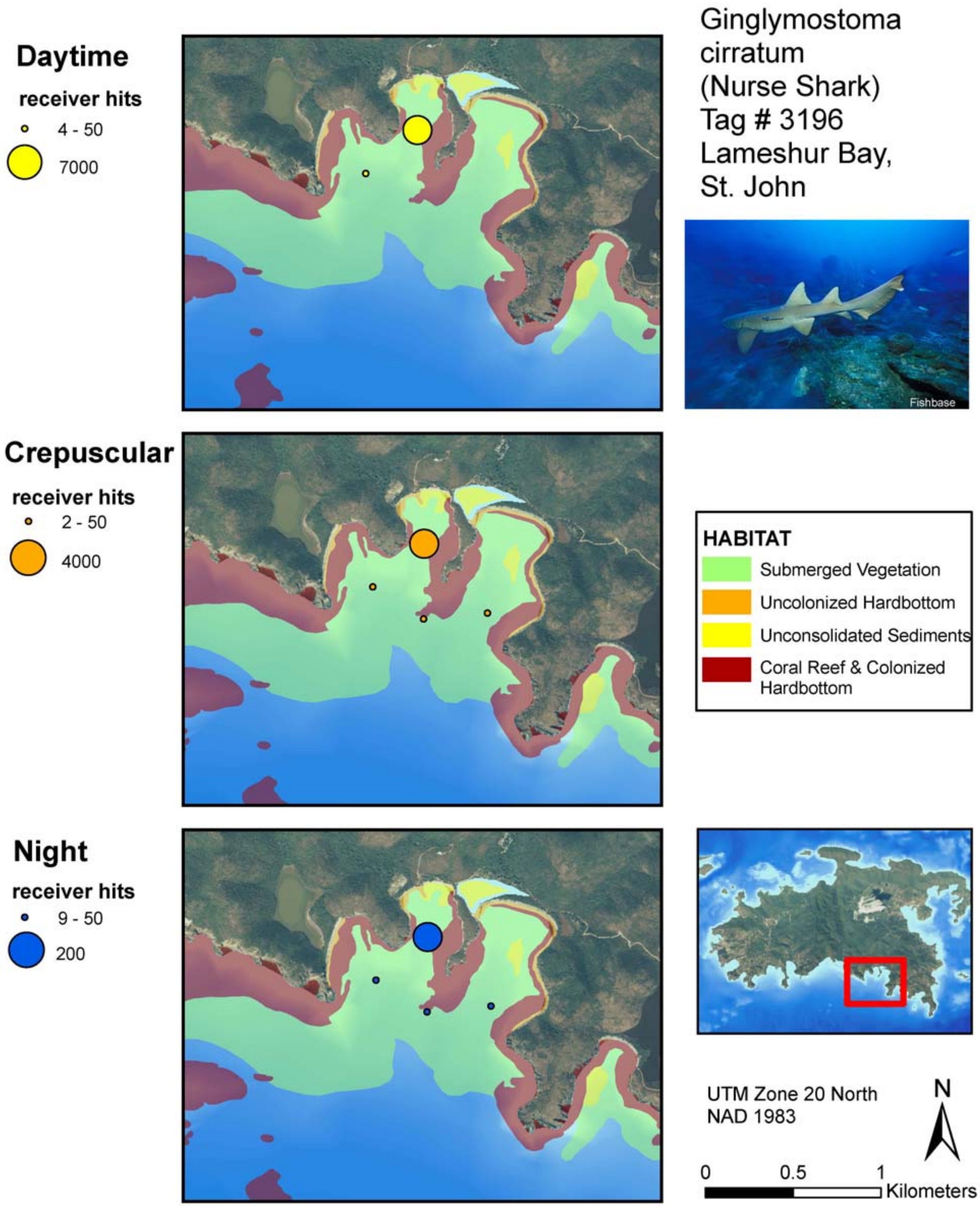

Figure 36. Detection patterns for fish #3196 by time period (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Bay-wide habitat utilization

The greatest number of total detections was recorded at Station 5 (55%), followed by Station 3 (20%), and Station 6 (16%), respectively. This is despite the fact that 51% of all of the releases during this period of the study (July 2006 to April 2007) occurred at Station 6, with 27% released at Station 5 and 22% at Station 4. In addition, the receiver at Station 5 stopped collecting data after December 15, 2006 due to memory limitations, so these differences would have been even larger. The dense seagrass bed adjacent to Yawzi Point (Station 5) may have resulted in shorter migration distances to nighttime foraging areas that were still within the detection range of Station 5.

