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Original Investigation

Inferring spatial and temporal behavioral patterns of free-ranging manatees using saltwater sensors of telemetry tags

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ABSTRACT

Diving or respiratory behavior in aquatic mammals can be used as an indicator of physiological activity and consequently, to infer behavioral patterns. Five Antillean manatees, *Trichechus manatus manatus*, were captured in Chetumal Bay and tagged with GPS tracking devices. The radios were equipped with a micropower saltwater sensor (SWS), which records the times when the tag assembly was submerged. The information was analyzed to establish individual fine-scale behaviors. For each fix, we established the following variables: distance (D), sampling interval (T), movement rate (D/T), number of dives (N), and total diving duration (TDD). We used logic criteria and simple scatterplots to distinguish between behavioral categories: 'Travelling' ($D/T \geq 3$ km/h), 'Surface' (↓TDD, ↓N), 'Bottom feeding' (↑TDD, ↑N) and 'Bottom resting' (↑TDD, ↓N). Habitat categories were qualitatively assigned: Lagoon, Channels, Caye shore, City shore, Channel edge, and Open areas. The instrumented individuals displayed a daily rhythm of bottom activities, with surfacing activities more frequent during the night and early in the morning. More investigation into those cycles and other individual fine-scale behaviors related to their proximity to concentrations of human activity would be informative.

Introduction

For the last few decades, biotelemetry has proven to be a very useful tool for marine species tracking (Aarts et al., 2008). These tools offer increasingly sophisticated means – e.g. large-scale telemetry arrays, fine-scale positioning, and use of physiological and environmental sensors – of evaluating the behavior, spatial ecology, energetics, and physiology of free-living animals in their natural environment (Cooke, 2008). Telemetry has been widely used to investigate the behavior of seabirds (Adams and Flora, 2010; Wilson et al., 2009; Wood et al., 2000), marine mammals (Bailleul et al., 2007; Baumgartner and Mate, 2005; Mate et al., 1998), reptiles (Jonsen et al., 2007; McMahon et al., 2007; Read et al., 2007) and fishes (Mate et al., 1998; Sims et al., 2009).

Most of the broad scale studies of manatee radio tracking have employed VHF radio-transmitters and/or Platform Terminal Transmitters (PTTs) with the Argos System data service (www.argos-system.org) (Deutsch et al., 2003). A major limitation of VHF and PTT is the infrequent intervals between fixes limiting their application at finer spatial resolutions (Schofield et al., 2007). Another issue is the spatial precision of locations, which lack the high resolution accuracy needed for fine-scale tracking (Hazel, 2009). However, recent radio tracking studies of manatees in Florida and the Caribbean have utilized Argos-linked Global Positioning System (GPS) tags, which provide much more accurate spatial precision.

A large number of studies have addressed the fine-scale habitat selection by marine megafauna species such as turtles (Fossette et al., 2010; Schofield et al., 2007; Senko et al., 2010; Yasuda and Arai, 2009), cetaceans (Allen et al., 2001; Hastie et al., 2003; Johnston et al., 2005; MacLeod and Zuur, 2005; Skov and Thomsen, 2008), seals (Burns et al., 2008; Hindell et al., 2002; Lea and Dubroca, 2003), sea lions (Wolf and Trillmich, 2007) and dugongs (Sheppard et al., 2006). However, studies of fine-scale behavior of endangered manatees (Order Sirenia: *Trichechus* spp.) are underrepresented in the literature. Our understanding of fine-scale behavior may be improved by examining the diving behavior and correlating it with physical features (Burns et al., 2008).

Data loggers recording depth at a specific time interval (Time–Depth recorders, TDRs) have been widely used to describe

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fine-scale behavior of deep-diving mammals such as cetaceans (Aoki et al., 2007; Baird et al., 2002, 2005; Davis et al., 2007), sea otters (Bodkin et al., 2007), elephant seals (Campagna et al., 1999; Costa et al., 2003; Le Boeuf et al., 1993; Muelbert et al., 2004), seals (Bekkby and Bjorge, 2000; Blix and Nordoy, 2007; Frost et al., 2001), as well as in shallow-diving animals such as dugongs (Chilvers et al., 2004; Churchward, 2001) and turtles (Fossette et al., 2010; Hays et al., 2001a; Hochscheid et al., 2005; Reina et al., 2004). However, for shallow aquatic mammals such as manatees, the use of TDRs to study diving patterns has been limited due to issues in the interpretation of data (Hagihara et al., 2009), and alternative technical tools should be explored.

We aimed to investigate the fine-scale behavior of satellite-tagged Antillean manatees in Chetumal Bay. This technology not only enables animals to be located but can also provide information on their diving activities (Bailleul et al., 2007). The GPS radios were equipped with a saltwater sensor (SWS), which records the times when the tag assembly is submerged. Diving or respiratory behavior can be used as an indicator of physiological activity (Read and Gaskin, 1985), and consequently, to infer behavioral patterns (Boyd, 1997). Therefore, we used the information obtained from SWS to describe the diving behavior, and to infer behavioral patterns of manatees captured in Chetumal Bay.

