Neotropical Ichthyology, 8(4):893-898, 2010

Scientific Note

Nocturnal and diurnal activity of armored suckermouth catfish (Loricariidae: *Pterygoplichthys*) associated with wintering Florida manatees (*Trichechus manatus latirostris*)

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Several *Pterygoplichthys* species, members of the Neotropical catfish family Loricariidae, have been widely introduced outside their native ranges. In this paper, I present observations on the diel activity pattern of non-native *Pterygoplichthys*, tentatively identified as *P. disjunctivus*, with respect to their attachment and grazing on endangered Florida manatees, *Trichechus manatus latirostris*. The study was conducted in December 2009 at Volusia Blue Spring, an artesianal spring system in the St. Johns River basin, Florida (USA). Supplemented by information gathered during previous visits to the spring site, this study revealed that adult *Pterygoplichthys* are active throughout the diel period (day, twilight and night). However, juvenile *Pterygoplichthys* were largely nocturnal and only at night did they consistently join adults in attaching to manatees. The juveniles generally remain hidden during the day, probably responding to presence of diurnal predators, mainly birds. Differences in diel behaviors among different *Pterygoplichthys* size classes in Florida are consistent with published observations on loricariids inhabiting clearwater streams within their native ranges.

Várias espécies de *Pterygoplichthys*, siluriformes Neotropicais da família Loricariidae, tem sido largamente introduzidos além de suas áreas naturais de ocorrência. Neste artigo, eu apresento observações dos padrões de atividade diária de uma população não nativa de *Pterygoplichthys*, identificada tentativamente como *P. disjunctivus*, associados com a espécie ameaçada de peixe-boi nativa da Flórida, *Trichechus manatus latirostris*. O estudo foi conduzido em dezembro de 2009 em Volusia Blue Spring um sistema artesiano na bacia do rio St. John, Flórida (USA). Suplementado por informações reunidas durante visitas prévias ao sítio em análise, este estudo revelou que *Pterygoplichthys* adultos estiveram ativos durante a maioria dos períodos (dia, crepúsculo e noite). No entanto, jovens foram principalmente noturnos e somente a noite eles uniram-se aos adultos sobre os peixes-boi. No sistema estudado na Flórida, jovens de *Pterygoplichthys* geralmente permanecem escondidos durante o dia, provavelmente respondendo a presença de predadores visuais diurnos, principalmente aves. As diferenças observadas na atividade diária entre diferentes classes de tamanho são semelhantes ao descrito para certos loricariídeos que habitam cursos d'água de águas límpidas em suas áreas nativas de ocorrência.

Key words: *Pterygoplichthys*, Diel activity pattern, Non-native fish, Invasive species.

Several *Pterygoplichthys* species, members of the Neotropical catfish family Loricariidae, have been widely introduced outside their native ranges and over the past few decades non-native populations have established reproducing populations in inland waters of North and Central America, the Caribbean, Hawaii, and Asia (Nico *et al*., 2009a). In many regions where introduced, these loricariids have become common, yet relatively little is known about their behavior or the ecological role they play in invaded environments.

Among the various loricariid taxa established in Florida (USA) are species previously identified as *Pterygoplichthys disjunctivus* (some populations may actually be *P. anisitsi* or unusual hybrids with *P. disjunctivus*), *P. multiradiatus* (although recent reexamination of specimens indicate many or most may actually represent *P. pardalis*), and one or more *Hypostomus* species. In the St. Johns River basin of Florida, a form tentatively identified as *P. disjunctivus* is widespread and abundant. Within the basin, this non-native catfish has invaded many spring habitats, sites used by endangered Florida manatees (*Trichechus manatus latirostris*) as winter thermal refuges (Deutsch *et al*., 2003; Nico *et al*., 2009b). During cold periods when the two species co-occur in large numbers in certain spring systems, *Pterygoplichthys* regularly attach to manatees and graze on their skin epibiota.

Previous observations, restricted to daylight hours, indicated that only adult *Pterygoplichthys* associated with manatees.

