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Short-term Movement, Home Range, and Behavior of Red Snapper around Petroleum Platforms in the Northern Gulf of Mexico, as Determined by High Resolution Acoustic Telemetry



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ABOUT THE COVER

Sunset image of platforms in the Gulf of Mexico south of Port Fourchon, Louisiana. Image by James H. Cowan, Jr., Louisiana State University.

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ABSTRACT

Understanding the behavior, including the 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 commercially and recreationally important 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. The VRAP acoustic telemetry system was used 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. The probability of fish presence 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.

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1.0 INTRODUCTION

The Magnuson-Stevens Fishery Conservation and Management Act, the 1996 revision and reauthorization of the 1976 Public Law 94-265 (Act), require 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 (GOM) 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 0–1 year class 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 GOM. Red snapper spend most of their first year over sand and mud bottom on the shrimping grounds in the northern GOM, 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 use these various habitats as they grow, e.g. for feeding, protection, or both, is unknown. Information on the 0–1 year class 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.

In the waters of the northern GOM there are over 4,000 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 they are a positive influence on reef stock dynamics. There have been doubts about whether they produce or attract fish. 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 simply be 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 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 show only 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 be 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 about 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 at the local scale, i.e., at an individual reef or a collection of reefs. Lindberg 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 halos force these predators to search beyond feeding halos to find available prey. Further, they hypothesized that spacing would be important in this dynamic—reefs that were close together would have overlapping halos and more intense prey depletion. The more intense the prey depletion, the higher the energetic cost of searching for available prey; 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 we 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 halos should inform their decisions about where to place artificial reefs.

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, researchers can use these data to look at patterns. For example, if fish are moving away from reefs, telemetry can show when these movements are occurring. If fish are leaving the coverage area entirely, telemetric data can also show where fish are and where they are not in the coverage area.

2.0 METHODS

Two telemetry experiments were performed on platforms in the GOM. Red snapper were collected 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 surround a salt dome, a common geological formation in southern Louisiana from which 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 1a and Figure 1b). All platforms in the Circle are owned and operated by Chevron/Texaco. Although the fish used in this study were caught at several platforms, all fish were released at the platforms around which the Vemco® radio acoustic positioning (VRAP) system was deployed. In 2005, the VRAP was deployed around ST 135-M; in 2006, it was deployed around ST 134-S (Figure 1a and Figure 1b). 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.

Chevron/Texaco personnel at the Circle platforms have historically been willing to allow researchers access to study sites via helicopter. For this experiment, a site was also provided to house the VRAP’s base station, where power and existing radio communication infrastructure were available.

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

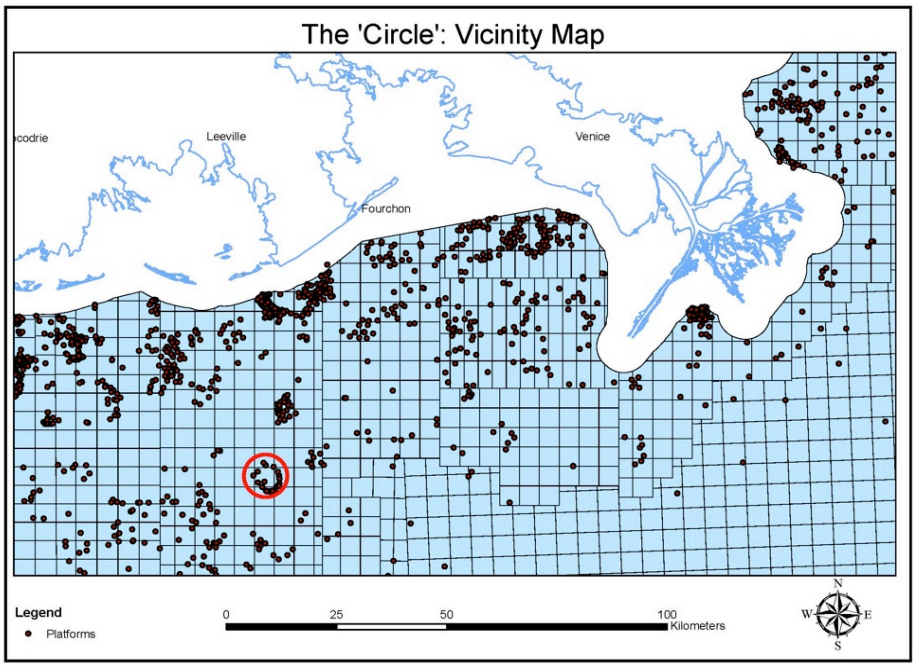


Figure 1a. Map of the study area showing the position of "the Circle" (in red) in the Gulf of Mexico.

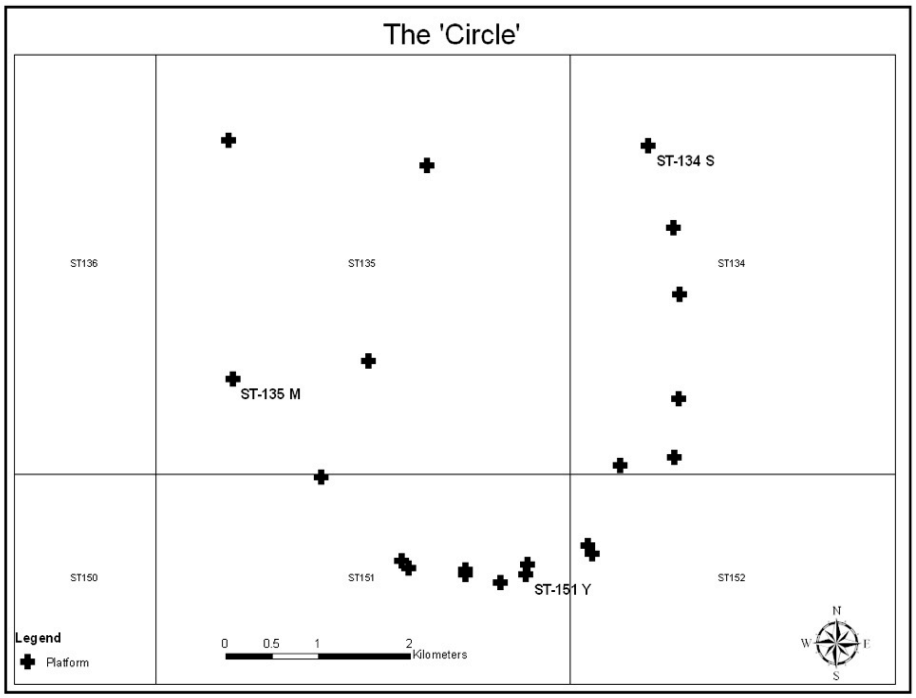


Figure 1b. Map of the study area showing the positions of platforms ST-135 M, ST-134 S, and ST-151 Y within the Circle.

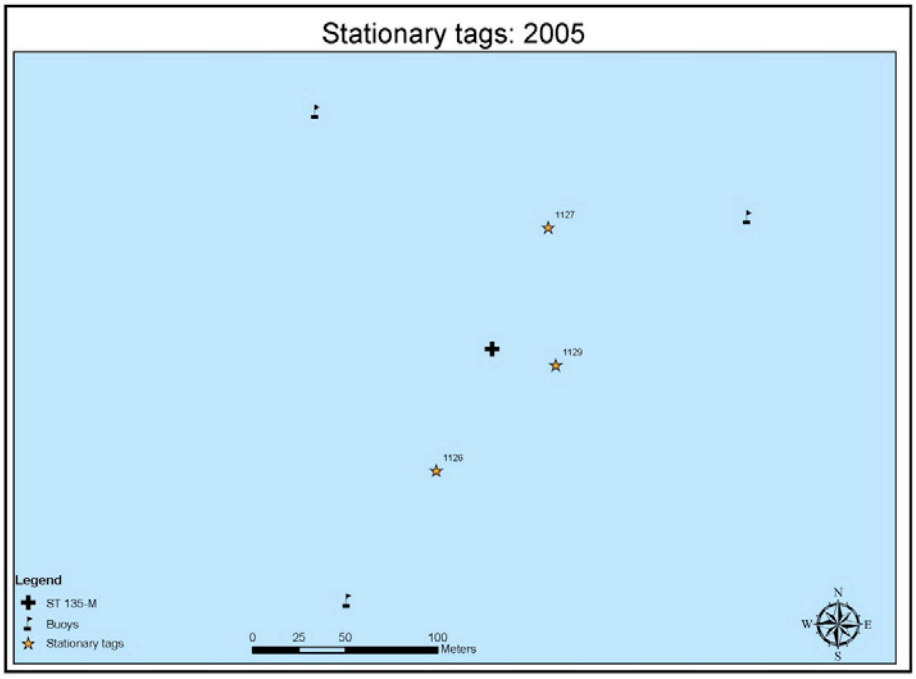


Figure 2a Plots of the buoy deployment in 2005

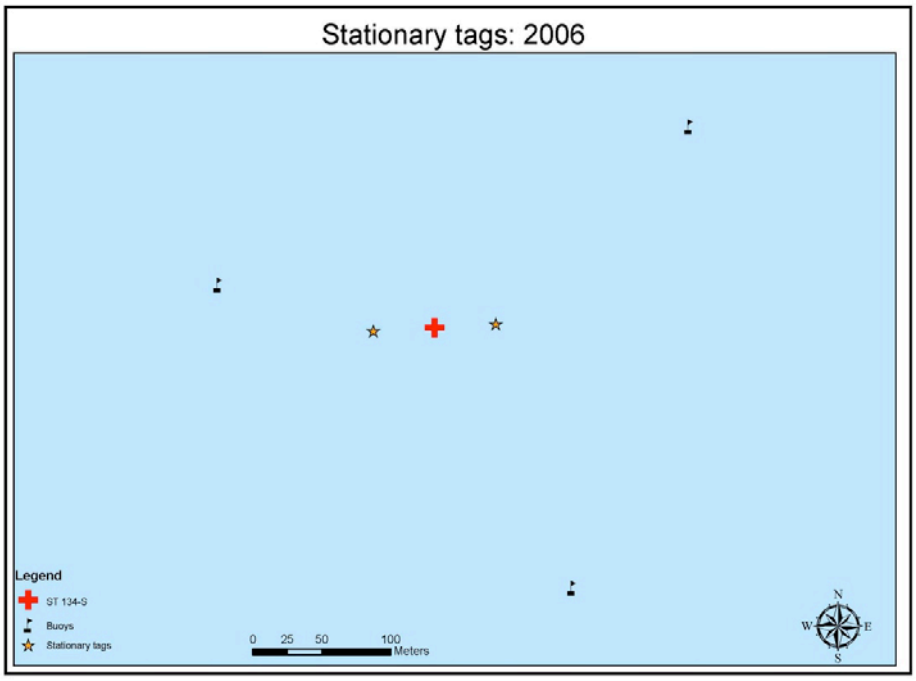


Figure 2b. Plots of the buoy deployment in 2006.

Each 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 (six in 2005, and nine in 2006), and communicated depth during transmission.

A base station kept on ST-151 Y (Figure 1b) 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.

Stationary tags were also deployed within the array for two purposes (Figures 2a and b). Because the buoys were moored and moved with the currents, we 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 is possibly 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 that 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, the VRAP was deployed for five days in May (26–30) before one of the receivers was struck and damaged by a supply boat. Re-deployment was not possible until August, when it was possible to get another seven days of data (6–12 August). In 2006 it was possible to get a continuous two-week dataset (17–30 May). The study length was determined because two weeks is the effective battery life of the buoys. Long-term movements or behavior of red snapper were not the goal of the study

Red snapper were collected 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), 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. An ultrasonic transmitter (Vemco, Ltd.) was inserted (a Floy® anchor tag (or visual identification in case of recapture) into the incision, and closed the incision with two catgut sutures and an acrylic adhesive (Krazy Glue®). Fish were transferred to a post-surgery recovery tank and held until they again were able to swim upright. To estimate acute mortality, fish were monitored for ability to orient (Patterson et al., 2001).

To analyze the data, fish positions were plotted. To account for movement of the buoys, the mean position of each stationary tag was 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) was then calculated. Because the VRAP system cannot 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, dx and dy were interpolated over the times during which fish positions were recorded and these numbers were used 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, positions and unresolved tags were combined. If an individual was detected by VRAP during any hour of the study fish were considered to be "present" during that hour. By definition, a fish would be either present each hour, even if detected more than once, or absent, if not detected at all. The fish identification codes (ID) by hour of the study were plotted by placing a "dot" on the x-axis for each hour of the study the fish was present (Figure 6). The number of fish detected per hour were then plotted. 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, we modeled the average hourly detections of stationary tags. (The average was calculated by day of the study, so that we are looking at day 1's average detections per hour vs. day 2's vs. day 3's, etc.). We 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.) We 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, we performed a spectral analysis (PROC SPECTRA, SAS Institute, Inc., 2007) on fish detected per hour. Spectral analysis can detect cycles in presences and absences. We used the spectra to determine whether there was identifiable periodicity in the presence/absence data on a daily or sub-daily basis. To resolve trends within a day, we 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.

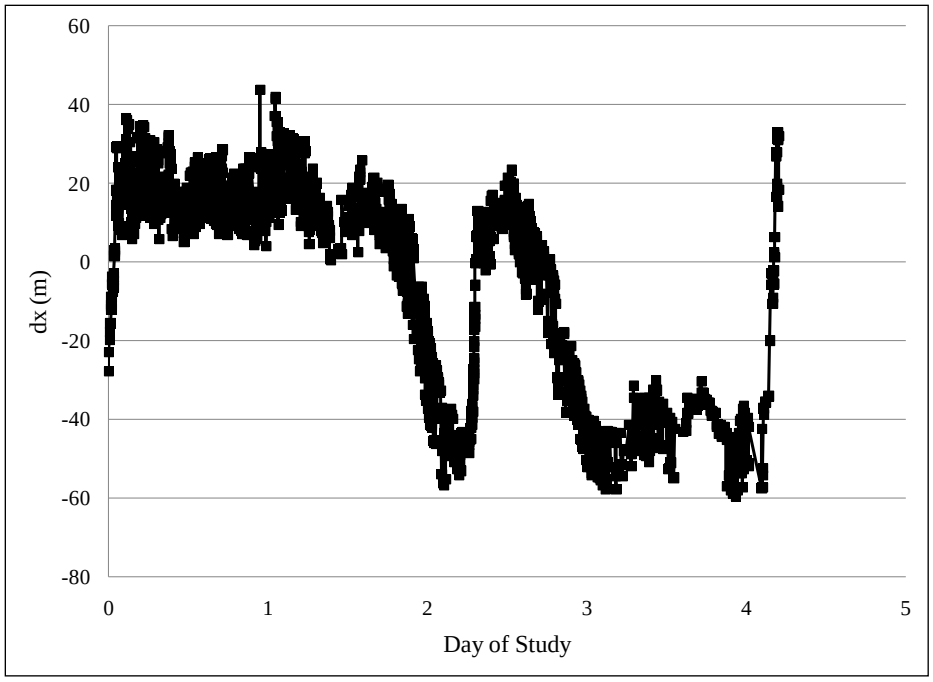


Figure 3a) Plot of the dx-corrections for fish positions in May 2005.

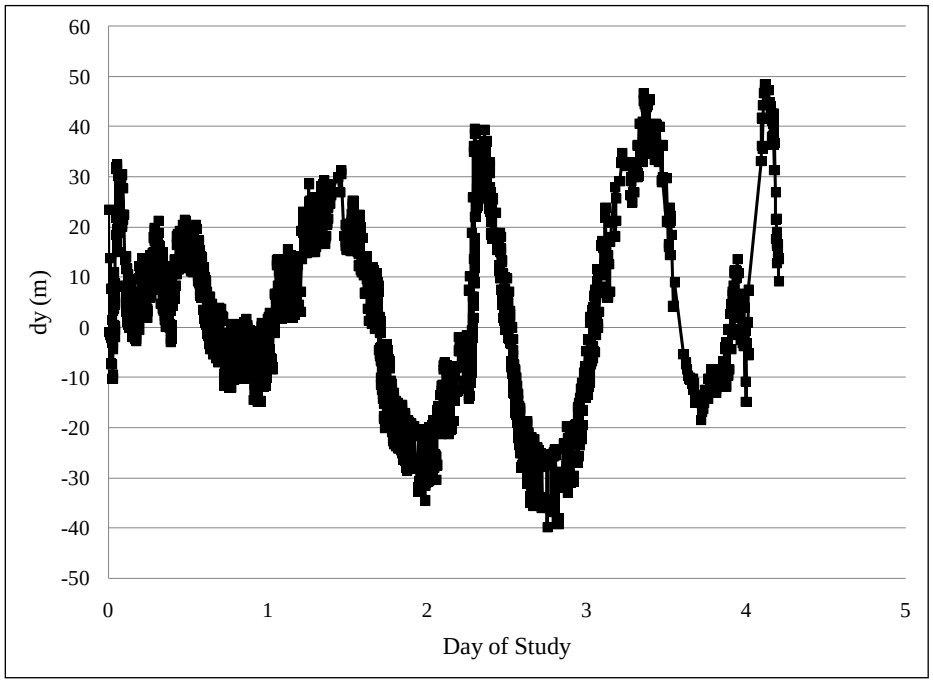


Figure 3b) Plot of the dy-corrections for fish positions in May 2005.

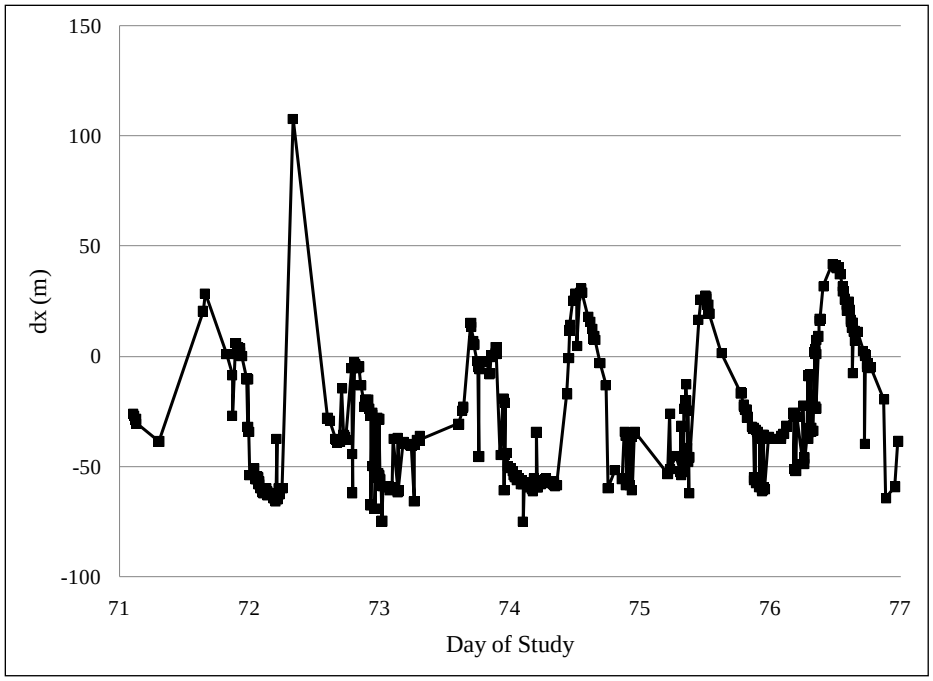


Figure 4a) Plot of the dx-corrections for fish positions in August 2005.

