MANATEE BEHAVIORAL RESPONSES TO VESSEL APPROACHES:
Results of Digital Acoustic Data Logger Tagging of Manatees in Belize

FLORIDA FISH AND WILDLIFE CONSERVATION
COMMISSION CONTRACT 01078
DRAFT REPORT

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30 September 2002

Mote Marine Laboratory Technical Report Number 847
Executive Summary: Manatee Behavioral Responses to Vessel Approaches: Results of Digital Acoustic Data Logger Tagging of Manatees in Belize

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The West Indian manatee, *Trichechus manatus*, faces a variety of serious threats from humans, including hunting, habitat loss, entanglement in fishing gear, entrapment in water control structures, and collisions with boats. These threats vary in intensity from one location to the next, and over time. Even where manatees are subject to seemingly strong protection measures, rates of manatee mortality and serious injury from human activities can be exceedingly high.

Many issues remain to be resolved if manatee mortality, serious injury, and disturbance from boats are to be reduced. One of the most important issues is the determination of how much time manatees have from detection of vessels to impact. Observations of manatees making significant behavioral changes in apparent response to approaching boats suggest that detection of vessels does occur. The fact that apparent responses occur at distances exceeding the possible visual range of the animals argues that acoustic cues are important for and used by manatees to detect and avoid oncoming boats. Thus, a critical step in the development of our understanding of manatee responses to boats should be to refine our knowledge of when manatees detect boats acoustically. In the current absence of field capabilities to directly measure detection through sensitive physiological measures such as auditory brainstem response, observations of consistent gross behavioral changes as vessels approach have been used as a surrogate measure of detection. It is understood that the behavioral observation approach has an inherent bias as the detectable response by the manatee occurs at an undetermined time following detection of a boat.
Developing technology provides the means to relate fine-scale behavioral changes to measures of received level of sound at the animal, thereby allowing researchers to detect behavioral changes earlier, at times more closely approaching actual acoustic detection. This has been made possible through the development of an attached digital data logger, the DTAG. The DTAG simultaneously records the sound(s) occurring at the animal and a number of physiological and behavioral signals (e.g., pitch, roll, compass heading, fluke strokes, vocalizations), making a very direct connection between sound and response.

During March 2001 and 2002 we deployed DTAGs on manatees in the quiet waters of Southern Lagoon, Belize, to test the utility of this technique for application in the more acoustically-complex waters of Florida. The results of our deployments of DTAGs demonstrate the potential value of the DTAG for collecting data of importance to manatee management. The DTAG provided the means to relate fine-scale behavioral changes to changes in a manatee’s acoustic environment. In each of the boat approach experiments conducted during 2001 and 2002, manatees appeared to respond to approaching vessels by changing or increasing their activity. Our DTAG data from 2001 suggested that under some circumstances reactions began at distances of about 160 m to 800 m (well in excess of the boat-manatee separation distances reported by previous behavioral studies). Our study provides additional support for the importance of acoustic cues to manatee detection of approaching vessels.

There are important implications for management, especially if these relatively long-distance acoustic detections are confirmed through additional studies. The problem of collisions between manatees and boats then becomes an issue of determining the animals’ response threshold under a variety of circumstances and either providing the animals with sufficient time to process the acoustic information they receive and to develop an appropriate response, or minimizing the potential damage from a vessel in the event of an inappropriate response. Either way, these results would indicate that minimizing boat speed in the vicinity of manatees would be an effective management strategy.
Our preliminary conclusions are based on a very small sample size of manatees’ responses to vessel approaches. Further confirmation and characterization of manatee responses are required. We believe that a larger sample size of DTAG deployments under carefully controlled conditions will make it possible to statistically analyze fine-scale behavioral responses to vessel approaches, looking closely at duration of response and the range and received sound level at which a manatee responds. Our field tests in 2001 and 2002 demonstrated that the electronics of the DTAG are well-fitted to the questions surrounding manatee behavioral and acoustic responses to boat approaches, and that this system would be appropriate for deployment in the acoustically-complex manatee habitats in Florida. Larger scale deployments depend upon the development of a reliable attachment/release system that eliminates the need for recapturing manatees. We made important strides in the development of the releasable belt during 2002, but more research and development are required before efficient DTAG deployments in Florida will be possible.
**Title of Project:** Manatee behavioral responses to vessel approaches: results of digital acoustic data logger tagging of manatees in Belize

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**Introduction**

The West Indian manatee, *Trichechus manatus*, inhabits the warm, coastal, marine and fresh water systems fringing the Caribbean Sea, Gulf of Mexico, and western Atlantic Ocean (Lefebvre et al. 2001). Within this range, these slow-moving, shallow-water animals face a variety of serious threats from humans, including hunting, habitat loss, entanglement in fishing gear, entrapment in water control structures, and collisions with boats. These threats may vary in intensity from one location to the next, and over time (O'Shea 1988). Even where manatees are subject to seemingly strong protective measures, rates of manatee mortality and serious injury from human activities can be exceedingly high (Reynolds 1999).

The Florida subspecies of the West Indian manatee, *Trichechus manatus latirostris*, ranges through the waters of Florida, sometimes venturing into other states along the Gulf and Atlantic coasts. The Florida manatee, more than any other subspecies, is faced with frequent
encounters with boats, sometimes leading to death or serious injury from collision impact or cuts from propellers (Ackeman et al. 1995, Wright et al. 1995). More than 864,000 vessels are registered within the state of Florida (Florida Department of Highway Safety and Motor Vehicles website: www.hsmv.state.fl.us/reports/facts_mv.html), and many other boats are brought to Florida waters each year by visitors.

**Manatee Mortality and Serious Injury from Boats**

On average, about 25% of documented manatee deaths each year are due to collisions with vessels (Ackeman et al. 1995, Wright et al. 1995). During 2000, at least 78 of 272 (28.6%) manatee deaths recorded in Florida were believed to have resulted from boats; to date in 2002 boat collisions account for about 32% of mortalities (T. Pitchford, Florida Fish and Wildlife Conservation Commission, pers. comm.). Deaths from boat strikes involve all age classes and occur year-round over much of the subspecies’ range (O’Shea 1988, 1995, Ackerman et al. 1995).

The number of documented mortalities is only a minimum estimate of the direct impact of boats on manatees. It does not include animals struck by vessels but not killed, or those killed but whose carcasses were not recovered or found. Many Florida manatees bear scars of multiple past collisions with boats; some of these injuries appear debilitating (O’Shea 1995). Of the 1,184 living individuals in the identification scar catalog that bear boat strike scars, 97% have scar patterns indicative of more than one strike (O’Shea et al. 2001). The Florida Marine Research Institute’s Marine Mammal Pathobiology Laboratory in St. Petersburg, Florida, has examined two carcasses with scar evidence of more than 50 past collisions (O’Shea et al. 2001;
S.A Rommel, Florida Fish and Wildlife Conservation Commission, pers. comm.). The long-term effects, both at the individual and population levels, of repeated serious injuries on manatee survivorship, reproduction, and quality of life remain to be evaluated.

Boats have apparently been a primary source of human-related manatee mortality in Florida waters since the 1950s or 1960s, with reports available of manatee deaths from boat strikes from as far back as 1943 (Hartman 1979; O'Shea 1988, 1995). In spite of the large numbers of injuries and deaths resulting from watercraft, few observations of collisions or manatee behavior in response to boat approaches have been recorded (Wright et al. 1995). In the absence of systematic observations of manatee-boat interactions, there has been much speculation about why manatees are struck by boats. In general, speculation revolves around the ability of manatees to detect or avoid approaching boats. Examples of these theories include:

- Manatees do not detect approaching boats in time to avoid them. Given the distances involved and limitations of vision in many of the habitats used by manatees, this has been interpreted as meaning that manatees are unable to adequately hear approaching boats.
  - Manatee normal hearing lacks sensitivity in the frequency range of boat engine acoustic emissions.
  - Manatee hearing is impaired.
- Hearing loss results from anthropogenic sources.
  - Manatees suffer short-term hearing loss, including temporary threshold shifts, from exposure to nearby boat noise, making them increasingly vulnerable to boat approaches.
- Manatees suffer ear damage and long-term hearing loss from noise in the environment, making them increasingly vulnerable to subsequent boat approaches.

