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Home Ranges of Bottlenose Dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida: Environmental Correlates and Implications for Management Strategies

Marilyn Mazzoil,¹ John S. Reif,² Marsh Youngbluth,¹ M. Elizabeth Murdoch,¹ Sarah E. Bechdel,¹ Elisabeth Howells,¹ Stephen D. McCulloch,¹ Larry J. Hansen,³ and Gregory D. Bossart¹

¹Center for Marine Ecosystem Health—Marine Mammal Research and Conservation Program, Harbor Branch Oceanographic Institute at Florida Atlantic University, 5600 U.S. 1 North, Fort Pierce, FL 34946

²Department of Environmental and Radiological Health Sciences, Colorado State University, Fort Collins, CO 80523

³National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 101 Pivers Island Road, Beaufort, NC 28516

Abstract: Photo-identification surveys conducted between 2002 and 2005 were used to determine dolphin home ranges and site fidelity within the Indian River Lagoon (IRL), Florida. The IRL was divided into six segments based on hydrodynamics and geographic features for purposes of characterization. Among the 615 dolphins with identifiable dorsal fins, 339 had ≥ 6 sightings and were used in segment and linear range analyses. The majority (98%) of dolphins were seen in ≤ 3 consecutive segments (331/339); of these, 44% (144/331) occurred in two segments, and 33% (109/331) in one segment. No dolphins were observed in all six segments. The largest number of dolphins was sighted in segment 1C (North Indian River). However, the highest density of dolphins was found in segment 2 (North-Central Indian River). Re-sighting rates for dolphins with ≥ 6 sightings ranged from 2.8 to 8.7 times observed. The mean linear home range varied from 22 to 54 km. Distributional analyses indicated that at least three different dolphin communities exist within the IRL: Mosquito Lagoon, and the North and South Indian River. No statistically significant correlations were found between the total number or density per km² of dolphins and surface water area, salinity, or contaminant loads within segments of the lagoon. These results suggest that dolphins do not selectively avoid areas with relatively unfavorable water quality. IRL dolphins should be studied on smaller spatial scales than currently practiced, and potential anthropogenic impacts should be evaluated based on geographic partitioning.

Keywords: bottlenose dolphin, Indian River Lagoon, photo-identification, environmental characterization, home range, ecosystem health

INTRODUCTION

Bottlenose dolphins (*Tursiops truncatus*) have been recognized as marine mammal sentinels in aquatic and coastal environments (Reddy et al., 2001; Wells et al., 2004;

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Correspondence to: Marilyn Mazzoil, e-mail: Mmazzoil@hboi.fau.edu

Bossart, 2006). Dolphins residing in nearshore habitats are exposed to an increasing variety of persistent pollutants (Berrow et al., 2002; Stein et al., 2003; Irwin, 2005) from anthropogenic sources that degrade their habitat, limit their food resources, and increase their susceptibility to diseases (Fair and Becker, 2000). As a long-lived species, dolphins are apex predators in the Indian River Lagoon

(IRL), Florida, exhibit site fidelity to the region (Odell and Asper, 1990; Mazzoil et al., 2005), and serve as important indicators for the effects of exposure to pollutants in the marine environment.

The IRL was declared an Estuary of National Significance in 1990 by the United States (U.S.) Environmental Protection Agency (EPA). This designation was the result of expansive human population growth, habitat, fisheries, and species loss, invasive species, freshwater inflow, excessive nutrients, sedimentation, pollutants, and toxins (U.S. EPA, 1996) negatively impacting the most biodiverse estuary in North America (Gilmore, 1977). Key biological indicators, including dolphins, were identified for implementation of research, management, and protection actions in the IRL Comprehensive Conservation and Management Plan (U.S. EPA, 1996). Dolphins in this ecosystem, which spans over one-third of the east coast of Florida, are exposed to marked variation in water quality and localized pollution.

Pathologic evidence from stranded IRL dolphins showed a high prevalence of infectious and inflammatory diseases, suggestive of immunologic dysfunction (Bossart et al., 2003). Photo-identification surveys conducted in the IRL identified a variety of dermal lesions on dolphins (Mazzoil et al., 2003). Further, increased stranding incidents in 1996 and 2000 (Stolen et al., 2007), and an Unusual Mortality Event in 2001 (Marine Mammal Commission, 2002) prompted the initiation of a Bottlenose Dolphin Health and Risk Assessment (HERA) project in 2003, to investigate anthropogenic contaminants (e.g., trace metals, PCBs, organochlorine pesticides, perfluorinated compounds, and polybrominated diphenyl ethers) and infectious disease agents in this population (Fair et al., 2006).

Dolphins in the IRL form part of a complex mosaic of stocks identified along the eastern seaboard of the U.S. (Waring et al., 2002). For purposes of conservation under the U.S. Marine Mammal Protection Act of 1972, the coastal western North Atlantic bottlenose dolphin population is defined in seven management units from New Jersey to Florida (Waring et al., 2002). Additional resident estuarine stocks exist, but are not differentiated from the coastal management units, and are in need of further investigation (Waring et al., 2008). For example, vessel-based photo-identification research has indicated that year-round resident dolphins occur in the sounds and estuaries within the South Carolina management unit (Gubbins, 2002; Zolman, 2002; Speakman et al., 2006), the northern Florida unit (Caldwell, 2001), and the central Florida unit

(Odell and Asper, 1990; Mazzoil et al., 2005). This article describes spatial distributions of dolphins within the IRL during a 3-year period (2002–2005). Knowledge of home ranges in conjunction with ongoing investigations of environmental pollution and health issues will serve to refine management strategies on both broad and fine geographic scales that are relevant to the ecology and behavior of IRL dolphins.

