Aquatic Mammals 2009, *35*(3), 367-377, DOI 10.1578/AM.35.3.2009.367

Prevalence and Impacts of Motorized Vessels on Bottlenose Dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida

Sarah E. Bechdel,[1] Marilyn S. Mazzoil,[1] M. Elizabeth Murdoch,[1] Elisabeth M. Howells,[1] John S. Reif,[2] Stephen D. McCulloch,[1] Adam M. Schaefer,[1] and Gregory D. Bossart[1]

[1]*Harbor Branch Oceanographic Institute at Florida Atlantic University, Center for Coastal Research – Marine Mammal Research and Conservation, 5600 U.S. 1 North, Ft. Pierce, FL 34946, USA; E-mail: sbechdel@hboi.fau.edu*
[2]*Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO 80523, USA*

Abstract

Vessel-based anthropogenic impacts on bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon (IRL), Florida, were investigated by quantifying visible physical injuries to dorsal fins from photo-identification data collected from 1996 to 2006. Forty-three dolphins, 6.0% of the distinctly marked population, had injuries related to vessel impact. Impact was determined from previously published vessel-related wound definitions and the elimination of other possible wound sources. Spatial distribution was determined by dividing the IRL into six segments based on hydrodynamics and geographic features. Dolphins were assigned to a segment(s) and corresponding county according to ranging patterns. Segment 4, consisting of St. Lucie and Martin Counties, had the highest prevalence (9.9/100 distinct dolphins) of boat-injured dolphins and had the highest number of registered boaters per km^2 of habitat. These preliminary data suggest that vessel impacts on dolphins occur disproportionally in the IRL and should be considered a high-priority management issue for local governments. Behavioral data collected during photo-identification surveys support the possibility of a low tolerance and sensitization to vessel interactions. Recommendations to reduce direct and indirect impacts from vessels on dolphins are discussed.

Key Words: dolphin, *Tursiops truncatus*, boat, vessel, watercraft, wound, injury, direct impact, indirect impact, propeller

Introduction

Bottlenose dolphins (*Tursiops truncatus*) are known to be impacted physically and behaviorally by motorized vessels in their habitat. In 1996, the U.S. Environmental Protection Agency created a Comprehensive Conservation and Management Plan (CCMP) to protect the living resources of the Indian River Lagoon (IRL), Florida, from anthropogenic activities negatively affecting the estuary. Action Items were created to (1) measure boating impacts on wildlife such as manatees (*Trichechus manatus latirostris*), sea turtles (*Caretta caretta*, *Chelonia mydas myda*), and dolphins; (2) establish resource protection zones; and (3) raise environmental awareness through education of boat and personal watercraft operators. In 2004, Florida became the nation's leader in the number of registered boats (U.S. Coast Guard [USCG], 2002-2005), in addition to being the foremost in boating fatalities (Florida Fish and Wildlife Conservation Commission [FWC], 2008a). Despite increasing awareness of human injuries and deaths attributable to boating and the establishment of manatee resource protection zones, current levels of boat traffic within the IRL continue to directly and indirectly cause marine animal disturbance, injuries, and mortality.

Vessel collisions have been confirmed for over 18 species of small cetaceans worldwide (Van Waerebeek et al., 2007). Direct impacts are instantaneous involving body to boat contact with propellers, skegs, and hulls (Wright et al., 1995; Wells & Scott, 1997). Injuries range from minor physical disfigurations to extensive trauma and death. Collision interactions are identified by prominent external parallel lacerations or blunt force impact. Blunt force impact is manifested by external characteristics such as massive bruising and deformities, which might not be immediately obvious on physical examination (Laist et al., 2001), and by internal characteristics such as hemorrhages; pneumothorax; ruptured diaphragm; and fractures of the skull, vertebrae, and other bones as documented in necropsies (Lightsey et al., 2006). Direct effects can also include secondary infection from the wound source and decreased immune response due to energy allocation to address the injury (Duffus & Dearden, 1993; Robbins, 1993).

Indirect effects include short-term behavioral responses, which might have long-term detrimental implications. Many studies have shown an increase in cetacean avoidance reactions to approaching vessels. Initial reactions revealed extended interbreath intervals and altered surfacing patterns away from oncoming vessels (Janik, 1996; Nowacek et al., 2001; Lusseau & Higham, 2004; Sini et al., 2005). Both horizontal and vertical changes in course direction and orientation have been documented for porpoises (*Phocoena phocoena*), killer whales (*Orcinus orca*), and dolphins (Polacheck & Thorpe, 1990; Kruse, 1991; Mattson et al., 2005). Increased erratic behavior in dolphins has been observed due to limited water depth or encroaching vessel distance (Au & Perryman, 1982; Bejder et al., 2006a; Lusseau, 2006). Anti-predatory responses, such as increased group cohesion and synchronous behavior, also increase directly with boat traffic (Bejder et al., 1999; Hastie et al., 2003). Separate avoidance strategies for males vs females illustrate negative vessel impacts on energetics and reproduction that might lead to decreased population size (Moberg, 2000; Lusseau, 2003a). Noise pollution studies have shown that vessels mask cetacean auditory ability, cause an increase in vocalizations after single events, and may cause permanent hearing loss after several extended submissions (Richardson et al., 1995; Van Parijs & Corkeron, 2001; Erbe, 2002). Vessel interactions interrupt dolphin behaviors such as foraging, resting, and socializing (Lusseau, 2003b; Constantine et al., 2004; Stockin et al., 2008). Further research has suggested that continual behavioral interferences can create long-term problems, including habituation that increases strike vulnerability (Spradlin et al., 1998; Stone & Yoshinaga, 2000), sensitization (Allaby, 1999; Bejder & Samuels, 2003), shifts in ranging patterns and habitat utilization (Wells, 1993; Allen & Read, 2000; Lusseau, 2005; Bejder et al., 2006b), decreased reproductive success (Whelan, 1993; Bejder & Samuels, 2003), and habitat desertion (Crouse et al., 1987; Kaiya & Xingduan, 1991).