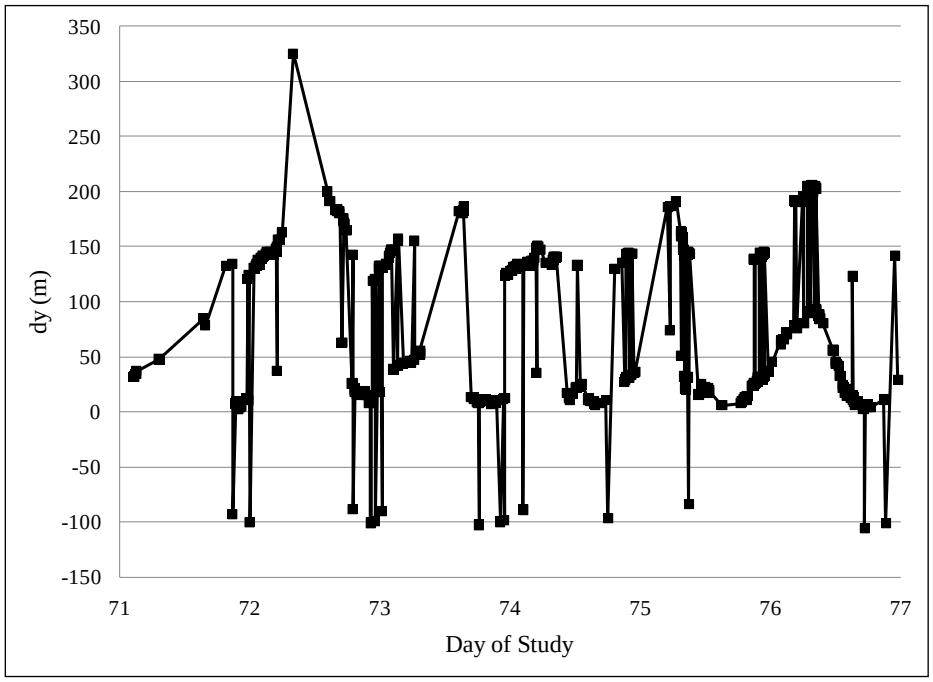


Figure 4b. Plot of the dy-corrections for fish positions in August 2005.

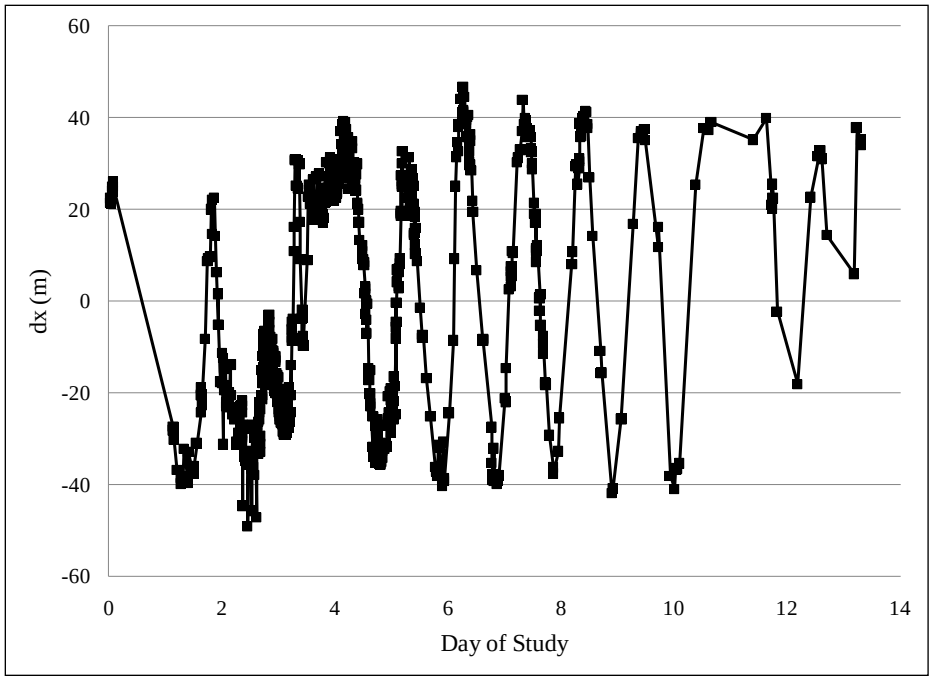


Figure 5a) Plot of the dx-correction for fish positions in 2006.

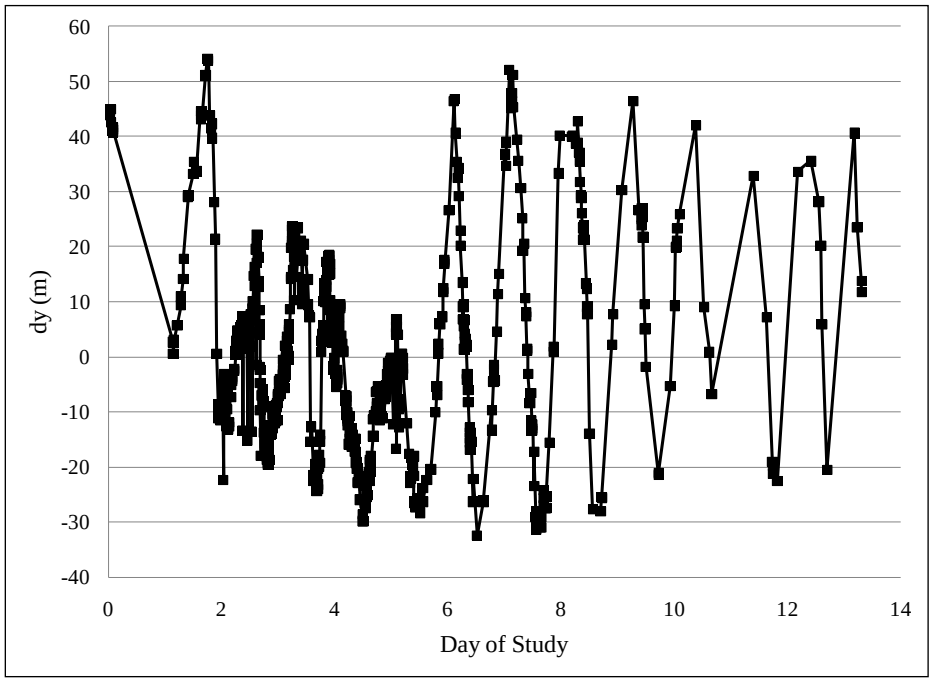


Figure 5b). Plot of the dy-corrections for fish positions in 2006.

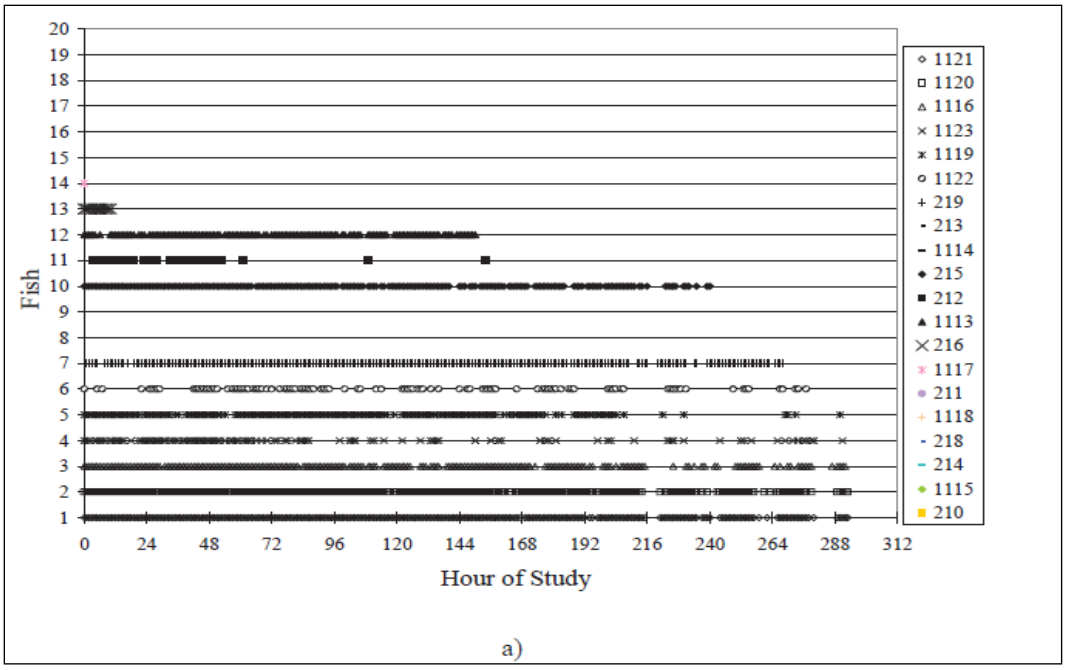


Figure 6a) Fish “presences” for 2006 — the hours of the study each fish registered a detection.

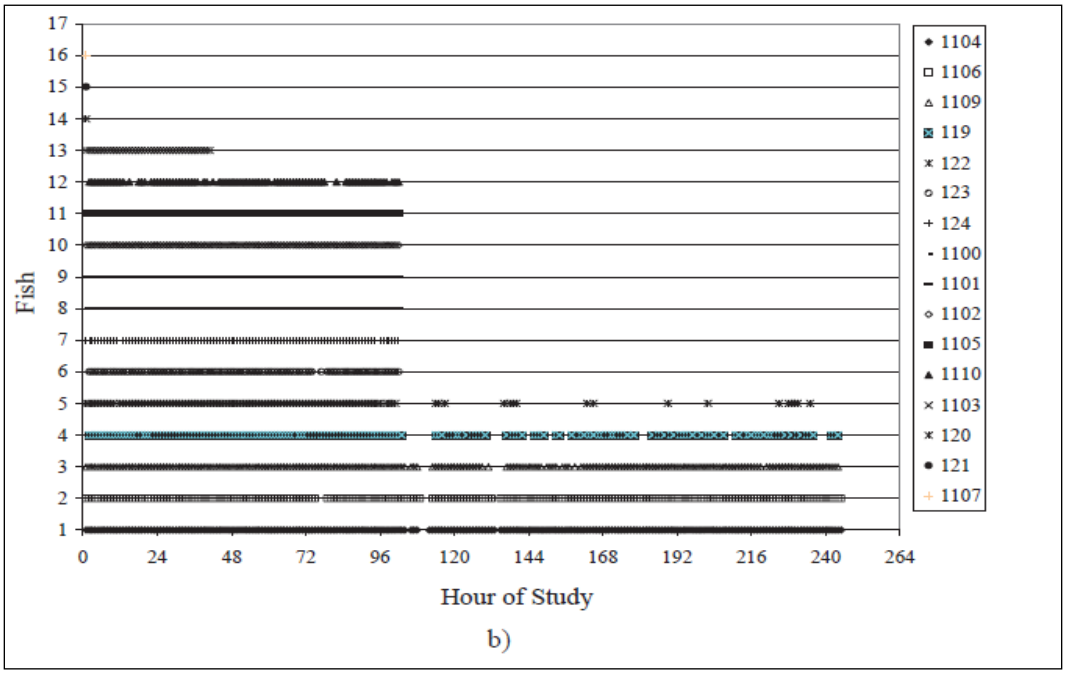


Figure 6b) Fish “presences” for 2005—the hours of the study each fish registered a detection.

To further resolve periodicity, we modeled the presence and absence data with logistic regression (PROC REG, SAS Institute, Inc., 2007) and PROC GIMMIX (SAS Institute, 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. We 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; moon phase; photo-period; wind speed; wave height; tide level and stage (WAVCS; 90° 29', 28° 52'; Louisiana State University).

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

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

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;

$$Logit(Y)=(Y)/Y-1), \qquad (2)$$

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 moon phase) 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;

$$E[Y|\gamma]= g^{-1}(X\cdot \beta + Z\cdot \gamma), \qquad (3)$$

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. We used this GLIMM to specify individuals as clusters, so that individual fishes' probability of presence was 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.

We 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. We 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, we calculated the distance moved in the x and y direction (dx and dy, respectively) between successive points. We plotted dx and dy on feather plots, so that the angle and distance of successive movements could be visualized. We 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). We also calculated distance from the platform for each position of a red snapper, after which we calculated and plotted mean distance from the platform by hour-of-study, and hour-of-day.

We 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, we plotted interval vs. speed to see if there was asymptote that 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, we calculated and plotted mean depth by both hour-of-study and hour-of-day. We also performed spectral analysis (PROC SPECTRA, SAS Institute, Inc., 2007) on the all depths for each hour of the study.

3.0 RESULTS

In 2005, we captured and implanted 16 red snapper. In 2006, we 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). We report the 2006 results first because the study period was not interrupted. We 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 had 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; we 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, we 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 we redeployed on 23 August, there were five fish still at the platform; all of these fish remained until the end of the study (12 August).

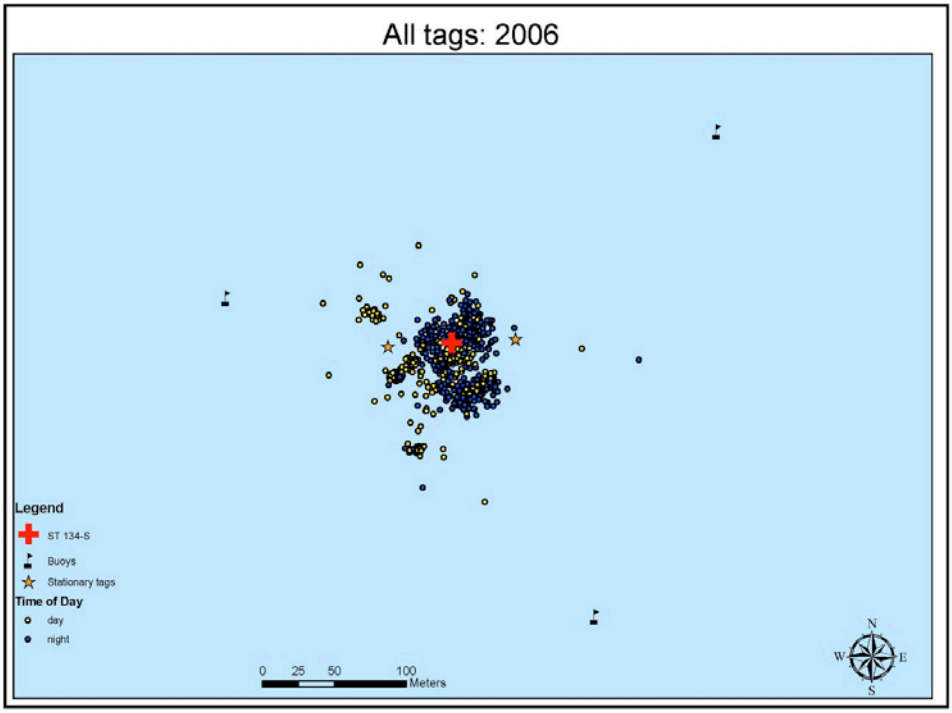


Figure 7. Plot of all fish for which positions were calculated in 2006.

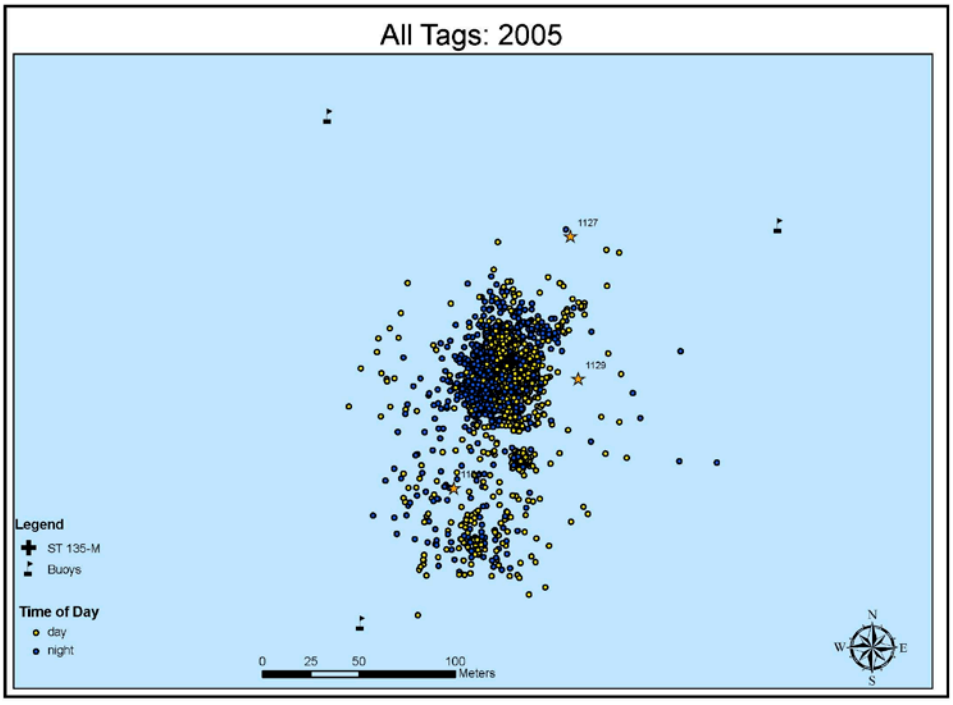


Figure 8. Plot of all fish for which positions were calculated in 2005.

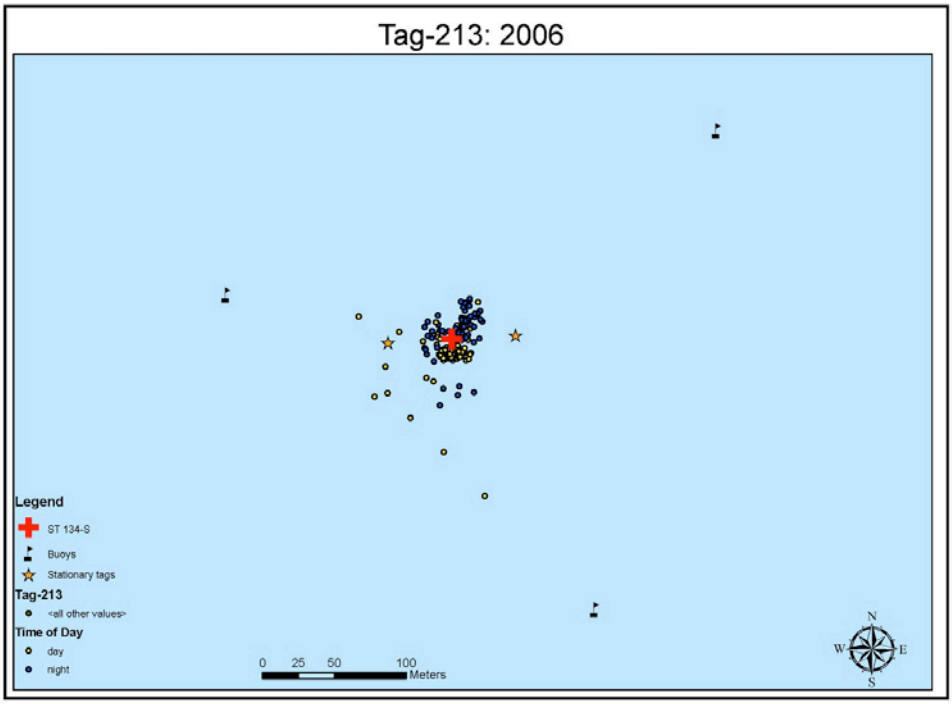


Figure 9. Plot of fish #213.

