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A Pilot Study of Hogfish (*Lachnolaimus maximus* Walbaum 1792) Movement in the Conch Reef Research Only Area (Northern Florida Keys)

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A Pilot Study of Hogfish (*Lachnolaimus maximus* Walbaum 1792) Movement in the Conch Reef Research Only Area (Northern Florida Keys National Marine Sanctuary)

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COVER

A tagged hogfish forages on the coral rubble adjacent to the *Aquarius* Undersea Habitat. Photo Credit: Rick Riera-Gomez, RSMAS/University of Miami

SUGGESTED CITATION

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ABSTRACT

The largely sedentary behavior of many fishes on coral reefs is well established. Information on the movement behavior of individual fish, over fine temporal and spatial scales, however, continues to be limited. It is precisely this type of information that is critical for evaluating the success of marine reserves designed for the conservation and/or management of vagile fishes. In this pilot study we surgically-tagged eight hogfish (*Lachnolaimus maximus* Walbaum 1792) with coded-acoustic transmitters inside the Conch Reef Research Only Area (a no-take marine reserve) in the northern Florida Keys National Marine Sanctuary. Our primary objective was to characterize the movement of *L. maximus* across Conch Reef in the vicinity of the reserve. All fish were captured, surgically-tagged and released *in situ* during a saturation mission to the *Aquarius* Undersea Laboratory, which is located in the center of the reserve. Movement of tagged *L. maximus* was recorded for up to 95 days by three acoustic receivers deployed on the seafloor. Results showed clear diel patterns in *L. maximus* activity and regular movement among the receivers was recorded for seven of the eight tagged fish. Fidelity of tagged fish to the area of release was high when calculated at the scale of days, while within-day fidelity was comparatively low when calculated at the scale of hours. While the number of fish departures from the array also varied, the majority of departures for seven of the eight fish did not exceed 1-hr (with the exception of one 47-day departure), suggesting that when departures occurred, the fish did not travel far. Future efforts will significantly expand the number of receivers at Conch Reef such that fish movement behavior relative to the reserve boundaries can be quantified with increased temporal and spatial resolution.

KEY WORDS

Hogfish, *Lachnolaimus maximus*, acoustic telemetry, fish movement patterns, Florida Keys National Marine Sanctuary

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INTRODUCTION

Hogfish (Labridae: *Lachnolaimus maximus* Walbaum 1792) are dichromatic, protogynous hermaphrodites (Colin 1982; McBride et al. 2001). They are found in subtropical and tropical waters from South Carolina to Brazil, including the Gulf of Mexico, in between three to 30 m water depth (Lieske and Meyers1999). *L. maximus* are opportunistic, non-specific predators on a wide variety of benthic invertebrates (Randall and Warmke 1967; Davis 1976), and are common in low-relief hard-bottom, seagrass and patch reef habitats. Though information on the early life history of *L. maximus* is limited (Colin 1982), observations suggest there may be an ontogenetic shift in habitat from coastal embayments and seagrass beds as juveniles to coral reefs and low-relief hard-bottom habitats as adults (see Davis 1976; Ault et al. 2003).

L. maximus are highly esteemed food fish (Randall and Warmke 1967), and are actively sought in the Florida Keys (McBride et al. 2001). Little is known about the fine-scale movement patterns of individual *L. maximus* within the geographical range in which they occur (Tupper and Rudd 2002). However, it is precisely this information that will be vital for the conservation and management of this exploited species, particularly where spatial management measures are under consideration. For example, in 1997 a total of 23 no-take reserves were zoned and designated in the Florida Keys National Marine Sanctuary (FKNMS; U.S. Department of Commerce, 1996). The Tortugas Ecological Reserve was added in 2001 (U.S. Department of Commerce, 2000). The zones, designated primarily to protect the biological diversity and ecological integrity of heavily used reefs, as well as to reduce user conflicts, exclude all extractive activities from inside their boundaries (U.S. Department of Commerce, 1996). Understanding how particular fishes move relative to the boundaries of these reserves will be critical to successful management.

Data from traditional tag and recapture studies suggest that post-settlement movement of many tropical reef fishes is limited (Bardach 1958; Randall 1961; Chapman and Kramer 2000). Until recently, the difficulties in following individual fish for extended periods of time made precise quantification of fish movement rates one of the most difficult demographic parameters to assess (Jones 1991). Thus with respect to many species, even those for which a great deal of biological data are available, fundamental questions remain as to the fine-scale movement patterns of individuals of all size classes.