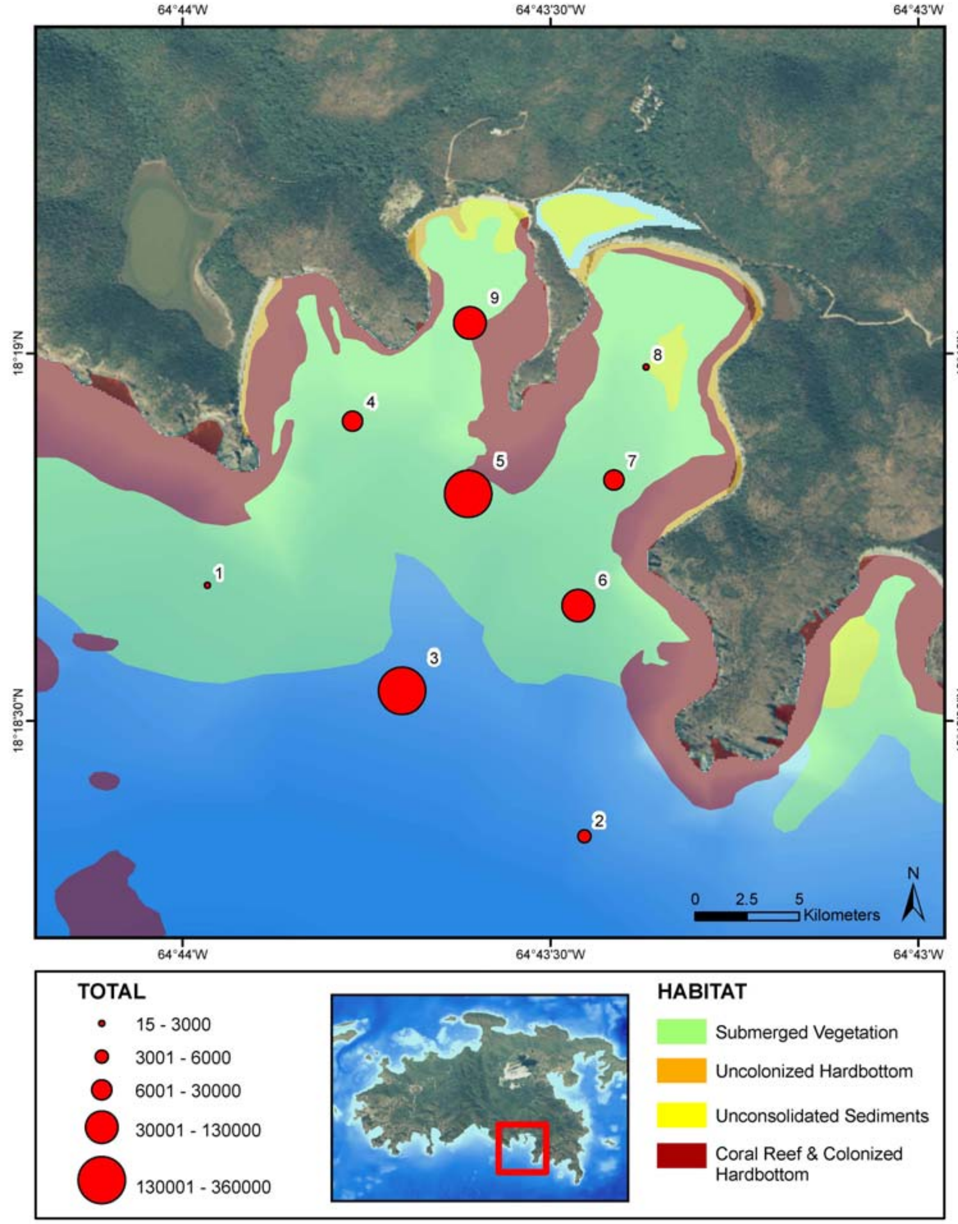

Figure 37. Total number of detections by receiver from July 2006 to April 2007. Note – Memory capacity was exceeded at the Station 5 receiver on December 5, 2006.