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Pterygoplichthys less than about 20 cm total length (TL) were rarely seen in the spring habitat during the day (Nico *et al*., 2009b). In this paper, I describe the diel activity of adult and juvenile *Pterygoplichthys* inhabiting a Florida spring system. Field observations were conducted over three winter days in late 2009 when Florida manatees were present. The study builds on previous published observations (Nico *et al*., 2009b). In addition, I reviewed the literature and summarize what is known about diel activity patterns and natural predators of loricariids.

The study site was Volusia Blue Spring (28º56’37”N 81º20’26”W), an artesian system in the St. Johns River basin (Florida). The spring run, located within Blue Spring State Park, Volusia County, is 650 m long, 20 to 30 m wide, and flows directly into the main channel of the much larger St. Johns River. The spring’s water has a year-round temperature of about 22.5ºC and is highly transparent, in marked contrast to the dark tannin-stained water of the St. Johns (O’Shea, 1986). During my field work, 9-11 December 2009, the sky was generally overcast to partly cloudy with occasional light rain and little to no wind. U.S. Naval Observatory data indicated the approximate local times of sunset and sunrise were 17:28 and 07:09 h, respectively (all times given as North American Eastern Standard Time [GMT-5]). Approximate moonrise and moonset were 02:32 and 13:18 h, respectively. Because of high cloud cover throughout much of the night of 10-11 December, lunar illumination was slight. Air temperature on 9 December was unseasonably warm (about 24-29ºC) but a cool front entered region on the evening of 10 December, bringing a low of about 11ºC by 04:00 h on 11 December.

Observations were conducted from elevated viewing platforms and walkways along the east bank of the spring run. Because water in the spring run is generally clear to the bottom, it enables relatively unobstructed observation of fishes and manatees. Preliminary observations were made on the evening of 9 December 2009: 17:30-18:00 h and 21:00-22:30 h. Subsequently, *Pterygoplichthys* and manatees were observed during 10 separate sessions within a 24-h period spanning 10-11 December. Each session lasted 20-55 min (mean = 33 min) and sessions were grouped according to major diel period (D = day; T = twilight; N = night): 10 December - 12:00-12:30 (D); 14:00-14:30 (D); 16:10-16:35 (D); 16:50-17:25 (T); 20:10-21:05 h (N); and 11 December - 01:05-01:25 (N); 04:00-04:35 (N); 06:50-07:20 (T); 07:50-08:25 (D); and 10:00-10:35 h (D).

During each observation session, I scanned the water to locate any nearby manatees and assessed each for presence-absence of catfish attached, and, if present, I counted and recorded the total number of catfish visible on each manatee. Large *Pterygoplichthys*, about 25-40 cm total length (TL), were considered adult; those less than about 25 cm TL were categorized as juveniles. To improve census accuracy, manatees included in surveys were required to meet two criteria: positioned within full or almost full view; and near enough (usually <15 m distance from observer) so that the number of attached catfish could be reliably tallied or, at minimum, reasonably estimated. Adult manatees are massive animals, ranging from 2.7 to 3.9 m long, with a maximum weight of 1600 kg (Marmontel *et al*., 1992). Because *Pterygoplichthys* freely attach to nearly any part of the mammal’s exterior, some may occasionally be hidden from view. However, I judged the risk of non-detection to be relatively low because the size, height (>2.5 m above water level), and position of viewing platforms allowed for observations from multiple angles. Also, manatees and any attached catfish frequently move or change position so that catfish initially hidden usually enter into view within a relatively short period of time.

