Oil Platforms and Red Snapper Movement and Behavior

Michael McDonough

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Michael McDonough
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Abstract

Understanding the behavior, including movement, of red snapper (*Lutjanus campechanus*), around and among the many oil and gas platforms in the northern Gulf of Mexico (GOM) is crucial to the management of this important commercial and recreational species. What role oil and gas production platforms play in the attraction vs. production continuum for red snapper is unknown, but it is certain these large structures have a role at some life history stage. We used the VRAP acoustic telemetry system to track red snapper around two platforms in the GOM in 2005 and 2006. Fish detections per hour generally decreased over the course of each experiment, and detections also fluctuated with strong periodicity. Spectral analysis revealed that red snapper had a 24-hour periodicity to their movements. Probability of presence of fish likewise fluctuated within a day, perhaps indicating foraging away from the platforms. Red snapper in this study showed much lower site fidelity than in previous studies of red snapper on artificial reefs. These results appear to support the hypothesis that platforms function largely as attracting devices.

Introduction

The Magnuson-Stevens Fishery Conservation and Management Act, the 1996 revision and reauthorization of the 1976 Public Law 94-265 (Act), requires that fishery management plans include an identification and description of essential fish habitat (EFH), adverse impacts on EFH (including the effects from fishing), and actions to conserve and enhance EFH (Gallaway et al, 1999). One of the most pressing federal fisheries management concerns in the Gulf of Mexico (Gulf) region is the overfished status of red snapper *Lutjanus campechanus* (Schmitten, 1999). National Marine Fisheries Service (NMFS) data collection provides evidence that the primary cause of overfishing on red snapper is bycatch of age-0 and age-1 (juvenile) red snapper by shrimp trawls (Schirripa and Legault, 1999). As such, the conservation and enhancement of red snapper EFH may act to reduce the impacts of shrimp trawl mortality on juvenile red snapper (Schmitten, 1999).

Red snapper are demersal reef-associated fish that are distributed along the continental shelf throughout the Gulf. Young red snapper spend most of their first year over sand and mud bottom on the shrimping grounds in the northern Gulf, after which they move offshore to reef environments (Patterson et al, 1998). Adult snapper are found in deeper offshore waters near coral, rocks, banks, outcrops, and manmade submerged objects such as oil and gas platforms and artificial reefs (Workman and Foster, 1994).

The way in which different life stages of red snapper utilize these various habitats as they grow, e.g. for feeding, protection or both, is unknown. Information on the age-0 juvenile stage of red snapper is sparse, especially at first settlement (Szedlmayer and Conti, 1999). However, it has been demonstrated that as red snapper grow they show

strong preferences for natural and artificial habitat with vertical relief. It is these areas that are considered by many to constitute red snapper EFH.

In the waters of the northern Gulf there are over 4000 functioning oil and gas platforms (Stanley and Wilson, 1998). Since the first platform was installed, fishers and scientists have been aware of their associated nekton assemblages (Stanley and Wilson, 1997). They act as artificial reefs by providing habitat that potentially increases the growth and survival of the individuals, by affording shelter for protection from predation and spawning substrate, and by acting as a visual attractant for organisms not otherwise dependent on hard bottom (Gallaway et al, 1981). Oil and gas platforms differ from most natural habitats and from traditional artificial reefs in that their vertical profile extends throughout the water column into the photic zone (Stanley and Wilson, 1991). Increased habitat quality on, or immediately around, oil and gas platforms is believed to be derived from increased *in situ* food production associated with encrustation by fouling organisms and also by any amount of fortification of the bottom for support of the structure.

Artificial reefs, such as oil and gas platforms, may be useful tools for fishery managers if they increase production, but many researchers question whether or not they are a positive influence on reef stock dynamics. There have been doubts about whether or not they produce or attract fish and the resolution to this question is essential to the management of reef fish stocks. If they indeed constitute EFH for reef fish, then they can be considered as viable management tools. If they are simply attracting fish to the area, they may be simply promoting overfishing. Currently, the Gulf Management Council does not include oil and gas platforms, or any other artificial reef habitat, in their treatment of EFH.

Understanding the movement and behavior of red snapper (*Lutjanus campechanus*) around and among the many oil and gas platforms in the northern Gulf of Mexico (GOM) is crucial to the management of this important commercial and recreational species. It has long been known that artificial reefs such as oil platforms are good fishing localities. Several scientific studies have confirmed that platforms are common sites for fish aggregation (Seaman et al., 1989; Stanley, 1994; Love et al., 1999; 2000; Jennings et al. 2001) and that red snapper comprise a significant percentage of these communities (Stanley and Wilson, 1997; Nieland and Wilson, 2002; Wilson and Nieland, 2004). Platforms have also been implicated in the partial recovery of some fish stocks—reasons for this include increased food production and refuge from predators around platforms. However, they may simply make red snapper more vulnerable to fishing. Knowledge of how fish use platforms is relatively scarce.

Estimates of abundance can only show that red snapper do associate with platforms, not why. Acoustic telemetry enables researchers to investigate site fidelity and observe temporal and spatial patterns in red snapper movement and behavior. Site fidelity can serve as a proxy for the suitability of a platform as red snapper habitat—if the platform does provide some benefit, the hypothesis is that red snapper would not risk predation and the energy costs involved with seeking new habitat (Werner and Anholt, 1993). Investigating red snapper movement temporally can reveal if snapper exhibit any patterns, such as diel periodicity and diurnal/nocturnal or crepuscular movements. Temporal patterns often correspond to feeding behavior (Hobson, 1965; Helfman, 1986) and may give insight into whether platforms play some role in feeding by red snapper. Whether red snapper do or do not exhibit strong site fidelity to platforms, and do or do

not gain nutrition directly from food webs dependent upon platforms, also contributes to the resolution of the attraction vs. production debate (Bohnsack, 1989).

Bohnsack (1989) proposed that the varying hypotheses regarding why artificial reefs hold such high numbers of fish could be summarized by two mechanisms: attraction and production. Artificial reefs may merely attract high numbers of fish—this mechanism would be likely to dominate for species that are reef-associated, recruitment-limited, and exhibit low site fidelity. Artificial reefs may actually increase the fitness of and produce biomass for some species, particularly those that are reef-dependent, habitat-limited, and show high site fidelity.

The attraction versus production hypothesis attempts to explain these phenomena at a population level. The Resource Mosaic Hypothesis may explain how attraction versus production may be operating that the local scale, i.e., at an individual reef or collection of reefs. Lindbergh et al. (1990) concluded that reef-associated species feeding upon non-reef-associated benthic dwelling prey create areas of intense prey depletion around the reefs they inhabit. These feeding haloes force these predators to search beyond feeding haloes to find available prey. Further, they hypothesized that spacing would be important in this dynamic—reefs that were close together would have overlapping haloes and more intense prey depletion. The more intense the prey depletion, the higher the energetic cost of searching for available prey; and this higher energetic cost would decrease site fidelity, abundance, and growth.

Researchers have studied whether the resource mosaic hypothesis might apply to red snapper associated with artificial and natural reefs. Strelchek et al. (2005) found that red snapper biomass and CPUE both decreased with increasing density of reefs. McCawley and Cowan (2007) found that red snapper do indeed feed upon non reef-

associated prey surrounding both natural and artificial reefs. Westmeyer et al. (2007) concluded that red snapper were exhibiting very low site fidelity to platforms in the GOM (<1% yr-1). From these studies it may be surmised that red snapper are exhibiting behavior consistent with the resource mosaic hypothesis, however, that behavior has never been observed. A major goal of this study was to see if I could observe behavior that would be consistent with red snapper moving away from oil platforms to feed. Because the resource mosaic hypothesis has implications for the spacing of reefs, managers of artificial reef programs might be interested to know whether the existence of foraging haloes should inform their decisions about where to place artificial reefs.

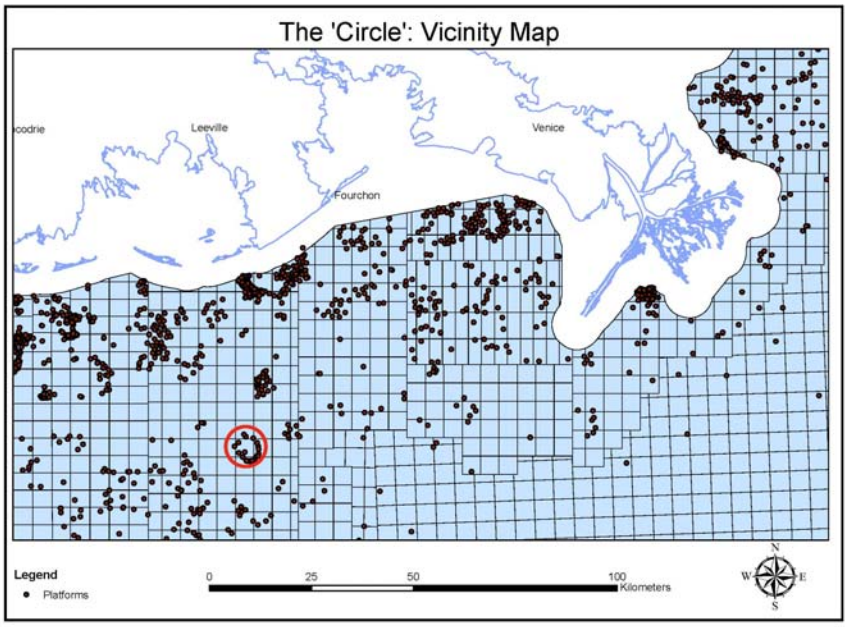
Another major goal of this study was to observe 'a day in the life of a fish.' Telemetry can collect data that gives more information than just where fish are. Because the date and time of both positions and detections are collected also, researchers can use these temporal data to look at temporal patterns. For instance, if fish are making movements away from reefs, telemetry can also show when these movements are occurring. If fish are leaving the coverage area entirely, telemetric data can also show when fish are in the coverage area, and when they are not.

Methods

I performed two telemetry experiments on platforms in the GOM. I collected red snapper aboard a charter fishing vessel during the summers of 2005 and 2006. Collections were performed at a complex of petroleum production platforms known as 'the Circle,' because they roughly form a circle around the salt dome from which crude oil is extracted. The Circle (28˚39.402 N, 090˚14.126 W) is located about 50 km off Louisiana in the northern GOM (Figure 1); all platforms in the Circle are owned and operated by Chevron-Texaco. Although I caught fish at several platforms, I released all fish at the platforms around which I deployed the Vemco® radio acoustic positioning (VRAP) system. In 2005, I deployed VRAP around ST 135-M; in 2006, ST 134-S (Figure 1). Platform 135-M stands at the southwestern end of the Circle in 45 m of water; platform 134-S stands at the northern end in 37 m of water. The combined platforms in the Circle have a 2.5 km radius.

I chose this site because of an existing relationship between LSU researchers and the Chevron-Texaco personnel at the Circle platforms. They were not only willing to allow us to perform experiments on and near platforms; we also were provided with information regarding boat traffic and logistical support such as transportation to study sites via helicopter. For this experiment, they also provided us with a site to house the VRAP's base station, where power and existing radio communication infrastructure were available.

I deployed the VRAP system around one platform each year to track the movements of red snapper around the structures (Figure 2). The VRAP system is composed of three receivers that detect and record transmitters with independent hydrophones. Each



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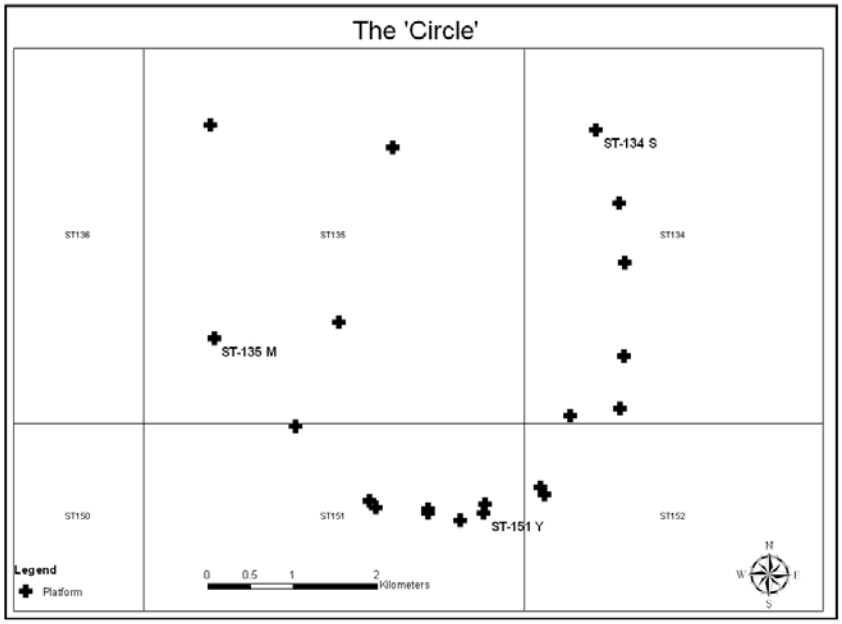
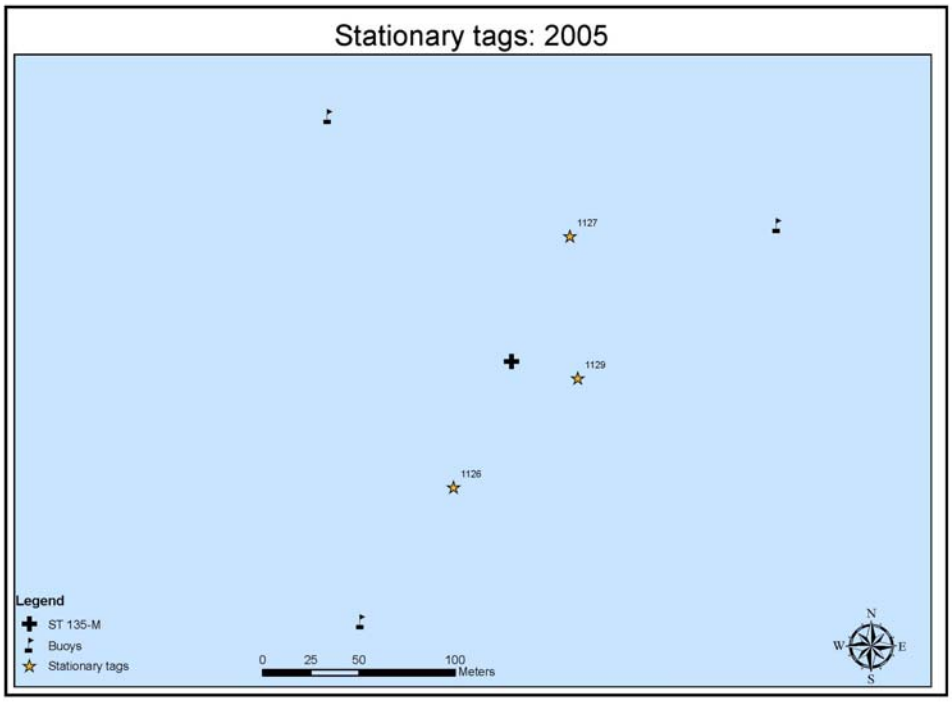
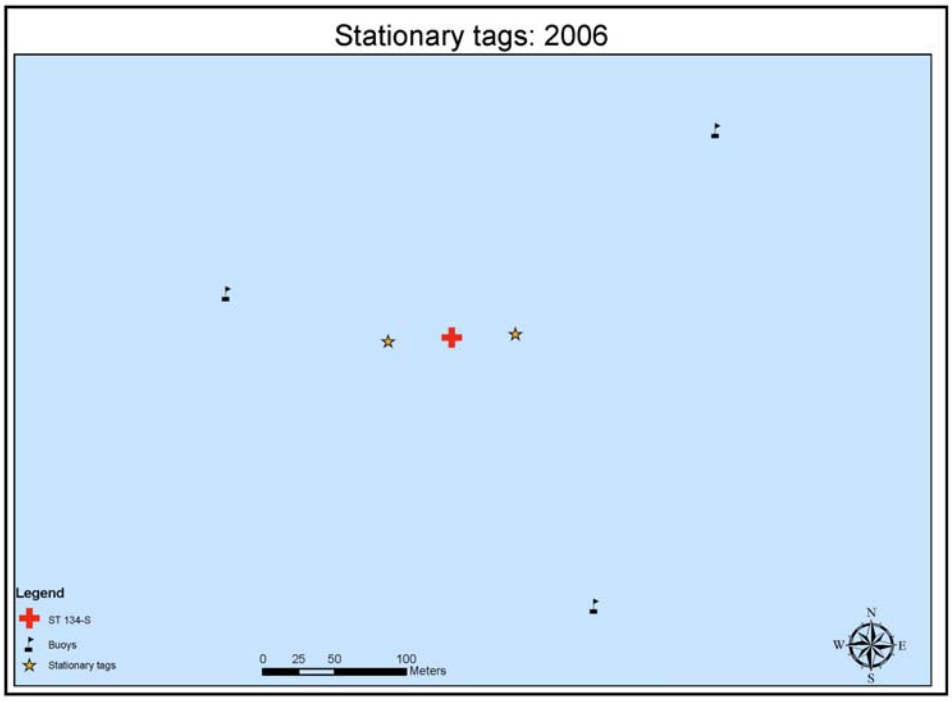


b)

Figure 1. Maps of the study area showing the position of a) 'the Circle' (circled in red) in the Gulf of Mexico and b) the positions of platforms ST-135 M, ST-134 S, and ST-151 Y within the Circle.



a)



b)

Figure 2. Plots of the buoy deployment in a) 2005 and b) 2006.

transmitter has a unique code and emits a ping at random intervals, so that VRAP can identify and track multiple individuals. Random intervals minimize simultaneous transmissions from multiple transmitters—VRAP cannot record more than one transmission at a time. All transmitters had battery lives (approximately one year) that exceeded the length of the study, which was designed to study short-term movement and site fidelity. Some of the transmitters also were equipped with depth sensors (6 in 2005, and 9 in 2006), and communicated depth during transmission.

A base station kept on ST-151 Y (Figure 1) in both years initialized the receivers for recording and uploaded data at user-defined intervals. When all three receivers recorded a transmission, the base station calculated a position for that fish. The base station also recorded 'unresolved tags'—transmitters detected by two or fewer receivers. This feature allows VRAP to detect fish presence, even when it is unable to calculate position. The base station then recorded the positions or unresolved tags, along with the date and time of transmission, for each fish.

I also deployed stationary tags within the array for two purposes (Figure 2). Because the buoys were moored and moved with the currents, I needed a way to subtract this movement from the fish positions. Stationary tags also allow estimation of error in detectability. When fish are not detected by the system, it could be because they are not present in the array or the system is unable to detect them. Because stationary tags are always present in the array, any loss in detectability will be due to the limitations of the system, hydrographic features in the area, battery loss in either the tags or the hydrophones, or other factors which could all be considered system-wide error. The effects of those factors can be estimated by trends in detections of stationary tags.

Each experiment was intended to last two weeks during the spring/summer—after cold fronts were no longer a threat, and before hurricane season was likely to affect the GOM. In 2005, I deployed VRAP for five days in May (26-30) before one of the receivers was struck and damaged by a supply boat. I was not able to re-deploy until August, when I was able to get another seven days of data (6-12 August). In 2006, I was able to get a continuous two-week dataset (17-30 May). I chose the study length because two weeks is the effective battery life of the buoys, I was not attempting to observe long-term movements or behavior.

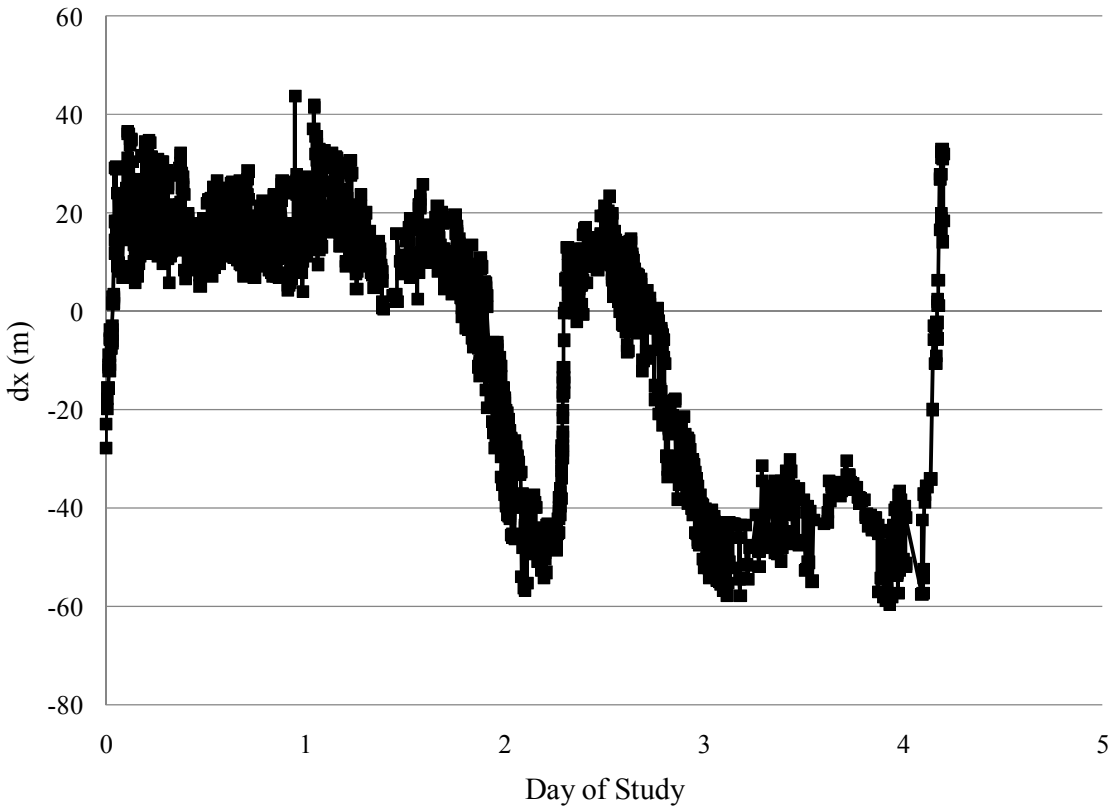
I collected red snapper for tracking with hook and line. Each fish was checked for visible signs of catastrophic decompression—bulging eyes, external hemorrhaging, or everted stomachs (Rummer and Bennett, 2005)—and then placed into a pre-surgery holding tank after their air bladder was vented. The fish remained in the pre-surgery tank until they were able to swim upright on their own. At that point, fish were determined to be suitable for transmitter implantation. Fish were brought to level four anesthesia in a 325 mg l^{-1} solution of MS-222. A small incision was made just dorsal to the ventral midline, between the pelvic fins and the anus, with a sterile, disposable scalpel. I then implanted an ultrasonic transmitter (Vemco, Ltd.), inserted a Floy® anchor tag (for visual identification in case of recapture) into the incision, and closed the incision with two catgut sutures and an acrylic adhesive (Krazy Glue®). Fish then were transferred to a post-surgery recovery tank and held until they again were able to swim upright. To estimate acute mortality, I monitored fish for ability to orient to the bottom and swim down upon release (Patterson et al., 2001).