This paper summarizes direct and indirect vessel events affecting IRL dolphins and suggests management options that could prevent further negative impact on the population within the region. Our objectives were to (1) identify boat-injured dolphins within the IRL from a photo-identification database, (2) determine the spatial distribution of boat-hit dolphins by segment and county, (3) determine whether dolphin injury rates are correlated with boater registration statistics, and (4) determine whether the behavioral patterns of IRL dolphins are disturbed by the presence of boats.

Materials and Methods

Study Area

The IRL spans 256 km (⅓ of the east coast of Florida) and is connected to the Atlantic Ocean by five inlets and one lock (Figure 1). The IRL includes the Mosquito Lagoon, Banana River, Indian River, and the St. Lucie River Estuary. The average depth is 1.5 m, and its width ranges from 0.93 to 9.3 km. The study area is surrounded by five counties from north to south: Volusia, Brevard, Indian River, St. Lucie, and Martin.

Data Collection

Data were acquired from photo-identification studies within the IRL (Mazzoil et al., 2005, 2008a). Every dolphin encountered was photographed during vessel-based surveys from September 1996 to October 2006. A 4-y subset of data from January 2002 to December 2005 was used for temporal and spatial analysis to match available county boater registration statistics. Data, including environmental conditions, dolphin behavior, and GPS coordinates, were recorded in addition to image collection. Images were obtained using Canon digital camera systems (i.e., EOS 1D, IDS, and IDS Mark II, 100 to 400 mm lens). Analysis of photographic data was performed using protocols described by Mazzoil et al. (2004).

Definition of Boat Hit

Boat-injured dolphins were categorized using a combination of wound definitions described for manatees (Beck et al., 1982) and Cetacea (Wells & Scott, 1997; Visser, 1999; Laist et al., 2001; Van Waerebeek et al., 2007). Vessel impact results in clean-edged, evenly spaced, parallel cuts from propellers and skegs or in blunt force trauma from hulls, keels, and rudders which usually lack initial visual confirmation of a collision. Individuals were excluded if parallel cuts were visually narrow in width or shallow in depth supporting possible conspecific interaction from teeth (rake marks) as the wound source (Scott et al., 2005). Candidates were also eliminated from analysis if other possible wound sources could be a factor (e.g., sharks, fisheries interactions, conspecifics, or marine debris). Propeller impacts generally injure the dorsal fin as it is the closest part of the body to the surface of the water (Morgan & Patton, 1990). Due to the large study area, photo-identification efforts did not allow for repeated daily or weekly encounters with individuals; thus, the majority of the data collected were based on photographic evidence of healed wounds (Bruce-Allen & Geraci, 1985). Healed wound injuries had three manifestations: (1) separation of dorsal fin from the body resulting in a straight wound without curvature, dentition, or

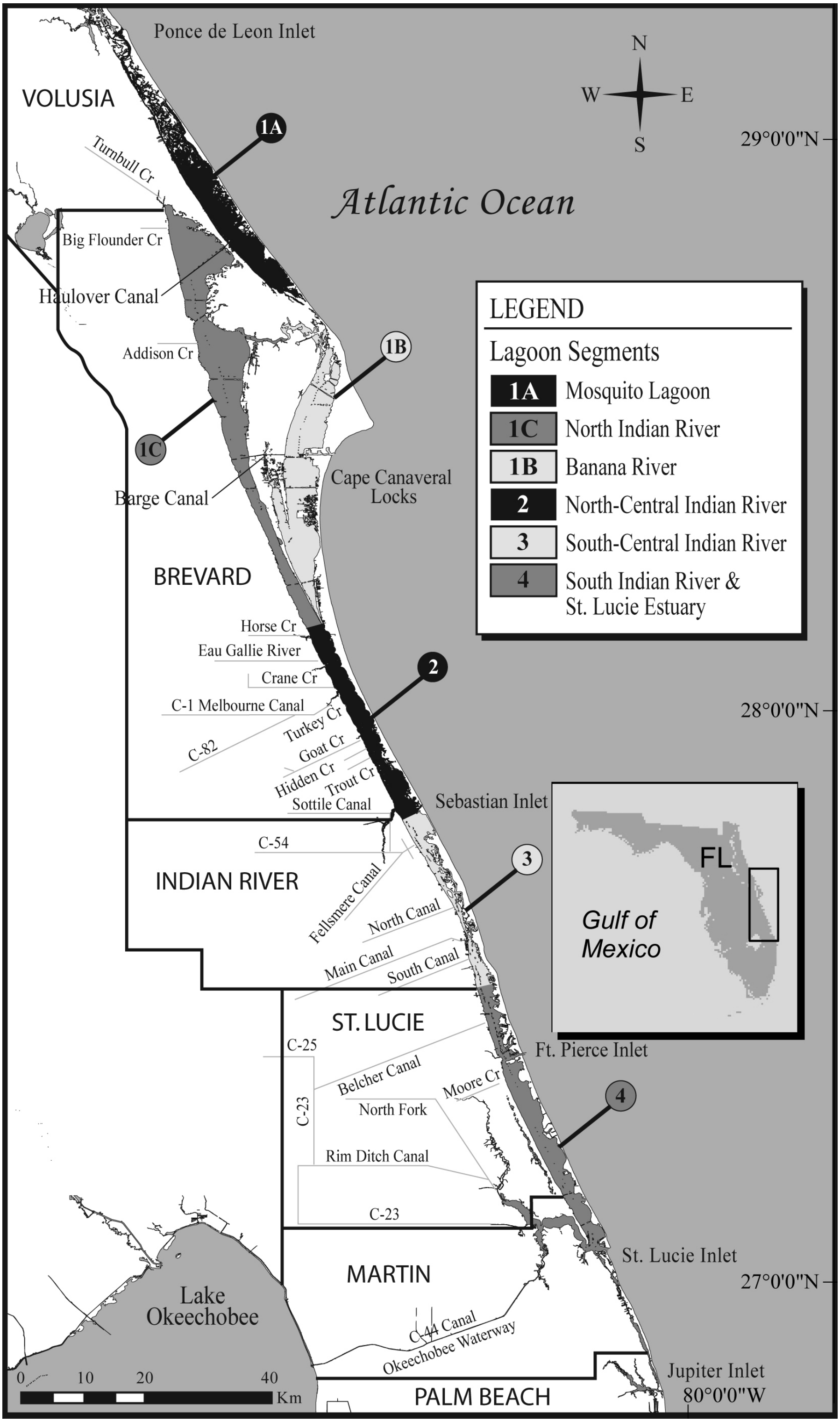

Figure 1. Indian River Lagoon study area divided into five counties overlaid with the six IRL CCMP segments

parallel angle to body axis; (2) partial separation of dorsal fin, creating a deformity which causes the fin to flop or curl to the side; and (3) intact fin with canting to one side, as if broken, with accompanying straight line scar on the opposite side of the fin.