METHODS

Study Area

The Indian River Lagoon is a 250-km linear estuary located on the east central coast of Florida. Four distinct water bodies, Mosquito Lagoon, Indian River, and Banana River, interconnected via man-made canals, and the St. Lucie Estuary, constitute the major habitats (Fig. 1). The system is bisected by an Intracoastal Waterway (ICW) that extends from Maine to Miami, Florida. The average depth of the lagoon is 1.5 m, with maximum depths averaging 3.7 m in the dredged channels and harbors; widths vary from a few meters to 8.9 km (Gilmore, 1977). Five inlets and the Canaveral Lock connect the IRL to the Atlantic Ocean.

The IRL ecosystem was divided into six segments based on hydrodynamics and geographic features for purposes of characterization and management (Woodward-Clyde Consultants, 1994) (Fig. 1). The northern segments (1A, 1B, and 1C) have wide expanses of water, small watersheds, and low tidal ranges and flushing. The large surface area results in precipitation and evaporation being the most important parameters of the hydrologic cycle, and also provides a potential for mixing and dilution. However, the lack of inlets or tidal exchange in the northern areas makes these habitats highly susceptible to pollutant loading. Water quality in the central and southern segments of the lagoon (2, 3, and 4) is influenced by infusions of water from flood control drainage canals, e.g., in particular, runoff from agricultural watersheds and freshwater releases from Lake Okeechobee (Sime, 2005). Discharges from these sources introduce higher amounts of nutrients, metals, pesticides, and suspended solids into the system (Woodward-Clyde Consultants, 1994).

Field Program

From September 2002 to August 2005, photographic surveys of dolphins were conducted once monthly using a

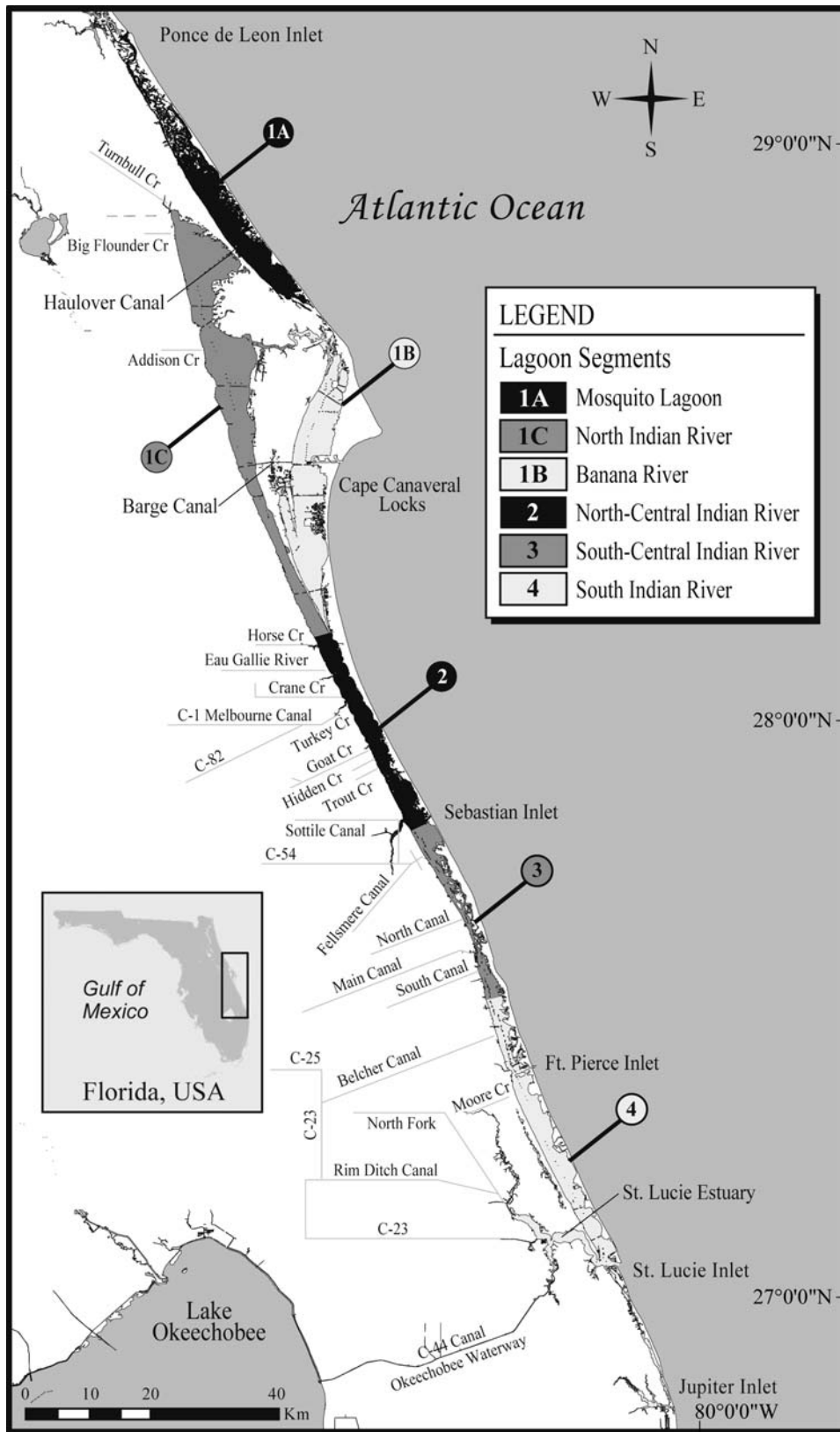


Figure 1. The Indian River Lagoon, Florida, U.S., sub-divided into six segments based on hydrodynamics and geographic features.