During day and twilight sessions, binoculars (8 x 40) were used to verify the presence-absence of catfish. Night-vision goggles were inadequate to detect catfish, so all night observations were conducted using small spotlights (without red filters). During night sessions, the spotlight was briefly directed at single or clustered manatees, usually less than one minute per manatee, sufficient time to allow detection and counting of any attached catfish. Spotlight illumination of catfish did not appear to illicit a “light shock effect” (*sensu* Reebs, 2002). Occasionally, my artificial light and noise appeared to startle some catfish, causing them to scatter, but the response was usually not immediate and all or most catfish that disengaged typically reattached to manatees within a few seconds or minutes. Similarly, although some manatees slowly swam away during and possibly in response to my presence, many remained relatively stationary and others, previously out of view, swam into the area being illuminated. A digital camera (with 18-200 mm zoom lens and flash) was used to photograph manatees and catfish during most sessions. Resulting images were later examined and used to verify or, if necessary, adjust field counts of catfish. At night, a spotlight beam produces a noticeable red light reflection off the retina of *Pterygoplichthys*, aiding in their detection. Catfish eye shine was also evident in flash-generated photographic images shot at night, further aiding count verification.

Many adult and subadult Florida manatees can be individually recognized because of their unique scar patterns, results of collisions with watercraft (Langtimm *et al*., 2004). Aided by photographs taken during the study, I learned to recognize many of the larger manatees. Individual identification also reduced the likelihood that the same manatee was inadvertently surveyed more than once during a single observation session. However, there was no attempt to exclude manatees surveyed during an earlier session from being surveyed in subsequent sessions, but overlap was judged to be low due to the large numbers of new manatees entering the spring system from the St. Johns River and the many individuals within the spring habitat moving into and out of the area surveyed. Total number of wintering manatees present in the Volusia Blue Spring system fluctuates broadly on a daily and even hourly basis. Park staff conduct daily morning inventories of wintering manatees and reported 94 individuals present in the spring on 11-December.

Unless otherwise indicated, data and statistical analyses relied on the highest count of catfish on an individual manatee for any one observation session. A Kruskal-Wallis nonparametric one-way analysis of variance (on medians) was used to test for differences in the intensity of catfish-manatee interactions over the diel period, including a test to compare the 10 different observation sessions and a second to compare night, day and twilight periods. A 3 x 2 Chi-square test was used to determine if there was a statistical difference in the number of manatees "with" *vs*. "without" attached catfish among the three diel periods. Statistics and graphics were accomplished with the software GraphPad Instat 3.06 and GraphPad Prism 4.02.

My field observations revealed *Pterygoplichthys* were active and attached to manatees during all major periods: day, twilight, and night (Figs. 1 and 2). Over the 24-h period (10-11 December), 58 (72%) of the 81 manatees included in the survey had one or more attached catfish. A Kruskal-Wallis test indica≈d no significant difference in the numbers of attached catfish per manatee, either across the 10 different ol≈ervation sessions (Kruskal-Wallis, H_9 (corrected for ties) = 7.132, p 0.6233), or in a comparison of day, twilight, and night groupings of the data (H_2 (corrected for ties) = 2.361, p 0.3072) (Fig. 2). Post tests were not conducted because p values were greater than 0.05. Number of catfish per manatee varied widely, ranging from 0 to 22 (mean = 2.7, SD = 4.68; median 1). Taking into account only manatees with attached catfish (n = 58), the mean number of catfish per manatee was 3.8 (SD = 5.16; SE = 0.68, median = 2). Recorded counts were probably slightly below the true value because of the likelihood that one or a few catfish were not detected. Although many *Pterygoplichthys* congregated around manatees, the catfish were also common in areas without manatees. Typically catfishes were observed resting or slowly moving, sometimes grazing on submerged logs or other substrates, intermittently hitting the surface to gulp air. Late 10 December I also observed several hundred *Pterygoplichthys* moving up the spring run, presumably behaving similar to manatees by seeking refuge from lowering temperatures in the St. Johns River.

Juvenile *Pterygoplichthys* were rarely observed during daylight or twilight hours but they were highly active at night when they were frequently observed joining adult catfish in attaching to manatees. Of the 218 catfish classified as being attached to manatees during the 24-diel study, 25 (11%) were considered juveniles or possibly juveniles. Most of these attached juveniles (22 of 25) were seen during the night sessions. Of the 58 manatees with attached catfish, one or more juvenile catfish were present on 8 (14%).

