Response of Manatees to Vessel Traffic: Simultaneous Measurements of Behavioral Responses and the Acoustic Environment

Final Progress Report to the Florida Fish and Wildlife Conservation Commission

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PROGRESS REPORT SUMMARY

The major challenge faced by managers charged with promoting the recovery of a viable manatee population is to design and implement actions that are effective in reducing human-caused mortality and injury while minimizing undue impacts on waterborne human activities, all in the face of a continually increasing human population in Florida's coastal areas. At least one-third of documented manatee deaths in Florida are directly attributable to human activities, and the largest single source of human-related mortality is watercraft strikes. The primary conservation and management tool used to prevent vessel strikes is the establishment of speed restriction zones in habitats frequented by manatees. A thorough understanding of the behavioral and sensory mechanisms underlying manatee-boat collisions is necessary in order to devise effective avoidance approaches, whether they be technological or regulatory. A crucial and sometimes controversial piece of the manatee-boat interaction puzzle that has been missing is the acoustic environment around the manatee. That is, what does a manatee hear as a motorized vessel approaches and at what distance? Detailed behavioral observations of manatee reactions are also lacking due to the turbid nature of most waters that they inhabit.

Through a unique collaboration among scientists and engineers from FWC's Fish and Wildlife Research Institute, Florida State University, Duke University, and the Woods Hole Oceanographic Institution, we embarked on a multi-year study to characterize manatee behavioral responses to approaching vessels while simultaneously recording the acoustic environment during the encounters. The goal of the project is to create a combined picture of manatee behavior, acoustics, and vessel trajectories so that we can better understand the responses displayed by manatees when approached by boats and the acoustic cues that may mediate such responses. A secondary objective is to quantify the frequency of manatee-boat interactions and disturbances, and how that varies spatially and temporally. This research relies on the application of a state-of-the-art digital acoustic recording tag, known as the DTAG, developed by WHOI engineers to measure the responses of marine mammals to anthropogenic sound. In addition to sound, the DTAG also records a suite of behavioral parameters (pitch, roll, depth, heading, fluke strokes) that permit a detailed three-dimensional reconstruction of the manatee's movements, behavior, and orientation underwater.

We captured and tagged 20 manatees during the spring and summer of 2007 and 2008, all but two in Lemon Bay, Placida Harbor, and Gasparilla Sound of southwest Florida (Charlotte and Sarasota Counties). We deployed the DTAGs along with buoyant, satellite-linked GPS tags attached to a padded belt around the manatee's peduncle. The DTAGs were programmed to start recording 2-3 days after deployment for a period of 34-48 hr. The GPS tags were programmed to attempt location fixes at 5-minute intervals, providing fine-scale information on movement tracks and habitat use. Manatees were tracked in near real-time through the Argos Data Collection and Location System and located in the field with conventional VHF and ultrasonic telemetry. A field crew tracked the tagged manatees by boat on weekends, recording characteristics of passing vessels, manatee responses, and habitat. A laser range finder was used to record bearing and distance to passing vessels in order to reconstruct their trajectories in a GIS. Aerial videography was also used to provide a clearer perspective of manatee behavior and to truth the reconstructions of manatee-vessel encounters.

This final *progress report* details the study's objectives, field methods, and data processing procedures and provides preliminary summaries and analyses. Data entry, verification, and processing in relational databases and in GIS are ongoing, so most of the numbers presented in this report will change. Only a small portion of the DTAG data has been processed, as the auditing of the acoustic files is very time-consuming. Nevertheless, the data collected by the field team, combined with massive data streams from the various tags, demonstrate the promise of this integrated approach for elucidating manatee behavioral responses to approaching vessels and for correlating those responses with vessel acoustic signatures at the manatee's location. The tables and figures provide an indication of the types of analyses and graphics that are possible with these data. For instance, the DTAG sensor data were used to create three-dimensional reconstructions of the manatee's movements during a boat approach, allowing us to visualize behavioral responses that can be nearly invisible to field observers. Combining this three-dimensional visualization of manatee movements and orientation with temporal changes in acoustical parameters provides a powerful means of investigating manatee response to vessels.

This study has been successful on several fronts. This is the first time that the newly redesigned manatee DTAG was deployed on manatees. The housing withstood the harsh conditions of repeated deployments well and the programmed release mechanism functioned correctly 13 of 20 times. All DTAGs were recovered and successfully recorded a wealth of acoustic and behavioral data on the focal manatees, totaling 741 hours. DTAG sensor data were calibrated and methods for aligning the data from the various sensors were successfully demonstrated. All GPS tags were also recovered and logged a large volume of data on manatee movements and habitat use, averaging 245 GPS locations per day. The fine temporal and spatial resolution of the travel paths obtained is unprecedented for a marine mammal. With a few exceptions due to weather or animal elusiveness, we were able to conduct continuous focal follows of tagged manatees during weekend days to collect data on the attributes of all watercraft (>4,200) passing within about 500 m of the focal manatee and on manatee response to boat passes. A complex relational database was developed to incorporate the various types of information collected in the field; it is being populated to link the data from the observation boat GPS, range finder data, vessel attributes, manatee behavioral observations, environmental data, and information on observation effort and observation boat engine activity.

The number of motorized vessels that passed or approached tagged manatees per hour was quantified for the first time based on field observations. Preliminary analyses show that, on average, 23.6 boats passed by a focal manatee per hour but this varied greatly among individuals (0.2 – 63.8) depending on location. Highest rates occurred on holidays and in frequently used boating corridors; for example, up to 118 boats per hour on Labor Day weekend near the ICW in Lemon Bay. The vast majority of vessels passed at distances that did not threaten the focal manatees; 1% and 3.7% of boat passes with recorded distance class came within 10 m and 50 m, respectively, of the manatee. Combined with the behavioral data from field observations and the DTAG, this will provide insight into the frequency with which manatees are disturbed by boats each day.

Based on a preliminary analysis of the field observations entered to date, tagged manatees were more likely to respond to boat approaches at closer distances. Field observers noted a response by the manatee about half of the time when a vessel passed by within 10 m. Manatees typically responded by increasing mobility and speed and by moving away from the approaching boat, indicating a flight response. There was no noticeable effect of vessel speed class on the probability or type of response in this preliminary analysis, but this warrants further investigation.

A sample of manatee vocalizations was characterized according to fundamental frequency, duration, frequency contour, and rate. Vocal parameters were generally similar to those found in previous studies. The overall vocalization rate in this sample was 0.47 per minute. Vocalization rate in relation to the presence of motorized vessels is being analyzed. This information is important to have if considering deployment of an automated manatee vocalization detector as part of a manatee avoidance program for boaters.

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INTRODUCTION

The Florida manatee (*Trichechus manatus latirostris*) inhabits coastal and inland waters in the southeastern United States. This endangered species' long-term survival is threatened, in part, by human influences, such that human activity accounts for about half of documented adult deaths (MPSWG 2005). Of those deaths, approximately 75% result from a collision with a watercraft (Ackerman et al. 1995, MPSWG 2005). Runge et al. (2007) conducted a population viability analysis to compare the effects of altering the levels of different threats on future population status of the Florida manatee. Removing or reducing the watercraft threat reduced the probability of quasi-extinction (i.e., population of 250 adults) far more than an equivalent reduction of any other modeled threat (loss of warm-water, red tide, and entanglement). This means that watercraft-related mortality poses the single greatest threat to the manatee's long-term persistence in Florida. The low genetic diversity of the Florida manatee (Garcia-Rodriguez et al. 1998, Garcia-Rodriguez et al. 2000, Tringali et al. 2008) may represent another vulnerability of this population, making the loss of individuals to human-related causes particularly detrimental to the genetic health of the population.

Boat collisions injure manatees in two ways: cuts from the propeller and blunt trauma. The severity of cuts from a propeller is determined partly by the size of the propeller. The speed of the propeller may determine how readily the blade cuts through the manatee's skin, so faster boats may cause more severe injury from propeller cuts. The severity of injury from blunt force on the other hand is directly related to the mass and speed of the boat. Blunt force trauma can be caused by collision with a boat's hull, keel, rudder, skeg, propeller, or anything else that extends below the water (Calleson and Frohlich 2007). The majority of boat-related manatee deaths are caused by blunt force injuries (Lightsey et al. 2006). The impact force a manatee receives from a boat collision is related to the energy provided by the moving boat, which increases with the square of the boat's speed (Calleson and Frohlich 2007). So for example, a boat traveling at 48 km/hr (30 mph) has 36 times the energy of the same boat traveling at 8 km/hr (5 mph). Therefore, when boaters decrease their speed they are greatly reducing the severity of potential injury to manatees caused by blunt force of a collision.

Boat noise is a result of cavitation (the formation and collapse of bubbles in liquid formed by low pressure) and the machinery used to propel a boat, such as diesel engines and gears (National Research Council 2003). This produces noise across a wide range of frequencies that may extend to 100 kHz, but usually peaks in sound intensity between 5 and 500 Hz (Richardson et al. 1995). Boat noise is comprised of both tonal and broadband sounds, the tonal component is primarily related to propeller blade rate and the broadband component is primarily from cavitation. The sound levels and frequency characteristics are loosely related to boat size and speed, but many other characteristics affect the sound output of a boat engine. Boats with outboard engines, like the recreational boats manatees commonly encounter, can produce sound levels of 175 dB re 1 μPa-m (Richardson et al. 1995).

In addition to physical harm, elevated noise levels from watercraft can potentially impact animals in three ways: inducing temporary or permanent hearing threshold shifts (meaning a sound must be louder to be detected than under normal circumstances); masking of acoustic signals important to the animal; and altering the animal's normal behavior. These factors could affect foraging, reproduction, and survival of the animal (Nowacek et al. 2007). Preliminary aerial observations of manatee-boat interactions in Lemon Bay showed an average of one encounter every 15 minutes, with disturbances resulting in changes in manatee behavior every 49.5 minutes (Keith et al. 2008). While relatively little research into how anthropogenic noise can affect manatees has been conducted, the effect has been examined in other marine mammals. There is evidence that boat traffic, a large source of anthropogenic noise, can cause changes in the behavior of other marine mammals (e.g., Hastie et al. 2003). Nowacek et al. (2001) found that in the presence of boats bottlenose dolphins remained closer to one another, changed their heading more often, dove for longer periods, and swam faster. Buckstaff (2004) that bottlenose dolphins produced whistles at a higher rate when a boat was approaching when compared to a boat moving away or in the absence of boats. This increase in whistle rate could be a result of individuals using whistles to reunite or compensating for potential signal masking from the boat noise.

Sound is certainly the predominant cue available to manatees for detecting motorized vessels in most Florida waterways. One reason is the limited visual acuity of manatees discovered from psychophysical experiments (Bauer et al. 2003). Moreover, manatee vision is unlikely to be the first indicator of an approaching boat because they typically live in turbid environments where water clarity severely limits their range of visual detection. Manatee hearing on the other hand, likely allows for early detection of boats. Gerstein et al. (1999) determined auditory thresholds for two manatees from 0.4 to 46 kHz, finding peak sensitivity at 16 to 18 kHz (50 dB re:1 μPa). Work on behavioral hearing thresholds is being continued by Mann et al. (unpublished) which will double the sample size of manatees used to obtain behavioral audiograms. Bullock et al. (1982) used evoked potentials to examine manatee hearing and determined they could hear up to 35 kHz with the largest peaks from 1 kHz to 1.5 kHz. Manatees can hear in the frequencies that most boat engine noise occurs, but with less sensitivity than higher frequencies. The manatee auditory system also has a high temporal resolution, roughly ten times that of humans (Mann et al. 2005), suggesting that they should have good sound localization capabilities underwater. This has been verified recently in behavioral experiments conducted by Mann et al. (2007), where manatees performed well above chance in discriminating among sounds produced by 8 speakers arranged around the animal. The broadband nature and frequency range of the stimuli used in this experiment was similar to boat noise, suggesting that manatees should be capable of localizing sounds produced by boats.

The primary tool used to reduce the risk to manatees of injury by boats is the implementation of slow speed zones in areas manatees frequent. Having boats travel at slower speeds is believed to reduce injuries and death of manatees in three ways: (a) by allowing the boat driver more time to see a manatee and therefore take evasive action; (b) by providing more time for the manatee to detect and move away from the boat; and (c) by reducing the severity of injuries to a manatee if it is struck (Calleson and Frohlich 2007). There is little hard evidence on the effectiveness of speed zones in reducing watercraft-related deaths and injuries, but a recent analysis of carcass recovery data provides preliminary evidence for a decline in watercraft-related manatee deaths following the posting of slow speed zones (Laist and Shaw 2006). These findings suggest that implementation of speed zones may indeed have been effective at reducing deaths within the area under study. There are some inherent problems, however, with using salvage data for this purpose, including the lack of annual data on important covariates (e.g., boat traffic, manatee abundance, reporting rate) that could confound the analysis. Calleson and Frohlich (2007) provide a cogent discussion of the rationale for the use of slow speed zones to reduce manatee injury and mortality.

Given the management emphasis on reducing this source of manatee mortality over the past two decades, there have been relatively few rigorous published studies on manatee behavioral response to passing or approaching watercraft. Nowacek et al. (2004a) collected aerial video observations using a remotely operated camera attached to a small aerostat during both opportunistic and controlled boat approaches. Some manatees demonstrated marked responses to vessel approaches while others did not. The engine type (outboard, inboard, jet, or non motor) and boat speed did not significantly affect whether or not the manatee responded. The typical response was flight toward deeper water (i.e., boat channel), but this was most frequent when the boat approached to within 10 m of the manatee and the manatee was located in shallow seagrass habitat (<2 m depth). That is, when the manatee was most directly threatened and most vulnerable. This behavioral response often took the manatee into the path of the approaching watercraft, which may partly explain the high frequency of vessel-inflicted injuries and scars in the manatee population (Beck and Reid 1995, Wright et al. 1995). When manatees responded to the approaching boat they commonly began responding when the boat was 25 m away and as far as 68 m away. While this study was an important first step, behavioral observations were sometimes limited by water turbidity, depth of the manatee, and wake of the passing vessel (46% of boat passes were unsuitable for analysis), and only gross responses could be scored reliably. Finer resolution of behavioral responses (e.g., changes in orientation, depth, fluke stroke rate) should provide insight into the many cases where manatees do not show a marked flight response. That is, a more sensitive suite of behavioral metrics could indicate whether and when a manatee detects a vessel in situations where there is no apparent gross response.

An alternative approach to this problem was taken by Miksis-Olds et al. (2007). They simulated boat approaches using playbacks of sounds recorded during boat approaches (to 10 m) at idling or planing speeds, including a personal watercraft (PWC) on a plane. These simulated approaches varied in duration, amplitude, and rise time, as expected for the different pass types. Figure 1 displays the power spectra for all three approach types 15 seconds before the closest point of approach and at the closest point of approach along with the ambient noise level and the hearing sensitivity of manatees. Prior to the closest point of approach the PWC was either at or below detectable levels; at the closest point of approach all three types were above detectable levels. The sounds were played back to manatees while they either rested or foraged on a seagrass bed. While only 35% of the manatees responded to the idle speed approach (usually with slow swimming), 65% responded to the planing approach, and almost all manatees responded to the PWC approach, which also elicited the greatest response in terms of swim speed. Overall the most pronounced response was to the simulated PWC approach with respect to behavioral and respiratory parameters. The PWC approach had a very short rise time with the sound level not differing greatly from the ambient background until approximately 5 seconds before the closest point of approach; this could explain the more drastic reaction because the manatees did not have time to respond in a more energetically favorable manner. The behavioral responses lead to a disruption in feeding behavior and in some cases the manatees left the area. The differential proportions of responses between the conditions shows that manatees discriminated between types and speed of boat approaches based on sound.

Both manatee behavior and the acoustic environment need to be sampled simultaneously during a variety of types of vessel approaches. Such a combined picture is desperately needed to better understand the precise responses displayed by manatees approached by boats and the acoustic cues that may mediate such responses. Incorporating this acoustic component is critical to furthering our understanding of manatee-boat interactions because it tells us what the manatee hears (or should hear, given the species' audiogram) when approached by motorized vessels traveling at different speeds and distances, and in different habitats with different levels of background noise. In this study we have addressed this knowledge gap through application of manatee-borne acoustic recording and GPS tags, in combination with boat-based and aerial observations of manatee-vessel encounters.

Objectives

The overarching goal of this study is to understand how manatees respond to watercraft in their natural environment in order to provide managers with a solid scientific basis for taking actions to reduce the risk of vessel strikes. The specific objectives of this research project are:

- To provide a comprehensive and detailed description of manatee behavioral response to approaching and passing watercraft in the coastal waters of Florida.
- To correlate the timing and type of behavioral response with the acoustic characteristics of the vessel's signature as received at the manatee.
- To assess the relative importance of factors affecting the occurrence and type of manatee response to watercraft, including vessel characteristics, habitat characteristics, and manatee activity and group size.
- To quantify the frequency of manatee-boat interactions by habitat type.
- To quantify vocalization rates of free-ranging manatees in relation to time of day, activity, and watercraft approaches.

STUDY AREAS

Our most important criterion in selection of a study area and season was spatial and temporal coincidence of relatively high abundance of manatees and relatively high vessel traffic. While there are many such areas in Florida, we focused on the southwest region of the state where population trend appears to be declining (Runge et al. 2004), in part due to watercraft-related mortality. Lemon Bay, including Placida Harbor, was identified as the primary study area. The proximity of this region to the main concentration of trained, experienced crew in St. Petersburg (FWRI headquarters) minimized travel expenses associated with captures and tracking. We avoided the winter season because manatees are known to spend extended amounts of time at thermal refuges where watercraft are restricted and often prohibited (Deutsch et al. 2003a). The highest number of manatee deaths due to vessel collisions typically occurs during the spring, as manatees disperse to warm season use areas and boaters increase activity on the water. Based on aerial survey counts, manatee use of Lemon Bay is seasonally highest during the spring months (Koelsch and Pitchford 1998) and vessel traffic also peaks in spring (Gorzelany 2006, Sidman et al. 2007). Capture and tagging of manatees was centered in Lemon Bay during summer 2007 and in Placida Harbor and Gasparilla Sound in spring and summer 2008 (Fig. 2). Due to manatee dispersal after capture, the study area expanded to include the portion of southwest Florida between Sarasota Bay to the north and Charlotte Harbor to the south. Before committing staff and funds toward capture of free-ranging manatees, however, we tested the redesigned DTAG hardware and software in the laboratory (Johnson et al. 2007), on a manatee in captivity (WHOI 2007), and in two field trials. The field tests also allowed us to improve and refine our data collection protocols.

Trial 1: Kings Bay, Crystal River, Florida

The first field test took place in Kings Bay with a tagged manatee that was scheduled for recapture as part of a USGS health assessment study. On the central west coast of Florida, Kings Bay is an approximately 600-acre spring-fed water body that flows into Crystal River as it makes its way northwest for 11 km to the Gulf of Mexico (28.888^{o}N, 82.601^{o}W) (Fig. 3). More than thirty known springs distribute fresh water into Kings Bay and from the side creeks; however, the area is also tidally influenced thereby resulting in a brackish environment. While depths at spring vents are up to 17.6 meters, the remainder of Kings Bay averages 1 to 3 meters deep (Southwest Florida Water Management District 2000). Marsh and hardwood palm populate the area to the west with the City of Crystal River to the east (Scott et al. 2004). Exotic freshwater plants, including floating and submerged mats of dark green filamentous algae (*Lyngbya* spp.), *Hydrilla verticillata, and Myriophyllum spicatum*, choke much of the area resulting in removal projects to keep the water navigable (Southwest Florida Water Management District 2000). This first magnitude spring system serves as a major warm-water refuge for the manatee during the winter, and increasingly manatees are found year-round in Kings Bay. The waters in Kings Bay and Crystal River comprise the Crystal River National Wildlife Refuge. During the summer Kings Bay is a popular water sports recreation area and the state speed limit for much of the main part of the bay is 35 mph during the day (25 mph at night). The southern end of the bay, as well as the side canals and lagoons, are regulated at idle speed year-round. Most of Crystal River proper is restricted to 25 mph in the central corridor and idle speed outside.

Trial 2: Card Sound, Key Largo, Florida

The second field trial was conducted by tagging a rehabilitated manatee at release into Card Sound (25.285°N, 80.361°W). Part of a larger system of protected waters and lands between the southeast Florida coast and the Florida Keys (e.g., Biscayne Bay-Card Sound Aquatic Preserve), Card Sound comprises 17,000 acres of seagrass meadows, hard bottom communities, and mangrove wetlands (Fig. 4). The estuarine environment is separated from the Atlantic Ocean by the upper Florida Keys. Salinities approach marine values except in areas of canals where freshwater run-off occurs, and tidal mixing is most pronounced at the vicinity of tidal inlets between the barrier keys. Water depths generally range between 2-6 meters deep with the exception of two banks, Cutter Bank in the north and Card Bank in the south. Card Bank is less than 1 meter below the surface, essentially isolating Little Card Sound to the south. The Intracoastal Waterway (ICW) traverses Card Sound through the center in a northeast/southwest direction (Florida Department of Natural Resources 1991). The Florida Power and Light Turkey Point power plant is located on the west side of Biscayne Bay near the boundary of Card Sound; as with other power plants throughout the state, manatees use the discharge canal area as a thermal refuge in winter. While no federal or state boat speed restriction zones exist in this region, both the discharge and intake canals are no entry zones as part of Homeland Security regulations.

Primary Study Area: Charlotte Harbor National Estuary, centered on Englewood, Florida

Located along the southwest coast of Florida, the Charlotte Harbor National Estuary comprises eight interconnected smaller estuaries including (from north to south): Lemon Bay, Gasparilla Sound, Cape Haze, Charlotte Harbor, Pine Island Sound, Matlacha Pass, San Carlos Bay, and Estero Bay. Separated from the Gulf of Mexico by a string of barrier islands, salt water flows through passes between these islands while three major rivers---Myakka, Peace, and Caloosahatchee---provide fresh water to the greater estuary (Duffey et al. 2007). Our main study area included the northern portion of this large region (27.010°N south to 26.707°N, 82.440°W east to 81.935°W) (Fig. 2).

Lemon Bay (including Placida Harbor) is a long (~21 km) and narrow (0.2-1.9 km, averaging 1.2 km wide) water body separated from the Gulf of Mexico by two barrier islands. Composed of marine and estuarine waters, inlets, bays, tidal creeks, mudflats, sand bars, beaches, and salt flats, Lemon Bay is shallow outside of dredged channels, averaging 1.8 meters deep at mean high water. Channels include the ICW, which runs the length of the bay, and associated access channels westward to the Gulf of Mexico through two passes (Stump and Gasparilla) and eastward to numerous freshwater creeks and residential canal systems. Salinity varies depending on the amount of rainfall and on proximity to these passes and creeks. Lemon Bay is a complex system that supports diverse flora and fauna including extensive seagrass meadows most commonly comprised of *Halodule wrightii* (shoal grass), *Syringodium filiforme* (manatee grass), and *Thalassia testudinum* (turtle grass) (Bureau of Submerged Lands and Preserves Division of State Lands 1992). The federal U.S. Fish and Wildlife Service (FWS) designated the area from the Sarasota County and Charlotte County boundary south to a line approximately 1.6 km south of the Tom Adams (Bay Road) Bridge as a manatee refuge. The state Fish and Wildlife Conservation Commission (FWC) manatee protection zone overlaps the federal refuge, extending north to Alligator Creek and south to the Boca Grande Causeway (at the junction of Placida Harbor and Gasparilla Sound). Both zones require vessels to operate at no more than 25 mph while navigating within the ICW and at slow speed when outside the ICW year-round in their respective regulatory areas, with two exceptions in the FWC zone: the area at the northern extent of Placida Harbor is a slow speed zone throughout for boating safety and the channel to Forked Creek is an idle speed zone.

As the mainland becomes wetland southbound, the estuarine environment of Lemon Bay and Placida Harbor widens into Gasparilla Sound (Fig. 2). The Sound is separated from the Gulf of Mexico by Gasparilla Island and bounded by oceanic passes to the north (Gasparilla Pass) and south (Boca Grande Pass). A maze of mangrove islands and sand bars blur the distinction to the east where Bull Bay and Turtle Bay comprise the Cape Haze Estuary. The entire area is bounded to the south and east by Charlotte Harbor and, altogether, is generally described and managed as Charlotte Harbor Proper, approximately 91,000 acres of sovereign submerged land. The bathymetry of the area is generally uncomplicated, flat and shallow averaging only 2.1 meters in depth (Florida Division of Recreation and Parks 1983, Stoker 1986). The Myakka and Peace rivers provide large inputs of fresh water to the estuary at the northwest and northeast corners of Charlotte Harbor, respectively. During low tributary flows, tidal waters travel several kilometers upstream while during high flows, freshwater travels into the harbor, particularly along the west bank between Hog Island and Cape Haze, commonly referred to as the “West Wall” of Charlotte Harbor (Post et al. 1999). Thus, salinity varies depending on the amount of rainfall, the freshwater flow, and proximity to these tributaries. Extensive seagrass meadows are found in shallow bays and sounds throughout the area, with *T. testudinum*, *S. filiforme*, and *H. wrightii* being the three most common seagrasses found. *Ruppia maritima* (widgeon grass) is found in areas of low salinity, such as near the mouth of the Myakka and Peace Rivers. Tidal flats may have sporadic vegetation or no vegetation at all, but do have extensive algal growth areas

(Florida Division of Recreation and Parks 1983). As with the Lemon Bay estuary, the diverse water bodies and extensive vegetation make this larger Charlotte Harbor Proper estuary attractive to a wide variety of fish and wildlife, including the manatee. FWC manatee protection zones are designated in two areas of Turtle Bay, across its mouth and at a seagrass bed in the central area of the bay; both zones require boats to operate at idle speeds in the designated areas and at 25 mph or less outside of it. There are also FWC slow speed zones throughout the Myakka River in Sarasota County and in much of the Peace River in Charlotte County.

The Lemon Bay Estuary is connected to the Sarasota Bay Estuary to the north by a 7-km-long dredged canal near Venice, Florida. Approximately 90 km long and spanning from Anna Maria Sound south to the Venice Inlet, greater Sarasota Bay is not a classic estuary but rather a coastal lagoon that includes a number of smaller interconnected water bodies (e.g., Sarasota Bay, Little Sarasota Bay, Blackburn Bay) that are separated by narrows between the mainland and barrier islands (Fig. 2). While the average depth is 2 meters, each of the individual embayments differ in overall size, shape, and depth. As with Lemon Bay, salt water enters through oceanic passes and inlets while fresh water flows from creeks and tidal tributaries on the east side of the bay; thus, salinity varies with regard to geographic placement of these features. Five common species make up the extensive seagrass meadows found throughout the area: *H. wrightii, T. testudinum, S. filiforme, R. maritima,* and *Halophila engelmanni* (star grass) (Sarasota Bay Estuary Program 2006). A variety of FWC manatee protection zones regulate watercraft operation throughout the area including, with particular reference to our focal follow areas, a year-round no entry zone at Pansy Bayou, a slow speed zone between City Island south to Coon Key on the west side of Sarasota Bay, and a slow speed zone with an upper speed limit of 25 mph permitted in the ICW throughout Little Sarasota Bay.

METHODS

Our general approach was to combine visual observations with advanced, non-invasive tag technologies to document the behavior of manatees in the presence and absence of opportunistic vessel approaches. State-of-the-art multi-sensor digital acoustic recording tags (Johnson and Tyack 2003) and Argos-linked GPS tags (Deutsch et al. 2003a) were deployed on 20 free-ranging manatees over two years of field work. Boat-based visual observations and aerial videography were used to ground-truth the tag data and to provide a concurrent map of vessel activity in the area of tagged manatees. Full integration of the various data streams will permit a multi-dimensional reconstruction of the manatee's movements and behavior in relation to the trajectories and sounds of passing vessels.

Manatee Captures and Health Assessments

Manatees were captured and tagged during the warm seasons of 2007 and 2008. One or two manatees were captured during mid-week (Wednesday or Thursday) to allow for a 2-3 day acclimation period before weekend data collection. Standard capture techniques using nets from a specialized manatee rescue boat were employed (Weigle et al. 2001). Two to three additional support boats provided observers, safety crew, and gear; an aerial observer in a single-engine Cessna located target manatees and ensured that only single animals were set upon. The manatee was transferred to a stretcher and either moved to a nearby beach or worked up on the boat, depending on the location. The first field season was conducted from June to September 2007 with 10 tag deployments, as follows: one free-ranging manatee in Kings Bay, Crystal River

(Citrus County) that was slated for recapture as part of a USGS study; one rehabilitated mother-calf pair at their release in Card Sound, southern Biscayne Bay (Miami-Dade County); and eight free-ranging manatees in Lemon Bay near the town of Englewood (Sarasota County). The second field season extended from April to July 2008, during which we deployed tags on 10 more free-ranging manatees in the Placida Harbor/Gasparilla Sound region of Charlotte County; this was just south of the main study area from the first year. An additional 3 manatees were captured and not tagged because they were too small (2) or too large (1) to fit a belt around the peduncle.