Analysis by IRL Segment

The IRL ecosystem was divided into six segments based on hydrodynamics and geographic features for purposes of characterization and management (U.S. EPA, 1996; Figure 1). All distinctly marked dolphins were assigned a proportion of time spent in each segment based on the GPS coordinates of each sighting. All boat-injured dolphins were considered distinct. Vessel-associated injury rates per segment were determined by dividing total number of boat-injured dolphins by number of distinct dolphins sighted per segment.

Analysis by County

All distinctly marked dolphins were assigned to one of the five counties encompassing the IRL based on the GPS coordinates of each sighting (Figure 1). Segments 1A and 1C did not match county lines geographically, and home ranges were adjusted for county analysis to reflect these boundaries accordingly. In addition, the numbers of distinct dolphins sighted (including all boat-injured dolphins) in St. Lucie and Martin Counties were combined for comparison to USCG reported boater registration statistics. County analysis was also based upon 4-y of data within the 10-y study period (2002 to 2005) to complement boater registration statistics. Vessel-injured rates per county were determined by dividing the total number of boat-injured dolphins by the number of distinct dolphins sighted per county.

Potential habitat encroachment per individual was determined by combining county vessel data with environmental factors. Total surface area in km^2 for the study area was obtained from an earlier report (Woodward and Clyde Consultants, 1994). Boats per km^2 were determined by dividing the number of registered boats (USCG, 2002-2005) by the total surface area of each county in km^2. The number of distinct dolphins per km^2 was calculated by dividing the total distinct dolphins by the surface area. Habitat encroachment per distinct dolphin was derived by dividing the number of registered boats per km^2 by distinct dolphins per km^2 for each county.

Analysis of Behaviors

Dolphin activity and number of vessels within 100 m were recorded once per sighting. Dolphin behavior was determined prior to approach from > 100 m from the selected study group to decrease possible behavioral changes due to vessel influence. Summed activity was defined as the total number of times each boat-injured dolphin was observed in one of six general behavioral activities per sighting. Behavioral activities included traveling, feeding (e.g., swirling of water, fish jumping, or observed capture of fish), social interactions between conspecifics, milling, boat avoidance (i.e., avoidance of the research vessel), and rest (Urian & Wells, 1996). Changes in behavioral frequency due to increased boat abundance were determined by expressing the duration of each behavior on a total time percentage scale. Additionally, the number of boats in the area was categorized into three groups (0, 1 to 5, and > 5) for statistical analysis. Activity changes vs boat abundance was determined by tallying activities in the presence of "x" number of boats and then comparing to the referent (0 boats) using *EpiInfo*, Version 6 (Centers for Disease Control and Prevention, Atlanta, GA, USA).

Statistical Analysis

The proportion of dolphins observed with evidence of a boat interaction was compared overall between segments by chi-square (χ^2) analysis with $p < 0.05$ considered a significant result. The relative risk of boat hit by segment was estimated with the odds ratio and its 95% CI. The analysis was conducted using the segment with the lowest rate of boat strikes as the referent (1C, North Indian River). The analysis was repeated by county to make use of registered boat data, using the county with the lowest rate of boat interaction (Brevard) as the referent. Chi-Square tests and odds ratios with 95% CI were also calculated to compare behavioral patterns in the vicinity of boats with zero boats within 100 m as the referent. All analyses were done using *EpiInfo*, Version 6.

Results

Photo-identification surveys encompassed a total of 9,495 hours of survey effort with 3,224 dolphins (including repeated encounters) observed during 13,044 sightings. Forty-five percent of those sightings ($n = 5,859$) involved an interaction with a vessel within 100 m. Over 368,000 digital images were sorted, analyzed, and archived, and 714 individual dolphins with distinctly marked dorsal fins were used in the analyses.

Prevalence of Vessel-Related Injuries

During the 10-y study period, 43 dolphins (6.0% of the distinctly marked population) had injuries related to vessel impact. Approximately 54% of these boat-injured dolphins (23 of 43) were female, four were male (9.3%), and 16 were of unknown sex (37.2%). Sex was determined through physical examination during live capture studies (Bossart et al., 2006) or by repeated close association with a calf (Howells et al., 2009). Three dolphins (7.0%) received wounds during the years they were categorized as a calf as described by Bearzi et al. (1997). Age, behavior, and geographic location of dolphins with acute, initial injury could not be analyzed due to small sample size of freshly wounded individuals (n = 2). Four boat-injured dolphins (9.3%) were identified as presumed cases of lobomycosis (one was histologically confirmed), a chronic fungal disease of the skin possibly associated with sites of previous trauma such as boat strikes or shark bites (Murdoch et al., 2008).

Spatial Distribution of Vessel-Related Injuries

The highest rate of boat-hit dolphins (9.9/100) was found in Segment 4, Indian River South (including two deaths as described below), and the lowest rate (3.4/100) was in Segment 1C, Indian River North (Table 1). The rate of boat-hit dolphins in Segment 4 was approximately three times higher than that in Segment 1C (the referent segment) (p = 0.07). The frequency of boat hits across all segments was not significantly different. The segments with the three highest rates (Segments 1A, 2, and 4) include inlets to the ocean.