variety of vessels, ranging from 6 to 8 m in length, operated at a speed of 10–12 km/h. Due to the large expanse of the survey area, multiple days were needed each month to

assess the entire system. Surveys were conducted over consecutive days to the extent possible, with weather the most important factor in selecting days to ensure consistent

Table 1. Total surface water area, salinity, and non-point source pollutant loading rates projected for each segment through 2010

Segment no.	Total surface water area (km ²)	Salinity average	Biological oxygen demand (kg/year)	Total suspended solids (kg/year)	Total nitrogen (kg/year)	Total phosphorous (kg/year)	Lead (kg/year)	Zinc (kg/year)
1A	159	32.1	391,375	1,545,621	76,373	9802	2246	1571
1B	193	24.6	597,087	3,273,864	115,762	14,374	6232	4417
1C	286	27.1	1,038,213	4,673,337	228,102	27,099	7352	5311
2	93	24.5	1,666,942	6,550,482	367,008	44,113	11,410	7951
3	71	27.2	2,342,390	9,059,948	537,656	62,571	10,824	7617
4	125	33.8	6,024,699	38,071,868	1,823,098	227,471	34,317	28,022

sighting conditions. Monthly survey distance was determined using ESRI ArcGIS 9.0, by measuring the survey route in the ICW. This route allowed visual access to both shallow (<3 m) and deeper (≥ 3 m) sections of the IRL. Total survey distance for the complex was 344 km (segment 1A—52 km; segment 1B—38 km; segment 1C—82 km; segment 2—36 km; segment 3—35 km; segment 4—101 km). Field and photo-identification protocols have been described previously (Mazzoil et al., 2005).

Photo-identification Analyses

Field data were archived and analyzed with customized Microsoft Access software. Computer-based analyses of the digital images of dorsal fins were described previously (Mazzoil et al., 2004). In addition, the prototype image of each dolphin per sighting was assigned a score, based on a weighted system of photographic quality (Urian et al., 1999; Read et al., 2003) to reduce the chance of missing or making an incorrect identification (Friday et al., 2000). The distinctness of each dorsal fin was assigned a category (Urian et al., 1999; Read et al., 2003), and only those with major and intermediate features were used in the analyses.

Segment and Linear Analyses

Each dolphin (distinct and indistinct) was assigned to one of the six watershed hydrologic segments based on the GPS coordinates of a given encounter. The density of dolphins in each segment was calculated by dividing the total surface area of the segment in km² by the total number of dolphins sighted in that segment. The re-sighting rate for distinct dolphins was calculated by dividing the total number of sightings for distinct individuals by the total number of distinct dolphins seen in each segment. Linear ranges were

determined using a 1-km² latitudinal grid system, designed in ESRI ArcINFO, which was layered over individual sighting records. The difference in grid numbers between the two most distant points for each dolphin represented the total linear distance traveled for each individual.

Environmental Data

Total surface water area and salinity were defined for each segment from the literature (Table 1). Anthropogenic influences on the lagoon include pollution from non-point sources (e.g., stormwater runoff) that freshen the water and introduce oxygen-demanding materials (plant and animal matter), suspended solids (resulting in higher and longer bacterial survival rates), excessive nutrients (nitrogen and phosphorous), and toxic metals (lead and zinc) into the system. The pollutant loading rates for: biological oxygen demand (BOD), total suspended solids (TSS), total nitrogen (TN), total phosphorous (TP), lead (PB), and zinc (Zn) were calculated for expected land use conditions through 2010 (Woodward-Clyde Consultants, 1994) and quantified for each segment (Table 1). The relationship between total dolphin population and dolphin density per km² was evaluated by creating a correlation matrix for each demographic and environmental variable using Pearson's correlation coefficients. A *P* value <0.05 was considered statistically significant.

RESULTS

Field Program

Photo-identification surveys encompassed a total of 2755 h, with 1821 h spent actively searching for dolphins along the survey route ("on" survey), and 934 h spent

traveling to survey destinations and returning to port (“off” survey). If dolphins were encountered more than once while “on” survey or within the same survey month, only the first sighting was used in the analyses. “Off” survey sightings were not included in the analyses.

The mean number of days to complete each monthly survey was 8 (range: 4–12) and the mean number of total days spanned to complete each survey month was 20 (range: 8–28). Thirty-two of 36 monthly surveys, which covered the entire 344-km route, were completed. Four monthly surveys were incomplete due to mechanical failures, high winds, and multiple hurricanes. However, these less rigorous surveys (November 2002, December 2003, April 2004, and September 2004) obtained ample coverage of the entire complex (75–86%), and thus were included in the analyses.

Photo-identification Analysis

During the study period, 8686 dolphins were sighted during 1974 encounters and over 263,000 digital images were sorted, analyzed, and archived. Six-hundred and fifteen individual dolphins with distinct dorsal fins were identified.

Segment and Linear Range Analyses

Segment 1C (North Indian River) contained the highest number of dolphins (including indistinct dolphins) observed per area ($n = 2262$) and segment 3 (South-Central Indian River) the least ($n = 966$) (Table 2). However, the highest density of dolphins per km^2 was found in segment 2 (North-Central Indian River). The density of dolphins per km^2 in segment 2 was more than twice that of the density in segment 1B (Banana River).