The health and condition of each animal was assessed through collection of data on morphometrics (lengths, girths, weight), ultrasonic measurement of backfat thickness, monitoring of vital signs, on-site veterinary evaluation, and post-capture analysis of blood chemistry and hematology. Vital signs, including respiration rate, heart rate, oral temperature, and blood gases were monitored while the animal was on the beach. In addition, we collected urine and fecal samples and blood samples for genetic and hormone analyses. Two PIT tags (passive integrated transponder microchips) were inserted subdermally over the shoulders to aid in future identification (Wright et al. 1998). Each manatee was photo-documented, including all scars and lesions, and later compared for possible matches to manatees already documented in the Manatee Individual Photo-identification (MIPS) catalog. Time to tag, weigh and complete a full health assessment was typically about 1 hour; assessments of visibly pregnant females were expedited to minimize time out of water.

GPS Tag Deployment and Tracking

An Argos-linked GPS tag (TMT-460, Gen IV; Telonics, Inc.) was attached to a padded belt around each manatee's peduncle via a flexible 1.5-m-long tether, allowing the transmission and reception of radio signals at depths up to 2 m (Deutsch et al. 1998) (Fig. 5). The tags were programmed to acquire GPS fixes at 5-min intervals throughout the 24-hr cycle. This allowed us to track the study animals' movements remotely and in near-real-time, but only a portion of the GPS data collected could be transmitted via the satellite-based Argos Data Collection and Location System (Service Argos 1996). A 0.5 W platform transmitter terminal (PTT) transmitted the GPS data to polar-orbiting NOAA satellites via a UHF signal. The tags were programmed with satellite orbital data so that PTT transmissions occurred only when the satellites were passing overhead, hence extending operational life, increasing the number of Argos locations, and increasing data throughput. These GPS tags transmitted up to 18 GPS locations over the course of a typical satellite pass, as well as data on tag activity, tag dive behavior, tag temperature, and a low-voltage flag. A saltwater switch was linked to both the PTT and GPS units in order to time transmissions and fix attempts to tag surfacings and to save battery life. The entire data record was archived in the tag's memory and downloaded to computers after tag recovery.

The GPS tags were left on for several weeks in order to collect fine-resolution data on habitat use and travel paths, and to better place the brief dTag deployments in context. A programmable breakaway collar release unit (CR-2a, Telonics, Inc.) was incorporated into most of the belts as a means to automatically release the entire tag assembly from the animal at a pre-programmed date and time (usually 6-8 weeks after deployment). The CR-2a units employ a miniature pyrotechnic actuator enclosed within a machined plastic housing measuring approximately 4 x 5 x 1 cm. In cases where the CR-2a failed, tracking gear was removed by cutting off the belt with a specialized pole-mounted cutting tool while swimming behind the manatee or from a boat.

We tracked and located tagged manatees in the field with standard radio-tracking equipment by homing in on the unique VHF signal transmitted by the GPS tag. When the tag was underwater (e.g., manatee resting at depth or traveling) and at close range (<400 m), we used a directional hydrophone to track the ultrasonic beacon (70-80 kHz) that was attached to the tether.

Digital Acoustic Recording Tag (DTAG)

Digital acoustic recording tags (DTAGs) were used to measure and record pitch, roll, heading, depth, temperature, and the acoustic environment of tagged manatees. A three-axis accelerometer, three-axis magnetometer, pressure sensor, temperature sensor, and a hydrophone were used to sample these parameters. The pressure sensor was designed specifically for use in the types of shallow water habitats occupied by manatees. Acoustic data were recorded with a 64 kHz sampling rate with 16 bit resolution; this allowed the recording of sounds up to 32 kHz in frequency (low end of frequency range = 100Hz). The accelerometer, magnetometer, pressure, and temperature sensors all had a sampling rate of 50 Hz (i.e., 50 times per second). The difference in sampling rates between the sensors and hydrophone were synchronized by a digital signal processor. The sensor and acoustic data were stored in 6.6 GB of onboard FLASH memory (Johnson et al. 2007).

All of these components—including the sensors, hydrophone, digital signal processor, and FLASH memory, along with a lithium polymer rechargeable cell—were encapsulated in an epoxy resin housing (Fig. 6). Protruding from the housing are two prongs for recharging the lithium cell and a wire that connects to the release mechanism. The encapsulated sensors were then placed in a plastic housing that was especially designed for attachment to manatee telemetry belts (Johnson et al. 2007), as shown in Figures 5 and 6. The housing included flotation material and a VHF transmitter with a flexible whip antenna. At the programmed release time, a small motor was activated that rotated a shaft screw encased in a block of delrin. At the end of the shaft screw a nut was attached and positioned to hold the DTAG to a delrin release block that was attached to the manatees' belt. The nut was flat on top and held in place by a small plastic set screw. When the shaft screw began turning at the programmed release time, the nut was slowly pulled into the block of delrin. Once the nut was fully retracted into the block the DTAG was free to float away from the release block attached to the manatees' belt. As a backup release mechanism, the delrin block connecting the DTAG to the manatee's belt was secured by corrosive magnesium and titanium pins. The corrosive links were designed to release the DTAG from the manatee's belt 7-10 days after deployment; however, lab tests using similar water conditions to Southwest Florida yielded a much longer time frame (Johnson et al. 2007) and in the field these pins did not fully corrode even after 10 weeks in the water.

The DTAGs were programmed prior to deployment using an infra-red (IR) port on the DTAG to communicate with a computer. The programming included setting the date, time, audio sampling rate (64 kHz), resolution (16 bit), gain (12 dB), compression (on), date-time to begin recording, and date-time to trigger the release mechanism. During all 2007 deployments the DTAG recorded continuously, such that once it began sampling it continued until the DTAG ran out of memory, the battery was exhausted, or it was turned off by a researcher. During 2008 the DTAGs were programmed with a duty cycle (i.e., daily on/off times). For example, the

DTAG was often scheduled to begin sampling at 0700 hr and end sampling at 2000 hr; it would continue that sampling cycle each consecutive day until the DTAG ran out of memory, the battery was exhausted, or it was turned off by a researcher (Johnson et al. 2007). This allowed us to maximize sampling during daylight hours, when the manatee was most likely to encounter boats. The DTAGs were programmed to begin sampling no more than 3 days after deployment and to only record for 34-48 hours over a period of 2-3 days to ensure the battery life of the DTAG was sufficient to power the release mechanism. The duration of DTAG sampling was conservatively chosen to ensure that there was sufficient memory to sample while the observation crew was following the manatee.

Visual Observations of Vessels and Manatee Behavior

Boat-based Focal Follow Observations

One to four days after each manatee was captured and tagged they were followed by boat (21.5-ft Key West Bay Reef with 115HP Yamaha outboard engine or 200 HP Mercury outboard engine) and observed continuously for several hours to record interactions with watercraft. All except the first two manatees, tagged in Kings Bay and Card Sound, were tracked on weekends or holidays. If two manatees were tagged over a given weekend then the individual thought to be in the most desirable location (i.e., a greater chance of boat passes) was usually chosen to follow. The focal manatee was located using Argos data and the VHF signal from its GPS tag. Once the manatee was found, the observation boat's five-person crew began recording data on all manatee-boat interactions, including data on boat attributes, distance class to manatee at closest approach, time at closest approach, habitat features, and manatee response.

Whenever possible, the observation boat was anchored or used a small electric trolling motor in order to minimize disturbance and added boat noise to the environment around the focal animal. The anchor chain was covered in surgical tubing to eliminate noise that typically accompanies anchor operation. The observation crew maintained a field log to record field hours, on-effort follow times, attributes of the observation boat, list of crew and data recorders, environmental conditions (tides, salinity, wind speed/direction, water visibility, cloud cover, air and water temperature, and sea state), and general comments for each day. An engine log was maintained to record the times (to the nearest second) that the observation boat's main engine and trolling motor were turned on and off. All equipment was synchronized to atomic time each morning and event times were recorded in the field to the nearest second.

Each boat in the vicinity of the manatee was assigned a unique alphanumeric ID. Vessel attributes recorded were type, size class, speed class, engine type, number of engines, and when possible, 4- or 2-stroke engine and horsepower of engines. A hand-held laser range finder (Laser Atlanta Advantage, Norcross, GA) was used to obtain multiple waypoints along each boat's path (Fig. 7). The bearing and distance measurements recorded by the range finder were used to recreate the travel paths of all vessels in a GIS. The range finder was also used to periodically obtain bearing and distance to the manatee tag, particularly when recent GPS fix attempts were unsuccessful (as indicated by the VHF pulse rate); this information was used to estimate location of the manatee to fill in gaps in the manatee movement record. No range finder data were collected during the first deployment in Crystal River because the unit was not yet available. The observation boat carried multiple GPS units to ensure there was always a back-up in case of equipment failure and to have multiple records to reference in case any locations seemed implausible (see below).

When there was at least one boat underway within 500 m, the manatee's activity, habitat, water depth, group size, and reaction during the boat's approach were recorded for every boat pass. In addition, we recorded the time that the boat was closest to the manatee and categorized the distance between the boat and manatee at closest approach (0, 1-10, 11-50, and >50 m). The manatee's response to a boat pass was scored according to the following four categories: change in mobility, speed change, heading change (with respect to the boat), and movement towards a water channel. Each category was scored as positive, negative, no change, or not applicable. For example, a positive speed change was an increase in the manatee's speed and a negative heading change indicates that the manatee adjusted its heading away from the approaching boat. The manatee's activity before and just after the boat pass was also recorded to assess its response. Periodically, the focal manatee's surfacing/diving behavior, activity, and habitat were observed in closer detail and continuously recorded in order to correlate with DTAG parameters. This included manatee activity, group size (defined as all manatees observed within 200 m of the focal manatee), number of calves in group, bottom type of the habitat, depth of the habitat, and time that any part of the manatee (nose, back, or tail) broke the surface of the water (used to calibrate DTAG depth sensor, Fig. 8). See Appendix 1 for examples of all types of field data sheets used in this study.

Aerial Observations and Videography

Focal follows of tagged manatees in southwest Florida were conducted from the air using a Cessna 172 to record manatee behavior and manatee-boat interactions. The technique was modeled after a method developed by Wildlife Trust that used aerial videography to evaluate and monitor the effectiveness of manatee refuges and sanctuaries in Lemon Bay (Keith et al. 2008). Previous efforts for conducting continuous aerial observations of manatees used a remotely-operated video recording system suspended from a tethered helium-filled aerostat (Flamm et al. 2000, Nowacek et al. 2002). While this platform provided excellent visibility and video quality, its use was limited by weather and mobility constraints. Helicopters were also evaluated but the cost was prohibitive, given our budget. So the decision was made to employ fixed-wing aircraft as the platform of choice for recording manatee focal observations from the air. Although the quality of the video filmed from an airplane was not as good as that taken from a fixed platform, the increased mobility was important in tracking the tagged manatees. A Cessna 172 was selected as the most cost-effective and safe platform for the task. The aerial videographer was positioned in the front right seat of the airplane with a handheld, image-stabilized camcorder (Canon DV10) from which digital video was shot out the open window of the aircraft.

Our initial objective was to conduct two aerial focal follows of 1 hr duration each (one in the morning and one in the afternoon) during each weekend day in which manatees were carrying a recording dTag. Over the course of the study, this plan was modified so that focal follow observations were targeted toward situations where the subject manatee was likely to encounter boat traffic, rather than just filming an hour of continuous video regardless of whether vessels were present. The location of the manatee was transmitted to the aerial crew from the boat crew or by use of Argos satellite location data so no time was wasted in the air finding the manatee. After the plane was on station over the manatee, a team of two aerial observers alternated videotaping the tagged manatee with the digital video camera for the duration of the observation period. The aircraft's altitude was adjusted for weather and other conditions but ranged between 800 and 1000 ft (243-305 m).

The video analysis serves three important functions: (1) to provide a more accurate determination of manatee activity (e.g., feeding) and group size than is possible from a boat, especially since it is undesirable to disturb the manatee by approaching too closely with the boat; (2) to provide a clearer picture of the spatial arrangement of habitat, channels, vessels, and manatees, which will be important in ground-truthing the reconstruction of the scene using boat-based and tag-based data streams; and (3) to provide an archived visual record that can be analyzed, reanalyzed as needed, and displayed to interested parties.

Environmental Recording

Environmental conditions were assessed at the beginning of the focal follow and when any of the conditions changed, with coordinates and time of assessment recorded on the datasheet. Wind speed was measured in knots using a hand-held pocket wind meter (Kestrel 1000) and described in relation to sea state using the Beaufort scale. Wind direction was noted using compass points (e.g. N, NE, SE, S). A portable conductivity, salinity and temperature meter (YSI 30) was used to measure water temperature, air temperature, and salinity. Water visibility was measured using a Secchi disk. Finally, sky conditions were described based on percent of the sky covered by opaque clouds and noted using general terms: sunny (0-10% cloud cover), partly cloudy (10%-50% cloud cover), mostly cloudy (50%-90% cloud cover), overcast (90%-100%), and rain.

Data Processing and Analysis

A number of different types of data were collected that need to be processed before they can be properly combined and integrated for final analyses. These data types include: observation boat GPS locations, field behavioral observations of manatee, field notes on vessel attributes, range finder data on vessels and focal manatee, manatee GPS tag data, environmental data, DTAG acoustic recordings, DTAG sensor data, manatee capture data, and aerial video. Processing may involve data entry, data verification, a variety of QA/QC procedures, acoustic auditing, sensor calibration, and video inventory; these are described below.

Observation Boat GPS Location Data

Observation boat locations were gathered in the field from four GPS sources with various fix rates: Garmin 76CS (the primary hand-held GPS unit for the observation boat; position stored every 5 sec); Garmin 76CSx (the backup hand-held GPS unit; position stored every 5 sec); a Tablet PC (Xplore Technologies iX104C2 with attached GPS module, with position displayed in real-time in ArcGIS every 5-10 sec); and Garmin GPSMap 188C Sounder (used for navigation on displayed nautical charts; position stored every 10 sec).

Two GPS datasets were assembled to test for outliers in the GPS data. The first was a GPS dataset comprised primarily of Garmin 76CS data and supplemented by other GPS locations when these data were unavailable. A secondary GPS dataset was compiled mostly of Garmin 76CSx data that were interpolated to one-second intervals using a user-developed SAS program. Potential outliers were identified by temporally aligning the data from the primary and secondary GPS datasets. The distances between simultaneous points in the two datasets were calculated using Geofunc, a Microsoft Excel add-in developed by the National Marine Mammal Laboratory (NOAA National Marine Fisheries Service). Records where the distance between the two points was greater than 10 meters were flagged as outliers and were brought into ArcGIS for visual verification. In ArcGIS, potential outliers were manually assessed by comparing the tracklines from the four different GPS sources and judging which path was the most reasonable. In questionable cases, the positions from the Garmin 76CSx were used by default. After outlier records were replaced, the corrected path was examined for additional potential outliers by looking for spikes in the path of the observation boat in ArcGIS at a scale of 1:5,000.

Once the final observation boat GPS dataset was complete, the final processing step was to interpolate the data to one-second intervals using the SAS program. Rangefinder data were collected at irregular intervals as vessels passed by the manatee; the final GPS dataset had positions for the observation boat approximately every 5-6 seconds. In order to estimate the position of a passing vessel, the position of the observation boat and the range and bearing to the target vessel at a given time were required to calculate the target vessel's position. To resolve this temporal discrepancy, the observation boat positions from the final dataset were interpolated to one-second intervals so there was a GPS location for each possible rangefinder shot.

Relational Databases from Field Observations

An extensive relational database was designed to store data collected in the field, including observers, boat-based effort, aerial effort, environmental information, engine activity of observation boat, manatee behaviors, manatee responses to passing vessels, and target vessel attribute data. After several major revisions, the development of the field database is complete (Fig. 9). At present, some data have been entered for 27 out of the 33 field days. Observers, boat effort, aerial effort, environmental data, and engine activity are completely entered for the 27 days (82%) currently represented in the database. Manatee focal activity data are entered for 24 of the 33 field days (73%); manatee response data are entered for 15 days (45%); and target vessel data (rangefinder and vessel attribute data) are entered for 13 days (39%). Currently, data from only one field day (3%) have been verified in their entirety. Data entry and data verification dates and staff are documented as a separate tab in the database.

A separate database was created for storing and managing the rangefinder data and for merging the final rangefinder data with the final interpolated observation boat GPS data. The QA/QC process for the rangefinder database, which consisted of several steps, is now complete. Rangefinder times were rounded to the nearest second to be compatible with the observation boat GPS data. Additionally, records lacking a range or bearing were removed from the dataset.

Vessel Path Creation and Verification

Estimated positions for the target vessels were generated based on the range and bearing from the rangefinder data and the GPS position of the observation boat at the time the rangefinder shot was taken. The final dataset contains 19,965 points that were used to recreate the target vessel paths. These points will be projected and converted to polylines based on the vessel ID, generating one path for each vessel. The associated target vessel attributes and manatee response data will be attached to each path by relating to the date and vessel ID fields in the field database.

Verified field data have been merged with rangefinder data to recreate vessel paths for one date during Labor Day weekend (1 Sep 2007). The field database on this date contained records for 1,113 vessel rangefinder shots and 42 manatee rangefinder shots; all except four of these records matched up with complete range and bearing data, allowing estimated positions of vessels to be calculated in 99.6% of the cases. A sample of individual vessel paths (n = 236) were visually inspected in ArcGIS to evaluate whether they appeared reasonable; in particular, did they plot in the water, maintain position throughout the path in the channel, and show a straight or curved path? Out of the 1,109 plotted vessel locations, only four plotted on land according to the 1:12,000 Florida shoreline. In general, the estimated paths closely followed known boating corridors (e.g., ICW) and appeared reasonable. Some apparent outliers and other issues were noted in this initial stage of the verification process. The next stage of verification and QA/QC will involve developing a speed and bearing filter to identify outliers and to develop an objective protocol for the manual verification of vessel tracks in ArcGIS. Once verification is complete, a SAS program will be written to interpolate the GPS locations to 1-second intervals that ultimately will be used in manatee-boat interaction analyses.

Manatee Location Data

Telonics software utilities were used to program and download the telemetry tags and to decode the compressed GPS data into a comma-delimited text format. The data archived in the tags' memory were processed for analysis, as that provided a complete record of GPS locations and fix attempts. Database creation and management were accomplished using SAS for Windows. ArcGIS and ArcView GIS software (ESRI, Redlands, CA) were employed for visualization of GPS locations and movement tracks and for identifying gross outliers. Manatee locations were also recorded opportunistically in the field with the rangefinder, as noted above. These data were processed and verified using the same analytic methods as described above for the vessel rangefinder data. These rangefinder locations will be integrated with the manatee GPS data to create a combined path for each manatee. Manatee locations were interpolated at 1-sec intervals for use in manatee-boat interaction analyses.

DTAG Data on Manatee Behavior

The raw output of the DTAGs was composed of measurements from a three-axis accelerometer, three-axis magnetometer, pressure sensor, temperature sensor, and a hydrophone. Using MATLAB (The MathWorks, Natick, MA) the raw accelerometer measurements were converted into pitch and roll, the magnetometer measurements into heading, and the pressure data into depth. Pitch and roll were adjusted for the orientation of the DTAG on each individual manatee by analyzing the measurements in relation to particular behaviors. For example, when a manatee is known to be surfacing the roll of the animal should approximate zero and when a manatee is traveling its pitch should average to zero. Likewise the animal is considered "level" (pitch and roll zero) when resting on the bottom. Using these assumptions appropriate pitch and roll offset values were determined. Heading was adjusted using the magnetic declination value associated with the date and area occupied by each tagged manatee. Depth was calibrated using times when the DTAG was known to be at the water's surface (depth equal zero), such as during observations of surfacings; we also allowed the DTAG to record for about 5 min at the surface after detaching from the manatee in order to obtain these known zero readings. Once these calibrations were completed, a file (referred to as a 'prh file') was created that combined the calibrated pitch, roll, heading, and depth variables (see example in Figure 10). The prh file was then used to create a three-dimensional reconstruction of the manatee's orientation and depth (using MATLAB scripts written by Mark Johnson). The reconstructions assumed the animal was always moving; while this facilitates visualization of changes in orientation, it also gives a false impression of movement when the manatee was not moving. To better interpret the figures, fluke strokes can be identified using oscillatory changes in pitch; the presence of fluke strokes can indicate when the manatee was moving and the rate of strokes can reflect how rapidly the manatee was moving.

Scoring Acoustic Events

The occurrence of boat noise, manatee vocalizations, manatee chewing, and other pertinent sounds were identified and noted in the acoustic recordings using MATLAB (script written by Mark Johnson, modified by Athena Rycyk). A trained human listener examined the spectrograms of the recordings while listening to the recordings to identify all sounds of interest. The beginning and end of boat noise is noted and any peaks in boat noise sound level are marked as such. The identification of peaks in boat noise is subjective and will be confirmed with precise sound level measurements. Identifying peaks in boat noise provides an estimate of when the boat was closest to the manatee and helps match up the sound of a boat pass to the boat attribute information recorded by the observation crew.

Each manatee vocalization was identified, its duration measured, and its contour (pattern of modulation of the vocalization) categorized; it was also noted whether or not the vocalization occurred in the presence of audible boat noise. The contour categories (flat, hill-shaped, decreasing, increasing, and U-shaped) are from O'Shea and Poché (2006) (Appendix 2). A short acoustic clip of each manatee vocalization was also created for more detailed analysis, such as measuring the fundamental frequency. Manatee feeding bouts were identified in the acoustic records from chewing sounds. A bout was defined as continuous chewing with no break longer than 5 seconds. Details on the acoustic auditing protocol can be found in Appendix 2.

We have concentrated our auditing efforts on recordings during the day, when the observation boat was potentially following the manatee and there was more boat activity. Thus far approximately 100 hours of the 741 hours recorded have been fully audited.

Acoustic Analyses

Manatees live in acoustically active environments that can be characterized by calculating received sound levels in octave bands. Separating the sound level measurements by octave frequency bands gives a more detailed picture of what sounds are occurring and how they might impact signal masking. For example, boat noise predominantly affects lower frequencies, but it can reach the frequencies manatees vocalize in. As the manatee's habitat has many natural noise sources in addition to boat noise, sound level measurements during boat passes require a reference level from samples without boat noise during a similar time of day. Using these measurements we can determine how often manatees are exposed to boat noise, the spatio-temporal patterns of such exposure (e.g., diel cycles), and if habitat or depth affects the occurrence and magnitude of exposure.

Vocalization rates were calculated as all vocalizations per unit time. A preliminary analysis examined variation in vocalization rates in relation to presence/absence of vessel noise and to presence/absence of conspecifics. Future analyses will further characterize vocalization parameters—including contours, durations, and fundamental frequencies—in relation to these variables. In a similar manner, the frequency and duration of feeding bouts (determined by the occurrence of chewing noises in the recordings) can be compared between times with no boat noise and times with boat noise.

Defining Manatee Response from DTAG Data

The data collected by the DTAGs allow us to quantitatively measure behavioral response. Changes in behavior will be identified with respect to the manatee's depth, roll, pitch, heading, and fluke stroke rate. Changes in depth of the manatee indicate that the manatee is either getting closer or farther away from the surface. Changes in roll indicate a change in body orientation and changes in pitch can indicate that the manatee is angling towards the surface or into deeper water. Changes in fluke stroke rate indicate a change in the manatee speed. All of these behavioral changes can be quantified further with respect to direction (such as an increase or decrease in depth of the manatee) and magnitude (such as a heading change of 90 degrees).

These changes in behavioral variables are used to determine if the manatee responded to a boat's approach and to describe the nature of the response. Two types of comparisons will be used to detect and evaluate manatee responses to boat passes: (1) comparing frequency and types of behavioral changes between time periods of no boat noise and periods of boat noise during a similar time of day; and (2) comparing frequency and types of behavioral changes across three time periods within a boat pass—boat approaching (before peak in sound level), boat near closest point of approach (around peak sound level), and boat moving away (after peak). Changes in behavior will be used to determine when a manatee begins to respond to a boat's approach in relation to distance and time to closest point of approach and, when possible, in relation to when the vessel's acoustic signature first becomes audible on the DTAG recording.

RESULTS AND DISCUSSION

Given that data entry and verification are ongoing, the numbers presented below are based on incomplete data and will change once the databases are finalized. Therefore, our findings should be considered preliminary as well.

Summary of Study Subjects and Tag Deployments

The 20 tagged manatees in this study included 12 females and 8 males; all were adults except for two large subadults. We avoided capturing females with calves, but the rehabilitated female (TFK007) was released with her large dependent calf. Three (possibly four) females were visibly pregnant (i.e., distended abdomen). Sizes of tagged manatees ranged from 254 to 329 cm standard length and from 730 to 1685 lb (331 - 764 kg). Physical attributes of these individuals are provided in Table 1. Two individuals had fresh wounds (days to weeks old) indicating recent collisions with vessels.

Summary statistics on tracking duration, number of GPS locations, and GPS fix success are presented in Table 2. Individual tracking durations ranged from 3.0 to 70.2 days. The first two deployments were only intended to last 3-4 days in order to field-test the DTAG hardware, software, and release mechanism. The GPS deployments in southwest Florida were planned to continue for several weeks after the DTAG was recovered. Four of these 18 tracking bouts were terminated earlier than planned in order to retrieve the DTAG after its primary release mechanism failed to operate properly; to do so required removing the entire tagging assembly by cutting off the belt. A total of 134,970 GPS locations were recorded over two years out of 160,468 fix attempts for 20 individuals. The percentage of GPS fix attempts that were successful in acquiring a location varied from 63.1% to 98.0% across individuals and averaged 84.9% (SD = 12.3). That is equivalent to an average of 245 GPS locations per day (maximum = 288 at 5-min intervals). The fix success rate for adult males (75.1% ± 8.5, N = 7) was substantially less than that of adult females (89.4% ± 11.5, N = 11) because males traveled further and more frequently than females during the warm season while searching for estrous females (Deutsch et al. 2003b). The GPS tag is pulled underwater during moderate to fast traveling, reducing the opportunity to obtain fixes.

This is the first study in which the newly redesigned manatee DTAG (Johnson et al. 2007) has been deployed on free-ranging manatees. The housings withstood the harsh conditions of repeated deployments well and the programmed release mechanism functioned successfully 13 of 20 times, facilitating quick retrieval at the end of the weekend. The DTAG failed on the other 7 occasions for a variety of reasons, including motor failure, broken shaft on the motor gearbox, the interface between the shaft screw and motor coming loose, and excessive grit in the shaft. In four of the cases where the DTAG failed to release, the entire belt assembly was removed by a swimmer or from the boat using a specialized cutting tool. All DTAGs were recovered and successfully recorded a wealth of time-synchronized acoustic and behavioral data on the focal manatees, totaling 741.3 and 755.6 hours respectively (Table 3). The deployment and sampling durations were chosen to be less than the estimated memory and battery lives. However, on a few deployments the DTAG became memory limited and ended sampling earlier than scheduled. We attribute the discrepancy between the estimated and the actual memory length to an acoustic environment that differed considerably from the previous DTAG projects used to calculate the estimates. Future estimates of memory length during deployments in this study area could be made more accurate by calculating new audio compression parameters tailored to the local acoustic environment based on the data collected in this study.

Boat Traffic Experienced by Tagged Manatees

Focal follows were concentrated in Lemon Bay during 2007 and were spread over a wider region (Sarasota Bay to Charlotte Harbor) in 2008 (Fig. 11). Over 4,200 boat passes were recorded by the observation team within approximately 500 m of the tagged manatees during 180 hr of boat-based focal observations (Tables 4 and 5). Nearly all involved recreational watercraft and 91% of vessels (with recorded size class) were less than 26 ft long (Table 6). The most frequently observed vessel type was open fisherman (44%), followed by cruiser (20%), personal watercraft (11%) and yacht (7%) (Table 6). Preliminary analyses of data for all focals pooled show that, on average, 23.6 boats passed by a focal manatee per hour but this varied greatly among individuals (0.2 – 63.8) (Tables 4 and 5). High rates occurred on holidays and in frequently used boating corridors; for example, 118 boats were recorded during an hour on Labor Day weekend near the ICW in Lemon Bay. Rates of manatee-boat encounters should vary with factors that affect the level of vessel traffic generally, such as season, day of the week, time of day, weather, and proximity to boating corridors, entry points, and destinations (Gorzelany 2005, Sidman and Flamm 2001). We focused our field work on weekends to maximize the opportunity to observe such encounters; consequently, the recorded rates of boat passes are probably substantially higher than what occurred during weekdays. Another factor that could affect the observed encounter rates was that if there were two manatees carrying DTAGs over the same weekend, we generally selected the one that was located in an area deemed more likely to have boat traffic. The acoustic record on the DTAG will provide an alternative and unbiased record of boat encounter rate from the manatee perspective.

Based on the data that have been entered into the field database to date (representing about 1/3 of the boat passes recorded), 3.7% of boat passes with recorded distance class came within 50 m of the focal manatee; about 1% passed within 10 m (Table 7). Most vessels (71%) with speed class recorded were traveling on a plane; 51% of vessels passing within 50 m of the manatee were on a plane (Table 7). Boat traffic showed a strong diurnal pattern, generally peaking at mid-day (Fig. 12). A map showing the locations of close manatee-boat interactions (<50 m) for the 2007 field season is shown in Figure 13. Initial evaluation of close boat encounters based on field observations and GIS queries suggests that manatees were either in or near seagrass beds or in or near boating channels at the time of the interaction.