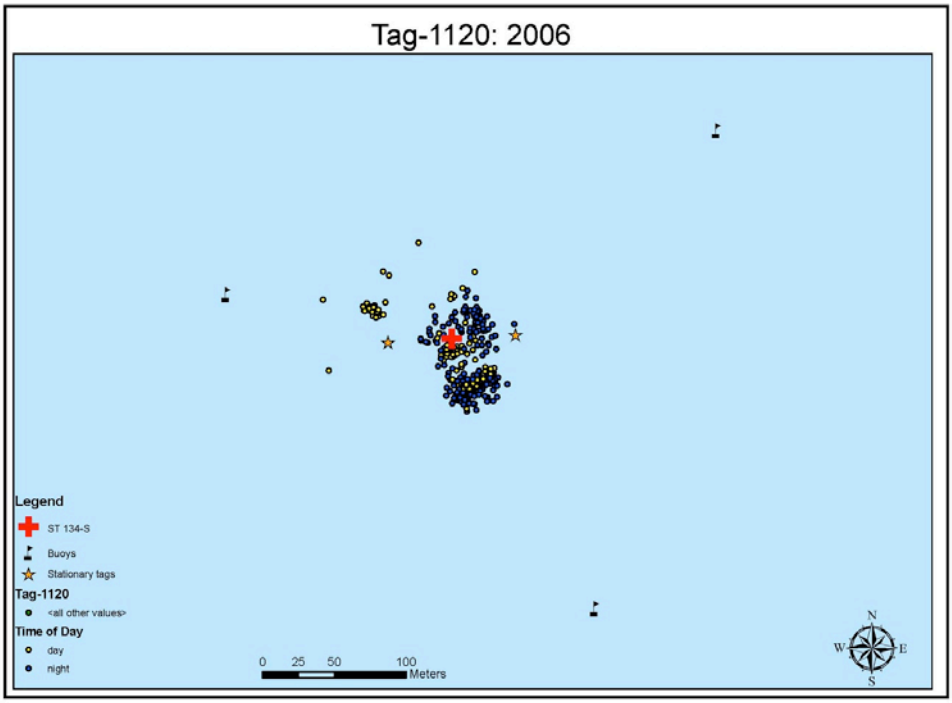


Figure 10. Plot of fish #1120.

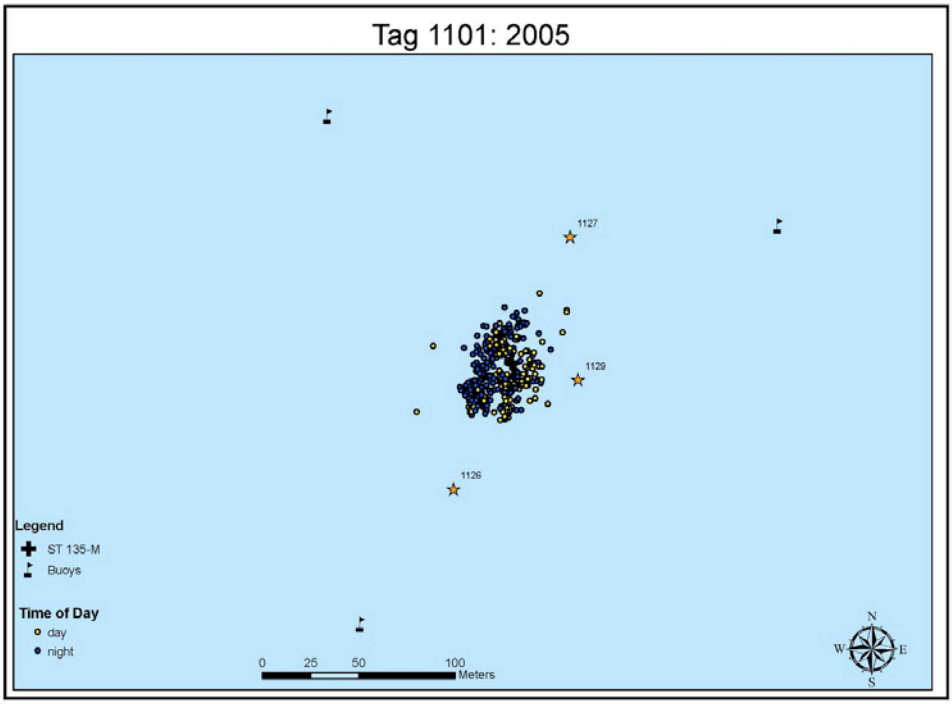


Figure 11. Plot of fish #1101; fish #1101 was not present when we redeployed in August.

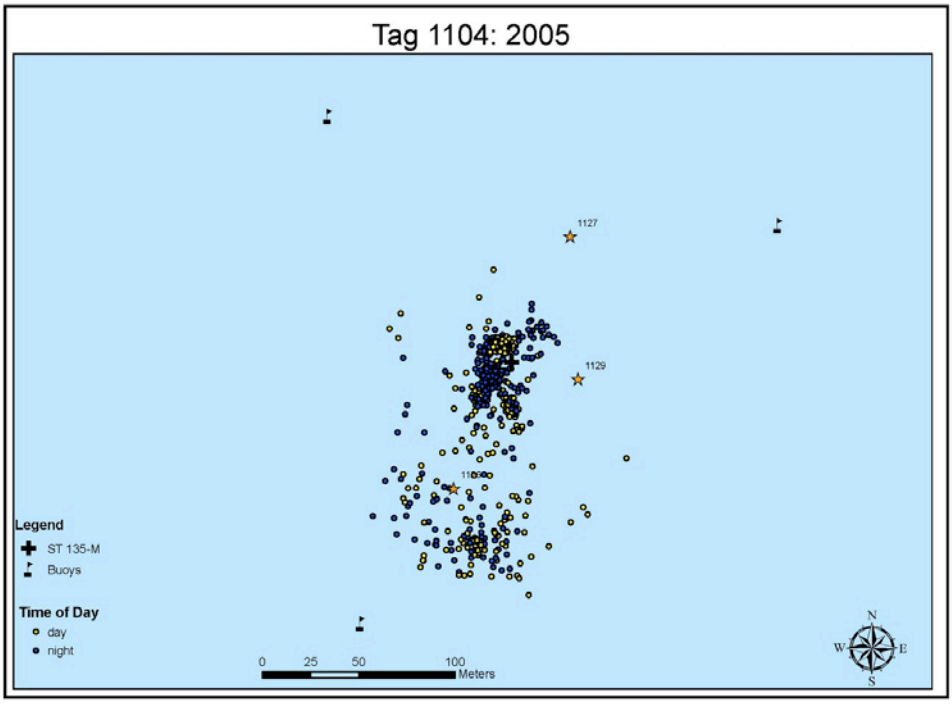


Figure 12. Plot of fish #1104; fish #1104 was present when we redeployed in August.

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.

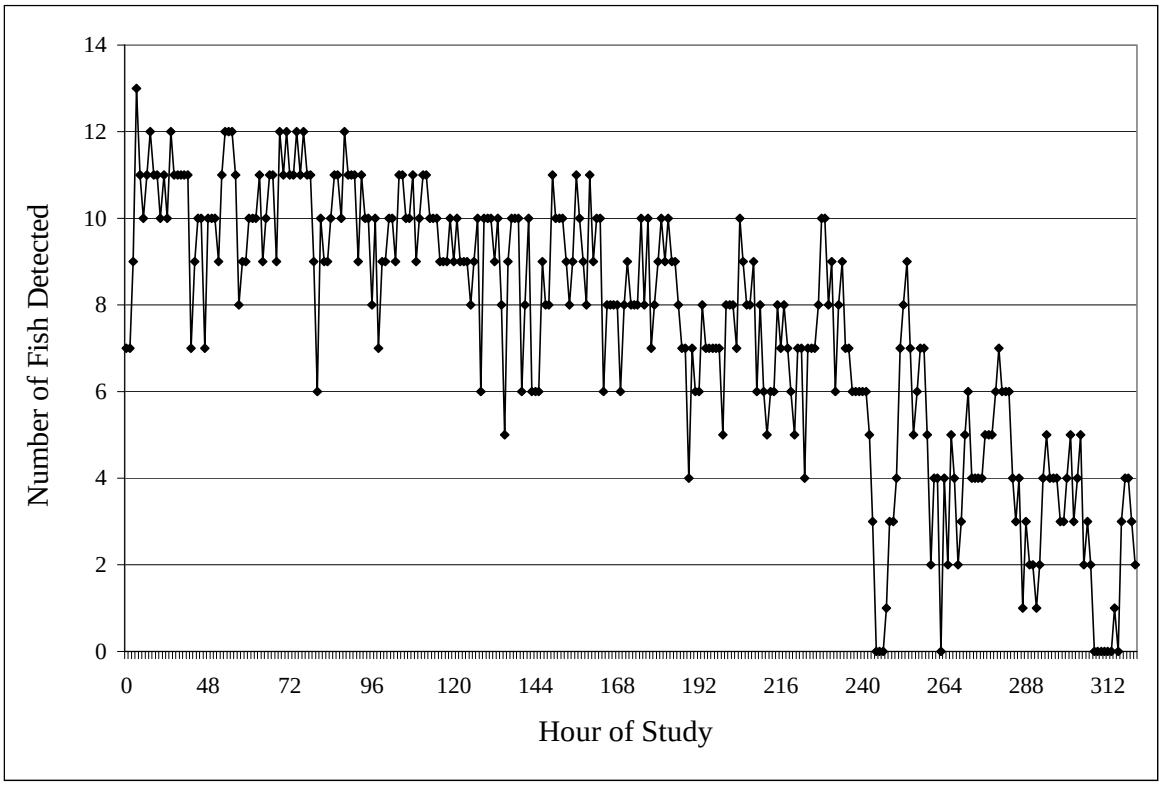


Figure 13. The number of fish detected per hour in 2006.

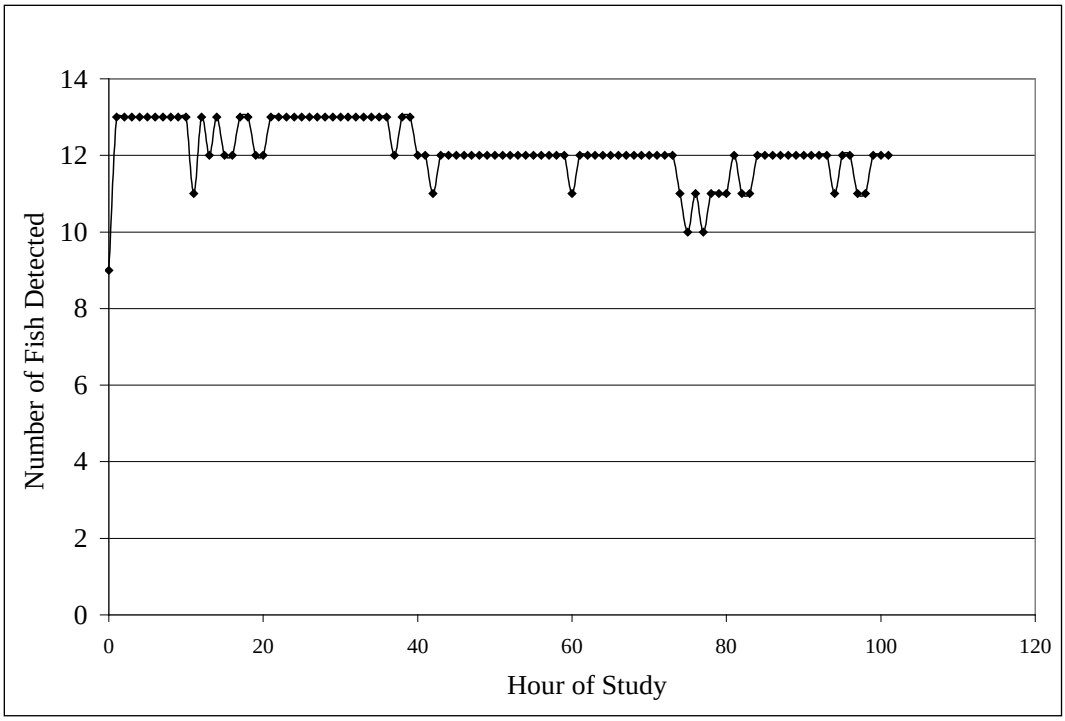


Figure 14a) The number of fish detected per hour in May 2005

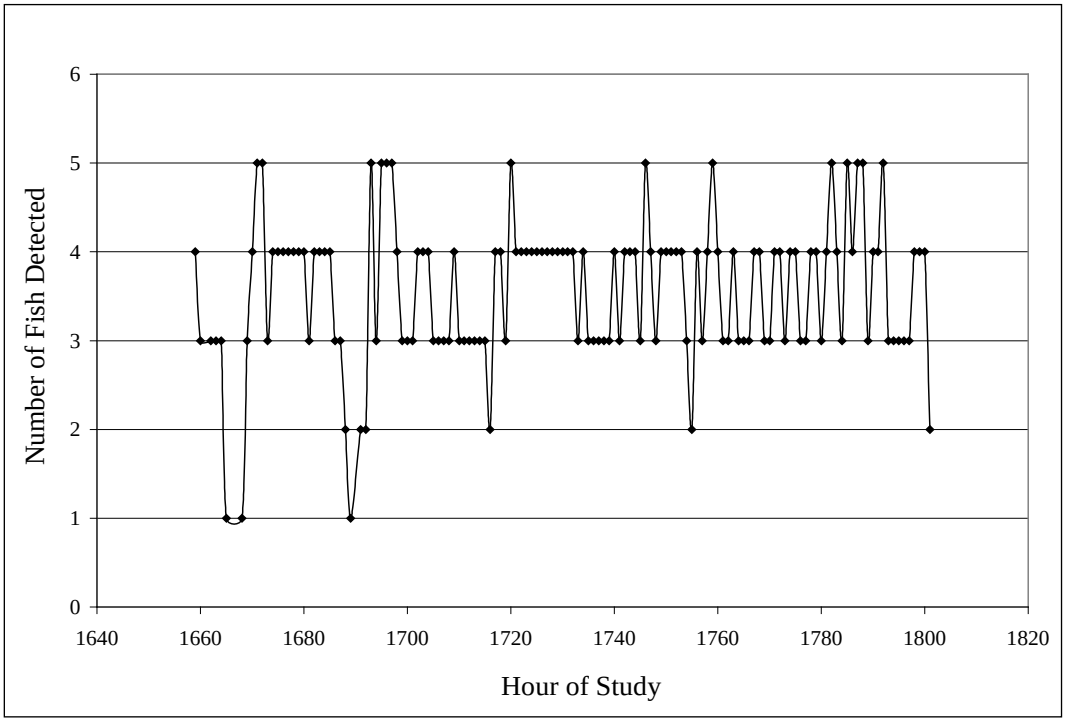
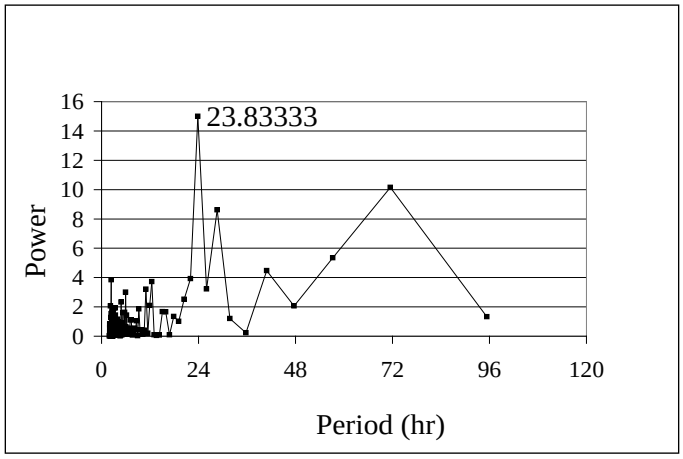
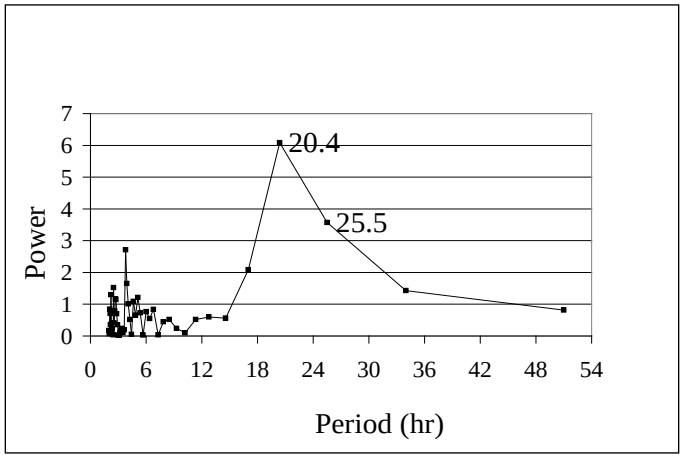


Figure 14b). The number of fish detected per hour in a) May and b) August 2005.

a)



b)



c)

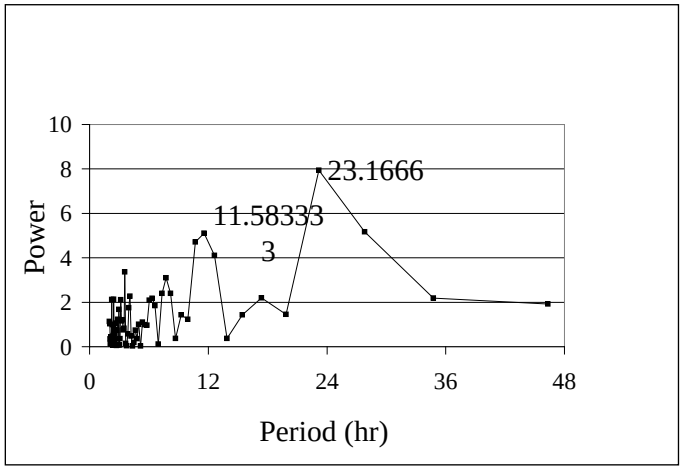


Figure 15. Periodogram from the spectral analysis on fish detections per hour in a) 2006; b) May 2005; and c) August 2005.

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 was a decline between deployments, but there is no apparent trend within either deployment (Figure 19).

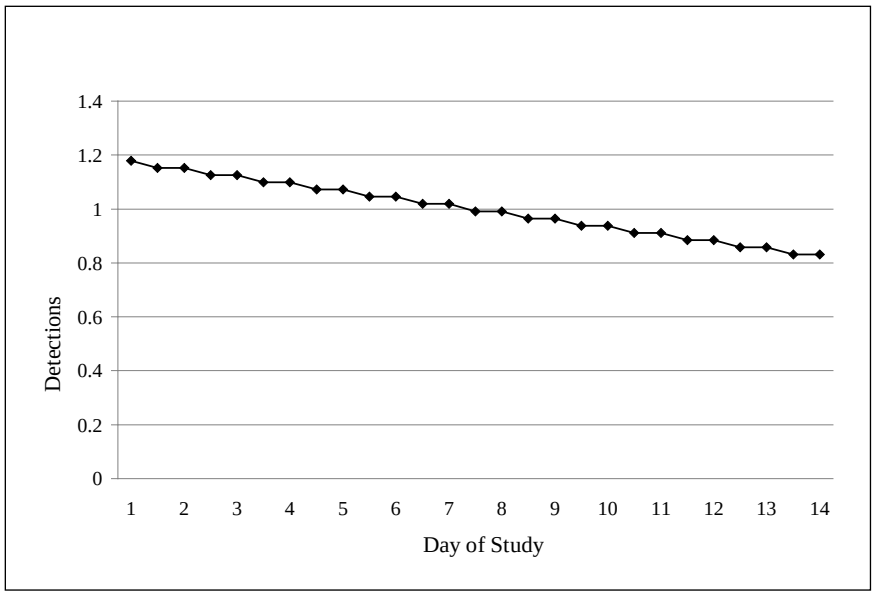


Figure 16. Values predicted from the regression on average hourly detections per day of stationary tags in 2006. The data are log-transformed.