The use of fixed acoustic receiver arrays to record the movements of tropical fishes is increasingly common (Chapman et al. 2005; Heupel and Simpfendorfer 2005; Humston et al. 2005; Lindholm et al. 2005a, b, 2006), making it possible to monitor fish movements at time-scales ranging from minutes to years. Specifically, telemetry has been used to track the movements of other Labrids, including *Tautogolabrus adspersus* (Bradbury et al. 1995), *Tautoga onitis* (Arendt et al. 2001a, b) and *Semicossyphus pulcher* (Topping et al. 2005; In press). In this pilot study, we tagged a small number of *L. maximus* with acoustic transmitters and monitored their movements at the Conch Reef Research Only Area, a no-take marine reserve located in the northern FKNMS. To our knowledge, this is the first use of acoustic telemetry to track the movements of *L. maximus*. Our goal was to characterize the movements of tagged fish in the vicinity of Conch Reef in anticipation of a larger project to be conducted at a future date. We report the results of the pilot study and suggest questions for future studies.

METHODS

L. maximus were caught, surgically-tagged with coded-acoustic transmitters and released within the Conch Reef Research Only Area (a no-take marine reserve) in August 2002 (Figure 1). All project elements were conducted *in situ* during a 10-day saturation diving mission to the *Aquarius* Undersea Laboratory (please see Lindholm et al. 2005a for a complete description of the field protocols). Using diver's mesh bags, saturation divers caught all *L. maximus* on the seafloor. The diver placed the open mesh bag in front of the foraging fish while the diver waved the fish into the bag. Each fish was surgically-tagged with a V8SC-1H (69 kHz) coded-acoustic transmitter (VEMCO, Ltd., Shad Bay, Nova Scotia). A spaghetti tag bearing contact information and an ID code was also attached externally at the base of the dorsal fin. Following surgery, each fish was swum around by a diver in the vicinity of its capture until revived. It was then released on the seafloor.