Vessel injury rates per county (Table 2) were comparable to segment rates as described above. Dolphins residing in St. Lucie and Martin Counties were approximately twice as likely to experience vessel activity within their habitat compared to Brevard County, but the difference was not statistically significant. The highest rate of boat hits per county (9.9/100) as well as the greatest number of boats per km^2 of habitat (237 boats/km^2) were found in St. Lucie and Martin Counties, corresponding to Segment 4 (Table 3).

Table 1. Spatial distribution of vessel-associated injuries in bottlenose dolphin by segment, Indian River Lagoon, Florida (2002 to 2005) *rounded values

Segment	No. of distinct dolphins sighted*	No. of dolphins with boat injuries*	Rate/100	p value
1A	173	12	6.8	0.14
1B	69	4	6.0	0.38
1C	157	5	3.4	Ref
2	92	7	7.2	0.14
3	74	5	6.2	0.24
4	76	8	9.9	0.07

Table 2. Spatial distribution of vessel-associated injuries in bottlenose dolphins by county, Indian River Lagoon, Florida (2002 to 2005) *rounded values

Segment	County	No. of distinct dolphins sighted*	Prevalence of boat hit dolphins per county*	Rate/100	p value
1A	Volusia	129	8	6.4	0.79
1C, 1B, 2	Brevard	362	20	5.4	Ref
3	Indian River	74	5	6.2	0.70
4	St. Lucie, Martin	76	8	9.9	0.26

Table 3. Registered boats and habitat encroachment per dolphin within counties bordering the Indian River Lagoon, Florida (2002 to 2005)

County	No. of distinct dolphins	Km^2 surface area	No. registered boaters	Boats/km^2	Distinct dolphins/km^2	Boats/distinct dolphin per km^2 habitat
Volusia	129	159	14,720	93	1.23	75
Brevard	362	572	38,446	67	1.58	43
Indian River	74	71	10,762	152	1.03	147
St. Lucie, Martin	76	125	29,597	237	1.66	143

Mortality
Two dolphins with photographic evidence of vessel-associated injury died as a consequence of that initial contact. A 2-mo-old calf died as a result of a propeller slice through the skull, and a breeding female died from a pneumothorax as a result of boat impact.

Analysis of Dolphin Behavior in the Presence and Absence of Vessels
Travel was the most frequently observed activity, and resting was the least expressed activity during encounters with 0 to 10 vessels other than the investigator's (Figure 2). Anomalous behavior was observed when dolphins encountered > 10 vessels. Behavioral activity significantly shifted with increasing vessel abundance for all behaviors except rest (Table 4). During encounters with one to five vessels, "travel" and "mill" behaviors significantly increased (1.35 and 1.60, respectively), while "feeding" and "boat avoidance" behaviors significantly decreased (0.82 and 0.59, respectively). "Socialization" significantly increased (1.61) with > 6 vessels present.

Discussion

The prevalence of scarred living individuals in the IRL (43 of 714, or 6%) is higher than the rates found for dolphins in similar habitats in Sarasota, Florida (3% of the resident community) (Wells, 1993; Wells & Scott, 1997), and Indo-Pacific hump-backed dolphins (*Sousa chinensis*) in Hong Kong (3% of catalogued individuals) (Jefferson, 2000; Parsons & Jefferson, 2000). Vessel injury rates for IRL dolphins could be lower than reported here since these rates were based only on the distinctly marked portion of the population. However, a dependent calf of a mortally wounded mother died within 3 wks of being

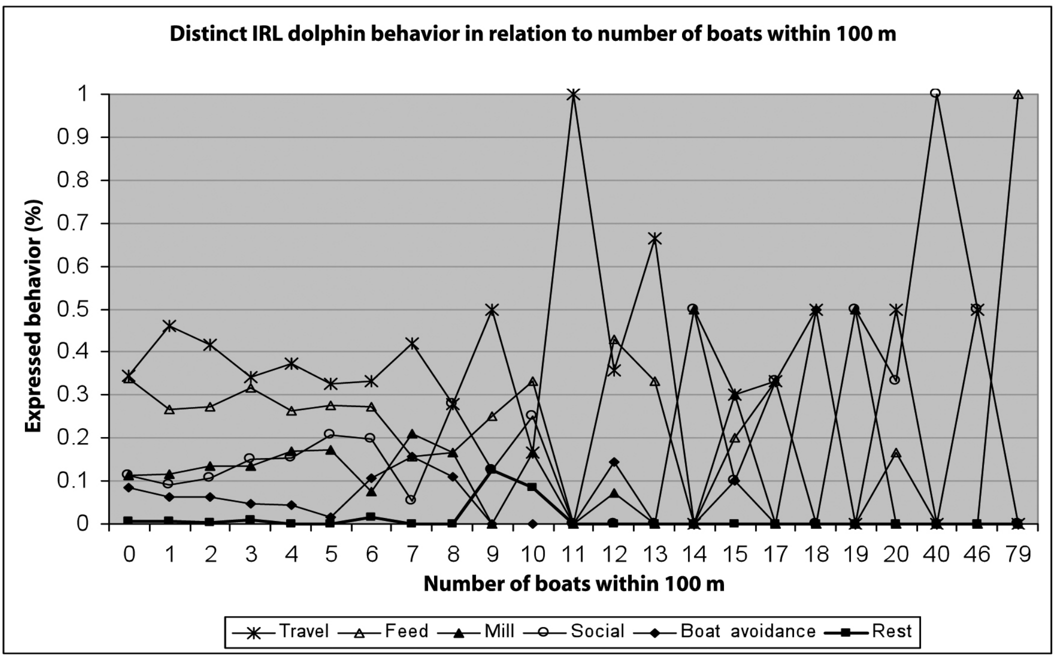

Figure 2. Bottlenose dolphin activity patterns and number of boats within 100 m in the Indian River Lagoon, Florida (1996 to 2006)

Table 4. Relative risk (95% CI) for behavior frequencies between categories of boats within 100 m; REF = referent category—investigator's boat only.

