NOTE: This paper has been submitted for publication in a peer-reviewed journal and as such the authors should be contacted for the correct citation information.

First descriptions of the behaviour of silky sharks (*Carcharhinus falciformis*) around drifting FADs, in the Indian Ocean, using acoustic telemetry

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ABSTRACT

The silky shark, *Carcharhinus falciformis* (Müller & Henle, 1839), is the primary elasmobranch bycatch species in industrial tuna purse seine fisheries throughout the world's major oceans. Juvenile silky sharks commonly associate with drifting fish aggregating devices (FADs) deployed in these fisheries as a strategy to enhance tuna catches. Despite their regular incidental capture around drifting FADs, no research has been conducted into the role that these floating objects play in the biology and ecology of these juvenile pelagic sharks. Here we present results from the first investigations into the behaviour of juvenile silky sharks associated with drifting FADs in the western Indian Ocean, using acoustic telemetry. A total of 10 silky sharks were equipped with coded acoustic transmitters (Vemco V13 and V16P – pressure sensor tags), tagged around four drifting FADs to which acoustic receivers where attached (Vemco VR2 and VR3-ARGOS). Eight sharks were detected around the FADs, all performing an excursion (from 0.10 to 3.50 d) away from the FAD after release, likely corresponding to stress after capture and tagging. Continuous residence periods (without day-scale absences) averaged around 5.19 d (SD = 3.15 d). Detailed analysis showed that excursions away from FADs were made at night, lasting a few hours. During periods of association, silky sharks typically occupied the upper 35 m of the water column for the majority of the observation period. These results, as well as perspectives on future research, are discussed in the framework of ecosystem-based management of tuna fisheries.

INTRODUCTION

The silky shark, *Carcharhinus falciformis*, (Müller & Henle, 1839) has been described as one of the three most common pelagic shark species (Compagno, 1984), along with the blue shark, *Prionace glauca* (Linnaeus, 1758) and the oceanic white tip shark, *Carcharhinus longimanus* (Poey, 1861). It is one of the targets of artisanal and industrial fisheries targeting pelagic sharks throughout the tropical and subtropical regions (Strasburg, 1958; Compagno, 1984; Bonfil et al., 1993; Hazin et al., 2007; Bonfil, 2008; Henderson et al., 2009) but also forms a major component of the shark bycatch incurred in both longline and tuna purse seine fisheries in all three oceans (Bane, 1966; Compagno, 1984; Santana et al., 1997; Romanov, 2002; Román-Verdesoto and Orozco-Zöller, 2005; Amandé et al. 2008; Watson et al., 2009). Despite being an important top predator and a major component of pelagic fisheries (both targeted and as bycatch), little is known about the behaviour of this species (Bonfil, 2008). Silky sharks commonly occur over deep-water reefs and in the offshore pelagic environment (Bonfil, 2008), where the juveniles are often found in association with drifting objects (Romanov 2002; Taquet et al., 2007b; Amandé et al., 2008). Drifting objects can either be natural (e.g. logs) or artificial (e.g. from human pollution or man-made rafts deployed for the purpose of catching fishes). Artificial objects are usually referred to as fish aggregating devices (FADs), but the term FAD is used with increasing frequency to refer to any floating object, regardless of its origin. Tropical tuna purse seiners regularly deploy large numbers of FADs (Moreno et al. 2007), with this fishing strategy increasing significantly in importance within the fishery in the past two decades (Fonteneau et al., 2000). Information regarding the associative behaviour of silky sharks, however, is particularly poor. It is now urgent to improve our knowledge on this behaviour as (i) it is responsible for catches of silky sharks by tropical tuna purse seiners throughout the world, and (ii) it is needed to assess the effects of FADs on their ecology. Marsac et al. (2000) and Hallier and Gaertner (2008) suggested that FADs could act as ecological traps for tropical tunas, an issue that actually concerns all FAD-associated species, including the silky shark. This hypothesis states that as artificial FADs modify the “surface” habitat of such species (Fauvel et al., 2009), they could have major impacts on their behaviour and biology. It is assumed that fishes could be trapped within networks of artificial drifting FADs, which could take them to areas where they would not usually have been or retain them in areas that they would otherwise leave. These areas could be biologically inappropriate and affect the biology (e.g. growth, reproduction) of fishes.
Through the use of acoustic telemetry, the current study aims to provide the first description of the behavioural characteristics of silky sharks at FADs, as well as highlighting the requirements for much needed future work on this subject.