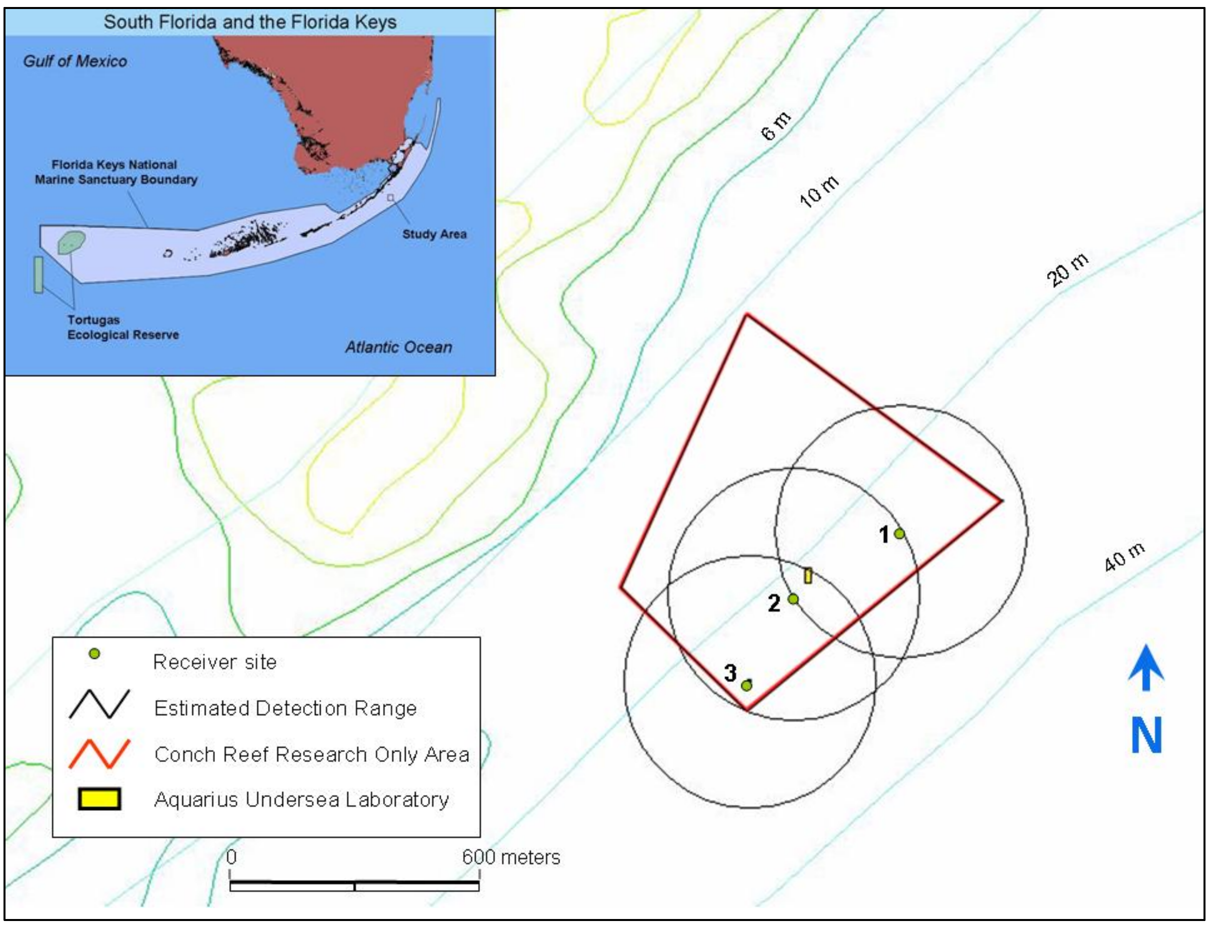

Figure 1. Bathymetric map of the Conch Reef study area, including the location of each acoustic receiver, an estimated 300 m radius of detection around each receiver, the location of the *Aquarius* Undersea Laboratory, and the boundaries of the Conch Reef Research Only Area and the Florida Keys National Marine Sanctuary (Inset).

Movement was recorded by three omni-directional, single-channel (69 kHz) VR2 acoustic receivers (VEMCO, Ltd., Shad Bay, Nova Scotia) deployed at Conch Reef (Figure 1) at 25 m (Site 1), 20 m (Site 2), and 25 m (Site 3). Preliminary tests indicated that the range of detection for a V8SC-1H transmitter at each VR2 receiver at Conch Reef had a radius of approximately 300 m. This range was considered an estimate and was likely to change somewhat over the course of the study with fluctuating water conditions. The projected battery life for the V8SC-1H transmitter was 95 days. In fact, data were collected for three of the eight fish for up to 210 days. However, due to the uncertainty in the quality of the data following the end of a transmitter's estimated battery life, those data were not included in this paper. Data are reported for each tagged fish from 29 August 2002 through 01 December 2002.

The recorded time at-liberty (calculated as the first recorded signal detection to the last signal detection for each fish at any of the three receivers) was quantified at the scale of individual 24-hr periods for each tagged *L. maximus*. We used a least squares linear regression to test for any effect of fish fork length (FL) on recorded time at-liberty. Fish fidelity to the area encompassed by the array was first calculated as the total number of days a fish was detected divided by the 95 days for which detection was possible. Further analyses were conducted to compare usage of receiver sites by tagged fish in hour-scale intervals throughout the study. Recorded signals were grouped into 1-hr time bins standardized for all receivers. There were a total of 24 1-hr time bins per day. Each bin was assigned a number with bin number 1 corresponding to 00:00:00 to 00:59:59. Analysis of diurnal fish movement behavior for each 24-hr period was conducted on the binned 1-hr data. The proportion of 1-hr bins recorded for each fish during daylight and night hours was weighted to account for the variable length of each period and for changes in the length of each period over the course of the study. All proportion data were arcsine transformed prior to analysis. A one-tailed t-test was used to examine the hypothesis that tagged *L. maximus* would be recorded more frequently during daylight hours when compared to the night hours (Sokal and Rohlf 1995). Daily fidelity of tagged fish to the area encompassed by the three receivers was investigated by quantifying 1) the proportion of 1-hr bins recorded for each fish within the array and at each receiver and 2) the number and duration of fish departures from the array for each tagged fish. A least squares linear regression was used to examine the relationship between the proportion of 1-hr time bins recorded per fish and the total number of departures per fish.

RESULTS

Eight *L. maximus* (mean FL = 175.6 mm SD = 3.2) were tracked for up to 95 days (Table 1). All fish were considered to be either late-juvenile or initial phase females based on coloration. No terminal phase male *L. maximus* were observed in the area during the study. We encountered *L. maximus* both as solitary individuals and as members of small aggregations of con-specifics. Where aggregations occurred all individuals were of a similar size class. Saturation divers observed each of the tagged fish for up to nine days post-release. All eight fish were observed to return to foraging along the seafloor following surgical tag implantation.

Table 1. Summary data for acoustically-tagged *L. maximus* released at Conch Reef in August 2002. Iph = initial phase female.