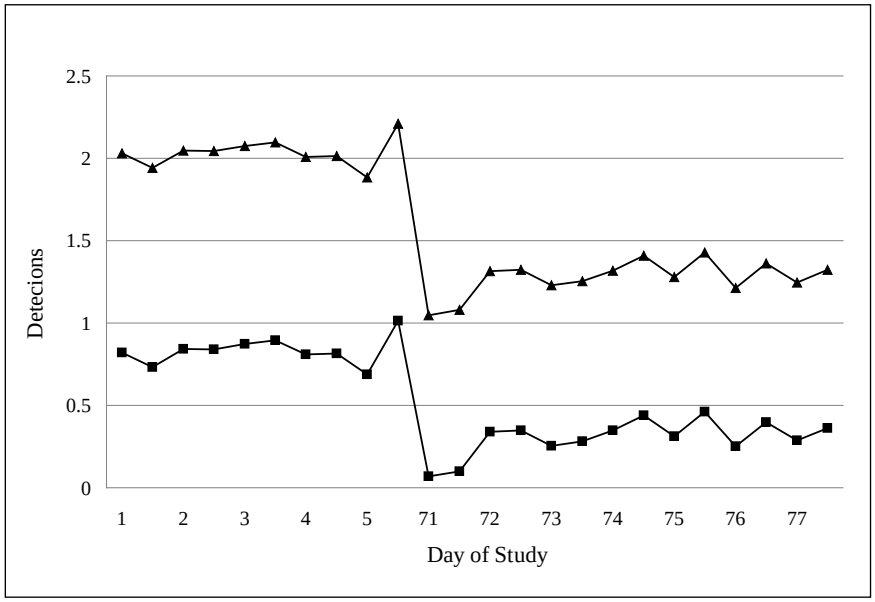


Figure 17. Values predicted from the regression on average hourly detections per day of stationary tags in 2005. The data are log-transformed.

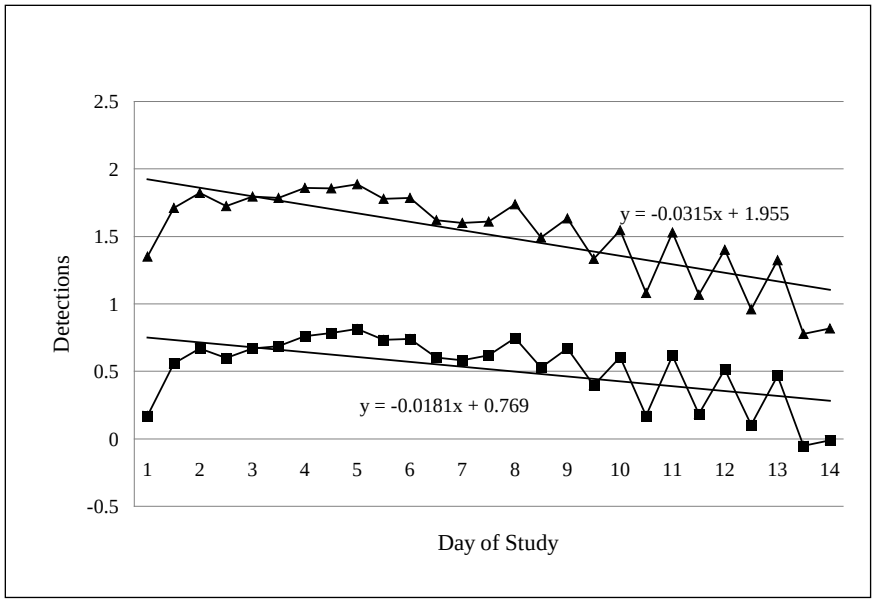


Figure 18. Average hourly detections per day of tagged fish in 2006; triangles are the original data, and squares are the detrended data. All data are log-transformed.

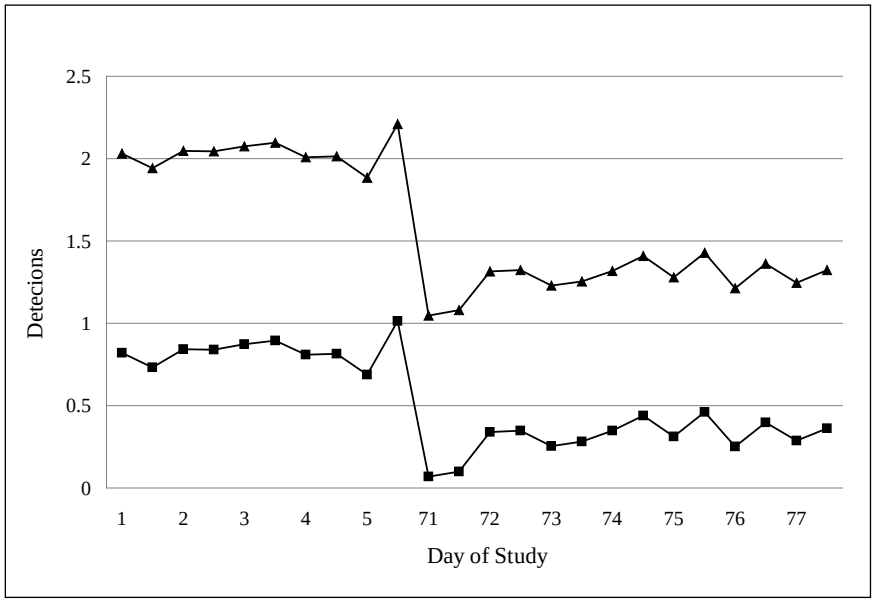


Figure 19. Average hourly detections per day of tagged fish in 2005; triangles are the original data, and squares are the detrended data. All data are log-transformed.

The LOESS regression plot from 2006 revealed highest values during nighttime hours; fewer detections occurred 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, moon phase, and photoperiod were significant variables, so we used them to form the model for the generalized linear mixed model (GLMM). The correlation between day and moon-phase was high (r= 0.77), so we 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.

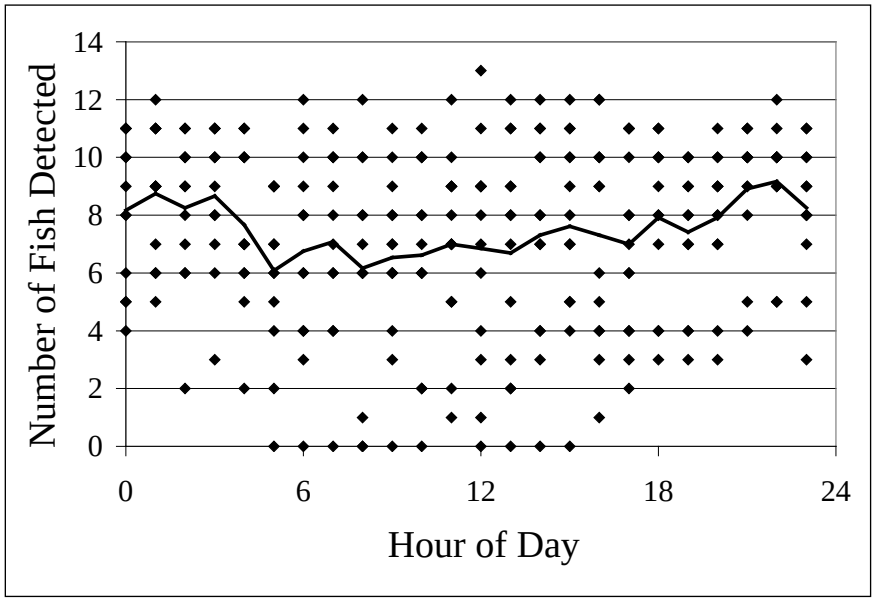


Figure 20. The number of fish detected per hour of day in 2006, with a LOESS regression fit to display diel trends.

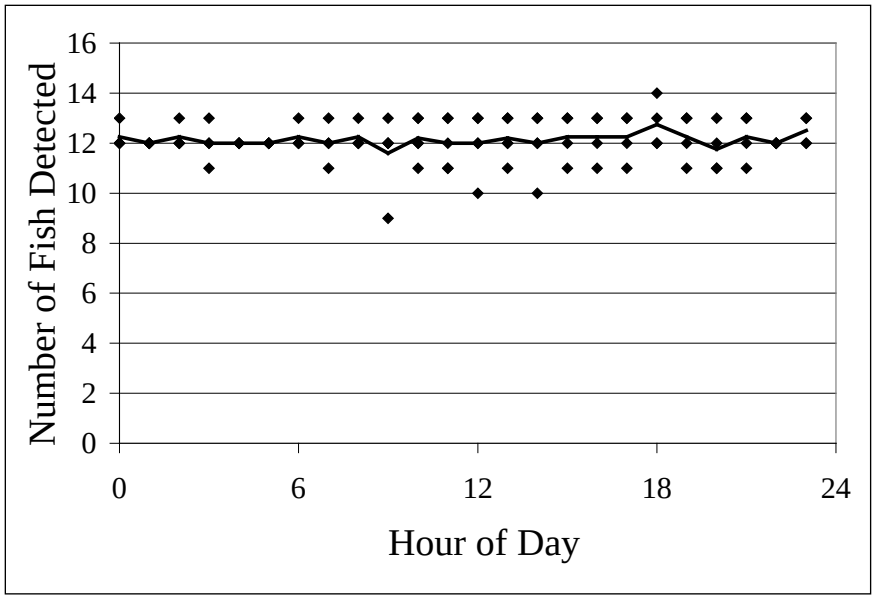


Figure 21. The number of fish detected per hour of day in May 2005, with a LOESS regression fit to display diel trends.

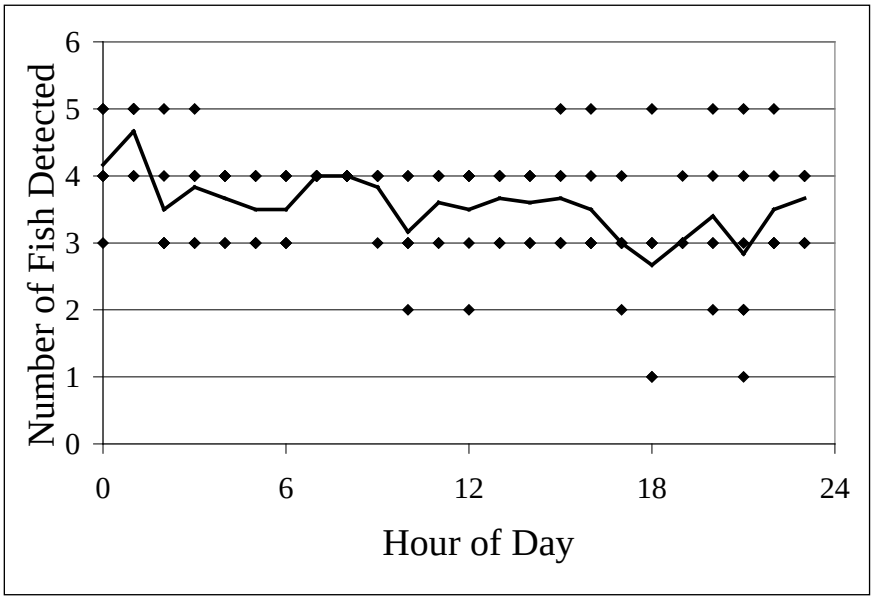


Figure 22. The number of fish detected per hour of day in August 2005, with a LOESS regression fit to display diel trends.

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).

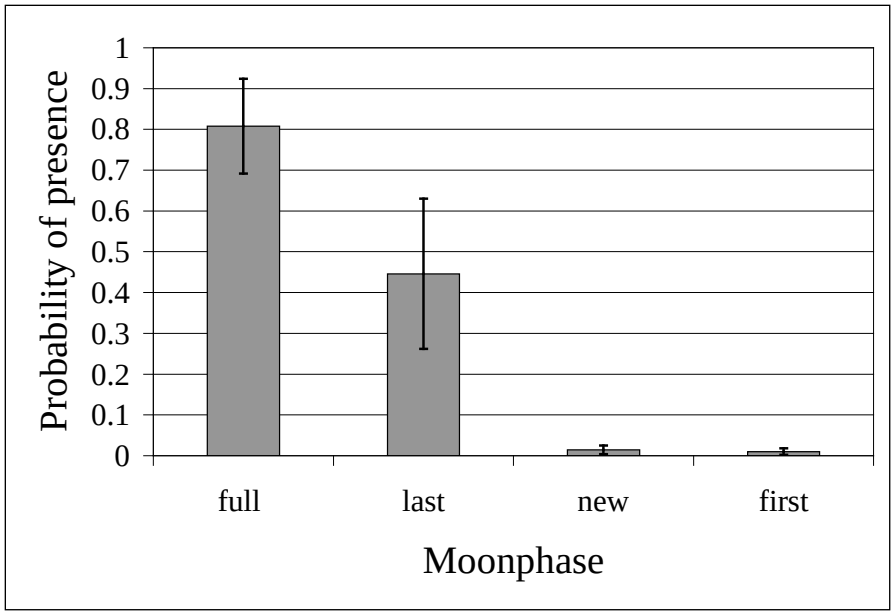


Figure 23. Mean probability of presence, across all fish and both years, by moon phase. Error bars indicate one standard error.

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).

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).

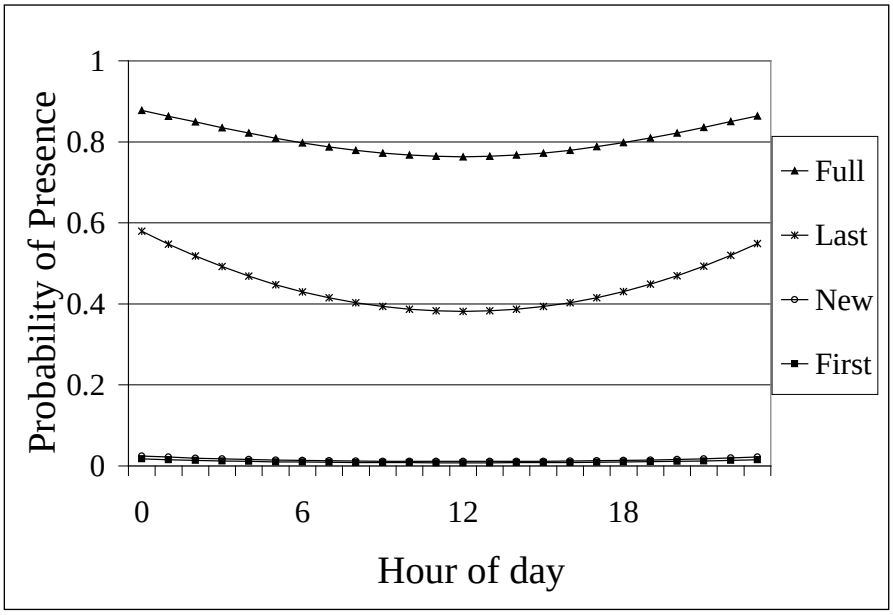


Figure 24. Probability of presence, across all fish, by hour of day.

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).

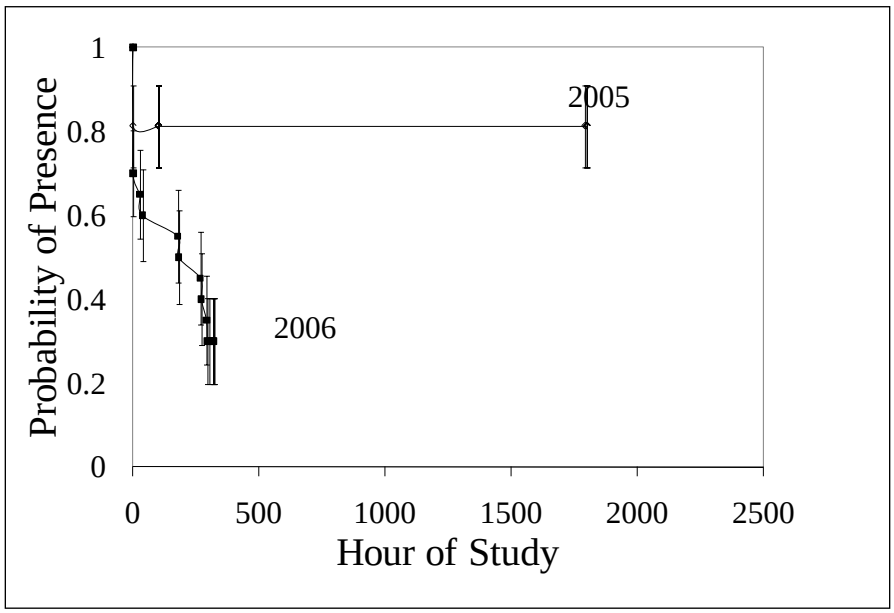


Figure 25. Probability of presence, as calculated by the survival analysis.

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 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 five 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).

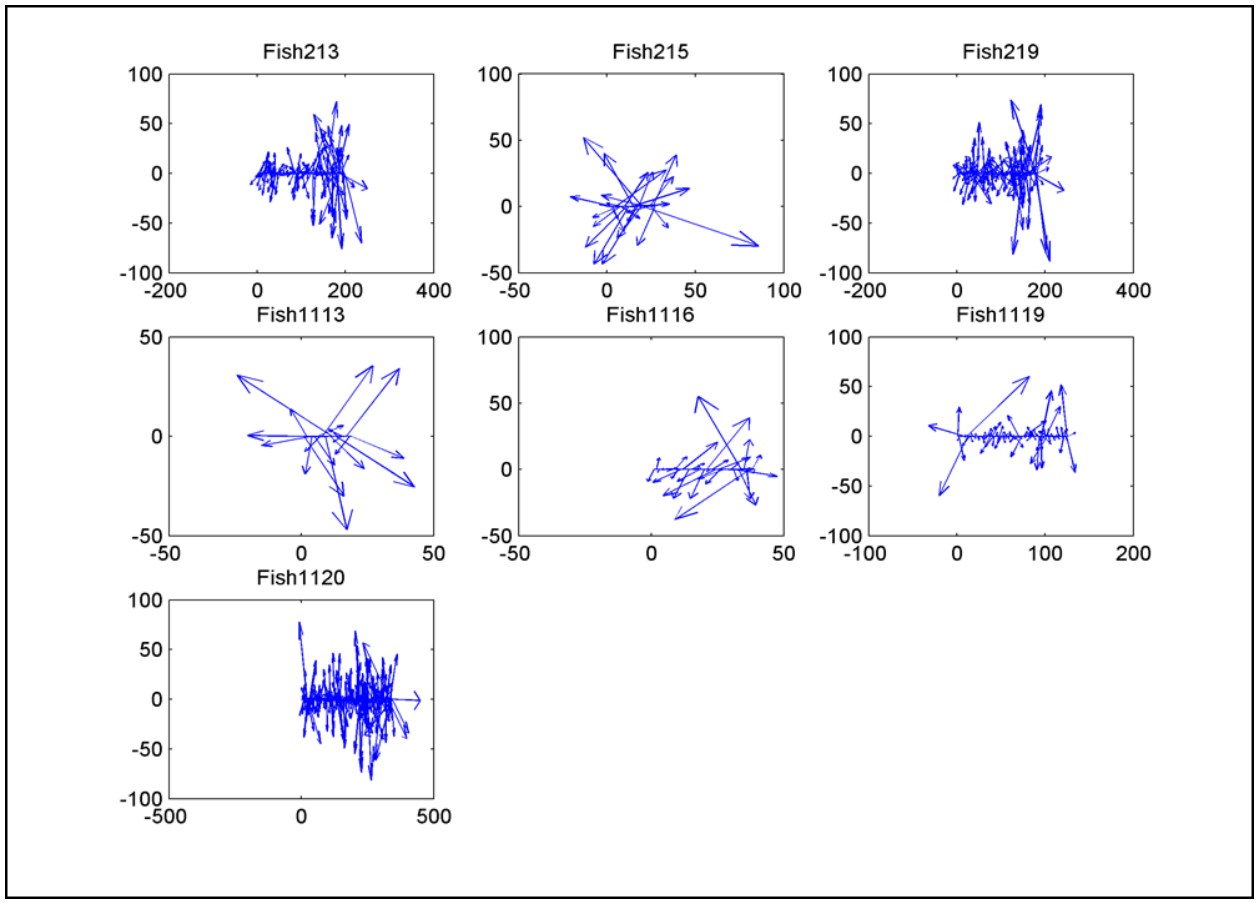


Figure 26. Feather plots showing the consecutive movements of fish during the 2006 experiment. Each vector represents a movement between consecutive points.