- Hearing is impaired because of environmental features.
  - Noise from approaching vessels is masked by noise from other vessels or other human activities.
  - Transmission of noise from approaching boats through the environment is impaired as a function of water depth, physiography, substrate type, or vegetation.

- Manatees can detect approaching boats but do not or cannot respond “appropriately.”
  - Manatees detect vessels but cannot or do not react soon enough to be able to avoid them.
  - Manatees can detect boats but are unable to localize the direction of threatening vessel approaches, and therefore may not move in an appropriate manner to avoid collision.
    - Manatees lack anatomical abilities to localize sound sources with sufficient precision to determine the approach path of a vessel.
    - Simultaneous approaches by multiple vessels increase the level of difficulty for manatees to localize and evaluate threats.
  - Manatees are distracted by their own activities, such as participation in intensively socializing “mating herds.”
  - Manatees move inadvertently into the path of boats as they try to move to “safer” waters.
Increasing numbers of shallow draft vessels encounter manatees in waters where the animals cannot avoid them by diving beneath them.

Manatees simply do not interpret an approaching vessel as a threat and therefore make no attempt to avoid a collision.

To solve the problem of manatees being struck by boats, it is necessary to understand the factors that lead to collisions. The first question to address is whether manatees can detect approaching boats. Anatomical, physiological, and behavioral studies suggest that manatees should be capable of detecting approaching vessels, a fact borne out by field behavioral studies (Weigle et al. 1994, S.M Nowacek et al. 2000, 2001a). Table 1 summarizes most of the studies exploring both manatee hearing and sound production. Whereas there is some disparity in the results, most of the hearing studies indicate a range of best hearing between 5-20 kHz, a frequency range in which vessels common to Florida waters produce significant sound energy (Evans et al. 1992, Richardson et al. 1995). Using auditory evoked potentials Bullock et al. (1982) found that manatees are most sensitive to sounds ~1.5 kHz. Ketten et al. (1992) concluded from the anatomy of the manatee ear that the frequency of best hearing is slightly above 5 kHz, i.e. the cochlea is structured such that it is most sensitive to sounds just higher than 5 kHz. Popov and Supin (1990) and Klishin et al. (1990), using auditory evoked potentials, found the range of best hearing in an Amazonian manatee (T. inunguis) to be between 5-20 kHz and found some ultrasonic sensitivity up to 50 kHz. Behavioral audiograms developed for two manatees, conducted in a zoological park setting, suggest that manatees' best hearing is also in this range (Gerstein et al. 1999) but with a best hearing closer to ~16 kHz. These reported
auditory ranges are consistent with the range of sounds manatees are reported to produce (Schevill and Watkins 1965, Sonoda and Takemura 1973).

<table>
<thead>
<tr>
<th>Study</th>
<th>Range of Sounds Produced (kHz)</th>
<th>Best Auditory Range (kHz)</th>
<th>Maximum Auditory Range (kHz)†</th>
<th>Frequency of Best Hearing (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schevill &amp; Watkins (1965)</td>
<td>0.5 - 16</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Evans &amp; Herald (1970)*</td>
<td>6 - 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sonoda &amp; Takemura (1973)</td>
<td>1 - 8</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sousa-Lima et al. (2002)</td>
<td>1 - 16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bullock et al. (1982)†</td>
<td>1 - 8</td>
<td>0.75 - 35</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Kishin et al. (1990)†</td>
<td>5 - 20†</td>
<td>0.75 - 50</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Popov &amp; Supin (1990)†</td>
<td>5 - 20†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ketten et al. (1992)²</td>
<td></td>
<td></td>
<td>5 - 6</td>
<td></td>
</tr>
<tr>
<td>Gerstein et al. (1999)³</td>
<td>6 - 20</td>
<td>0.4 - 45</td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

Table 1. Reported ranges of sound production and hearing in manatees. The first three studies reported sound production and the latter five reported audition. *Sound production reported for *T. inunguis. †Hearing sensitivity within 50 dB of best sensitivity. Both of these reports indicate that auditory sensitivity is similar throughout the range of best hearing. Missing values indicate no data reported for a given study. Audition studies were conducted using three different methods: †auditory evoked potentials in response to sound stimuli; ‡measurement and comparison of anatomical structures; §behavioral response to sound stimuli.

The localization capabilities of manatees are unknown, but their inner ear structures imply that they lack directional hearing capabilities compared with most marine mammals (Ketten *et al.* 1992). The zygomatic process in manatees has been explored as a structure that could increase overall sensitivity and possibly aid in localization by acting as a low frequency sound channel (Ames *et al.* 2002).

Observations from the field can supplement information on detection and help to resolve discrepancies among laboratory studies. If manatees exhibit consistent changes in behavior as boats approach, then detection can be implied (direct determination of actual detection would require sensitive physiological measures such as auditory brainstem response – a difficult
measure to achieve under field conditions). Opportunistic observations of manatees in the presence of boats as well as the results of systematic studies of manatee-boat interactions suggest that at least some manatees respond to approaching boats.

Reynolds (1981) suggested from field observations that manatee hearing may be good, based on the facts that they vocalize, they appear to respond to such vocalizations over distances of about 60 m, and they react to numerous sounds including approaching motor boats. Reynolds (1978) reported that the sound of an approaching boat caused manatees to flee early in the morning, but later in the day they failed to react to it (i.e. indicating perhaps habituation or a decreasing ability or motivation to avoid boats).

During a 1993 pilot study involving observations from an airship during 16 vessel passes, Weigle et al. (1994) noted that manatees changed their behavior in apparent response to approaching boats operating at a variety of speeds. The animals’ general reaction was to move or remain below the water’s surface. Depending on their circumstances at the initiation of experimental approaches, individuals remained resting on the bottom in shallow water, slowly submerged tail-first, left the shallows and moved to deeper water, turned horizontally, moved into shallower waters, or made head-first dives. Distances at which the first detectable changes in behavior were noted ranged from 15 m to 99 m, averaging about 50 m regardless of boat speed or direction of approach. Subsequent detailed studies of manatee behavioral responses to boat approaches have been conducted by S.M. Nowacek et al. (2000) in Sarasota Bay, Florida using a video recording system suspended from a tethered airship (D.P. Nowacek et al. 2001a, S.M. Nowacek et al. in review). They found that nearly half of observed manatees responded to boats approaching or passing within 100 m, confirming several of the patterns reported by
Weigle et al. (1994), and noted that behavioral changes were most commonly detected when the vessels were at distances of about 25 m to 50 m. Due to the observation conditions, it was not possible to detect subtle changes in behavior that might have indicated actual detection of vessels at greater distances.

S.M. Nowacek et al. (2000, in review) reported that the most common response for a manatee in shallow water when a boat approached was to move toward or into deeper water (channels), increasing speed as necessary. This response may take the manatee into the path of the approaching vessel before it can reach water of sufficient depth to be able to move safely beneath the boat (Wells et al. 1999). S.M. Nowacek et al. (2000, in review) found that responses to boat approaches varied with the individual manatee. For changes in both swimming speed and orientation or movement toward or into the channel, the identity of the focal animal significantly affected whether the animal made a change in the given behavior – different individuals responded differently, at least initially. General and consistent patterns of response did not become evident until changes in behavior were considered within very limited approach distance categories. Differential responses among individuals could be attributed potentially to any of a number of factors, such as age, exposure to boats, reproductive state, hearing ability, or activity. However, these potential factors diminished in importance for approaches at close range since at these distances the animals began to demonstrate a uniform response: increased swimming speed and movement toward or into deeper water.