	Boat avoidance	Travel	Feeding	Social	Rest	Mill
0 boats	REF	REF	REF	REF	REF	REF
1-5 boats	0.59 (0.48-0.73)*	1.35 (1.26-1.45)*	0.82 (0.69-0.97)*	0.97 (0.83-1.14)	1.37 (0.66-2.86)	1.60 (1.15-2.26)*
> 5 boats	1.09 (0.68-1.77)	0.96 (0.78-1.21)	1.32 (0.80-2.16)	1.61 (1.15-2.26)*	0.48 (0.15-1.56)	0.72 (0.47-1.11)

* Statistically significant at $\alpha < 0.05$

orphaned (Mazzoil et al., 2008b), suggesting that secondary deaths as a result of vessel strikes could be underrepresented. Evidence of human interaction was identified in 10% of carcasses recovered in the IRL from 1977 to 2005, but the interactions were not separated by type (Stolen et al., 2007).

Within the study area, 24% of manatee deaths were due to watercraft-related impact (Rommel et al., 2007). Although this species differs in many ways, they share the same habitat and similar human threats as inland dolphins. Our data represent survivors of boating interactions (excluding two known deaths), suggesting that dolphins might be more physically adept at avoidance, are sensitized (an increase in behavioral responsiveness over time when animals learn that repeated or ongoing stimulus has significant consequences; Richardson et al., 1995) to vessel interactions, occupy non-trafficked areas, or a combination of these factors.

The IRL population is separated into three separate communities that have distinct geographic boundaries and site fidelity (Mazzoil et al., 2008a). Although our research did not find a significant difference in the rate of boat-injured dolphins between the IRL segments, the highest rate occurred in Segment 4 (Martin and St. Lucie Counties). This segment also had the highest number of registered boaters, the smallest area of watershed habitat per km^2, and two deaths from boat collisions. Currently, each dolphin residing in Segment 4 shares the same physical space with 143 vessels. This estimate does not include unregistered vessels or vessels registered in different counties and states. Projected vessel registration for Martin County is forecasted to increase 20% by 2020 (FWC, 2008b).

In addition, the three highest segment and county rates of vessel strikes all included deep-water inlets to the Atlantic Ocean (Ponce, Sebastian, Fort Pierce, and St. Lucie River inlets). These inlets are the routes for recreational boaters to access the popular offshore waters from the IRL (FWC, 2008b). Similar studies have found that dolphins may cluster at deep-water areas to avoid heavy boat traffic occupying their preferred shallow-water habitat (Wells & Scott, 1997; Lusseau, 2005). Fort Pierce inlet (Segment 4) is the only inlet to require slow speeds while entering lagoon waters from offshore. The St. Lucie inlet (also in Segment 4), which connects the Indian and St. Lucie Rivers at a high-speed junction, is considered one of the region's most active inlets (FWC, 2008b). Failure to identify statistically significant differences in the prevalence of vessel-associated injuries by county suggests that the shallow nature of the lagoon may be the primary factor in determining strike risk. Segment and county rates for vessel strikes in the southern portion of the IRL are not markedly higher despite a higher level of human activity, suggesting that dolphins may have a low degree of tolerance (i.e., a measurable behavioral response in a single point of time: "the intensity of disturbance that an individual tolerates without responding in a defined way" [Nisbet, 2000, p. 315]) to boating activities, which might lead to long-term sensitization. Preliminary behavioral data discussed below also support the possible theory of sensitization.

In the IRL, changes in the frequency of traveling increased and feeding decreased during sightings with < 5 vessels within 100 m of the group. Similarly, bottlenose dolphins within the Mississippi Sound increased traveling and decreased feeding behaviors after exposure to vessels within 100 m (Miller et al., 2008). Irrawaddy dolphins (*Orcaella brevirostris*) immediately changed from traveling or socializing behaviors when boats were < 100 m, whereas animals exhibiting feeding behaviors were more prone to continue feeding (Van Waerebeek et al., 2007). The insignificant increase in "boat avoid" behavior between 1 to 5 vessels vs > 5 vessels, suggests that tolerance levels may be at an apex level with only a few boats. It is possible that the energetic demands of traveling and feeding are compounded with the stress of avoiding boat collisions, leaving the animal without ample time to replenish biological reserves (Lusseau & Bejder, 2007). Comparable studies found the lack of resting behavior a significant concern to dolphin energetic budgets (Lusseau, 2003b; Constantine et al., 2004; Lusseau & Higham, 2004; Stockin et al., 2008). Resting behavior was the least expressed activity (< 1%) during the 10-y study period. Lack of rest, continual vessel avoidance, and the projected increase in human impacts may ultimately result in chronic stress for this population.

Activity budgets and energy expenditures are also important in examining the sustainability of a distressed population. Vessel avoidance expends energy that could be allocated for feeding, mating, maternal care, or resting, ultimately effecting species survival (Bejder & Samuels, 2003; Hastie et al., 2003). As stress diverts attention from these critical behaviors, the animal progresses to distress, compromising the immune system (Moberg, 2000). Home ranges for three of the four boat-injured dolphins with presumed lobomycosis (*Lacazia loboi*), which is associated with immune system compromise (Bossart, 1984; Reif et al., 2008), were in the southern community (Segments 3 and 4) (Mazzoil et al., 2008a; Murdoch et al., 2008). Conceivably, the level of distress from continual vessel avoidance constitutes a chronic stress for members of the southern community, which might be adequate to increase susceptibility to diseases such as lobomycosis (Murdoch et al., 2008). Recent evidence shows that dolphins with lobomycosis have depressed adaptive immunity, which could increase susceptibility to infectious agents (Reif et al., 2008).

More than 50% of IRL boat-hit dolphins were female, raising concerns regarding fecundity. Research has indicated that loss of fitness from enduring an unsuitable environment can result in low reproductive success in dolphins (Lusseau & Bejder, 2007). Differences in behavioral responses have been observed between male and female killer whales experiencing the same stressor (Williams et al., 2002). Lusseau (2003a) suggested that female dolphins may have an increased risk for vessel interactions due to their lower energy stores. This increase in risk could lead to having a higher rate of boat collisions for females, potentially jeopardizing offspring. First-time mothers might also be at greater risk as experienced mothers have longer inter-breath intervals associated with avoiding vessels (Nowacek et al., 2001). In the IRL, of the 15 boat-injured known reproductive females, eight (> 50%) have lost one or more calves before the age of 1 y. Further, one vessel-related mortality was a first-time mother, while the second direct mortality was a calf < 2 mo of age.