Diel utilization of habitats in Lameshur Bay

The majority of the daytime detections occurred at Station 5 (69%), followed by Station 6 with 16%. During the crepuscular changeover, more fish were detected offshore, and by night, 42% of all nighttime detections took place at Station 3.

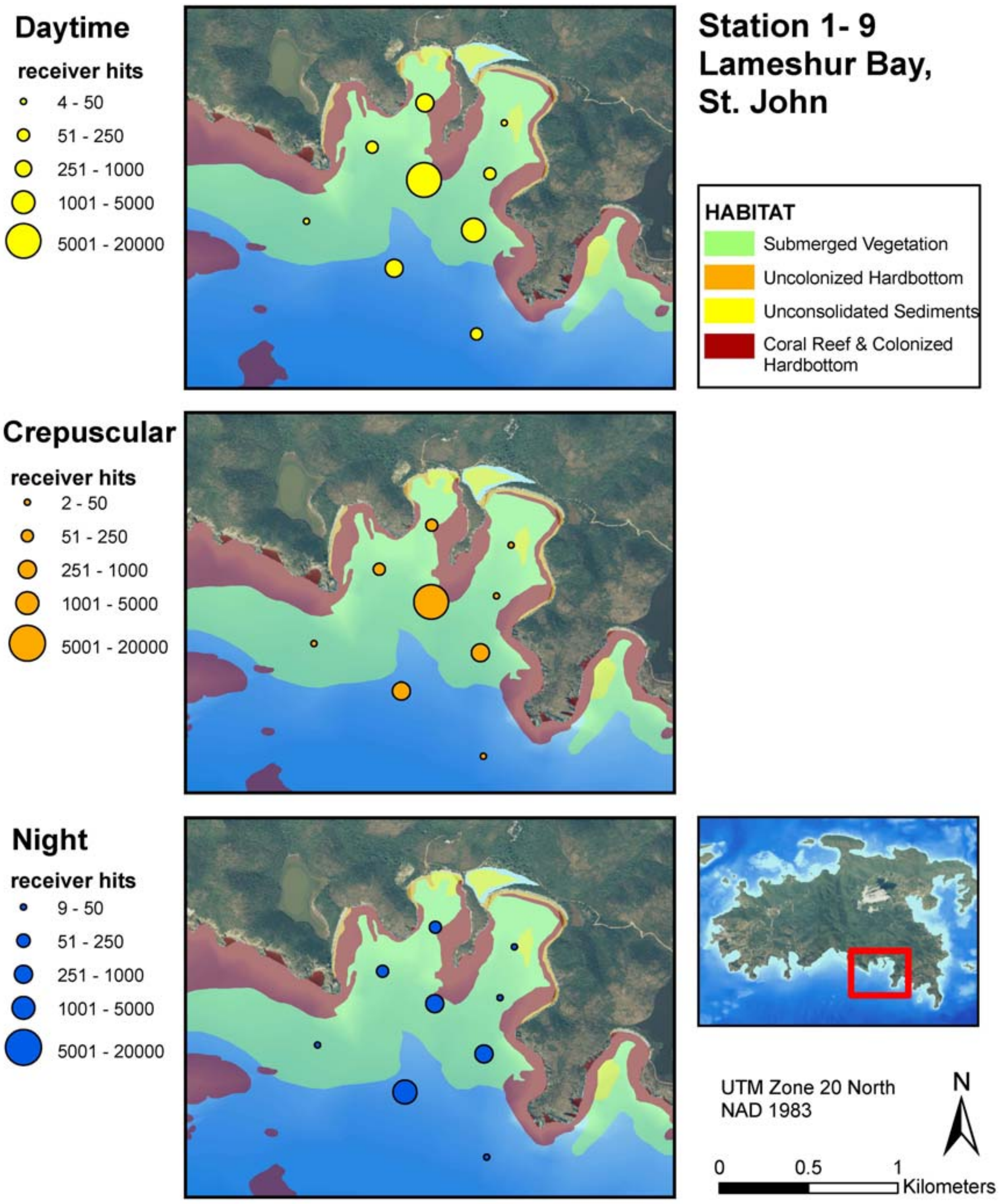

Figure 38. Number of detections by receiver and time of day from July 2006 to April 2007. Note – Memory capacity was exceeded at the Station 5 receiver on December 5, 2006. (night = 12:00 – 4:00 and 20:00 – 24:00, crepuscular = 4:00 – 8:00 and 16:00 – 20:00, daytime = 8:00 – 16:00).

Current Status

In July of 2007, all 30 receivers were downloaded to recover the telemetry data for the 123 fishes currently tagged. One additional receiver was deployed on hard substrate off Ram Head, the southeastern point of St. John and five receivers were deployed along the midshelf reef, approximately 8 km to the south of St. John (Fig. 39). The receiver located at Yawzi Point (#5) was replaced with VEMCO's next generation of receiver, the VR2w, which has a larger data memory and faster download time. The data capacity for this receiver was exceeded between previous trips and the new receiver should eliminate this problem.

Next Steps

Four additional receivers will be deployed along the mid shelf reef in December of 2007 (Figure 39). In addition, we will continue to explore the use of the VEMCO next version hydroacoustic receiver (the VR2w) and associated software. Three VR2w receivers will be deployed to determine if the existing array should be upgraded with new software that would include expanded memory for tag detections (up to 1 million dectections/receiver). In addition, we will continue to examine telemetry data from the July 2006 Lameshur Bay data on an individual species and tag basis to determine movement and habitat utilization patterns by individual fishes and families. We will also analyze the data for the 77 fishes tagged in April 2007 through July 2007.