MATERIALS AND METHODS

Scientific cruises were conducted onboard the MV Indian Ocean Explorer between September 2003 and October 2005 around the Seychelles in the western Indian Ocean (as a part of the FP5 European research program FADIO). During the cruises, drifting FADs, used by the European tuna purse seine fleet operating in the Indian Ocean, were equipped with Vemco VR2 and VR3-ARGOS acoustic receivers. Pelagic fishes caught around these FADs were then tagged with acoustic transmitters, as described by Dagorn et al. (2007a). Among the fishes tagged during these cruises, were ten silky sharks: two equipped with Vemco V13 coded acoustic pingers (69 kHz) and eight with V16P coded acoustic transmitters (69 kHz) with pressure sensors. Sharks were caught by means of a baited handline and ranged between 86 cm and 120 cm fork length (FL), all of which were juveniles. Four of the V16P tags were attached externally using a circle hook, hooked through the shark’s pelvic fin. All other tags were surgically implanted into the shark’s peritoneal cavity using standard implantation techniques (e.g. see Schaefer and Fuller, 2002). Two absorbable sutures were used to close the point of incision after the tag was inserted. Tagging was conducted onboard in a padded cradle and the shark’s gills were oxygenated using a hose pumping sea water from outside of the vessel into the shark’s mouth. The tagging operation lasted less than two minutes before the shark was released again near the point of capture.

When VR2 acoustic receivers were deployed on a FAD, the FAD was revisited several days later, the VR2 retrieved and the data downloaded. A VR2 records every time a tag is detected (with the corresponding depth if the tag is equipped with a pressure sensor). Alternatively, where a VR3-ARGOS receiver was deployed on a FAD, it was left to drift freely with the data being relayed via the ARGOS satellite system. However, one limitation of VR3-ARGOS is that in order to reduce the amount of data sent trough ARGOS, data were summarized into arrivals and departures, along with the number of detections between these two points in time (Dagorn et al., 2007a). A new period was started if the time between consecutive detections was greater than three hours. As a result, any short (< 3 hr) absence was not visible in the data from the VR3-ARGOS. Moreover, for this type of receiver, each day, depth data were computed as histograms, also to reduce the size of files transmitted through ARGOS. Data were put into eight classes, with values in meters for these classes depending on the specifications of each tag (slope and intercept). Therefore, all fish had different classes of depths for the histograms transmitted to ARGOS. However, tags with the same settings provided depth classes that were very comparable. In order to compare swimming depths of different fish, we adopted equal depth classes (in m) for all fish: 0-35, 36-85, 86-135, 136-185, 186-235, 236-285, 286-335, 336-385. As the histograms were calculated daily the interpretation of any diurnal changes in vertical behaviour was not possible.

Different scales to define presence and absence around receivers (i.e. FADs) were considered in the present study. We first defined the total time of association for each fish, which corresponds to the time from the first to the last detection (without considering any possible absence in-between). It is important to note that these values are underestimates of total residence times of fish at FADs, as it is not possible to know when the association with the FAD originally began (Dagorn et al., 2007b) before the shark was tagged. Similarly, when the observation was interrupted (by either removal of the acoustic receiver or a fishing set on the FAD), an underestimation occurred. Previous studies on the behaviour of large pelagic fishes at FADs (Ohta and Kakuma, 2005; Dagorn et al., 2007b; Taquet et al., 2007a) have defined continuous residence time (CRT) as the period for which a tagged fish was detected around a FAD by an acoustic receiver without an absence of more than 24 hr. For the purpose of comparison, the same definition was applied to the data in this study. Finally, for periods where sharks were present without any day-scale absence (CRTs), analysis of excursions away from FADs was done by considering a threshold of three hours for measuring an absence (which allows to combine data from VR2 and VR3-ARGOS receivers), and identifying the time (day versus night) of each event (departure or arrival) associated to an excursion.