Fish #	FL (mm)	Life History Phase	Recorded Days At-Liberty	Location of Release	Number Receivers Visited
1	170	Iph	83	Receiver 2	3
2	175	Iph	95	Receiver 2	3
3	175	Iph	76	Receiver 2	1
4	180	Iph	95	Receiver 2	3
5	175	Iph	95	Receiver 2	3
6	180	Iph	56	Receiver 2	2
7	175	Iph	55	Receiver 2	2
8	175	Iph	17	Receiver 2	3
A					

The total time at-liberty (Figure 2) varied widely among tagged *L. maximus* (mean = 71.5 days; SD = 25.7). Three fish (Tags 2, 4 and 5) were recorded at least once daily for each day of the 95-day study period, while Tag 8 was recorded for only the first 17 days. Tag 1 was the only fish to return to the array following a 57 day departure. A least-squares linear regression of total days at-liberty on fish fork length was not significant (ANOVA, $P > 0.947$) with a correlation coefficient of 0.0 percent.

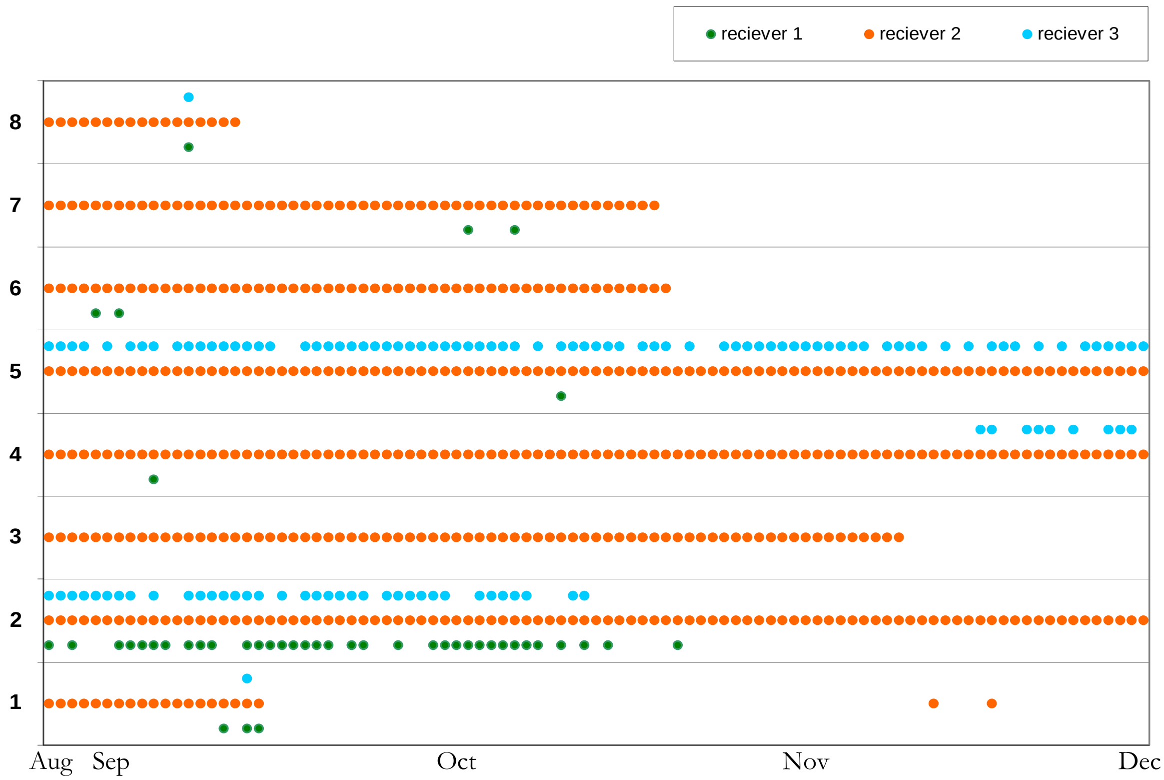

Figure 2. Recorded time at-liberty for eight tagged *L. maximus* released at Conch Reef. Each fish was monitored from 29 August through 01 December 2002 by three acoustic receivers deployed on the seafloor. Each circle represents a day on which a fish was detected by a receiver, with circles color-coded to represent each of the three receivers.

Tagged *L. maximus* showed clear diurnal behavior (Figure 3). A one-tailed t-test used to test the hypothesis that detections for tagged *L. maximus* would be higher during daylight hours when compared to night was highly significant ($t = 4.07$, $df = 14$, $p < 0.0006$). Tagged fish were recorded more frequently during daylight hours (mean = 621 1-hr bins, SD = 317) than at night (mean = 226, SD = 147). All fish were recorded at night, though only Tag 8 was recorded more frequently at night. As no fish movement among receivers was recorded during the night hours, all subsequent analyses were conducted using detections recorded during the daylight hours.