To analyze the data, I first plotted fish positions. To account for movement of the buoys, I first calculated the mean position of each stationary tag. I then calculated the

difference between each position of a stationary tag and its mean position in the x-direction (dx) and in the y-direction (dy). Because the VRAP system can not detect more than one tag at a time, the time at which a stationary tag was detected was never the same as when a fish was detected. For this reason, I interpolated dx and dy over the times at which fish positions were recorded and used these numbers to correct the fish positions in both the x- and y-direction (Figures 3 -5).

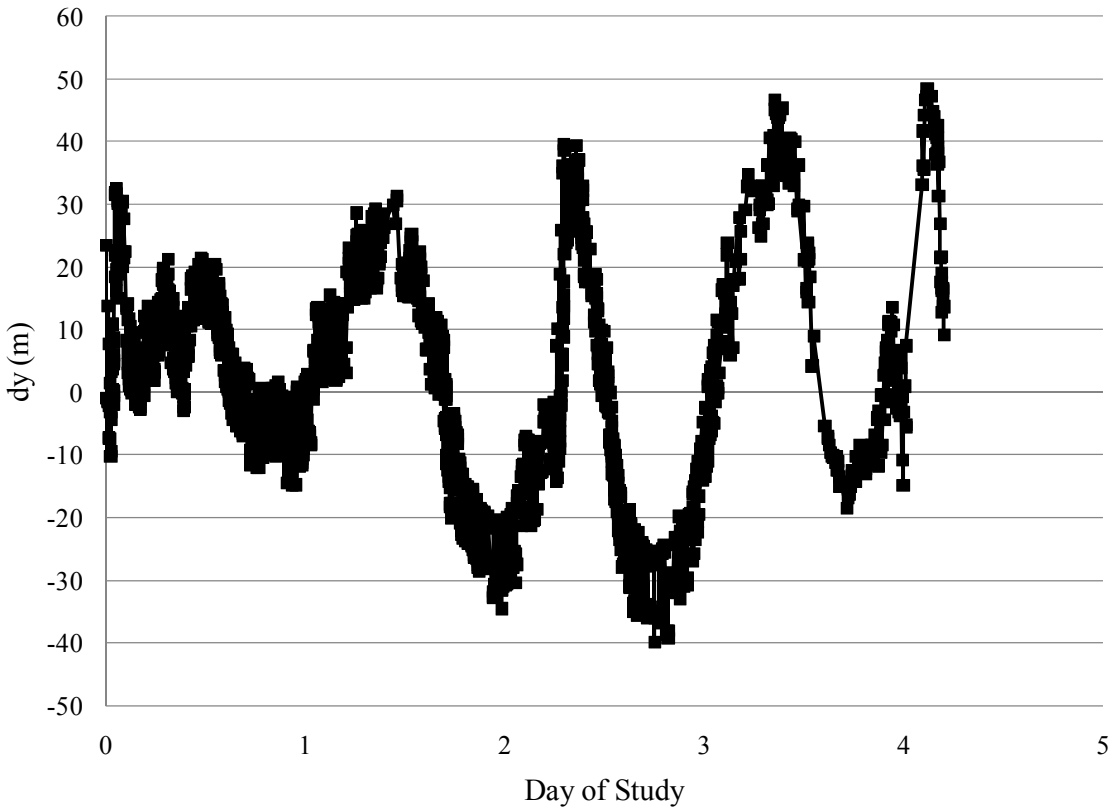
To determine when red snapper were present at the platform, I combined positions and unresolved tags. If an individual was detected by VRAP during any hour of the study, I considered that fish to be 'present' during that hour. By definition, a fish would either be present each hour, even if detected more than once, or absent, if not detected at all. First I plotted the fish identification codes (ID) by hour of the study, placing a 'dot' on the x-axis for each hour of the study the fish was present (Figure 6). I then plotted the number of fish detected per hour (if a fish was detected at least once in an hour, it was counted once and no more) for each hour of the study. To estimate system-wide error, I modeled the average hourly detections of stationary tags (the average was calculated by day of the study, so that I am looking at day 1's average detections per hour vs. day 2's vs. day 3's, etc.). I regressed on ID, time of day (day vs. night), and day of study. ('Day' hours were 0600-2000, and 'night' hours were the remaining hours.) I then subtracted the values predicted by the model from the average hourly detections by day of study of tagged fish and calculated the slopes of the de-trended data.

To detect periodicity, I performed a spectral analysis (PROC SPECTRA, SAS Institute, INC., 2007) on fish detected per hour. Spectral analysis can detect cycles in presences and absences. I used the spectra to determine whether there was identifiable



a)

Figure 3. Plot of the a) dx- and b) dy- corrections for fish positions in May 2005 (figure continued).



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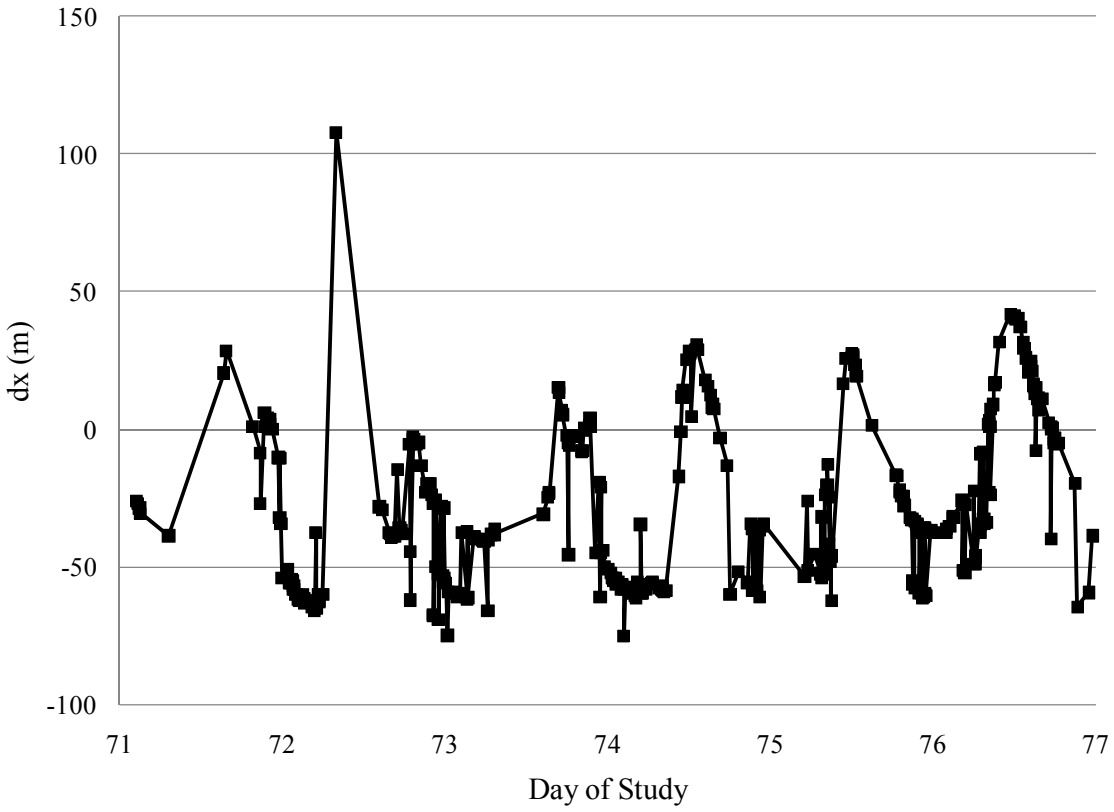
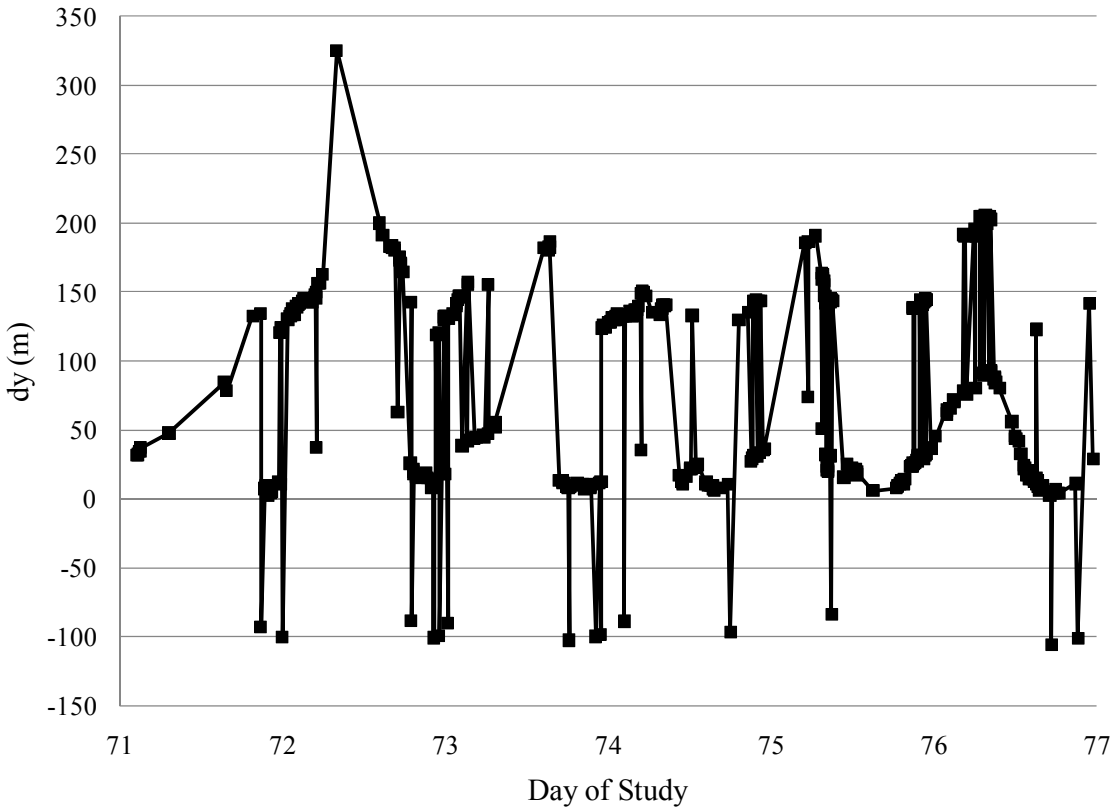
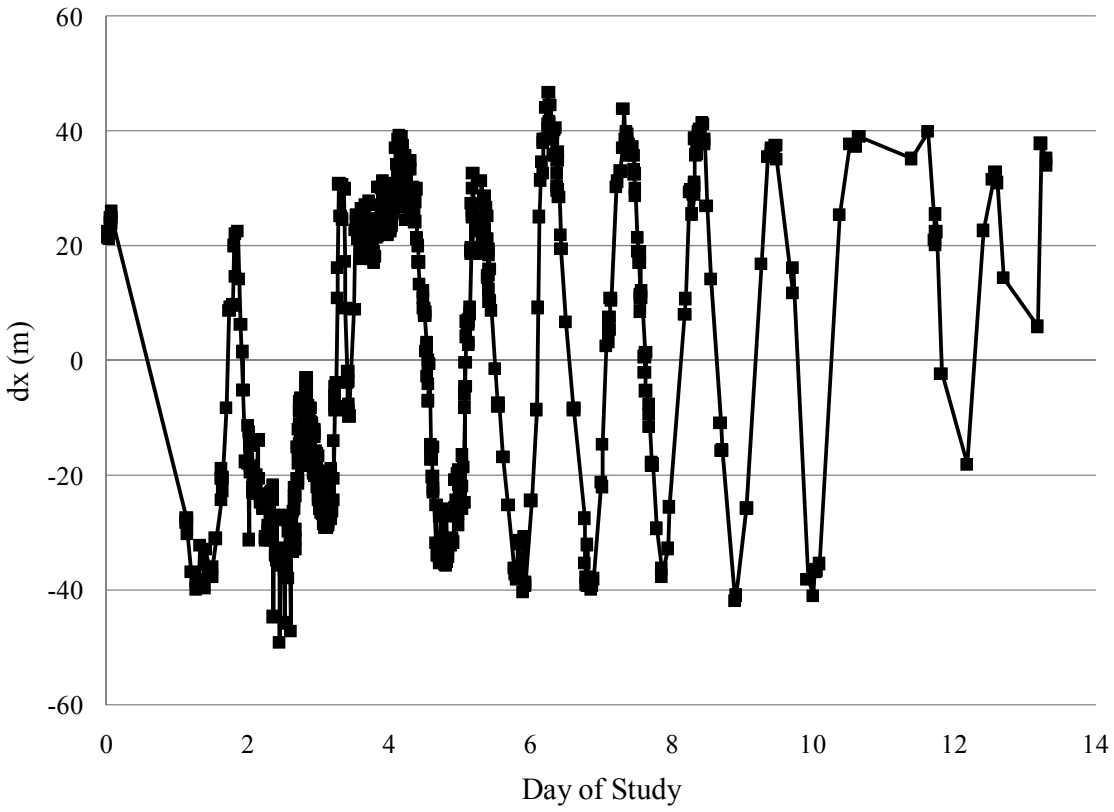


a)

Figure 4. Plot of the a) dx- and b) dy- corrections for fish positions in August 2005 (figure continued).

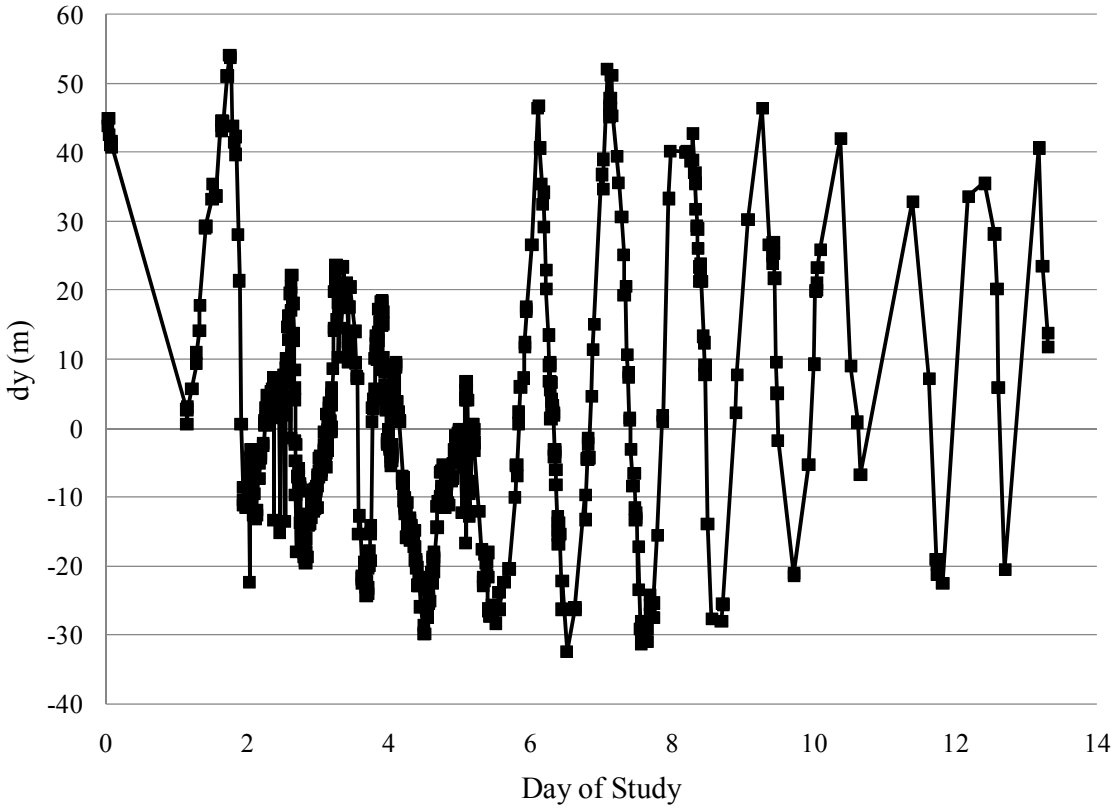

350
300
250
200
150
100
50
0
-50
-100
-150
dy (m)
71
72
73
74
75
76
77
Day of Study

b)



a)

Figure 5. Plot of the a) dx- and b) dy- corrections for fish positions in 2006 (figure continued).



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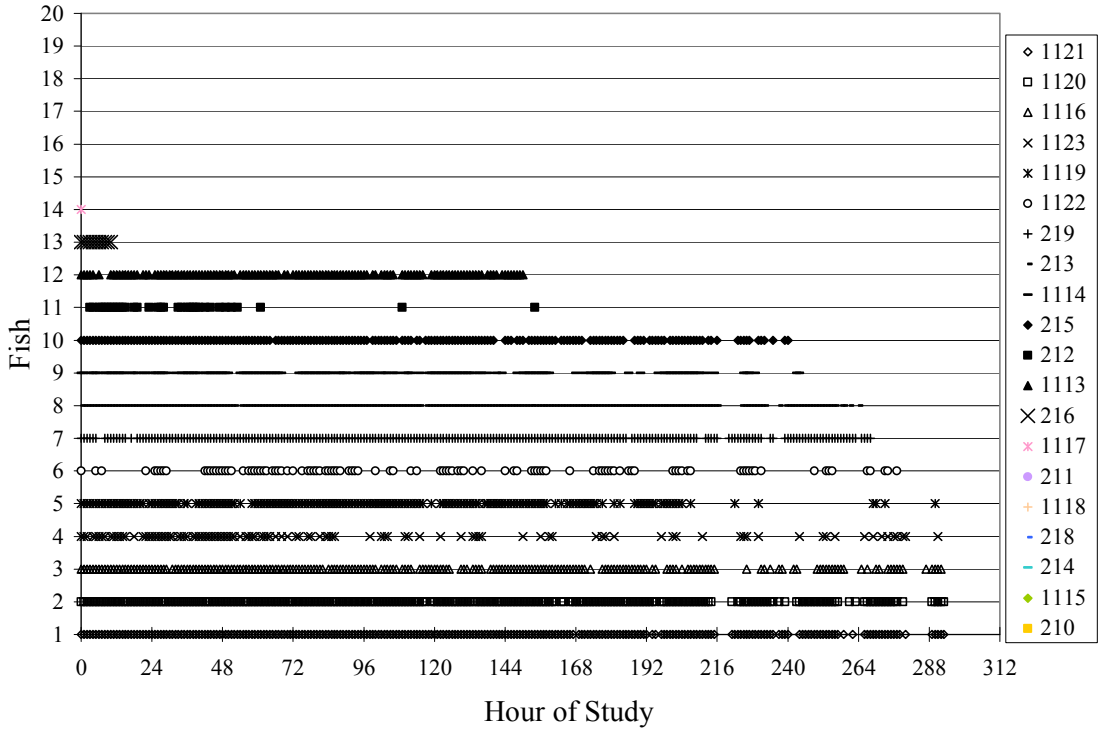
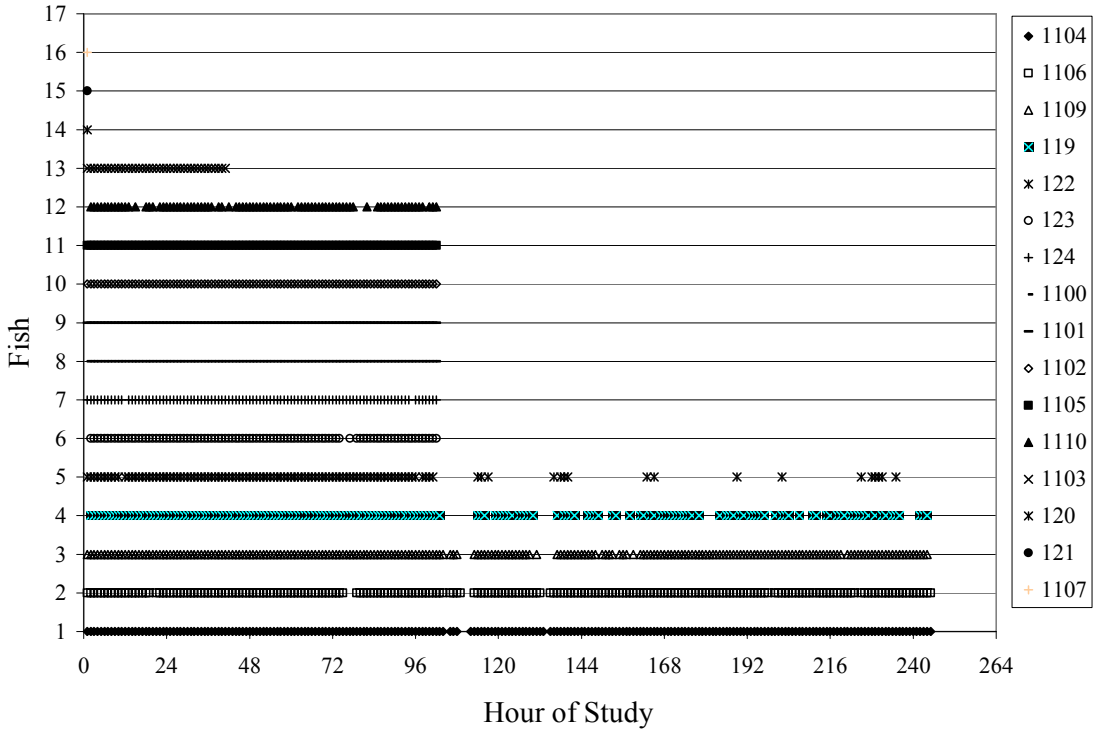


a)



b)

Figure 6. Fish 'presences' for a) 2006 and b) 2005—the hours of the study each fish registered a detection.

periodicity in the presence/absence data on a daily or sub-daily basis. To resolve trends within a day, I also plotted the number of fish detected per hour by time of day (in hours) and applied a LOESS regression fit (PROC LOESS, SAS Institute, INC., 2007). The LOESS regression helps visualize maximums and minimums in the number of detections per hour of the day. So, if the spectral analysis shows diel periodicity, the LOESS regression can show at what times of day more and fewer snapper are present.