A total of 1714 minutes (28.6 hr) of videotape was recorded over 24 flights in 2007 and 2008. The durations of video recordings during focal observations ranged from 19 - 122 minutes (see video inventory in Table 8). A series of video clips have been created to provide examples of manatee-boat interactions as well as examples of the manatee engaged in normal activities, such as resting, traveling, feeding, and socializing. The video recordings will be compared to behavioral data acquired by the DTAG to help interpret the DTAG data and eventually be able to translate it into a gross daily activity budget.

Manatee Fine-scale Movements and Diving Behavior

This is the first time that manatee GPS tags have been programmed to attempt fixes as frequently as every 5 minutes. The resulting travel paths are unprecedented in their fine resolution over time and space. An example is the movement of TSW060 along the ICW in the narrow waters of northern Lemon Bay (Fig. 14). GPS locations were obtained every 5 minutes as the manatee traveled north of Forked Creek over the course of the morning; based on GIS data, this individual crossed the ICW channel nine times over a 4-hour period. We speculate that shallow waters to either side of the ICW may have driven the manatee to cross the channel so that it could travel northward outside of the main vessel corridor. Additional examples of tagged manatees entering, crossing, traveling along, and exiting the ICW channel in Lemon Bay in relation to vessel tracks are illustrated in Figures 15-17. Traveling in the ICW on Labor Day weekend, these manatees were passed by boats about every 1-2 minutes for the periods shown. They generally stayed along the edge or to one side of the main channel (e.g., Fig. 17), but sometimes they crossed the channel (e.g., Fig. 15). Tagged manatees in this study commonly made this round-trip between central Lemon Bay to Forked Creek, traveling along the narrow ICW. Clearly they needed to be adept at negotiating this busy channel to avoid being struck by vessels, most of which were traveling on a plane.

Depth measurements, combined with data on three-dimensional orientation and movements inferred from the DTAG's tri-axis magnetometer and tri-axis accelerometer sensors (all sampled at 50 times per second), permit the reconstruction of underwater movements in four dimensions (3 spatial plus time). Figure 18 shows two deep dives as manatee TSW062 traversed Boca Grande pass and appeared to swim along the bottom. Reaching depths of 15 m, this was similar to the maximum depth of 16.3 m recorded in a manatee diving study in Tampa Bay (Deutsch et al. 2006). A manatee diving and traveling in shallow water, more typical of manatee habitat, is illustrated in Fig. 19. Although the manatee only dove to a depth of 1.4 m over the 4-minute period displayed, the surfacing behavior is clearly indicated. Furthermore, the pressure sensor was sufficiently sensitive and accurate to detect the manatee's fluke strokes, which are shown by the repeated, short up-and-down movements of the DTAG's path (Fig. 19). Quantifying changes in fluke stroke rate will be helpful in characterizing manatee response to watercraft.

The DTAG depth data can also be combined with manatee GPS tracks to examine how differences in habitat can influence the manatee's behavior and susceptibility to boat strikes. Figure 20 illustrates how the percentage of time spent at different depths differed for two manatees in different habitats: the manatee crossing Charlotte Harbor (TSW070) spent nearly ¾ of its time at least 3 m below the surface, whereas the manatee occupying the Peace River

(TSW068) spent about ¾ of its time less than 1 m from surface, making it potentially more vulnerable to passing watercraft.

Boat Noise Exposure

The DTAGs recorded all sounds in the manatee's environment from 0.1 – 32 kHz, including those produced by the manatee, boats, and ambient noise from other organisms and abiotic sources (e.g., wind, rain). This includes noise from the observation boat when either of its engines was on and within acoustic range of the focal manatee. The DTAG did not record the noise from the aircraft that circled overhead the manatee for focal follows in any of the recordings audited thus far. Figures 21 and 22 display the percentage of time the manatee's acoustic environment was at certain received sound levels for three manatees. The received levels were measured for one-second time windows every 5 seconds within the 0.4-10 kHz and 10-20 kHz frequency bands. The first range covers the frequencies that most boat-generated sound occurs in and the latter range of frequencies is where manatee hearing is most sensitive (Gerstein et al. 1999). The received levels for all three manatees in both ranges exhibited a peak in time spent at a particular sound level bracket, but the modal bracket varied among manatees from 100-105 to 105-110 dB re 1μPa for the 0.4-10 kHz range and from 85-90 to 95-100 dB re 1μPa for the 10-20 kHz range (Figs. 21 and 22). TSW062 spent more time in a louder environment than the other two individuals for both frequency ranges. These sound levels are considerably higher than the level of ambient noise measured in other studies (e.g., Miksis-Olds 2007, Gerstein et al. 2008). Water flow noise (when the manatee is traveling) and the DTAG rubbing against the manatee can be heard on the acoustic records. Because these sounds originate very near to the hydrophone, the received sound level measurements may be higher than the actual ambient sound levels.

Four spectrograms illustrating different types of boat approaches are presented in Figures 23-26. A spectrogram shows the intensity of sound recorded by the DTAG across the frequency spectrum over time; the color represents sound intensity, with red indicating the loudest sounds. The first case is of a personal watercraft (A01) that passed on a plane within 10 m of TSW060 (Fig. 23); the received levels at the closest point of approach were 127.8 and 118.6 dB re 1μPa for frequencies of 0.4-10 and 10-20 kHz, respectively (Table 9). The received level alone does not indicate whether the sound is loud enough to be distinguished from background noise. Using a time prior to the boat's pass when no boats were audible the signal-to-noise ratios (SNR) were calculated to be 17.2 and 14.0 for frequencies of 0.4-10 and 10-20 kHz, respectively (Table 9). Therefore, at the boat's closest point of approach the sound was not only loud, but had a high SNR too. In the next case a yacht (M63) traveled slowly past the manatee at a closest distance category of 10 m (Fig. 24). The received levels were quieter at the boat's closest point of approach than in the above example for the 10-20 kHz bracket, but were louder for the 0.4-10 kHz bracket. The signal-to-noise ratio for the 0.4-10 kHz bracket was similar to the previous example, but was much lower in the 10-20 kHz band. (Table 9). This means that the sound of the approaching boat may have been more difficult to detect above background noise. The dense vertical red lines in this spectrogram represent the broad-band sounds produced by snapping shrimp, a major source of background noise.

The third example is of an open fisherman (Y01) that traveled on a plane within 11-50 m of the manatee (Fig. 25). The received levels were 129.4 and 108.8 dB re 1μPa for the 0.4-10 and 10-20 kHz brackets, respectively. In addition to the loud received levels at this boat's closest point of approach, the SRNs were high as well---29.5 and 16.0, respectively. The last case involves an open fisherman boat (K02) that was plowing within 10 m of the focal manatee (Fig. 26). The received levels at the closest point of approach were 138.1 and 119.5 dB re 1μPa for frequencies of 0.4-10 and 10-20 kHz, respectively (Table 9). Signal-to-noise ratios were particularly high---33.9 and 32.6, respectively. These high SNRs within the manatee's most sensitive hearing range indicates that the manatees should have had no trouble in hearing these vessels approach.

Manatee Response to Vessel Approaches

Based on a preliminary analysis of field observations, tagged manatees were more likely to respond to boat approaches at closer distances. In nearly all cases (97% or greater), manatees did not noticeably react to vessels passing more than 50 m away (Table 10). Changes in mobility, speed, or heading were observed in 22-27% of boat passes 11-50 m from the manatee and in 41-55% of interactions where the closest approach distance was <10 m (Table 10). Changes in mobility and speed were much more likely to be an increase then a decrease, indicating a flight response (Table 10). When the animal altered its heading, it was more often away from the approaching boat. In the vast majority of cases the manatee did not change its movement in relation to a channel, but this analysis needs to consider manatee distance from the nearest channel to be meaningful. Nowacek et al. (2003) also found that distance at closest approach was a significant factor affecting the probability of manatee response, and that reactions were most prominent at distances less than 10 m.

How the speed of the approaching boat affected the probability and type of manatee response was evaluated based on a preliminary analysis of field observations for approaches within 50 m of the manatee. In approximately two-thirds to three-quarters of these boat approaches the manatee did not change its mobility, speed, or heading (Table 11). Although the data are too preliminary to conduct statistical analyses, there was no noticeable effect of vessel speed class (idle/slow, plow, and plane) on the probability or type of response (Table 11). This tentative finding is also supported by the study conducted by Nowacek et al. (2003). As noted above, changes in mobility and speed were much more likely to be an increase then a decrease, and changes in heading were more likely to be away from the approaching boat.

Examining the detailed data on manatee behavior and orientation collected by the DTAG before, during, and after a boat's approach can determine if and how a manatee responded in relation to the timing of received acoustic signals. Figure 27 aligns the dTag sensor data on pitch, roll, depth, and heading with the acoustic spectrogram for a close boat pass (within 10 m). The vessel was a fisherman type between 16 and 26 feet in length and was traveling on a plane. About 9-10 sec before the planing vessel passed by the manatee, and about 2 sec after the vessel noise was audible on the DTAG recording, the manatee responded with five rapid fluke strokes, some small changes in heading, and then appeared to glide away from the vessel along the bottom of this shallow water body. Field observers noted that the manatee was resting prior to the boat's approach and that it increased its mobility and speed in response to the boat. The manatee changed its heading away from the boat and there was no channel in the area for the manatee to approach.

An alternative way of visualizing the fine-scale changes in pitch, roll, depth, and heading of a manatee as it responds to an approaching watercraft is to generate a color-coded three-dimensional path derived from the tri-axis magnetometer and tri-axis accelerometer measurements. Figure 28 shows a reconstruction of manatee TSW062's behavior when an open fisherman boat slowly passed within 10 m. The field observations noted that the manatee increased its speed and changed its heading away from the approaching boat. The diagram clearly shows that the manatee's fluke strokes became erratic immediately after the boat's closest point of approach and that the manatee also altered its heading.

Integrating the three-dimensional visualization of movement with the temporal changes in acoustical parameters provides another avenue to examining manatee response to vessels. Detailed reconstructions of manatee behavioral response to selected vessel approaches are shown in Figures 23-26, with corresponding vessel and manatee paths displayed in Figures 29-32. Each case study includes a table, spectrogram of the acoustic environment at the manatee, and a three-dimensional figure of the manatee's orientation and movements underwater. The spectrograms were discussed above under the Boat Noise Exposure section. The table contains basic information on the interaction, including vessel type, size class, boat speed category, and closest distance category between the boat and manatee. The reconstructions of the manatee's 3-dimensional orientation are accurate representations of the manatee's roll, depth, and heading. Two-dimensional travel is not as accurately represented because it does not account for current or the manatee gliding (i.e., moving without fluke strokes). The absolute value of roll (in degrees) is represented by the color of the line; zero roll (shown as dark blue) denotes the manatee is level; in these figures there is no a distinction between the manatee rolling right versus left. Both the spectrograms and 3-dimensional reconstructions cover the same time period, with the green arrows representing the beginning of that time period, the red arrow the closest point of approach, and the purple arrow the end of the time period.

In the first case a personal watercraft passed closely (<10 m) by the focal manatee in the middle of Lemon Bay (Figs. 23, 29). The spectrogram shows that the vessel produced high sound levels with a sudden onset. The sound of the vessel's approach, while loud, occurred quickly due to the vessel's high speed and its jet-propulsion system. The three-dimensional reconstruction of the manatee's behavior shows that the manatee did not change its heading and there were no changes in pitch indicative of fluke strokes. This confirms the field observations that there was no change in mobility, speed, or heading. In the second example, the open fisherman boat approached the manatee slowly in Forked Creek, passing within 10 m (Figs. 24, 30). The noise produced by this boat was not as loud as the first example and its sound level increased gradually over time, as expected given its slower speed. Field observations indicated that the manatee responded by increasing its speed, orienting away from the approach boat, and traveling away from a channel. The reconstruction shows the manatee continued to travel when the boat reached its closest point of approach. The third case involves a planing open fisherman boat that approached within 50 m of the focal manatee (Figs. 25, 31). The boat became audible several seconds before its closest point of approach and had a relatively rapid onset of intense sound levels. Field observers recorded the manatee's response as increasing its mobility and a change in heading towards the approaching boat. The reconstruction shows a sharp turn in heading after the boat reached its closest point of approach and slow fluke strokes increasing after the boat passed. The last selected case is of an open fisherman boat that motored within 10 m of the manatee while plowing (Figs. 26, 32). Onset of high sound levels near the closest point of approach was more even rapid than in the previous example, probably due to the closer proximity. There were only several seconds from when the boat became audible to when the boat was closest to the manatee. The field observations noted an increase in mobility and a change in heading away from the boat. The reconstruction also shows the manatee increased its speed (larger changes in pitch) and the manatee altered its heading just after the boat reached its closest point of approach. These two examples of fast-approaching boats both demonstrate changes in mobility and heading, however, one manatee move closer to the approaching boat and the other moved away from it.

Manatee Vocalization Rate

To examine how boat noise affects manatee vocal behavior, portions of the acoustic record were selected from times when our observation boat's motor was off and we had estimated the number of manatees within acoustic range of the focal manatee. The fundamental frequencies of the vocalizations ranged from 0.8 – 7.4 kHz, the average being 2.8 kHz (Table 12). This range and distribution of fundamental frequencies is similar to that found in vocalizations of manatees recorded in Crystal River, Florida and Belize (Nowacek et al. 2003). The range of vocalization durations also overlaps with the durations recorded in Crystal River and Belize, however the average duration of vocalizations from this study (0.131 sec) was shorter than that recorded in Crystal River (0.228 sec) and in two of the days sampled in Belize (0.161 and 0.217 sec), but longer then one of the days sampled in Belize (0.032 sec) (Nowacek et al. 2003). The vocalizations from this study fell into the same contour classifications used by O'Shea and Poché (2006), indicating similar vocalization structure to previously studied manatee vocalizations.

The average overall vocalization rate (vocalizations/minute) when boat noise was present was lower (0.29) than when there was no boat noise (0.56). This rate does not take into account the acoustic group size, however it can be useful when considering application of an automated manatee vocalization detector as part of a manatee avoidance program for boaters. These rates estimate the number of vocalizations that can be detected when there is at least one manatee within acoustic range. When the focal manatee was alone the vocalization rate in the presence of boat noise (0.56) was similar to that recorded in the absence of boat noise (0.49). As expected, vocalization rate was higher (0.74) when the manatee was in a group (with 1-8 other manatees) and absent any boat noise. However, the group vocalization rate was considerably suppressed (0.17) during periods of boat noise; this might partly be accounted for signal masking, especially of manatees distant from the focal animal, but other factors must also play a role given that the rate was lower than that for a lone manatee. There was also a difference in the types of vocalizations used in the presence of boat noise. More vocalizations had an increasing frequency contour when there was boat noise than when there was not boat noise. The increasing contour might possibly indicate an alarmed state. Average duration of vocalizations in the presence of boat noise was also longer than when there was no boat noise audible (Table 12). These preliminary findings need to be confirmed with a larger sample size, tested statistically, and other factors affecting vocalizations need to be accounted for as well.

CONCLUSIONS

This is the first study on Florida manatees to sample both their behavior and their acoustic environment simultaneously. Incorporating this acoustic component is crucial to furthering our understanding of manatee-boat interactions because it tells us what the manatee can hear when approached by motorized vessels traveling at different speeds and distances, and in different habitats. We are still busy entering, verifying, and processing the many streams of data and have just scratched the surface with our analyses and graphics. Even so it is clear that the approach we have adopted in this study—which integrates boat-based and aerial field observations with remote data collection using state-of-the-art electronic tags—will provide valuable insights into manatee behavioral response to boats. The four-dimensional reconstructions (4 spatial axes plus time) of manatee movements allow us to visualize behavior that can be nearly invisible to field observers. Combining this visualization of manatee movements and orientation with temporal changes in acoustical parameters provides a powerful means of investigating manatee response to vessels.

Based on our extensive hours observing manatees in the field for this project, we can infer some strategies manatees may use to avoid boat collisions. At a qualitative level, the primary strategy seemed to be selecting habitat with lower vessel traffic. There were certainly times when manatees occupied high boat traffic areas, but much of the time manatees were found in lower traffic areas, such as seagrass beds, creeks, and protected bays. Most of these areas are regulated as slow speed zones for boats. Whether their habitat selection would differ in the absence of watercraft is debatable—given the separation of major boating corridors from most manatee habitat—but this question might be addressed through analysis of diurnal versus nocturnal habitat use patterns. When manatees did venture into high-traffic areas such as channels, we observed movement behavior that could be interpreted as reducing the risk of being struck by watercraft. For example, on a number of occasions we observed the focal manatee swimming slowly just below the surface parallel to the Intracoastal Waterway (ICW); then it dove and crossed the ICW at depth, surfacing again only once it was far from the channel on the other side. This behavior appears to be one means by which manatees reduce time in the near-surface danger zone while crossing a deep channel with potential high-speed vessel traffic, such as the ICW. An analysis of diving behavior and three-dimensional movements underwater during channel crossings, especially in the presence of planing vessels, should yield further insights into their boat-avoidance strategies.

Preliminary summary of a subset of the field observations collected indicates that the probability a manatee would respond to a passing boat increases as distance at closest point of approach decreases. Given that hundreds of watercraft may pass within several 100 m of a manatee over the course of a weekend day, it makes sense that these animals monitor vessel noise and only alter their normal activities when one presents a threat by approaching closely. Furthermore, an initial examination of these data did not find an effect of boat speed class on the likelihood of response but a proper analysis accounting for distance and other variables is needed. Observed manatee responses most frequently involved increasing swim speed away from the approaching vessel. These findings are similar to those found by Nowacek et al. (2004) who used a tethered aerostat to videotape manatee behavioral responses to approaching watercraft. Some manatees demonstrated marked responses to vessel approaches (often starting at distances of 25-50 m) while others did not. The typical response was flight toward deeper water (i.e., boat channel), but this was most frequent when the boat approached to within 10 m of the manatee and the manatee was located in shallow seagrass habitat. That is, when the manatee was most directly threatened and most vulnerable. Speed of the vessel was not a significant factor in affecting manatee response. While that study was an important first step, behavioral observations were often limited by water turbidity and by the wake of the passing vessel, and only gross responses could be scored reliably.

Next Steps

There is a tremendous amount of data entry, database management, QA/QC, acoustic auditing, and statistical analyses to do before concrete findings will be available from this study. This work forms the basis for a doctoral dissertation by Athena Rycyk, hence it is a multi-year project. Over the coming year, the remainder of the field data will be entered into the database and checked for quality. These field observations will be integrated with the acoustic results, dTag sensor data, and manatee movements to allow us to directly address the study's principal objectives.

The immediate next steps in data processing include the following:

1. *Field Observations Database:* Finish entering field data into the Access® database. Manually verify the accuracy and completeness of all data entered into the database. Run QA/QC checks of the database.
2. *Vessel Movement Paths:* Link boat ID's to locations estimated with the range finder data for the entire data set. Create movement paths for each boat ID, filter for potential outliers, and evaluate quality of individual tracks in relation to known boating corridors in GIS and with any available video footage. Calculate and assign speed and heading to each segment in all boat passes.
3. *Manatee Movement Paths:* Rangefinder locations of the manatee will be integrated with the manatee GPS locations to create a combined path for each manatee.
4. *DTAG Acoustic Recordings:* Finish auditing (listening and scoring) all sound recordings, noting boat noise, vocalizations, and manatee feeding sounds. Check inter-observer reliability of acoustic audits. Identify peaks in boat noise to flag individual passes by measuring sound levels in MATLAB.
5. *DTAG Analyses of Manatee Response:* Once sound level peaks are identified, the data will be broken down into meaningful temporal blocks, such as before the boat is audible, before the peak in boat noise, after the peak in boat noise, and after the boat is no longer audible. Changes in the following variables will be examined across these time blocks: (a) manatee depth, (b) heading, (c) fluke stroke rate, (d) fluke stroke amplitude, (e) pitch, and (f) roll. For each time block, values for the following variables will be calculated: received sound level in octave bands, and vocalization rate and duration. Programs need to be written in MATLAB to extract and calculate fluke stroke rate and amplitude.
6. *3D Movement Path Reconstructions:* Truth the two-dimensional (x-y) movements estimated with the DTAG sensor against movements based on GPS locations. Refine algorithm in MATLAB script to incorporate GPS fixes. Use available video footage to aid in biological interpretation of DTAG data streams.
7. *GIS Analyses of Habitat Variables:* Assign depth, bottom type, and distance to channel to manatee and vessel locations for use in manatee-boat interaction analyses. GIS layers first need to be evaluated and compiled.
8. *Aerial Observations and Videography:* The videotaped focal observations will be analyzed to supplement the boat-based field observations and the data from the manatee-borne tags. Relevant manatee-boat interaction segments will be cataloged and referenced in the database. Use video footage to evaluate and interpret other data sources (see above).

9. *Manatee-boat Interaction Database:* This database will integrate key fields and outputs of all other databases and analyses above, including: the time and distance between the focal manatee and the target boat at closest point of approach (calculated for all boat passes and compare to field observations); habitat at manatee and vessel; vessel characteristics recorded in the field and calculated in GIS (e.g., speed); manatee behavioral response from field observations and from DTAG data; acoustic variables; availability and quality of video; etc. This will form the basis for most of the subsequent analyses of manatee response in relation to vessel speed, distance, habitat and other features.

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TABLES

Table 1. Identity and physical attributes for 20 manatees tagged in this study.

Manatee ID	Manatee Name	Age Class	Sex	Reproductive Status	Length (cm)	Weight (lb)	Mass (kg)	Comments
TCR005	Pilo	Subadult	M	NA	265	730	331	Borderline subadult
TFK007	Ocean Reef	Adult	F	Nursing Calf	282	NT	NT	Calf: "Pumpkin", F, 229 cm
TSW055	Seven	Adult	F	Pregnant	299	NT	NT	
TSW056	Dodger	Subadult	F	N	254	785	356	
TSW057	Little Devil	Adult	F	N	302	1155	524	
TSW058	Mayday	Adult	F	Pregnant	276	NT	NT	
TSW059	Jetty	Adult	M	NA	274	760	345	
TSW060	Repita	Adult	F	N	258	845	383	Captured twice; length is average of both measurements (257, 259)
TSW061	Amazon	Adult	F	N	305	1350	612	
TSW062	Rambler	Adult	F	N	269	880	399	
TSW063	Armand	Adult	M	NA	283	890	404	Healing wounds (~3-6 wks old) on right shoulder and right side.
TSW064	Striker	Adult	M	NA	295	955	433	Fresh prop/skeg wounds (1-7 days old) on back and tail
TSW065	Scram	Adult	M	NA	285	975	442	
TSW066	Tracer	Adult	F	Pregnant?	268	1070	485	Possibly pregnant

Manatee ID	Manatee Name	Age Class	Sex	Reproductive Status	Length (cm)	Weight (lb)	Mass (kg)	Comments
TSW067	Cappy	Adult	M	NA	285	915	415	
TSW068	Snoopy	Adult	M	NA	297	1045	474	
TSW069	Passport	Adult	M	NA	329	1220	553	
TSW070	Houdini	Adult	F	N	277	870	395	
TSW071	Snicket	Adult	F	Pregnant	285	NT	NT	Probably pregnant
TSW072	Telemark	Adult	F	N	327	1685	764	

NA = not applicable
NT = data not taken; pregnant females were not weighted in order to minimize time out of water.

Table 2. GPS tracking bout information for 20 manatees tagged during 2007 and 2008. All date-time values are in local Eastern Daylight Time.

Manatee ID	Manatee Name	Tagging Location	Tag ID	Bout Start Date-Time	Bout End Date-Time	Bout Duration (days)	No. GPS Fixes	% GPS Fix Success
TCR005	Pilo	Kings Bay, Crystal River	54722	18-Jun-2007 13:59:35	22-Jun-2007 10:42	3.9	1062	95.4
TFK007	Ocean Reef	Card Sound, Key Largo	54722	17-Jul-2007 13:22:00	20-Jul-2007 12:39	3.0	815	95.3
TSW055	Seven	Lemon Bay	54723	25-Jul-2007 12:00:12	17-Sep-2007 15:09	54.1	15099	96.8
TSW056	Dodger	Lemon Bay	54727	9-Aug-2007 11:58:20	4-Oct-2007 9:35	55.9	15206	94.5
TSW057	Little Devil	Lemon Bay	54728	9-Aug-2007 14:31:23	19-Sep-2007 10:29	40.8	11481	97.6
TSW058	Mayday	Lemon Bay	54730	16-Aug-2007 13:38:01	11-Sep-2007 16:57	26.1	7375	98.0
TSW059	Jetty	Lemon Bay	54729	22-Aug-2007 10:52:51	25-Sep-2007 16:06	34.2	9095	92.3
TSW060**	Repita	Lemon Bay	54726, 54722	22-Aug-2007 13:01:32	17-Sep-2007 15:09	21.7	6002	96.1
TSW061	Amazon	Lemon Bay	54725	30-Aug-2007 13:10:18	7-Sep-2007 15:26	8.4*	2144	92.0
TSW062	Rambler	Lemon Bay	54726	5-Sep-2007 12:57:06	9-Sep-2007 18:00	4.2*	918	75.7

Manatee ID	Manatee Name	Tagging Location	Tag ID	Bout Start Date-Time	Bout End Date-Time	Bout Duration (days)	No. GPS Fixes	% GPS Fix Success
TSW063	Armand	Gasparilla Sound	54723	22-Apr-2008 11:48:20	1-Jul-2008 15:25	70.2	14805	73.4
TSW064	Striker	Gasparilla Sound	54727	22-Apr-2008 14:14:29	3-Jun-2008 16:23	42.1	9297	76.8
TSW065	Scram	Placida Harbor	54724	30-Apr-2008 10:56:58	7-May-2008 14:15	7.1	1388	67.6
TSW066	Tracer	Gasparilla Sound	54728	30-Apr-2008 13:59:52	6-May-2008 11:35	5.9*	1350	79.5
TSW067	Cappy	Placida Harbor	54729	15-May-2008 11:54:27	14-Jul-2008 14:01	60.1	13146	76.0
TSW068	Snoopy	Placida Harbor	54730	15-May-2008 14:42:59	19-Jun-2008 11:43	34.9	6705	66.8
TSW069	Passport	Placida Harbor	54731	22-May-2008 15:19:05	9-Jul-2008 8:37	47.7	9953	72.5
TSW070	Houdini	Placida Harbor	54726	4-Jun-2008 11:32:22	17-Jun-2008 11:30	13.0*	2356	63.1
TSW071	Snicket	Placida Harbor	75785	4-Jun-2008 13:55:08	26-Jun-2008 11:56:29	21.9	5547	96.9
TSW072	Telemark	Placida Harbor	54728	11-Jun-2008 11:33:25	16-Jun-2008 2:01	4.6	1226	92.5

* These tracking bouts were terminated earlier than planned in order to recover the DTAG.

** There were two tracking bouts for TSW060 during this period because her first tag detached four days after the first capture.

Table 3. DTAG deployment bout information for 20 manatees tagged during 2007 and 2008. All date-time values are in local Eastern Daylight Time.

Manatee ID	DTAG ID	Bout Start Date-Time	Bout End Date-Time*	Duty Cycle	Recording Duration (hr)† Audio	Sensor	DTAG Release Mechanism	DTAG Recovery Method
TCR005	223	20-Jun-2007 10:00:02	22-Jun-2007 08:00:00	Continuous	42.6	46.0	Functioned	Programmed release
TFK007	223	18-Jul-2007 12:00:00	20-Jul-2007 10:00:00	Continuous	43.1	43.1	Functioned	Programmed release
TSW055	224	28-Jul-2007 00:00:02	29-Jul-2007 16:00:00	Continuous	39.0	40.0	Functioned	Programmed release
TSW056	224	11-Aug-2007 00:00:02	12-Aug-2007 16:00:00	Continuous	37.9	40.0	Malfunctioned	Detached after strong fluke-up dive
TSW057	223	11-Aug-2007 00:00:02	12-Aug-2007 17:00:00	Continuous	41.0	41.0	Functioned	Programmed release
TSW058	223	18-Aug-2007 00:00:02	19-Aug-2007 13:00:00	Continuous	37.0	37.0	Functioned	Programmed release
TSW059	224	25-Aug-2007 00:00:02	26-Aug-2007 17:00:00	Continuous	36.4	41.0	Functioned	Programmed release
TSW060	224	1-Sep-2007 03:00:02	2-Sep-2007 15:30:00	Continuous	36.5	36.5	Functioned	Programmed release
TSW061	223	1-Sep-2007 04:00:02	2-Sep-2007 17:00:00	Continuous	37.0	37.0	Failed	Cut off belt
TSW062	224	8-Sep-2007 03:00:02	9-Sep-2007 17:00:00	Continuous	33.8	37.0	Failed	Cut off belt

Manatee ID	DTAG ID	Bout Start Date-Time	Bout End Date-Time*	Duty Cycle	Recording Duration (hr)[†] Audio	Sensor	DTAG Release Mechanism	DTAG Recovery Method
TSW063	223	25-Apr-2008 07:00:17	27-Apr-2008 15:00:00	0700-2000	34.0	34.0	Functioned	Programmed release
TSW064	224	25-Apr-2008 07:00:17	27-Apr-2008 17:00:00	0700-2000	36.0	36.0	Functioned	Programmed release
TSW065	223	3-May-2008 06:00:17	5-May-2008 14:00:00	0600-2000	36.0	36.0	Functioned	Programmed release
TSW066	224	2-May-2008 07:01:17	4-May-2008 17:00:00	0700-2000	36.0	36.0	Failed	Cut off belt
TSW067	223	16-May-2008 07:00:17	18-May-2008 17:00:00	0700-2000	36.0	36.0	Functioned	Programmed release
TSW068	224	17-May-2008 06:00:17	19-May-2008 14:00:00	0600-2000	36.0	36.0	Malfunctioned	Detached after strong fluke-up dive
TSW069	223	24-May-2008 07:00:17	26-May-2008 16:00:00	0700-2000	35.0	35.0	Malfunctioned	DTAG detached on its own
TSW070	224	7-Jun-2008 06:00:17	9-Jun-2008 14:00:00	0600-2000	36.0	36.0	Failed	Cut off belt
TSW071	223	7-Jun-2008 02:00:17	8-Jun-2008 17:00:00	0200-2300	36.0	36.0	Functioned	Programmed release
TSW072	223	14-Jun-2008 02:00:17	15-Jun-2008 17:00:00	0200-2300	36.0	36.0	Functioned	Assisted release

* End time here refers to the scheduled time of DTAG detachment.