The fidelity of tagged *L. maximus* to the area of Conch Reef encompassed by the receiver array, measured at the scale of 24-hr bins, was quantified for each individual at each receiver (Table 2). A fish was considered present at a receiver on a given day if a minimum of one signal detection was recorded during daylight hours. At this temporal scale, fidelity was high (mean = 67%, SD = 34%). All *L. maximus* were recorded most frequently at receiver 2 where they were tagged and released. Three of the eight fish (Tags 2, 4 and 5) were recorded for 100 percent of the 95 days possible by at least one of the three receivers. In addition to being recorded at receiver 2, Tag 2 was also recorded at both receivers 1 and 3 for more than 35 percent of the study, Tag 4 rarely left receiver 2 and Tag 5 was also recorded for 81 percent of the study at receiver 3. Three fish (Tags 3, 6 and 7) were recorded for more than 50 percent of the study period at receiver 2, while Tags 1 and 8 were recorded for less than 25 percent of the study. The within-day fidelity of *L. maximus* was also investigated by calculating the weighted proportion of 1-hr daylight time bins in which a tagged fish was recorded (Table 2). Here a minimum of one signal detection was required per 1-hr bin for a fish to be considered present. At this temporal scale, the site fidelity of tagged *L. maximus* was comparatively low (mean = 37%, SD = 18%). Again, all fish were recorded most frequently at receiver 2. Only two fish (Tags 3 and 4) were each present for more than 50 percent of the 1-hr time bins over the course of the 95-day study, while the remaining four fish were recorded between 14 and 47 percent. When compared to fish fidelity at the scale of 24-hr bins, the mean percent-recorded for tagged *L. maximus* declined by 3.8 to 69.6 percent (mean = -30%, SD = 21.5%).

Within-day fish fidelity was further investigated by calculating the number of fish departures from the receiver array and the duration of each departure during daylight hours (Table 3). A departure was defined as the lack of detection at any receiver in the array for one or more consecutive 1-hr daylight time bins. The absence of a fish from the array during the night hours was not considered a departure based on the results of the diel pattern analysis described above. All tagged *L. maximus* made multiple departures from the receiver array during their time at-liberty. The total number of departures per tagged fish varied considerably (mean = 92, SD = 68). With the exception of Tag 7, the majority of departures for each fish did not exceed 1-hr. A least-squares linear regression of total departures per fish on percent 1-hr bins recorded per fish was not significant (ANOVA, $P > 0.082$) with a correlation coefficient of 32.5 percent.