S.M. Nowacek et al. (2000; in review) also noted that habitat types of the manatee and the approaching boat significantly affected frequencies of behavioral change. Sound propagation
is typically poor in shallow water and manatees may have no way of clearly localizing the
direction from which a vessel is approaching. In many cases, multiple vessels may be
approaching from different directions, providing the potential for further acoustic confusion.
Manatees in deep water have more options for responding to approaching boats. In channels
they increased their swimming speed, changed their heading, and/or changed their swimming
depth, typically to depths in excess of the drafts of most of the vessels common to the area.

The occurrence of clear responses to approaching boats indicates that at least some
manatees are capable of detecting vessels approaching at a range of speeds. Most responses
occurred at distances that far exceeded visual range, as measured by secchi disk (S.M. Nowacek
et al. 2000), and likely exceed the visual capabilities of the manatees, suggesting that hearing is
the primary initial sensory mode involved in detection.

Given that detection occurs, we can focus on an important set of questions: 1) When can
manatees detect boats, under the best of circumstances? 2) Is this detection time sufficient to
allow avoidance? and 3) What factors adversely affect detection, thereby limiting response time?
Knowledge of how much time manatees have from detection to impact can lead to development
of appropriate mitigation measures. If the time is insufficient for an appropriate response by the
manatees due to: manatee sensory abilities, interference with these sensory abilities, response
capabilities, habitat features, or boat speed, then what actions can be taken to provide the animals
with additional time to respond? To date, protection measures in Florida have been based on
assumptions that the greatest threat from vessels derives from speed, resulting in the
establishment of boat speed zones in regions frequented by manatees. This approach is based on
premises that boats traveling at slow speed will collide with manatees at lower impact forces, and boat operators and manatees will have more time to avoid each other (O’Shea 1995).

**Manatee Disturbance by Boats**

Little information is available about the possible cumulative effects from repeated disruption of manatee activities by approaching boats. The potential for disturbance assumes that manatees detect and respond to boats. Based on studies involving other mammals, it would be reasonable to expect that manatees exhibit disturbance responses to human activities such as boating, and that these responses can have potentially important effects on individuals and populations. Research on terrestrial mammals such as deer, sheep, and elk has shown that these animals tend to move away from the source of the disturbance (Freddy et al. 1986, Tyler 1991, Cassirer et al. 1992), shift use of their home range (Dorrance et al. 1975, Schultz and Bailey 1978, Cassirer et al. 1992), alter their behavior or activity (Richens and Lavigne 1978; Freddy et al. 1986), or alter their social interactions (Patterson 1988).

A number of studies of disturbance responses of marine mammals have been conducted (see Richardson 1995 for a review). For example, bowhead whales (*Balaena mysticetus*) react strongly and consistently to approaching vessels by altering their normal behavior and their surfacing, respiration, and dive cycle, and by moving rapidly away (Richardson et al. 1985, Richardson 1995). Some odontocete cetaceans exhibit tolerance to watercraft, but apparent disturbance reactions have also been documented. Spotted, spinner, and striped dolphins (*Stenella attenuata, S. longirostris, S. coeruleoalba*, respectively) changed their swimming track to avoid the path of an approaching vessel (Au and Perryman 1982). Killer whales (*Orcinus*
orcas) observed in an area of increasing boat traffic off British Columbia, increased their swimming speed and leave the area if more than one boat is present (Kruse 1991). Subsequent work demonstrating the continued existence of disturbance responses after more than 20 years of exposure to vessels indicated that killer whales become more erratic in their paths in the presence of boats, and females swim faster (increased speed with decreased distance to vessel, rather than number of vessels, as per Kruse (1991)) and dive more steeply (Williams et al. 2002). Similar results were found with harbor porpoises, *Phocoena phocoena*, which tended to swim away from approaching vessels (Polacheck and Thorpe 1990). Harbor porpoises also showed differential responses based on the size and behavior of the approaching vessel (Evans et al. 1993).

In coastal habitats shared by manatees and bottlenose dolphins (*Tursiops truncatus*), both animals face similar threats from boats. In fact, bottlenose dolphins are also occasionally struck and injured or killed by vessels in coastal waters (Wells and Scott 1997). Bottlenose dolphin disturbance responses include changes in dive length (Evans et al. 1992), surfacing patterns (Janik and Thompson 1996), and foraging habitat selection (Allen and Read 2000). In Sarasota Bay, Florida, short-term shifts in local habitat use have been observed during periods of heavy boat traffic (Wells 1993). Recent detailed studies in Sarasota Bay, Florida, showed that longer inter-breath intervals were associated with boat approaches, and dolphins decreased inter-animal distance, changed heading, and increased swimming speed significantly more often in response to an approaching vessel than during control periods (S.M. Nowacek et al. 2001b). These responses were heightened when dolphins were approached while in shallow water -- a habitat shared locally with manatees.
Mounting evidence indicates that boat traffic can disturb manatee behavior patterns. Escape from perceived immediate danger could disrupt such activities as feeding, resting, and nursing, and thereby potentially adversely impact activity budgets and energy balances (O'Shea 1995). Changes in manatee distributions relative to boat traffic have been reported (Buckingham et al. 1999). The cumulative long-term effects of repeated short-term changes in behavior in response to boat approaches, as reported by S.M. Nowacek et al. (2000), remain to be determined.

**Critical Data Gaps and Uncertainties**

Many issues remain to be resolved if manatee mortality, serious injury, and disturbance from boats are to be reduced. One of the most important issues remaining is the determination of how much time is available to manatees between the time of detection of vessels and the time of impact. Observations of manatees making significant behavioral changes in apparent response to approaching boats suggest that detection of vessels does occur. The fact that apparent responses occur at distances exceeding the possible visual range of the animals argues that acoustic cues are important for and used by manatees to detect and avoid oncoming boats. Thus, a critical step in the development of our understanding of manatee responses to boats should be to refine our knowledge of when manatees detect boats acoustically. As described above, in the absence of field capabilities to directly measure detection through sensitive physiological measures such as auditory brainstem response, observations of consistent gross behavioral changes as vessels approach have been used as a surrogate measure of detection. It is understood that the
behavioral observation approach has an inherent bias as the detectable response occurs at an undetermined time following detection.

The majority of studies on the responses of marine mammals to on-coming vessels and/or anthropogenic noise rely on one of three assessment methods: (1) surface observations (Swartz and Cummings 1978, Swartz and Jones 1978, Tyack 1983, Richardson and Malme 1993, Clark and Fristrup 1997); (2) overhead observations (Richardson et al. 1985, Koski and Johnson 1987, Wells et al. 1999, S.M. Nowacek et al. 2000, D.P. Nowacek et al. 2001a, S.M. Nowacek et al. 2001a) or observations from elevated shore stations (Malme et al. 1983, Malme et al. 1984, Frankel and Clark 1998, Tyack and Clark 1998); and (3) acoustic recordings of vocalizations from the target animal with a fixed or towed array (Clark and Fristrup 1997, Clark and Tyack 1998, Rendell and Gordon 1999). A significant piece of data that none of these methods can supply is the received level (RL) of sound heard by the animal under observation.