To further resolve periodicity, I modeled the presence and absence data with logistic regression (PROC REG, SAS Institute, INC., 2007) and PROC GLIMMIX (SAS Intistute, INC., 2007). For each hour of the study, a fish was coded '1', if it was detected by VRAP during that hour, and '0', if it was not. I then regressed this binary response on the variables: day (of the study, starting with 1); hour of day (from 0-23) and its square, cube, and fourth power; year; moonphase; photo-period; wind speed; wave height; tide level and stage (WAVCIS; 90° 29', 28° 52'; Louisiana State University).

Logistic regression is a generalized linear model (GLM) of the form;

$$E(Y)= g^{-1}(X\cdot \beta + \alpha),$$

where X is a vector of the independent variables (Table 1), and β is a vector of the fixed effect (independent) parameters (β is not a slope, even though it is part of a linear equation; in GLM, the linear function is linked to the dependent variable), and α is the intercept. The function g(·) is the monotonic link function, which links the mean value of Y, E(Y), to the linear predictor, $X\cdot \beta + \alpha$; $g^{-1}(\cdot)$ is its inverse.

Table 1. Independent variables used in the logistic regression, and their units and descriptions.

Variable	Units	Type	Values
Day	1-14	Ordinal	2006
Day	1-5, 71-77	Ordinal	2005
Hour of day	1 hour, but (0-23)/100 for purposes of regression	Ordinal	0.0, 0.01, 0. 02, . . ., 0. 23
(Hour of day)^2	(0-23/100)^2	Ordinal	0.0, 0. 001, 0. 004, . . ., 0.00529
(Hour of day)^3	(0-23/100)^3	Ordinal	0.0, 0.0001, 0. 0008, . . ., 0.00121
(Hour of day)^4	(0-23/100)^4	Ordinal	0.0, 0.00001, 0.000016, . . ., 0.000280
Year	1 year	Nominal	2005, 2006
Moon-phase	Quarter moon	Nominal	Full, last, new, first
Photoperiod	Hours of daylight	Continuous	
Wind speed	Kilometers-per-hour	Continuous	
Wave height	Meters	Continuous	
Tide level	Meters	Continuous	
Tide stage	Ebb, flood	Nominal	

For logistic regression, the link function is the logit transform;

$$\text{Logit}(Y)=(Y)/Y\text{-}1);$$

Where Y is the dependent variable and takes the values of 0 for absent and 1 for present, and E(Y) is the expected or mean value of the dependent variable, and gives the predicted probability of presence.

The logistic regression model did not converge, so variables found to be significant (day, hour, hour-squared, year, photoperiod, and moonphase) then were used in PROC GLIMMIX. The GLIMMIX procedure performs a generalized linear mixed model (GLMM), which uses both random variables and fixed effects in model building. The addition of the random variables allows the GLMM to account for observations that cluster—clustered observations will tend to be more alike than observations from other clusters because they are positively correlated.

The form of the GLMM equation is a conditional model:

$$E[Y|\gamma]= g^{-1}(X\cdot \beta + Z\cdot \gamma)$$

The expected value of Y is conditional on γ, a vector of random effects, which is univariate normal with mean 0 and covariance matrix G. The univariate random effect γ adds to the GLM the use of cluster-level terms that take the same value for observations in a cluster, but different values for different clusters; it adjusts the intercept at the level of the cluster, but does not modify the fixed effects. Simply, it produces a separate intercept for each cluster. I used this GLMM to specify individuals as clusters, so that individual fishes' probability of presence were not part of the calculation of the fixed-effect terms. Z is a design matrix for the random effects. With only one random effect, it is comprised of only one column—the intercept column.

I ran different combinations of these variables in GLIMMIX to achieve the most parsimonious model as determined by the lowest pseudo-AIC, a measure of model fit (smaller is better).

Pearson's product moment correlation (PROC CORR, SAS Institute, INC., 2007) was used to test for correlation among variables. I ran a 'survival' or time-to-event analysis (PROC LIFETEST, SAS Institute, INC., 2007), which gives both probability of survival, or continued presence at the platform, and the mean period before permanent absence occurs. It is important to note that absence can be the result of emigration or mortality, including fishing mortality.

To examine spatial patterns, I calculated the distance moved in the x and y direction (dx and dy, respectively) between successive points. I plotted dx and dy on feather plots, so that the angle and distance of successive movements could be visualized. I then calculated a mean angle for each fish (Zar, 1998), which gives the mean of all the angles of movement, and a radius which can be used as a measure of dispersion about the mean angle (the longer the radius, the less the dispersion). I also calculated distance from the platform for each position of a red snapper, after which I calculated and plotted mean distance from the platform by hour-of-study, and hour-of-day.

I also calculated speed between positions by dividing distance moved over the interval (in seconds) between positions. When it became clear that the vast majority of the intervals were too large to permit an accurate estimate of speed, I plotted interval vs. speed to see if there was asymptote which could provide a maximum time interval as a threshold. Speeds below this threshold were multiplied by body length (m, SL) to calculate mean speed in body length s^{-1} by hour-of-study and hour-of-day.

For those tags that gave depth, I calculated and plotted mean depth by both hour-of-study and hour-of-day. I also performed spectral analysis (PROC SPECTRA, SAS Institute, INC., 2007) on the all depths for each hour of the study.

Results

In 2005, I captured and implanted 16 red snapper. In 2006, I captured and implanted 20 red snapper. Table 2 gives information about the captured fish.

Table 2. The year of capture, identification code (ID) of the tag implanted, the standard length, capture sight and release sight of each individual implanted for the study.

Year	ID	Std Length (mm)	Capture sight	Release sight
2005	1101	356	ST-67 B	ST-135 M
2005	1100	368	ST-67 B	ST-135 M
2005	1102	279	ST-67 B	ST-135 M
2005	1103	279	ST-67 B	ST-135 M
2005	1104	318	ST-128 X	ST-135 M
2005	1105	338	ST-128 X	ST-135 M
2005	1106	483	ST-135 M	ST-135 M
2005	1107	279	ST-135 M	ST-135 M
2005	1109	300	ST-135 M	ST-135 M
2005	1110	356	ST-135 M	ST-135 M
2005	119	292	ST-135 M	ST-135 M
2005	120	279	ST-135 M	ST-135 M
2005	121	318	ST-135 M	ST-135 M
2005	122	401	ST-135 M	ST-135 M
2005	123	318	ST-128 X	ST-135 M
2005	124	318	ST-128 X	ST-135 M
2006	1113	410	ST-135 V	ST-134 S
2006	1114	445	ST-128 R	ST-134 S
2006	1115	451	ST-128 R	ST-134 S
2006	1116	480	ST-128 R	ST-134 S
2006	1117	420	ST-128 R	ST-134 S
2006	1118	360	ST 134 W	ST-134 S
2006	1119	472	ST-128 R	ST-134 S
2006	1120	410	ST-128 R	ST-134 S
2006	1121	554	ST-135 V	ST-134 S
2006	1122	423	ST-135 V	ST-134 S
2006	210	460	ST 134 W	ST-134 S
2006	211	395	ST 134 W	ST-134 S
2006	212	405	ST-135 M	ST-134 S
2006	213	432	ST-135 M	ST-134 S
2006	214	415	ST-135 M	ST-134 S
2006	215	470	ST-135 M	ST-134 S
2006	216	404	ST-135 M	ST-134 S
2006	218	482	ST-135 M	ST-134 S
2006	219	476	ST-135 V	ST-134 S
2006	1123	430	not recorded	ST-134 S

All red snapper implanted with a transmitter were able to swim down and were assumed to have survived surgery. The positions recorded by VRAP appear to cluster largely around the platform for each fish in each year over the experimental time interval (figures 7-12). I report the 2006 results first, because the study period was not interrupted. I will then report the 2005 results, because they often complement or support the 2006 study.

In 2006, the VRAP system was able to detect 14 of the 20 red snapper implanted with transmitters; and the number of individuals detected decreased over the study period (Figure 6). Six left immediately or were consumed by a migratory predator that left the study area (before being tracked by VRAP); another two left after two days, and another two after eight days. Ten stayed near the platform for at least twelve days, but only five remained at the end of the 14 day study. One fish was detected only once (as an unresolved tag) during the two weeks of tracking; I strongly suspect that this was a ghost tag. The VRAP system is designed such that if two transmissions occur simultaneously, it will ignore both. However, sometimes it translates this "collision" of transmissions as a coded tag—a ghost tag. Often the ghost tag has an unknown ID, and is easily identified as a ghost tag. Rarely, the ghost tag will have the ID of a one of transmitters used. In this case, transmitter 210 was not detected on day 1, but was detected subsequently, and just once, on day 10. For this reason, I believe this record is a ghost tag.

In 2005, VRAP detected 15 of 16 individuals; two of those left on day 1 of the study (Figure 6). Another fish left during day 2, and all others remained until the experiment was interrupted (day 5). When I redeployed on August 23rd, there were five fish still at the platform; all of these fish remained until the end of the study (12 August).

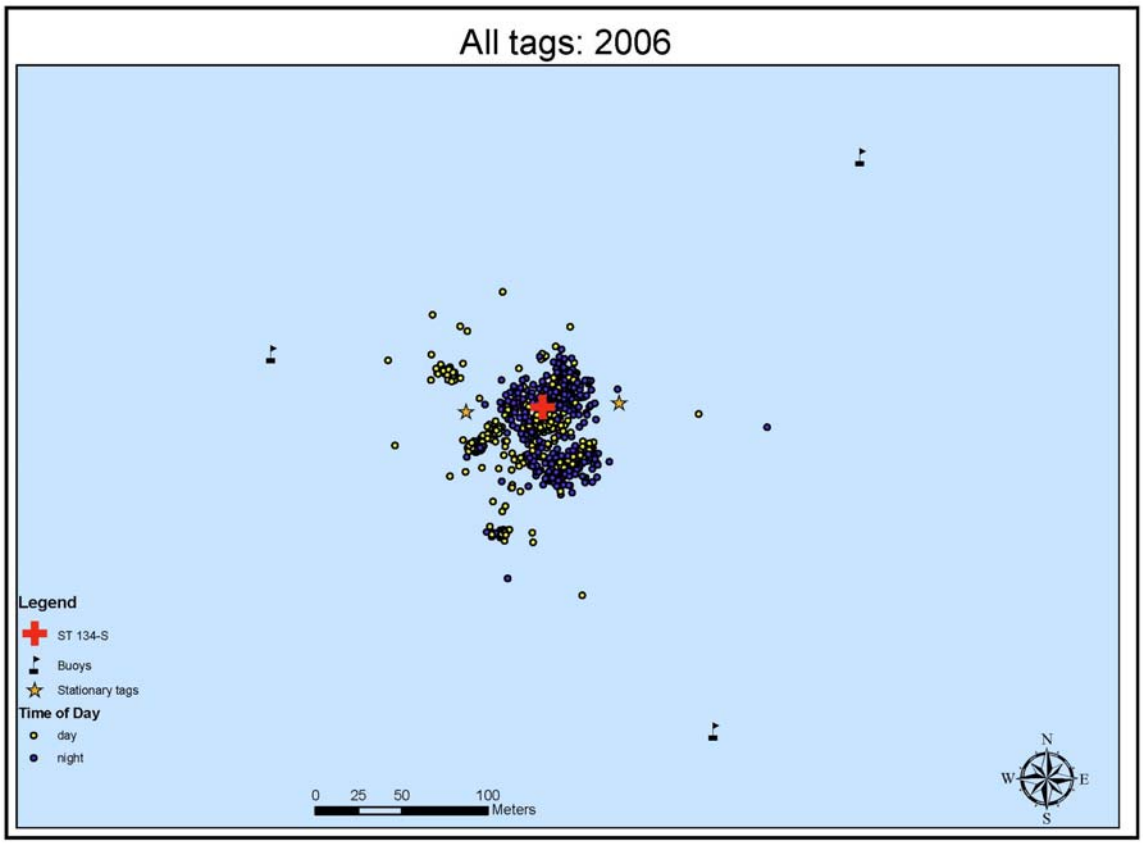


Figure 7. Plot of all fish for which positions were calculated in 2006.

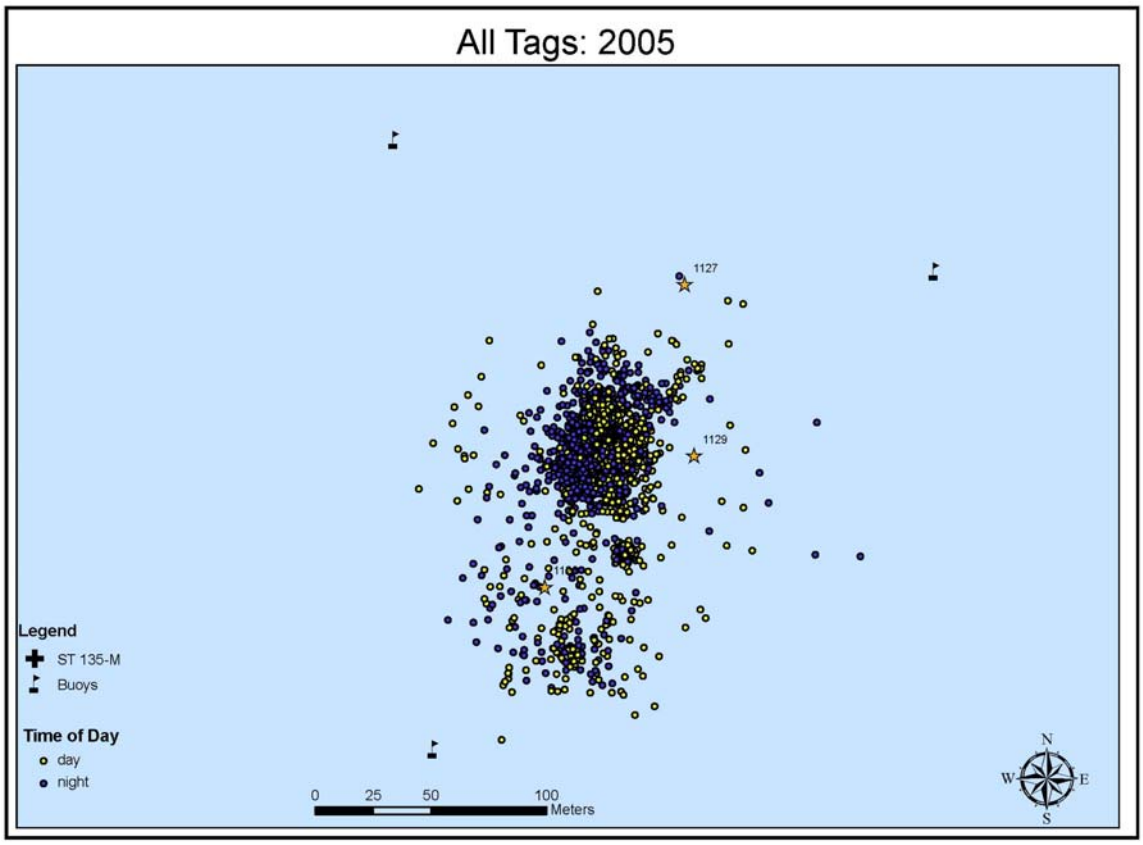


Figure 8. Plot of all fish for which positions were calculated in 2005.

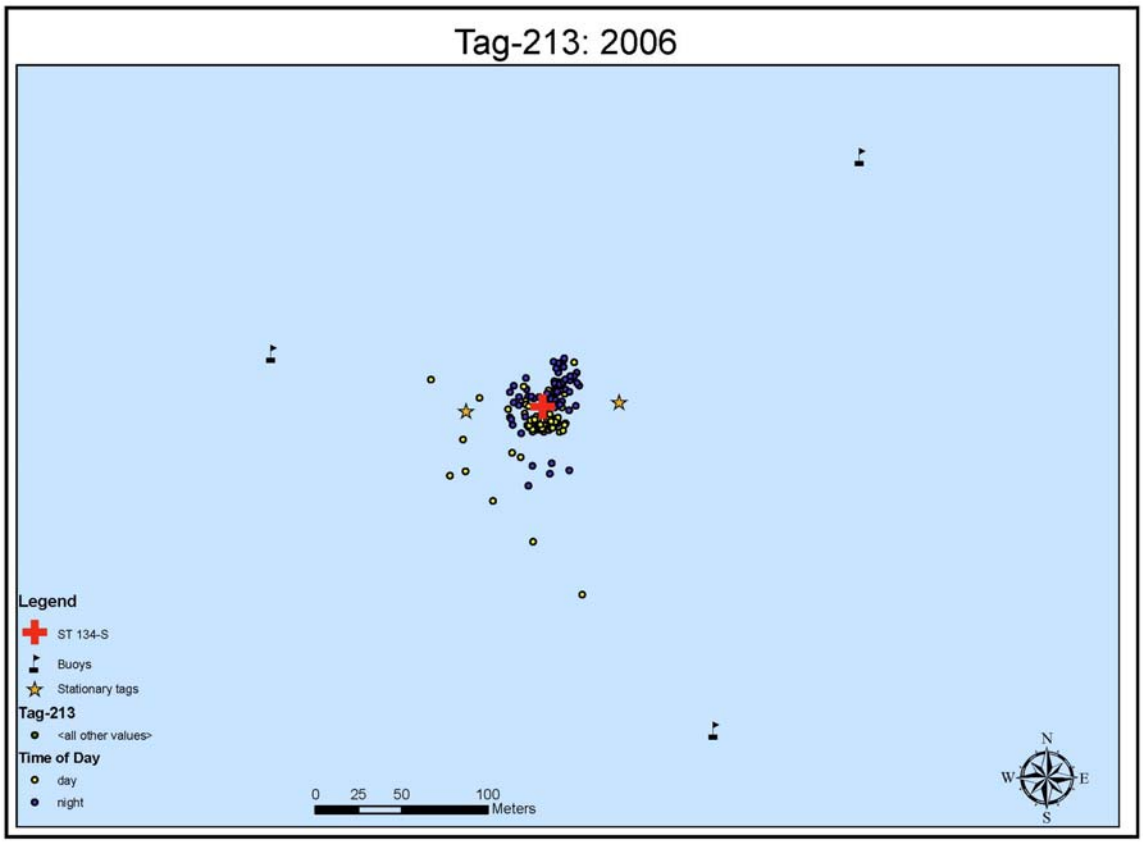


Figure 9. Plot of fish #213.

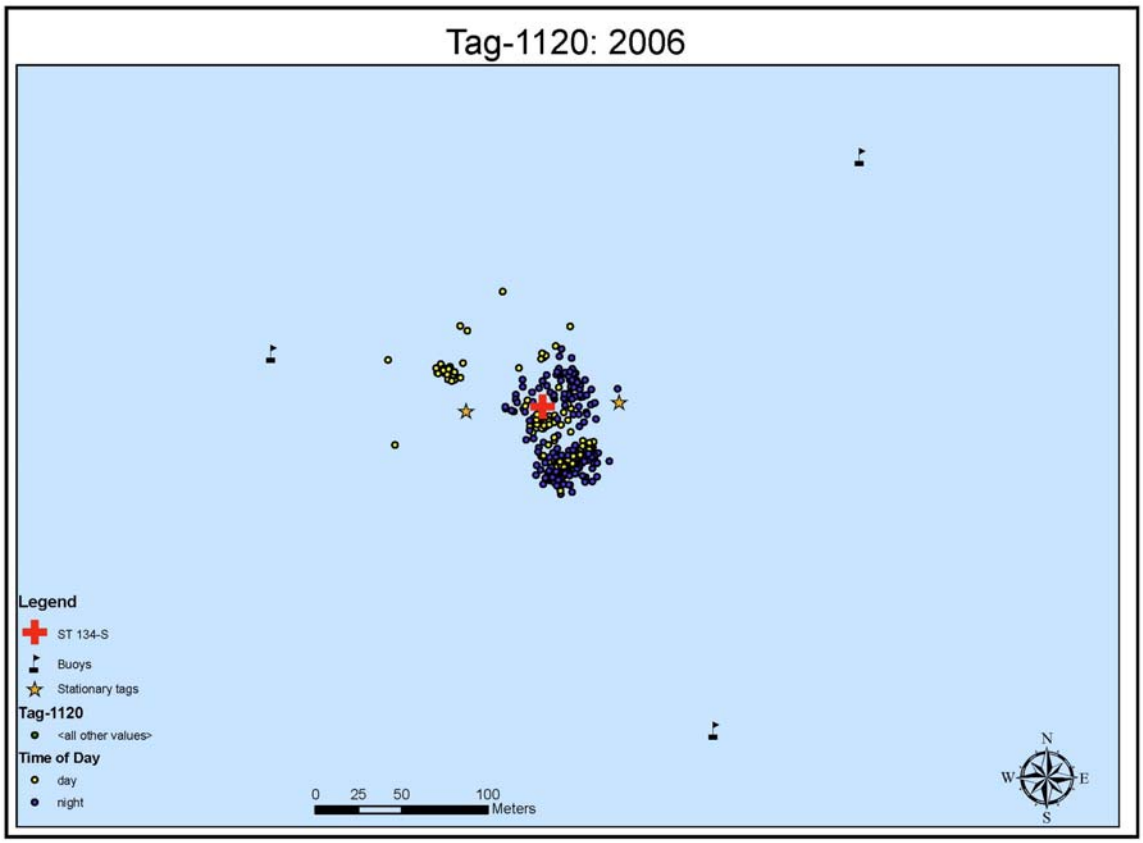


Figure 10. Plot of fish #1120.