[†] Recording duration here refers to the programmed duration, except when the memory filled earlier than programmed. Actual recording durations were often longer when the DTAG did not detach on schedule.

Table 4. The dates, locations, and observation effort of focal follows and the number of boat passes observed for each manatee in 2007. Numbers are preliminary.

Manatee ID	Dates	Location	Observation Hours	No. Boat Passes Observed	Boat Pass Rate (no. per hr)
TCR005	6/20/2007 6/21/2007	Kings Bay and Crystal River	6.5	154	23.7
TFK007	7/18/2007 7/19/2007	Card Sound	9.5	5	0.5
TSW055	7/28/2007 7/29/2007	Lemon Bay	11.2	517	46.3
TSW056	8/12/2007	Lemon Bay	5.2	332	63.8
TSW057	8/11/2007 8/12/2007	Lemon Bay	8.2	409	49.8
TSW058	8/18/2007 8/19/2007	Lemon Bay	10.8	360	33.3
TSW059	8/25/2007 8/26/2007	Little Sarasota Bay	13.6	577	42.5
TSW060	9/01/2007 9/02/2007	Lemon Bay	5.5	220	40.0
TSW061	9/01/2007 9/02/2007	Lemon Bay	6.7	386	57.6
TSW062	9/08/2007 9/09/2007	Gasparilla Sound; Placida Harbor	14.6	191	13.1
Pooled Total			91.8	3151	34.3

Table 5. The dates, locations, and observation effort of focal follows and the number of boat passes observed for each manatee in 2008. Numbers are preliminary.

Manatee ID	Dates	Location	Observation Hours	No. Boat Passes Observed	Boat Pass Rate (no. per hr)
TSW063	4/26/2008 4/27/2008	Sarasota Bay	13.6	103	7.6
TSW064	4/27/2008	Myakka River	1.0	21	21.0
TSW065	5/03/2008 5/04/2008	Myakka River; Charlotte Harbor, Gasparilla Sound	9.2	214	23.3
TSW066	5/03/2008 5/04/2008	Myakka River; Charlotte Harbor	6.0	31	5.1
TSW067	5/17/2008 5/18/2008	Charlotte Harbor; Peace River	6.5	89	13.7
TSW068	5/17/2008 5/18/2008 5/19/2008	Peace River (and tributaries)	8.7	2	0.2
TSW069	5/24/2008 5/25/2008 5/26/2008	Gasparilla Pass; Boca Grande Pass, Cayo Costa Is.	13.2	399	30.3
TSW070	6/07/2008 6/08/2008 6/09/2008	Turtle Bay; Charlotte Harbor	12.4	94	7.6
TSW071	6/08/2008	Lemon Bay	3.7	71	19.2
TSW072	6/14/2008 6/15/2008	Gasparilla Sound	14.1	78	5.5
Pooled Total			88.4	1102	12.5

Table 6. Vessel passes characterized by type and size of vessel.

	Vessel Size (feet)						
Boat Type	0-15	16-25	26-40	>40	Unknown	Total	% of Total
Cruiser	1	599	13	0	26	639	20.0%
Fisherman	1	96	47	16	8	168	5.3%
Open fisherman	32	1300	44	0	34	1410	44.2%
Personal watercraft	357	0	0	0	0	357	11.2%
Pontoon	0	71	1	0	6	78	2.4%
Racer	1	5	6	2	1	15	0.5%
Sailboat	2	4	6	4	3	19	0.6%
Small flats	40	14	0	0	6	60	1.9%
Yacht	0	114	100	5	11	230	7.2%
Unknown	7	11	22	3	171	214	6.7%
Total	441	2214	239	30	266	3190	
% of Total	13.8%	69.4%	7.5%	0.9%	8.3%		
% of Known	15.1%	75.7%	8.2%	1.0%			

Note: Numbers are preliminary, based on only a subset of the data.

Table 7. Distance to manatee and speed class of vessel at point of closest approach (estimated in the field).

	Distance Class at CPA						
Speed Class	0	1-10 m	11-50 m	> 50 m	Unknown	Total	% of Total
Neutral	0	1	0	8	0	9	0.6%
Idle/Slow	1	8	12	161	3	185	12.5%
Plow	0	0	3	214	7	224	15.2%
Plane	0	5	21	958	41	1025	69.4%
Unknown	0	0	1	29	5	35	2.4%
Total	1	14	37	1370	56	1478	
% of Total	0.1%	0.9%	2.5%	92.7%	3.8%		
% of Known	0.1%	1.0%	2.6%	96.3%			

Note: Numbers are preliminary, based on only a subset of the data.

Table 8. Inventory of videotape taken during aerial observations of tagged manatees and interactions with watercraft.

Date	Tape #	Approximate Timeframe	Manatee ID(s)	Location	Minutes
7/28/2007	1	1109-1215	TSW055	Lemon Bay: NE Tom Adams/ shoreline	62
7/28/2007	2	1402-1447	TSW055	Lemon Bay: NE Tom Adams / grass flats	43
7/29/2007	1	1245-1345	TSW055	Lemon Bay: NE Tom Adams/ grass flats	60
7/29/2007	2	1509-1545	TSW055	Lemon Bay: NE Tom Adams/ grass flats	34
8/11/2007	1	1037-1142	TSW057	Lemon Bay: SE of Stump Pass	58
8/11/2007	2	1329-1452	TSW057	Lemon Bay: SE of Stump Pass	61
8/12/2007	1	1041-1142	TSW056	Lemon Bay: SE Tom Adams	60
8/12/2007	2	1351-1512	TSW057	Lemon Bay: SE of Stump Pass/ residential area	60
8/18/2007	1	1354-1455	TSW058	Lemon Bay: NW Tom Adams	61
8/19/2007	1	1124-1222	TSW058	Lemon Bay: NW Tom Adams	57
8/19/2007	2	1241-1257	TSW058	Lemon Bay: NW Tom Adams/ flats N of marina	16
8/25/2007	1	1200-1230	TSW059	Little Sarasota Bay	30
9/1/2007	1	1052-1152	TSW060, TSW061	Lemon Bay: Across ICW from Indian Mounds	60
9/1/2007	2	1154-1304	TSW060, TSW061	Lemon Bay: N of Indian Mounds	61
9/2/2007	1	1047-1100, 1427-1438	TSW060, TSW061	Lemon Bay: Across ICW from Indian Mounds	24
9/8/2007	1	1127-1231	TSW062	Gasparilla Sound: Boca Grande area	62
9/8/2007	2	1238-1244	TSW062	Gasparilla Sound: Boca Grande Golf Course	6
9/9/2007	1	1030-1123	TSW062	Placida Harbor: NW corner	33
4/26/2008	1	1057-1143	TSW063	Sarasota Bay: Cove on W side	38
4/27/2008	1	0925-1014	TSW063	Sarasota Bay: City Island grass flats	45
5/3/2008	1	1522-1626	TSW065	Myakka River: Big Slough	50

Date	Tape #	Approximate Timeframe	Manatee ID(s)	Location	Minutes
5/4/2008	1	1031-1133	TSW065	Gasparilla Sound: Boca Grande area	60
5/4/2008	2	1139-1213	TSW065	Gasparilla Sound: Along Boca Grande golf course	62
5/4/2008	3	1520-1541	TSW066	Charlotte Harbor: West wall	19
5/24/2008	1	1043-1149	TSW069	Gulf of Mexico: Off Cayo Costa	54
5/24/2008	2	1341-1507	TSW069	Gasparilla Sound: Gasparilla Pass area	62
5/24/2008	3	1509-1538	TSW069	Gasparilla Sound: Gasparilla Pass area	29
5/25/2008	1	1004-1048	TSW069	Gulf of Mexico: Off Cayo Costa	33
5/25/2008	2	1050-1124	TSW069	Gulf of Mexico: Off Cayo Costa, near beach	33
5/26/2008	1	1116-1148	TSW069	Gulf of Mexico: Off Cayo Costa, further offshore	29
5/26/2008	2	1504-1551	TSW069	Gasparilla Sound: In Boca Grande Pass	41
5/26/2008	3	1552-1614	TSW069	Gasparilla Sound: In Boca Grande Pass	20
6/7/2008	1	1050-1153	TSW070	Charlotte Harbor: West wall	60
6/7/2008	2	1157-1225, 1435-1510	TSW070	Charlotte Harbor: West wall and Turtle Bay	62
6/14/2008	1	1034-1100, 1327-1430	TSW072	Gasparilla Sound	60
6/15/2008	1	1020-1126	TSW072	Gasparilla Sound	49
6/15/2008	2	1256-1429	TSW072	Gasparilla Sound	60
				Total minutes recorded	1714

Table 9. Received sound levels at a boat's closest point of approach (measured during a one-second time window) and the corresponding signal-to-noise ratio for four selected boat approaches.

						0.4-10 kHz		10-20 kHz	
Corresponding Figure Nos.	**Boat ID**	**Boat Type**	**Boat Size (feet)**	**Distance between manatee & boat at CPA (m)**	**Boat Speed at CPA**	**Received Level (dB re 1μPa)**	**SNR**	**Received Level (dB re 1μPa)**	**SNR**
23, 29	A01	Personal watercraft	<15	1-10	planing	127.8	17.2	118.6	14.0
24, 30	M63	Yacht	26-40	1-10	idle/slow	133.7	15.8	110.0	4.7
25, 31	Y01	Open fisherman	16-26	11-50	planing	129.4	29.5	108.8	16.0
26, 32	K02	Open fisherman	16-26	1-10	plow	138.1	33.9	119.5	32.6

CPA = closest point of approach

Table 10. Manatee response to boat approaches as a function of closest distance category between the manatee and boat. Responses were categorized by field observers and are summarized as changes in mobility, speed, heading with respect to boat, and movement in relation to channel (if applicable). This includes only a subset of data and only interactions where the response was known.

Mobility

Distance (m)	No Change	Decrease	Increase	Sample Size
0	0%	0%	100%	2
<10	50%	9%	41%	22
<50	78%	5%	17%	64
>50	98%	1%	1%	1545

Speed

Distance (m)	No Change	Decrease	Increase	Sample Size
0	0%	0%	100%	2
<10	50%	0%	50%	20
<50	73%	5%	22%	60
>50	97%	1%	2%	1550

Heading in Relation to Boat

Distance (m)	No Change	Away	Towards	Sample Size
0	50%	0%	50%	2
<10	60%	30%	10%	20
<50	77%	18%	5%	56
>50	99%	1%	0%	1463

Movement in Relation to Channel

Distance (m)	No Change	Away	Towards	Sample Size
0	50%	0%	50%	2
<10	91%	9%	0%	11
<50	82%	9%	9%	44
>50	99%	0%	1%	1367

Table 11. Manatee response to boat approaches as a function of the speed class of the boat. Responses were categorized by field observers and are summarized as changes in mobility, speed, heading with respect to boat, and movement in relation to channel (if applicable). This includes only a subset of data, interactions where the response was known, and interactions where the boat approached within 50 m of the manatee.

Mobility

Boat Speed	No Change	Decrease	Increase	Sample Size
idle/slow	75%	4%	21%	24
plow	73%	0%	27%	11
plane	69%	7%	24%	29

Speed

Boat Speed	No Change	Decrease	Increase	Sample Size
idle/slow	64%	0%	36%	22
plow	78%	0%	22%	9
plane	65%	8%	27%	26

Heading in Relation to Boat

Boat Speed	No Change	Away	Towards	Sample Size
idle/slow	73%	23%	5%	22
plow	73%	18%	9%	11
plane	75%	18%	7%	28

Movement in Relation to Channel

Boat Speed	No Change	Away	Towards	Sample Size
idle/slow	75%	25%	0%	12
plow	100%	0%	0%	5
plane	90%	10%	0%	20

Table 12. Fundamental frequencies, durations, and rates of vocalizations as a function of grouping (alone versus in a group of 2-9 manatees) and presence of boat noise.

	Group Size		**Background Sounds**		
	Alone	**Group**	**Boat Noise**	**No Boat noise**	**All samples**
Average Fundamental Frequency (kHz)	2.97	2.60	2.94	2.80	2.80
Average Duration (seconds)	0.088	0.154	0.108	0.140	0.131
Vocalization Rate (vocalizations/minute)	0.50	0.43	0.29	0.56	0.47

Note: Numbers are preliminary, based on only a subset of the data.

FIGURES

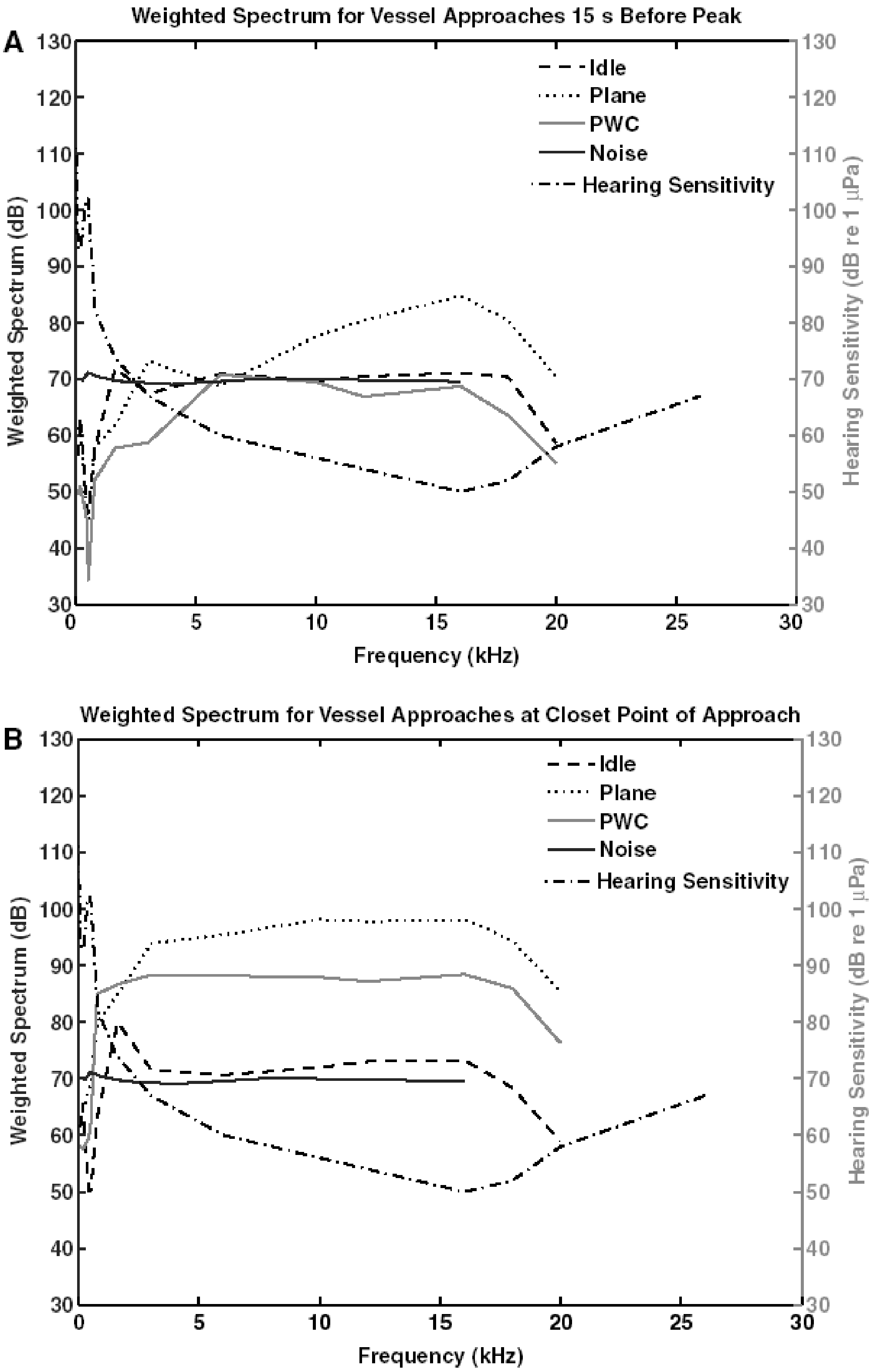


Figure 1. Spectra of approaching boats (idling, planing, and a PWC) weighted by manatee hearing thresholds, the ambient noise level, and manatee hearing sensitivity (from Miksis-Olds et al. 2007).

Figure 2. Map of the study area in southwest Florida, showing major water bodies. Manatees were captured and tagged in Lemon Bay, Placida Harbor, and Gasparilla Sound.

Figure 3. Google Earth map of Kings Bay, Crystal River study area where the first DTAG deployment and focal tracking was conducted on TCR005.

Figure 4. Google Earth map of Card Sound study area where the second DTAG deployment and focal tracking was conducted on TFK007.

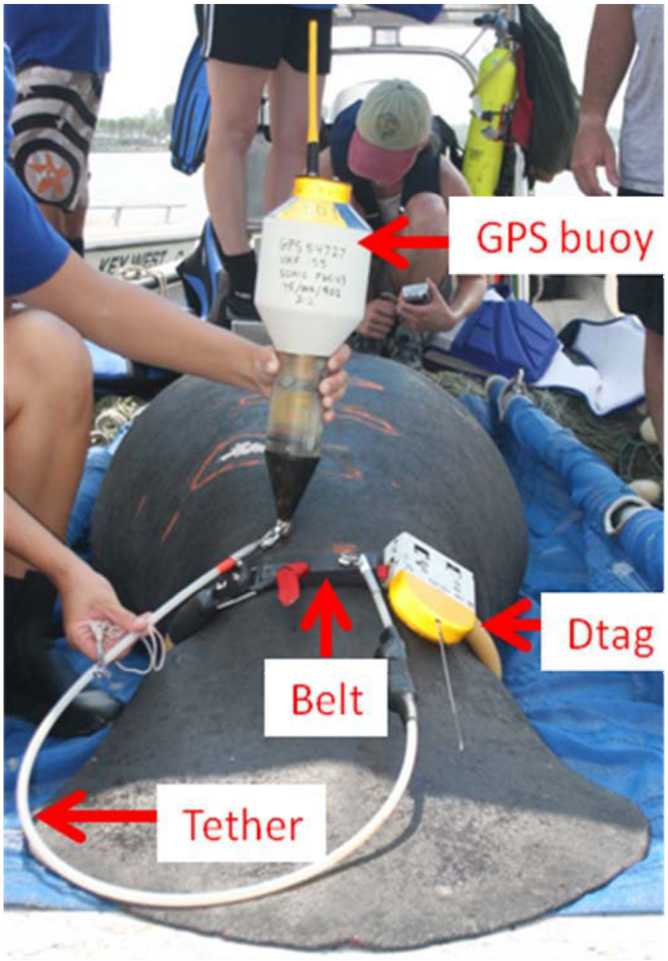


Figure 5. The tagging assembly showing the placement of the DTAG on the belt that is fit around the manatee's peduncle and the buoyant GPS tag tethered to the belt via a flexible 5-foot-long nylon rod.

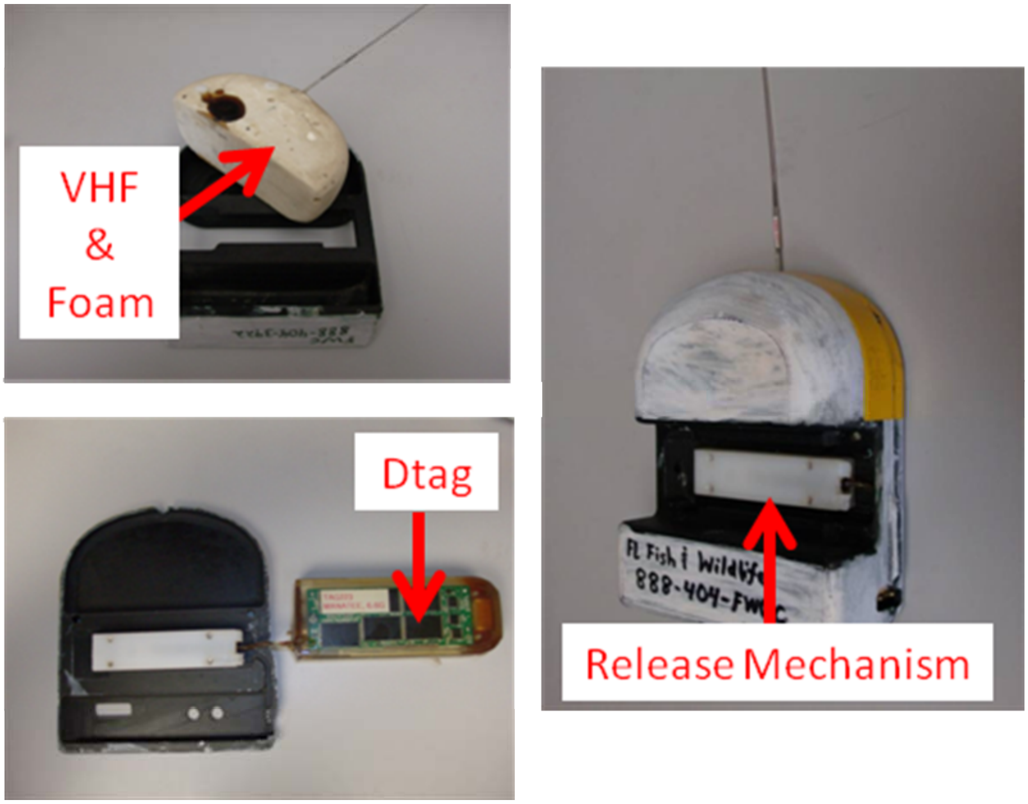
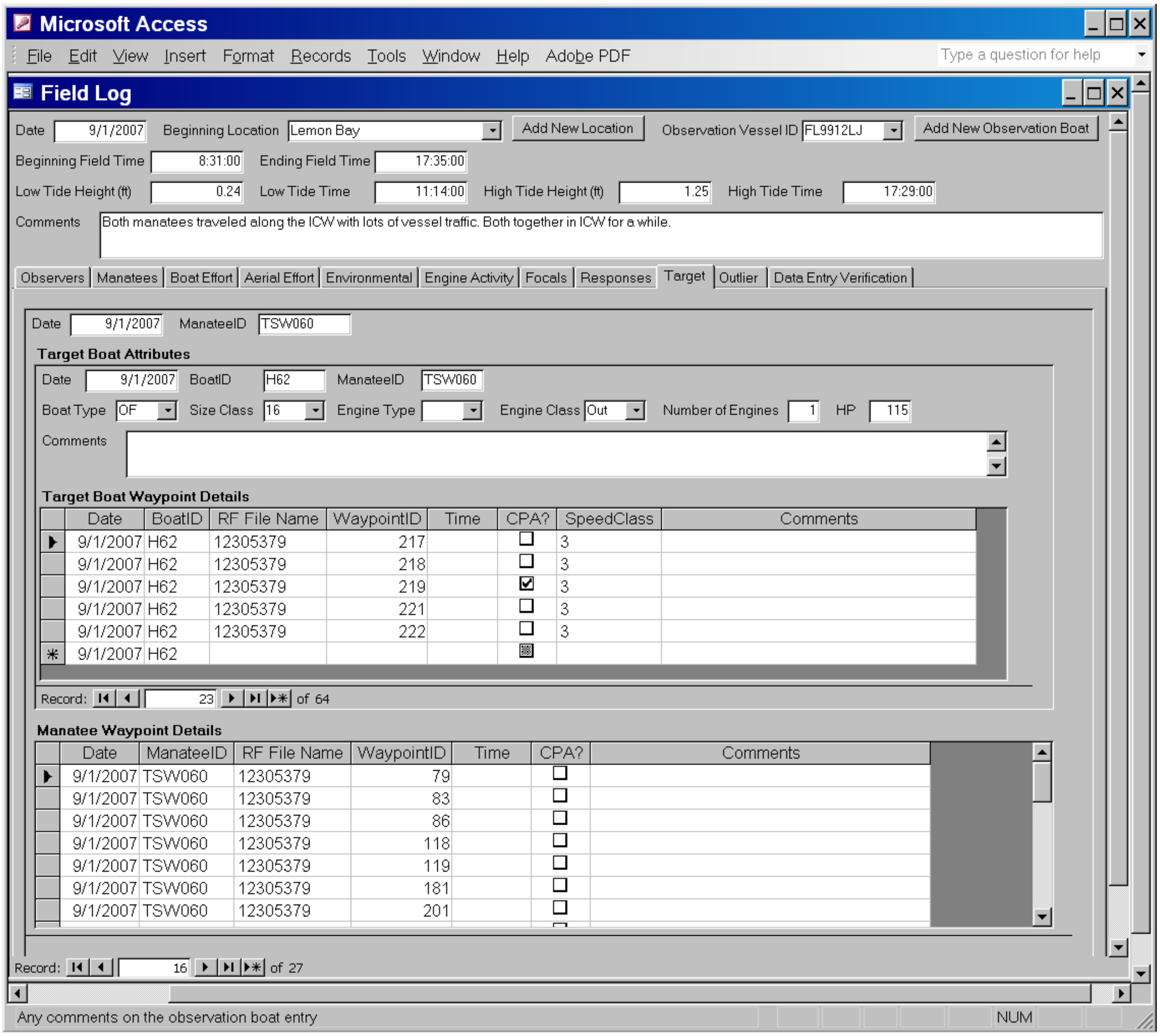


Figure 6. Components inside the DTAG's plastic housing: the DTAG electronics in an epoxy resin casing (lower left), VHF transmitter, and foam for flotation (upper left). An assembled DTAG and the location of the release mechanism that connects to the release block on the manatee's belt is shown at right.

Figure 7. A laser range finder was used to collect distance and bearing to all vessels that passed the focal manatee under observation, identified by the floating GPS tag on the left side of the image.

Figure 8. A tagged manatee dives after surfacing to breathe while swimming through the canals of Boca Grande. The DTAG attached to the belt is visible as it breaks the surface of the water and the buoyant GPS tag trails behind on a 5-foot-long tether.



Date 9/1/2007 Beginning Location Lemon Bay Observation Vessel ID FL9912LJ

Beginning Field Time 8:31:00 Ending Field Time 17:35:00

Low Tide Height (ft) 0.24 Low Tide Time 11:14:00 High Tide Height (ft) 1.25 High Tide Time 17:29:00

Comments Both manatees traveled along the ICW with lots of vessel traffic. Both together in ICW for a while.

Date 9/1/2007 ManateeID TSW060

Target Boat Attributes

Date 9/1/2007 BoatID H62 ManateeID TSW060

Boat Type OF Size Class 16 Engine Type Engine Class Out Number of Engines 1 HP 115

Comments

Target Boat Waypoint Details

	Date	BoatID	RF File Name	WaypointID	Time	CPA?	SpeedClass	Comments
▶	9/1/2007	H62	12305379	217		☐	3	
	9/1/2007	H62	12305379	218		☐	3	
	9/1/2007	H62	12305379	219		☑	3	
	9/1/2007	H62	12305379	221		☐	3	
	9/1/2007	H62	12305379	222		☐	3	
✱	9/1/2007	H62				▨		

Record: 23 of 64

Manatee Waypoint Details

	Date	ManateeID	RF File Name	WaypointID	Time	CPA?	Comments
▶	9/1/2007	TSW060	12305379	79		☐	
	9/1/2007	TSW060	12305379	83		☐	
	9/1/2007	TSW060	12305379	86		☐	
	9/1/2007	TSW060	12305379	118		☐	
	9/1/2007	TSW060	12305379	119		☐	
	9/1/2007	TSW060	12305379	181		☐	
	9/1/2007	TSW060	12305379	201		☐	

Record: 16 of 27

Any comments on the observation boat entry NUM

Figure 9. Screen shot of the MS Access relational database used to enter, store, verify, and query data collected in the field, including observers, boat-based effort, aerial effort, environmental information, engine activity of observation boat, manatee behaviors (focals), manatee responses to passing vessels, and target vessel attribute data. This figure shows the data entry form for target vessel attributes. Nine tabs are devoted to data entry; two additional tabs are for documenting range finder outlier records and the status of data entry and verification.