Developing technology is providing the means to relate fine-scale behavioral changes to measures of received level of sound at the animal, allowing researchers to detect behavioral changes earlier, at times perhaps approaching an actual response threshold. This has been made possible through the development of an attached digital data logger, the DTAG (D.P. Nowacek et al. 1998, Johnson et al. 1999). The DTAG simultaneously records the sound(s) occurring at the animal with a number of physiological and behavioral signals (e.g., pitch, roll, compass heading, fluke strokes, vocalizations), making a very direct connection between sound and response. Specific advantages of the DTAG are: (1) the sound level at the animal, RL, is measured directly; there is no reliance on transmission loss models to estimate RL; (2) there are
no time alignment errors when correlating sound exposure and behavioral response; (3) subtle and/or short-duration responses can be measured, such as sudden increase in fluke beat frequency or amplitude. In addition, the DTAG records the depth at which the animal occurs in the water column. Knowledge of the proportion of time spent at particular depths, when compared to boat traffic patterns and habitat use patterns, facilitates evaluation of the risks faced by the animals, based on the occurrence of vessels and their draft. The DTAG has been successfully deployed by several of the authors on a variety of cetaceans, including bottlenose dolphins, northern right whales (*Balaena glacialis*) (D.P. Nowacek *et al.* 2001b), and sperm whales (*Physeter macrocephalus*).

It was recognized during its early development that the DTAG might offer tremendous potential for addressing important information gaps relative to manatee responses to vessels. To this end, staff of Mote Marine Laboratory’s Center for Marine Mammal and Sea Turtle Research combined efforts with the Woods Hole Oceanographic Institution electronic engineers responsible for developing the DTAG to conduct a pilot study to evaluate the feasibility of deploying DTAGs on manatees. We conducted a first season of field trials with the DTAG on manatees during March 6-13, 2001 at the manatee research site developed since 1997 by one of us (Powell) in Southern Lagoon, Belize. The waters of Southern Lagoon offered an excellent opportunity to conduct controlled single-boat approach experiments with manatees in an environment that is largely free of confounding vessel noise, such as the common complications in Florida waters of numerous vessels operating simultaneously in the vicinity of a manatee. The manatees of Southern Lagoon live in a very natural situation, where they are not subject to hunting, where they face minimal harassment, and where noise from human activities (boat
traffic, construction, aircraft, vehicles crossing bridges, etc.) is minimal. Typical powerboat traffic through the lagoon system is limited to only a few small vessels each day. Long-term, ongoing research efforts in this lagoon system have identified a high degree of residency by many of the manatees in the region. Powell’s previous work at this site demonstrated that these animals could be easily and safely captured for tagging, and can be recaptured for tag repairs, replacement, or removal. Shallow waters throughout the lagoon system facilitate captures, affording us the opportunity to deploy and retrieve DTAGs and conduct vessel approaches.

During March 2001 we deployed DTAGs on two manatees in Southern Lagoon to test the utility of this technique for application in the more acoustically complex waters of Florida. The results of our initial deployments of DTAGS on manatees demonstrated the potential value of the DTAG for collecting data of importance to manatee management (S.M. Nowacek et al. 2001a). The DTAG provided the means to relate fine-scale behavioral changes to changes in a manatee’s acoustic environment. Control data indicated very little activity on the part of the manatees. In strong contrast, experimental approach and opportunistic approach data indicated frequent and rapid changes in both manatee heading and fluke stroke rates. The two tagged manatees clearly responded to vessel approaches, and our data suggest that reactions apparently began at estimated distances of 160 m to 800 m under the riverine conditions of our experiments, well in excess of the boat-manatee separation distances reported by previous behavioral studies. Our pilot study thus provided additional support for the importance of hearing to manatee detection of approaching vessels. Especially if these relatively long-distance acoustic detections are confirmed through additional studies, then there are important implications for management. The problem of collisions between manatees and boats then becomes an issue of determining the
animals' response threshold, and providing the animals with sufficient time to process the acoustic information it is receiving and develop an appropriate response, or minimizing the potential damage from a vessel in the event of an inappropriate response.

It must be stressed that our preliminary conclusions were based on a very small sample size of manatees, under a limited set of conditions and vessel approaches. Further confirmation and characterization of manatee responses was required. We believed that a larger sample size of DTAG deployments under carefully controlled conditions would make it possible to statistically analyze fine-scale behavioral responses to vessel approaches, looking closely at duration of response and the range and received sound level at which a manatee responds. This calibration of the technique and understanding of the manatee’s abilities under controlled circumstances would greatly enhance our ability to interpret the results of planned DTAG deployments in the much more complex conditions of the manatee’s habitat in Florida. To this end, we returned to Southern Lagoon in March 2002 for additional DTAG deployments.

Materials and Methods

Study Area

Experiments were conducted in Southern Lagoon, a shallow (typically < 3 m deep), enclosed estuarine lagoon in Belize (Figure 1). Southern Lagoon connects to another similar lagoon through narrow waterways, and to coastal marine waters through a short, narrow river. The primary freshwater input into Southern Lagoon is the Manatee River, a narrow (up to approximately 50 m wide, 4 m deep) waterway accessible to manatees by crossing a shallow sandbar at the mouth. Gales Point, which projects northward from the southern end of the
lagoon, served as the base of operations (Lat/Long: 17°12.02 N, 88°20.05 W). Vessel traffic is minimal in Southern Lagoon. Controlling the anthropogenic noise environment of the manatees enables behavioral responses to be more clearly linked to specific boat/approaches/sound levels.

**Digital Acoustic Data-logging Tags (DTAG)**

The DTAGs were secured to peduncle belts attached to briefly-restrained manatees, which were subsequently released and tracked to allow recovery of the tags. The DTAG uses solid-state, non-volatile memory in place of magnetic tape or a disk-drive. Using solid-state memory allows the tag to be potted, eliminating the need for a pressure housing and enhancing the robustness of the device. By processing all of the sensor data digitally, and storing it contiguously, precise time-alignment is maintained. The dimensions of the tag, excluding the housing, are approximately 10 cm by 5 cm by 2 cm depending on the sensor suite, and it weighs approximately 500 g (Figure 2). Programming and off-loading of the DTAG are achieved with a high-speed infrared interface, eliminating an underwater connector and allowing the operating parameters to be changed in the field.

The DTAG can document responses on at least three time scales. A manatee’s behavior may change, for example, on the order of seconds with an erratic dive or other startle behavior such as violent rolling that can occur when a marine mammal is distressed (Weinrich 1999). On time scales of minutes, a manatee may change its regular dive pattern or activity, for instance, by spending more time at the bottom or seeking even deeper water. Finally, at the outer limit of our ability to detect a disturbance reaction, a manatee may abandon a particular area, a change that would occur over a period of tens of minutes to hours. All three of these types of changes can be
captured by the DTAG. The high sensor-sampling rate (46 samples/sec) is sufficient to resolve the shortest duration behavioral events such as a roll or a rapid dive. A change in regular dive pattern would be evident on many of the sensors (e.g., pressure, pitch, roll), and a directed departure from an area would be recorded by the magnetometers.

We selected one of three available tags for deployment on each manatee. The tags were of various sizes enabling different recording lengths ranging from 4.5 hours to over nine hours. The acoustic data were sampled at 32 kHz, (allowing us to listen to sounds from 125 Hz - 15.5 kHz) and the sensor data were sampled at 46 Hz. In order to develop control data for subsequent comparisons to data recorded by the tag during approaches, the DTAGs were programmed to sample all sensors (acoustic, acceleration, heading, roll, pitch, depth) intermittently during the period 1800 through 0700, prior to the 0800 start of a four hour (minimum) window of continuous sampling when the directed boat approaches were scheduled to occur. Recording began when the tag was attached to the manatee and continued for up to one hour continuously before beginning the above sampling schedule.