During each of the 10 observation sessions, most manatees (range 58-100%) surveyed had attached catfish. The proportion of manatees observed to have attached catfish ranged from 60% during night sessions to 84% during diurnal sessions, with twilight sessions intermediate (73%) (Fig. 3). A Chi-square test indicated the observed differences in the actual numbers of manatees with, versus without, catfish, across major diel periods were not statistically significant ($\chi^2 = 4.634$, 3 x 2 comparison, df = 2, p = 0.0986). Sedentary manatees tended to attract the most catfish and if manatees entered areas where catfish were already congregated, the catfish commonly converged and began massing on the mammal, irrespective of diel period. A few manatees, at least temporarily, had considerable numbers of catfish attaching to their body or surrounding them. Manatees (n = 6) with the highest catfish loads (13 to 22 catfish per manatee) were observed during sessions within day, twilight, and night periods.

All manatees with $\geq$13 catfish attached were largely stationary, and 9 of the 10 manatees with >4 catfish attached, were at rest or largely stationary and the catfish tended to remain on or near stationary manatees for extended times, often several minutes or more. In contrast, active manatees (*e.g*., swimming, playing, milling) had few (1 to 3) attached catfish and the engagement was usually brief, either a few seconds to-at most-a few minutes. Most manatees do not appear to visibly react to attachment, but they occasionally perform body rolls, one of several behaviors the mammals presumably use in attempting to dislodge attached *Pterygoplichthys* (Nico *et al*., 2009b). Over the 24-h diel period, I only observed 8 (14%) of 58 manatees with attached catfish displaying rolling behavior, but the behavior was displayed day and night, and, in most cases, did cause catfish disengagement.

A number of fishes demonstrate high plasticity in terms of diel activity patterns, although evidence for some is based largely on laboratory observations (Ericksson, 1978; Reebs, 2002). *In situ* observations of fish communities in Neotropical fresh waters suggest that there is often a marked changeover in activity at dawn and dusk between diurnal fishes (mostly cichlids and characins) and nocturnal species (mostly catfishes and gymnotoid eels) (Lowe-McConnell, 1964, 1975; LGN, pers. observation). Many or most loricariids-particularly members of the subfamily Hypostominae-are considered nocturnal or crepuscular (Zaret & Rand, 1971; Lowe-McConnell, 1975, 1987, 1991; Burgess, 1989). Yet, much of what has been written on loricariid diel behavior is brief or largely anecdotal. For example, Zaret & Rand (1971) reported that a "*Plecostomus*" inhabiting a stream in Panama "feeds off bottom at night". More informative is the naturalist Lowe-McConnell (1991:74), who briefly described her day and night observations of fishes inhabiting a small, clearwater Amazonian stream. She noted that members of at least three different loricariid genera were active at night, including several species of *Hypostomus* seen grazing rock substrates during the night but hiding in rocky crevices by day. In other publications, Lowe-McConnell (1975, 1987) reiterated that *Hypostomus* feed by night and hide under rocks by day, adding that such behavior occurs in brightly lit clearwater streams.

Since Lowe-McConnell's field observations, other researchers working in the Neotropics have provided additional details on loricariid diel activity patterns, all studies in small, clearwater streams in which observations of catfishes were conducted directly from shore or underwater (Power, 1983, 1984, 2003; Buck & Sazima, 1995; Casatti & Castro, 1998; Casatti *et al*., 2005). A synthesis of their findings reveals that diurnal, nocturnal and crepuscular activity patterns of loricariids are highly variable and more complex than early investigators supposed. The accumulated evidence indicates that their diel activity varies broadly, with differences not