As theoretical ranges of detection are rarely obtained under field conditions, due to a variety of influential factors (sea state, water temperature, turbidity, current strength etc.), it was necessary to estimate the range of detection for the two types of tags under the environmental conditions where tagging was conducted. Detection ranges were tested by attaching an acoustic receiver to the FAD and then deploying two tags (V13 and V16P) under the vessel while it drifted away from the FAD in silence. During this process the distance between the receiver (FAD) and the tags (vessel) was frequently measured using a GPS. Range tests were conducted around three different FADs, with maximum detection ranges (i.e. last detections) in the order of 400-500 m for V13 and 600-1000 m for V16P tags.

RESULTS

RESIDENCE TIMES AROUND FADS

Eight of the ten silky sharks tagged (Table 1) were detected by the drifting acoustic receivers. All total association periods were found to equal all CRTs as no excursions greater than 24 hr were observed. At FAD 1165, where two sharks were tagged, the ARGOS-VR3 became detached from the FAD after 3.62 d, and was only replaced 3.04 d later (Fig. 1). Both sharks were still present at the FAD when the new VR3-ARGOS was installed. As no day-scale absences were observed for any of the other sharks monitored in this study, we assumed that no excursions (> 24 hr) were undertaken by these two sharks while the receiver was absent. The total time of association, as well as CRTs, for these fish therefore includes this period of 3.04 d with no monitoring. The longest period of association (or CRT) with the same drifting FAD was 10.7 d (range: 0.41 d to 10.70 d), with an average of 5.19 d (SD = 3.15 d). Of the eight sharks detected, the absolute time of association (no interruption of the observation) with the FAD after tagging could only be obtained for the two sharks tagged at FAD 1165 (showing total CRTs of 5.89 d and 10.70 d, see Table 1). At FAD 1129, where two sharks were tagged, the VR2 was removed after two days. At FAD 888 where one shark was detected, detections of all fish tagged around the FAD ended simultaneously after roughly 6.8 d, suggesting either a fishing set (not reported to the research team) or the detachment of the ARGOS-VR3. When FAD 154 was fished by a tuna purse seine vessel the ARGOS-VR3 was removed ending the monitoring activity after roughly 5.5 d. Three sharks were associated with the FAD at the time of fishing. The purse seiner reported catching one of the sharks. A second shark associated with the FAD at the time of the set was recaptured 23 d later by a longline fishing vessel, roughly 300 km to the east, on the edge of the Mahé plateau. It is noteworthy that the third tagged shark present at this FAD was not recaptured (or not reported as such).

Excursions

All sharks displayed a tendency to depart from the immediate proximity of the FAD directly after tagging and release with an average time between tagging and first detection of 0.94 d (SD = 1.14 d). The soonest a shark returned to the FAD after being tagged was 0.10 d. Seventy five percent of tagged sharks were first detected after more than seven hours and one individual, shark 108 (93 cm TL), was first detected 3.50 d after release (Fig. 2). During this time away, the FAD drifted a minimum straight-line distance of approximately 150 km.

Five of the eight sharks undertook excursions away from the FADs during the monitoring period (in addition to the excursion directly after tagging and release) (Fig. 1). The extent of these excursions (bearing in mind the minimum of 3 hr) varied between animals (from 0.14 to 0.36 d, or 3 hr 20 min to 8 hr 38 min) but averaged around 0.24 d (or 5 hr 45 min) (SD = 0.09 d or 2 hr 9 min). Activity events (defined here as departures from, or returns to, the FAD when excursions were undertaken as well as natural departures ending the association period) were found to only occur between dusk and dawn (Fig. 3). A total of 18 activity events were recorded during this period (18:00 – 06:30) while none were observed during daylight hours (06:31- 17:59). Two sharks (2729 and 2742) made multiple excursions from the FAD and both showed a high degree of regularity in the time at which these excursions occurred. Shark 2729 undertook two excursions on consecutive nights, starting at 21:24 and 21:13 and ending at 01:27 and 01:28 respectively. Shark 2742 undertook an excursion every night for the duration of the five day monitoring period. These excursions typically started between 19:00 and 20:00 and showed a general increase in duration over the five days. The first excursion lasted 0.16 d (3 hr 51 min), followed by 0.14 d (3 hr 21 min) , 0.31 d (7 hr 31 min), 0.33 d (7 hr 59 min) and 0.36 d (8 hr 38 min). Shortly after returning from the last excursion the FAD was fished by a tuna purse seine vessel ending the monitoring.