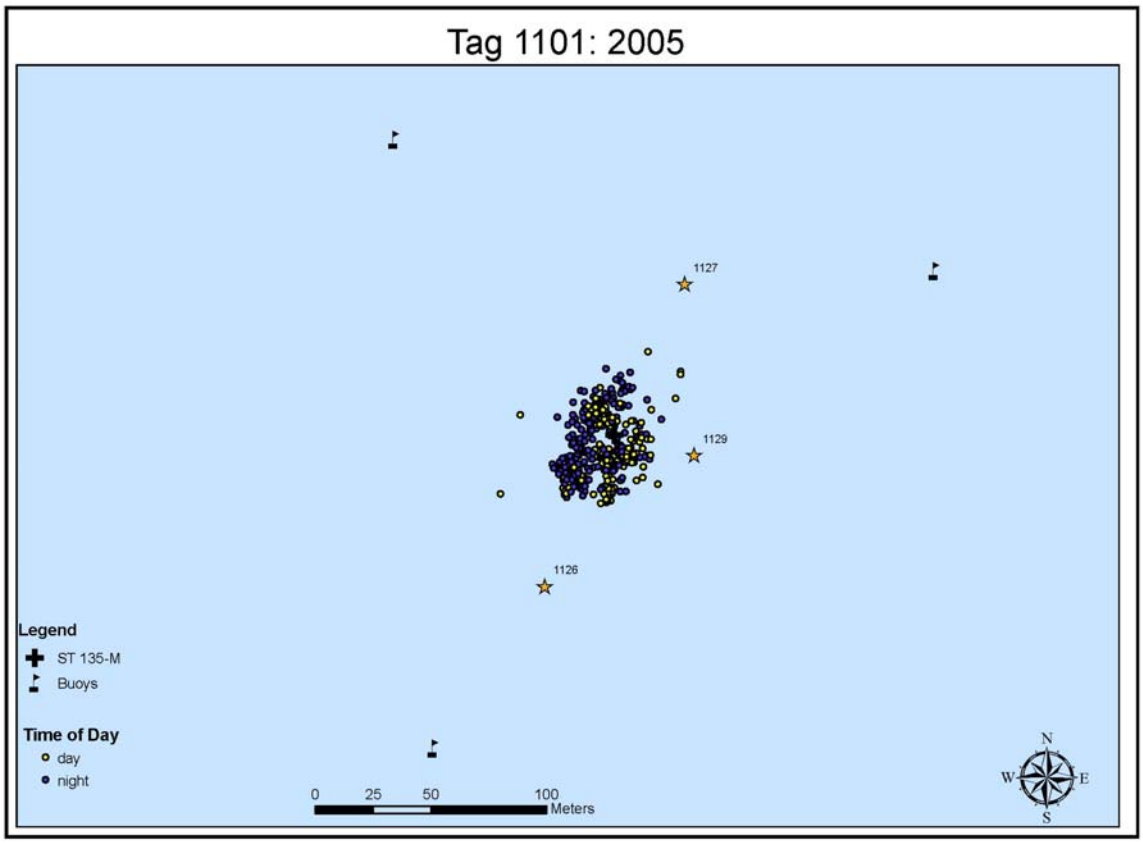


Figure 11. Plot of fish #1101; fish #1101 was not present when I redeployed in August.

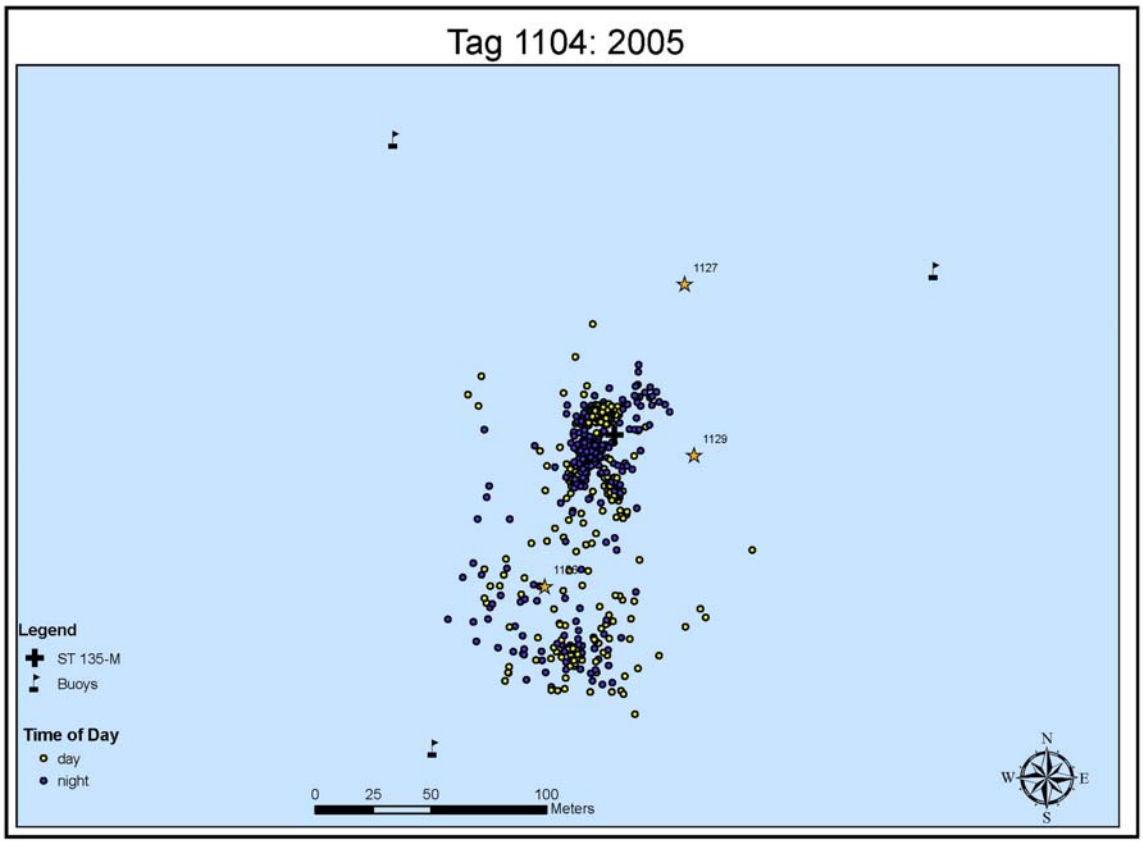


Figure 12. Plot of fish #1104; fish #1104 was present when I redployed in August.

Plotting the number of fish detected per hour-of-study revealed that detections appeared to decrease through time in both years, (most apparent in 2006, Figures 13 and 14). In addition, the number of detections varied periodically at smaller temporal scales (Figures 13 and 14b). Spectral analysis revealed peaks at 23.8 hours in 2006, 20.4 hours in May 2005, and 23.2 hours in August 2005 (Figure 15), strongly indicating diel periodicity in detections, and by inference red snapper behavior. The August 2005 plot also shows a less prominent peak at 11.6 hours, indicating semi-diel periodicity.

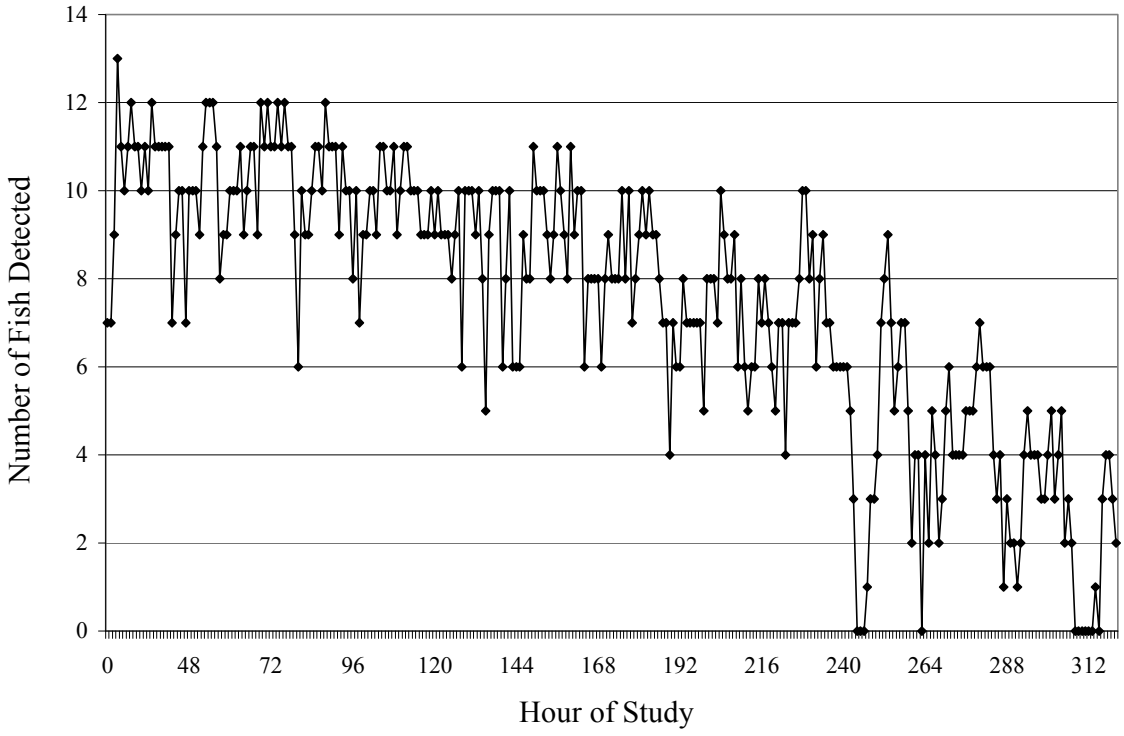
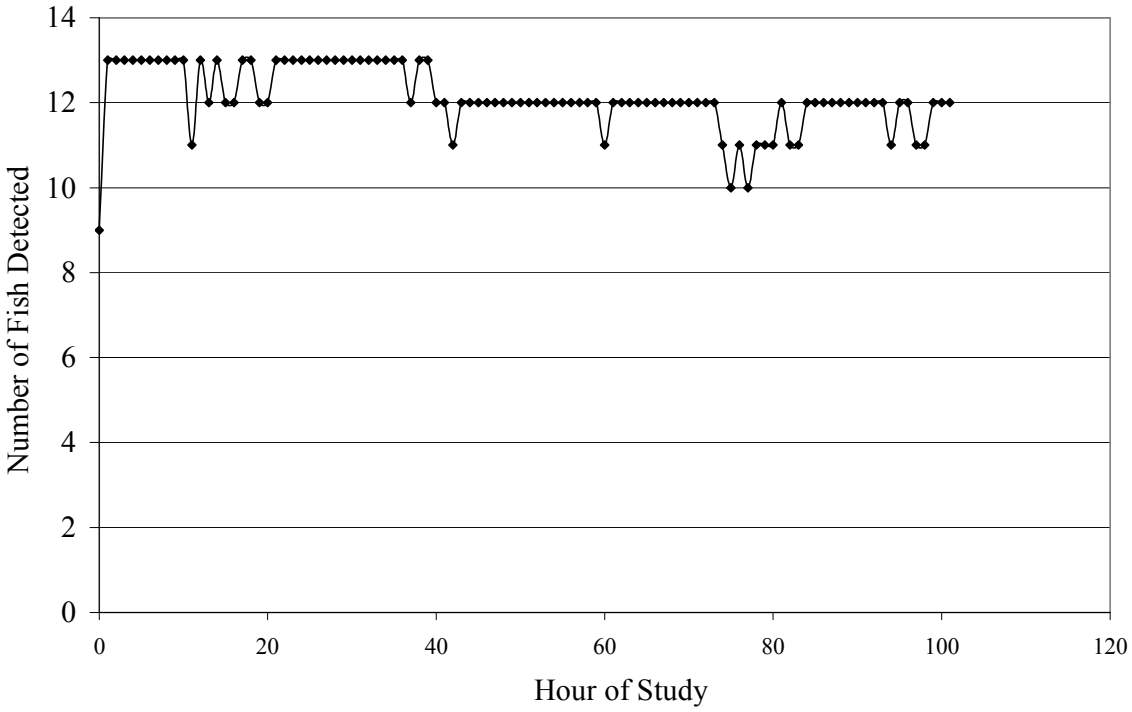
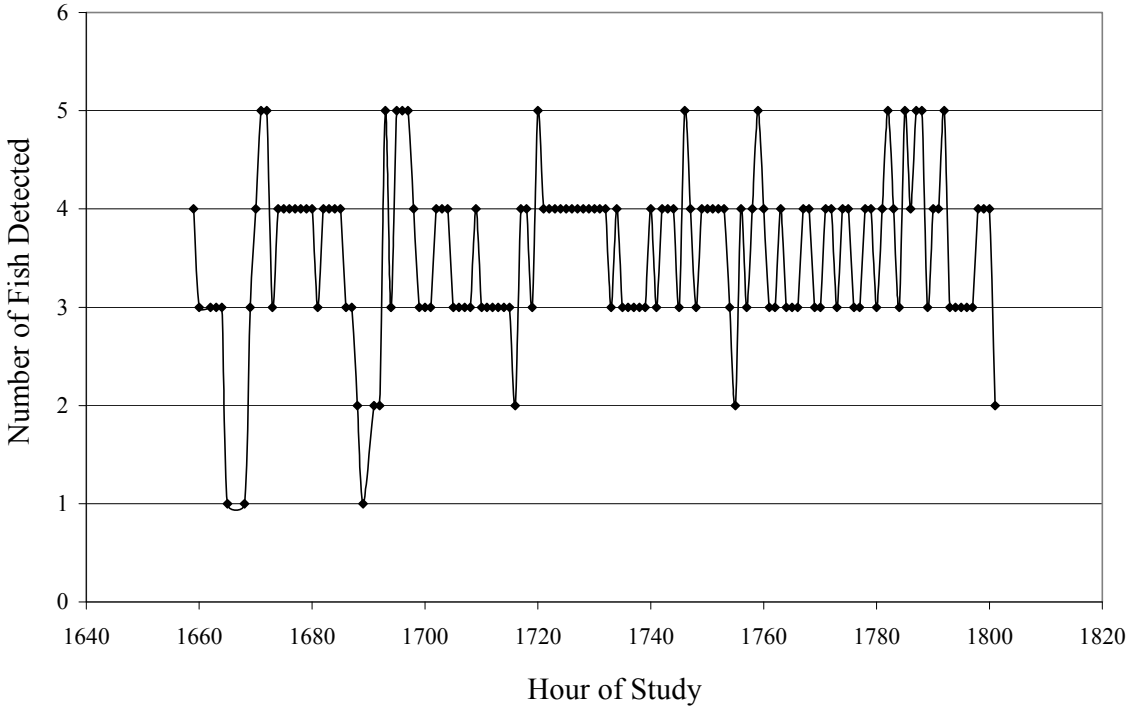


Figure 13. The number of fish detected per hour in 2006.

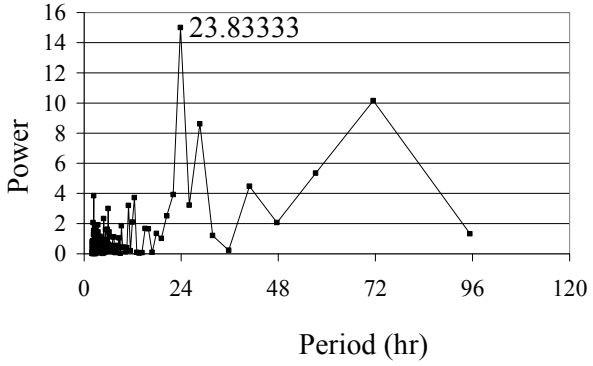


a)

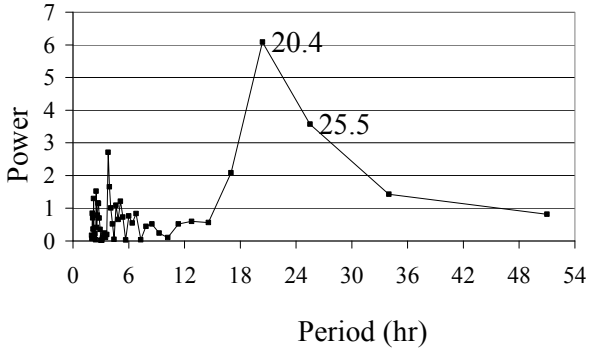


b)

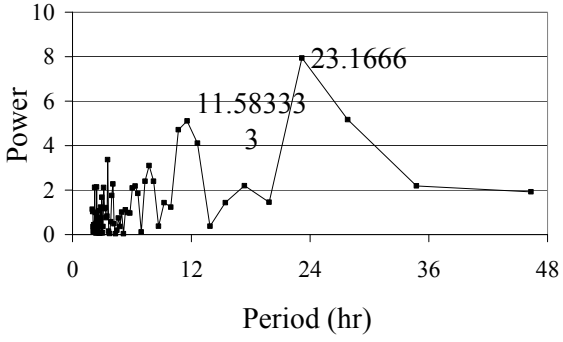
Figure 14. The number of fish detected per hour in a) May and b) August 2005.



a)



b)



c)

Figure 15. Periodogram from the spectral analysis on fish detections per hour in a) 2006, b) May 2005, and c) August 2005.

Stationary tags did show a decline in detections in both years (Figures 16 and 17). There was a decline in the average number of fish detected for each day of the study in 2006, even after the de-trending (Figure 18). In 2005, it looks like there a decline between deployments, but there is no apparent trend within either deployment (Figure 19).

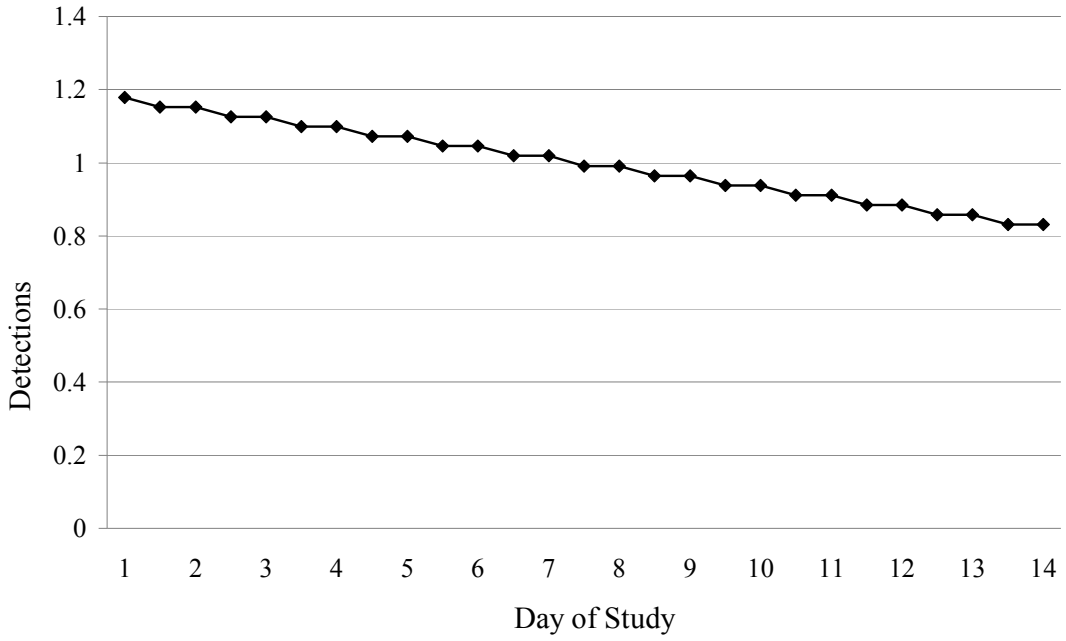


Figure 16. Values predicted from the regression on average hourly detections per day of stationary tags in 2006. The data are log-transformed.