Possible improvements to legislative and management practices include mandatory boater education and the creation and enforcement of slow speed zones in high disturbance areas within dolphin habitats. The creation, enforcement, and compliance of slow speed zones within critical manatee habitats have reduced the number of deaths of Florida manatees dramatically (Laist & Shaw, 2006; Calleson & Frohlich, 2007). A similar decline in injuries would be expected for dolphins if critical habitats are defined and protected. However, despite increased efforts to educate boaters, boating fatalities and accidents continue to rise in Florida, suggesting that voluntary education may be insufficient to address safety issues.

The long-term survival of IRL dolphins should be a priority for Florida residents and local, state, and federal agencies charged with protecting this valuable resource. Slight changes within the environment can be detected by monitoring the health and population dynamics of these sentinel animals (Reddy et al., 2001; Wells et al., 2004; Bossart, 2006). Our study supports and adds to previous studies that show that human encroachment might negatively affect the delicate balance of aquatic and terrestrial life in the estuarine ecosystem. This study highlights the need for continued research and alerts the regional community to take action to preserve our shared resource.

Acknowledgments

This research was conducted under NOAA Fisheries permits: General Authorization 32 (File 39) issued to M. Mazzoil and Scientific Research Permit 998-1678 issued to G. Bossart. Funding was provided by the Florida Protect Wild Dolphins license plate. Special gratitude is extended to David S. Kilpatrick, DVM, for necropsy analysis of vessel-impacted dolphins, Greg O'Corry-Crowe for discussions regarding behavior, and Nelson Beaman for database support. HBOI contribution number 1786.

Literature Cited

Allaby, M. (1999). *A dictionary of zoology*. Oxford, UK: Oxford University Press.

Allen, M. C., & Read, A. J. (2000). Habitat selection of foraging bottlenose dolphins in relation to boat density near Clearwater, Florida. *Marine Mammal Science*, *16*, 815-824.

Au, D., & Perryman, W. (1982). Movement and speed of dolphin schools responding to an approaching ship. *Fishery Bulletin*, *80*, 371-379.

Bearzi, G., Notarbartolo di Sciara, G., & Politi, E. (1997). Social ecology of bottlenose dolphins in the Kvarneric (Northern Adriatic Sea). *Marine Mammal Science*, *13*, 650-668.

Beck, C. A., Bond, R. K., & Rathbun, G. B. (1982). Analyses of propeller wounds on manatees in Florida. *Journal of Wildlife Management*, *46*, 531-535.

Bejder, L., & Samuels, A. (2003). Evaluating the effects of nature-based tourism on cetaceans. In N. Gales, M. Hindell, & R. Kirkwood (Eds.), *Marine mammals: Fisheries, tourism and management issues* (pp. 229-256). Collingwood, Australia: CSIRO Publishing. 480 pp.

Bejder, L., Dawson, S., & Harraway, J. A. (1999). Responses by Hector's dolphins to boats and swimmers in Porpoise Bay, New Zealand. *Marine Mammal Science*, *15*, 738-750.

Bejder, L., Samuels, A., Whitehead, H., & Gales, N. (2006a). Interpreting short-term behavioral responses to disturbance within a longitudinal perspective. *Animal Behavior*, *72*, 1149-1158.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., et al. (2006b). Decline in relative abundance of bottlenose dolphins (*Tursiops* sp.) exposed to long-term disturbance. *Conservation Biology*, *20*, 1791-1798.

Bossart, G. D. (1984). Suspected acquired immunodeficiency in an Atlantic bottlenose dolphin with chronic-active hepatitis and lobomycosis. *Journal of the American Veterinary Medical Association*, *185*, 1413-1414.

Bossart, G. D. (2006). Marine mammals as sentinel species for oceans and human health. *Oceanography*, *19*, 44-47.

Bossart, G. D., Goldstein, J. D., Murdoch, M. E., Fair, P. A., & McCulloch, S. D. (2006). *Health assessment of bottlenose dolphins in the Indian River Lagoon, Florida and Charleston, South Carolina* (Harbor Branch Oceanographic Institution Technical Report No. 93). 36 pp.

Bruce-Allen, L. J., & Geraci, J. R. (1985). Wound healing in the bottlenose dolphin (*Tursiops truncatus*). *Canadian Journal of Fisheries and Aquatic Sciences*, *42*, 216-228.

Calleson, C. S., & Frohlich, R. K. (2007). Slower boat speeds reduce risks to manatees. *Endangered Species Research*, *3*, 295-304.

Constantine, R., Brunton, D. H., & Dennis, T. (2004). Dolphin-watching tour boats change bottlenose dolphins (*Tursiops truncatus*) behavior. *Biological Conservation*, *117*, 299-307.

Crouse, D. T., Crowder, L. B., & Caswell, H. (1987). A stage-based population model for loggerhead sea turtles and implications for conservation. *Ecology*, *68*, 1412-1423.

Duffus, D. A., & Dearden, P. (1993). Recreational use, valuation, and management of killer whales (*Orcinus orca*) on Canada's Pacific coast. *Environmental Conservation*, *20*, 149-156.

Erbe, C. (2002). Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science*, *18*, 394-418.

Florida Fish and Wildlife Conservation Commission (FWC) (2008a). *Florida Fish and Wildlife Conservation Commission: Boating accident statistics.* Retrieved 20 February 2009 from http://myfwc.com/SAFETY/Safety_Boat_Safety_AccidentStats.htm.

FWC. (2008b). *Florida Fish and Wildlife Conservation Commission: Martin County vessel traffic study.* Retrieved 20 February 2009 from www.floridaconservation.org/boating/Docs/traffic_report/1BIntroduction.pdf.