Several investigators plan to conduct complementary acoustic tagging studies in the area on several species, including queen conch, groupers, grunts, sharks, and snappers and we will coordinate with the investigators to make maximum use of the existing array and deployment of additional receivers. In addition, a US Geological Survey and University of Florida study will begin in fall 2007 that will characterize benthic communities and trophic dynamics of key reef fish species using stable isotope analyses. Plans are to expand the NOAA Biogeography Branch array to Buck Island Coral Reef National Monument north of St. Croix, USVI in 2008. A web site will be developed for various investigators to share information on species tagged and acoustic tag ID codes (Appendix 1).

This investigation, in consultation with others planned or underway acoustic studies, will enable documentation of resource conditions of important taxa in VICRNM and VIIS, and for development of an understanding of the linkages between ecosystem components of the two NPS management units. Potential benefits of the VICRNM to adjacent areas are adult "spillover" into VIIS and adjacent harvested areas and enhanced reproductive output. The linkages between VICRNM 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 organisms into and out of the management units and to identify resources that may require greater (or lesser) management focus. Inventory and characterization of existing marine resources within VIIS has been progressing during recent years and has been initiated for VICRNM to establish current baseline conditions of fish and macro-invertebrates (e.g., species density) and quality of benthic habitats (percent cover) (Monaco, et al. 2007). Our current investigation will provide data necessary for development of 'ecosystem management' strategies for VIIS, VICRNM, and the Territory.