The LOESS regression plot from 2006 revealed highest values during nighttime hours, with fewer detections occurring during the day (Figure 20). Similarly, the 2005 data and LOESS regressions indicate the number of detections were higher during nighttime hours, but lowest near dusk, 1600-2000 hours (Figures 21 and 22). The logistic regression did not converge; but day, hour, hour^2, moonphase, and photoperiod were significant variables, so I used them to form the model for the generalized linear mixed

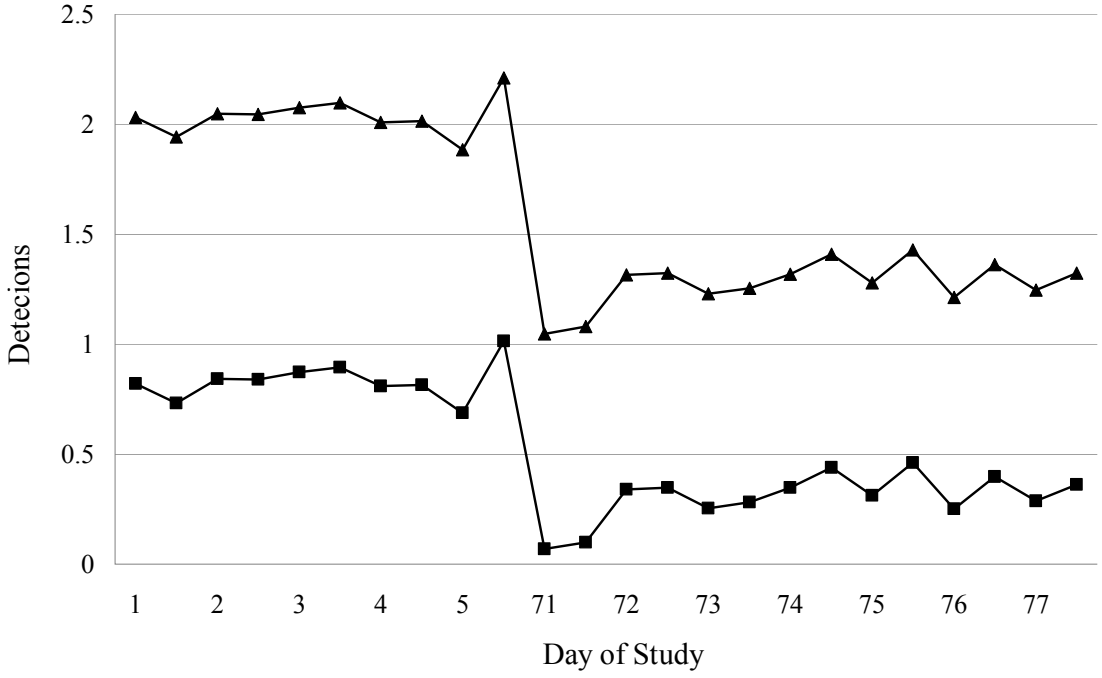


Figure 17. Values predicted from the regression on average hourly detections per day of stationary tags in 2005. The data are log-transformed.

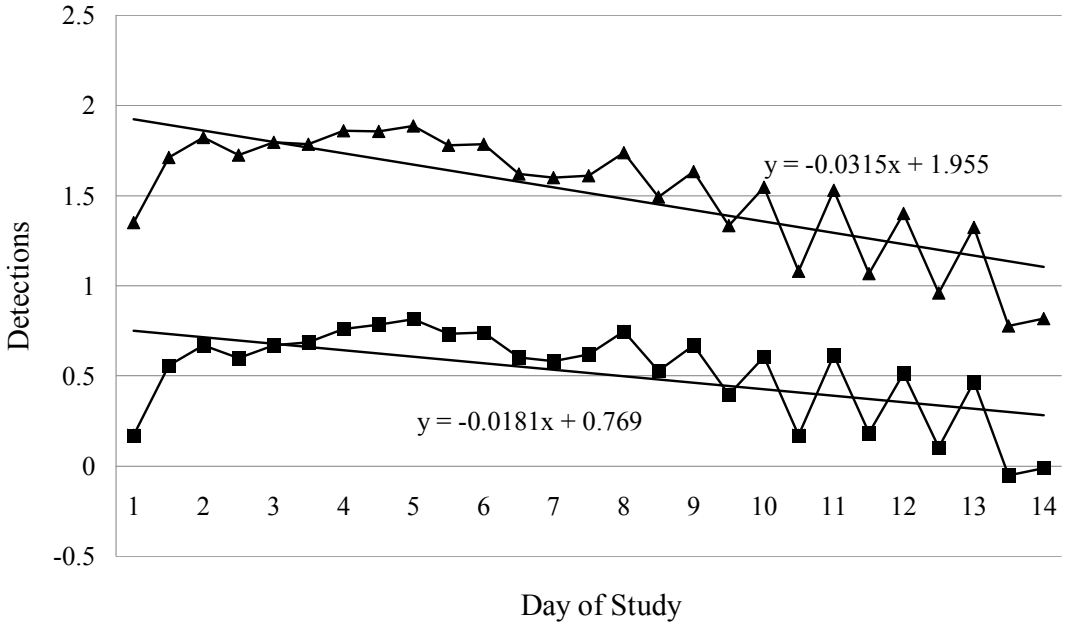


Figure 18. Average hourly detections per day of tagged fish in 2006; triangles are the original data, and squares are the detrended data. All data are log-transformed.

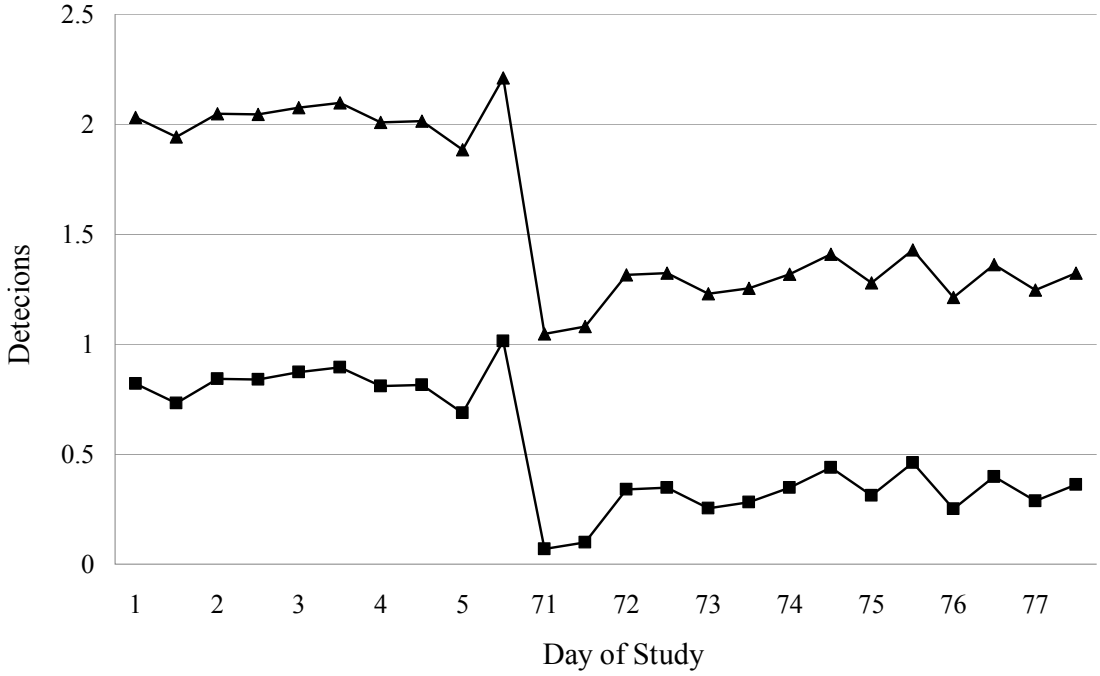


Figure 19. Average hourly detections per day of tagged fish in 2005; triangles are the original data, and squares are the detrended data. All data are log-transformed.

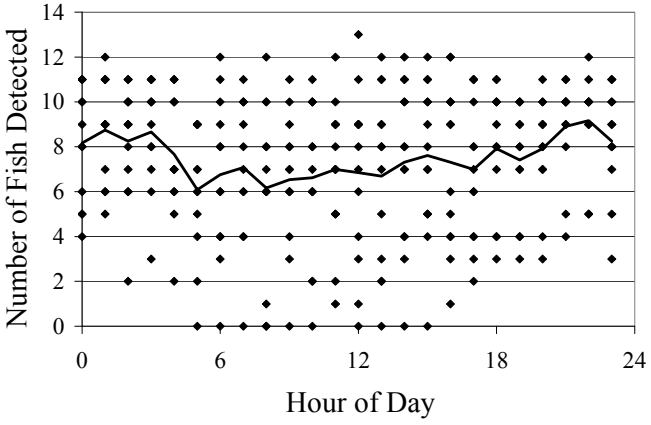


Figure 20. The number of fish detected per hour of day in 2006, with a LOESS regression fit to display diel trends.

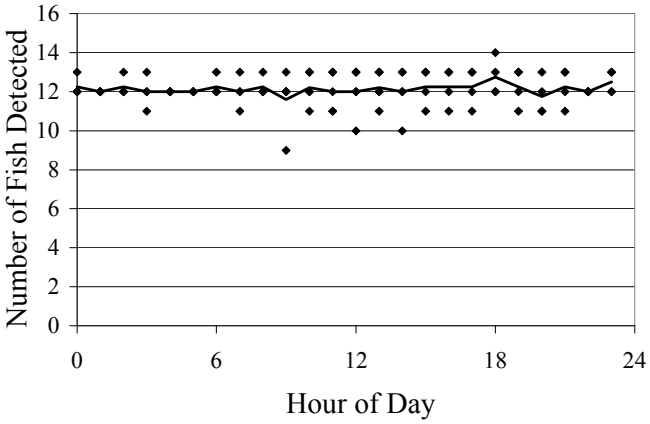


Figure 21. The number of fish detected per hour of day in May 2005, with a LOESS regression fit to display diel trends.

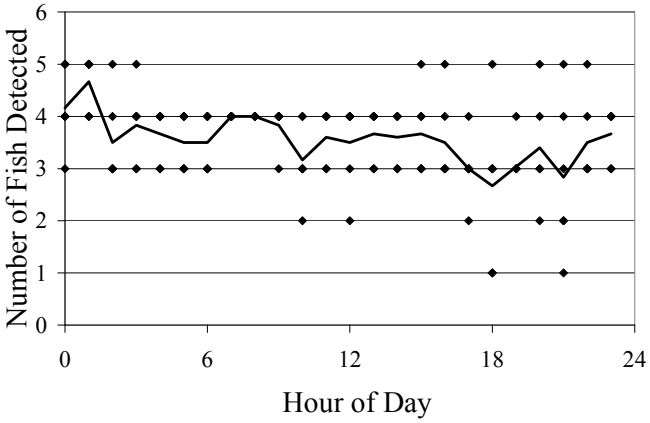


Figure 22. The number of fish detected per hour of day in August 2005, with a LOESS regression fit to display diel trends.

model (GLMM). The correlation between day and moon-phase was high (r= 0.77), so I did not include day in the GLMM to reduce colinearity. The most parsimonious model, i.e., with lowest pseudo-AIC, contained the variables: hour, hour^2, and moon-phase. Probability of presence declined with successive moon-phases: 81% at full moon, 45% at last quarter, and 1% during new moons and first quarters (Figure 23). Both experiments began during a full moon, and occurred during similar cycles despite the interruption in 2005. Within a day, probability of presence was similar to the LOESS regression results: highest overnight and declining during the day (Figure 24).

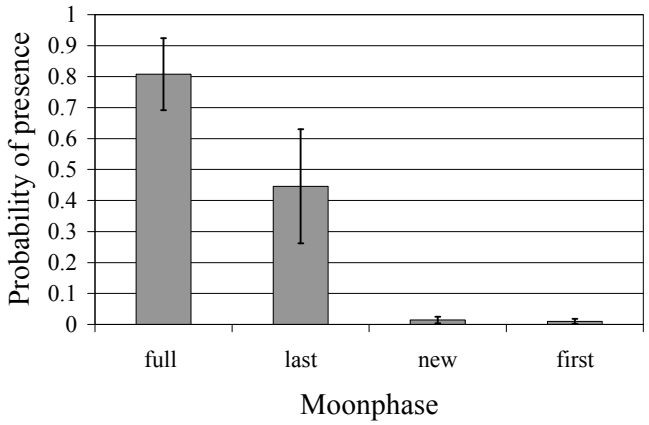


Figure 23. Mean probability of presence, across all fish and both years, by moonphase. Error bars indicate one standard error.

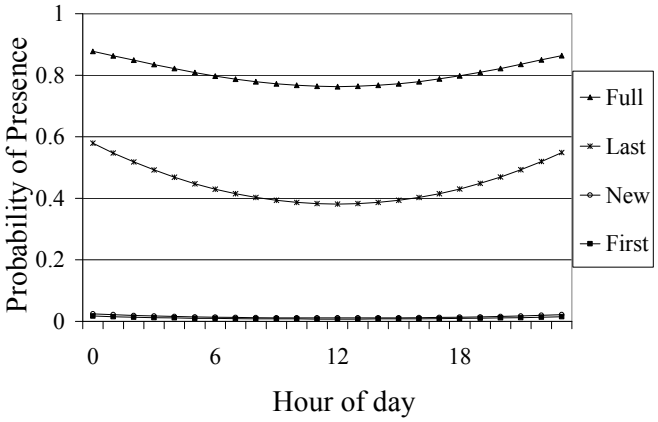


Figure 24. Probability of presence, across all fish, by hour of day.

The survival analysis found that mean survival time for 2006 was 165.8 hours, or 6.9 days; 70% of the data were 'events'—fish abandoning the platform, and 30% were censored (Figure 24). In 2005, the mean survival time was 0, because the only three events were fish that had left immediately; all other data were censored (Figure 25).

The feather plots of 2006 data do not indicate directed (non-random) movements; however, fish 213, 219 and 1113 appear to have 'axes' to their movements—movements appear to be predominantly north/south; the 2005 feather plots show

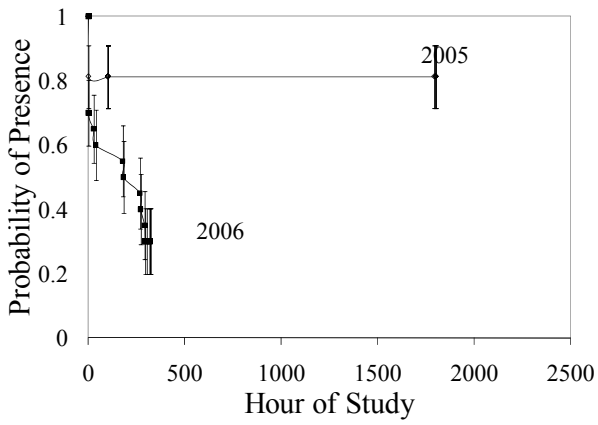


Figure 25. Probability of presence, as calculated by the survival analysis.

movements that again appear to be random in direction, although fish 1109 shows a similar north/south axis (Figures 26 and 27). However, the mean angles calculated for each fish did not confirm an 'axis' of movements. The radii of the fish with 'axes' were shorter (their mean angles showed more dispersion) than some of those for the fish without axes and fish appear to have made larger movements with time as the experiment progressed.

The distance from the platform results were mixed. In 2006, the fish showed a significant difference between day and night values (Figure 28), but this difference was quite small (3 meters). In 2005, fish were farther from the platform at night during May but farther during the day in August (Figure 29). The difference during August 2005 was not significant.

Figure 30 shows that speeds calculated with intervals less than 5 minutes showed the greatest range—speeds calculated for intervals greater than that were rarely larger than 1m/sec. Figures 31 and 32 show the speeds by hour-of-day with the mean values for each hour superimposed. Speeds were lower in 2006 than in 2005, but otherwise there were no observable patterns either within a day or throughout the study.

Mean depth by hour-of-study is plotted in figure 33 for 2006, in figure 34 for May 2005, and in figure 35 for August 2005. Depth, like detections, displays regular increases and decreases. Spectral analysis revealed a strong peak at 24.1 hours in 2006 (Figure 36); the 2005 data had peaks at 6.0 and 20.8 hours in May (figure 37) and some power at 11.8 hours in August (Figure 38).

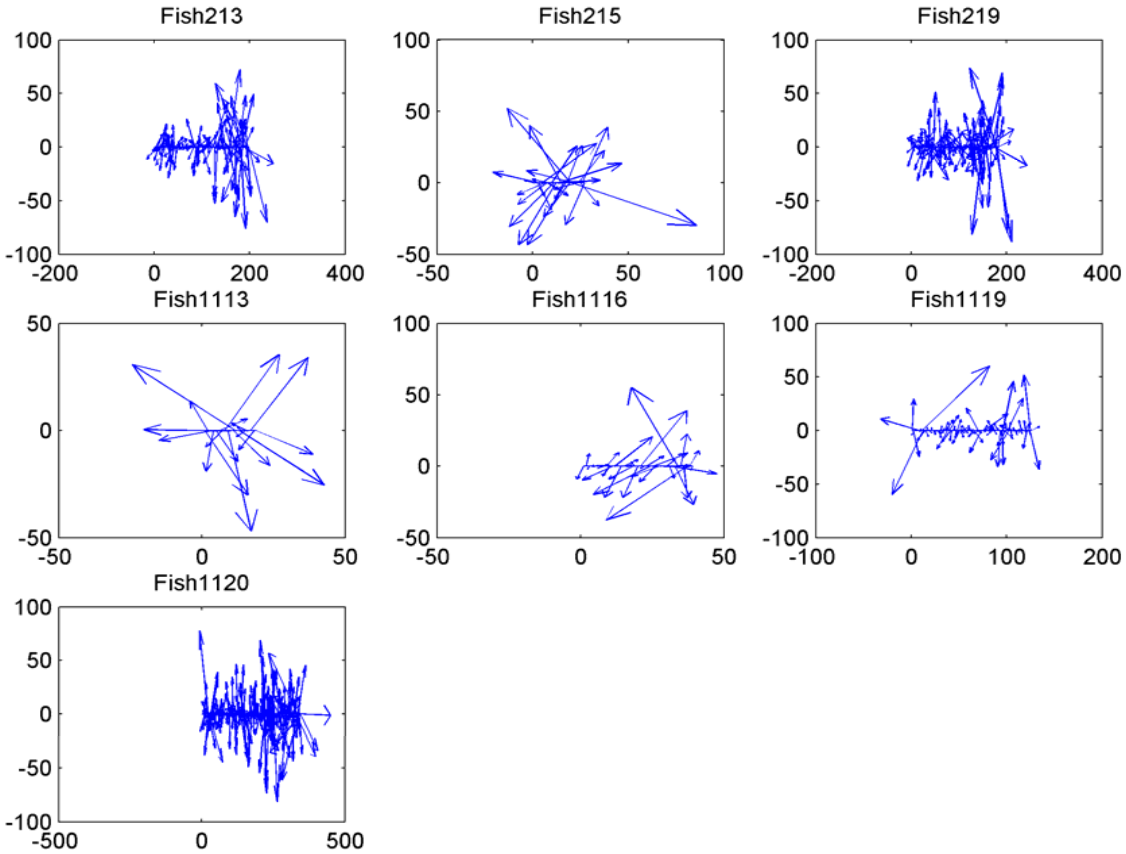


Figure 26. Feather plots showing the consecutive movements of fish during the 2006 experiment. Each vector represents a movement between consecutive points.

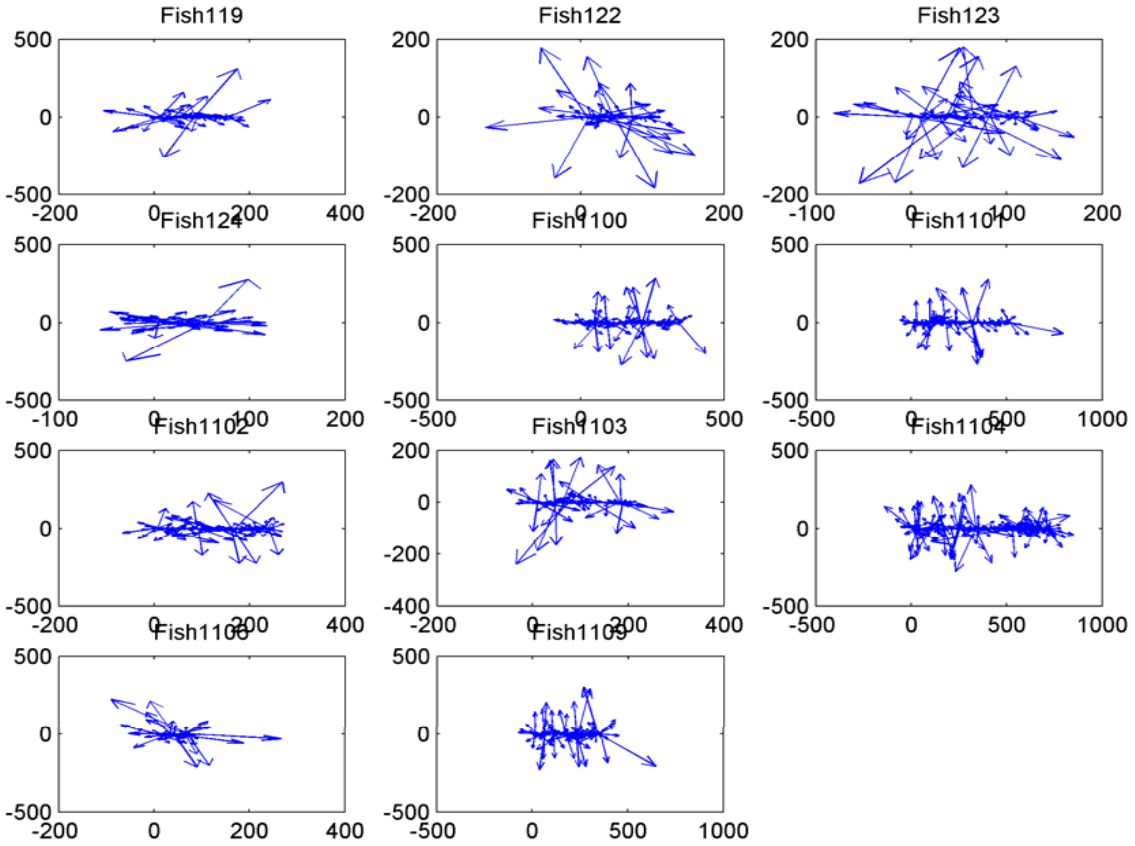


Figure 27. Feather plots showing the consecutive movements of fish during the 2005 experiment. Each vector represents a movement between consecutive points.