Vertical behaviour

The vertical distribution of sharks equipped with pressure sensor tags was found to be similar for most individuals (Fig. 4). Five of the six sharks spent more than 80 % of their time within 35 m of the surface whilst in the immediate proximity of the FAD. The sixth individual (104) was in this depth range 63 % of the time and between 36 and 85 m for the rest of the time.

For two individuals equipped with V13P tags at FAD 1129 where a VR2 receiver was deployed, detailed information on the vertical behaviour could be collected. Although the period where both individuals were present at the FAD together was short, potential for size segregation with depth is apparent (Fig. 5). During nighttime, swimming depths of both sharks (shark 64 mean = 30.5 m, SD = 13.6 m; shark 65: mean = 4.5 m, SD = 3.6 m) were significantly different (t-test, $p<0.01$, d.f. ≈ 213).

Discussion

The tendency of juvenile silky sharks to associate closely with drifting objects has been documented in the past from observers onboard purse seiners (Romanov, 2002; Amandé et al., 2008) but has never been the focus of a direct study aiming at describing and understanding this behaviour. The significance of the role of drifting objects in the early life history stages of these sharks has largely been ignored.

Homing behaviour

All detected sharks displayed a delay between release and first detection. Such delays have previously been observed in tunas and dolphinfish (Ohta and Kakuma, 2005; Dagorn et al., 2007b; Taquet et al., 2007a), but on rare occasions, and were not discussed by the authors. The reasons behind these immediate departures cannot be known but they are very likely a response to the stress of capture and tagging. The large proportion (80 %) that returned to the FAD where they were originally captured, after this period of absence, suggests the ability to home in on the same drifting FAD. The homing ability of these juvenile sharks is also confirmed by the excursions away from the FADs displayed by some individuals whilst associated with the FAD. Such homing behaviour, after natural excursions, has been observed for other fish species around anchored FADs: skipjack tuna, *Katsuwonus pelamis*, (Linnaeus, 1758) and yellowfin tuna, *Thunnus albacares*, (Bonnaterre, 1788) (Holland et al., 1990; Cayré, 1991; Marsac and Cayré, 1998; Brill et al., 1999; Dagorn et al*.,* 2000) and drifting FADs: dolphinfish, *Coryphaena hippurus* (Linnaeus, 1758) (Taquet et al., 2007a). Although we cannot know the distance that the sharks were from the FAD during their time of absence it was certainly further than the detection range of the drifting receivers (400 – 1000 m). Distances over which fish can orientate towards a FAD have been estimated for a few species thus far, with results varying considerably between species and studies: yellowtail, *Seriola lalandi*, (Valenciennes, 1833): 275 m (Dempster and Kingsford, 2003), dolphinfish: 275 m (Dempster and Kingsford, 2003), 820 m (Girard et al., 2007), yellowfin tuna: 10 km (Girard et al., 2004). Further studies are needed to investigate the orientation distances and the cues used by silky sharks to locate FADs, but our results tend to show that silky sharks could have the abilities to home to FADs from large distances.

Association with FADs

Apart from two studies on dolphinfish (Taquet et al., 2007a) and bigeye tuna (Schaefer and Fuller, 2002), data on residence times of fish around drifting FADs (including our study) come from very few individuals (Matsumoto et al., 2006; Dagorn et al., 2007a). It is therefore difficult to statistically compare residence times between species; however, based on these preliminary results it appears as though silky sharks could be among the most resident (comparable to dolphinfish, Taquet et al., 2007a). But, why do these small sharks associate to FADs?