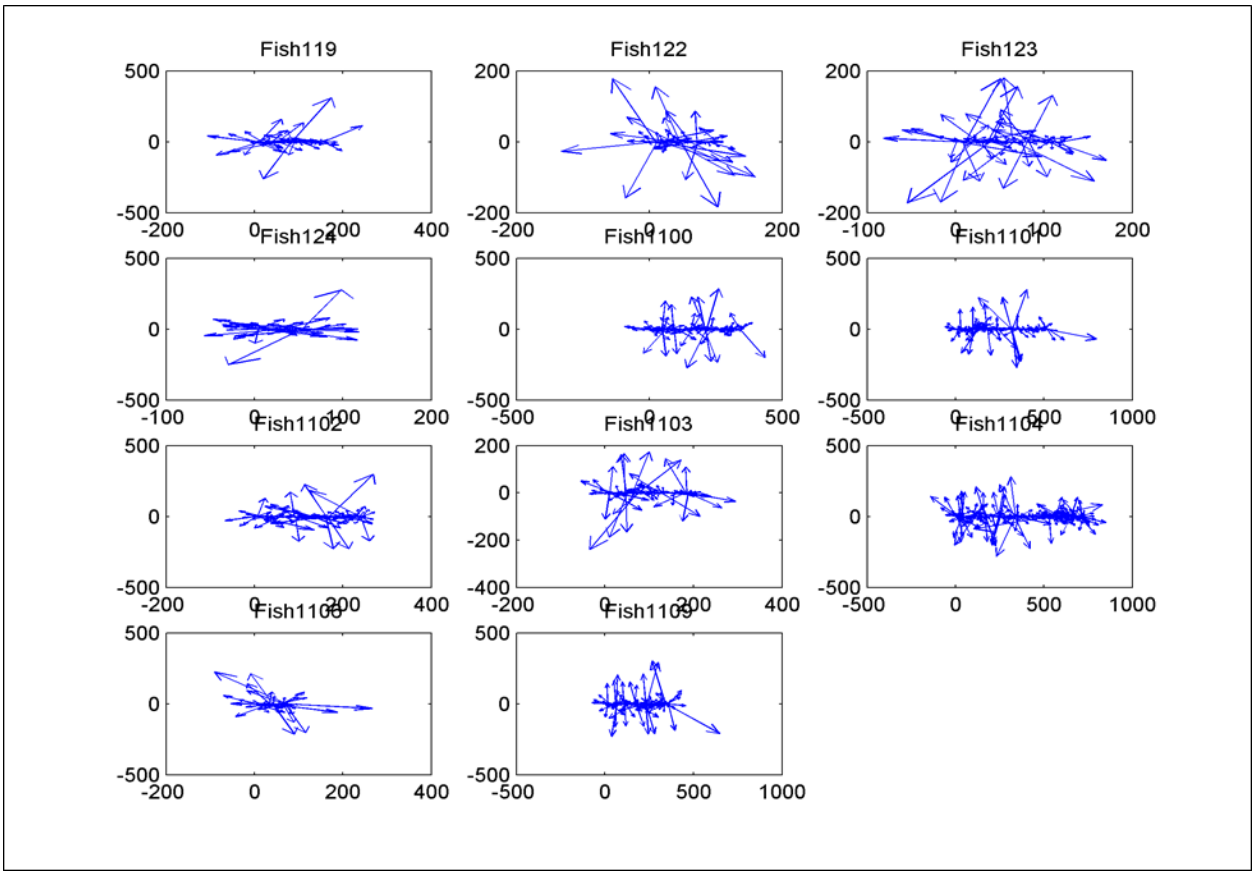


Figure 27. Feather plots showing the consecutive movements of fish during the 2005 experiment. Each vector represents a movement between consecutive points

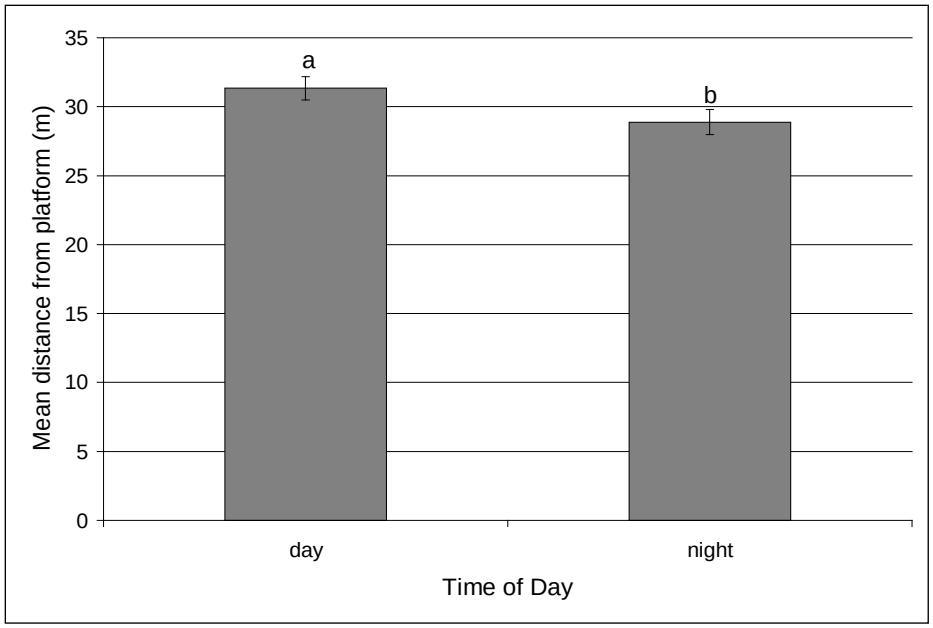


Figure 28. Mean distance from the platform for all fish by time of day in 2006. Letters indicate significant differences.

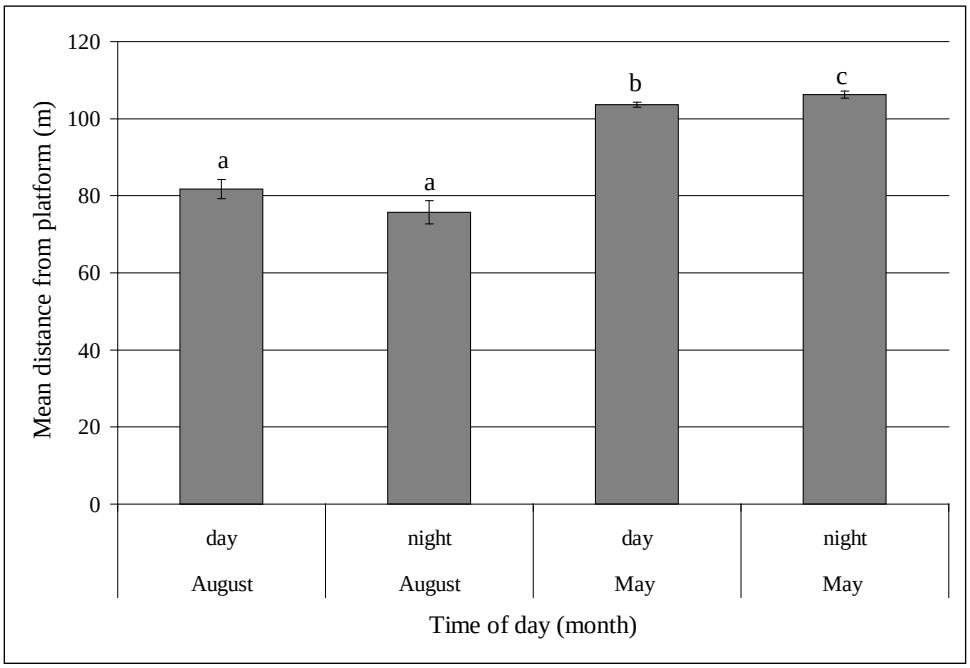


Figure 29. Mean distance from the platform for all fish by time of day in 2006. Letters indicate significant differences.

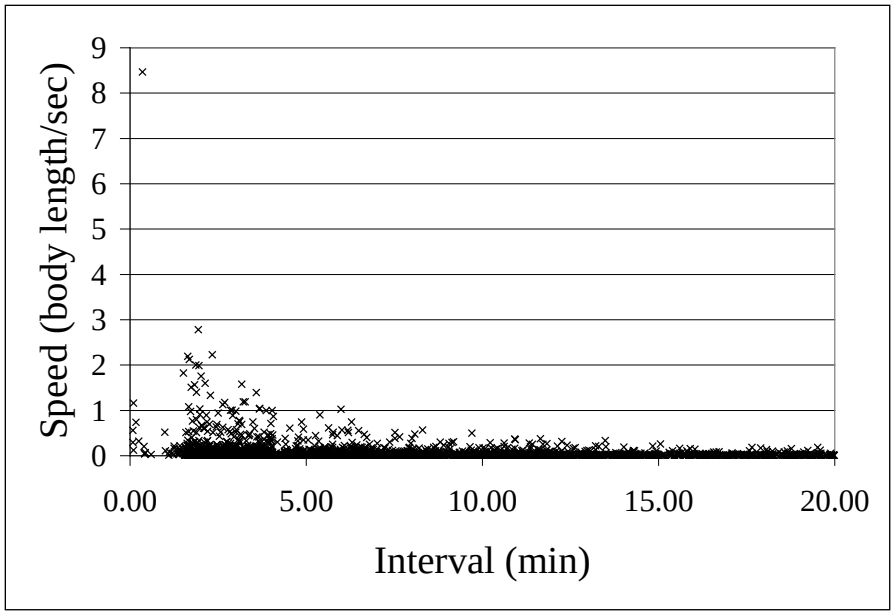


Figure 30. Interval, the time between two recorded positions, compared with the speed of movement between those two positions.

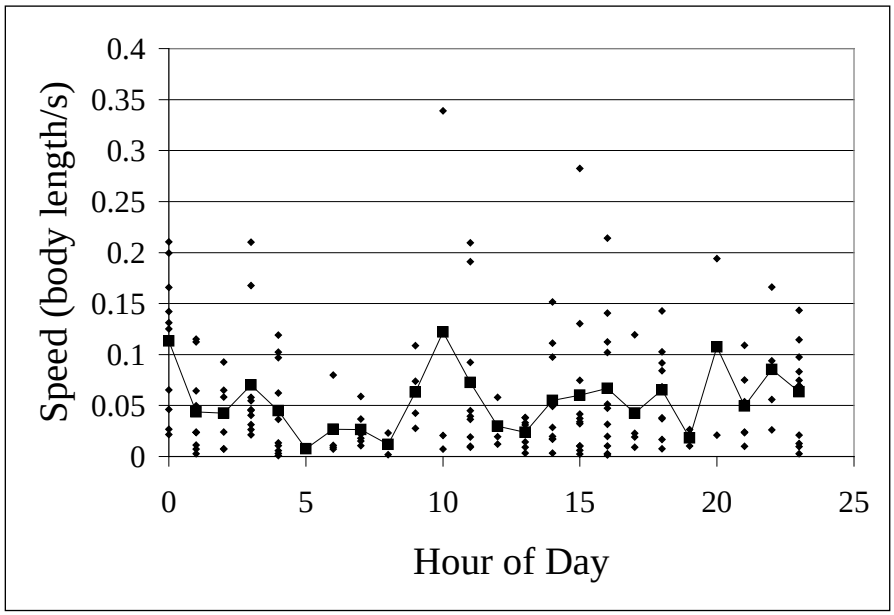


Figure 31. Speed, in body lengths per second, for hour of day for 2006. The mean value for each hour is superimposed.

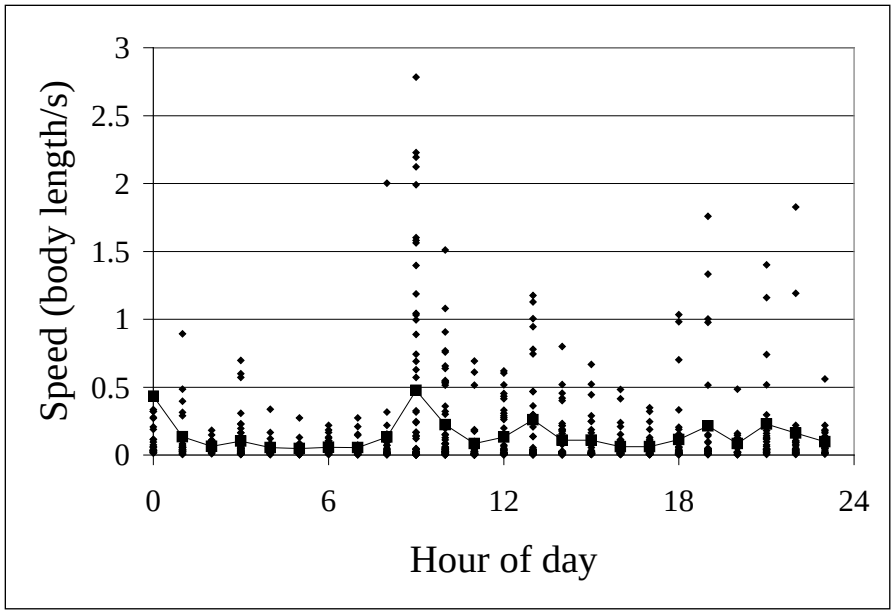


Figure 32. Speed, in body lengths per second, for hour of day for 2005. The mean value for each hour is superimposed.

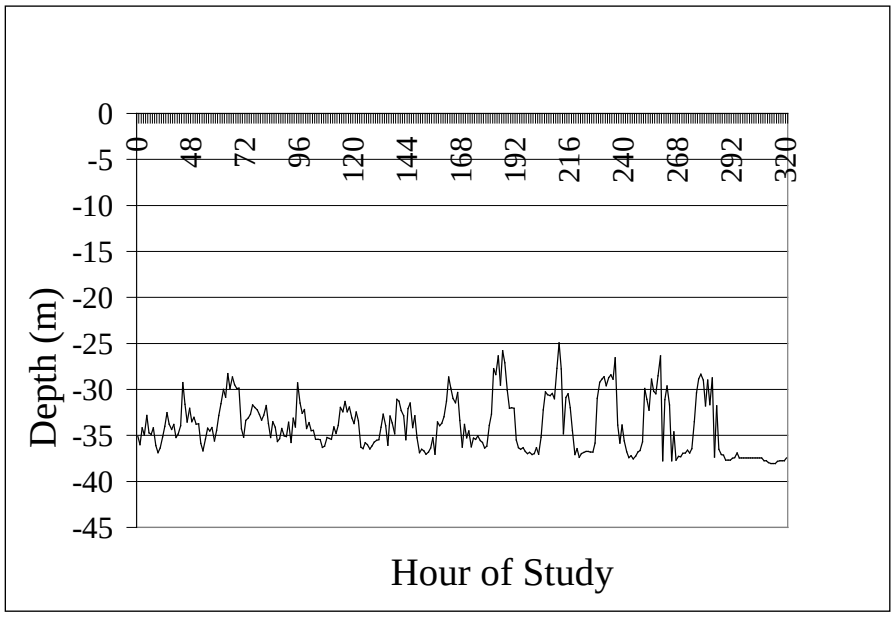


Figure 33. Mean depth, in meters, for each hour of the study in 2006.

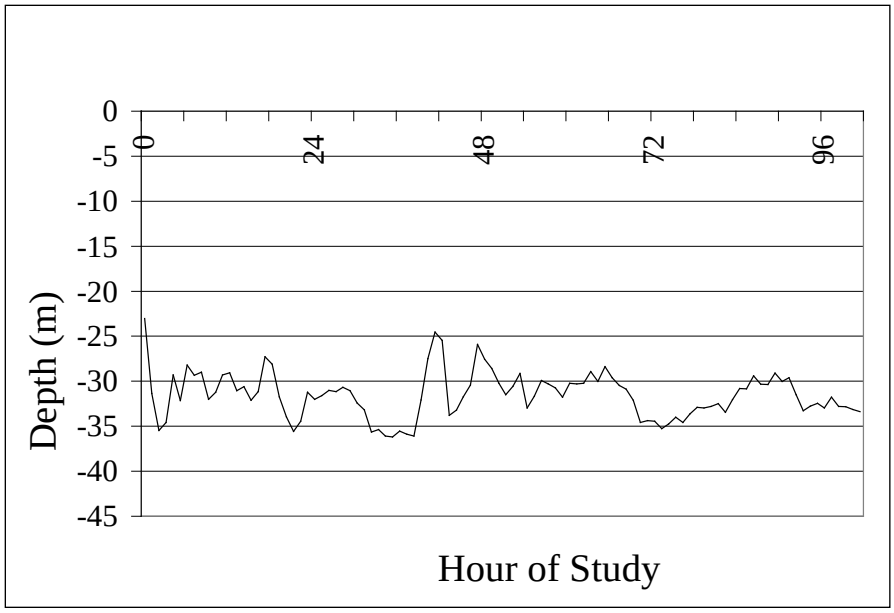


Figure 34. Mean depth, in meters, for each hour of the study in May 2005.

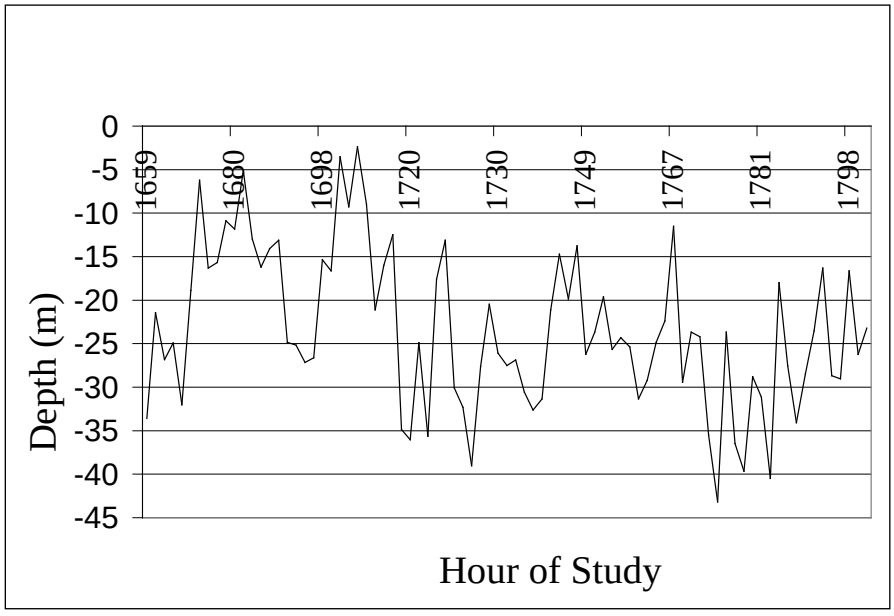


Figure 35. Mean depth, in meters, for each hour of the study in August 2005.