Distinct dolphins with ≥ 6 sightings ($n = 339$) were used for linear range analyses. This approach provided a

Table 2. Number of distinct and indistinct dolphins sighted in each IRL segment by km^2

Segment no.	Total surface water area (km^2)	Total no. of dolphins sighted	Dolphins per km^2
1A	159	1974	12.4
1B	193	1017	5.3
1C	286	2262	7.9
2	93	1319	14.2
3	71	966	13.6
4	125	1148	9.2

sufficient number of individuals for analysis of general patterns. Seventy-five percent of recognizable dolphins (253 of 339) were sighted in ≤ 2 segments, and of these, 32% (109 of 339) were seen only in one segment. The majority of dolphins (98%) were seen in ≤ 3 segments and no dolphins were seen in all six segments of the system (Table 3). Dolphins in the Mosquito Lagoon (segment 1A) exhibited the strongest site fidelity, with 71% (67 of 94) seen exclusively therein. Dolphins in the Mosquito Lagoon also had the highest re-sighting rate (Table 4).

The mean linear range for dolphins ($n = 67$) utilizing only the Mosquito Lagoon (segment 1A) was 22 km (range: 5–42 km). Dolphins ($n = 27$) seen in both the Mosquito Lagoon and Indian River, had average maximum distances of 10 km (range: 1–35 km) and 28 km (range: 4–88 km) per each water body, respectively. Only two dolphins seen in the Mosquito Lagoon were observed in Barge Canal, which connects the Banana River with the Indian River (Fig. 2).

The mean linear range for dolphins ($n = 56$) observed in the Banana River (segment 1B) was 14 (range: 1–29 km) or 19 (range: 6–28 km) km in the Banana River, adjusted for entrance at the northern or southern entryways, and 38 km (range: 1–87 km) in the Indian River (Fig. 2). Two dolphins were sighted only within the Banana River. The mean linear range for dolphins ($n = 56$) observed in the St. Lucie River (segment 4) was 2 km (range: 1–8) and 55 km (range: 5–106) when also sighted in the Indian River. No dolphins used the St. Lucie River exclusively. The mean linear range for dolphins ($n = 133$) seen only in the Indian River was 54 km (range: 7–106 km) (Fig. 2).

Analysis of Environmental and Population Variables

No statistically significant correlations were found between total population or dolphin density per segment with any of the environmental variables (Table 5). Some environmental variables were highly correlated with each other within IRL segments.

DISCUSSION

Segment Analysis

These results add to the previous findings of site fidelity reported for dolphins from freeze-branding (Odell and Asper, 1990) and photo-identification studies (Mazzoil

Table 3. Number and percentage of distinct dolphins with ≥ 6 sightings observed in one or more IRL segments

Segment no.	1 Segment	2 Segments	3 Segments	4 Segments	5 Segments	6 Segments
1A	67	20	5	2	0	0
1B	2	0	0	0	0	0
1C	17	68	14	1	3	0
2	2	28	59	2	0	0
3	1	28	0	0	0	0
4	20	0	0	0	0	0
Total	109	144	78	5	3	0
Percentage	32.2%	42.5%	23.0%	1.5%	0.9%	0.0%

Table 4. Re-sighting rate per segment for dolphins with ≥ 6 sightings

Segment no.	Total no. of sightings for distinct dolphins	No. of distinct dolphins	Re-sighting rate
1A	820	94	8.7
1B	160	58	2.8
1C	655	130	5.0
2	634	141	4.5
3	595	129	4.6
4	847	113	7.5

et al., 2005), and provide documentation for the persistence of a resident population of dolphins within the IRL over a 30-year period. Interestingly, the findings in this study identify geographic partitioning by dolphins within environmentally characterized regions of the system. The majority of dolphins (75%) were sighted in ≤ 2 adjacent segments, signifying long-term site fidelity (the tendency to remain in an area over an extended period) within relatively restricted home ranges (the area traversed by an individual for food gathering, mating, and caring for young) (Burt, 1943), forming overlapping communities (“distinct assemblages of dolphins that inhabit similar ranges and that interact more with each other than with adjacent assemblages”; Wells, 1986). These findings are similar to those reported for dolphins in Sarasota Bay, FL (Wells, 1991).

Linear Analysis

The mean linear distances traveled by dolphins were similar for dolphins seen exclusively in the Indian River (54 km) and for those found in the triangular configuration of the

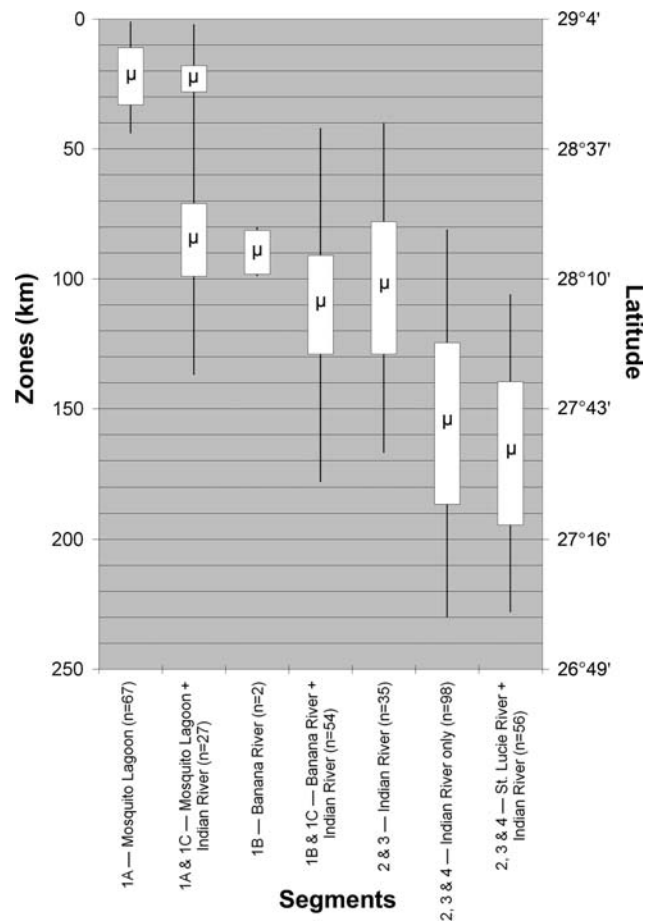


Figure 2. The linear home range represented by mean (rectangle) and extreme (line) for dolphins with ≥ 6 sightings.