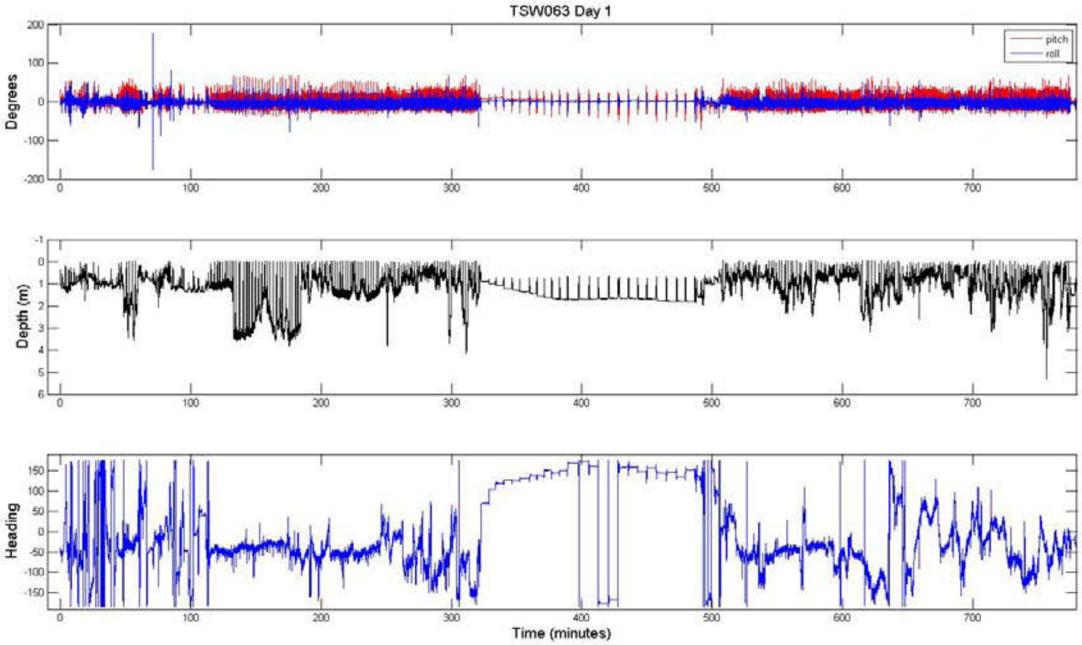


Figure 10. Example of DTAG sensor data collected from manatee TSW063 on April 25, 2008 from 7:00 – 20:00 hr. Sensor shown are pitch and roll (top), depth (middle), and heading (bottom).

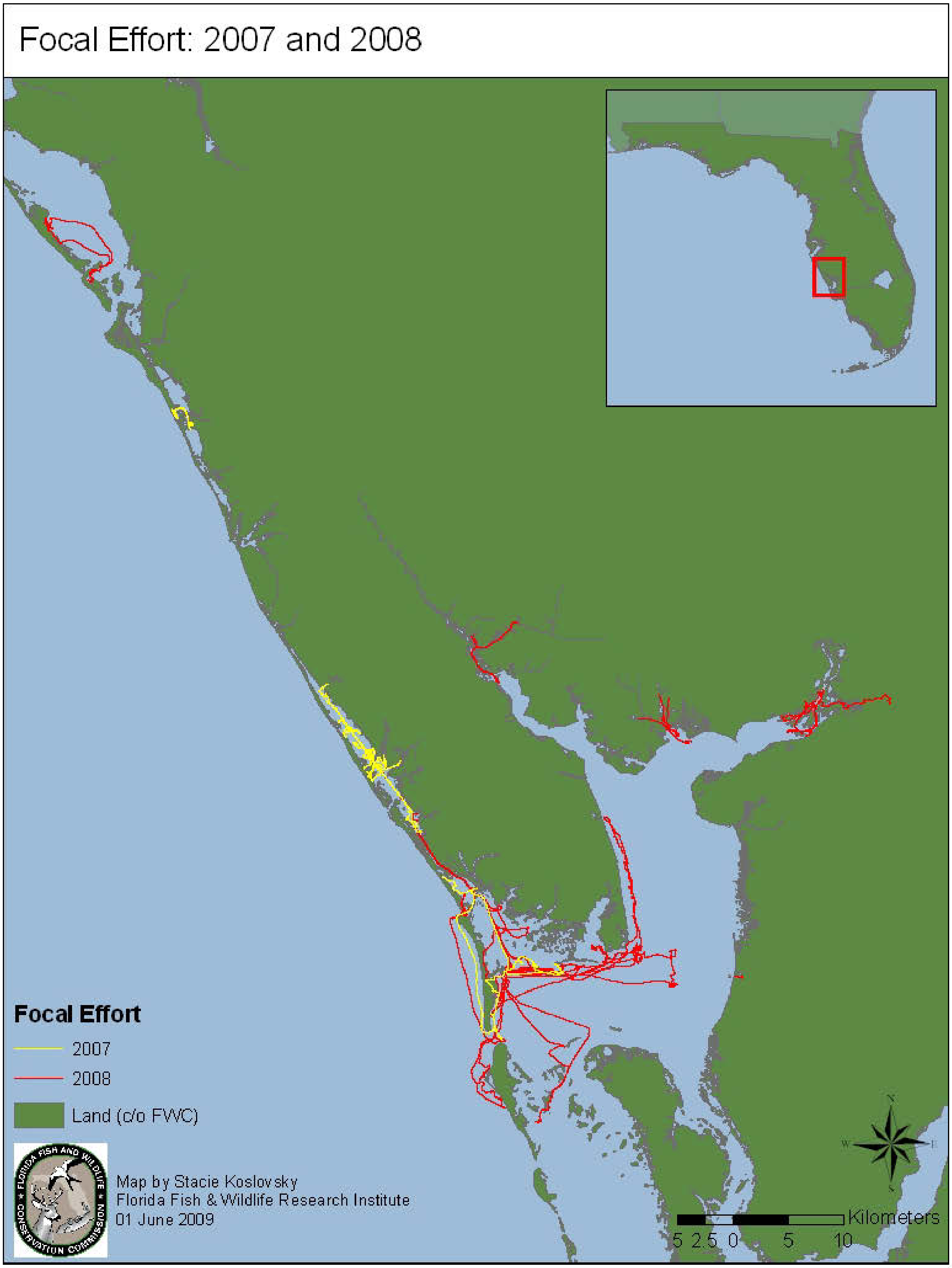


Figure 11. Map of observation boat GPS tracks on dates of focal follows of tagged manatees in the southwest Florida study area.

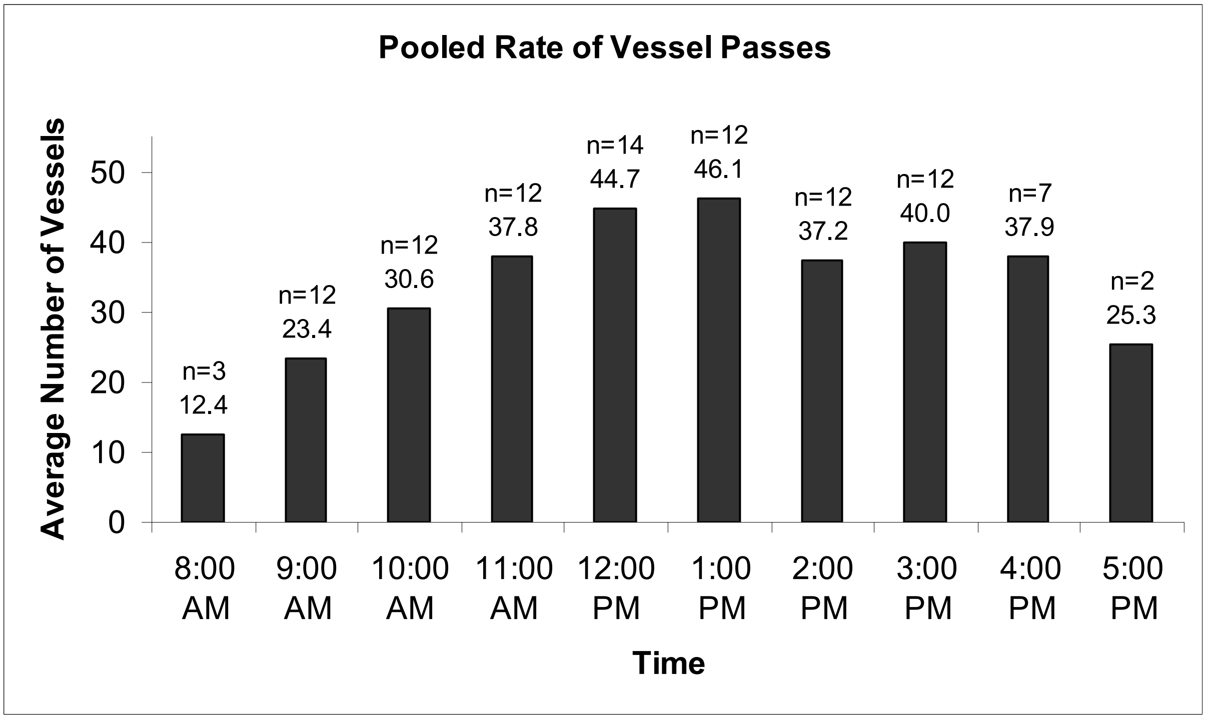


Figure 12. Pooled rate of boat passes (within about 500 m of tagged manatee) by hour of the day (Eastern Daylight Time). Numbers are preliminary, based on only a subset of the data.

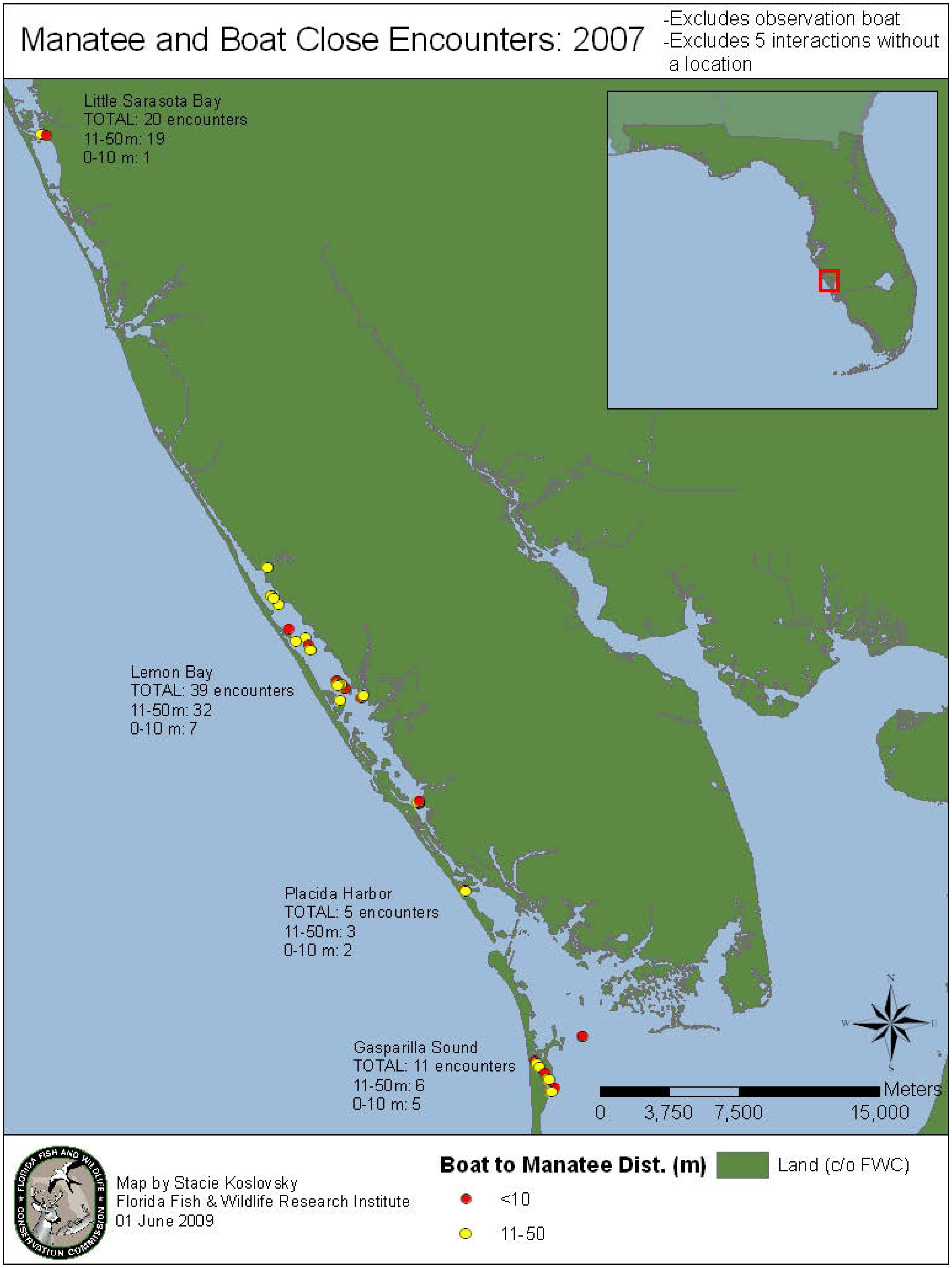


Figure 13. Locations of observed close encounters (<50 m) between the focal manatee and boats in the southwest Florida study area during 2007.

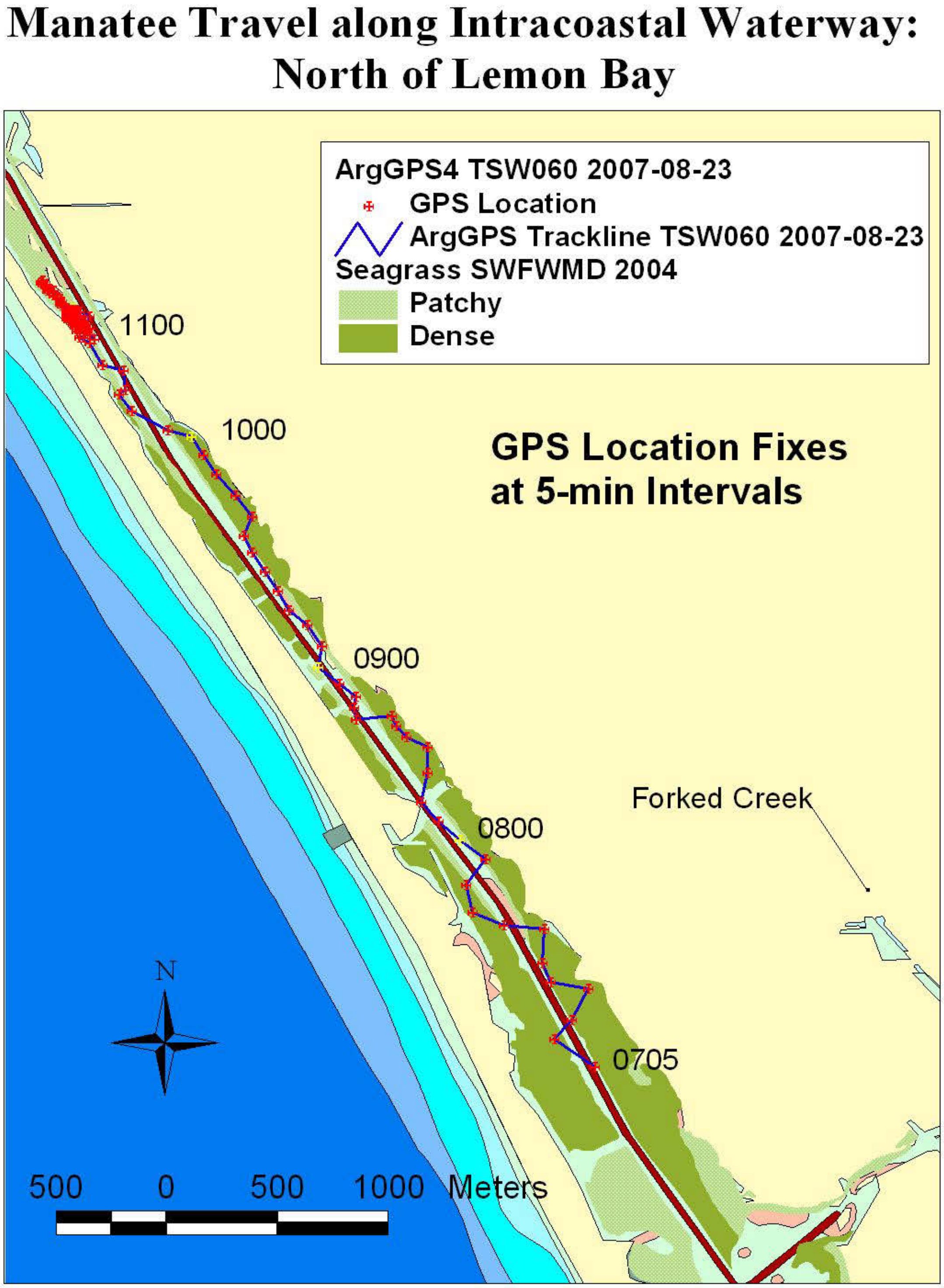


Figure 14. Travel path of TSW060 north of Forked Creek, Sarasota County, on 23 August 2007. Manatee GPS locations were obtained every 5 minutes during the movement along the Intracoastal Waterway (shown in maroon); numbers denote times. Note the frequent channel crossings (9 over the 4-hr period) and the fine temporal and spatial resolution of the travel path.

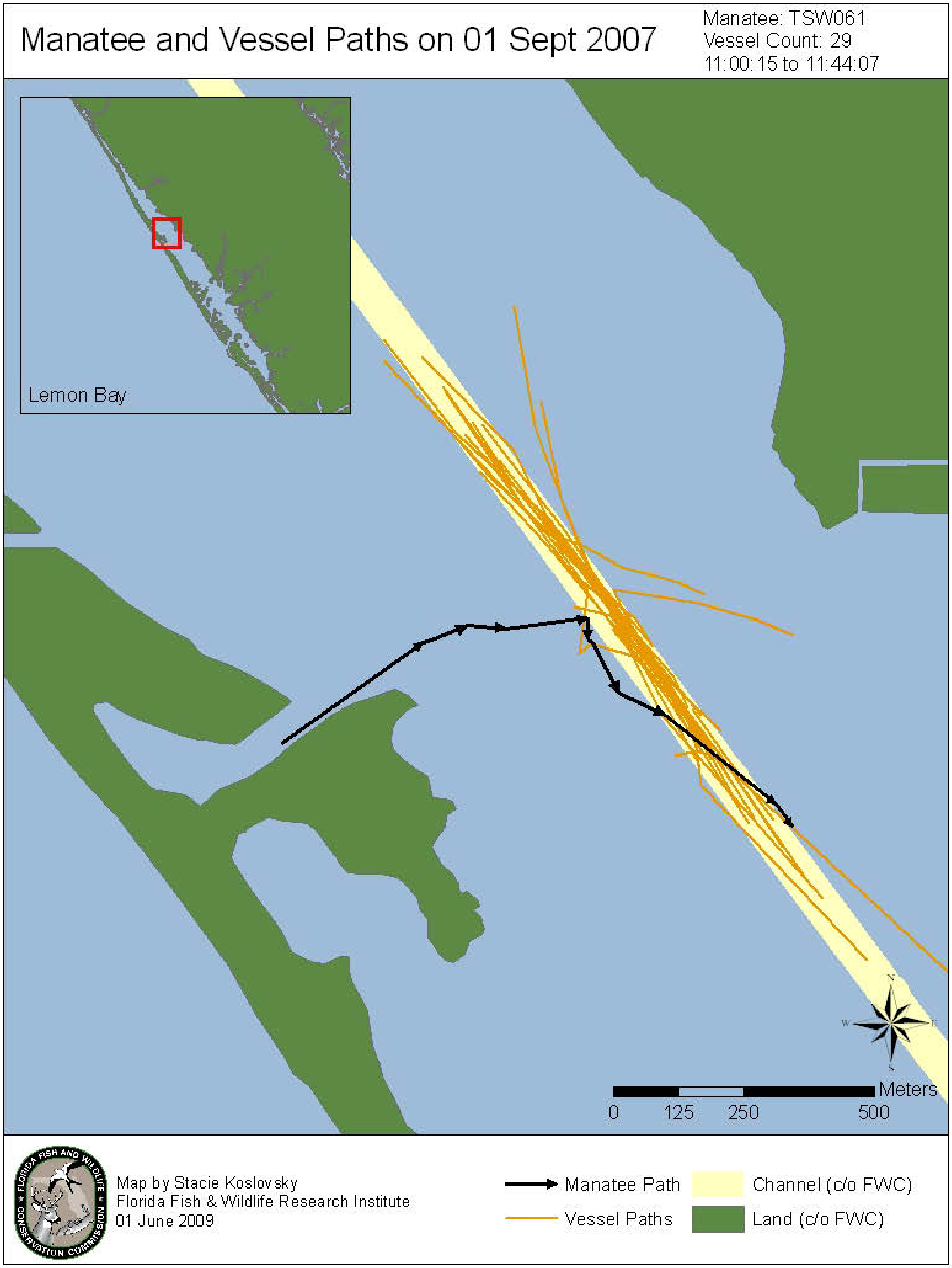


Figure 15. Map showing travel path of manatee TSW061 into the ICW of Lemon Bay on 1 September 2007, along with the paths of 29 vessels passing by during a 44-minute time period.

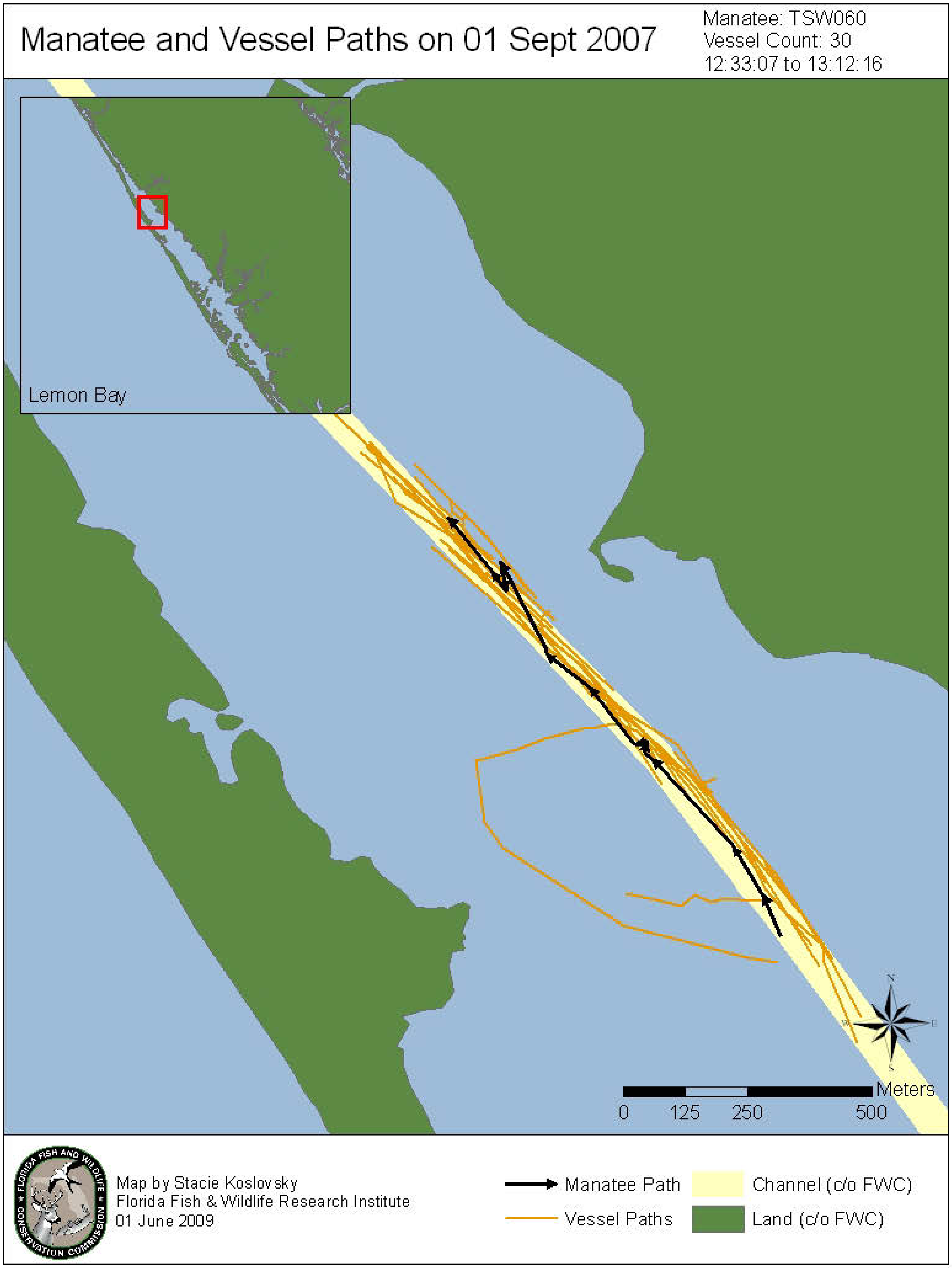


Figure 16. Map showing travel path of manatee TSW060 in the ICW of Lemon Bay on 1 September 2007, along with the paths of 30 vessels passing by during a 39-minute time period.

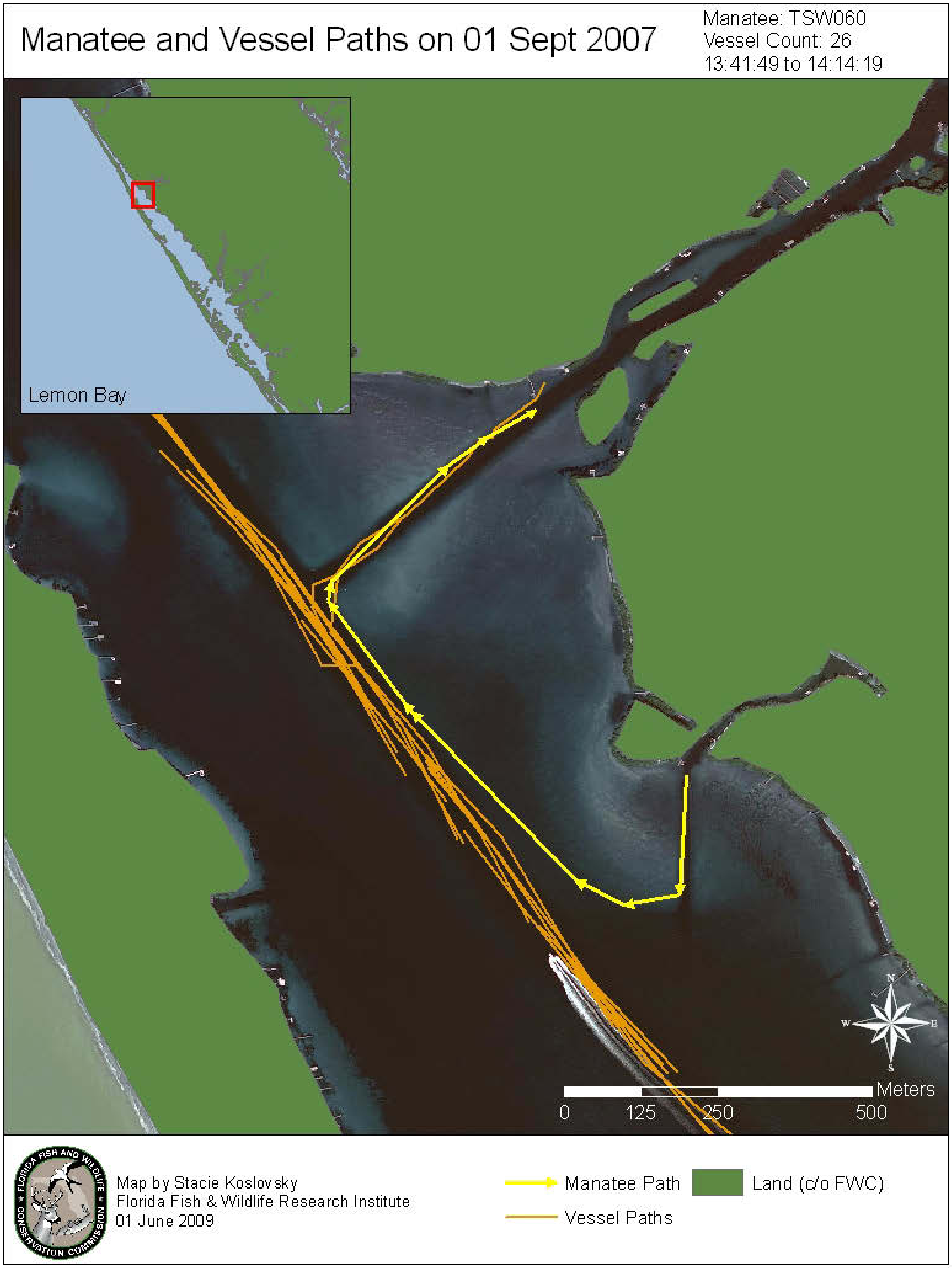


Figure 17. Map showing travel path of manatee TSW060 along the ICW of Lemon Bay and into Forked Creek on 1 September 2007, along with the paths of 26 vessels passing by during a 32.5-minute time period.