**Manatee Capture/Tagging/Release Operations**

We participated in regularly-scheduled manatee capture-release operations in Southern Lagoon in order to deploy and recover DTAGs. Manatees were located from a 28 ft Tremblay capture boat equipped with an observation tower and a forward-mounted 115 hp Yamaha four-stroke engine or from a British Army helicopter. Selected manatees were encircled by a seine net (500 ft long, 20 ft deep, 5” stretch mesh) in shallow water, and brought aboard the capture vessel for health assessment, measurements, and tagging.
In order to avoid the problems experienced in 2001 associated with re-capture to recover DTAGs, we designed a releasable belt. Our primary motivation for developing this system was so that we would not need to recapture the manatee to retrieve the belt and tag. Recapture causes additional stress to the animals, requires additional field time, and the possibility exists that a tagged animal would leave the area compounding tag retrieval. The releasable belt was fastened around the animal using a two-part clasp held together by suction force (Figure 2). The left half of the clasp was a bored cylinder with a barbed port on the closed side. The right half of the clasp was a cylindrical shaft with a rubber stopper on one end. The shaft was inserted into the hollow cylinder, which in turn pushed the air out of the clasp through the barbed port. The rubber stopper on the end of the shaft sealed the volume in the clasp and a valve connected to the barbed port prevented air from returning to the evacuated space. The small amount of remaining air in the clasp was then pumped out to create the maximum vacuum force possible to hold the two ends of the belt together.

The clasp was also connected to a time controlled corrodirble release. The barbed port of the clasp was joined to a length of kinked tubing in a small volume of salt water on the belt. The kink in the tubing was wrapped with a length of nickel-chromium (NiCr) wire to prevent it from opening and allowing fluid to fill the vacuum holding the clasp together. The NiCr wire was connected to the battery powering the DTAG, because NiCr will corrode away in the presence of salt water and an applied voltage. At a predetermined time the DTAG sends a small amount of current to the NiCr wrap. After approximately 15 minutes the wire corrodes away,
allowing the kinked tubing to open, fluid to flood the clasp, and the belt to release from the animal.

The manatees carried a variety of transmitters and instruments for tracking and location data collection. Continuously transmitting sonic tags were encased in the peduncle belts for underwater tracking. A standard flexible nylon rod tether (approximately 1.5 - 2.0 m long x 9.5 mm diameter, with a breakaway connection at the swivel on the belt) connected the belt to a transmitter/data collection float. The float housed a Lotek GPS receiver, as well as two VHF radio transmitters for real-time tracking when the float was at the surface. The intent of the GPS tag was to allow direct distance measurements between the approach vessel (with its continuously-recording Garmin GPS 12 hand-held unit) and the manatee. However, the highest resolution available from the Lotek GPS tag was every five minutes. Many of the acquisitions at five minute intervals were unsuccessful because the tag only acquired satellite signals yielding data about once every ten to fifteen minutes. This acquisition rate was not sufficient to allow the desired comparisons.

**Experimental Approach Methods**

Four experimental approaches were to be conducted on each tagged manatee, two at fast speed and two at slow speed. The order of these approaches was selected randomly. The approach vessel was a 7 m long “ponga” boat with a 70 hp 2-cycle engine. The vessel was driven at 12-13 km/hr (7.5 mi/hr) for the slow approaches and 25 km/hr (15.5 mi/hr) for the fast approaches at a steady heading, passing the animal, and moving at least one km beyond the animal before shutting down for approximately 45 minutes, then repeating the approach from the
opposite direction. Observers on the approach vessel closely monitored the waters ahead of the boat during approaches, watching for the floating VHF or GPS tag, and/or water movement or anatomical indications of manatee presence in the path of the boat. Using the VHF transmitter we were able to roughly estimate the manatee’s location. We did not want to disturb the manatee before the approaches began so we did not move close enough to obtain a visual confirmation on the tagged animal until after all four experimental approaches had been conducted.

**Analyses**

Following recovery of the tags, the data were downloaded from the tags as .DTG files. Each .DTG file was broken apart into two files: the .SEN and the .WAV file. The .WAV files were suitable for immediate analysis. The .SEN file contained all of the data recorded by the pressure sensor, accelerometers, magnetometer, and thermometer. The sensor data were corrected for angle of attachment and position of the tag on the animal, as determined from photographs from several angles prior to release. We used these data along with bench calibrations of the individual sensors to calibrate the data to yield depth data in meters, compass heading data in degrees, and pitch in degrees. Bench testing and calibrations of all sensors occurred at the time of each tag’s construction. Additionally, prior to each deployment tags were degaussed to remove residual magnetic fields that could affect the magnetometers. After retrieval a set of standard measurements made on the bench provided the offsets for each magnetometer, which change with each deployment as variation occurs in the earth’s magnetic fields. All other sensors are characterized and calibrated at the time of tag construction.
Acoustic recordings were cataloged from each tagged manatee. Manatee vocalizations, though comprised in part of single chirps, tended to be clumped in their distribution throughout the acoustic record. The determination of sounds as vocalizations was based on previous reports of manatee sounds (Schevill and Watkins 1965, Sonoda and Takemura 1973). All behaviors were recorded as states having some duration. Animal movement periods, defined as time when paddle movement could be detected (most often periods of continuous swimming) usually lasted less than one minute; however, one period lasted about 15 minutes immediately following release. Generally, most movements of the fluke could be detected on the acoustic record. Directed swimming was most obvious as the regular fluke beats were very audible. Chewing sounds indicated feeding and each bout lasted about 30 seconds. Detectable in the acoustic record were short periods (<30 seconds) when air bubbles were breaking the surface of the water. These were thought to be indicative of flatulence and recorded as such. Respirations were recorded when possible but were rarely audible and typically only the exhalation portion could be heard. Duration and loudest point of all vessel noise were recorded. Few instances of presumed contact noise were recorded. These were periods when the tag came into contact with another object or manatee. Fish vocalizations were also recorded.

Analyses of the motor and acoustic behavior of the manatees in relation to boats were broken into two categories: control segments and segments including experimental boat approaches. Each of these segments was of four minutes duration. For experimental approaches, the point of closest approach was assumed to be the time of greatest vessel noise amplitude, and the segment included two minutes before and two minutes after this point. Control segments were defined as four minute periods when no boats were audible. They were
identified to provide some means of comparison to experimental approach segments. Control segments were chosen midway between the experimental approaches.

Although graphical representation of these data is appropriate, the graphs have limitations. Plots of heading are two-dimensional and therefore sometimes contribute to an exaggeration of behavior. Changes in heading from 360° to 10°, for example, will appear to be a large change in heading when in reality it is a change of only 10°. For this reason, we also plotted change in heading in degrees per second, which shows true changes in behavior. For the general heading plots we used the more intuitive 0° - 359° scale, whereas we calculated change in heading using a continuous scale (i.e., -180° to 180°) to minimize artifacts that would be introduced by an animal changing its heading from, for example, 360° to 10°. The plots of pitch can also be difficult to interpret. The placement of the tag on the manatee, at the base of the peduncle, ensured that our measure of pitch is likely to be an accurate measure of swim stroke. Every time the manatee moved its fluke, the tag recorded a change in pitch. The tag also recorded changes in the overall pitch of the longitudinal axis of the animal; with fluke strokes recorded as smaller oscillations superimposed on the pitch record. These changes in pitch normally occurred on a slower time scale than swim strokes. To better illustrate these changes in fluke stroke rate, we plotted angular stroke rate, i.e., the degrees through which the fluke moved per second. Large changes that occur quickly can then be interpreted as fluke strokes while slow changes can be interpreted as changes in body angle.

Since the DTAG recorded depth of the tag on the animal 46 times per second, we were able to look at what percentage of time an animal spent at various depths. Following correction
of the pressure sensor data for depth (meters), we pooled and plotted the data in 0.5-meter depth bins. For each bin, we calculated the percentage of time the animal spent within that depth range.

Given the small number of reasonably successful tag deployments (n = 4) during 2002, we are limited to presenting only descriptive results. Rigorous statistical comparisons and response characterizations will require the collection of data from a larger number of deployments.