combined Indian and Banana Rivers (52–57 km), suggesting that these habitats may be similar in resources. Home range dimensions have been linked to habitat differences (Shane, 1990), food resources (Balance, 1992; Defran et al., 1999), and reproductive resources (Scott et al., 1990). Odell and Asper (1990) found that dolphins using both the Indian and Banana Rivers averaged 30–

Table 5. Relationship between total dolphins and dolphin density with environmental variables and IRL segment

Population parameter	Environmental parameter						
	Salinity	Biological oxygen demand	Total suspended solids	Total nitrogen	Total phosphorous	Lead	Zinc
Total dolphins	0.19 ^a	-0.42	-0.36	-0.38	-0.37	0.40	0.38
	0.72*	0.41	0.48	0.46	0.47	0.43	0.46
Dolphin density/km ²	0.07 ^a	0.03	-0.08	-0.02	-0.03	0.06	0.08
	0.89*	0.95	0.88	0.98	0.96	0.91	0.88

^aCorrelation coefficient.**P* value.

45 km in total range versus 12 km for those dolphins only in the Indian River. The greater linear distances traversed in the current study may reflect a more comprehensive and longer duration of survey coverage.

The smaller mean distance traveled by dolphins in the Mosquito Lagoon can be associated with its non-impaired waterway status (Florida Department of Environmental Protection, 2007). This segment may be richer in prey resources that are uniformly distributed in space and time, and can support more dolphins as seen in South Carolina (Gubbins, 2002). However, travel distance may be an artifact of survey effort in this region, as coverage did not extend past the northern boundary of Ponce Inlet. For example, dolphins seen in the northern Indian River were reported as far as St. Augustine (Odell and Asper, 1990) and a dolphin freeze-branded in the Mosquito Lagoon in 2004 (Fair et al., 2006) stranded alive in St. Augustine [W. Noke, personal communication, 2006], suggesting that at least some of the dolphins in the Mosquito Lagoon range further north.

The linear analyses included single “outlier” sightings, likely overestimating the range size for some dolphins. Even the largest range (106 km) should be considered relatively small, given no geographic barriers preclude movement between segments. Further, while some home ranges overlapped, core areas (areas used more frequently than others) (Ewer, 1968) did not, for the four dolphins seen in the northernmost (segment 1B) and southernmost (segment 4) Indian River. Spatial separation patterns indicated disparate communities for each outermost region: Mosquito Lagoon, and the northern and southern portions of the Indian River. Genetic analyses would be informative to determine the degree of relatedness between these communities.

Environmental Analysis

No statistically significant correlations were observed between total population or dolphin density and surface water area, salinity, or contaminant loads (BOD, TSS, TN, TP, Pb, Zn) within the six segments of the lagoon. These results suggest that other factors determine dolphin distribution patterns in the IRL and have important implications for the development of protection and management strategies. For example, dolphins exhibit strong fidelity to well-defined segments of the system and do not avoid areas with poor environmental conditions (i.e., the high volume of freshwater intrusion in the St. Lucie Estuary and the high concentrations of nitrates and phosphates from agricultural activity). Similarly, resident dolphins in the Moray Firth, Scotland, exhibit persistent geographical segregation, indicating that they do not move freely within the Firth, and thus may be more susceptible to localized disturbance or pollution (Wilson et al., 1997). Along the Texas coast, dolphins consistently did not avoid slick and oil sheens from a major oil spill (Smultea and Würsig, 1995) and did not leave their preferred habitat during a 3-month-long red-tide event (Irwin, 2005), thereby increasing their exposure to chemicals and biotoxins. Exposure to brevetoxins produced by harmful alga blooms has been associated with marine mammal mortalities (Bossart et al., 1998; Flewelling et al., 2005; Fire et al., 2007), suggesting that dolphins are vulnerable to localized health hazards.

The concept that dolphins can simply move if their environment is disturbed reflects a common misperception of the marine environment as a uniform space (Wilson et al., 1997) and does not account for other influences on distribution such as prey availability (Shane, 1990), predation risk (Corkeron, 1990; Heithaus and Dill,

2002), calving events (Mann et al., 2000), gender (Wells et al., 1990), and social organization (Bräger, 1999). Further, when negative impacts are not uniformly distributed, some population units may be overexploited while others remain intact (Wade and Angliss, 1997). Two examples of regional site fidelity and localized disturbances are illustrated for the IRL, whereas a third example demonstrates the impact of disease due to overlapping community boundaries.

Example 1

An Unusual Mortality Event was declared by the National Marine Fisheries Service in 2001 (Marine Mammal Commission, 2002) when a record number of dolphin deaths occurred in the IRL within a 4-month period. Most dolphins (32 of 34) stranded in a small geographic area (Stolen et al., 2007), in segments 1B, 1C, and the northern tip of segment 2. The stranding locations were representative of the home range characteristics of dolphins seen within the Indian and Banana River triangular complex in this study, indicating that the cause of the mortality was confined to a particular geographic range. The etiology of these mortalities remains undetermined, but a link to saxitoxin producing puffer fish poisoning has been suggested (Landsberg et al., 2006).