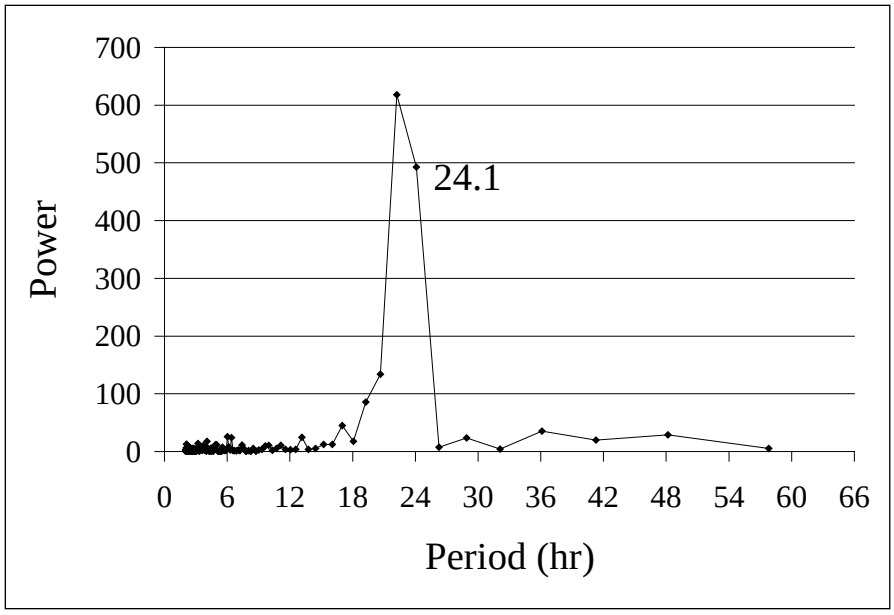


Figure 36. Periodogram from the spectral analysis on all depths per hour of study in 2006. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

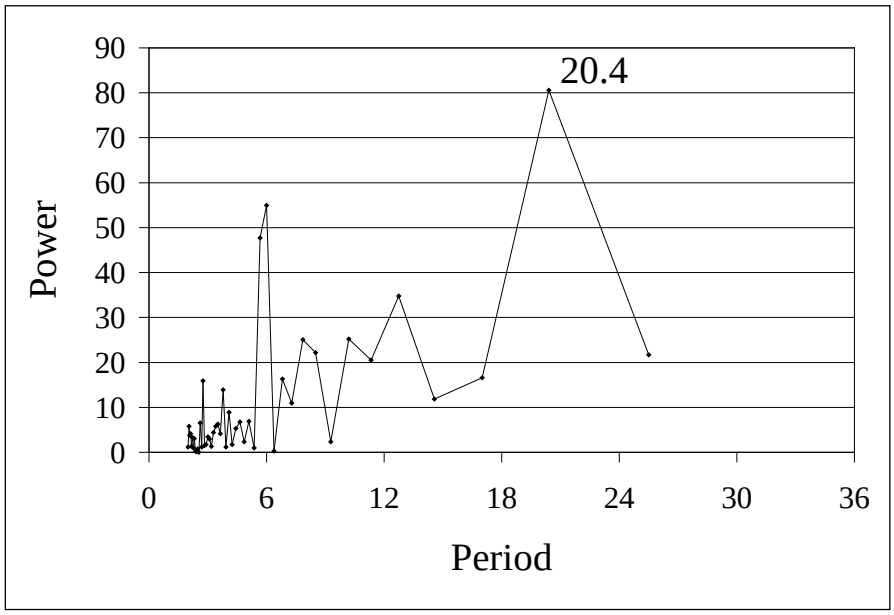


Figure 37. Periodogram from the spectral analysis on all depths per hour of study in May 2005. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

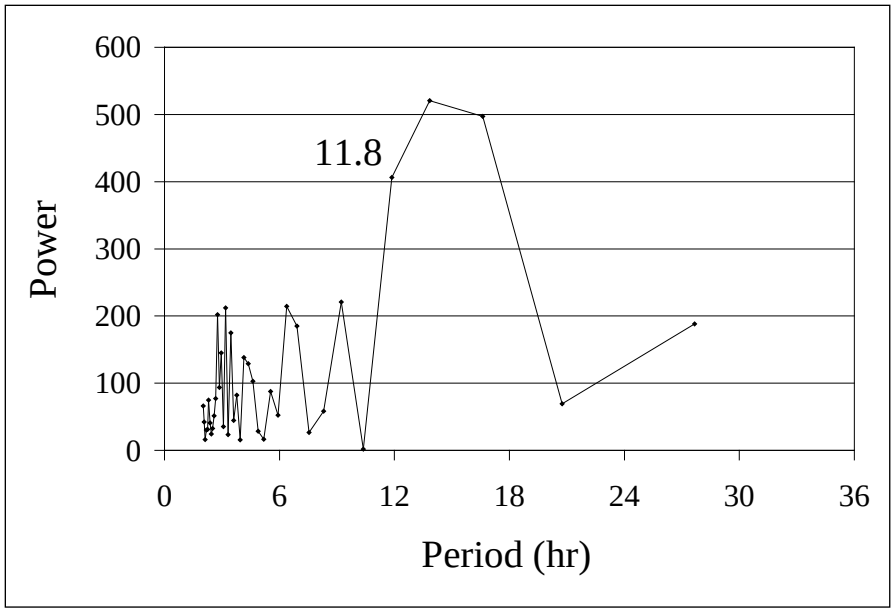


Figure 38. Periodogram from the spectral analysis on all depths per hour of study in August 2005. Hours are on the x-axis, and the y-axis shows the power of the periodicity.

4.0 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, provides 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, we were able to collect a complete two-week dataset that provides the best short-term picture. In 2005, our experiment was interrupted. However, we were able to redeploy when a few of the 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 appeared to have left before the VRAP was initialized. It is possible that these fish were consumed by predators during swim down, as we frequently observed marine mammals and fish predators in close proximity to the charter boat

where the tagging was taking place. In 2006, we 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 we 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 our 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 we believe that moon phase 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 at the beginning of the experiment) and less likely to be present during the first quarter (rather than at the end of the experiment), we 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 halos 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 et 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). We 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 occurred 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). We 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 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 this 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. We 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; Cowan et al., 2010), suggests to us 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 we 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 three species, namely red snapper, gag grouper, and grey trigger fish (Strelcheck et al., 2005). These three species account for more than 85% of the fish biomass observed, and red snapper alone accounted 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, we 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 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. Our 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 this 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 on 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 fish remaining within 50-kmwide 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 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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REFERENCES

Attwood, C.G. and B.A. Bennett. **1994**. Variation in dispersal of galjoen (*Coracinus capensis*) (Teleostei: Coradinidae) from a marine reserve. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 1247-1257.

Beamish, R.J. and G.A. McFarlane. **1988**. Resident and dispersal behavior of adult sablefish (*Anaplopoma fimbria*) in the slope waters off Canada's West Coast. *Canadian Journal of Fisheries and Aquatic Sciences* 45: 152-164.

Beaumariage,D.S. **1969**. Returns from the 1965 Schlitz Tagging Program including a cumulative analysis of previous results. St. Petersburg, Florida, Marine Research Laboratory-Florida Department of Natural Resources-Division of Marine Resources**:** iii - 38.

Bohnsack, J.A. **1989**. Are high densities of fishes at artificial reefs the result of habitat limitations or behavioral preference? *Bulletin of Marine Science* 44: 631-645.

Bortone, S.A., R.P. Cody, R.K. Turpin, C.M. Bundrick. **1998**. The impact of artificial-reef fish assemblages on their potential forage area. *Italian Journal of Zoology* 65: 265-267.

Cowan, J.H. Jr., C.B. Grimes, W.F. Patterson III, C.J. Walters, A.C. Jones, W.J. Lindberg, D.J. Sheehy, W.E. Pine III, J.E. Powers, M.D. Campbell, K.C. Lindeman, S.L. Diamond, R. Hilborn, H.T. Gibson and K.A. Rose. **2010**. Red snapper management in the Gulf of Mexico: science- or faith-based? *Reviews in Fish Biology and Fisheries*, DOI 10.1007/s11160-010-9165-7.

Fable, W.A. **1980**. Tagging studies of red snapper (*Lutjanus campechanus*) and vermilion snapper (*Rhomoplites aurorubens*) off the south Texas coast. *Marine Science* 23: 115-121.

Gallaway, B.J., L.R. Martin, R.L. Howard, G.S. Boland, and G.D. Dennis. **1981**. Effects on artificial reef and demersal fish and macro-crustacean communities. *In* Environmental effects of offshore oil production: the Buccaneer gas and oil field study. *Edited by* B.S. Middleditch. *Marine Science* Vol. 14. Plenum Press, New York. Pp. 237-299.

Gallaway, B.J., J.G. Cole, R. Meyer, and J.P. Roscigno. **1999**. Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico. *Transactions of the American Fisheries Society* 128:713-726.

Helfman, G.S. **1986**. Fish behaviour by day, night and twilight. *In* The Behavior of Teleost Fishes. T.J. Pitcher (ed.) Johns Hopkins University Press, Baltimore. pp 366-387.

Hobson, E.S. **1965**. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California. *Copeia* 3: 291-302.

Jennings, S., M.J. Kaiser, J.D. Reynolds. **2001**. Acoustic methods. Pages 209-210 in *Marine Fisheries Ecology*. Blackwell Science, Ltd., Malden, Massachusetts.

Lindberg, W.J., T.K. Frazer, and G.R. Stanton. **1990**. Populations effects of refuge dispersion for adult stone crabs (Xanthidae, *Menippe*). *Marine Ecology Progress Series* 66: 239-249.

Lindquist, D.G., L.B. Cahoon, I.E. Clavijo, M.H. Posey, S.K. Bolden, L.A. Pike, S.W. Burk, and P.A. Cardullo. **1994**. Reef fish stomach contents and prey abundance on reef and sand substrata associated with adjacent artificial and natural reefs in Onslow Bay, North Carolina. *Bulletin of Marine Science* 55: 308-318.

Love, M.S., J. Caselle, and L. Snook. **1999**. Fish assemblages on mussel mounds surrounding seven oil platforms in the Santa Barbara channel and Santa Maria Basin. *Bulletin of Marine Science* 65: 497-513.

Love, M.S., J. Caselle, and L. Snook. **2000**. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. *United States Fishery Bulletin* 98: 96-117.

McCawley, J.A., and J.H. Cowan, Jr. **2007**. Seasonal and size specific diet and prey demand of red snapper on Alabama artificial reefs. *In* W.F. Patterson, J.H. Cowan, Jr., G.R. Fitzhugh, and D.L. Nieland, editors. Red snapper ecology and fisheries in the US Gulf of Mexico. *American Fisheries Society Symposium 60*, Bethesda, Maryland.

Nieland, D.L., and C.A. Wilson. **2002**. Red snapper recruitment to and disappearance from oil and gas platforms in the northern Gulf of Mexico. *American Fisheries Society Symposium* 36: 73-81.

Ouzts, A.C., and S.T. Szedlmayer. **2003**. Diel feeding patterns of red snapper on artificial reefs in the north-central Gulf of Mexico. *Transactions of the American Fisheries Society* 132: 1186-1193.

Patterson, W.F., III, J.H. Cowan, Jr., E.Y. Graham, and W.B. Lyons. **1998**. Otolith microchemical fingerprints of age-0 red snapper, *Lutjanus campechanus* for the northern Gulf of Mexico. *Gulf of Mexico Science* 16: 83-91.

Patterson, W. F., J.C. Watterson, R.L. Shipp, and J.H. Cowan, Jr. **2001**. Movement of tagged red snapper in the northern Gulf of Mexico. *Transactions of the American Fisheries Society* 130: 533-545.

Patterson, W. F., J.H. Cowan, and R.L. Shipp. **2003**. Site fidelity and dispersion of red snapper associated with artificial reefs in the northern Gulf of Mexico. *American Fisheries Society Symposium* 37: 181-194.

Rummer, J.L., and W.A. Bennett. **2005**. Physiological effects of swim bladder overexpansion and catastrophic decompression on red snapper. *Transactions of the American Fisheries Society* 134: 1457-1470.

SAS Institute, Inc. 2007. SAS 9.1.3. Cary, North Carolina, USA.

Seaman, W.J., W.J. Lindberg, C.R. Gilbert, and T.K. Frazer. **1989**. Fish habitat provided by obsolete petroleum platforms off southern Florida. *Bulletin of Marine Science* 44: 1014-1022.

GMFMC (Gulf of Mexico Fishery Management Council). **2005**. SEDAR 7: Southeast data, assessment, and review--stock assessment report of SEDAR 7 Gulf of Mexico red snapper. Available at http://www.gulfcouncil.org/downloads/SEDAR7%20AW%20report%20main.pdf [2006, February 7].

Schirripa, M.J., and C.M. Legault. **1999**. Status of red snapper in U.S. waters of the Gulf of Mexico: updated through 1998. NMFS, SFD, Miami, Florida. SFD-99/00-75.

Schmitten, R.A. **1999**. Essential fish habitat: Opportunities and challenges for the next millennium. *American Fisheries Society Symposium* 22: 3-10.

Sedberry, G.R. and N. Cuellar. **1993**. Planktonic and benthic feeding by the reef-associated vermilion snapper, *Rhomboplites aurorubens* (Teleostei, Lutjanidae). *United States Fishery Bulletin* 91: 699-709.

Stanley, D.R. **1994**. Seasonal and spatial abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico, Ph. D. Thesis, Louisiana State University. Baton Rouge.

Stanley, D.R. and C.A. Wilson. **1991**. Factors affecting the abundance of selected fishes near oil and gas platforms in the Northern Gulf of Mexico. *United States Fishery Bulletin* 89:149-159.

Stanley, D. R. and C. A. Wilson. 1997. Seasonal and spatial variation in the abundance and size distribution of fishes associated with a petroleum platform in the northern Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences 54:1166-1176.

Stanley, D. R. and C. A. Wilson. 1998. Spatial variation in fish density at three petroleum platforms as measured with Dual-Beam hydroacoustics. Gulf of Mexico Science 16:73-82.

Strelcheck, A.J., J.H. Cowan, and A. Shah. **2005**. Influence of reef location on artificial-reef fish assemblages in the northcentral Gulf of Mexico. *Bulletin of Marine Science* 77: 425-440.

Szedlmayer, S.T. **1997**. Ultrasonic telemetry of red snapper, *Lutjanus campechanus*, at artificial reef sites in the northeast Gulf of Mexico. *Copeia* 4: 846-850.

Szedlmayer, S.T. and J. Conti. **1999**. Nursery habitats, growth rates, and seasonality of age-0 red snapper, *Lutjanus campechanus*, in the northeast Gulf of Mexico. *United States Fishery Bulletin* 97:626-635.

Szedlmayer, S.T. and R.L. Schroepfer. **2005**. Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico. *Transactions of the American Fisheries Society* 134: 315-325.

Szedlmayer, S.T. and R.L. Shipp. **1994**. Movement and growth of red snapper, *Lutjanus campechanus*, from an artificial reef area in the northeastern Gulf of Mexico. *Bulletin of Marine Science* 55: 887-896.

Versar. **2008**. Literature search and data synthesis of biological information for use in management decisions concerning decommissioning of offshore oil and gas structures in the Gulf of Mexico.

Wells, R.J.D., J.H. Cowan Jr., and B. Fry. **2008**. Feeding ecology of red snapper, *Lutjanus campechanus*, in the northern Gulf of Mexico. *Marine Ecology Progress Series* 361: 213-225.

Werner, E.E. and B.R. Anholt. **1993**. Ecological consequences of the trade-off between growth and mortality rates mediated by foraging activity. *American Naturalist* 142: 242-272.

Westmeyer, M.P., C.A. Wilson, and D.L. Nieland. **2007**. Fidelity of red snapper to petroleum platforms in the northern Gulf of Mexico. *In* W.F. Patterson, J.H. Cowan, Jr., G.R. Fitzhugh, and D.L. Nieland, editors. Red snapper ecology and fisheries in the US Gulf of Mexico. *American Fisheries Society Symposium 60*, Bethesda, Maryland.

Willis, T.J., D.M. Parsons, and R.C. Babcock. **2001**. Evidence of long-term site fidelity of snapper (*Pagrus auratus*) within a marine reserve. *New Zealand Journal of Marine and Freshwater Research* 35: 581-590.

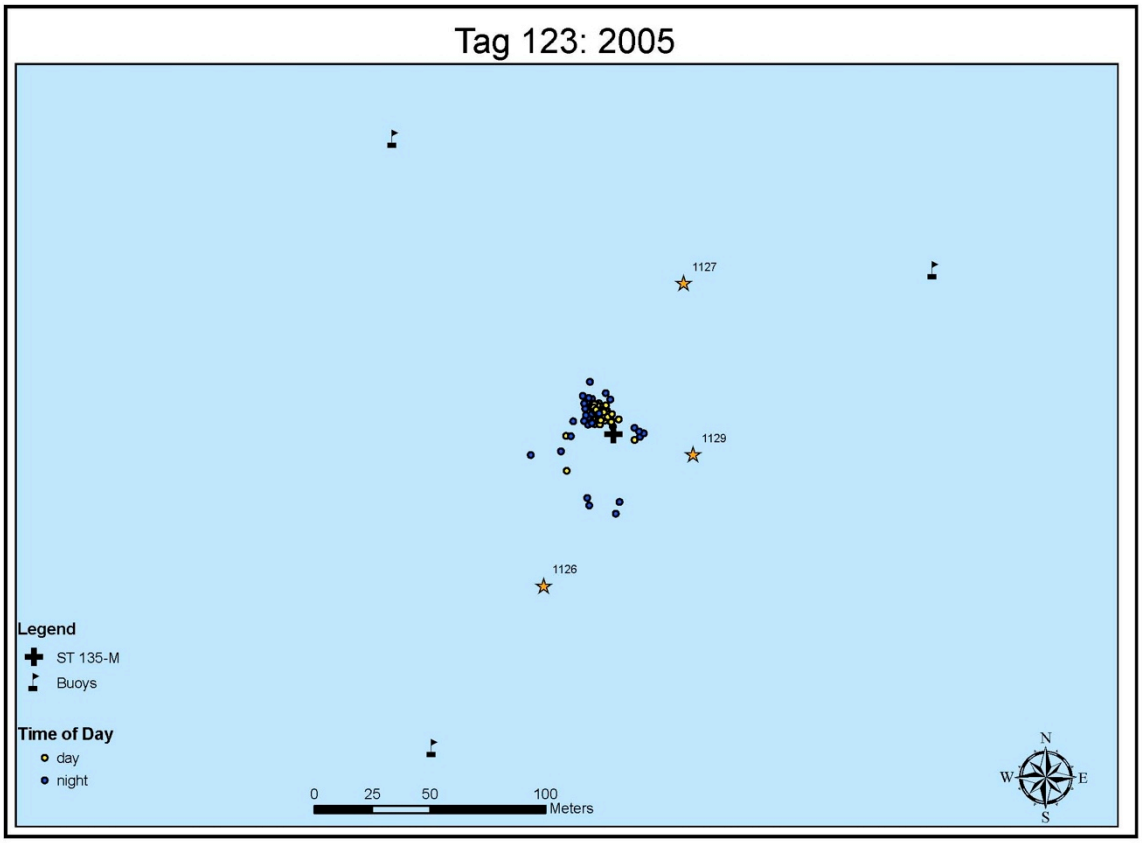
Wilson, C.A., and D.L. Nieland. **2004**. The role of oil and gas platforms in providing habitat for northern Gulf of Mexico red snapper, *Lutjanus campechanus*. *Proceedings of the Gulf and Caribbean Fisheries Institute* 55: 757-764.