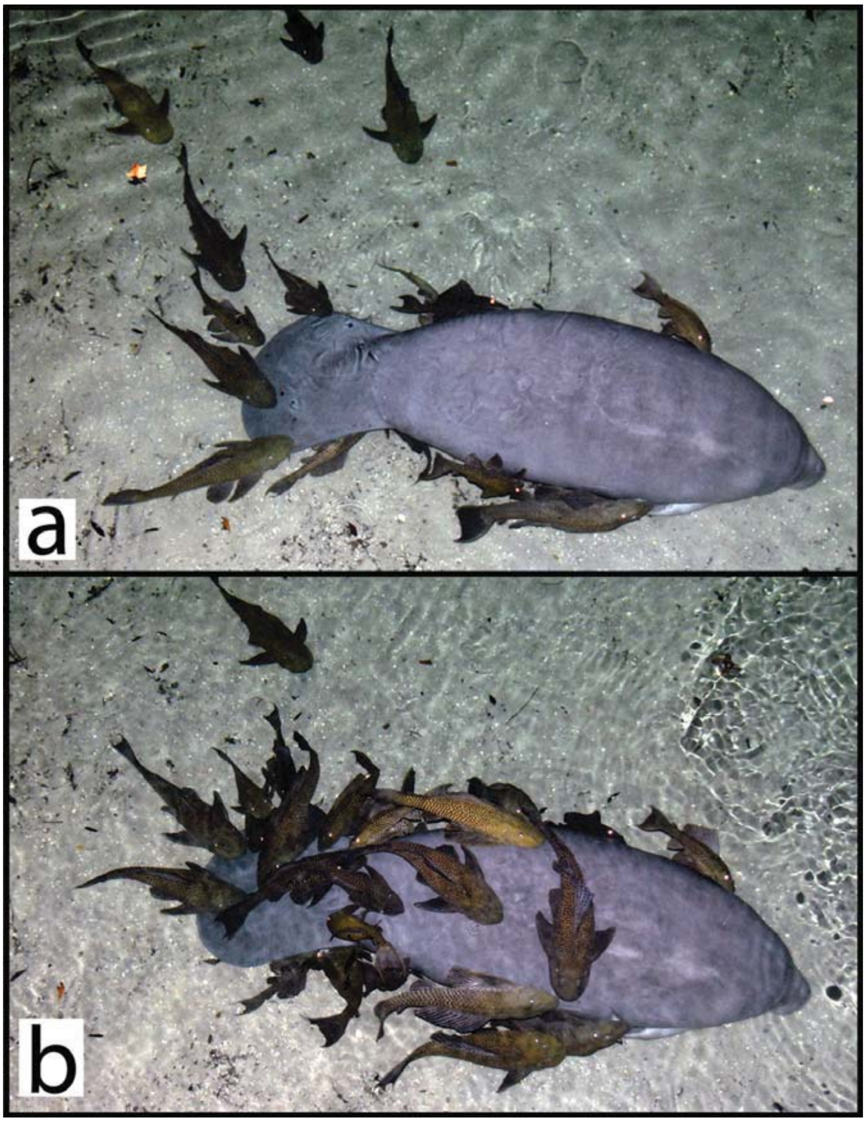

Fig. 1. Photographs showing nocturnal activity of adult and juvenile non-native *Pterygoplichthys* as evidenced by attachment on a resting Florida manatee (*Trichechus manatus latirostris*) yearling calf (about 1.3 m long), Volusia Blue Spring, Florida (11 December 2009). Photo **a**) Time 4:21:16 h, catfish re-converging on manatee shortly after most had temporarily dispersed in response to presence of human observer. Photo **b**) Time: 4:23:02 h, at least 20 catfish attached and additional individuals gathering around manatee; most of those attached are likely grazing on epibionts growing on mammal's skin. Note eye shine of catfish resulting from camera flash. Photographs by Leo G. Nico.

dependent just on the particular species involved, but also age or size class of the catfish, as well as a suite of environmental and ecological factors, possibly most important being degree and kind of predation pressure, amount and types of cover present, water depth and clarity, and local abundance and distribution of their main food resource, periphyton (Power 1983, 1984, 2003; Casatti & Castro, 1998; Buck & Sazima 1995; Casatti *et al*., 2005).