One hypothesis justifying the associative behaviour displayed by silky sharks involves social interactions. These sharks were always observed in groups around FADs (Taquet et al., 2007b). The FADs could act as 'meeting points' (Dagorn & Fréon, 1999; Fréon & Dagorn, 2000) for the sharks. The meeting point hypothesis stipulates that fish can make use of floating objects to increase the encounter rate between isolated individuals or small schools and other schools, as a mechanism to form larger groups or schools. It has recently been demonstrated for a small pelagic fish species, the bigeye scad, *Selar crumenophthalmus* (Bloch, 1793) (Soria et al., 2009). Our results, although preliminary and with limits, highlight the fact that further investigations into these types of interactions are important.

An alternative hypothesis is based on the obvious reason of feeding on the other species associated to the FADs. This could explain the long residence times observed in this study. Several short (hours) nocturnal excursions, away from the FADs, were undertaken by some of the sharks (Fig. 1). The motivations for these excursions cannot be known. Short excursions (hours) observed in tunas (Holland et al., 1990; Cayré, 1991; Marsac and Cayré, 1998; Brill et al., 1999; Dagorn et al., 2000) and dolphinfish (Taquet et al., 2007a) around FADs were attributed to foraging behaviour. We believe that the excursions shown by the silky sharks in this study could also be attributed to foraging activities. It is possible that the length of the excursions could be directly related to the success of the foraging forays and similarly the availability of prey items within the general area of the FAD. However, this does not imply that silky sharks do not prey on other species associated to FADs. Taquet (2004) found that a quarter of the diet of dolphinfish associated to FADs consists of prey from within the associated biomass. To supplement this proportion, foraging excursions were undertaken away from the FAD. It is possible that a similar situation exists for juvenile silky sharks which are likely to have high energetic requirements during this early life history stage, as has been found to be the case for juveniles of other elasmobranch species (Bethea et al., 2007). However, the fact that several individuals never left the FAD for longer than 3 hr throughout their entire residence period could indicate firstly that feeding on other associated fish species could be a viable strategy for some individuals, and secondly that they performed shorters (< 3 hrs) excursions which could fulfill their feeding requirements. To validate this hypothesis it is important to conduct an in depth dietary analysis of silky sharks caught around FADs.

Of the 10 sharks tagged, two were reported as recaptured. Interestingly, both of these sharks were tagged at FAD 154 which was fished by a purse-seine vessel. Data from the VR2 suggests that all three sharks tagged at FAD 154 were in the area when the set was made. The last detection time for each was 06:07 (2742), 07:10 (114) and 08:23 (2729). Of these three, only shark (114) was reported as being recaptured by the purse seine vessel. The second recapture (2742) made 23 d later, indicates that the shark either evaded capture by the purse seine or survived the set after being released by the crew. Judging from the time of the last detection, it is also possible that the shark was on an excursion away from the FAD at the exact time of the set and was never captured at all. The fate of the third shark (2729) is unknown. It is highly probable that it was captured by the purse seiner, considering the time series above, but we do not know whether it was released dead or alive or retained on the vessel and not reported.

Vertical behaviour

During their association with the FADs, all sharks spent the majority of their time in the upper 35 m of the water column. It has been well documented that the majority of smaller teleost species forming the intranatant / extranatant (see Parin and Fedoryako (1999) and Fréon and Dagorn (2000) for definitions of these terms) components of the aggregation occupy the area within 50m of the FAD (Fréon and Dagorn, 2000; Taquet et al., 2007b). Although it is not possible to know whether the sharks were feeding on the other associated species, there certainly was potential for interactions between them. Nevertheless, the depth range occupied by the silky sharks when associated with FADs makes them highly vulnerable to capture by a tuna purse seine.

Conclusions

Although the data set presented here is small, we feel that it shows some interesting trends and exposes the requirements of future research. The significance of these data are high considering the difficulties associated with the collection of data on such off shore pelagic species. Similarly the large concerns regarding the use of FADs by purse seiner fisheries and the effects this method has on the silky shark populations highlight the urgent requirement for ecological information on this species (Bonfil, 2008).