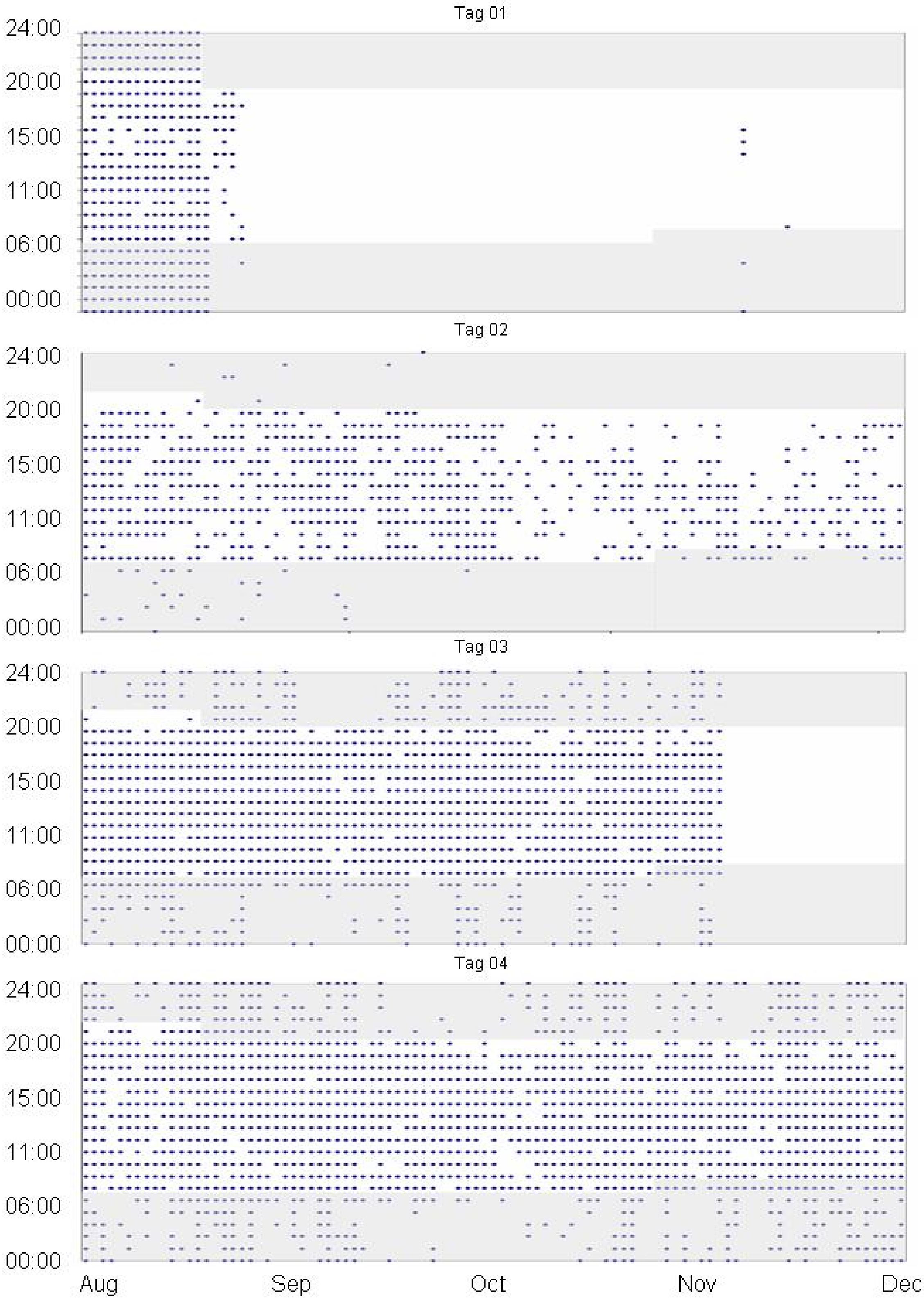

Figure 3. Diel patterns in the detections of eight *L. maximus* tagged at Conch Reef from 29 August 2002 to 01 December 2002. Areas of shading represent darkness.