Methods

Study area

Chetumal Bay is a large estuary located between Belize and the southern section of the state of Quintana Roo, Mexico (17°52′–18°50′ N, 87°50′–88°25′ W) (Fig. 1). It covers an area of about 2450 km^2. The connection with the sea is located in the southeast section of the bay, and it receives fresh water from the Hondo River and many smaller creeks. Its depth ranges from 1 to 7 m, with several nearly circular depressions known as “pozas” that can attain up to 40 m depth (Carrillo et al., 2009b). With an average salinity of 13 psu it is considered hyposaline (Gasca et al., 1994) and has low productivity (Gasca and Castellanos, 1993). The climate is tropical with seasonal rains between June and September and an annual precipitation of 1245 mm on average; the mean annual air temperature is 27 °C with a maximum of 31 °C and a minimum of 20 °C (Carrillo et al., 2009a). The region has three climatic seasons typified by drought (February to May), rains (June to October), and north winds (November to January) (Carrillo et al., 2009b). The bay is characterized by a low abundance and variety of sub-aquatic vegetation (Espinoza-Ávalos et al., 2009), although manatees can also forage on mangroves and other riparian plants (Castelblanco-Martínez et al., 2009b).

Capture, tagging and radio-tracking

From March 2006 to May 2007, five Antillean manatees (three females and two males) were captured in northwestern Chetumal Bay and fitted with radio tags (Table 1). Capture procedures are explained in Morales-Vela and Padilla-Saldívar (2009). The tag assembly consisted of a buoyant, cylindrical housing containing an Argos-linked GPS tag (TMT-460, Telonics, Inc.) that was attached by a flexible nylon tether to a belt that fit snugly around the caudal peduncle (Reid et al., 1995). The tags collected GPS position data every 20 or 30 min with a measured accuracy of <5 m for >95% of the locations. In this research, the tag also incorporated a micro-power saltwater sensor (SWS) that functions to suppress transmissions while the unit is submerged thereby saving power (Telonics, Inc.). The SWS synchronize uplink transmissions to resume at the precise time when the tag actually breaks the sea surface following a dive. By transmitting immediately upon resurfacing, the unit has the best chance of successfully sending uplink transmissions to available orbiting satellites. The units were recovered at the completion of the study, the GPS locations and sensor data (number and duration of individual tag submergences/dives) were downloaded from memory for analysis.

Data analysis

Each manatee was treated as a sampling unit to avoid pseudo replication (Hurlbert, 1984). The telemetry data were edited to eliminate telemetry fixes before and after tracking time and while on land. Points were also eliminated based on excessive speed between consecutive fixes. Each fix was associated to a depth value using the nearest-neighbor interpolation of ArcMap. Bathymetric information was obtained by Laboratory of Physic Oceanography of ECOSUR (Chetumal), and complementary depth values for the freshwater system of Guerrero Lagoon were collected by the authors. To reduce the effect of shallow depths on data interpretation, fixes obtained at depth values less than 2 m were discarded from the analysis.

The information obtained by the SWS was used to record submergence frequency and duration. The start of the dive was defined by the time that the SWS perceived that the transmitter was submerged, and the end of the dive was defined when the SWS recorded the transmitter breaking the surface (Hays et al., 2004). For each 20 or 30 min interval between the remaining consecutive fixes, distance (D) between coordinates, number of dives (N), and total diving duration in seconds (TDD) were used to infer the behavioral category performed by the individual during the interval. Four behavioral categories were broadly defined based on prior knowledge of the species behavior. Long distances between two consecutive fixes – i.e. >1000 m (for 20 min interval) or >1500 m (for 30 min interval) – suggested that the manatee was traveling >3 km/h, so the second fix was classified as ‘traveling fast’. For all intervals that were shorter than this distance criterion, the interval end point was labeled as idling, which were further subdivided among behavioral categories using simple logic criteria, as shown in Table 2, Fig. 1. Bottom behaviors can be interpreted as resting or feeding. When a manatee is resting on the bottom, it surfaces only a few times to breathe (↓N° dives), while the underwater time is high (↑dive duration). When a manatee is feeding on the bottom, the total dive duration is also high, but since the individual is more active, it comes to the surface to breathe more often (↑N° dives). When a manatee is resting at the surface, the number of dives is low, and the duration of those dives is shorter (often 0). This pattern could also correspond to feeding or other behaviors in shallow water. All behaviors calculated from analysis of these time intervals were assigned to the second, or ending point of the interval (Table 2, Fig. 2).

Scatter plots of the data were created first to allow visual assessment of the data and to establish cut points for behavioral types based on the appearance of the data. The occurrence of behavioral categories was expressed as the proportion of fixes where each behavior pattern occurred (Martin and Bateson, 1993). To test if there was a correlation between behavior and ecological variables, habitat categories were qualitatively assigned according to the locality and general geomorphologic characteristics, and were mutually exclusive, as follow: Lagoon, Channels, Caye shore, City shore, Channel edge, and Open areas. Behavioral frequency was represented in terms of percentages [$F_{b1} = (n_{b1}/N_1) \times 100$; where F_{b1} = frequency of the behavior b in the habitat 1, n_{b1} = number of fixes assigned to the behavior b in the habitat 1, and N_1 = total of fixes in the habitat 1]. The Pearson rank correlation (R^2 statistic) method was used to determine a level of correlation between the rough behavior category