Differences in the diel activity behavior by adult versus juvenile *Pterygoplichthys* in Volusia Blue Spring are similar to those described for other hypostomine loricariids inhabiting clearwater streams within their native ranges (Buck & Sazima, 1995; Casatti & Castro, 1998; Power, 2003; Casatti *et al*., 2005). Observed differences may be related to differences in predation pressure. Juvenile *Pterygoplichthys*, because of their smaller body size, are potential prey to a broader array of predators and at greater risk of being preyed upon than adults. Restricting activity to the night hypothetically is a behavioral response to living in a clearwater environment where visual, daytime predators are common. Similar arguments have been provided to explain activity patterns of certain loricariids in their native ranges. For example, Power (2003:597) stated that loricariids in some Neotropical sites, habitats where there is little structural cover and also possible human predation, appear to be exclusively nocturnal. Even in sites where loricariids are often active during daytime, Power (1984, 2003) noted a tendency for smaller individuals to avoid shallow waters, sites commonly occupied by diurnally active, fish-eating birds.

Additional field work is needed to document the range of Florida animals that prey on *Pterygoplichthys* and associated predation pressure influences. During the present study, on three separate occasions I observed double-crested cormorants (*Phalacrocorax auritus*) feeding on juvenile *Pterygoplichthys*. Each event involved a solitary bird that had foraged underwater and returned to the surface grasping a small (about 10-20 cm TL) *Pterygoplichthys* in its beak. In each case, the floating cormorant spent a few minutes shaking and hammering the catfish on the water, intermittently releasing and then retrieving the newly injured or killed prey, just prior to swallowing it whole. Feeding bouts were restricted to daylight (morning and late afternoon): 07:51-07:52 h and 16:12 h on 10 December, and at 08:23-08:24 h on 11 December. Cormorants are common in the area and their consumption of *Pterygoplichthys* has reportedly increased substantially over the years (Wayne C. Hartley, pers. comm.).Other diurnal piscivorous birds observed hunting in the Volusia Blue Spring system during the present study included great blue heron (*Area herodius*) and anhinga (*Anhinga anhinga*).

A family of river otters (*Lutra canadensis*) previously inhabited the Volusia Blue Spring system and were occasionally observed capturing and consuming *Pterygoplichthys* (Wayne C. Hartley, pers. comm.). The local park ranger recalled that *Pterygoplichthys* first appeared in Volusia Blues Spring about 2002 and noted that fish-eating birds and river otters initially tended to either ignore the non-native catfish or release any individuals captured-apparently unsure how to contend with the fish's heavy body armor and spines. However, over the course of a few years the predators began to more actively pursue and consume the new prey. Park ranger Wayne Hartley (pers. comm.) avowed that river otters eventually learned that they could penetrate the *Pterygoplichthys* body armor by flipping the catfish over and biting into the less protected ventral area.

A primary predator of adult *Pterygoplichthys* in the Volusia Blue Spring system may be resident American alligator (*Alligator mississippiensis*), a reptile documented as a consumer of *Pterygoplichthys* elsewhere in Florida (Rice *et al*., 2007). Because American alligators may be active day or night depending on season and environmental temperature (Smith, 1979), it is difficult to judge their influence the activity patterns habitat use of either adult or juvenile *Pterygoplichthys*.

Some of the predators of *Pterygoplichthys* in Florida are similar to those that prey on loricariids in their native range. For example, the olivacious cormorant (*Phalacrocorax olivaceus*) commonly consumes *Loricariichthys* and *Loricaria* (Willard, 1985) and wading birds reportedly prey on *Hypostomus*, *Ancistrus* and *Rineloricaria* (Power, 1984; Power *et al*., 1989). Loricariids in South America also are a main component in the diet of the neotropical otter *Lontra longicaudis* (Kasper *et al*., 2008) and are occasionally eaten by the giant otter *Pteronura brasiliensis* (Cabral *et al*., 2010). Other natural predators of *Pterygoplichthys* or other loricariids include crocodilians (*i.e.*, *Melanosuchus niger*;