Acknowledgements

Data were collected within the framework of the research project FADIO (Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems), with financial support from the Commission of the European Communities, specific RTD programme of Framework Programme 5, contract N◦ QLRI-CT-2001-02773, and data analysis was carried out with financial support from the Commission of the European Communities, specific RTD programme of Framework Programme 7, “Theme 2 – Food, Agriculture, Fisheries and Biotechnology”, through the research project MADE (Mitigating adverse ecological impacts of open ocean fisheries), contract #210496. This work does not necessarily reflect the Commission’s views and in no way anticipates its future policy in this area. We would like to thank the Spanish and French purse seine fleets in the Indian Ocean who provided invaluable assistance while at sea. We also thank the Indian Ocean Tuna Commission which kindly provided some of the acoustic tags used in this project. Finally, we would like to sincerely thank the entire crew of the RV Indian Ocean Explorer for their enthusiastic collaboration on each cruise, as well as all other scientists who participated in these cruises.

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Figure 1: Time series showing residence periods of juvenile silky sharks, *Carcharhinus falciformis*, around four drifting FADs in the western Indian Ocean. White rectangles indicate delays between tagging of individuals at the same FAD; black bars represent continuous detection periods; grey bars denote excursions out of the detection range of the receiver; black diagonals indicate equipment failure and black arrows denote a fishing set or removal of the receiver, ending the monitoring period.

Figure 2: Time delay between tagging/release and first detection by receiver for juvenile silky sharks, *Carcharhinus falciformis*, tagged with acoustic transmitters around drifting FADs in the western Indian Ocean.

Figure 3: Distribution of departures (from) and returns (to) FADs by day and night of juvenile silky sharks, *Carcharhinus falciformis*, associated with drifting FADs in the western Indian Ocean.

Figure 4: Depth distributions of six juvenile silky sharks, *Carcharhinus falciformis*, around drifting FADs in the western Indian Ocean. Bins below 135 m are not shown as no data was recorded beyond this depth. Numbers within the inserted rectangle indicated tag IDs.

Figure 5: Detailed vertical movement behaviour of two juvenile silky sharks, *Carcharhinus falciformis*, associated with a drifting FAD, equipped with a VR2 acoustic receiver, in the western Indian Ocean.