Hastie, G. D., Wilson, B., & Tufft, L. H. (2003). Bottlenose dolphins increase breathing synchrony in response to boat traffic. *Marine Mammal Science*, *19*, 74-84.

Howells, E. M., Reif, J. S., Bechdel, S. E., Murdoch, M. E., Bossart, G. D., McCulloch, S. D., et al. (2009). A novel case of non-offspring adoption in a free-ranging Atlantic bottlenose dolphin (*Tursiops truncatus*) inhabiting the Indian River Lagoon, Florida. *Aquatic Mammals*, *35*(1), 43-47.

Janik, V. M. (1996). Changes in surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science*, *12*, 597-602.

Jefferson, T. A. (2000). Population biology of the Indo-Pacific hump-backed dolphin in Hong Kong waters. *Wildlife Monographs*, *144*, 1-67.

Kaiya, Z., & Xingduan, Z. (1991). *Baiji: The Yangtze River dolphin and other endangered animals of China.* Washington, DC: Stone Wall Press.

Kruse, S. L. (1991). The interactions between killer whales and boats in Johnstone Strait, B.C. In K. Pryor & K. S. Norris (Eds.), *Dolphin societies: Discoveries and puzzles* (pp. 149-159). Berkeley: University of California Press.

Laist, D. W., & Shaw, C. (2006). Preliminary evidence that boat speed restrictions reduce deaths of Florida manatees. *Marine Mammal Science*, *22*, 472-479.

Laist, D. W., Knowlton, A. R., Mead, J. G., Collet, A. S., & Podesta, M. (2001). Collisions between ships and whales. *Marine Mammal Science*, *17*, 33-75.

Lightsey, J. D., Rommel, S., Costidis, A., & Pitchford, T. D. (2006). Methods used during gross necropsy to determine watercraft-related mortality in the Florida manatee (*Trichechus manatus latirostris*). *Journal of Zoology and Wildlife Medicine*, *37*, 262-275.

Lusseau, D. (2003a). Male and female bottlenose dolphins (*Tursiops* spp.) have different strategies to avoid interactions with tour boats in Doubtful Sound, New Zealand. *Marine Ecology Progress Series*, *257*, 267-274.

Lusseau, D. (2003b). The effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. *Conservation Biology*, *17*, 1785-1793.

Lusseau, D. (2005). Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecology Progress Series*, *295*, 265-272.

Lusseau, D. (2006). The short-term behavioral reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. *Marine Mammal Science*, *22*, 802-818.

Lusseau, D., & Bejder, L. (2007). The long-term consequences of short-term responses to disturbance experiences from whale watching impact assessment. *International Journal of Comparative Psychology*, *20*, 228-236.

Lusseau, D., & Higham, J. E. S. (2004). Managing the impacts of dolphin-based tourism through the definition of critical habitats: The case of the bottlenose dolphins (*Tursiops truncatus*) in Doubtful Sound, New Zealand. *Tourism Management*, *25*, 657-667.

Mattson, M. C., Thomas, J. A., & St. Aubin, D. (2005). Effects of boat activity on the behavior of bottlenose dolphins (*Tursiops truncatus*) in waters surrounding Hilton Head Island, South Carolina. *Aquatic Mammals*, *31*(1), 133-140.

Mazzoil, M., McCulloch, S. D., & Defran, R. H. (2005). Observations of the site fidelity of bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. *Florida Scientist*, *68*, 217-226.

Mazzoil, M., McCulloch, S. D., Defran, R. H., & Murdoch, M. E. (2004). Use of digital photography and analysis of dorsal fins for photo-identification of bottlenose dolphins. *Aquatic Mammals*, *30*(2), 209-219.

Mazzoil, M., McCulloch, S. D., Murdoch, M. E., Bechdel, S. E., Howells, E., Youngbluth, M., et al. (2008a). Home ranges of bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida: Environmental correlates and implications for the interpretation of health status. *EcoHealth*, *5*, 278-288. doi:10.1007/s10393-008-0194-9

Mazzoil, M., McCulloch, S. D., Youngbluth, M. J., Kilpatrick, D. S., Murdoch, M. E., Mase-Guthrie, B., et al. (2008b). Radio tracking and survivorship of two rehabilitated bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. *Aquatic Mammals*, *34*(1), 54-64. doi:10.1578/AM.34.1.2008.54

Miller, L. J., Solangi, M., & Kuczaj II, S. A. (2008). Immediate response of Atlantic bottlenose dolphins to high-speed personal watercraft in the Mississippi Sound. *Journal of Marine Biological Association of the United Kingdom.* Cambridge, UK: Cambridge University Press. doi:10.1017/S0025315408000908

Moberg, G. P. (2000). Biological response to stress: Implications for animal welfare. In G. P. Moberg & J. A. Mench (Eds.), *The biology of animal stress* (pp. 1-21). New York: CABI Publishing.

Morgan, M. A., & Patton, G. W. (1990). *Human dolphin interactions on the west coast of Florida: Documentation from MML's Marine Mammal Response Program.* (Mote Marine Laboratory Technical Report No. 191). 9 pp.

Murdoch, M. E., Reif, J. S., Mazzoil, M., McCulloch, S. D., Fair, P. A., & Bossart, G. D. (2008). Lobomycosis in bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon, Florida: Estimation of prevalence, temporal trends and spatial distribution. *EcoHealth*, *5*, 289-297. doi:10.1007/s10393-008-0187-8

Nisbet, I. C. T. (2000). Disturbance, habituation, and management of waterbird colonies. *Waterbirds*, *23*, 312-332.

Nowacek, S. M., Wells, R. S., & Solow, A. R. (2001). Short-term effects of boat traffic on bottlenose dolphins, *Tursiops truncatus*, in Sarasota Bay, Florida. *Marine Mammal Science*, *17*, 673-688.

Parsons, E. C. M., & Jefferson, T. A. (2000). Post-mortem investigations on stranded dolphins and porpoises from Hong Kong waters. *Journal of Wildlife Diseases*, *36*, 342-356.

Polacheck, T., & Thorpe, L. (1990). The swimming direction of harbor porpoise in relationship to a survey vessel. *Report of the International Whaling Commission*, *40*, 463-470.