Results

Tagging efforts from our March 2002 field season in Belize are summarized in Table 2. Poor weather limited the number of manatee capture opportunities within the field session. Seven manatees were tagged, but problems associated with tag attachment limited the number of successful tag deployments. Of these seven animals, only four deployments were of sufficient duration for consideration, as described below.

<table>
<thead>
<tr>
<th>No.</th>
<th>ID</th>
<th>Date</th>
<th>Time</th>
<th>Date</th>
<th>Time</th>
<th>Tag Size</th>
<th>Attachment Type</th>
<th>Approaches</th>
<th>Data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F-20</td>
<td>7</td>
<td>14:17</td>
<td>7</td>
<td>14:17</td>
<td>1.6 GB</td>
<td>Suction w/spring</td>
<td>0</td>
<td>0</td>
<td>Tag caught under boat upon release</td>
</tr>
<tr>
<td>2</td>
<td>F-18</td>
<td>8</td>
<td>12:07</td>
<td>9</td>
<td>x</td>
<td>1.6 GB</td>
<td>Non-release</td>
<td>4</td>
<td>0</td>
<td>DTAG lost during recapture escape</td>
</tr>
<tr>
<td>3</td>
<td>M-10</td>
<td>9</td>
<td>13:01</td>
<td>9-10</td>
<td>13:01</td>
<td>800 MB</td>
<td>Suction/no spring</td>
<td>0</td>
<td>0</td>
<td>Attachment test, 3 hr (?) recording</td>
</tr>
<tr>
<td>4a</td>
<td>F-22</td>
<td>10</td>
<td>12:53</td>
<td>10</td>
<td>12:55</td>
<td>900 MB</td>
<td>Suction w/spring</td>
<td>0</td>
<td>0</td>
<td>Tag off immediately upon release</td>
</tr>
<tr>
<td>4b</td>
<td>F-22</td>
<td>10</td>
<td>13:29</td>
<td>10</td>
<td>x</td>
<td>900 MB</td>
<td>Suction w/spring</td>
<td>0</td>
<td>0</td>
<td>Tag off immediately upon release</td>
</tr>
<tr>
<td>5</td>
<td>M-09</td>
<td>10</td>
<td>18:58</td>
<td>11</td>
<td>19:01</td>
<td>900 MB</td>
<td>Suction/no spring</td>
<td>3</td>
<td>2</td>
<td>Tag off before third trial</td>
</tr>
<tr>
<td>6</td>
<td>F-02</td>
<td>11</td>
<td>16:46</td>
<td>12</td>
<td>17:04</td>
<td>800 MB</td>
<td>Suction/no spring</td>
<td>4</td>
<td>0</td>
<td>Tag off after strong paddle beat</td>
</tr>
<tr>
<td>7</td>
<td>M-24</td>
<td>12</td>
<td>17:34</td>
<td>12</td>
<td>17:35</td>
<td>900 MB</td>
<td>Suction/no spring</td>
<td>0</td>
<td>0</td>
<td>Tag off immediately upon release</td>
</tr>
</tbody>
</table>

Table 2. Summary of manatee tagging efforts in Southern Lagoon, Belize, during March 2002.
The first tag was deployed on 8 March 2002 on a 276 cm female (F-18). The DTAG used was a 1.6 Gbyte tag capable of recording for 9 hours at 32 kHz. The animal was found via VHF transmitter on the morning of 9 March 2002 and we successfully completed four experimental approaches. In order to ensure that the belt would not release prematurely (as happened the day before), and in order to facilitate subsequently accessing this individual for longer-term PTT-tagging, this tag was secured to the belt in such a way that recapture was required to retrieve the tag. During recapture the tag casing opened and the DTAG and collected data were lost.

The second tag, an 800 Mbyte DTAG, was deployed on 9 March 2002 on a 255 cm male (M-10), in order to test modifications to the suction piston belt attachment and release mechanism. Data were recorded for 278 minutes at 32kHz. This attachment was simply to test the release design of the belt so no approaches were conducted on that animal. Three control segments, when no boats were present, were randomly selected to show activity level of the manatee. Two are presented as Figures 3 and 4. The third (Control period 2) showed no activity on the part of the manatee so it is not shown.

The third tag was deployed on 10 March 2002 on a 265 cm male (M-09) – a manatee that was tagged and approached during our March 2001 field study. The DTAG used was a 900 Mbyte tag capable of recording for five hours at 32 kHz. M-09 was found on 11 March via VHF transmitter and 4 approaches were conducted. Sensor data indicated that the tag was released from the animal 181 minutes and 43 seconds into recording time, immediately prior to the third approach. Behavioral data from Approaches 1 and 2 are presented (Figures 5 and 6). Again one
of the randomly selected control periods showed no activity so only Control period 2 is shown (Figure 7).

The fourth tag was deployed on 11 March 2002 on a 282 cm female (F-02). The 800 Mbyte DTAG recorded 278 minutes of data at 32 kHz. F-02 was found on 12 March via VHF transmitter and four approaches were conducted. The post-tag calibrations conducted upon retrieval of the tag indicated that about 20 minutes post-release, water seeped into the tag and ruined the sensors, thereby yielding no behavioral data for F-02. The acoustic record was unaffected.

Catalog of Acoustic Recordings

The acoustic recordings were reviewed aurally with the listener wearing headphones.

The sounds we heard were cataloged for each animal, as indicated in Table 3.

<table>
<thead>
<tr>
<th>Animal movements</th>
<th>M-10</th>
<th>M-09</th>
<th>F-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manatee vocalizations</td>
<td>48</td>
<td>43</td>
<td>16</td>
</tr>
<tr>
<td>Respiration</td>
<td>26</td>
<td>88</td>
<td>301</td>
</tr>
<tr>
<td>Flatulence</td>
<td>10</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>Chewing/feeding</td>
<td>0</td>
<td>0</td>
<td>39</td>
</tr>
<tr>
<td>Control noise</td>
<td>29</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Fish sounds</td>
<td>120</td>
<td>13</td>
<td>22</td>
</tr>
<tr>
<td>Controlled boat approaches</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3. Frequencies of occurrence of behaviors/events cataloged from acoustic recordings.

Control Segments (no boats present)

To compare manatee response to vessel approaches with ‘baseline’ behavior, we selected control segments for M-09. The control periods were arbitrarily chosen as four minute segments
(same length as approach segments), recorded by the DTAG at the midpoints between experimental approaches. Following the overall plot showing sound pressure level (SPL), pitch, heading, and depth for each control segment are two plots showing detail in the heading and pitch data. In addition to showing the same heading or pitch records as shown in the overall figure for the approach, these detailed plots show the rate of change in heading or pitch (i.e., the first differential). M-09 has one control period shown (Figure 7). Control Period 1 (16:01 local) shows little to no change in any parameter during the four minutes; therefore, it is not displayed. Control Period 2 (17:31 local) shows changes in pitch, heading, and depth focused around a "typical" surfacing event; outside of the surfacing there is also little to no change in any parameter, similar to what was detected throughout the entire Control Period 1.

M-10 was tagged to test the attachment mechanism, but it was not tagged under circumstances in which experimental approaches were possible. The data from M-10's tag provide additional indications of background activity of manatees in the absence of boat approaches. Three control segments evenly spaced through the tag deployment were selected for examination. The first period shows much activity, corroborated on the acoustic record by sounds of nearly continuous fluke strokes (Figure 3). The animal while swimming fast (the first half of the control segment) is swimming very close to the water's surface but as the manatee slows down, he swims deeper in the water column. Control Period 2 shows almost no activity and so is not displayed. Control Period 3 shows a single surfacing event followed by no activity (Figure 4).
Experimental Boat Approaches

The experimental boat approach segments for M-09 are shown in an identical fashion as the control periods, including detailed figures showing changes in heading and pitch for each approach (Figures 5,6). For M-09, changes in heading were more prevalent and sustained for longer periods of time during experimental approaches than during control periods. Control Period 1 shows little to no change in heading; Control Period 2 shows a surfacing interval, which has low rates of heading change mostly during the ascent. Experimental Approaches 1 and 2 show M-09 making no change in heading until immediately before the nearest approaches and then continuing changes in behavior throughout the rest of the approach segments. Changes in pitch followed the same pattern.