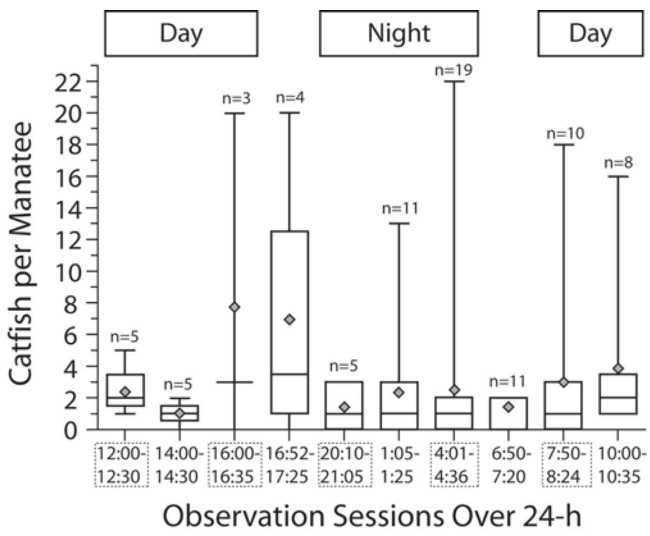

Fig. 2. Box plot illustrating the diel activity pattern of non-native *Pterygoplichthys* in Volusia Blue Spring (Florida) based on numbers of catfish per manatee. Columns represent results of the 10 observation sessions conducted over a 24-h period spanning 10-11 December 2009. Box-whisker plot composed of quartiles, central horizontal line = statistical median; diamond = mean; box encloses 25-75 percentiles; whiskers represent 0-25 and 75-100 percentiles, terminating in least and greatest observed values. Sample size above each column represents number of manatees included in survey. No significant difference were detected across observation sessions: Kruskal-Wallis, H_9 (corrected for ties) = 7.132, p $\approx$ 0.6233.

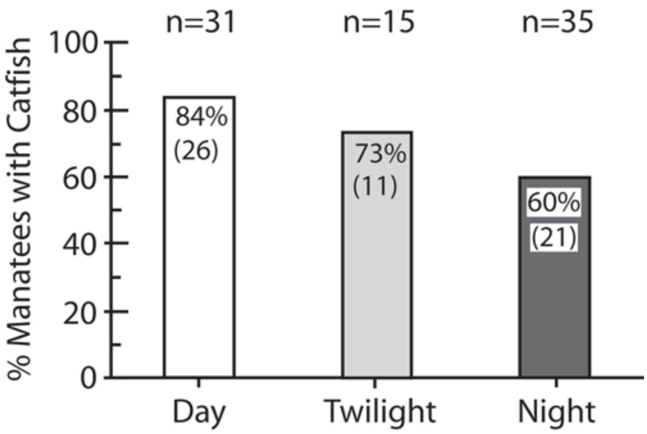

Fig. 3. Histogram comparing proportion of manatees with one or more attached *Pterygoplichthys* during each of the three major diel periods. Information based on results of direct observations conducted at Volusia Blue Spring (Florida) over a single 24-h period spanning 10-11 December 2009. Each column represents pooled data from multiple observation sessions: Day = 5 sessions; Twilight = 2 sessions (*i.e.*, dusk and dawn); and Night = 3 sessions). Numbers of manatees included in each session are given above columns. Chi-square (3 x 2 comparison) test indicated no statistical difference between major diel period and the proportion of manatees with armored catfish (χ^2 = 4.634, df = 2, p = 0.0986).

Willard, 1985; and *Caiman latirostris*; Borteiro *et al*., 2009), aquatic snakes (*e.g*., *Helicops*; Aguiar & Di-Beernardo, 2004), freshwater turtles (*e.g*., *Hydromedusa tectifera*; Bonino *et al*., 2009), the large catfishes *Phractocephalus hemioliopterus* and *Pseudoplatystoma fasciatum* and certain other predatory fishes (Nico & Taphorn, 1988; Bistoni *et al*., 1995; Barbarino-Duque & Winemiller, 2003).

Acknowledgements

Linda S. Nico assisted in the field. This paper benefited from conversations the author had with James P. Reid, Howard Jelks, and Wayne C. Hartley. I thank Cathy Beck, Mary Power, Amy Benson, Lisa Jelks and anonymous referees for reviewing drafts of the manuscript. Use of trade, product, or firm name does not imply endorsement by the U.S. government.

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Accepted July 31, 2010
Published December 16, 2010