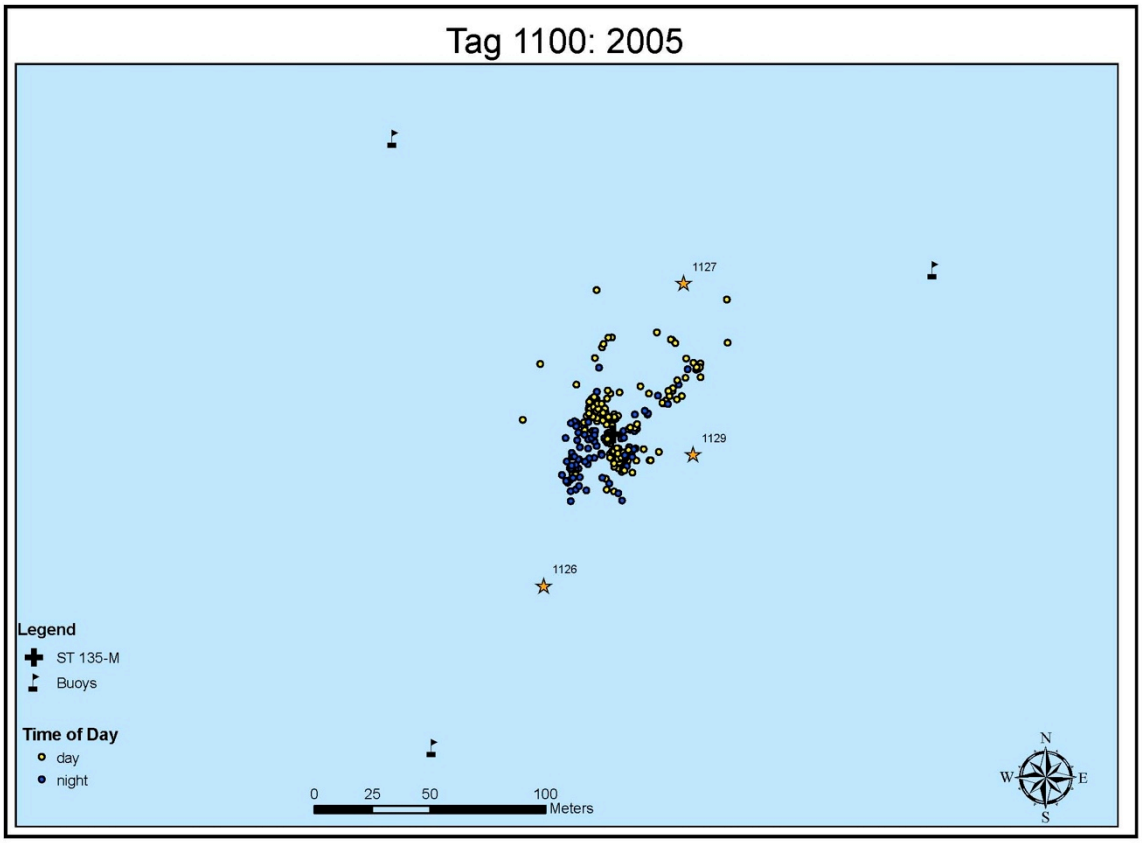
Workman, I.K., and D.G. Foster. **1994**. Occurrence and behavior of juvenile red snapper, Lutjanus campechanus, on commercial shrimp fishing grounds in the northeastern Gulf of Mexico. Marine Fisheries Review 56: 9-11.

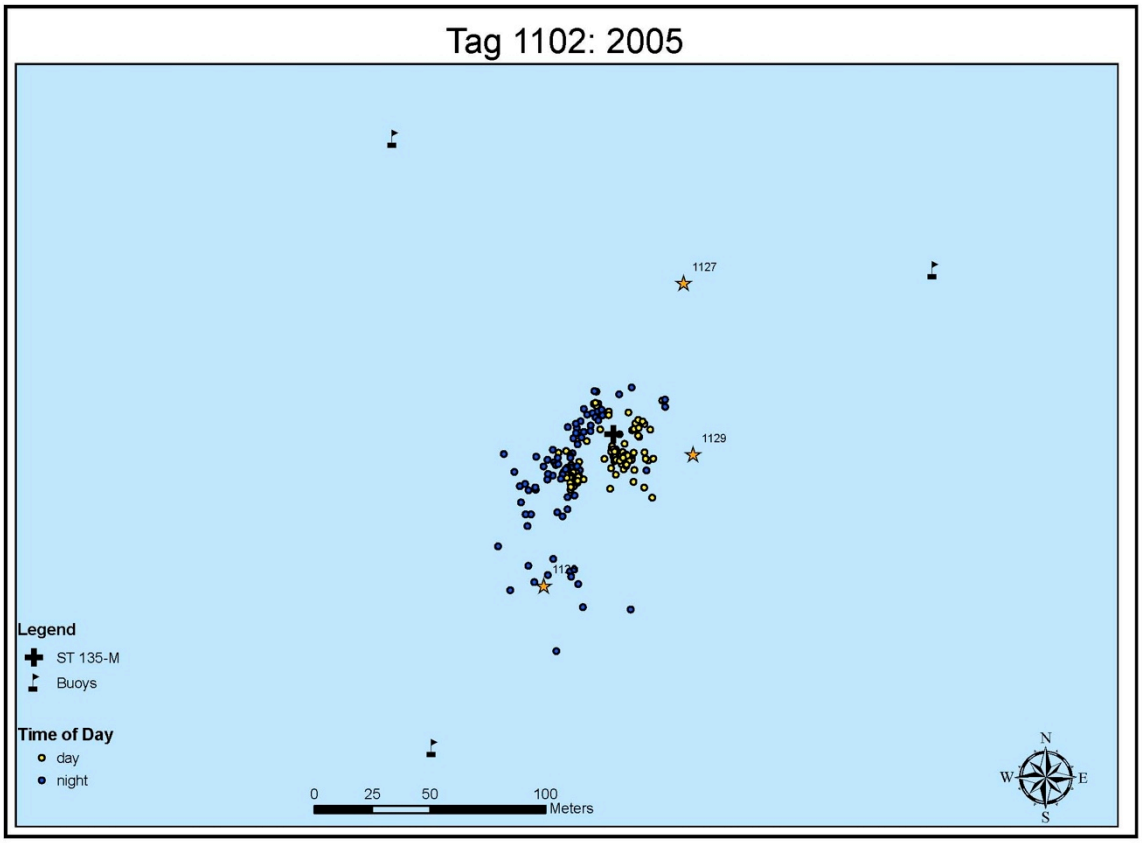
Zar, J.H. 1998. Biostatistical analysis, 4th ed. Prentice Hall, Upper Saddle River, New Jersey.

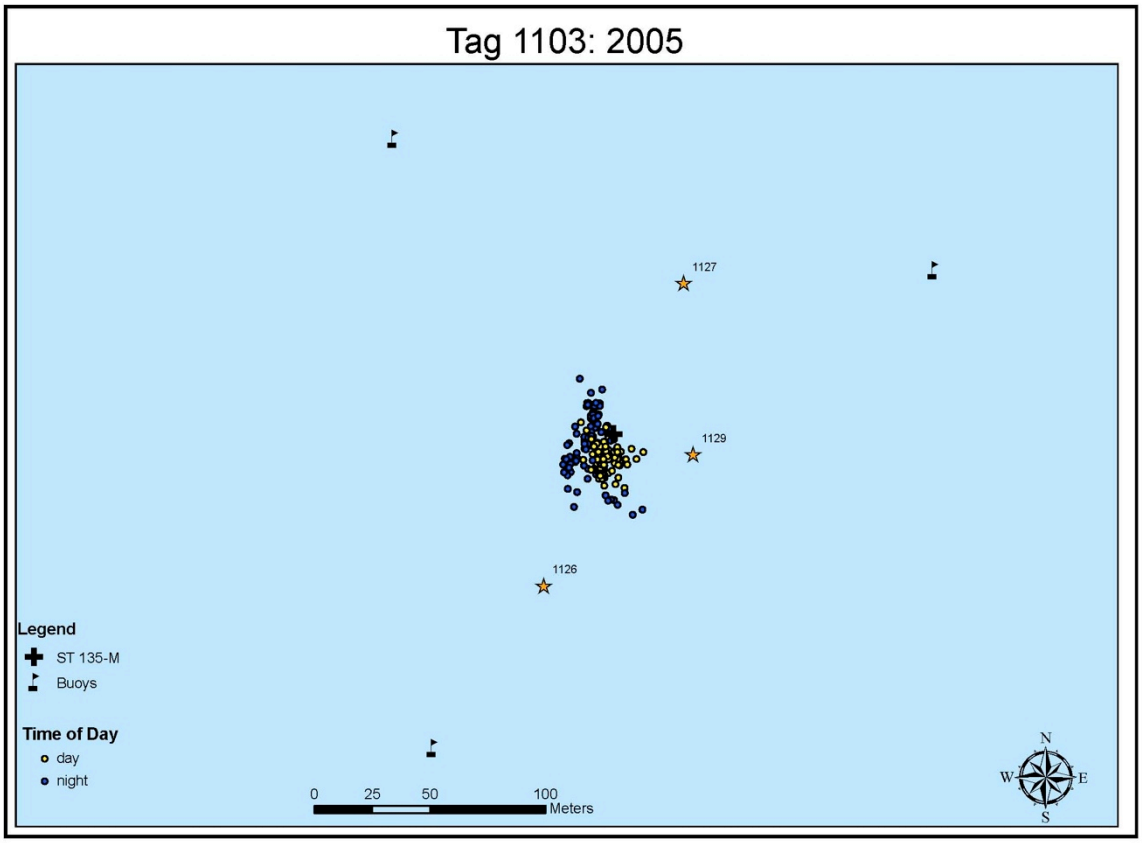
APPENDIX: REMAINING FISH PLOTS

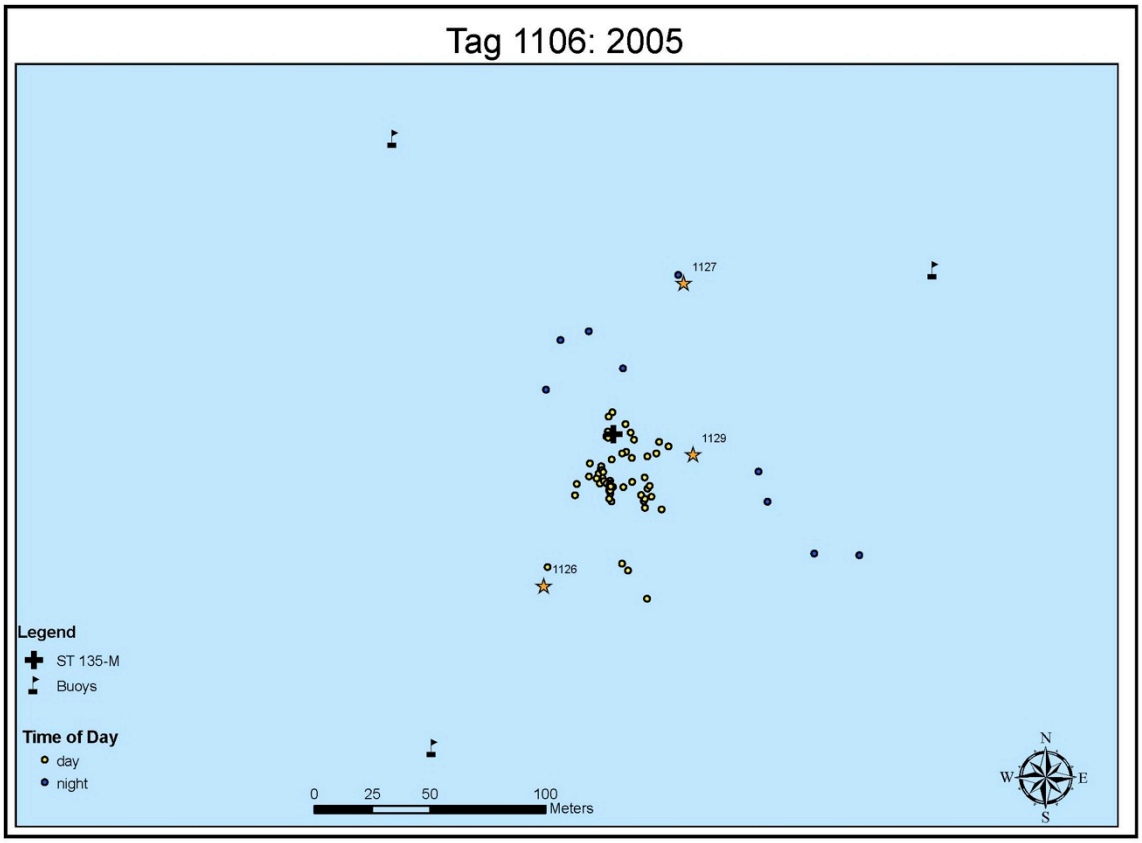
This appendix contains the plots of all fish for which there were more than 24 hours worth of positions.