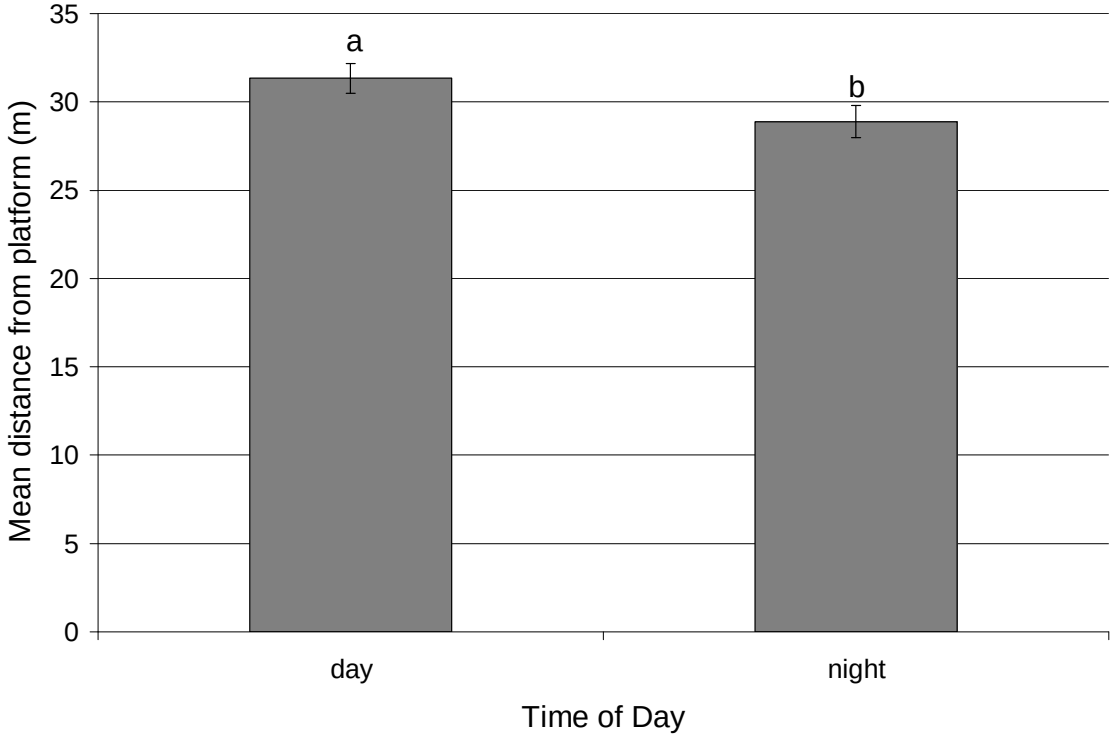


Figure 28. Mean distance from the platform for all fish by time of day in 2006. Letters indicate significant differences.

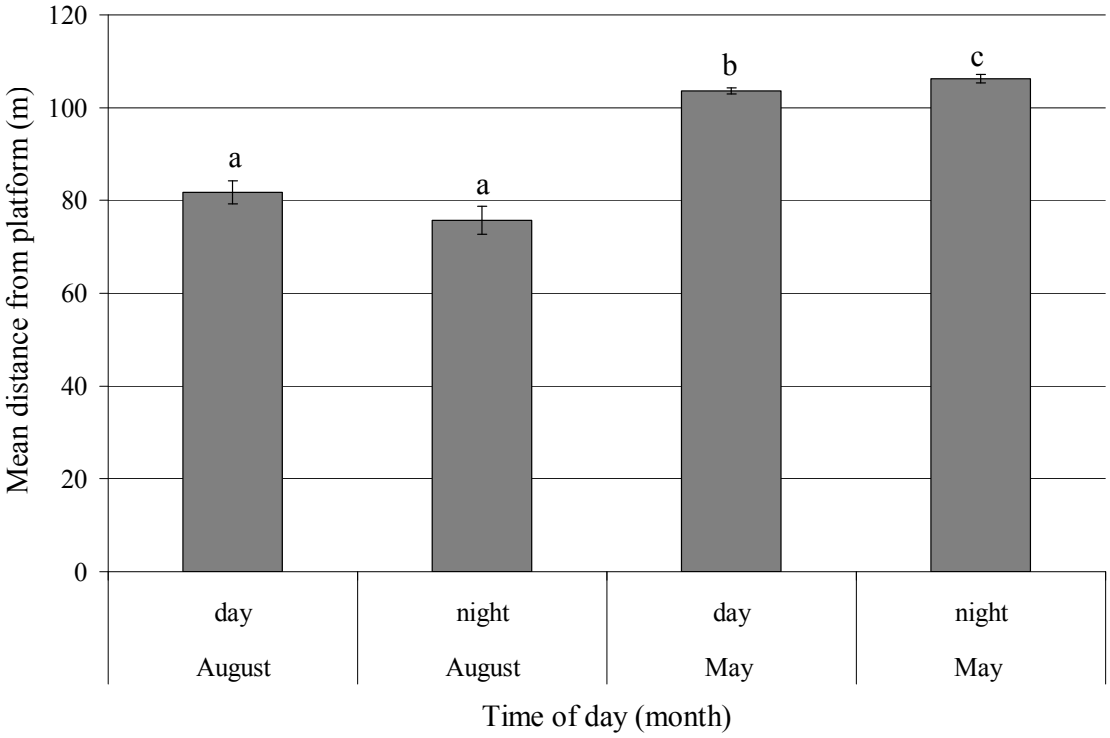


Figure 29. Mean distance from the platform for all fish by time of day in 2006. Letters indicate significant differences.

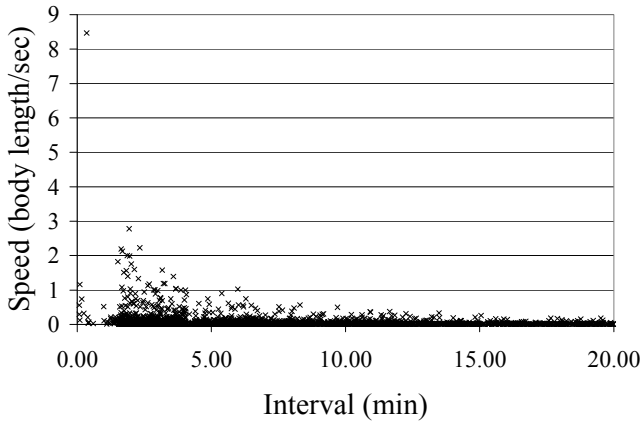


Figure 30. Interval, the time between two recorded positions, versus the speed of movement between those two positions.

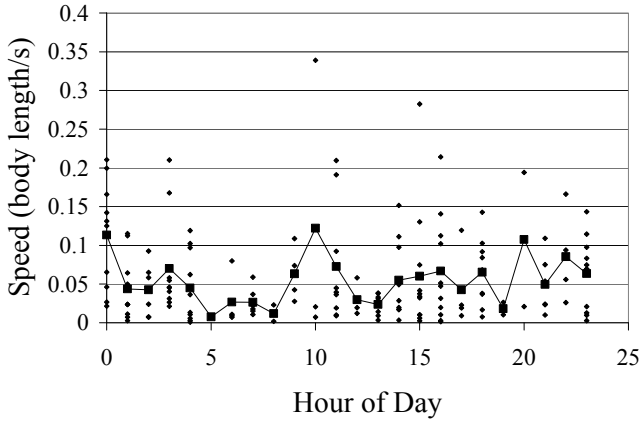


Figure 31. Speed, in body lengths per second, for hour of day for 2006. The mean value for each hour is superimposed.

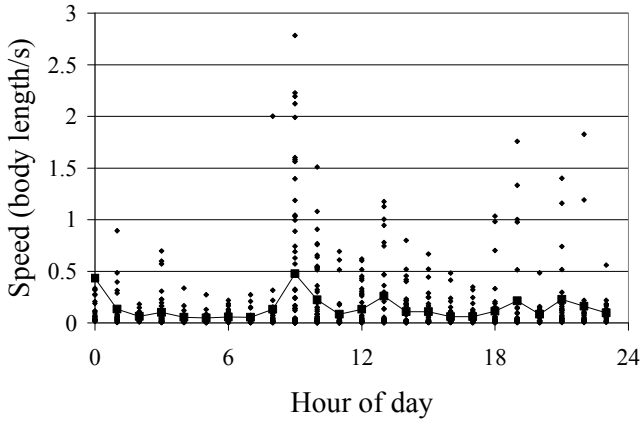


Figure 32. Speed, in body lengths per second, for hour of day for 2005. The mean value for each hour is superimposed

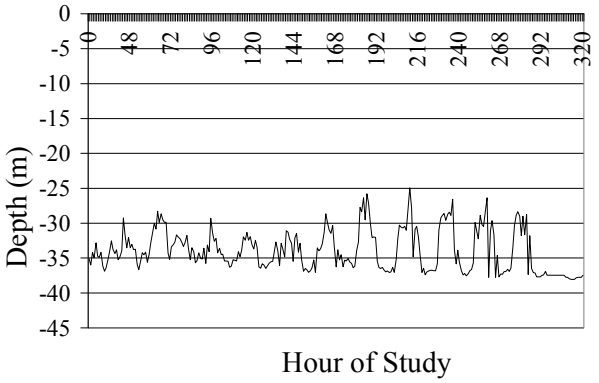


Figure 33. Mean depth, in meters, for each hour of the study in 2006.

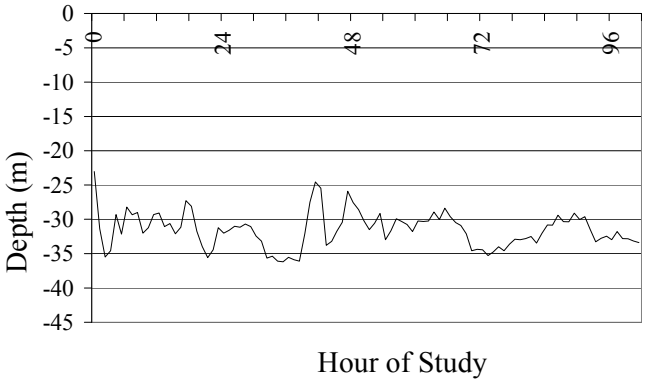


Figure 34. Mean depth, in meters, for each hour of the study in May 2005.

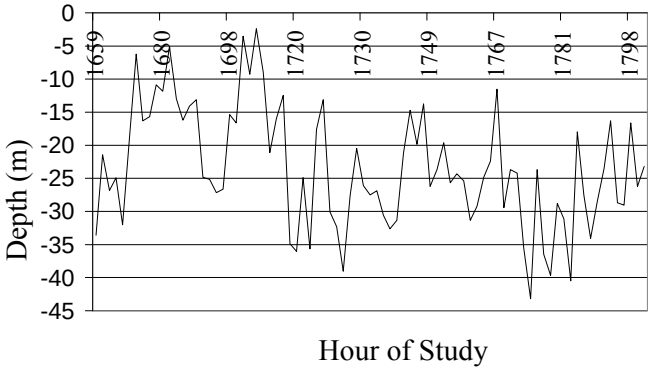


Figure 35. Mean depth, in meters, for each hour of the study in August 2005.

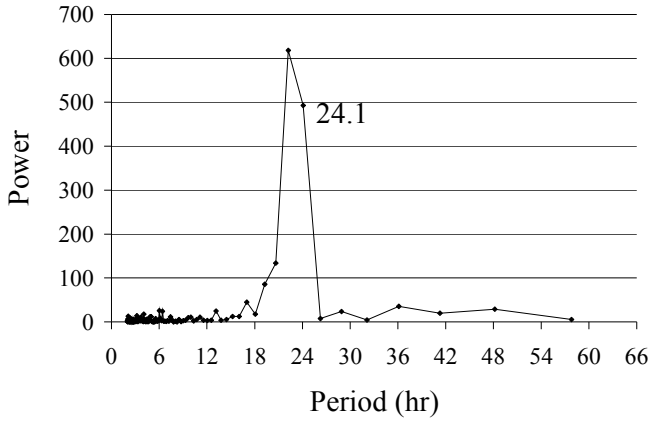


Figure 36. Periodogram from the spectral analysis on all depths per hour of study in 2006. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

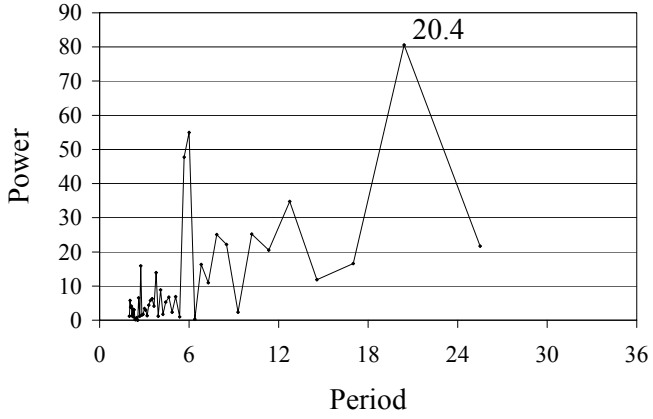


Figure 37. Periodogram from the spectral analysis on all depths per hour of study in May 2005. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

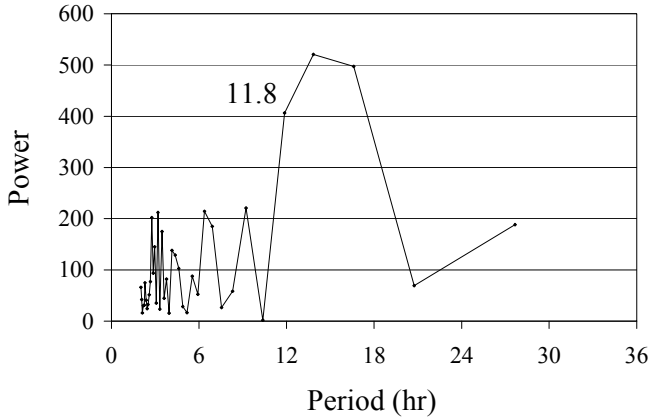


Figure 38. Periodogram from the spectral analysis on all depths per hour of study in August 2005. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

Discussion

Our study is the first to use a real-time telemetry system to describe the movement and behavior of red snapper. Population estimates have shown that red snapper congregate near platforms in large numbers (Stanley and Wilson, 1997; Nieland and Wilson, 2002; Wilson and Nieland, 2004); and site fidelity studies on a variety of artificial reef types and sizes have reported widely varying results, ranging from <25% to >60% yr^{-1} (Beaumariage, 1969; Fable, 1980; Szedlmayer and Shipp, 1994; Szedlmayer, 1997; Patterson et al., 2001; Patterson et al., 2003; Szedlmayer and Schroepfer, 2005). However, some tag-and-release studies show that one-way, long-term movements of red snapper are possible for fish that have been at large for many days (Szedlmayer and Shipp, 1994; Patterson et al., 2001). These results, sometimes conflicting, have contributed to the confusion over whether artificial reefs attract or produce red snapper, because of the role that site fidelity plays in some of the conceptual models defining the argument (e.g., Bohnsack, 1989; Lindberg et al., 1990; Strelcheck et al., 2005).

None of the above studies, however, provide insight about how red snapper use artificial habitats in the short-term, and this too has relevance to the attraction/production debate. The two years of data collected here provide this information, and together, illuminate to some extent how red snapper use platforms, albeit that pattern of use varied slightly between years. In 2006, I was able to collect a complete two-week dataset that provides the best short-term picture. In 2005, my experiment was interrupted. However, I was able to redeploy when a few of my tagged fish still were within the detection radius of the VRAP system, giving some additional short-term information, along with a longer-term perspective. In both years, there were departures on day 1 of the study; in fact, some of the fish appear to have left before the VRAP was initialized. It is possible that

these fish were consumed by predators during swimdown, as I frequently observed marine mammals and fish predators in close proximity to the charter boat where the tagging was taking place. In 2006, I found that fish departed individually throughout the two weeks (Figure 2), feather plots showing that large movements were possible beginning from the time of release support this contention (Figure 15). In 2005, the experiment was interrupted when 12 individuals were still at the platform. By the time I redeployed, there were only 5 remaining; these fish then remained until the end of the study. The fish tagged in this study exhibited almost binomial behavior; fish either exhibited high site fidelity—two months or more—or almost none at all—leaving the study area in less than two weeks.

It is interesting to note, however, that all of the red snapper exhibited low site fidelity when compared to results from more traditional tagging studies, particularly considering the brevity of my study. The GLMM shows declining probability of presence with successive moon-phases, from 81% at the beginning to 1% by the end of the experiments. This result is probably spurious, and I believe that moonphase is simply representing days-at-large. In 2005, a full moon cycle passed while the VRAP system was not deployed. No fish returned during this interval, despite the fact that the associated moon phases did. Similarly, Westmeyer et al. (2007), who collected presence/absence telemetry data on acoustic-tagged red snapper over a several month period, did not observe cyclical patterns in site fidelity. Presumably, if fish were more likely to be present during a full moon (rather than the beginning of the experiment) and less likely to be present during the first quarter (rather than the end of the experiment), I should have seen a cyclical pattern in the data.

The "survival" analysis models the decline in probability of presence on the scale of days, although the true fate of the fish is undetermined. The 2006 probability of survival curve declines quickly (Figure 14). In fact, there is a less than 50% chance of a fish remaining at 200 hours after release, or about 8.3 days. The mean survival time is only 6.9 days, so the average fish either emigrated or was preyed upon in less than a week. Westmeyer *et al*. (2007) also reported low site fidelity to platforms, <1%, than previous studies of red snapper site fidelity to artificial reefs (Szedlmayer and Shipp, 1994; Szedlmayer, 1997). It is worth noting that the structures in the above-cited studies were smaller by several orders of magnitude than platforms. It is possible that the number of red snapper and other reef-associated species inhabiting platforms (Stanley and Wilson, 1997; Nieland and Wilson, 2002; Wilson and Nieland, 2004) could create rather large foraging haloes of depleted prey resources (Lindberg et al., 1990; and Bortone et al., 1998), providing that these fishes mostly consume prey derived from the benthos as has been described for red snapper at artificial and natural reefs in other locations (McCawley and Cowan, 2007; Wells at al. 2008). As such, this could force red snapper to make long searches for available prey, a behavior that is consistent with the resource mosaic hypothesis (Lindberg et al. 1990). I hypothesize that if movement is fitness driven, large movements to forage may become so energetically costly there is no incentive for fish to return.

The number of fish detected each hour oscillated at regular intervals, in both 2006 and August 2005 (Figures 6 and 7); the Fourier periodogram reveals that these oscillations occur on roughly 24-hour periods (Figure 8). The tagged fish that remained in the study area consistently left and re-entered the area within the detection radius daily. Distances from the platform concur with the results of the detections, showing

differences between day and night values (Figures 18 and 20). Fish moved farther away during the day, and the distances they moved increased with the number of days at large (Figures 17 and 19). The LOESS regression fit from 2006 shows that detections were higher during nighttime hours and lower during daytime hours (Figure 9). The 2005 data are less clear, but the August 2005 data show a similar pattern (Figure 11). The lowest numbers of fish detected, however, are found between 1800-2100 h. The probability of presence calculated for both years confirms this pattern (Figure 22). I feel confident in saying that red snapper appeared to remain closer to the platforms during nighttime hours and dispersed during daytime hours.

Mean depth likewise showed regular increases and decreases; this pattern was identified as semi-diel or diel using spectral analysis (Figures 27 and 29). While there were no obvious patterns in mean depth by hour of day, 3-D plots reveal that fish are making larger movements at depth. It is likely that this diel periodicity represents feeding behavior; many diurnal and nocturnal fish school during their inactive phase and disperse to forage during their active phase (Hobson, 1965; Helfman, 1986). These facts could explain the observed patterns in fish detections—red snapper may be aggregating near the platform, but foraging away from the platform. This would be consistent with diet studies indicating that red snapper, and other reef-associated species, feed on non reef-associated prey items (Sedberry and Cuellar, 1993; Lindquist *et al*., 1994; McCawley and Cowan 2007). Such behavior by red snapper appears to be consistent for fish inhabiting both artificial and natural reefs (McCawley and Cowan 2007; Wells et al. 2008).

Red snapper in my study appear to have frequently moved away from the platforms and outside of the detection radius of VRAP (a maximum of 350 meters in

2006) on a diel basis. If these movements are indeed related to foraging, the resulting haloes of depleted prey are at least, 384,845 m^2, and could be much larger. I interpret these results to mean that foraging opportunities are not likely to be the primary factor that compels red snapper to aggregate at oil and gas platforms.

In most fishes, the necessity of foraging and the risk of being eaten while doing so is a constant struggle (Werner and Anholt 1993). If an individual red snapper must search a large area of the surrounding seafloor before finding sufficient prey, the risk of predation increases, thus making the choice of returning to a point of origin complicated, especially if large movements result in discovery of other nearby natural and artificial habitats. From the standpoint of Bohnsack's (1989) conceptual model, the lack of dependence on the platforms directly for prey resources, coupled with low site fidelity and high fishing pressure in the western Gulf (SEDAR 7 2005), suggests to me that it is unlikely that oil and gas platforms are directly responsible for increasing productivity of the red snapper stock.

It is also possible that what I have interpreted here to be low site fidelity may actually be a consequence of increased vulnerability to predation attributable to red snapper foraging behavior. In a recent synthesis of available information about fish use of oil and gas platforms (VERSAR 2008), results indicate that these very large structures likely affect red snapper much differently than do relatively small, low relief artificial reefs. The latter are well-studied compared to the much larger platforms, which may be attributable to the difficulty associated with sampling larger structures. That said, some clear differences are apparent: 1) low-relief reefs support a much less complex community of fishes than do platforms. In studies off Alabama, most of the biomass around small reefs was comprised by only 3 species, namely red snapper, gag grouper,

and grey trigger fish (Strelcheck et al. 2005). These 3 species account for more than 85% of the fish biomass observed, with red snapper alone accounting for about 75% of the biomass. Relatively few large piscivores were observed during visual surveys of the reefs, suggesting that large predators may not accumulate in large numbers around low-relief reefs on the inner shelf. In contrast, red snapper are abundant on platforms, but they comprise a relatively small fraction of total numbers and biomass of the fish assemblage (<15%, VERSAR 2008). While speculative, I conclude that if the high vertical relief of platforms is causing these structures to act as fish attraction devices for large predators such as sharks, barracuda, large jacks, king mackerel, etc., it is conceivable that increased predation mortality of red snapper who reside near platforms offsets any biomass accumulation that would otherwise occur in the absence of predators. This phenomenon could be driving my low site-fidelity numbers as much as, if not more than, any resource-mosaic dynamics and foraging haloes.