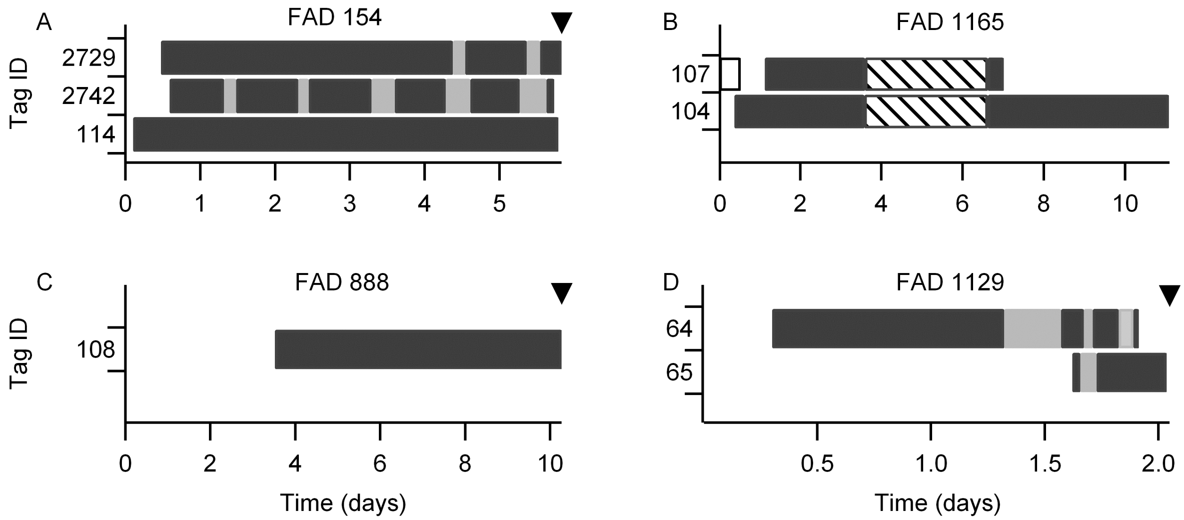

Figure 1

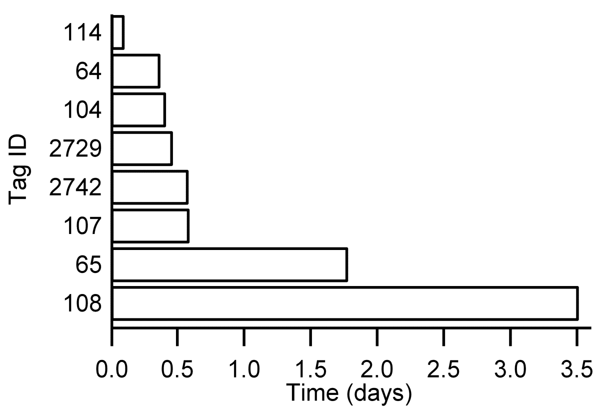

Figure 2

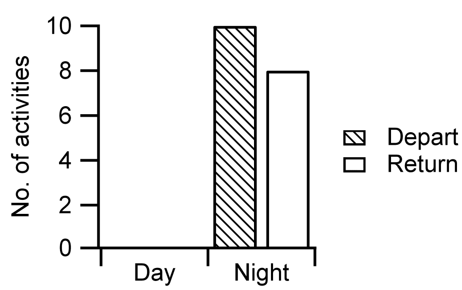

Figure 3

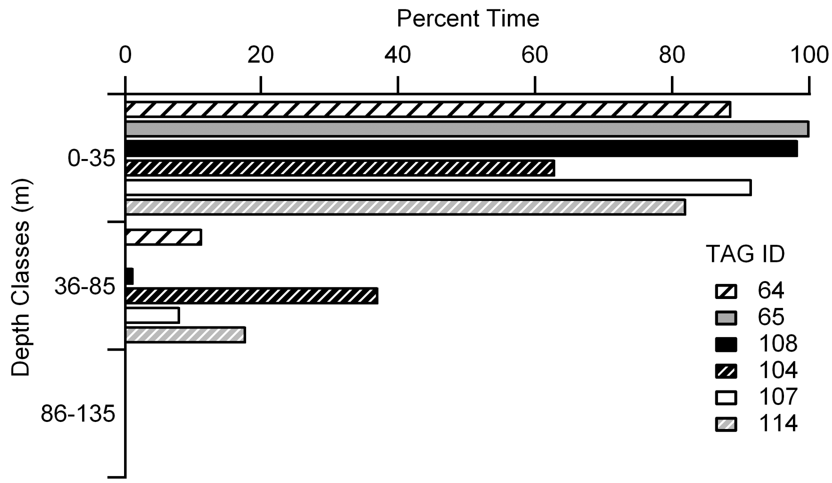

Figure 4

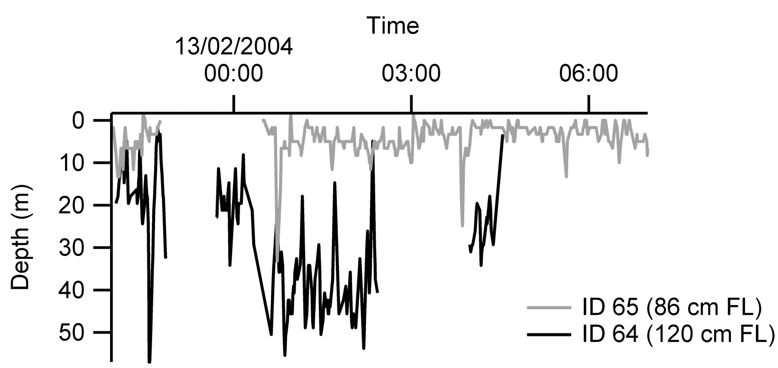

Figure 5