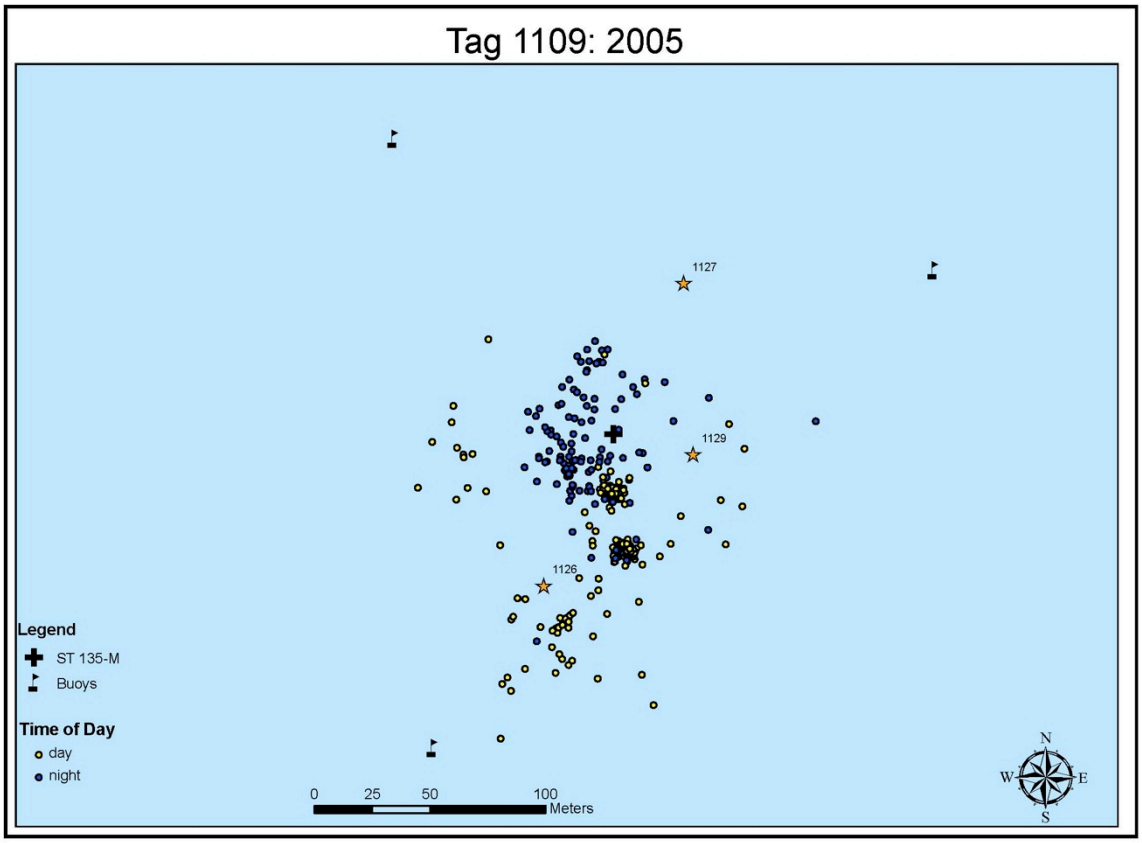

Tag 123: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

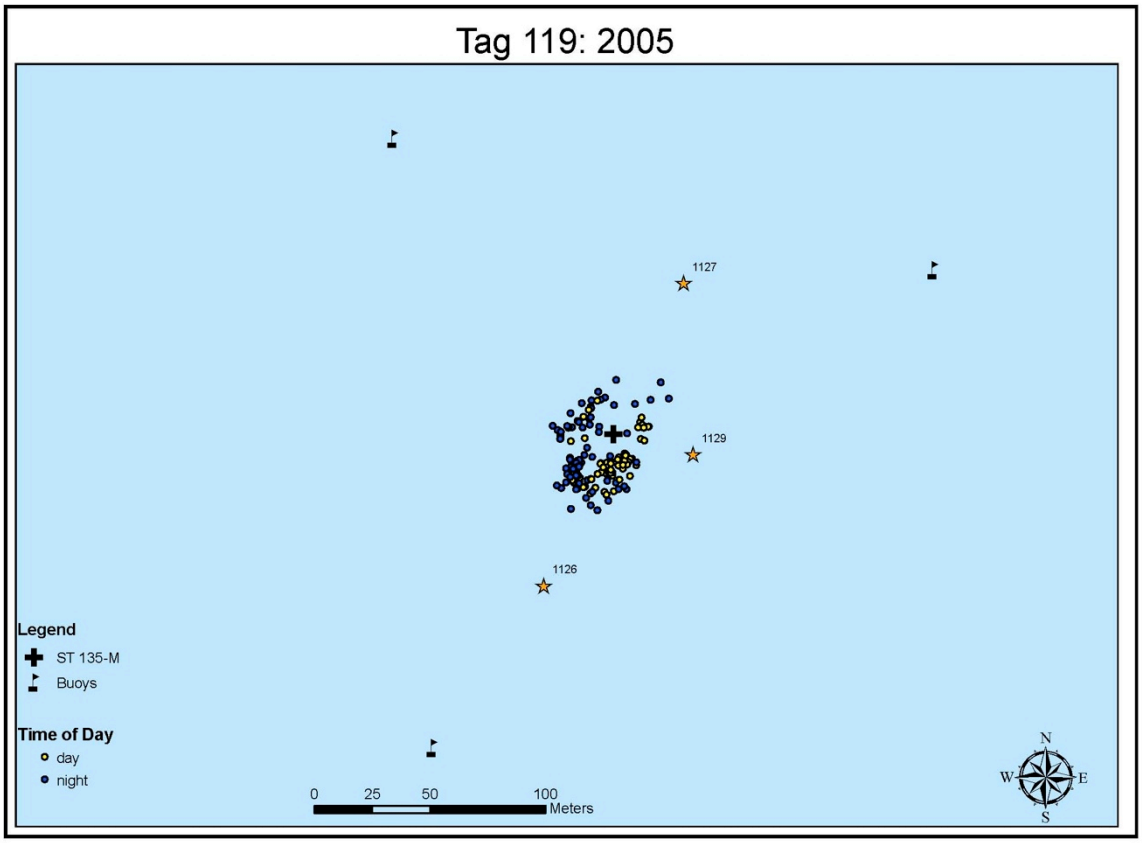

Tag 1100: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

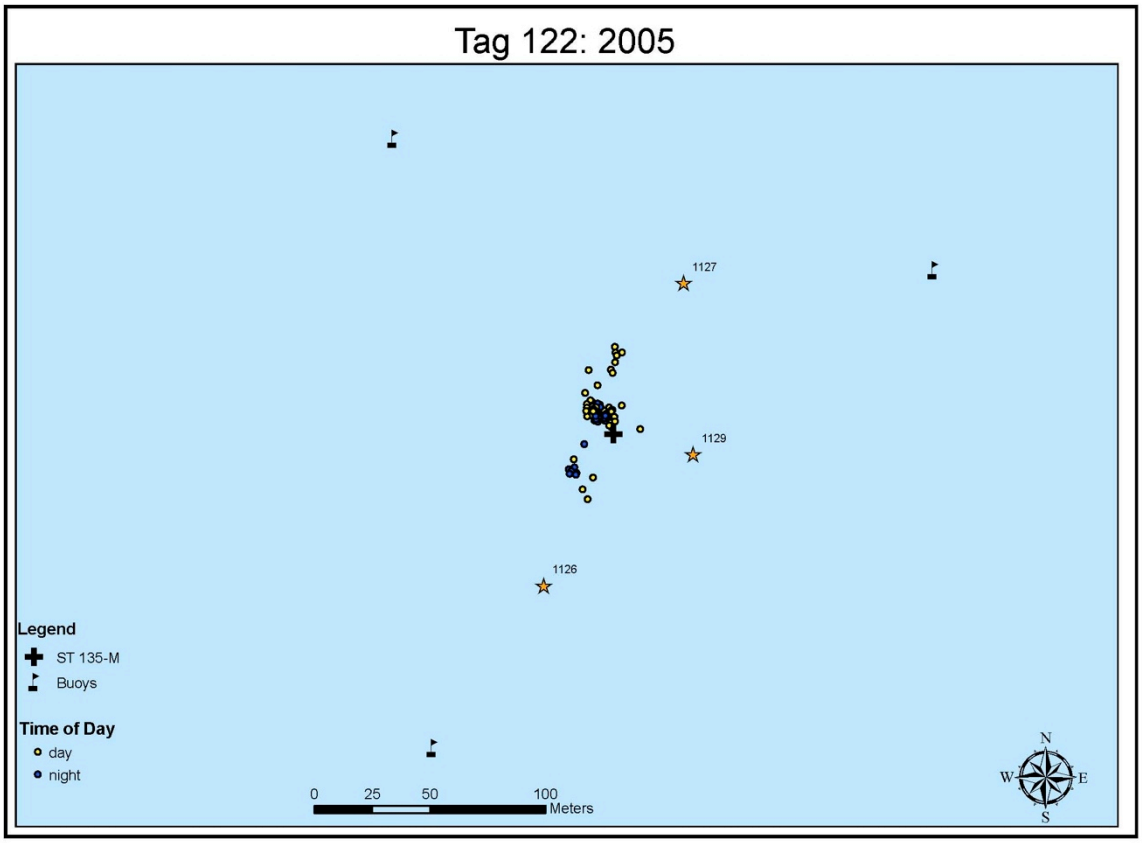

Tag 1102: 2005
1127
1129
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

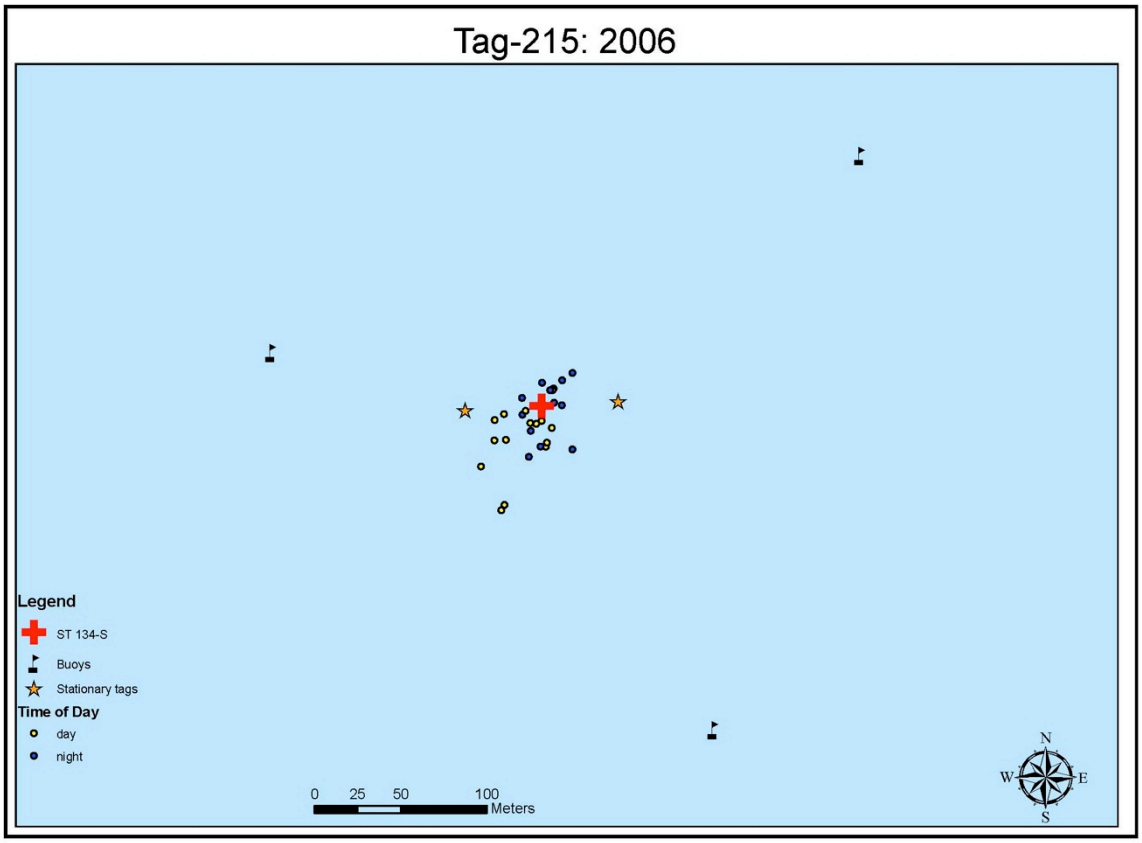

Tag 1103: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

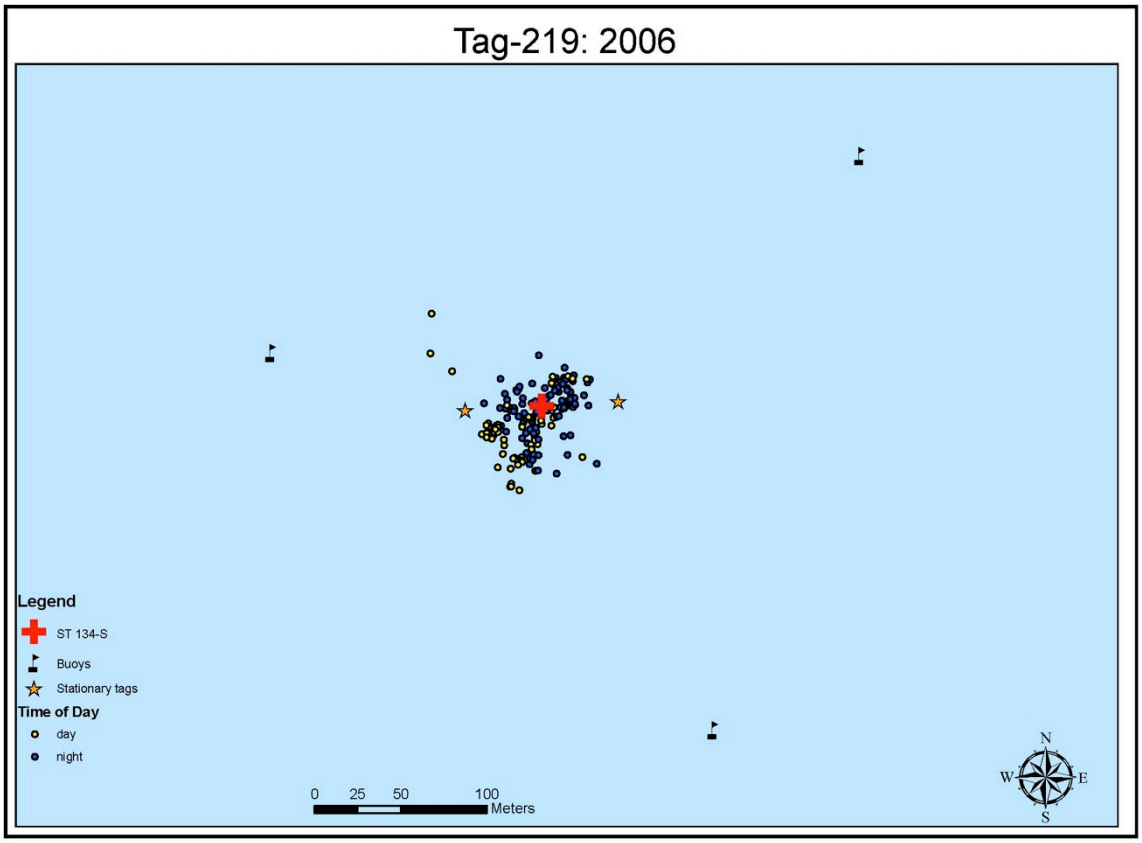

Tag 1106: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

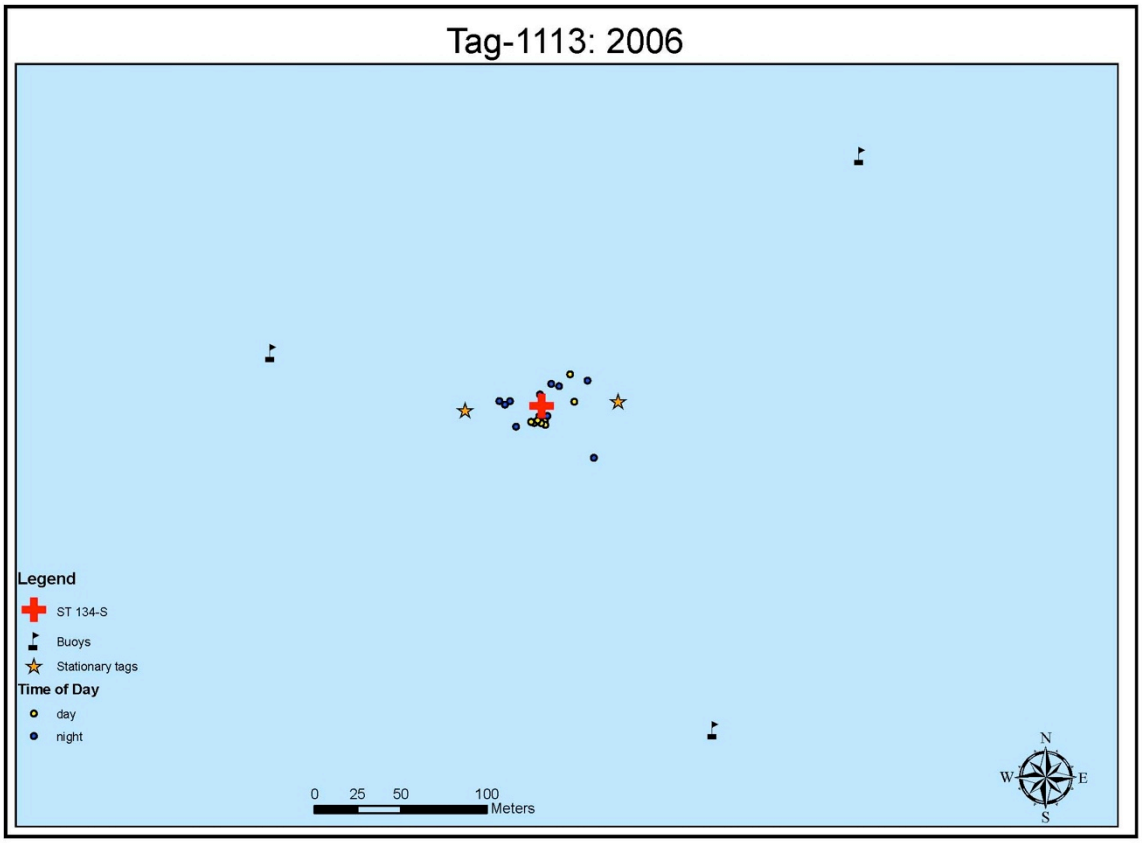

Tag 1109: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

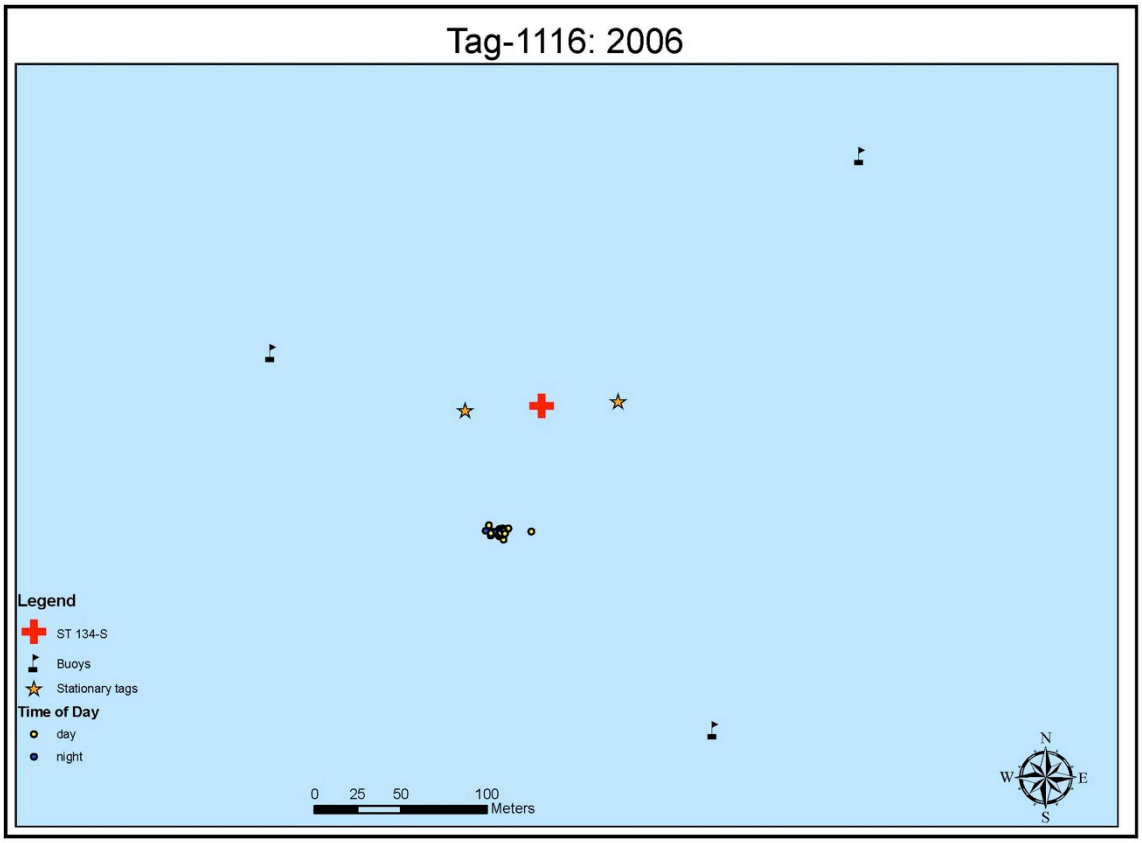

Tag 119: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S

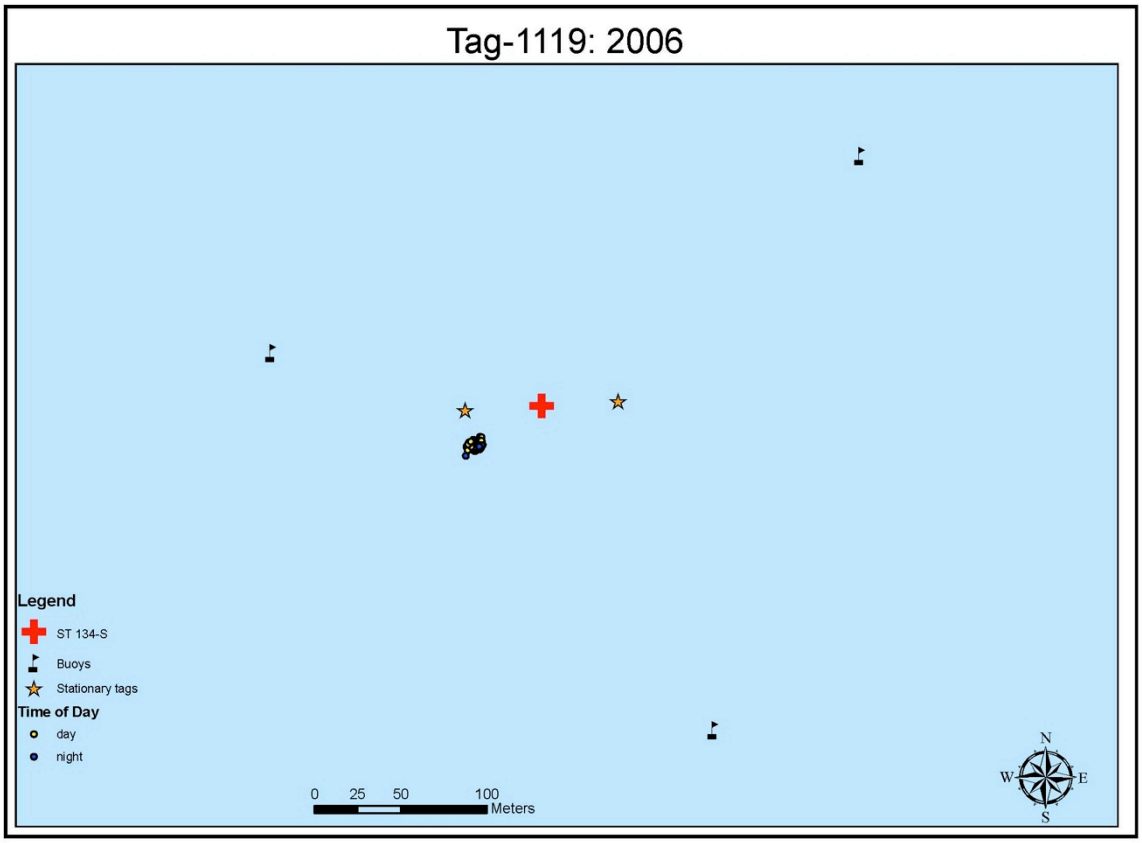

Tag 122: 2005
1127
1129
1126
Legend
ST 135-M
Buoys
Time of Day
day
night
0
25
50
100
Meters
N
W
E
S


Tag-215: 2006
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
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
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
W
E
S


Tag-1116: 2006
Legend
ST 134-S
Buoys
Stationary tags
Time of Day
day
night
0 25 50 100
Meters
N
W
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

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.

The Bureau of Ocean Energy Management Mission

The Bureau of Ocean Energy Management (BOEM) promotes energy independence, environmental protection, and economic development through responsible, science-based management of offshore conventional and renewable energy.