Radio-tracking data during experimental approaches on Manatee F-02 provided an anecdotal suggestion of the distance at which this animal responded to the approach vessel. Before we started our approach, our vessel was anchored with the engine off about 0.6 km from the deep hole where the manatee was located. Continuous VHF radio signals for about 30 minutes prior to the approach indicated that the animal was moving very little, remaining at or near the water’s surface. As soon as we began the 12 km/hr approach the float with the VHF radio transmitter submerged, and did not re-surface until we passed by and reached a distance of about 0.6 km beyond the hole, suggesting a dive by the manatee that lasted for the duration of the time that we were within about 0.6 km of it.

Two of the three manatees we approached during March 2002, M-09 and F-02, were in or near a small natural depression in Southern Lagoon about 1 km northeast of Gales Point. This
depression, aptly known as "The Manatee Hole," is about 39 m across, and at its deepest point is about 10.5 m deep. The waters immediately surrounding the hole are about 1.5 m – 2 m deep. It is well-known to locals and researchers as an aggregation site for manatees. Experimental Approach 1 for M-09 brought the approach vessel within 0.11 km of the hole as the boat passed from southwest to northeast. Experimental Approach 2 for M-09 was directly over the hole. The approaches for F-02 were at a greater distance from the hole than for M-09. DTAG data indicate that M-09 remained at about 3 m depth during the approaches, and the dive by F-02 likely indicated that it submerged deeper than the 2 m length of the tether, well below the propeller depth and keel of the approach vessel. Such manatee depths are comparable to those measured during approaches during 2001.

Discussion

The changes in behavior detected during the experimental approaches on M-09 show a definite increase in activity over the level of behavior noted during control segments. During Experimental Approach 1 (slow approach), small changes are made continuously throughout the approach beginning about 30 seconds before the nearest approach. The changes in both heading and pitch involve lower rates of change than those detected during Experimental Approach 2. During Experimental Approach 2 (fast approach), M-09 displayed a quick swimming burst as well as significant changes in heading about 30 seconds before the closest approach. The approach vessel was still underway but past the animal heading away when M-09 surfaced, and M-09 returned to depth maintaining a heading opposite the approach boat. This animal showed a similar behavior pattern during these two experimental approaches. Perhaps the difference in approach speed could account for some of the difference in response intensity.
We have the opportunity to compare the responses of M-09 during two different years, 2001 and 2002. In 2001, M-09 was approached in a narrow river while with other manatees. We found that while M-09 responded to the approaches both years, in 2001 the responses were more intense, involving more changes in behavior and those changes occurred much earlier in the approach sequence than in 2002. The two variables that differed most obviously were the approach location and the approach vessel. As mentioned earlier, the 2002 approaches were conducted in open water while the manatee was near or in the manatee hole, a deep spot in Southern Lagoon. Open water in general provides more horizontal response options than a narrow river might; additionally, the deep hole provides allows the animal to dive well below the depth of the boat. A pattern by Florida manatees of movement from shallow to deeper water was the most consistent response noted in observational studies (Nowacek et al. 2000, in review). The 2001 approaches conducted in a narrow river without deep spots could have limited response options for the approached manatee forcing M-09 to respond to the approaching vessel more intensely.

The received sound level of engine noise was slightly higher in 2001 than in 2002. The differences could be related to environmental differences or differences in the approach vessel characteristics. The level of sound reaching he manatee could easily be affected by transmission characteristics of its environment. Sound is likely to be transmitted differently in a narrow river than over a shallow basin, and into a small depression in the basin. In 2001, we used a 28 ft vessel with a 115 hp 4-stroke engine; 4-stroke engines are thought to be quieter vessels, yet we see changes in behavior occurring much earlier than when the same animal is approached with a
70 hp 2-cycle engine. We would expect the 2001 approach vessel to be quieter upon approach thereby not being detectable until later in the approach sequence. However, changes in behavior occur earlier. Possibly, since the 4-stroke vessel is extremely uncommon in those waters and since the more common boat type is similar to that used in 2002, the 2001 approach vessel was more startling to M-09 as it was a novel sound.

Tagging studies of this type have advantages and disadvantages. One of the disadvantages is that sample sizes are typically small, which is often due to the complexity of the equipment and access to individuals. In this case parts of the equipment were quite reliable while other parts were experimental. Our sample size in 2002 was smaller than we anticipated due to two primary failures. The DTAG itself is well characterized and reliable, with only three deployments suffering due to inherent failures of the tag over 3 years and >50 deployments on eight species of marine mammals. Unfortunately, one of those failures occurred during our 2002 experiment in Belize. To reset the tag a high voltage (9V) is applied across the salt water switch leads, and due to a human error this procedure caused one of the tags to fail (F-02). An unregulated voltage was applied causing the epoxy potting to crack slightly, which subsequently allowed water to enter the tag and break the sensors. For this deployment, only the acoustic data could be recovered.

The other failure that caused a reduced 2002 sample size was the experimental attachment system we attempted to use. This system, described above, consisted of a suction-piston buckle to hold the peduncle belt, and thus the DTAG, onto the manatee. Despite numerous successful tests on captive manatees, this system did not perform as anticipated in the
field. Specifically, the suction-piston buckle did not survive the release of the manatees as well as we had hoped. Often the manatees swam forcefully immediately after making contact with the water, and unfortunately the tether and/or float would catch on some part of the boat, with the resulting pulling pressure overwhelming the suction of the piston. We attempted to minimize this loss by moving the boat into relatively deep water and pushing the whole animal into the water quickly, but some belts still fell off as the manatees forcefully swam away. We also removed the internal spring from the piston, resulting in additional suction pressure, and this seemed to help, but did not eliminate the problem. After several of these failures we also bypassed this system and attached the peduncle belt with a ‘permanent’ closure, which necessitated recapturing the animal. During the recapture the manatee escaped under the net just before bringing it onboard, and during its escape the tag was torn off in the net and lost.

Despite these failures we believe that this technology still represents a promising and unique means to learn how manatees respond to vessels as well as for other experiments with these mammals. No other technology currently available possesses the capabilities of the DTAG for measuring the behavior and acoustics of free ranging marine mammals. The peduncle belt attachment system is also robust, although further testing and development of the suction-piston buckle or another self-releasing system must occur if having such a system is considered desirable. In addition to the fact that our results further our understanding of how manatees respond to approaching vessels, the data actually presented represent only a very small portion of that actually collected in Belize. We set out to measure the behavioral and/or acoustic response of manatees to approaching vessels, but by using the DTAG we collected a significant amount of other data, for example, the amount of time manatees normally spend at ‘risky’ depths (at the
fine scale resolution of 0.25 m). Both M-09 and M-10 spent relatively small percentages of time shallower than 0.5 m; however, M-10 spent about 30\% of his time between 0.5 and 1.0 m (Figure 8). Manatees within about one meter of the water surface are most vulnerable to boat collisions.

As another example of the usefulness of these data, the vocalizations recorded by the DTAG from Belize manatees in 2001 and 2002 have been analyzed for a manuscript to be submitted to the *Journal of the Acoustical Society* comparing the structure and features of these sounds with those produced by Florida manatees. A great deal more data about the normal behavioral patterns of manatees are contained in these DTAG records. For example, surfacing patterns are emerging as being rather distinct. Our initial evaluation characterizes them as short in duration, involving many changes in heading and few changes in pitch (fluke stroke). The DTAG enables us to begin to see signature patterns specific to different behaviors. These data contribute to our basic understanding of these animals, an understanding that we hope will continue to inform the efforts to design boat strike mitigation efforts.