Example 2

Lobomycosis is a chronic, mycotic disease caused by a yeast-like organism (*Lacazia loboi*), and found only in humans and dolphins (Rodriguez-Toro, 1993). A 30% (9 of 30) prevalence of lobomycosis was reported among HERA dolphins captured in segment 4 (South Indian River), with no cases detected among 45 dolphins captured in the northern sections (Reif et al., 2006). The localization of photographically identified lobomycosis among dolphins with home ranges in segment 3 (South-Central Indian River) and segment 4 (South Indian River) (Murdoch et al., 2008), characterized by freshwater intrusion and lower salinity, suggests that exposure to localized environmental conditions may contribute to the unusually high prevalence of the disease. The source of the organism for the disease in humans is believed to be an aquatic environment or soil and vegetation associated with the natural habitat of the fungus (Rodriguez-Toro, 1993). The specific environmental factors contributing to the distribution of the disease in dolphins remain unknown.

Example 3

Bossart et al. (2005) reported oral and genital neoplasms among IRL dolphins captured during HERA between 2003 and 2005. Evidence suggests that these tumors contain a papillomavirus as well as a herpesvirus (Bossart et al., 2005; Rehtanz et al., 2006), and are spread horizontally by dolphin-to-dolphin contact. Home ranges for these dolphins included segments 1A, 1B, 1C, 2, and 4. Since dolphins in the IRL exhibit a fluid social structure (Kent et al., 2008), are promiscuous breeders, and use adjacent segments of the IRL as shown in this report, these and other infectious disease agents have the potential to be transmitted throughout the ecosystem.

CONCLUSION

Overall findings suggest that at least three different dolphin communities exist within the IRL as important functional elements of the ecosystem and should be managed, at minimum, as a separate stock along the western North Atlantic seaboard. IRL dolphins appear to be susceptible to localized environmental disturbances as well as far-reaching epizootic events. The limited ranging behavior of these dolphins suggests that applying the appropriate spatial scales to assess deleterious environmental impacts will be necessary to fully address localized conservation and management strategies.

Recent studies have highlighted the significance of long-term monitoring data on dolphin habitat use, environmental characterization, and health (Wells et al., 2005; Adams et al., 2008; Litz et al., 2008). As additional data regarding the health status of IRL dolphins become available from capture/release health assessments (Bossart et al., 2006), they should be evaluated by incorporating the ranging characteristics of individuals in order to explore environmental factors that may adversely impact dolphin health. The approach outlined here will be used in the future to explore fine-scale variation in the distribution of contaminants which may, in turn, provide clues as to their origins and inform management strategies to mitigate these exposures. Conversely, pooling health data among all IRL dolphins may obscure intra-regional variability and obscure exposure to small-scale environmental hazards.

Future investigations to elucidate dolphin population structure and habitat use within the IRL will be essential for developing appropriate strategies to protect and monitor

their health. Such investigations should include using photo-identification in conjunction with other field techniques (e.g., telemetry) as tools to study population dynamics and life history, and monitor spatial and temporal trends, the prevalence/occurrence of dermal disease, reproductive success, and mortality patterns. Furthermore, field studies should be conducted in concert with biopsy sampling—to delineate genetic structure within the various communities, and measure individual fitness and population viability—and capture-release sampling of dolphins for health assessment.

Longitudinal trends in home range patterns and health status should be combined and used to measure the results of restoration efforts undertaken by the U.S. EPA National Estuary Program (1996), the Comprehensive Everglades Restoration Plan (2000), and others to reduce pollutants and restore water quality in the IRL. As key components in monitoring the environment (Wells et al., 2004; Bossart, 2006), dolphins play an integral role in mankind's stewardship of the irreplaceable and valued resources of the Indian River Lagoon.