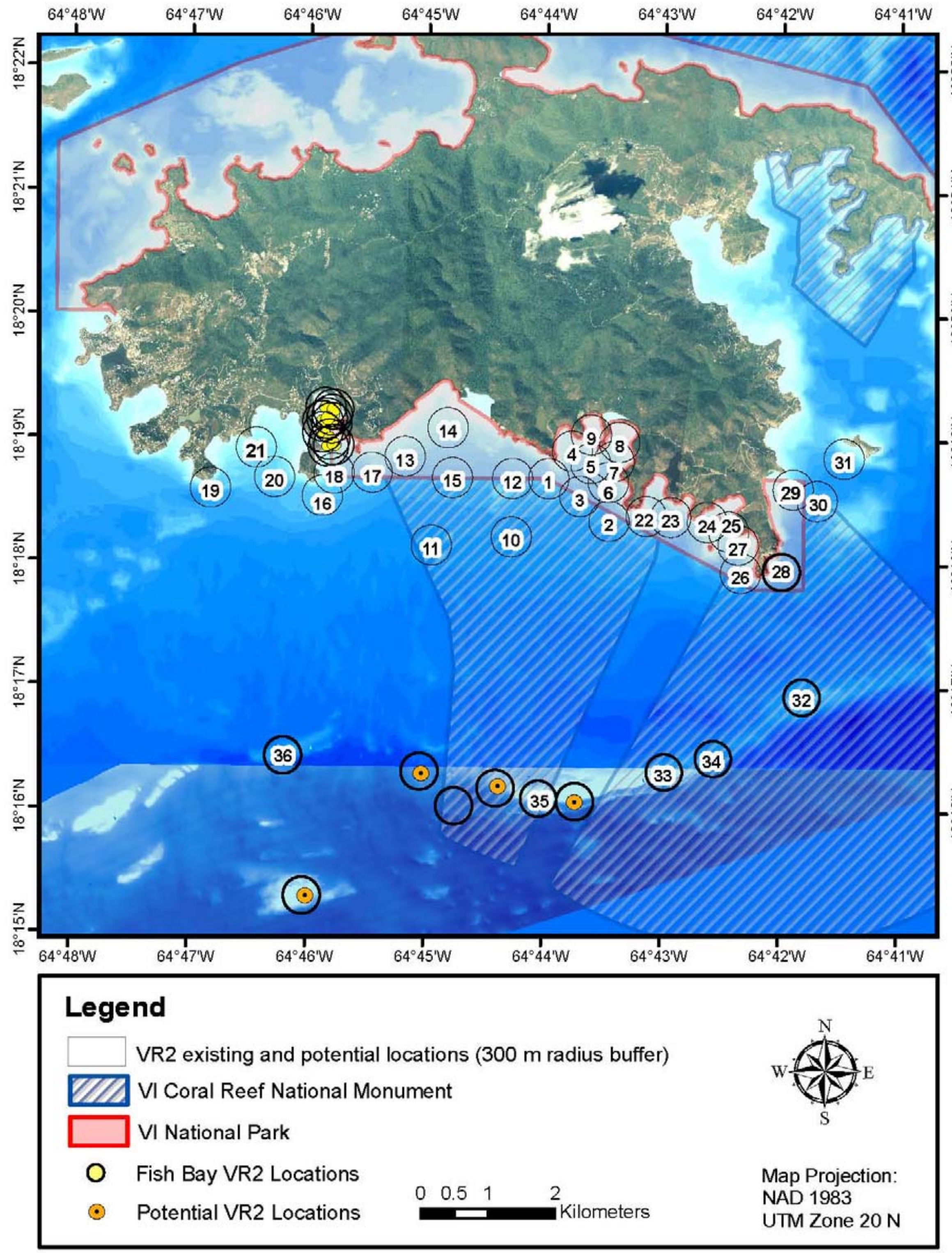

Figure 39. VR2 array design to examine large-scale movement patterns of fishes inside and outside VI National Park, VI Coral Reef National Monument and outside areas (N = 40).

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Appendix I. Information on acoustically tagged fish from July 2006 to April 2007. See Figure 2 for location codes.