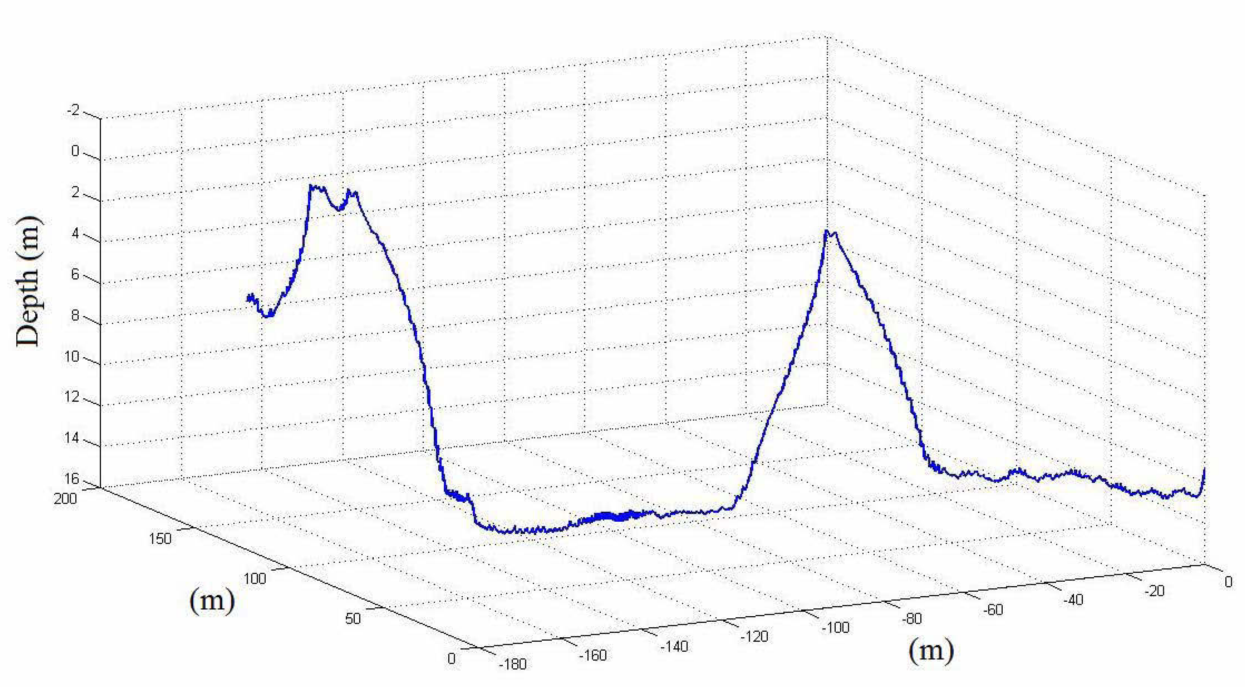


Figure 18. A 3-dimensional reconstruction of TSW062's movements over a 5.3-minute period as it traversed Boca Grande Pass at depths of 15 m. The manatee covered over 200 m in this time frame indicating that it was traveling quickly.

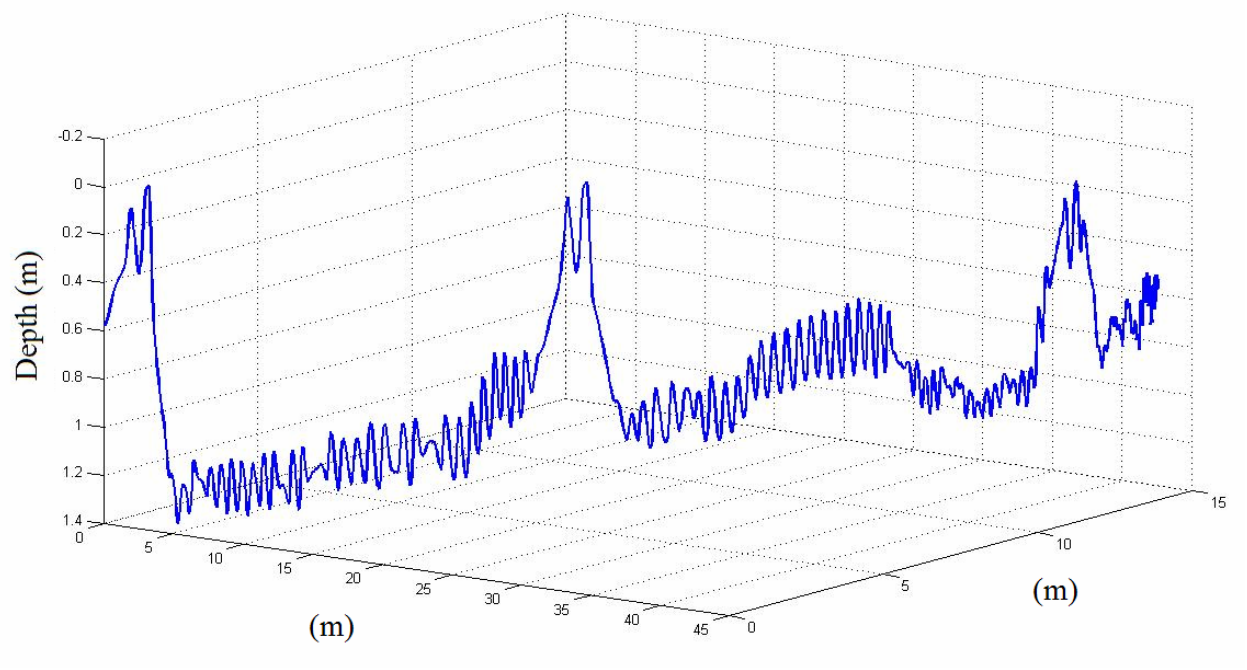


Figure 19. A 3-dimensional reconstruction of TSW062's movements over a 4-minute period. The manatee is traveling in shallow water. The short up-and-down movements represent the fluke strokes recorded by the dTag. The three larger depth changes represent surfacings.

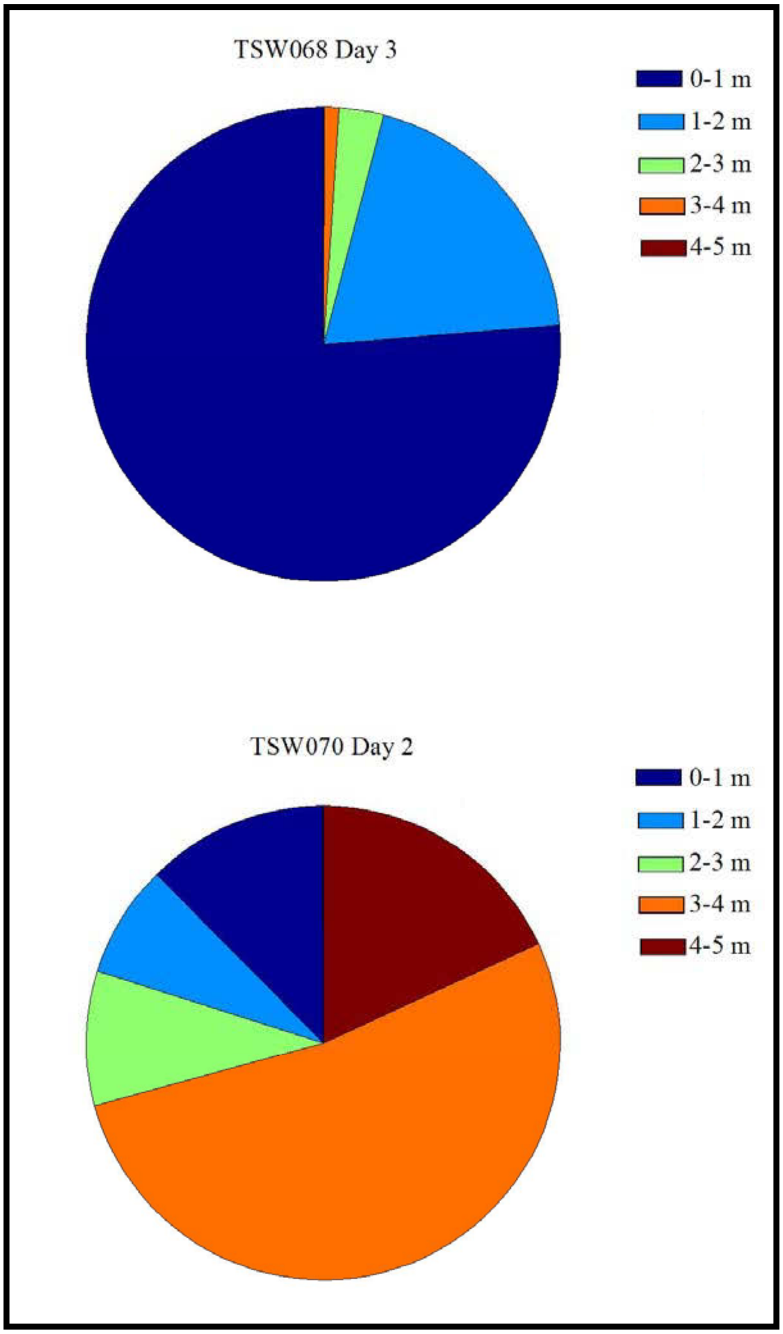


Figure 20. Distribution of depths (measured at DTAG on peduncle) that two manatees spent over a given day. TSW068 spent the day pictured in the Peace River (top chart), whereas TSW070 spent the day pictured crossing Charlotte Harbor (bottom chart).

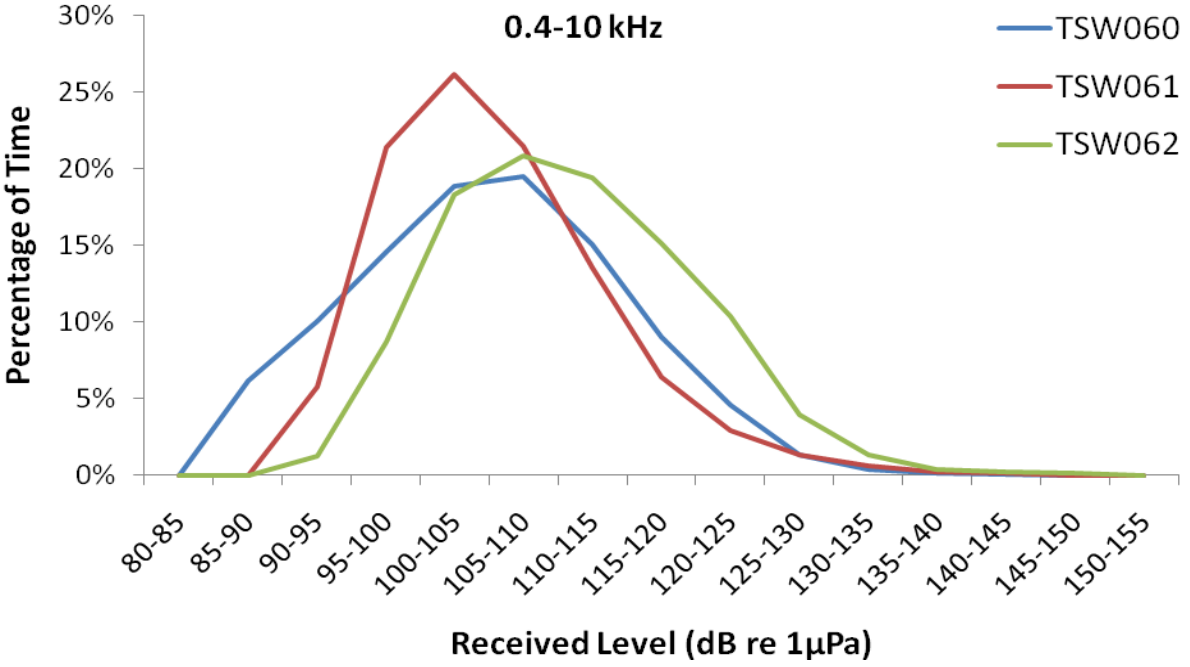


Figure 21. Relative distribution of received sound levels within the 0.4-10 kHz frequency band for three tagged manatees over their entire DTAG recording periods (about 37 hr each).

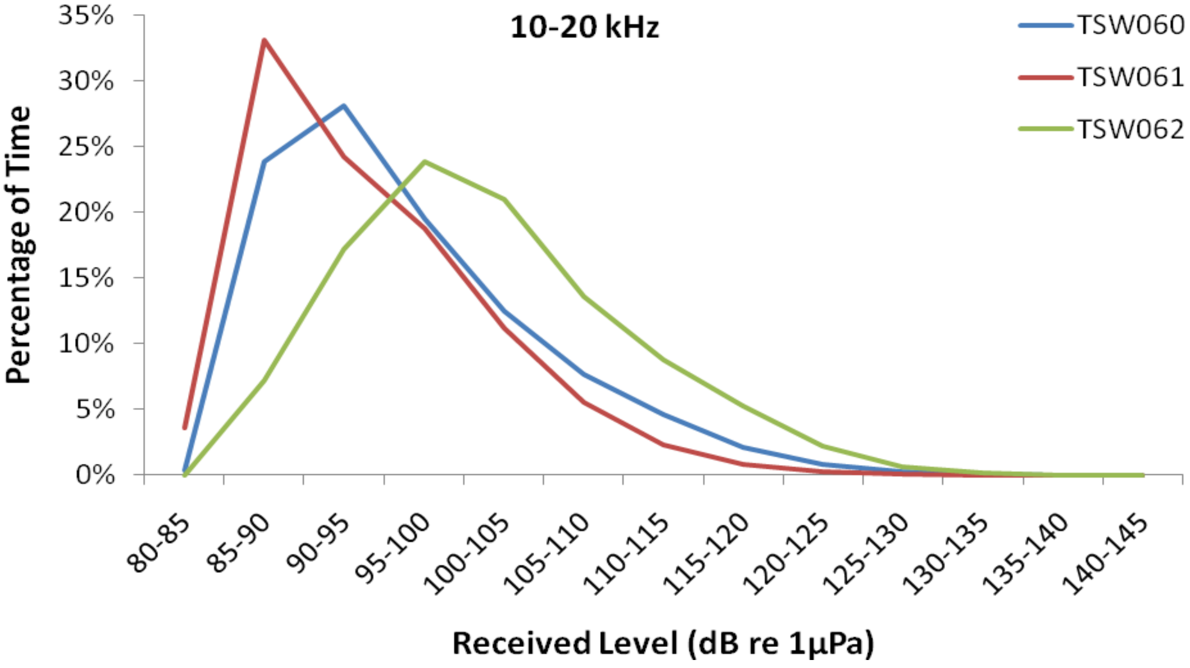


Figure 22. Relative distribution of received sound levels within the 10-20 kHz frequency band for three tagged manatees over their entire DTAG recording periods (about 37 hr each).

Manatee ID	Boat ID	CPA Time	Boat Type	Boat Size (feet)	Boat Speed at CPA	Distance at CPA (m)
TSW060	A01	9:05:05	personal watercraft	<16	planing	<10

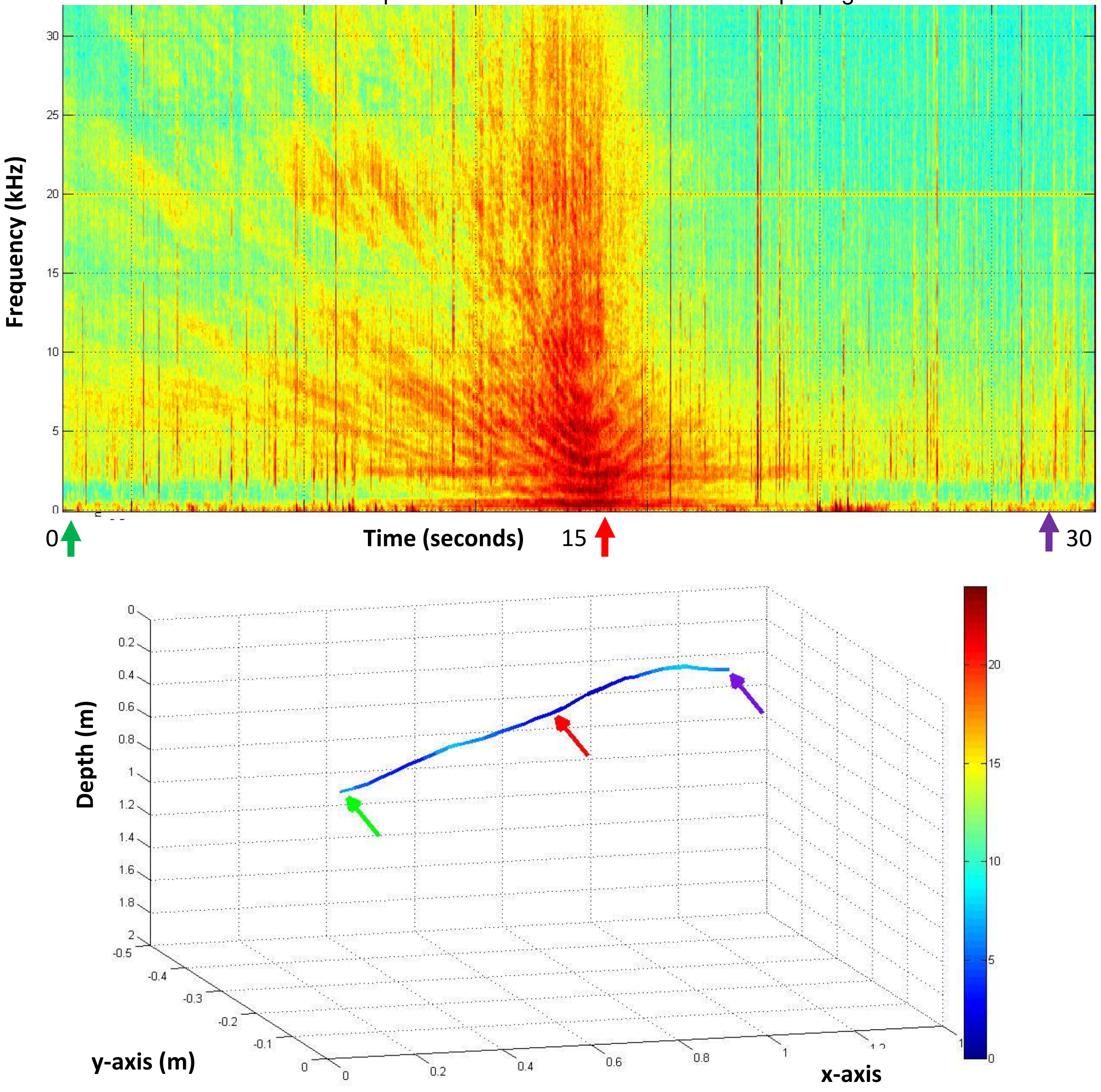


Figure 23. Acoustics and manatee response to approach of a personal watercraft (A01) to within 10 m on 2 Sept 2007. The table supplies information about the boat. The spectrogram shows the noise produced by the boat (red is louder). Despite the intense sound level and sudden onset of the boat's approach, the manatee displayed no changes in heading and a lack of fluke strokes, as displayed in the 3-dimensional reconstruction of the manatee's behavior. The green arrow indicates the beginning of the reconstruction, the red the closest point of approach, and the purple the end of the reconstruction. The color indicates the roll of the manatee (degrees); a roll of zero indicates that the manatee is level. The x, y, and z axes are all distances measured in meters.

Manatee ID	Boat ID	CPA Time	Boat Type	Boat Size (feet)	Boat Speed at CPA	Distance at CPA (m)
TSW060	M63	14:29:12	yacht	26-40	idle/slow	<10

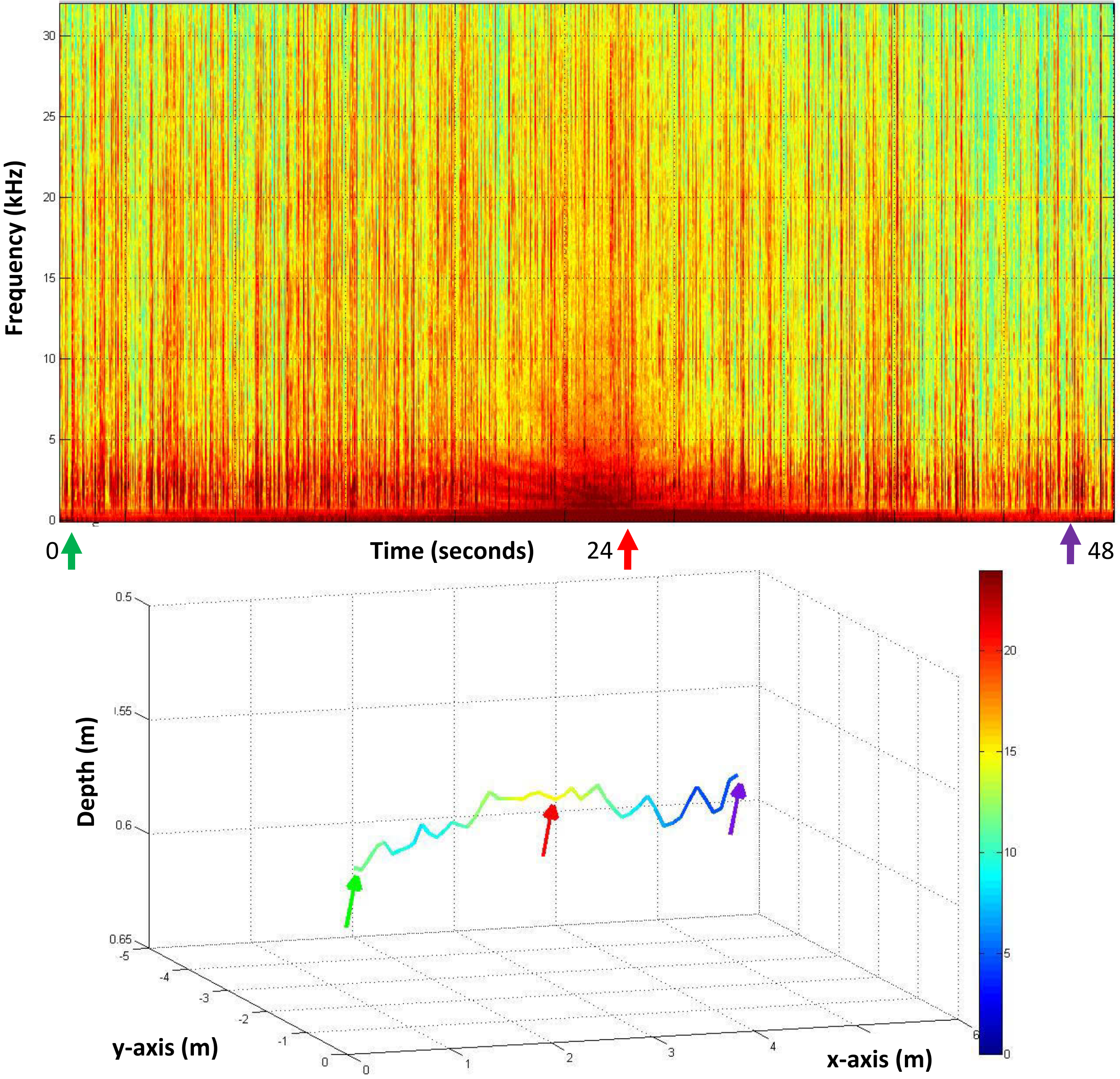


Figure 24. Acoustics and manatee response to approach of a yacht (M63) to within 10 m on 1 Sept 2007. The table supplies information about the boat. The spectrogram shows the noise produced by the boat (red is louder). The boat's approach could be heard long before it came close to the manatee. The manatee continued to travel when the boat reached its closest point of approach, as displayed in the 3-dimensional reconstruction of the manatee's behavior. The green arrow indicates the beginning of the reconstruction, the red the closest point of approach, and the purple the end of the reconstruction. The color indicates the roll of the manatee (degrees); a roll of zero indicates that the manatee is level. The x, y, and z axes are all distances measured in meters.

Manatee ID	Boat ID	CPA Time	Boat Type	Boat Size (feet)	Boat Speed at CPA	Distance at CPA (m)
TSW062	Y01	11:19:05	open fisherman	16-26	planing	<50

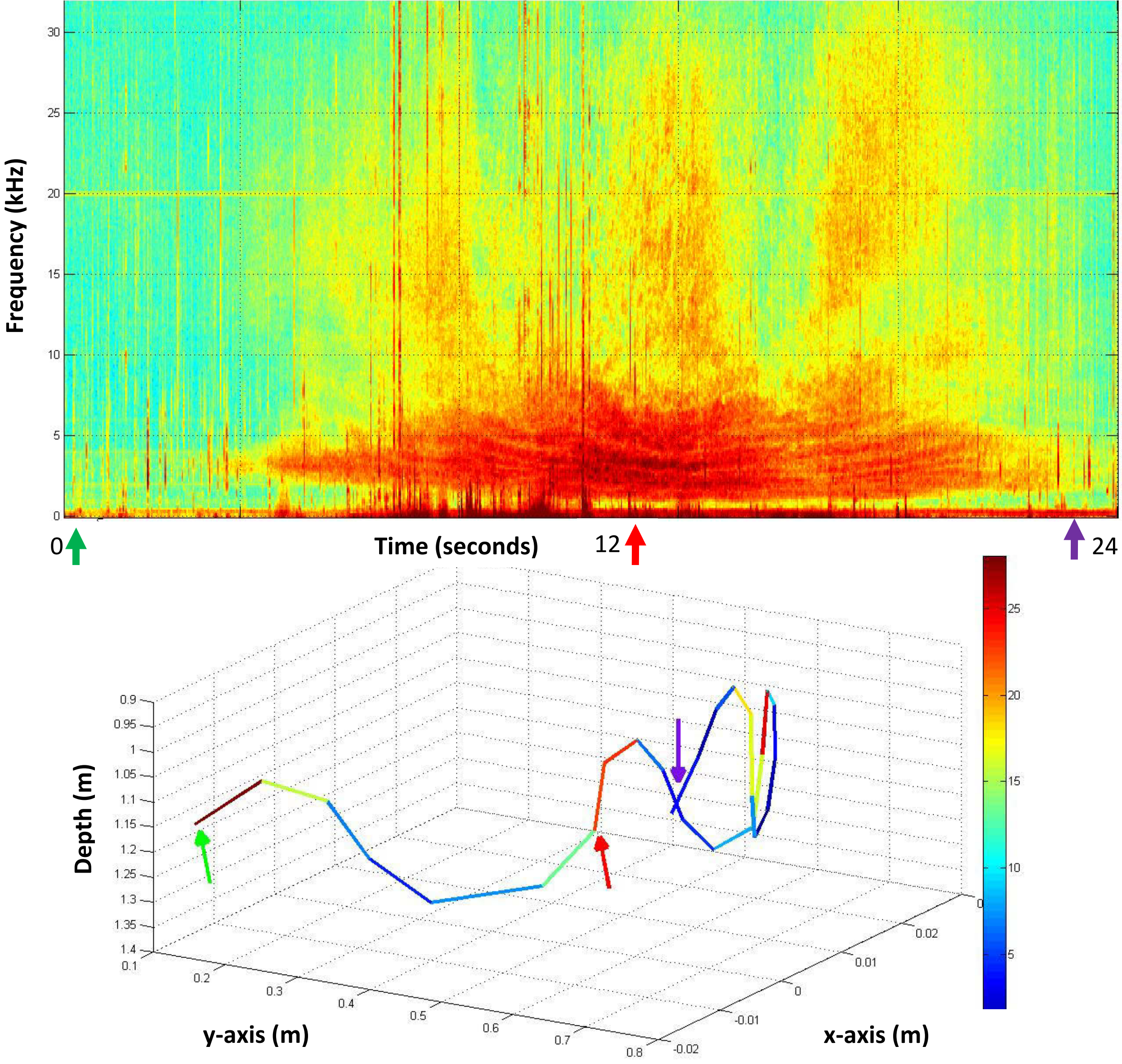


Figure 25. Acoustics and manatee response to approach of an open fisherman boat (Y01) to within 50 m on 9 Sept 2007. The table supplies information about the boat. The spectrogram shows the noise produced by the boat (red is louder). As displayed in the 3-dimensional reconstruction, the manatee increased its mobility (fluke strokes) and altered its heading after the boat passed. The green arrow indicates the beginning of the reconstruction, the red the closest point of approach, and the purple the end of the reconstruction. The color indicates the roll of the manatee (degrees); a roll of zero indicates that the manatee is level. The x, y, and z axes are all distances measured in meters.