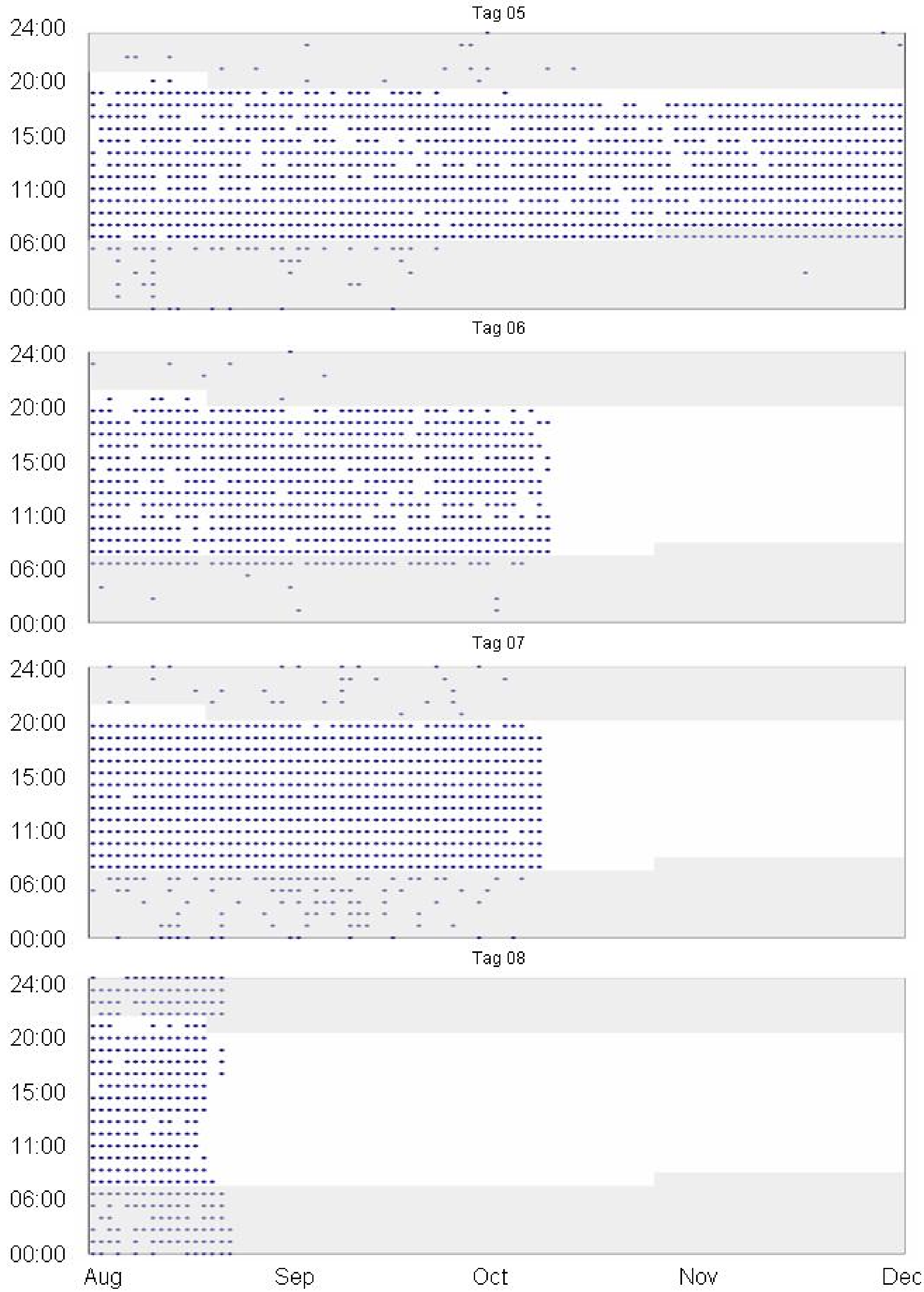

Figure 3, continued.

Table 2. Detections for tagged *L. maximus* at each receiver expressed as a percentage of 24-hr time bins and 1-hr daylight time bins recorded from 29 August through 01 December, 2002. None = the percentage of time bins in which no signal was recorded. The percent change describes the difference between 24-hr and 1-hr bin data.

	Acoustic Receiver				
Fish Number	1 (24-hr / 1-hr)	2 (24-hr / 1-hr)	3 (24-hr / 1-hr)	None (24-hr / 1-hr)	Percent Change
1	3.2 / 0.2	22.1 / 15.7	1.1 / 0.0	77.9 / 84.2	-6.3
2	36.8 / 3.0	100 / 26.2	37.9 / 3.2	0.0 / 69.6	-69.6
3	0.0 / 0.0	80 / 52.1	0.0 / 0.0	20 / 47.9	-27.9
4	1.1 / 0.04	100 / 67.5	9.5 / 0.4	0.0 / 32.5	-32.5
5	1.1 / 0.04	100 / 47.3	81.1 / 9.0	0.0 / 48.8	-48.8
6	2.1 / 0.01	58.9 / 30.4	0.0 / 0.0	41.1 / 69.6	-28.5
7	2.1 / 0.01	57.9 / 35.4	0.0 / 0.0	42.1 / 64.6	-22.5
8	1.1 / 0.01	17.9 / 14.1	1.1 / 0.04	82.1 / 85.9	-3.8

Table 3. Frequency of consecutive 1-hr time bins in which no receivers recorded signals from tagged *L. maximus* during daylight hours.

	Consecutive Hours				
Fish Number	1	2	3	4	5
1	15	5	2	1	0
2	111	46	27	11	5
3	73	19	11	7	4
4	110	34	21	13	3
5	58	21	3	5	3
6	30	13	6	1	1
7	22	19	8	8	1
8	16	4	2	0	0

DISCUSSION

We used acoustic telemetry to collect preliminary data on the movement of tagged *L. maximus* inside a marine reserve in the northern Florida Keys. Movement among receivers was recorded for seven of eight tagged fish, and diel patterns in fish movement conformed to our *a priori* hypothesis that tagged *L. maximus* would be recorded more frequently during daylight hours. The small number of receivers deployed in this preliminary effort did not allow for the precise quantification of home range for *L. maximus*, which has been estimated to be 600 m^2 for small (< 250 mm TL) individuals (Tupper and Rudd 2002). Our results do not preclude a home range of this size and suggest that at Conch Reef the home range of some individuals may be much greater than 600 m^2.

Davis (1976) suggested that sandy areas adjacent to hard bottom reef are common habitats for *L. maximus*. While diving during this and previous *Aquarius* missions, we observed *L. maximus* to be present in the vicinity of *Aquarius* in moderate numbers (10 to 20 individuals) sporadically throughout the daylight hours on a sand flat adjacent to spur and groove topography. Receiver 2 was sited on a small reef patch in the center of this sand flat. Seven of the eight fish made multiple movements away from receiver 2, with three fish recorded at other receivers frequently over their respective times at-liberty (Figure 2). In the case of Tag 2, daily movements occurred to both the north and the south of its release point indicating a wide individual ambit. The behavior of Tag 2 also suggests that movement behavior may change over time, as the movement away from receiver 2 ceased in mid-October and did not resume again during the course of the study.