Date caught	Caught near Receiver	Species	TL	Serial #	ID #	Release date	Released Near Receiver
9-Jul-06	6	*Ocyurus chrysurus*	22.5	6100	3247	10-Jul-06	6
9-Jul-06	6	*Ocyurus chrysurus*	23.0	6110	3257	10-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	27.5	6093	3240	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	21.5	6094	3241	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	27.0	6098	3245	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	22.0	6099	3246	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	27.5	6104	3251	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	27.0	6108	3255	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	23.0	6109	3256	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	27.0	6116	3263	11-Jul-06	6
10-Jul-06	6	*Lutjanus synagris*	29.0	6117	3264	11-Jul-06	6
11-Jul-06	5	*Epinephelus guttatus*	29.5	6111	3258	12-Jul-06	5
11-Jul-06	6	*Lutjanus synagris*	28.0	6102	3249	12-Jul-06	6
11-Jul-06	6	*Ocyurus chrysurus*	31.5	6061	3208	12-Jul-06	6
11-Jul-06	6	*Ocyurus chrysurus*	31.5	6101	3248	12-Jul-06	6
12-Jul-06	5	*Ocyurus chrysurus*	31.0	6058	3205	13-Jul-06	5
12-Jul-06	5	*Ocyurus chrysurus*	32.0	6090	3237	13-Jul-06	5
12-Jul-06	5	*Ocyurus chrysurus*	37.0	6103	3250	13-Jul-06	5
12-Jul-06	6	*Ocyurus chrysurus*	31.0	6106	3253	13-Jul-06	6
12-Jul-06	6	*Ocyurus chrysurus*	26.0	6107	3254	13-Jul-06	6
13-Jul-06	5	*Calamus calamus*	28.0	6089	3236	14-Jul-06	5
13-Jul-06	6	*Haemulon flavolineatum*	20.0	6091	3238	14-Jul-06	6
13-Jul-06	5	*Haemulon sciurus*	30.5	6060	3207	14-Jul-06	5
13-Jul-06	5	*Haemulon sciurus*	30.5	6095	3242	14-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	31.5	6035	3182	15-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	31.0	6036	3183	15-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	36.0	6037	3184	15-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	32.0	6050	3197	15-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	36.0	6059	3206	15-Jul-06	5
13-Jul-06	5	*Lutjanus synagris*	31.0	6097	3244	14-Jul-06	5
14-Jul-06	4	*Ginglymostoma cirratum*	70.0	6049	3196	14-Jul-06	4
14-Jul-06	6	*Ocyurus chrysurus*	38.0	6105	3252	15-Jul-06	6
15-Jul-06	6	*Calamus calamus*	35.0	6039	3186	16-Jul-06	6
15-Jul-06	5	*Haemulon plumieri*	25.0	6047	3194	16-Jul-06	5
16-Jul-06	6	*Caranx ruber*	47.0	6113	3260	17-Jul-06	6
16-Jul-06	6	*Lutjanus synagris*	27.0	6053	3200	17-Jul-06	6
16-Jul-06	4	*Lutjanus synagris*	20.0	6096	3243	17-Jul-06	4

Appendix I. Continued.