Manatee ID	Boat ID	CPA Time	Boat Type	Boat Size (feet)	Boat Speed at CPA	Distance at CPA (m)
TSW062	K02	12:16:25	open fisherman	16-26	plow	<10

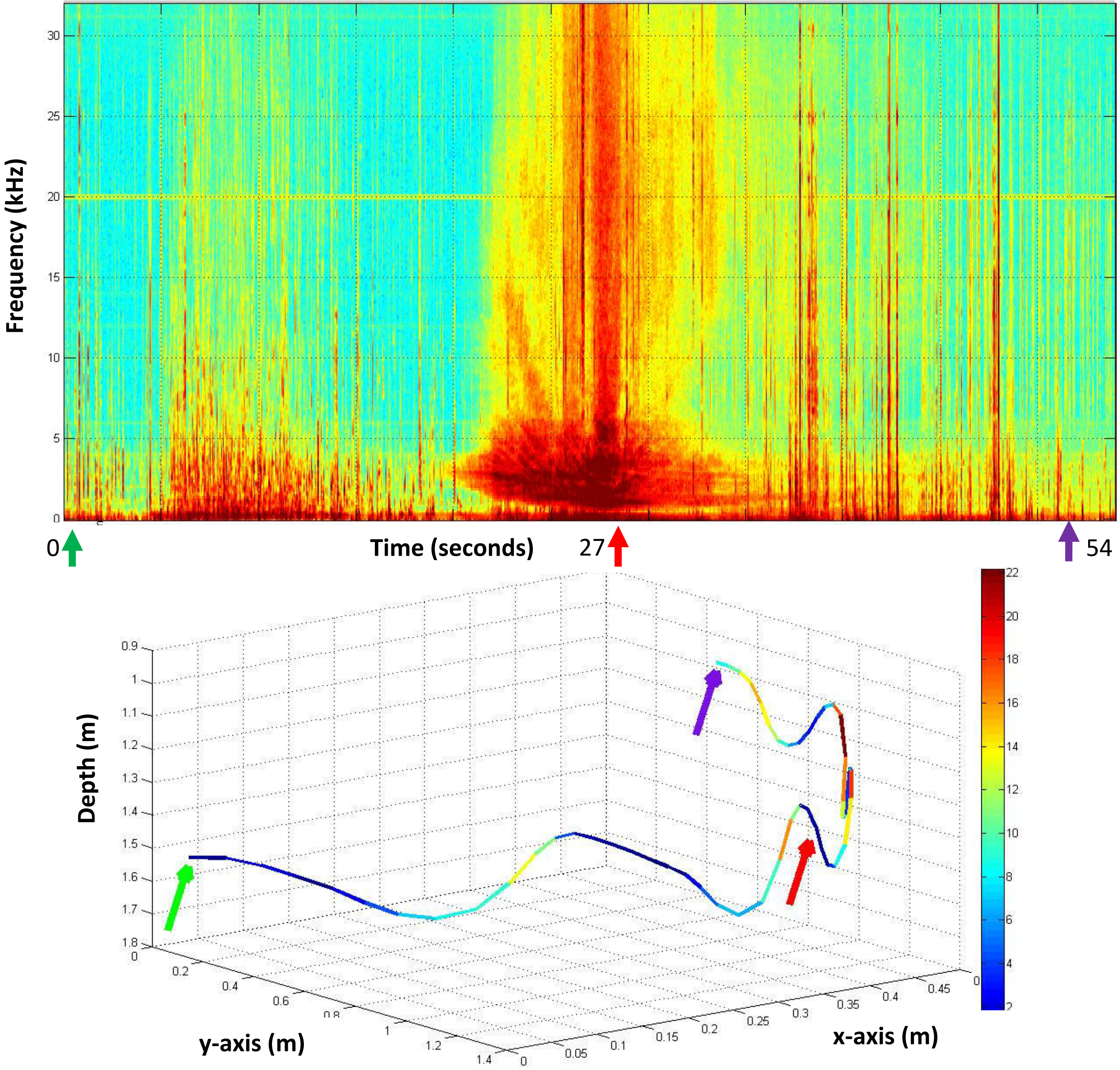


Figure 26. Acoustics and manatee response to approach of an open fisherman boat (Y01) to within 50 m on 9 Sept 2007. The table supplies information about the boat. The spectrogram shows the noise produced by the boat (red is louder). The manatee increased its mobility, as displayed in the 3-dimensional reconstruction, and after the boat's closest point of approach the manatee altered its heading. The green arrow indicates the beginning of the reconstruction, the red the closest point of approach, and the purple the end of the reconstruction. The color indicates the roll of the manatee (degrees); a roll of zero indicates that the manatee is level. The x, y, and z axes are all distances measured in meters.

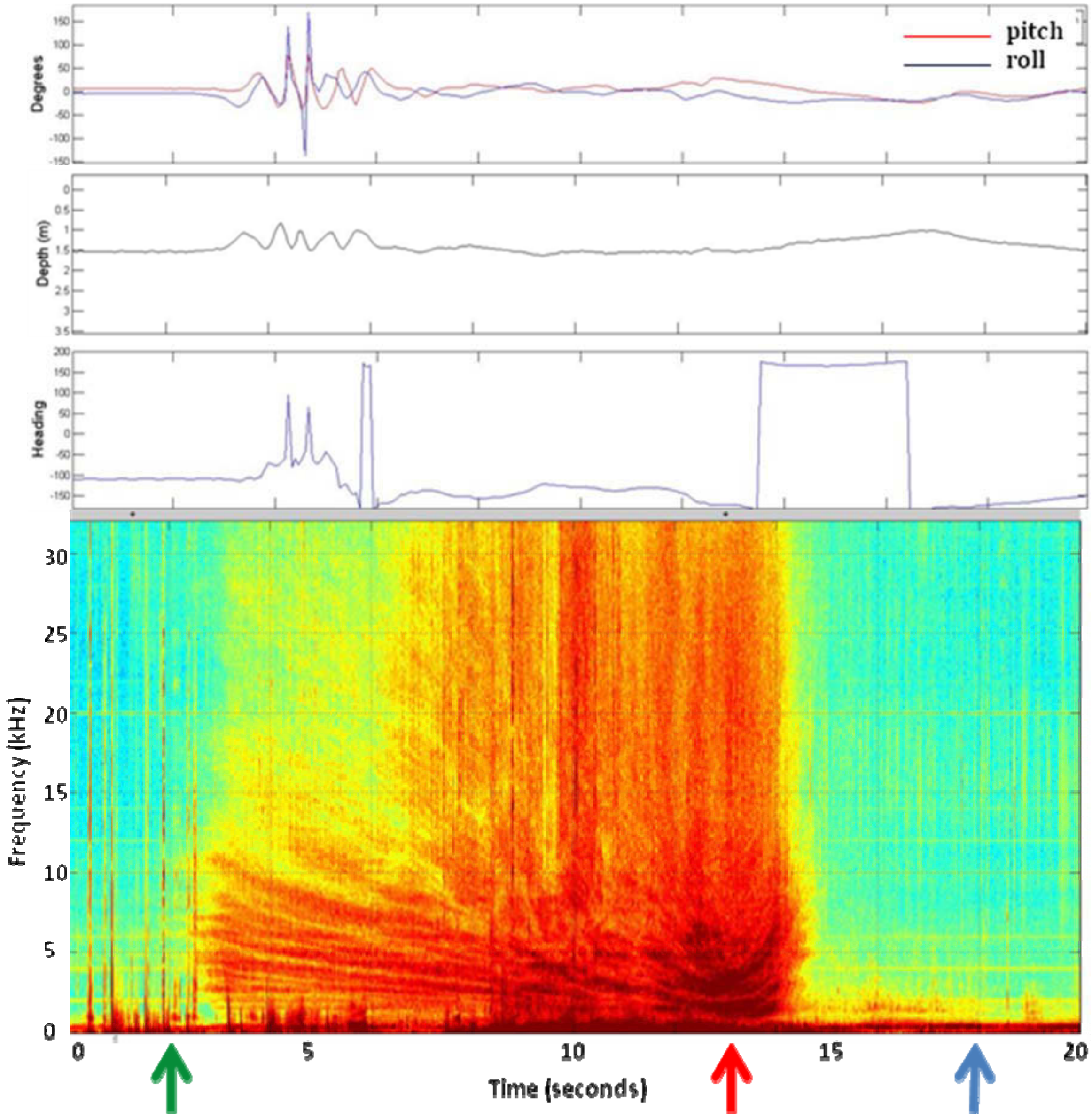


Figure 27. Manatee response to a boat approaching on a plane to within 10 m of the manatee's location. Top panel shows dTag pitch and roll; 2nd panel shows depth (~1.5 m); 3rd panel shows compass heading; and the bottom figure is the spectrogram from the dTag acoustic record during this 20-sec timeframe (red color indicates greater sound amplitude). The green arrow is the onset of boat noise (audible to the listener), the red arrow is the peak in boat noise, and the blue arrow is when boat noise was no longer audible on the recording. The manatee showed an apparent reaction about 9-10 sec before the closest point of vessel approach. The boat was a fisherman type between 16-26 feet in length with a 150 hp 4-stroke engine.

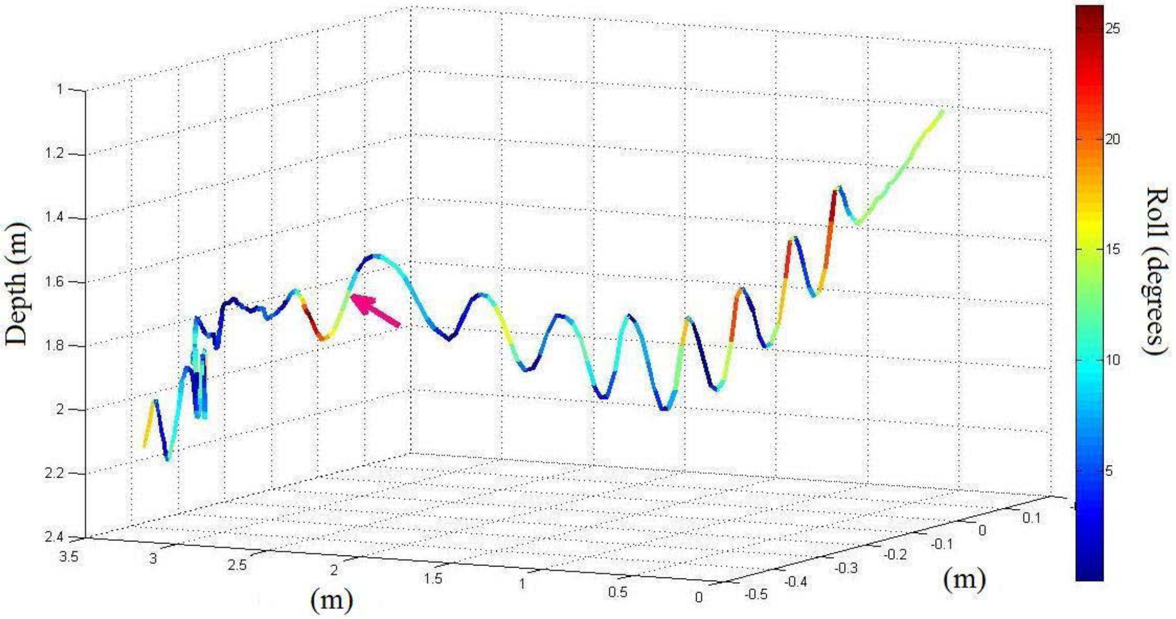


Figure 28. A 3-dimensional reconstruction of TSW062's behavior over a 12 second period. The manatee was swimming with even fluke strokes (right side of figure) as it moved to the left. The pink arrow indicates when a boat pass reached its peak sound level. After the peak in sound amplitude the manatee's fluke strokes became erratic, indicating a response to the passing boat. The color of the line indicates the roll of the manatee (zero degrees = level).

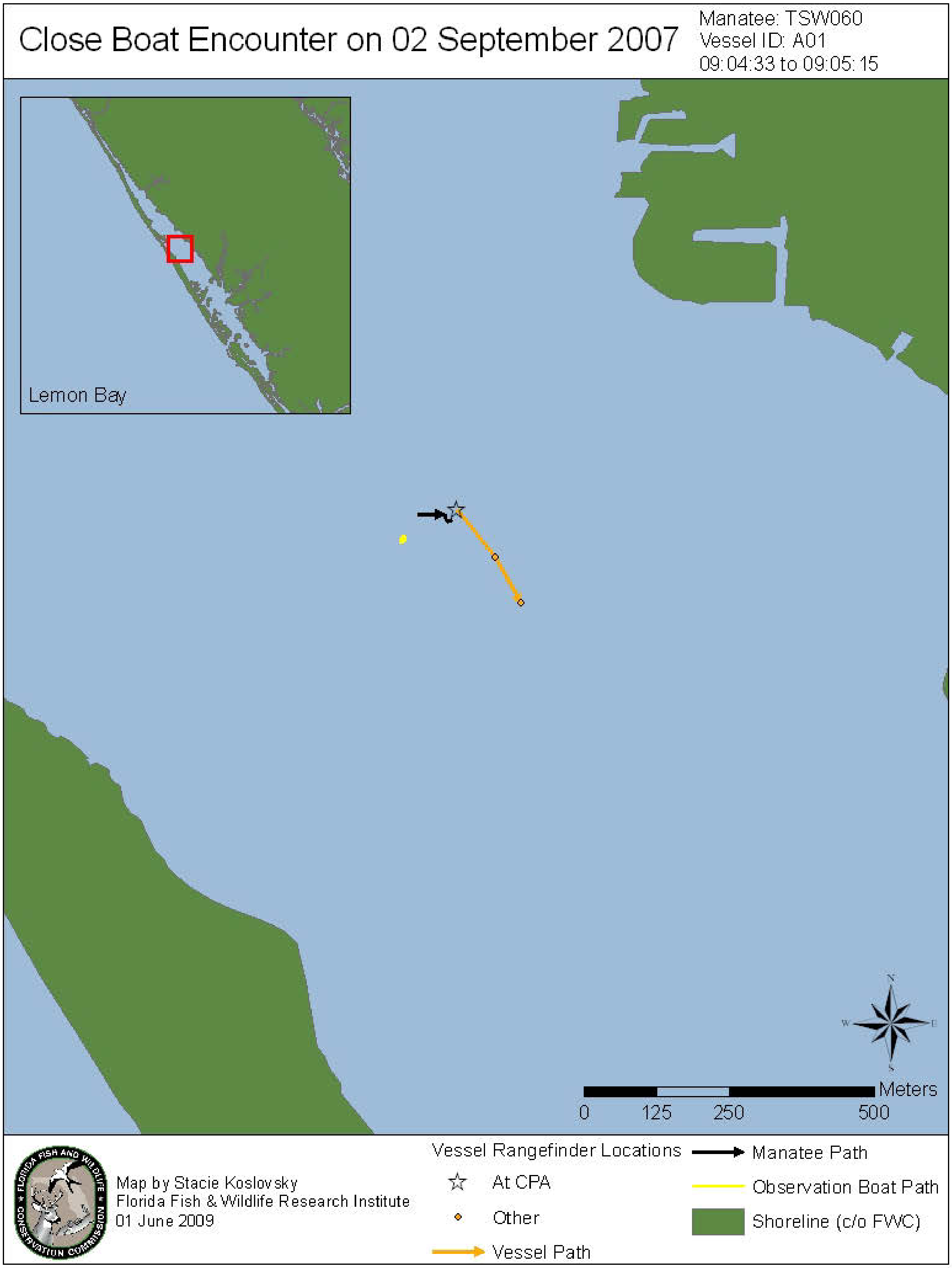


Figure 29. Map of a manatee-boat interaction in the ICW of Lemon Bay on 2 September 2007, showing the movement paths of manatee TSW060, the observation boat, and a personal watercraft over a 0.7-minute time period. This matches DTAG data in Figure 23.

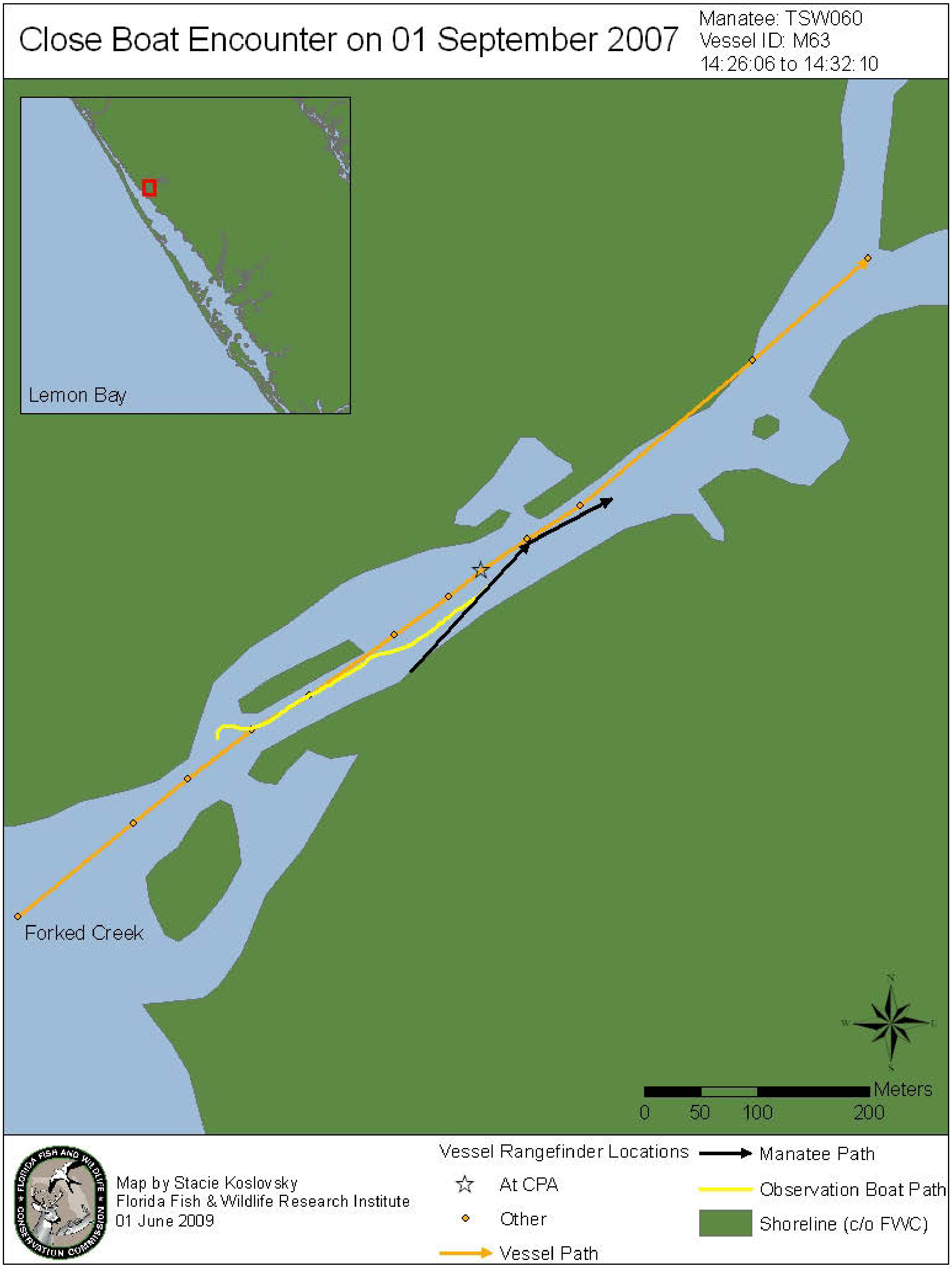


Figure 30. Map of a manatee-boat interaction in Forked Creek (Lemon Bay) on 1 September 2007, showing the movement paths of manatee TSW060, the observation boat, and a slow-moving yacht over a 6-minute time period. This matches DTAG data in Figure 24.

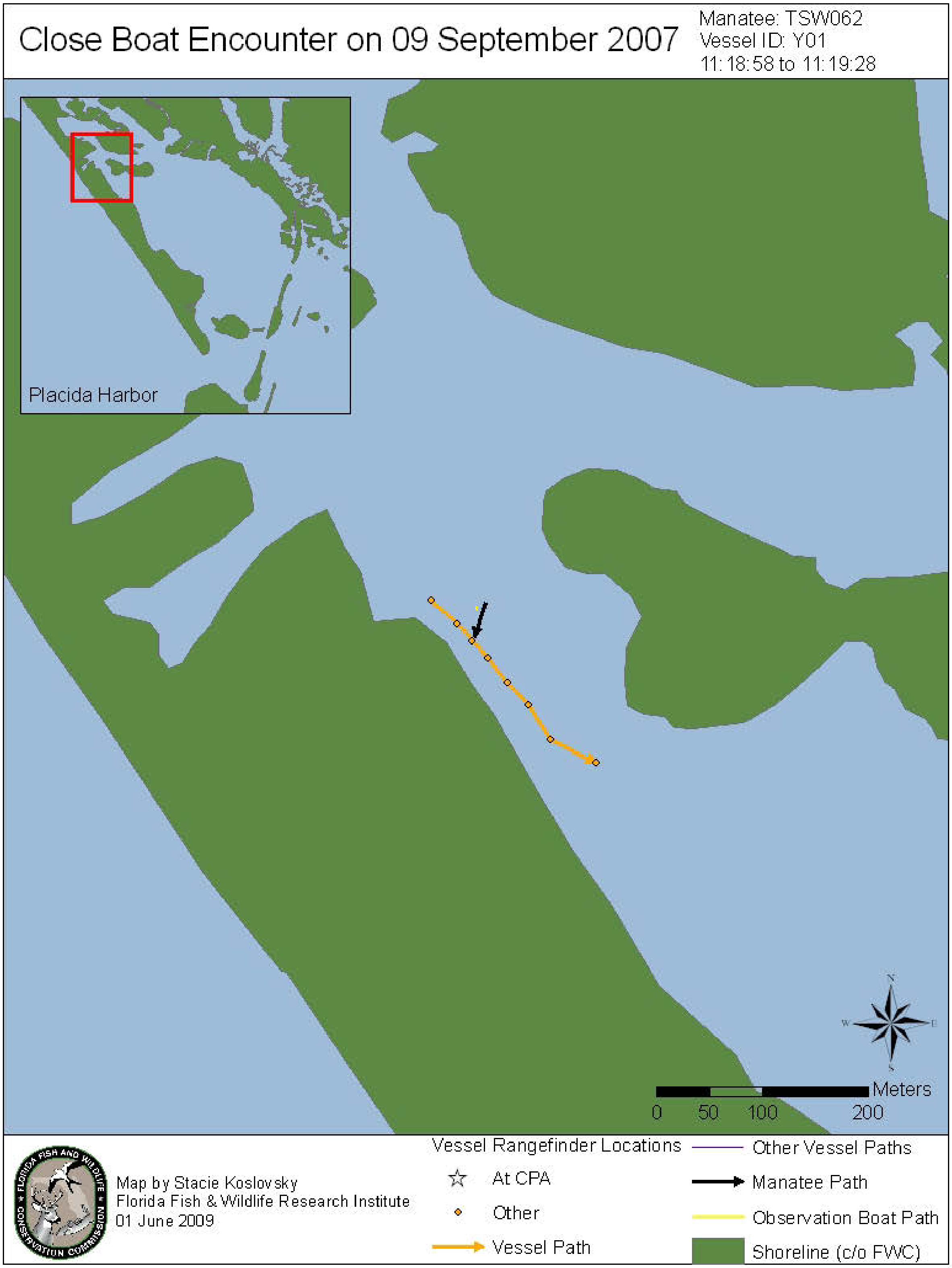


Figure 31. Map of a manatee-boat interaction in Placida Harbor on 9 September 2007, showing the movement paths of manatee TSW062, the observation boat, and a planing open fisherman boat over a 0.5-minute time period. This matches DTAG data in Figure 25.

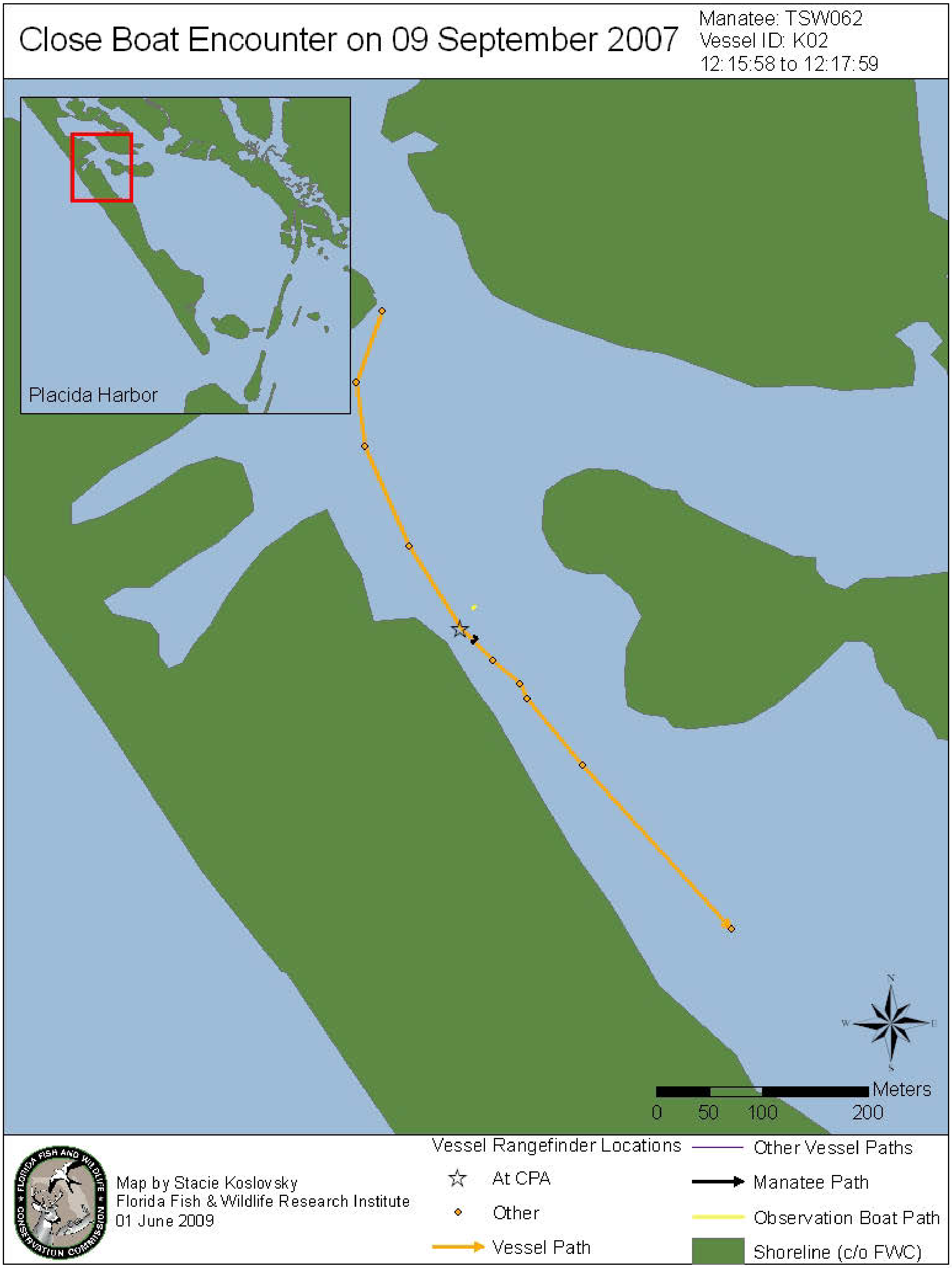


Figure 32. Map of a manatee-boat interaction in Placida Harbor on 9 September 2007, showing the movement paths of manatee TSW062, the observation boat, and a plowing open fisherman boat over a 2-minute time period. This matches DTAG data in Figure 26.

APPENDICES

Appendix 1. Variable definitions and data sheets used in field data collection. All field data sheets used in the field can be found at the end of this appendix, including samples of filled in data sheets.

Definitions (variable names are consistent between data sheets)

<u>dTag Study Field Log</u>

Date: The date that the field data were collected.

Observers: First initial and last name of all crew members present aboard the observation boat.

Location: A general description of the location, including the name of the water body, where most of the manatee follows occurred for that day.

Total Field Time: The time when we left and returned to the dock, in local time (most often EDT).

Aircraft: The type of aircraft used for video focal follows on that field day. Generally, this field is blank because that information was not necessarily relayed from the aircraft to the observation boat.

Low Tide: Height (feet) and time (local time) of low tide according to predicted tide charts for the location of the focal follow.

High Tide: Height (feet) and time (local time) of high tide according to predicted tide charts for the location of the focal follow.

Manatee ID #1 and Manatee ID #2: The identification number assigned to the individual manatee (e.g. TSW055) that was followed during the day. If only one individual was followed on that field day, the Manatee ID #2 and associated fields are blank.

Manatee Name: The nickname assigned to the individual manatee. This field is typically blank because nicknames were assigned toward the end of the field season, after a verification process to check for previous identifiers.

Boat time(s): Start and stop times (local time) of focal follows for the manatee indicated by the preceding Manatee ID. If the observation boat switched between two focal manatees multiple times on one day, the start and stop times for each is noted in relation to their manatee ID and breaks are noted with semicolons.

Aerial time(s): Start and stop times (local time) of aerial follows for the indicated manatee. Because the observation boat crew was focused on field data collection, this is often not noted.

Comments: Interesting observations or boat IDs that could be important for future analysis of the data collected during the field day.

Environmental: Field conditions of the location during the focal follow(s). See the methods portion of the report for a specific description of how the data were collected.

Observation Boat Engine Activity: A log that keeps track of what time (local time) the engine or trolling motor is turned on or off. For example, if the engine was turned on, the time was noted and E was circled. When the engine was turned off, the time was noted and Off was circled.

Manatee Surface Behavior, Activity, and Habitat Sheet

Manatee ID: The identification number assigned to the individual manatee (e.g. TSW055) to whom these data apply.

Manatee Name: The nickname assigned to the individual manatee. This field is typically blank because nicknames were assigned toward the end of the field season, after a verification process to check for previous identifiers.

Recorder: First initial and last name of the crew member(s) recording information on this data sheet.

Date: The date that the field data were collected.

Start and End Time: The time when we began and finished collecting this data, in local time (most often EDT).

Location: A general description of the location, including the name of the water body, during the times that manatee's behavior, activity, and habitat were recorded.

Comments: Interesting observations that could be important for future analysis of the data collected during the field day.

Habitat: A general description of the habitat during the times the manatee's behavior, activity, and habitat were recorded.

Time: The time (local standard) at which the particular activity or surfacing event occurred.

N: The manatee's nose broke the surface of the water.

B: The manatee's back (area from behind the head and before the fluke) was at the surface of the water.

T: The manatee's tail was at the surface of the water.