While our experimental work has yielded smaller sample sizes than we anticipated, we feel that the results are sufficient to demonstrate this technique as a viable means to assay the behavior of manatees in the presence of boats. In our continuing effort to respond to management needs relative to manatee mortality and disturbance from boats, we feel it is important for us to work over the next year to examine the data we have collected and the problems we have encountered in order to focus our future research in Florida. Carefully planned and informed experiments will be optimally responsive to management needs for
understanding manatee behavior in response to boat approaches. A reasonable next step will be to use the DTAG to characterize the responses of manatees under the complex acoustic conditions of Florida waters, with a focus on the period from the time of first indication of behavioral change to the time of potential impact under a variety of conditions. We have considered general directions for this work, and depending on complete evaluation of existing data and consultation with other manatee researchers we can make more firm recommendations within a few months. The response of manatees to boats can be affected by many factors, and while we acknowledge the existence of these factors we believe that effort should be focused on answering very specific questions about the animals' behavior. With unequivocal answers to carefully chosen questions, mitigation strategies can be wisely designed.

The integration of management needs with DTAG capabilities yields a number of possible research directions, each involving a variety of parameters. Attachment issues remain to be resolved before the DTAG can be deployed efficiently in Florida waters. Recognizing the need for this multi-stage approach, we suggest that the following experiments be undertaken:

- Experiments with Florida manatees
  - Several important questions remain to be addressed with Florida manatees in the presence of vessels
    - In what horizontal (i.e., GPS) and vertical (i.e., depth) locations do manatees spend significant time, and how do these locations compare to the occurrence of vessels in the area, i.e., can these data be incorporated into a risk assessment?
How do animals respond in the presence of single vs. multiple boats?
How do animals respond in the presence of fast vs. slow moving boats?
How do animals respond in the presence of vessels approaching from different angles?
How do animals respond to different engine types and speeds?
Does the habitat type of boat and/or animal affect manatees’ responses?
Does the time between sequential approaches affect manatees’ responses?
Does the age/sex class of a manatee affect its response?
How does natural and/or current behavior affect response?

Using DTAGs with Florida manatees

Short duration attachments necessary for DTAG experiments argue for self-releasing belts so that impact on wild animals can be minimized.

- The suction-piston system has potential but the maximum possible suction pressure should be increased to decrease failures during high energy behavior.
- Whatever self-releasing system is to be used with wild manatees should be tested on captive animals, preferably with animals that can mimic some of these high energy behaviors.
- If this technique is to be pursued, significant time for engineering and testing (6 mos.) should be allocated

Detailed profiles of manatee behavior are possible in the presence of single vs. multiple boats, fast vs. slow boats, and in the absence of boats.
• DTAG experiments should include GPS sampling of fine enough resolution to permit speed and distance analyses

We hope the suggestions we have made will provide a roadmap for future experiments, and we are interested in discussing our role in those experiments. The permutations of “dose-response experiments” are obviously large, and the sample sizes necessary to adequately answer specific questions increases dramatically with each variable added, e.g., age/sex class differences, habitat effects. Concomitantly, the research staff time necessary to design, conduct, and analyze the experiments increases with the variables to be tested. Preparations will require the involvement of engineers, statisticians, manatee biologists, and researchers involved in ongoing manatee capture-release operations. It will be necessary to obtain permits for this work. At the very least we feel that preparation time of 6-12 months and multiple field efforts will be necessary to sample enough individuals' behavior/response in the presence of boats to confidently extrapolate to the manatee population in general.

Acknowledgments

Primary support for this project was provided by the Florida Fish and Wildlife Conservation Commission, contracted through the Florida Marine Research Institute. Wildlife Trust provided invaluable assistance by capturing and re-capturing the tagged manatees, and allowing us to share the Gales Point field station and resources. We would like to thank the Department of Forestry, Government of Belize for providing permits and the Belize Coastal Zone Management Authority for facilitating the study in Belize. The capture vessel was made available to us by Wildlife Trust and the Chicago Zoological Society. Wells' time for
participating in the project was provided by the Chicago Zoological Society. Woods Hole Oceanographic Institution provided access to DTAG equipment (DTAGs, download computer, IR link, Palm Pilot, etc).

Many people helped with the preparations, fieldwork, and analyses for the project, including Alonso Aguirre, Kevin Andrewyn, Kira Barton, Robert Bonde, Mesha Gough, Peter McGuire, Rene Meisner, Maureen Powell, Mark Sweat, Martha Wells, and a team of Gales Point residents. Our protocols were developed with the help of Sheri Barton who provided assistance on recording manatee behavioral observations. Tom Hurst helped prepare the DTAGs for the project. Kate Williams helped with construction of belts for use in Belize. Debi Colbert, Joseph Gaspard, and Brandie Littlefield were helpful in testing versions of the release mechanism. Lastly, a special thanks goes to David Mann who helped to identify biological sounds on the acoustic recordings.

Research in Belize was conducted under a Scientific Collection/Research Permit from the Conservation Division of the Forestry Department of the Ministry of Natural Resources, the Environment and Industry, issued to J. Powell under the Wildlife Protection Act No. 4/1981.

This report is available as Mote Marine Laboratory's Technical Report No 847.
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Figure 1: Map of study area in Belize. Dots show release locations of tagged manatees F-02, M-09, and M-10. Approaches for M-09 were conducted between Gales Point Field Station and the entrance to Quashie Trap Lagoon.
Figure 2a: Picture showing placement of DTAG on manatee from overhead.

Figure 2b: Picture showing placement of DTAG from the side.
Figure 3a: Tag sensor data recorded for M-10 (over 4 minutes) during Control period 1. The large plot (a) shows changes in received sound level over all frequencies, pitch (fluke strokes), compass heading and manatee depth. The two plots below (b, c) show again changes in compass heading and pitch, respectively, with those changes also shown in degrees per second.
Figure 4a

M-10: Control Period 3, 9 March 2002 17:31 local

- dB re uPa
- Pitch, deg
- Heading, deg
- Depth, m

Minutes into Pass

Figure 4b

M-10: Detail of heading for control period 3

Minutes into Pass

Figure 4c

M-10: Detail of pitch/paddle stroke for control period 3

Minutes into Pass

Figure 4a,b,c: Tag sensor data recorded for M-10 (over 4 minutes) during Control period 3. The large plot (a) shows changes in received sound level over all frequencies, pitch (fluke strokes), compass heading and manatee depth. The two plots below (b, c) show again changes in compass heading and pitch, respectively, with those changes also shown in degrees per second.
Figure 5a, b, c: Tag sensor data recorded for M-09 (over 4 minutes) during Experimental approach 1. The large plot (a) shows changes in received sound level over all frequencies, pitch (fluke strokes), compass heading and manatee depth. The two plots below (b, c) show again changes in compass heading and pitch, respectively, with those changes also shown in degrees per second.
Figure 6a, b, c: Tag sensor data recorded for M-09 (over 4 minutes) during Experimental approach 2. The large plot (a) shows changes in received sound level over all frequencies, pitch (fluke strokes), compass heading and manatee depth. The two plots below (b, c) show again changes in compass heading and pitch, respectively, with those changes also shown in degrees per second.
Figure 7a, b, c: Tag sensor data recorded for M-09 (over 4 minutes) during Control period 2. The large plot (a) shows changes in received sound level over all frequencies, pitch (fluke strokes), compass heading and manatee depth. The two plots below (b, c) show again changes in compass heading and pitch, respectively, with those changes also shown in degrees per second.
Figure 8: Percent time spent at various depths for M-10 and M-09. These percentages represent 278 minutes for M-10 (recorded during the afternoon hours) and 181 minutes for M-09 (recorded mostly during the morning hours during the experimental approach period).