Date caught	Location caught	Species	TL	Serial #	ID #	Release date	Released Near Receiver
16-Jul-06	5	*Lutjanus synagris*	20.5	6114	3261	17-Jul-06	5
16-Jul-06	4	*Lutjanus synagris*	21.0	6115	3262	17-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	27.0	6038	3185	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	28.0	6040	3187	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	29.0	6043	3190	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	25.0	6045	3192	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	29.0	6046	3193	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	26.0	6048	3195	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	28.0	6051	3198	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	29.5	6054	3201	24-Jul-06	4
22-Jul-06	4	*Haemulon sciurus*	28.0	6055	3202	24-Jul-06	4
22-Jul-06	6	*Haemulon sciurus*	29.0	6092	3239	24-Jul-06	6
25-Jul-06	6	*Lutjanus synagris*	31.0	6052	3199	26-Jul-06	6
25-Jul-06	6	*Lutjanus synagris*	31.0	6056	3203	26-Jul-06	6
25-Jul-06	6	*Lutjanus synagris*	30.0	6057	3204	26-Jul-06	6
27-Jul-06	6	*Balistes vetula*	29.0	6034	3181	28-Jul-06	6
27-Jul-06	6	*Haemulon sciurus*	26.0	6041	3188	28-Jul-06	6
27-Jul-06	6	*Lutjanus analis*	45.0	6044	3191	28-Jul-06	6
13-Apr-07	5	*Acanthurus chirurgus*	19.2	6027	3174	14-Apr-07	5
14-Apr-07	2	*Haemulon sciurus*	27.8	6023	3170	16-Apr-07	2
14-Apr-07	2	*Haemulon sciurus*	26.0	6028	3175	16-Apr-07	2
14-Apr-07	2	*Haemulon sciurus*	27.4	6042	3189	16-Apr-07	2
14-Apr-07	2	*Holocentrus adscensionis*	27.5	6033	3180	16-Apr-07	2
14-Apr-07	2	*Holocentrus adscensionis*	27.5	6118	3265	16-Apr-07	2
14-Apr-07	2	*Holocentrus adscensionis*	26.0	5566	3266	16-Apr-07	2
14-Apr-07	2	*Lutjanus griseus*	25.2	6022	3169	16-Apr-07	2
16-Apr-07	6	*Calamus calamus*	24.5	6029	3176	17-Apr-07	6
16-Apr-07	6	*Calamus calamus*	28.2	6031	3178	17-Apr-07	6
16-Apr-07	6	*Calamus calamus*	25.0	6062	3209	17-Apr-07	6
16-Apr-07	6	*Calamus calamus*	24.5	6063	3210	17-Apr-07	6
16-Apr-07	6	*Haemulon sciurus*	29.5	6021	3168	17-Apr-07	6
16-Apr-07	6	*Lutjanus synagris*	22.1	6030	3177	17-Apr-07	6
17-Apr-07	24	*Acanthurus chirurgus*	23.9	5590	3290	18-Apr-07	24
17-Apr-07	25	*Acanthurus coeruleus*	21.0	6024	3171	18-Apr-07	25
17-Apr-07	24	*Acanthurus coeruleus*	24.0	6025	3172	18-Apr-07	24
17-Apr-07	11	*Balistes vetula*	39.0	6026	3173	18-Apr-07	11
17-Apr-07	24	*Haemulon sciurus*	27.0	6019	3166	18-Apr-07	24

Appendix I. Continued.