Activity: Each time a change in activity was observed, the time and new activity was noted. Activities were: travel, socialize, rest, feed, accelerate, human interaction, nurse, drink, mill, unknown, or other

BT: The type of bottom habitat at the time the time noted. Bottom types were: vegetated, bare, or unknown.

Ch?: The contour of the bottom habitat at the time noted. Contours included: channel, edge of a channel, marina, canal, edge of a canal, or none of the above.

Total # of Tm: The total number of manatees (including focal manatee) within 200 m of the focal manatee.

# of Calves: The total number of calves (including focal manatee) within 200 m of the focal manatee.

Depth @ Tm: Either a precise measurement of depth at the focal manatee (in feet) or an estimated range of the depth (bin): 0-3, 3-6, or >6 feet.

<u>Boat Attributes Sheet</u>

Date: The date that the field data were collected.

Location: A general description of the location, including the name of the water body, where the data were recorded.

Page: The page number for this datasheet of the total number of similar datasheets.

Manatee ID/ Name: The identification number assigned to the individual manatee (e.g. TSW055) to whom these data apply and/ or the nickname assigned to the individual manatee.

Recorder: First initial and last name of the crew member recording the data.

Time: The time (local standard) at which the particular boat passed. Due to the volume of boat traffic, not every time was noted; however, we tried to have at least one time noted on each data sheet to verify the time documented by the rangefinder way point.

TM LOC?: If the rangefinder waypoint is assigned to the manatee instead of a passing boat, circle Y. Waypoints of the manatee were used to fill in holes in the GPS track (see description in methods).

Boat ID: An alphanumeric identifier (e.g. A01, G05, X12) assigned to the boat passing by the focal manatee.

WYPT: The number of the waypoint taken using the rangefinder.

CPA?: If the waypoint was at the boat's closest point of approach, circle Y.

Speed Class: The general description of the speed of the boat passing by the focal manatee based on those adapted by Gorzelany (1996, 2000) from the Florida Administrative Code 68C-22.

0=neutral: boat is not moving under power of engine

1=idle/slow: the minimum speed that vessel will maintain steerage (idle) up to the speed at which the boat is fully off plane and settled in the water (slow); very little water is displaced by the boat and wake is minimal

2=plow: intermediate between slow and planning speeds; the boat is at an angle in the water such that the bow is higher than the stern and a large amount of water is displaced so that the boat "plows" through the water

3=plane: the boat is operating at a high enough speed so that it rises partially up out of the water with the bow and stern at equal level.

Boat Type: Based on those described by Gorzelany (1996, 1998)

Small Flats (SF) = A small, open skiff or johnboat that is operated from the stern and use a tiller for steerage.

Yacht (Y) = A vessel with a large enclosed space, such as a cabin, and with reduced deck space, generally noted by small windows in the hull.

Sailboat (S) = A vessel that is propelled at least partly by a sail.

PWC (J) = A jet ski (personal watercraft).

Fisherman (F) = A vessel with multiple tiers, outfitted and mostly suitable for offshore fishing.

Pontoon (P) = A vessel in which the deck sits atop of a pair of pontoons (generally aluminum).

Cruiser (C) = A vessel in which the steering console is to the left or right of the center of the boat, often has a windshield.

Open fisherman (OF) = A vessel with a steering console positioned in the center and open areas with no significant enclosed space.

Racer (R) = A vessel with a greatly elongated bow and a small open sitting in the rear of the vessel, such as Scarabs® and cigarette boats.

SIZE CLASS: The length of the boat from bow to stern.

15 = less than 16 feet,

16 = 16-25 feet

26 = 26-39 feet,

40 = greater than 40 feet.

ENG TYPE: The stroke-type of the engine (4-stroke or 2-stroke)

ENG: Type of engine on the boat.

In: The engine is mounted within the hull of the boat (inboard).

Out: The engine is mounted on the outside of the hull of the boat (outboard).

Jet: The watercraft is propelled by water ejected from the stern; no propeller.

# of ENG: The number of outboard engines mounted on the boat.

HP: The horse power of the engine.

Comments: Interesting observations that could be important for future analysis of the data collected during the field day.

Manatee Reaction Sheet

Date: The date that the field data were collected.

Location: A general description of the location, including the name of the water body, where the data were recorded.

Page: The page number for this datasheet of the total number of similar datasheets.

Manatee ID/ Name: The identification number assigned to the individual manatee (e.g. TSW055) to whom these data apply and/ or the nickname assigned to the individual manatee.

Recorder: First initial and last name of the crew member recording the data.

Time: The time (local standard) at which the particular boat passed and the observations were recorded.

Boat ID: An alphanumeric identifier (e.g. A01, G05, X12) assigned to the boat passing by the focal manatee.

CPA?: If the data were recorded at the boat's closest point of approach, circle Y. Ideally, each of these observations occurred at the CPA.

Boat to Tm Dist (m): The estimated distance between the focal manatee and boat (in meters) at the time that the data were recorded.

Pre ACT: The focal manatee's activity before the target boat's closest point of approach.

Post ACT: The focal manatee's activity after the target boat's closest point of approach.

BT: The type of bottom habitat at the time the time noted. Bottom types were: vegetated, bare, or unknown.

Ch?: The contour of the bottom habitat at the time noted. Contours included: channel, edge of a channel, marina, canal, edge of a canal, or none of the above.

Total # of Tm: The total number of manatees (including focal manatee) within 200 m of the focal manatee.

# of Calves: The total number of calves within 200 m of the focal manatee.

Depth @ Tm: Either a precise measurement of depth at the focal manatee (in feet) or an estimated range of the depth (bin): 0-3, 3-6, or >6 feet.

Reaction Mobility: Changes in movement of the manatee.

0 = no change in the manatee's mobility

\+ = an increase in mobility, such as a change from resting to traveling

\- = a decrease in mobility, such as a change from traveling to resting

U = unknown

Speed Change: Change in rate of movement of the manatee.

0 = no change in the manatee’s speed

+ = an increase in the manatee’s speed

- = a decrease in the manatee’s speed

U = unknown.

Heading Change: Change in direction or orientation of the manatee.

0 = the manatee did not change its heading

+ = the manatee changed its heading towards the target boat

- = the manatee changed its heading away from the target boat

U = unknown.

Move to Channel: Change in location of the manatee in relation to nearby channels.

0 = the manatee did not move towards the nearest channel

+ = the manatee move towards the nearest channel

- = the manatee moved away from the nearest channel

N/A = not applicable because no channel was present

U = unknown.

Comments: Interesting observations that could be important for future analysis of the data collected during the field day.

dTag Study Field Log

Date: ______________ 2008 **Observers:** ____

Location: ______________________________ **Total Field Time:** ________ - ________

Observation Vessel: _________________________ **Engine**: _______________

Aircraft: _______________ **Low Tide:** _____**ft** ____**:**____ **High Tide:** _____**ft** ____**:**____

Manatee ID#1: __________________ **Manatee Name:** __________________

Boat time(s): ______________________________________ **Total time:** _________

Aerial time(s): ______________________________________ **Total time:** _________

Manatee ID#2: __________________ **Manatee Name:** __________________

Boat time(s): ______________________________________ **Total time:** _________

Aerial time(s): ______________________________________ **Total time:** _________

Comments: ____

ENVIRONMENTAL (record hourly or when conditions change)

Time: ________ **Waypt. #:** ________ **Location: N** _____________ **W** _____________

Wind: _____ kts_____ **Sea State**: _____ **Water Temp:** ____ °C **Air Temp:** ____ °C

Secchi: ____ m ft **Salinity:** ____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: ________ **Waypt. #:** ________ **Location: N** _____________ **W** _____________

Wind: _____ kts_____ **Sea State**: _____ **Water Temp:** ____ °C **Air Temp:** ____ °C

Secchi: ____ m ft **Salinity:** ____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: ________ **Waypt. #:** ________ **Location: N** _____________ **W** _____________

Wind: _____ kts_____ **Sea State**: _____ **Water Temp:** ____ °C **Air Temp:** ____ °C

Secchi: ____ m ft **Salinity:** ____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

OBSERVATION BOAT ENGINE ACTIVITY

Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**

No engine=Off Engine (main)=E Troller=TR

Manatee ID(s) ________________________________ Date ________________ 2007 Page _____ of _____

Time: __________ **Waypt. #:** __________ **Location: N** _________________ **W** _________________

Wind: _____ kts_____ **Sea State**: ______ **Water Temp:** _____ °C **Air Temp:** ____ °C

Secchi: _____ m ft **Salinity:** _____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: __________ **Waypt. #:** __________ **Location: N** _________________ **W** _________________

Wind: _____ kts_____ **Sea State**: ______ **Water Temp:** _____ °C **Air Temp:** ____ °C

Secchi: _____ m ft **Salinity:** _____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: __________ **Waypt. #:** __________ **Location: N** _________________ **W** _________________

Wind: _____ kts_____ **Sea State**: ______ **Water Temp:** _____ °C **Air Temp:** ____ °C

Secchi: _____ m ft **Salinity:** _____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: __________ **Waypt. #:** __________ **Location: N** _________________ **W** _________________

Wind: _____ kts_____ **Sea State**: ______ **Water Temp:** _____ °C **Air Temp:** ____ °C

Secchi: _____ m ft **Salinity:** _____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Time: __________ **Waypt. #:** __________ **Location: N** _________________ **W** _________________

Wind: _____ kts_____ **Sea State**: ______ **Water Temp:** _____ °C **Air Temp:** ____ °C

Secchi: _____ m ft **Salinity:** _____ ppt **Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain**

Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**
Off E TR	**Off E TR**	**Off E TR**	**Off E TR**	**Off E TR**

No engine=Off Engine (main)=E Troller=TR

dTag Study Field Log

SEA STATE SCALE

Sea State	Description	Wind speed	Water Surface Conditions
0	Calm	No Wind	Sea smooth and mirror-like
1	Light air	1 to 5 kts	Scale-like ripples or small wavelets that do not break; no foam crests
2	Light breeze	6 to 10 kts	Large wavelets; some crests begin to break; occasional white foam crests
3	Moderate breeze	11 to 15 kts	Small waves; fairly frequent white foam crests
4	Moderate wind	16 to 20 kts	Moderate waves, taking a more pronounced long form; many white foam crests; there may be some spray
5+	Heavy wind	>20 kts	Large waves with foam crests, spray, & standing foam

No engine=Off   Engine (main)=E   Troller=TR

Page ____ of ____

Manatee Surface Behavior, Activity, and Habitat Sheet: dTag Study

Manatee ID: ______________ **Manatee Name:** ________________ **Recorder:** ________________________

Date: ____________________ 2007 **Start Time:** ____________ **End Time:** ____________

Location: ________________________________ **Habitat:** ____

Comments: ____

Time
N B T
N B T
N B T
N B T
N B T
N B T
N B T
N B T
N B T
N B T
N B T

Time	Activity	BT	Ch?	Total # of Tm	# of Calves	Depth @ Tm (bin)	(ft)	Comments
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		
						0-3 3-6 >6		

ACTIVITY: T=travel S=socialize R=rest F=feed A=Accelerate H=human interaction N=nurse D=drink C=cavort M=mill U=unknown O=other
BT=BOTTOM TYPE: V=vegetation B=bare U=unknown SURFACING N=Nose B=Back T=Tail
Ch?: Ch=channel ChE=channel edge M=marina Ca=canal CaE=canal edge N=None of the above

If found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

SPEED CLASS
0=neutral, 1=idle/slow
2=plow, 3=plane

SIZE
15=<16
16=<26
26<=40
40>40

TYPE: SF=small flats
Y=yacht S=sailboat
J=PWC F=fisherman
P=pontoon C=cruiser
OF=openfish R=racer

Date: ____________________________
Location: __________________________
Page _____of_____
Manatee ID/Name: ________________
Recorder: _________________________

		REQUIRED					BOAT					
TIME	TM LOC ?	BOAT ID	WYPT	CPA ?	SPEED CLASS	BOAT TYPE	SIZE CLASS	ENG TYPE	ENG	# of ENG	HP	COMMENTS
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y			Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			

If found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

REACTION:
0=No change
+=R→T, toward boat,
↑ speed, toward Ch
-=T→R, away boat
↓ speed, away Ch

ACTIVITY
T=travel S=socialize R=rest
F=feed A=Accelerate N=nurse
H=human interaction D=drink
U=unknown C=cavort M=mill

BT=BOTTOM TYPE
V=vegetation B=bare
U=unknown

Ch?
Ch=channel ChE=channel edge
Ca=canal CaE=canal edge
M=marina N=None of the above

Date: ______________________________
Location: ____________________________
Page _____of_____
Manatee ID/Name: ____________________
Recorder: ___________________________

				ACTIVITY AND HABITAT								MANATEE REACTION TO BOAT				
TIME	BOAT ID	CPA ?	Boat to Tm Dist (m)	Pre ACT	Post ACT	BT	Ch?	Total # Tm	# of Calves	Depth @ Tm (bin)	(ft)	Reaction Mobility	Speed Change	Heading Change	Move to Channel	COMMENTS
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						
		Y	0 <10 <50 >50							0-3 3-6 >6						

If found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

dTag Study Field Log

Date: 1Sep 2007 **Observers:** C Deutsch M Barlas A Rycyk K DiSalvo J Johnson

Location: LemonBay **Total Field Time:** 8:31 - 17;35

Observation Vessel: KeyWest L'il Easy **Engine:** Yamaha 200HP 2stroke

Aircraft: ______ **Low Tide:** 0.24 ft 11 : 14 **High Tide:** 1.25 ft 17 : 29

Manatee ID#1: TSW061 **Manatee Name:** ______

Boat time(s): 0903 – 12:09 ; 15:14 – 17:04 **Total time:** ______

Aerial time(s): ______ **Total time:** ______

Manatee ID#2: TSW060 **Manatee Name:** Repita

Boat time(s): 12:34:30 – 14:33:25 **Total time:** ______

Aerial time(s): ______ **Total time:** ______

Comments: Both manatees traveled along ICW with lots of vessel traffic. Both together in ICW for a while.

ENVIRONMENTAL

(record hourly or when conditions change)

Time: 0912 **Waypt. #:** 39 **Location:** N 26.96683 W 82.38026
Wind: 4.7 kts SSW **Sea State:** 1 **Water Temp:** 30.4 °C **Air Temp:** 30.2 °C
Secchi: <2 m [✓ ft] **Salinity:** 34.7 ppt Sunny - [✓ Partly Cloudy] - Mostly Cloudy - Overcast - Rain

Time: ______ **Waypt. #:** 40 **Location:** N ______ W ______
Wind: ______ kts ______ **Sea State:** ______ **Water Temp:** ______ °C **Air Temp:** ______ °C
Secchi: ______ m ft **Salinity:** ______ ppt Sunny - Partly Cloudy - Mostly Cloudy - Overcast - Rain

crabtrap that manatee passed directly next to.

Time: 1516 **Waypt. #:** 41 **Location:** N 26.95526 W 82.37457
Wind: 6 kts SW **Sea State:** 1 **Water Temp:** 32.7 [✓ °C] **Air Temp:** 34.7 [✓ °C]
Secchi: 4.8 m [✓ ft] **Salinity:** 34.9 ppt Sunny - [✓ Partly Cloudy] - Mostly Cloudy - Overcast - Rain

OBSERVATION BOAT ENGINE ACTIVITY

8:31 Off [✓ E] TR	aprox 9:34:46 [✓ Off] E TR	11:19:22 Off [✓ E] TR	13:4446 Off [✓ E] TR	14:21:11 [✓ Off] E TR
=0908 [✓ Off] E TR	9:35:10 Off E [✓ TR]	13:25:19 [✓ Off] E TR	14:00:00 [✓ Off] E TR	14:25:10 Off [✓ E] TR
~0927 Off E [✓ TR]	9:38:15 [✓ Off] E TR	13:36:40 Off [✓ E] TR	14:02:11 Off [✓ E] TR	15:14:03 [✓ Off] E TR Anchor TSW061
09:27:27 [✓ Off] E TR	11:16:30 Off E [✓ TR]	13:39:10 [✓ Off] E TR	14:04:10 [✓ Off] E TR	17:08:36 Off [✓ E] TR
09:28:07 Off E [✓ TR]	11:18:04 [✓ Off] E TR	13:39:50 Off [✓ E] TR	14:14:40 Off [✓ E] TR	Off E TR
9:33:52 Off E [✓ TR]	11:18:10 Off E [✓ TR]	13:[illegible] [✓ Off] E TR	14:15:19 [✓ Off] E TR	Off E TR

Weather for TSW060: Partly Cloudy, SS=1, Lt Wind (~5kt) (general info)

No engine=Off Engine (main)=E Troll~~er~~ing=TR

Page 1 2

Manatee Surface Behavior, Activity, and Habitat Sheet: dTag Study

Manatee ID: TSW061 **Manatee Name:** ______ **Recorder:** M Ballas
Date: 1 Sept 2007 **Start Time:** 9:46:00 **End Time:** 11:13
Location: Lemon Bay, W side N of Indian Mound Boat Ramp **Habitat:** Sandy bottom w/ syringodium manatee is along edge of unmarked channel through flats
Comments: ______

Time
094800 [✓ N] B T
094950 [✓ N] B T
0955:18 [✓ N] B T
10:00:02 [✓ N] B T
10:00:36 N B [✓ T]
10:01:45 [✓ N] B T
10:05:38 [✓ N] B T
10:09:38 [✓ N] B T
10:14:24 [✓ N] B T
10:19:17 [✓ N] B T
10:26:13 [✓ N] B T

Time	Activity	BT	Ch?	Total # of Tm	# of Calves	Depth @ Tm (bin)	(ft)	Comments
0946	R	V	N	2	0	0-3 [✓ 3-6] >6		TSW059 is socializing with 6 others nearby
10:00:25	T	V	N	2	0	0-3 [✓ 3-6] >6		Moving toward other grp dive at surface @ 10:00:36
10:05:10	R	V	N	2	0	0-3 [✓ 3-6] >6		did not make it to other grp.
10:10:28	S	V	N	2	0	0-3 [✓ 3-6] >6		
10:10:59	R	V	N	2	0	0-3 [✓ 3-6] >6		1 w/TSW061
10:38:15	R	V	N	4	1	0-3 [✓ 3-6] >6		our manatee did nothing; a different manatee spook at ± 40 fish who jumped out of the water which spooked the mating herd and
—	—	—	—	—	—	0-3 3-6 >6	-	those manatees splashed, dove, surfaced 30 seconds later and went back to mating
10:44:05	T	V	N	4	1	0-3 [✓ 3-6] >6		Moving away from mating herd which is moving closer
10:45:20	R	V	N	4	1	0-3 [✓ 3-6] >6		grp of 5 mating is now within 20m of our group of 4
10:59:10	S	V	N	9	1	0-3 [✓ 3-6] >6		
11:02:06	T	V	N	9	1	0-3 [✓ 3-6] >6		moving away from mating grp w/ mom, calf

ACTIVITY: T=travel S=socialize R=rest F=feed A=Accelerate H=human interaction N=nurse D=drink C=cavort M=mill U=unknown O=other
BT=BOTTOM TYPE: V=vegetation B=bare U=unknown SURFACING N=Nose B=Back T=Tail
Ch?: Ch=channel ChE=channel edge M=marina Ca=canal CaE=canal edge N=None of the above

If found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

SPEED CLASS
0=neutral 1=idle/slow
2=plow 3=plane

SIZE
15=<16
16=<26
26<=40
40>40

TYPE:
Y=yacht
J=PWC
P=pontoon
OF=openfish

SF=small flats
S=sailboat
F=fisherman
C=cruiser
R=racer

Date: 5-18-08
Location: Peace Harbor
Page 4 of 13
Manatee ID/Name: tsw068
Recorder: JCOPE

		REQUIRED					BOAT					
TIME	TM LOC ?	BOAT ID	WYPT	CPA ?	SPEED CLASS	BOAT TYPE	SIZE CLASS	ENG TYPE	ENG	# of ENG	HP	COMMENTS
	Y	E	73	[✓ Y]	0 1 2 [✓ 3]	F	15 [✓ 16] 26 40	[✓ 4] 2	IN [✓ OUT] JET	1	115	
	Y	E	74	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
	Y	E	75	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
10:24	Y	E	76	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
	Y	E	77	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
	Y	E	78	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
	Y	E	79	Y	0 1 2 [✓ 3]		15 16 26 40	4 2	IN OUT JET			
10:26	[✓ Y]		80	Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
10:30	[✓ Y]		82	Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			OOS boatpass at ≈ 2.7 mph
10:36	[✓ Y]		85	Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
10:46	Y	F	91	Y	0 1 2 [✓ 3]	C	15 [✓ 16] 26 40	4 2	IN [✓ OUT] JET	1	200	
	[✓ Y]		92	Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			
	Y	F	93	Y	0 1 2 3		15 16 26 40	4 2	IN OUT JET			

If found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

REACTION:
0=No change
+=R→T, toward boat, ↑ speed, toward Ch
-=T→R, away boat ↓ speed, away Ch

ACTIVITY
T=travel S=socialize R=rest
F=feed A=Accelerate N=nurse
H=human interaction D=drink
U=unknown C=cavort M=mill

BT=BOTTOM TYPE
V=vegetation B=bare
U=unknown

Ch?
Ch=channel ChE=channel edge
Ca=canal CaE=canal edge
M=marina N=None of the above

Date: 24 May 2008
Location: Gasparilla Pass
Page 1 of 8
Manatee ID/Name: TJW06 9
Recorder: C. Deutsch

Tm resting w/ another Tm ~25 m offshore, S side of Gasp. Pass from shore

TIME	BOAT ID	CPA ?	Boat to Tm Dist (m)	Pre ACT	Post ACT	BT	Ch?	Total # Tm	# of Calves	Depth @ Tm (bin)	(ft)	Reaction Mobility	Speed Change	Heading Change	Move to Channel	COMMENTS
				ACTIVITY AND HABITAT								MANATEE REACTION TO BOAT				
1241:54	A	[✓ Y]	0 <10 <50 [✓ >50]	R	R	B	N	1	0	0-3 [✓ 3-6] >6		0	0	N/A	0	~~12404338.txt~~
1242:33	B	[✓ Y]	0 <10 <50 [✓ >50]	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	
1245:26	C	[✓ Y]	0 <10 [✓ <50] >50	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	~17 m from Tm at CPA
1248:35	D	[✓ Y]	0 <10 [✓ <50] >50	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	Jetski
1250:40	E	Y	0 <10 <50 [✓ >50]	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	Moved GPS unit 4 m to NW to Rt position at 1250 Echo (Magic) ~80 m from manatee
1251:51	F	[✓ Y]	0 <10 <50 [✓ >50]	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	Jetski again
1253:43	E	[✓ Y]	0 <10 <50 [✓ >50]	R	R	B	N		0	0-3 [✓ 3-6] >6		0	0	N/A	0	Tm still 33 m away from RO,
1255:29	G	[✓ Y]	0 <10 <50 [✓ >50]	R	R	B	N	↓	0	0-3 [✓ 3-6] >6		0	0	N/A	0	Tag submerged upon approach & surfaced soon after pass. Boat 80 m from T.m.
1257:57	H	Y	0 <10 <50 >50	?	?	B	N	↓	0	0-3 [✓ 3-6] >6		?	?	?	?	Approx CPA T.m underwater - response unknown.

found, please call: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute: 727-896-8626 (Marine Mammals)

Appendix 2. Acoustic auditing protocol.

To open an audit (example ‘tag’ = ‘tm07_244a’; cue = time (seconds) to start audit at):

```
R=loadaudit(‘tag’)
R=tagaudit(‘tag’,cue,R)
```

OPERATION

Type or click on the display for the following functions:

- type 'f' to go to the next block
- type 'b' to go to the previous block
- click on the graph to get the time cue, depth, time-to-last and frequency of an event. Time-to-last is the elapsed time between the current click point and the point last clicked. Results display in the matlab command window.
- type 's' to select the current segment and add it to the audit. You will be prompted to enter a sound type on the matlab command window.
- type 'l' to select the current cursor position and add it to the audit as a 0-length event. You will be prompted to enter a sound type on the matlab command window.
- type 'x' to delete the audit entry at the cursor position. If there is no audit entry at the cursor, nothing happens. If there is more than one audit entry overlapping the cursor, one will be deleted (the first one encountered in the audit structure).
- type 'p' to play the displayed sound segment through the computer speaker/headphone jack.
- type 'q' or press the right hand mouse button to finish auditing.

To save an audit:

Use the ‘q’ operation to close out the audit window

```
Saveaudit(‘tag’,R)
```

An ‘s’ segment is when you want to create a record for an event that has a duration, this will only be used for vocalizations. When a vocalization is found click where the vocalization begins, then where the vocalization ends and hit the ‘s’ key. You then type the event (voc), contour code (see codes), b or n (b if the vocalization was during boat noise and n if it was not), and press ‘enter’. An ‘l’ event has no duration and is used to mark when an audit has started or stopped, boat noise has started or stopped, there is a peak in sound level for a boat passing (sound level corresponds to the color intensity on the spectrogram), and when a chewing bout has started or stopped (a bout is when chewing does not stop for more than 5 seconds). An ‘l’ event is created by clicking once at the time of the event and hitting ‘l’. Then type the event description using the codes below and press ‘enter’. When you press ‘enter’ after entering text the audit window will be brought to the front again and you can resume auditing.

Audits are automatically saved to the external hard drive in the tag/data/audit folder. The audits are saved as txt files and look like this:

```
32828.1     0.000   start audit

32831.9     0.000   sboat
```

```
32925.1     0.000   pboat
32931.7     0.089   voc u b
32935.7     0.115   voc u b
32962.6     0.000   eboat
33000.0     0.000 schew
33100.0     0.000 echew
33237.0     0.000   end audit
```

If you need to change anything in the audit files you can open it in wordpad and change it by hand and save (you can alter them in matlab too, but that can be less user friendly). The header for the text file would be:

Time (seconds)	Duration (seconds)	**Event**	**Contour**	Boat noise? (b/n)	Comments

The blue fields are only for vocalizations, and the **bold** fields are described in the following tables. Underlined fields are entered by the auditor after selecting 's' or 'l' and are separated by a space. Time and duration is automatically recorded by matlab and an acoustic clip of any 's' segment is automatically created. Boat noise, chewing, and vocalizations are identified by both listening and visually examining the spectrogram.

Event	Description
startaudit	when you start an auditing session
endaudit	when you end an auditing session
voc	manatee vocalization
sboat	when boat noise starts
pboat	peak in boat intensity, if one is identifiable
eboat	when boat noise ends
schew	when a chewing bout starts
echew	when a chewing bout ends

Contour Code	Description
F	flat, unmodulated
H	hill-shaped, increases in frequency and then decreases in frequency
U	U-shaped, decreases in frequency and then increases in frequency
D	decreases in frequency
I	increases in frequency
O	other

Identifying manatee Vocalizations

Manatee vocalizations sound like chirps or squeaks and contain multiple harmonics. Vocalization durations are 118-900 ms, with an average of 271 ms. The vocalizations can have frequencies as low as 600 Hz and as high as 18 kHz. The fundamental frequency (lowest band) is typically between 1.75 and 3.90 kHz. The shape, also known as contour, of the vocalization varies and can be categorized into one of 5 categories: flat, hill-shaped, U-shaped, decreasing in frequency, and increasing in frequency (see examples below).

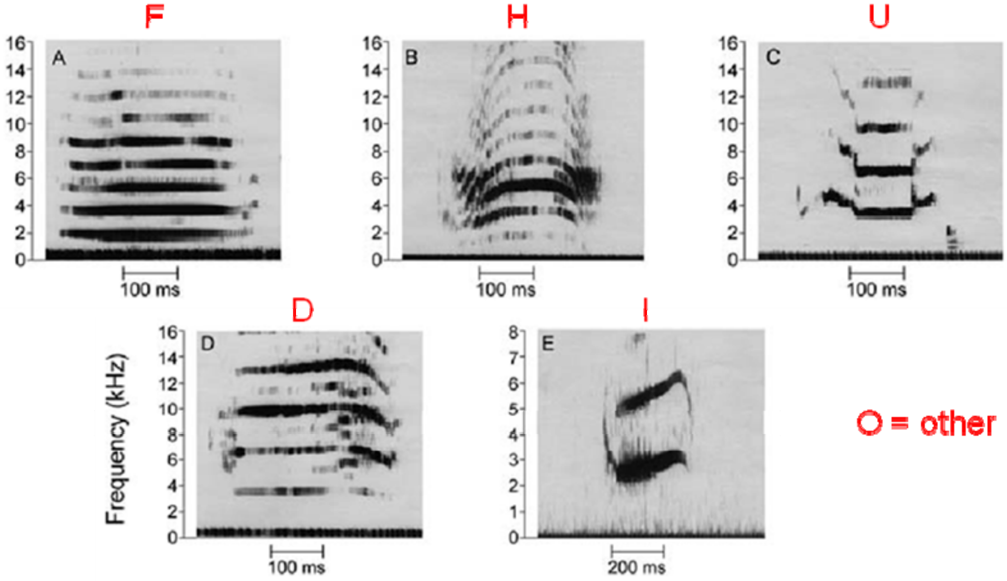


Fig. 2.—Contour categories for Florida manatee (*Trichechus manatus latirostris*) calls. A) Flat, unmodulated; B) hill-shaped (begins at low frequency, rises, then descends in frequency); C) U-shaped (begins at high frequency, descends, then rises); D) decreasing in frequency; E) increasing in frequency; F–I) complex modulations.

Figure from O'Shea & Poché, 2006.