The VRAP system is not without weaknesses, and these should be considered in future attempts to work with this system around large structures like platforms. One issue that must be addressed is the ability of VRAP to detect transmitters. The receivers are contained within moored buoys that do move with the tides, and were moored around an oil platform with eight piles, which undoubtedly obstructed transmissions. My assumption is that these obstructions did not vary with time, and as such would not preclude identification of diel patterns of behavior. The VRAP system also is limited by detection radius, as all telemetry systems are affected by the acoustic noise at the site of deployment. Platforms 134-S and 135-M were both active during my study and surrounded by other active production platforms—the study area is quite noisy acoustically, and our detection radius (150 m in 2006, 350 in 2005) no doubt was limited

by this noise. In addition, high numbers of snapping shrimp on platforms also creates noise that can affect detection radius (personal observation).

Problems related to detection radius appear to have affected other red snapper site fidelity estimates, although the issue has received little discussion. Szedlmayer (1997) described high site fidelity based upon red snapper that remained within the maximum detection radius of the receiver, which was 1.6 km, but failed to include those that left immediately or those did not stay within 1.6 in subsequent calculations. In a mark and recapture study, Szedlmayer and Shipp (1994) considered movement less than 2 km to demonstrate high site fidelity. In contrast, Patterson et al. (2003) modeled decline in recaptures at experimental reefs following saturation tagging to estimate red snapper site fidelity. They reported more conservative (24.8-26.5% per year) site fidelity estimates for the same types and sizes of artificial reefs as did Szedlmayer and coauthors, but included fish reefs in their calculations that left immediately or that were recovered nearby but on other experimental reefs. Establishing the proper distance in this context can be difficult, but should not be arbitrary or merely based on detection radius, which, as seen above, can vary widely. Even examples from the literature may offer little guidance, as minimum distances required to indicate emigration can vary widely by species. In a study of the dispersal of Galjoen, Attwood and Bennett (1994) concluded that fish remaining within 50 km wide transects to be residents. Beamish and McFarlane (1988) concluded that movements of less than 200 km to be exhibiting resident behavior for sablefish. Willis et al. (2001) considered fish captured within 500 m of their original tagging site to have remained residents.

Perhaps a better approach would be to study site fidelity in the context of home range. Researchers studying both wildlife and fish have used the home range concept to

study habitat affinity for their species. Determining well-defined home ranges for red snapper could enlighten their habitat affinities and whether oil and gas platforms or other artificial reefs coincide with these affinities. Determining site fidelity to that home range could then be far more informative.

This new study and that of Westmeyer et al. (2007) indicate that site fidelity to platforms may be very low, and it appears that red snapper move away from the platforms to forage. Both of these behaviors would be interpreted to lie on the attraction end of the spectrum as defined by Bohnsack (1989).

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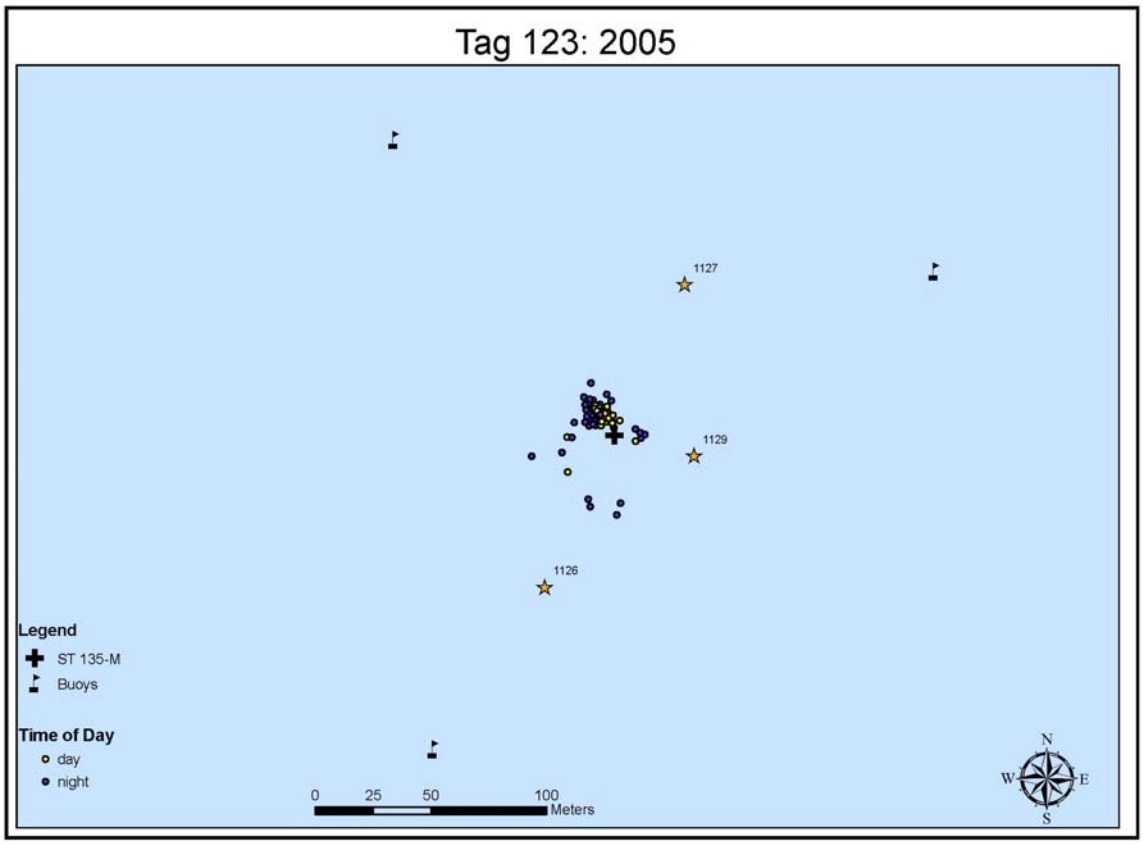
Appendix: Remaining Fish Plots

This appendix contains the plots of all fish for which there were more than 24 hours worth of positions.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1129
1126
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ST 135-M
Buoys
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night
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25
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100
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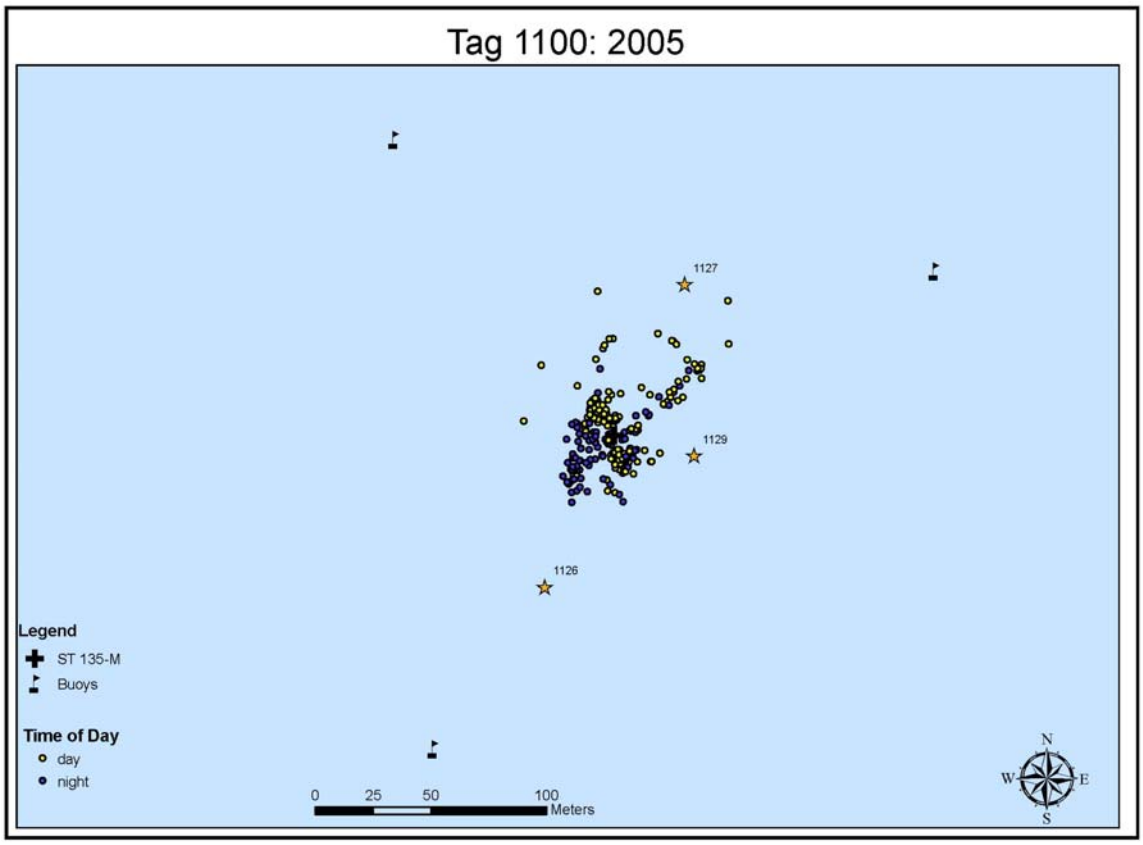
S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1129
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Buoys
Time of Day
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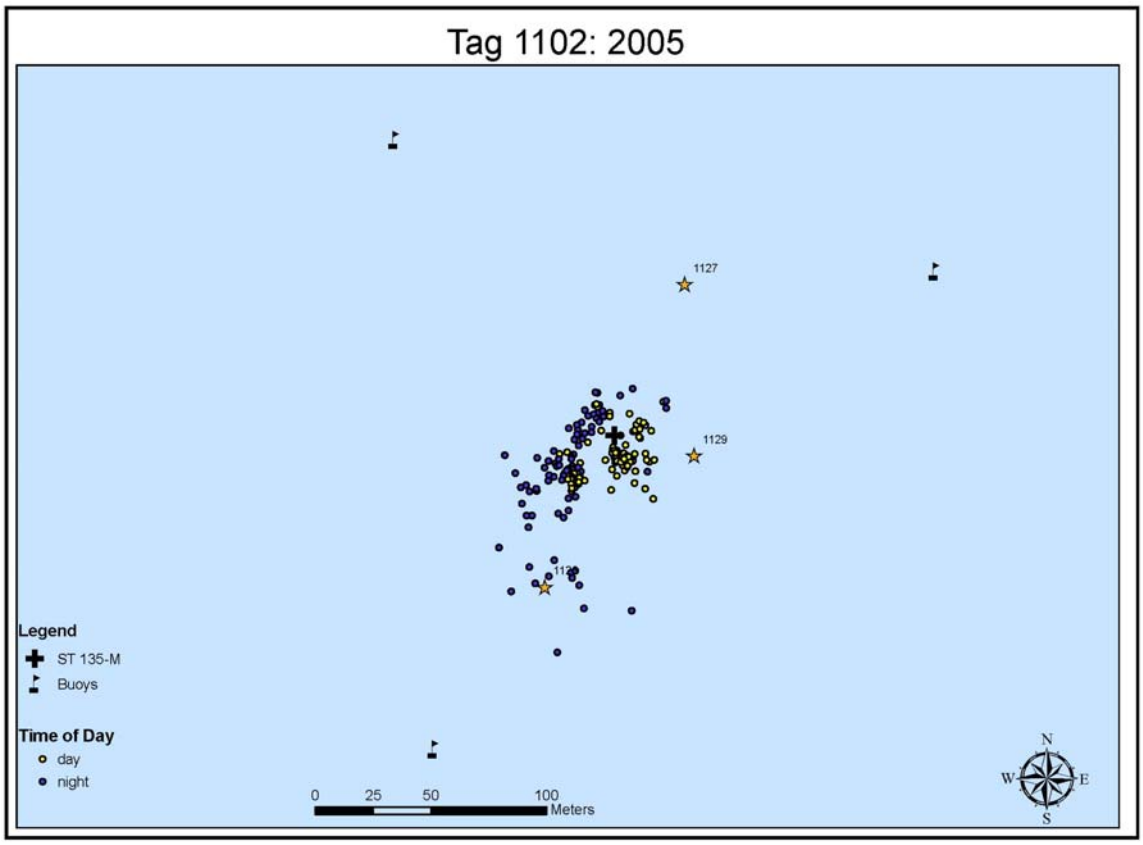
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ST 135-M
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Time of Day
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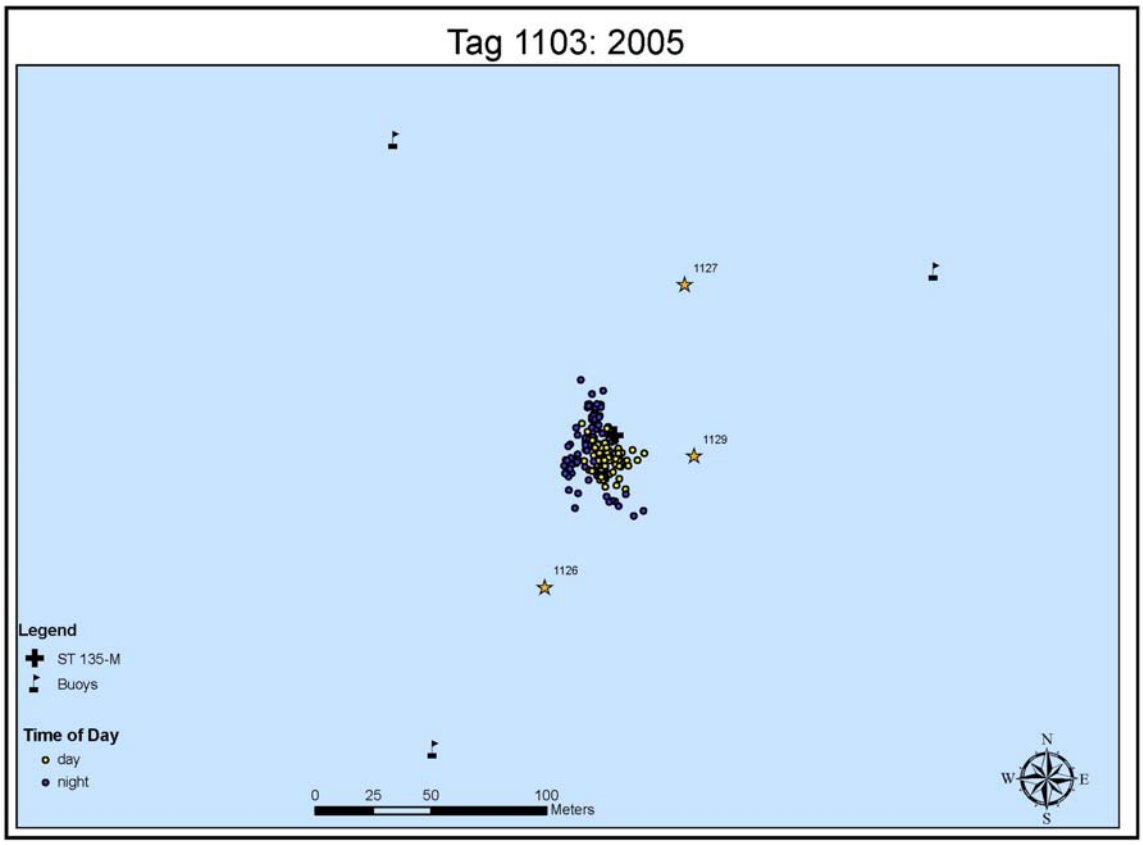
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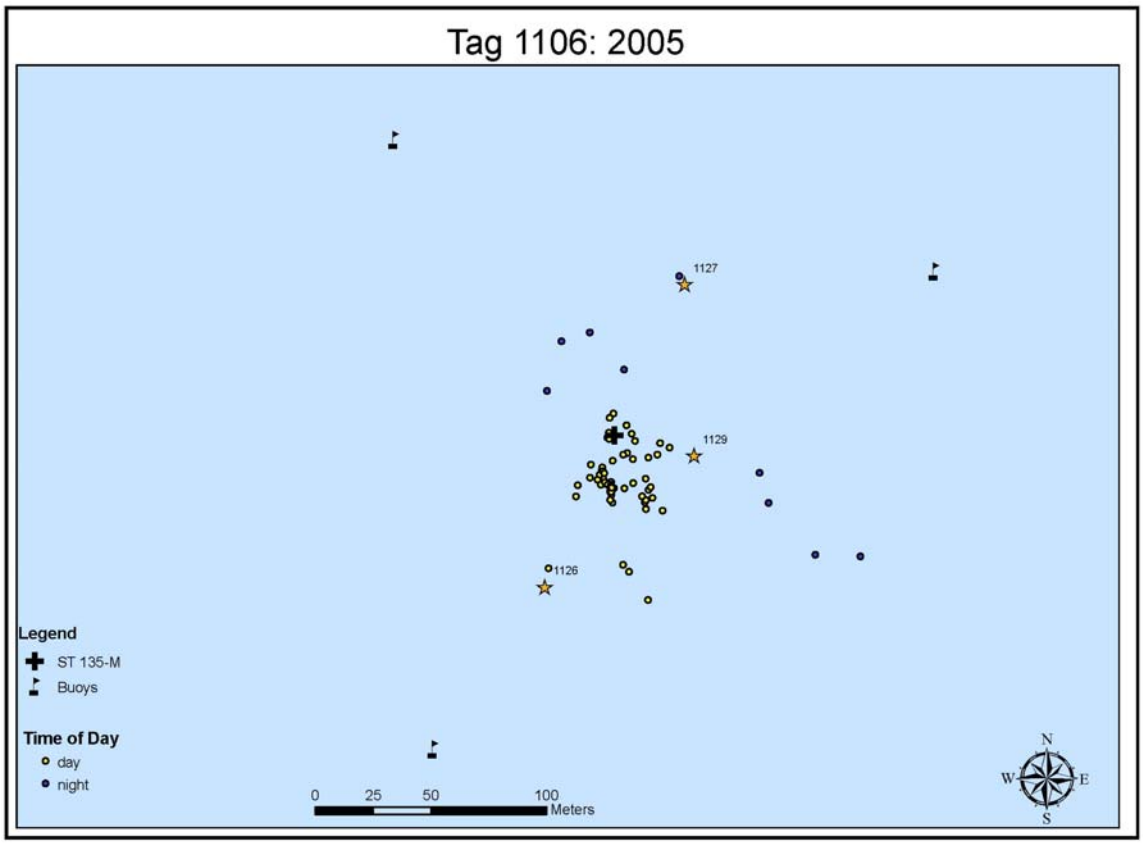
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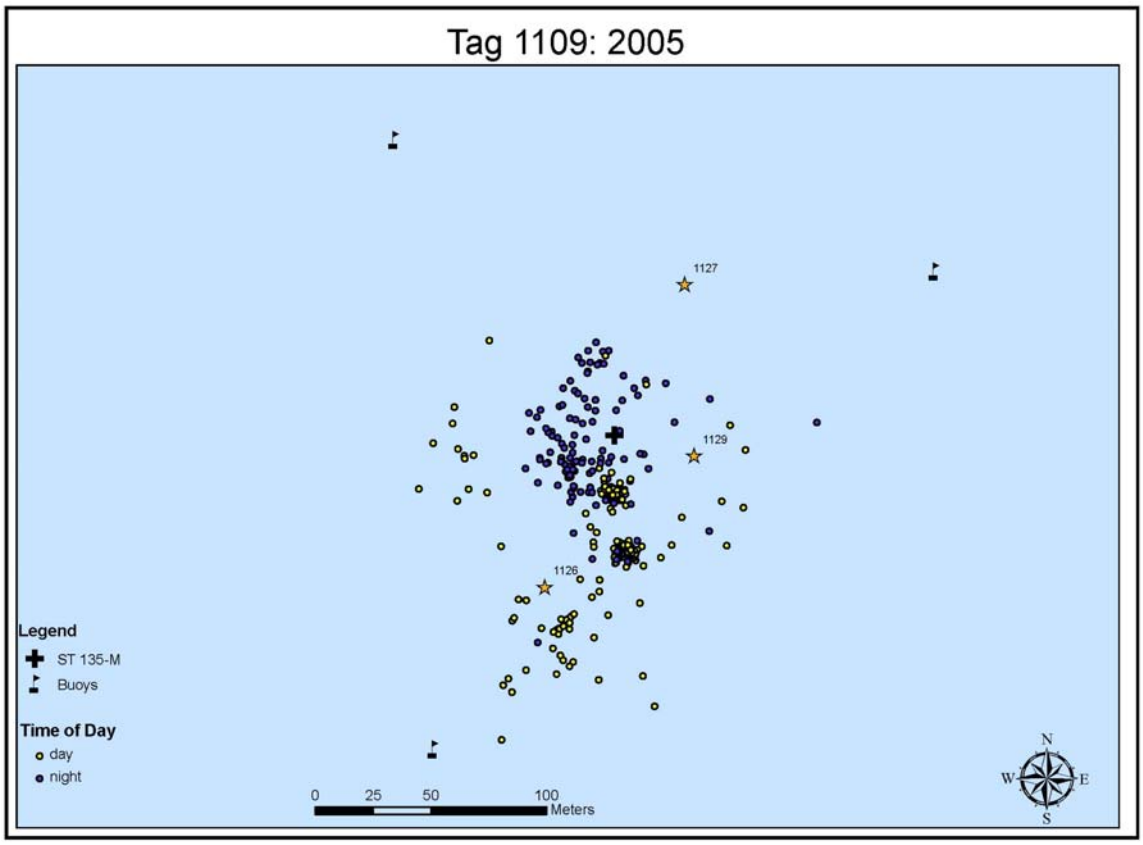
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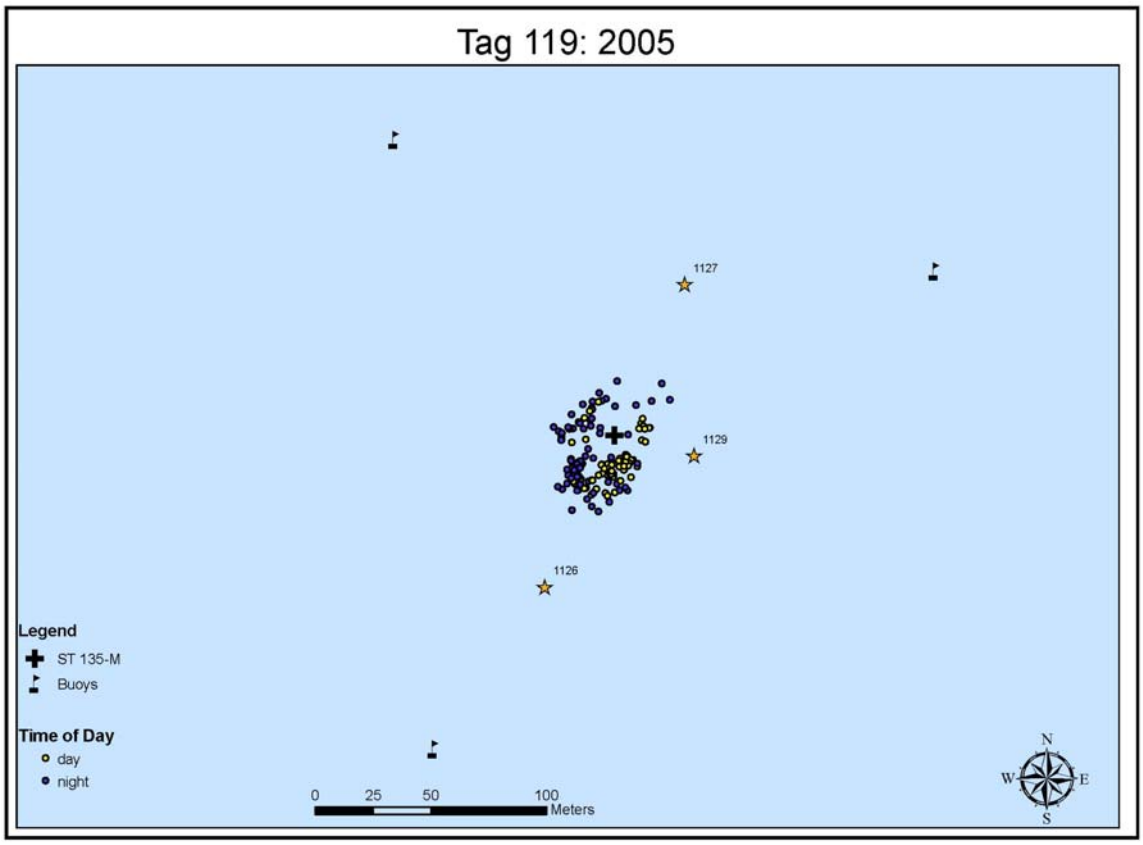
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Time of Day
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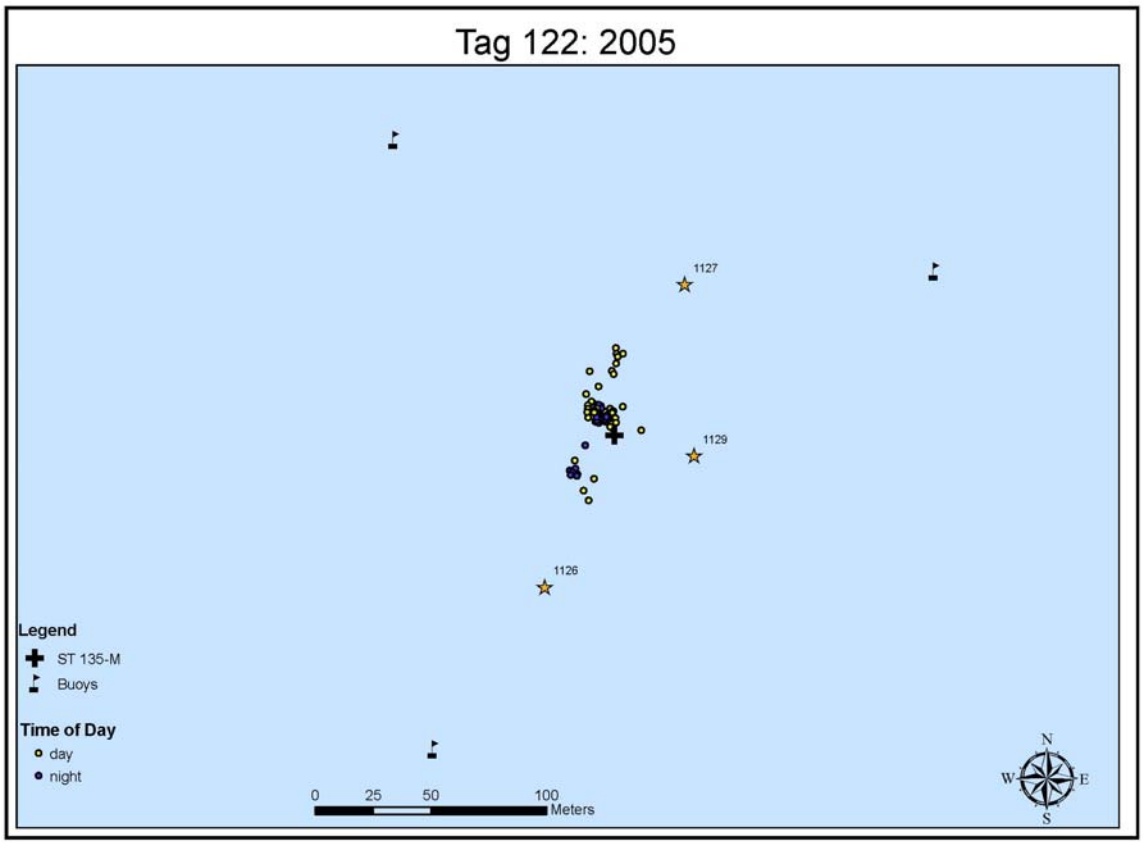
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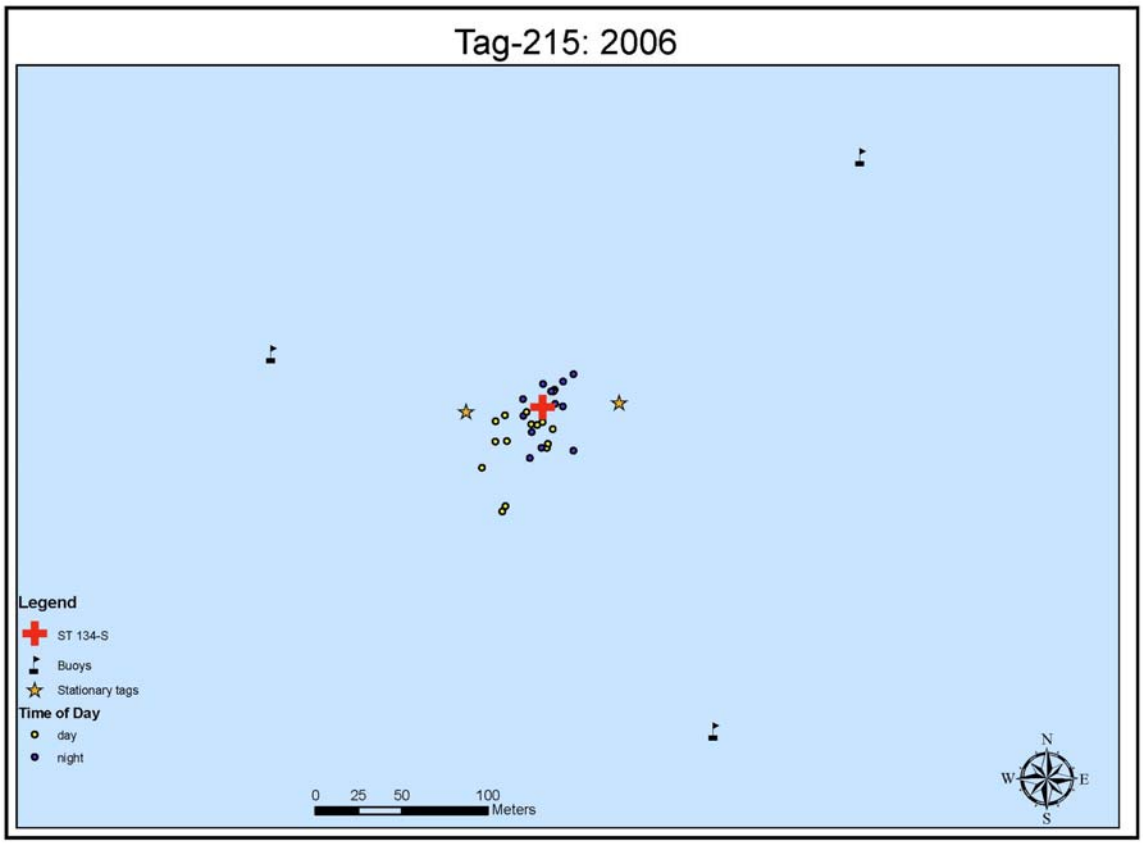
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S