Date caught	Location caught	Species	TL	Serial #	ID #	Release date	Released Near Receiver
17-Apr-07	24	*Haemulon sciurus*	29.0	6020	3167	18-Apr-07	24
17-Apr-07	24	*Haemulon sciurus*	24.5	5579	3279	18-Apr-07	24
17-Apr-07	24	*Haemulon sciurus*	30.0	5580	3280	18-Apr-07	24
17-Apr-07	24	*Haemulon sciurus*	30.0	5581	3281	18-Apr-07	24
17-Apr-07	24	*Haemulon sciurus*	29.5	5584	3284	18-Apr-07	24
17-Apr-07	24	*Haemulon sciurus*	28.0	5589	3289	18-Apr-07	24
17-Apr-07	24	*Lutjanus analis*	33.0	6032	3179	18-Apr-07	24
17-Apr-07	24	*Lutjanus analis*	31.0	5574	3274	18-Apr-07	24
17-Apr-07	24	*Lutjanus analis*	35.0	5577	3277	18-Apr-07	24
17-Apr-07	24	*Lutjanus analis*	41.5	5587	3287	18-Apr-07	24
17-Apr-07	24	*Lutjanus synagris*	21.0	5576	3276	18-Apr-07	24
17-Apr-07	24	*Mulloidichthys martinicus*	31.0	5583	3283	18-Apr-07	24
17-Apr-07	24	*Ocyurus chrysurus*	31.0	5586	3286	18-Apr-07	24
17-Apr-07	24	*Ocyurus chrysurus*	29.5	5588	3288	18-Apr-07	24
18-Apr-07	17	*Acanthurus coeruleus*	22.0	5567	3267	18-Apr-07	17
18-Apr-07	14	*Acanthurus coeruleus*	19.0	5568	3268	18-Apr-07	14
18-Apr-07	17	*Acanthurus coeruleus*	19.0	5572	3272	18-Apr-07	17
18-Apr-07	26	*Balistes vetula*	30.5	8648	2350	19-Apr-07	26
18-Apr-07	24	*Calamus calamus*	29.5	5571	3271	19-Apr-07	24
18-Apr-07	20	*Ginglymostoma cirratum*	55.0	8635	2337	19-Apr-07	20
18-Apr-07	26	*Haemulon plumieri*	31.5	8634	2336	19-Apr-07	26
18-Apr-07	24	*Haemulon sciurus*	26.0	8642	2344	19-Apr-07	24
18-Apr-07	24	*Haemulon sciurus*	28.0	8643	2345	19-Apr-07	24
18-Apr-07	24	*Haemulon sciurus*	27.5	8645	2347	19-Apr-07	24
18-Apr-07	24	*Haemulon sciurus*	24.0	8646	2348	19-Apr-07	24
18-Apr-07	24	*Haemulon sciurus*	29.5	5569	3269	19-Apr-07	24
18-Apr-07	24	*Haemulon sciurus*	24.1	5570	3270	19-Apr-07	24
18-Apr-07	24	*Lutjanus analis*	43.2	5573	3273	19-Apr-07	24
18-Apr-07	24	*Lutjanus griseus*	29.0	8631	2333	19-Apr-07	24
18-Apr-07	24	*Lutjanus griseus*	25.9	8632	2334	19-Apr-07	24
18-Apr-07	10	*Lutjanus griseus*	35.4	5582	3282	19-Apr-07	10
18-Apr-07	24	*Lutjanus synagris*	26.0	8629	2331	19-Apr-07	24
18-Apr-07	24	*Lutjanus synagris*	28.0	8630	2332	19-Apr-07	24
18-Apr-07	10	*Lutjanus synagris*	26.5	8644	2346	19-Apr-07	10
18-Apr-07	10	*Lutjanus synagris*	25.1	8647	2349	19-Apr-07	10
18-Apr-07	24	*Lutjanus synagris*	27.0	5578	3278	19-Apr-07	24
18-Apr-07	24	*Lutjanus synagris*	29.5	5585	3285	19-Apr-07	24

Appendix I. Continued.

Date caught	Location caught	Species	TL	Serial #	ID #	Release date	Released Near Receiver
18-Apr-07	23	*Ocyurus chrysurus*	30.0	5575	3275	19-Apr-07	23
18-Apr-07	23	*Pseudupeneus maculatus*	27.0	8652	2354	19-Apr-07	23
19-Apr-07	24	*Calamus calamus*	21.3	8649	2351	20-Apr-07	24
19-Apr-07	23	*Haemulon sciurus*	28.9	8639	2341	20-Apr-07	23
19-Apr-07	24	*Haemulon sciurus*	28.1	8650	2352	20-Apr-07	24
19-Apr-07	24	*Holocentrus adscensionis*	28.5	8637	2339	20-Apr-07	24
19-Apr-07	24	*Holocentrus adscensionis*	28.0	8638	2340	20-Apr-07	24
19-Apr-07	24	*Holocentrus adscensionis*	28.0	8640	2342	20-Apr-07	24
19-Apr-07	24	*Holocentrus adscensionis*	27.5	8641	2343	20-Apr-07	24
19-Apr-07	24	*Holocentrus adscensionis*	29.0	8651	2353	20-Apr-07	24
19-Apr-07	23	*Lutjanus apodus*	27.0	8628	2330	20-Apr-07	23
19-Apr-07	24	*Lutjanus synagris*	22.5	8636	2338	20-Apr-07	24

United States Department of Commerce

Carlos M. Gutierrez
Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr. USN (Ret.)
Under Secretary of Commerce for Oceans and Atmospheres

National Ocean Service
John H. Dunnigan
Assistant Administrator for Ocean Service and Coastal Zone Management

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