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REFERENCES

- Adams JA, Houde M, Muir D, Speakman T, Bossart G, Fair P (2008) Land use and the spatial distribution of perfluoroalkyl compounds as measured in the plasma of bottlenose dolphins (*Tursiops truncatus*). *Marine Environmental Research*; doi: 10.1016/j.marenvres.2008.07.004
- Balance LT (1992) Habitat use patterns and ranges of the bottlenose dolphin in the Gulf of California, Mexico. *Marine Mammal Science* 8:262–274
- Berrow SD, McHugh B, Glynn D, McGovern E, Parsons KM, Baird RW, et al. (2002) Organochlorine concentrations in resident bottlenose dolphins (*Tursiops truncatus*) in the Shannon estuary, Ireland. *Marine Pollution Bulletin* 44:1296–1313
- Bossart GD (2006) Marine mammals as sentinel species for oceans and human health. *Oceanography* 19:44–47
- Bossart GD, Baden DG, Ewing RY, Roberts B, Wright SD (1998) Brevetoxicosis in manatees (*Trichechus manatus latirostris*) from the 1996 epizootic: gross, histologic, and immunohistochemical features. *Toxicologic Pathology* 26:276–282
- Bossart GD, Meisner R, Varela R, Mazzoil MS, McCulloch SD, Kilpatrick D, et al. (2003) Pathologic findings in stranded Atlantic bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon, Florida. *Florida Scientist* 66:226–238
- Bossart GD, Ghim S, Rehtanz M, Goldstein J, Varela R, Ewing R, et al. (2005) Orogenital neoplasia in Atlantic bottlenose dolphins (*Tursiops truncatus*). *Aquatic Mammals* 31:473–480
- Bräger S (1999) Association patterns in three populations of Hector's dolphin, *Cephalorhynchus hectori*. *Canadian Journal Zoology* 77:13–18
- Burt WH (1943) Territoriality and home range concepts as applied to mammals. *Journal of Mammalogy* 24:346–352
- Caldwell MJ (2001) Social and genetic structure of bottlenose dolphin (*Tursiops truncatus*) in Jacksonville, Florida. PhD dissertation, University of Miami, Coral Gables, Florida, p 143
- Comprehensive Everglades Restoration Plan (2000). Available: <http://www.evergladesplan.org> [accessed June 18, 2008]
- Corkeron PJ (1990) Aspects of the behavioral ecology of inshore dolphins *Tursiops truncatus* and *Sousa chinensis* in Moreton Bay, Australia. In: *The Bottlenose Dolphin*, Leatherwood S, Reeves RR (editors), San Diego, CA: Academic Press, pp 285–293
- Defran RH, Weller DW, Kelly DL, Espinosa MA (1999) Range characteristics of Pacific coast bottlenose dolphins (*Tursiops truncatus*) in the Southern California bight. *Marine Mammal Science* 15:381–393
- Ewer RF (1968) *Ethology of Mammals*, London: Legos Press
- Fair PA, Becker PR (2000) Review of stress in marine mammals. *Journal of Aquatic Ecosystem Stress and Recovery* 7:335–354
- Fair PA, Adams JD, Zolman E, McCulloch SD, Goldstein JD, Murdoch ME, et al. (2006) Protocols for conducting dolphin capture-release health assessment studies. Bottlenose Dolphin Health and Risk Assessment Project. NOAA Technical Memorandum NOS NCCOS 49, p 83
- Fire SE, Fauquier D, Flewelling LJ, Henry M, Naar J, Pierce R, et al. (2007) Brevetoxin exposure in bottlenose dolphins (*Tursiops truncatus*) associated with *Karenia brevis* blooms in Sarasota Bay, Florida. *Marine Biology* 152:827–834
- Flewelling LJ, Naar JP, Abbott JP, Baden DG, Barros NB, Bossart GD, et al. (2005) Red tides and marine mammal mortalities. *Nature* 435:755–756
- Florida Department of Environmental Protection (2007) Group five basins impaired waters list. Available: <http://www.dep.state.fl.us/water/tmdl/index.htm> [accessed June 18, 2008]
- Friday N, Smith TD, Stevick PT, Allen J (2000) Measurement of photographic quality and individual distinctiveness for the photographic identification of humpback whales, *Megaptera novaeangliae*. *Marine Mammal Science* 16:355–374
- Gilmore RG Jr (1977) Fishes of the Indian River Lagoon and adjacent waters, Florida. *Bulletin of the Florida Museum of Natural History. Biological Sciences* 22:101–148
- Gubbins C (2002) Use of home ranges by resident bottlenose dolphins (*Tursiops truncatus*) in a South Carolina estuary. *Journal of Mammal Research* 83:178–187