For the purpose of this project, we chose not to focus on site fidelity per se, but rather we focused on quantifying the repeated returns of individual *L. maximus* to a particular receiver, an area of up to 282,743 m^2 per receiver. We investigated fidelity in a temporal context at two scales, that of individual 24-hr time bins and that of 1-hr time bins. At the scale of 24-hr bins, the fidelity of tagged *L. maximus* to their release location was very high. Each fish was recorded by receiver 2 at least once for every day that it was recorded by the receiver array, whether the fish was present within the array for 17 days (Tag 8) or 95 days (Tags 2, 4 and 5). In the case of Tag 1, after departing the array on September 17th, it was absent for nearly 2 months before returning to receiver 2 on November 14th. At the scale of 1-hr time bins, the fidelity of the tagged *L. maximus* was comparatively low. Interestingly, at this scale, fish such as Tag 2, which was present every day of the 95-day study (Figure 2), was actually only recorded by the receivers for 26.2 percent of the total 1-hr daylight time bins possible during that period.

Our experience suggests that the comparatively small number of 1-hr time bins in which fish were recorded, when compared to the 24-hr bins, was likely a result of the interaction of seafloor topographic complexity at Conch Reef, fish behavior and limitations of the acoustic receivers. The topography at Conch Reef is diverse, including walls and extensive spur and groove formations, which creates a number of acoustic shadows (areas where acoustic receivers are blocked from recording a transmission). Tagged *L. maximus* were rarely observed more than three body lengths away from the seafloor, either over hard bottom or adjacent sand areas. This behavior would likely have placed the fish frequently in these shadows and out of range of the receivers. Support for this explanation comes from the data on the number and duration of fish departures from the array (Table 3). The fact that the majority of departures for seven of the eight tagged *L. maximus* did not exceed 1 hour suggests that rather than leaving the array entirely, these fish were simply dropping in and out of the shadows created by the reef. Subsequent studies will attempt to minimize the presence of acoustic shadows to more accurately characterize fish movement close to the reef.

Where individual tagged *L. maximus* were not present for the entire 95-day study, it is possible that they were caught by fishing activity in adjacent areas. *L. maximus* are highly sought animals by the recreational fishing industry in Florida where reef habitats occur (McBride et al. 2001) and are currently classified as over-fished (Ault et al. 2003). While conducting research adjacent to *Aquarius* we have often observed multiple fishing boats moored to the buoys immediately adjacent to the no-take reserve at Conch Reef. In fact, on numerous occasions we have observed fishing boats stray within the boundaries of the no-take reserve, including potential spear fishing operations. Absence from the acoustic receiver array is also potentially explained by movements away from Conch Reef for spawning purposes given that in Florida *L. maximus* spawning occurs from September to April (Davis 1976); however, the size of the fish tagged (< 180 mm FL) make this unlikely, and it is not clear that *L. maximus* move very far for spawning (Colin 1982).

Clearly, there are limits to what can be extrapolated from this study alone, particularly with respect to the implications for the design of marine reserves. While we recorded high fidelity of *L. maximus* to the area of Conch reef encompassed by the receivers, the distribution of receivers was insufficient to characterize the fine-scale movement of those fish. Given the relatively small-scale of the reserve at Conch Reef (less than 0.23 km^2) and the fishing activity around the perimeter of those reserves, this fine-scale movement will be important.

The differences we recorded in fish fidelity at the scale of 24-hr and 1-hr time bins have obvious consequences for conservation and management. Key questions include whether this difference was ecological, or simply a result of the limits of acoustic telemetry technology. Assuming that the topographic complexity of Conch Reef was largely responsible for the lack of more signal detections, a greater number of receivers, deployed up in the water column rather than down on the reef, should allow us to characterize the movements of these and other species more accurately. The greater number of receivers should improve our ability to triangulate the position of a particular fish that is recorded by more than a single receiver. An increase in the resolution of movement data for this species relative to the boundaries of the no-take reserve should provide important information on the efficacy of small reserves for the conservation and management of vagile species.

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ONMS CONSERVATION SERIES PUBLICATIONS

To date, the following reports have been published in the Marine Sanctuaries Conservation Series. All publications are available on the National Marine Sanctuary Program website (http://www.sanctuaries.noaa.gov/).

Comments on Hydrographic and Topographic LIDAR Acquisition and Merging with Multibeam Sounding Data Acquired in the Olympic Coast National Marine Sanctuary (ONMS-06-05)

Conservation Science in NOAA's National Marine Sanctuaries: Description and Recent Accomplishments (ONMS-06-04)

Normalization and characterization of multibeam backscatter: Koitlah Point to Point of the Arches, Olympic Coast National Marine Sanctuary - Survey HMPR-115-2004-03 (ONMS-06-03)

Developing Alternatives for Optimal Representation of Seafloor Habitats and Associated Communities in Stellwagen Bank National Marine Sanctuary (ONMS-06-02)

Benthic Habitat Mapping in the Olympic Coast National Marine Sanctuary (ONMS-06-01)

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