Reddy, M. L., Reif, J. S., Bachand, A., & Ridgway, S. H. (2001). Opportunities for using Navy marine mammals to explore associations between organochlorine contaminants and unfavorable effects on reproduction. *Science of the Total Environment*, *274*, 171-182.

Reif, J. S., Peden-Adams, M. M., Romano, T. A., Rice, C. D., Fair, P. A., & Bossart G. D. (2008). Immune dysfunction in Atlantic bottlenose dolphins (*Tursiops truncatus*) with lobomycosis. *Medical Mycology*. doi: 10.1080/13693780802178493

Richardson, W. J., Greene, C. R., Jr., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise* (pp. 252-274). San Diego: Academic Press.

Robbins, C. T. (1993). Disease and injury. In C. T. Robbins (Ed.), *Wildlife feeding and nutrition* (pp. 238-239). San Diego: Academic Press.

Rommel, S. A., Costidis, A. M., Pitchford, T. D., Lightsey, J. D., Snyder, R. H., & Haubold, E. M. (2007). Forensic methods for characterizing watercraft from watercraft-induced wounds on the Florida manatee (*Trichechus manatus latirostris*). *Marine Mammal Science*, *23*, 110-132.

Scott, E. M., Mann, J., Watson-Capps, J. J., Sargeant, B. L., & Connor, R. C. (2005). Aggression in bottlenose dolphins: Evidence for sexual coercion, male-male competition, and female tolerance through analysis of tooth-rake marks and behaviour. *Behaviour*, *142*, 21-44.

Sini, M. I., Canning, S. J., Stockin, K. A., & Pierce, G. J. (2005). Bottlenose dolphins around Aberdeen harbor, north-east Scotland: A short study of habitat utilization and the potential effects of boat traffic. *Journal of Marine Biological Assessment United Kingdom*, *85*, 1547-1554.

Spradlin, T. R., Terbush, A. D., & Smullen, W. S. (1998). NMFS update on human/dolphin interactions in the wild. *International Marine Animal Trainers' Association, Soundings*, *23*, 25-27.

Stockin, K. A., Lusseau, D., Bindell, V., Wiseman, N., & Orams, M. B. (2008). Tourism affects the behavioural budget of the common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series*, *355*, 287-295.

Stolen, M. K., Noke Durden, W., & Odell, D. K. (2007). Historical synthesis of bottlenose dolphins (*Tursiops truncatus*) stranding data in the Indian River Lagoon system, Florida from 1977-2005. *Florida Scientist*, *70*, 45-54.

Stone, G. S., & Yoshinaga A. (2000). Hector's dolphin (*Cephalorhynchus hectori*) calf mortalities may indicate new risks from boat traffic and habituation. *Pacific Conservation Biology, 6*, 162-170.

U.S. Coast Guard [USCG]. (2002-2005). *U.S. Department of Homeland Security United States Coast Guard* (Commandant Publications P16754.16, P16754.17, P16754.18, P16754.19). Retrieved 11 August 2009 from www.uscg.mil.

U.S. Environmental Protection Agency, National Estuary Program. (1996). *Indian River comprehensive conservation and management plan.* Retrieved 20 February 2009 from www.sjrwmd.com/itsyourlagoon/CD_order_form.html.

Urian, K. W., & Wells, R. S. (1996). *Bottlenose Dolphin Photo-Identification Workshop: March 21-22, 1996* (NOAA Technical Memorandum NMFS-SEFSC-393). Charleston, South Carolina.

Van Parijs, S. M., & Corkeron, P. J. (2001). Boat traffic affects the acoustic behaviour of Pacific humpback dolphins, *Sousa chinensis*. *Journal of Marine Biological Association of the United Kingdom*, *81*, 533-538.

Van Waerebeek, K., Baker, A. N., Felix, F., Gedamke, J., Iniguez, M., Sanino, G. P., et al. (2007). Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere: An initial assessment. *Latin American Journal of Aquatic Mammals*, *6*, 43-69.

Visser, I. N. (1999). Propeller scars on and known home range of two orca (*Orcinus orca*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research*, *33*, 635-642.

Wells, R. S. (1993). The marine mammals of Sarasota Bay. In P. Roat, C. Ciciccolella, H. Smith, & D. Tomoasko (Eds.), *Sarasota Bay: 1992 framework for action* (pp. 9.1-9.23). Sarasota Bay, FL: Sarasota National Estuary Program.

Wells, R. S., & Scott, M. D. (1997). Seasonal incidence of boat strikes on bottlenose dolphins near Sarasota, Florida. *Marine Mammal Science*, *13*, 475-480.

Wells, R. S., Rhinehart, H. L., Hansen, L. J., Sweeny, J. C., Townsend, F. I., Stone, R., et al. (2004). Bottlenose dolphins as marine ecosystem sentinels: Developing a health monitoring system. *Ecohealth*, *1*, 246-254.

Whelan, J. J. (1993). Recreational access and use assessment. In P. Roat, C. Ciciccolella, H. Smith, & D. Tomoasko (Eds.), *Sarasota Bay: 1992 framework for action* (pp. 13.1-13.20). Sarasota Bay, FL: Sarasota National Estuary Program.

Williams, R., Trites, A. W., & Bain, D. E. (2002). Behavioural responses of killer whales to whale-watching traffic: Opportunistic observations and experimental approaches. *Journal of Zoology London*, *256*, 255-270.

Woodward and Clyde Consultants. (1994). *Biological resources of Indian River Lagoon* (Final Technical Report, Project Number 92F274C). Melbourne, FL: Indian River Lagoon National Estuary Program.

Wright, S. D., Ackerman, B. B., Bonde, R. K., Beck, C. A., & Banowetx, D. J. (1995). Analysis of watercraft-related mortality of manatees in Florida, 1979-1991. In T. J. O'Shea, B. B. Ackerman, & H. F. Percival (Eds.), *Population biology of the Florida manatee* (Information and Technology Report 1) (pp. 259-268). Washington, DC: National Biological Service.