Tag-215: 2006
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
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night
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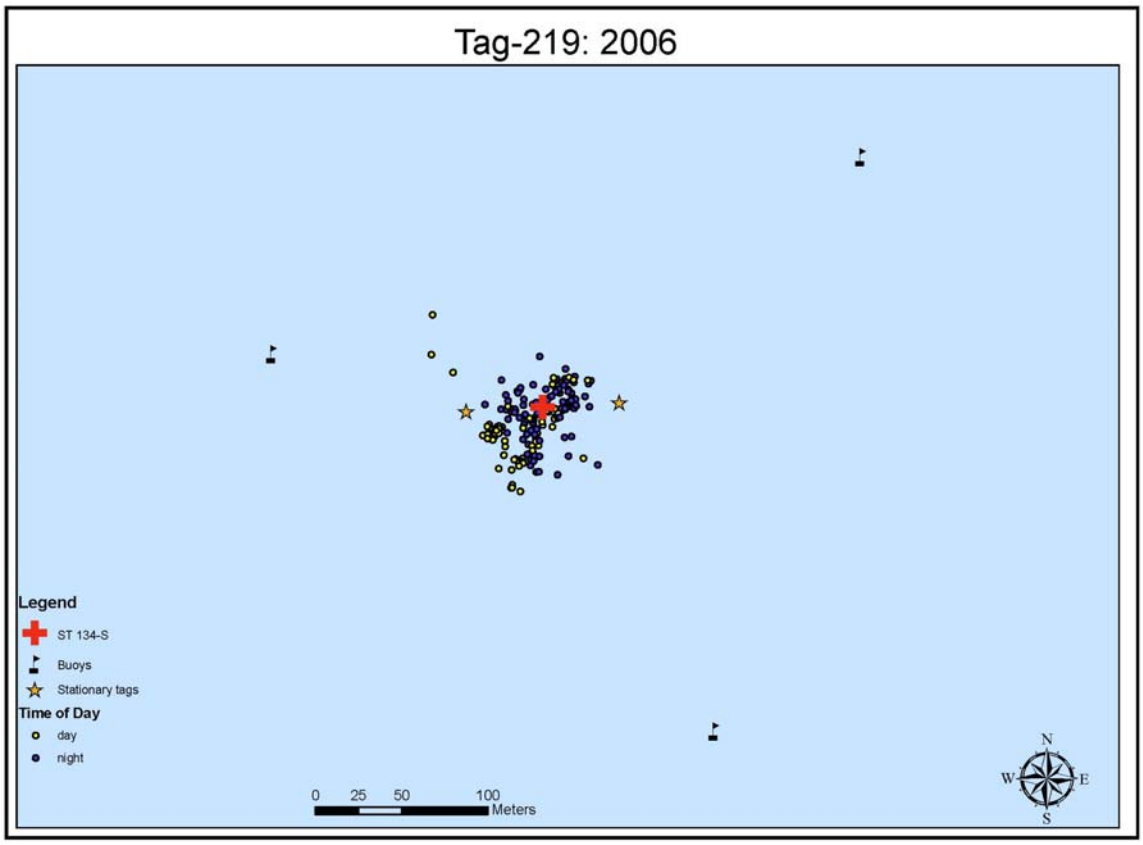
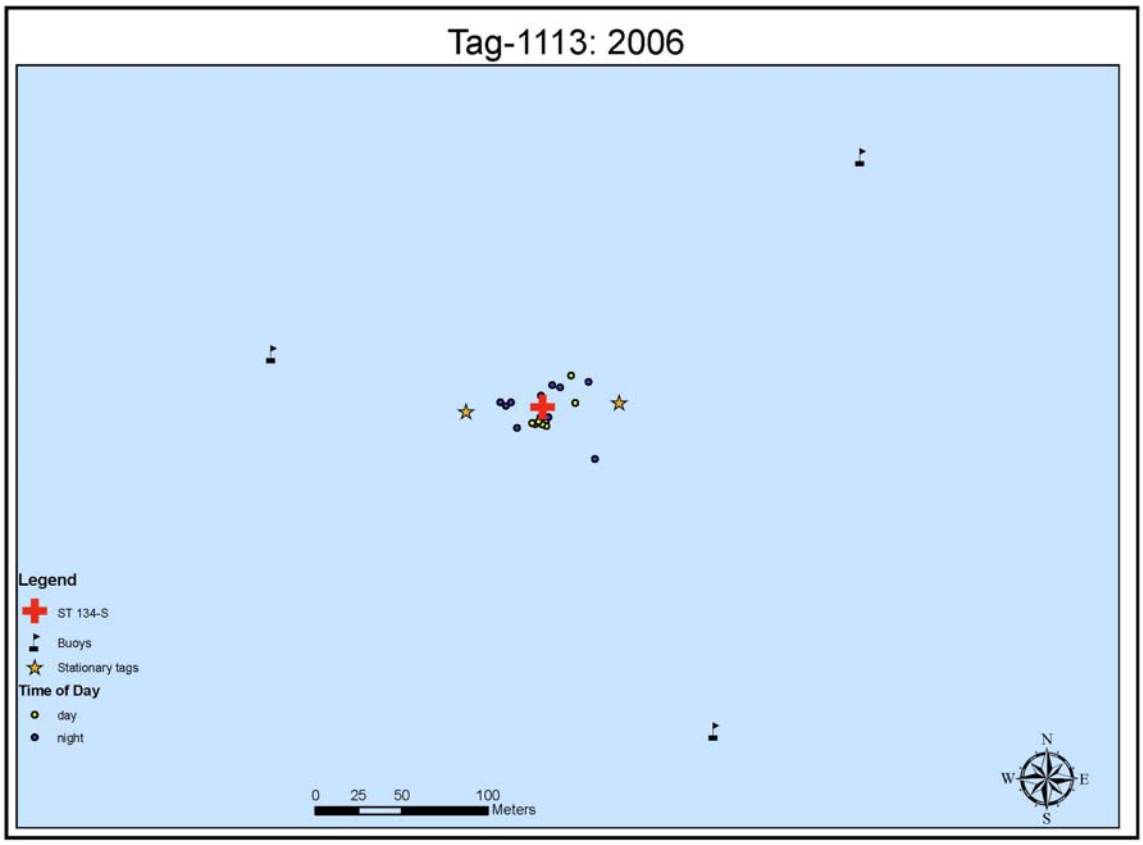
Meters
N
W
E
S


Tag-219: 2006
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
W
E
S


Tag-1113: 2006
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ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
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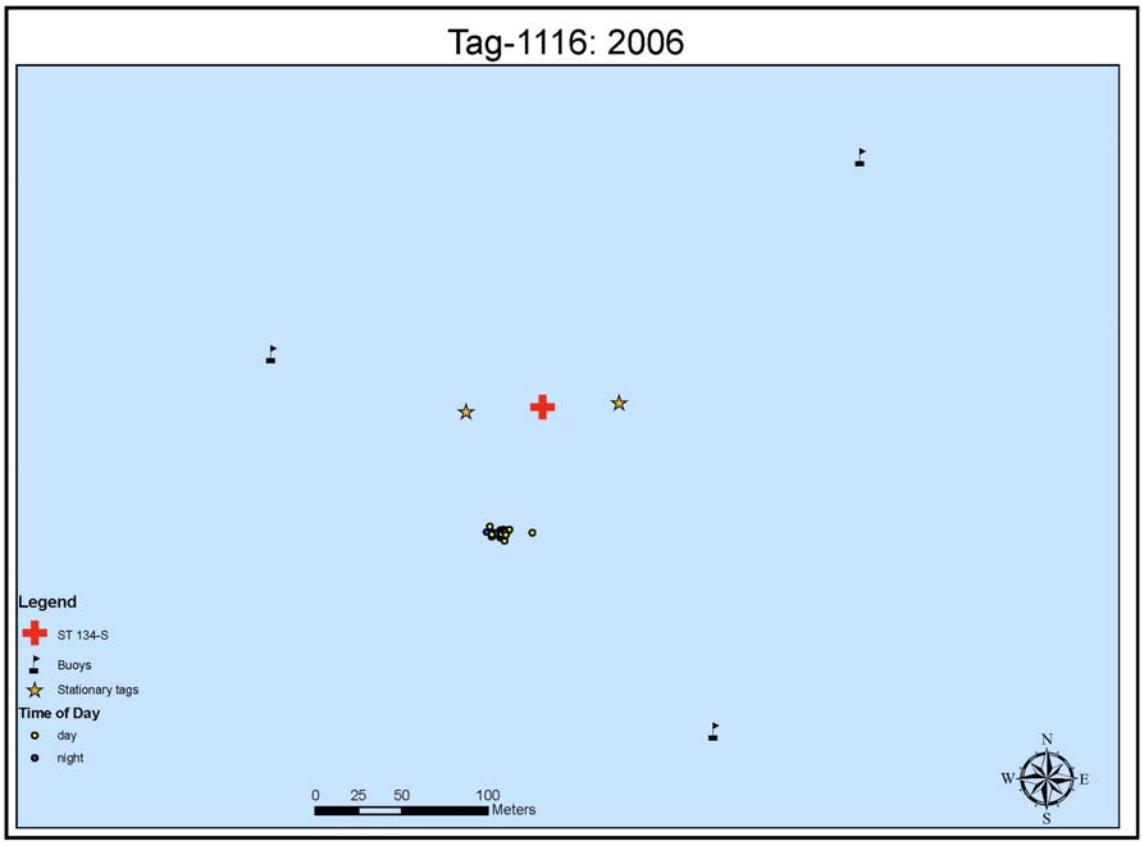
E
S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ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
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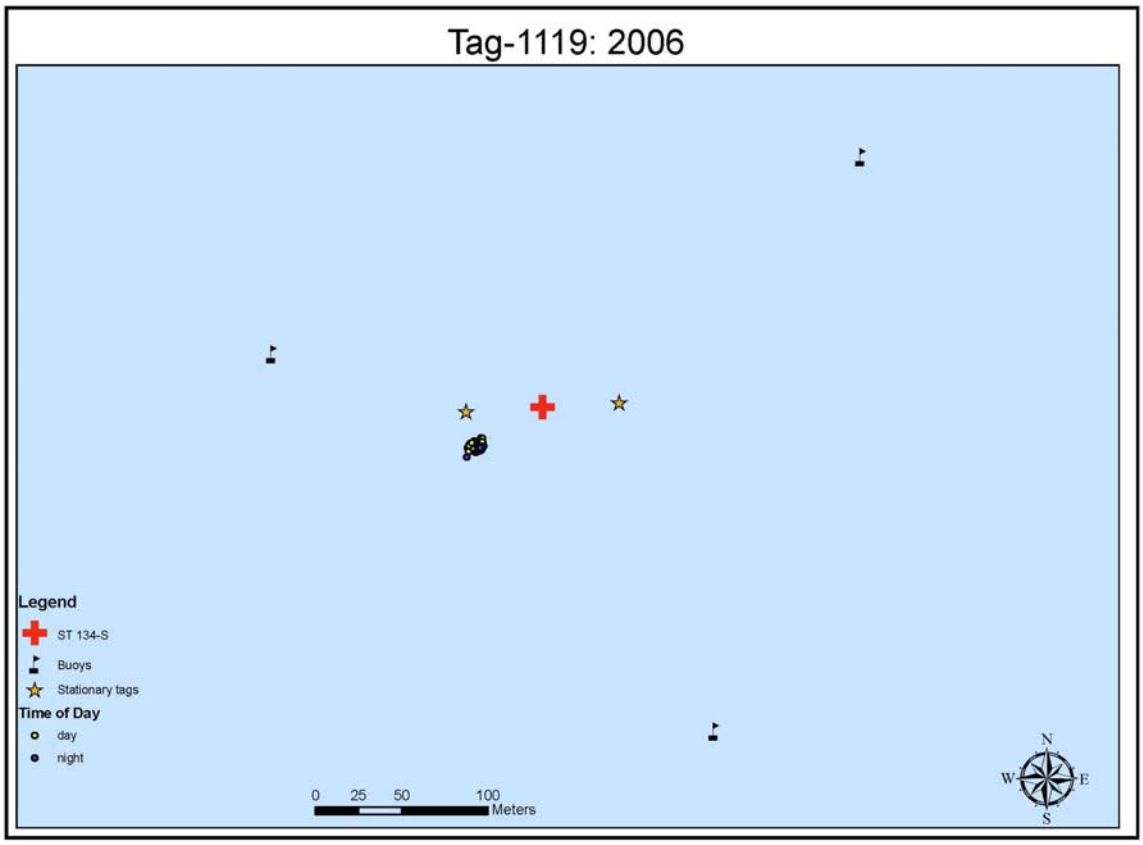
E
S


Tag-1119: 2006
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
W
E
S

Vita

Michael McDonough was born in Harrisburg, Pennsylvania, in 1978. He attended the University of Notre Dame beginning in the fall of 1996, and received a Bachelor of Science degree in biological sciences in the spring of 2000. He then moved to Baton Rouge, Louisiana, to work as a research associate in the Department of Biological Sciences. He began working on his Master of Science degree in the fall of 2003 in the Department of Oceanography and Coastal Sciences. The degree of Master of Science will be conferred in May of 2009.