- Heithaus MR, Dill LM (2002) Food availability and tiger shark predation risk influence bottlenose dolphin habitat use. *Ecology* 83:480–491
- Irwin LJ (2005) Marine toxins: adverse health effects and bio-monitoring with resident coastal dolphins. *Aquatic Mammals* 31:195–225
- Kent E, Mazzoil M, McCulloch S, Defran RH (2008) Group characteristics and social affiliation patterns of bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. *Florida Scientist* 71:149–168
- Landsberg JH, Hall S, Johannessen JN, White KD, Conrad SM, Abbott JP, et al. (2006) Saxitoxin puffer fish poisoning in the United States, with the first report of *Pyrodinium bahamense* as the putative toxin source. *Environmental Health Perspectives* 114:1502–1507
- Litz JA, Garrison LP, Fieber LA, Martinez A, Contillo JP, Kucklick JR (2008) Fine-scale variation of persistent organic pollutants in bottlenose dolphins (*Tursiops truncatus*) in Biscayne Bay, Florida. *Environmental Science and Technology* 41:7222–7228
- Mann J, Connor RC, Barre LM, Heithaus MR (2000) Female reproductive success in bottlenose dolphins (*Tursiops sp.*): life history, habitat, provisioning, and group-size effects. *Behavioral Ecology* 11:210–219
- Marine Mammal Commission (2002) Annual Report to Congress, 264 p. Available: <http://www.mmc.gov/reports/annual> [accessed June 18, 2008]
- Mazzoil M, McCulloch SD, Bossart GD, Defran RH, Reif JS (2003) Epidemiologic analysis of dermatologic conditions in Atlantic bottlenose dolphins from the Indian River Lagoon, Florida using a geographic information system. Abstracts of the 15th Biennial Conference on the Biology of Marine Mammals, Greensboro, NC, p 106
- Mazzoil M, McCulloch SD, Defran RH, Murdoch ME (2004) Use of digital photography and analysis of dorsal fins for photo-identification of bottlenose dolphins. *Aquatic Mammals* 30:209–219
- Mazzoil M, McCulloch SD, Defran RH (2005) Observations on the site fidelity of bottlenose dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. *Florida Scientist* 68:217–227
- Murdoch E, Reif JS, Mazzoil M, McCulloch SD, Fair PA, Bossart GD (2008) Lobomycosis in bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon, Florida: estimation of prevalence, temporal trends and spatial distribution. *EcoHealth* 5(3); doi:10.1007/s10393-008-0187-8
- Odell DK, Asper ED (1990) Distribution and movements of freeze-branded bottlenose dolphins in the Indian and Banana Rivers, Florida. In: *The Bottlenose Dolphin*, Leatherwood S, Reeves RR (editors), San Diego, CA: Academic Press, pp 515–540
- Read AJ, Urian KW, Wilson B, Waples DM (2003) Abundance of bottlenose dolphins in the bays, sounds, and estuaries of North Carolina. *Marine Mammal Science* 19:59–73
- Reddy ML, Reif JS, Bachand A, Ridgeway SH (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
- Rehtanz M, Ghim S, Rector A, Van Ranst M, Fair PA, Bossart GD, et al. (2006) Isolation and characterization of the first American bottlenose dolphin papillomavirus: *Tursiops truncatus* papillomavirus type 2. *Journal of Genetic Virology* 87:3559–3565 . doi:10.1099/vir.0.82388-0
- Reif JS, Mazzoil MS, McCulloch SD, Varela RA, Goldstein JD, Fair PA, et al. (2006) Lobomycosis in Atlantic bottlenose dolphins from the Indian River Lagoon, Florida. *Journal of the American Veterinary Medical Association* 228:104–108
- Rodriguez-Toro G (1993) Lobomycosis. *International Journal of Dermatology* 32:324–332
- Scott MD, Wells RS, Irvine AB (1990) A long-term study of bottlenose dolphins on the west coast of Florida. In: *The Bottlenose Dolphin*, Leatherwood S, Reeves RR (editors), San Diego, CA: Academic Press, pp 235–244
- Shane SH (1990) Behavior and ecology of the bottlenose dolphin at Sanibel Island, Florida. In: *The Bottlenose Dolphin*, Leatherwood S, Reeves RR (editors), San Diego, CA: Academic Press, pp 267–283
- Sime P (2005) St. Lucie Estuary and Indian River Lagoon conceptual ecological model. *Wetlands* 25:898–907
- Smultea MA, Würsig B (1995) Behavioral reactions of bottlenose dolphins to the Mega Borg oil spill, Gulf of Mexico 1990. *Aquatic Mammals* 21:171–181
- Speakman T, Zolman E, Adams J, Defran RH, Laska D, Schwacke L, et al. (2006) Temporal and spatial aspects of bottlenose dolphin occurrence in coastal and estuarine waters near Charleston, South Carolina. U.S. Department of Commerce, NOAA Technical Memorandum NOS-NCCOS-37, p 56
- Stein JE, Tilbury KL, Meador JP, Gorelany J, Worthy GAJ, Krahn MM (2003) Ecotoxicological investigations of bottlenose dolphins (*Tursiops truncatus*) strandings: accumulation of persistent organic chemicals and metals. In: *Toxicology of Marine Mammals*, Vos JG, Bossart GD, Fournier M, O'Shea TJ (editors), London: Taylor and Francis, pp 458–485
- Stolen MK, Noke-Durden W, Odell DK (2007) Historical synthesis of bottlenose dolphin (*Tursiops truncatus*) stranding data in the Indian River Lagoon System, Florida, from 1977–2005. *Florida Scientist* 70:45–54
- U.S. EPA (1996) National Estuary Program, Indian River Comprehensive Conservation and Management Plan. Available: <http://www.epa.gov/owow/estuaries/programs/irl.htm> [accessed June 18, 2008]
- Urian KW, Hohn AA, Hansen LJ (1999) Status of the photo-identification catalog of coastal bottlenose dolphins of the western North Atlantic: report of a workshop of catalog contributors. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-SEFSC-425, p 24
- Wade P, Angliss R (1997) Guidelines for assessing marine mammal stocks: report of the GAMMS Workshop, in Seattle, Washington: April 3, 1996–April 5, 1996. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-OPR-12, p 93
- Waring GT, Quintal JM, Fairfield CP (2002) U.S. Atlantic and Gulf of Mexico marine mammal stock assessments—2002. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NE-169, p 318
- Waring GT, Josephson E, Fairfield CP, Maze-Foley K (2008) U.S. Atlantic and Gulf of Mexico marine mammal stock assessments—2007. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NE-205, p 415
- Wells RS (1986) Structural aspects of dolphin societies. PhD dissertation. University of California, Santa Cruz, p 234
- Wells RS (1991) The role of long-term study in understanding the social structure of a bottlenose dolphin community. In: *Dolphin Societies: Discoveries and Puzzles*, Pryor K, Norris KS (editors), Berkeley, CA: University of California Press, pp 199–225
- Wells RS, Hansen LJ, Baldrige A, Dohl TP, Kelly DL, Defran RH (1990) Northward extension of the range of bottlenose dolphins

- along the California coast. In: *The Bottlenose Dolphin*, Leatherwood S, Reeves RR (editors), San Diego, CA: Academic Press, pp 421–431
- Wells RS, Rhinehart HL, Hansen LJ, Sweeny JC, Townsend FI, Stone R, et al. (2004) Bottlenose dolphins as marine ecosystem sentinels: developing a health monitoring system. *EcoHealth* 1:246–254 . doi:[10.1007/s10393-004-0094-6](https://doi.org/10.1007/s10393-004-0094-6)
- Wells RS, Tornero V, Borrell A, Aguilar A, Rowles TK, Rhinehart HL, et al. (2005) Integrating life-history and reproductive success data to examine potential relationships with organochlorine compounds for bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Science of the Total Environment* 349:106–119
- Wilson B, Thompson PM, Hammond PS (1997) Habitat use by bottlenose dolphins: seasonal distribution and stratified movement patterns in the Moray Firth, Scotland. *Journal of Applied Ecology* 34:1365–1374
- Woodward-Clyde Consultants (1994) Biological resources of Indian River Lagoon. Indian River Lagoon National Estuary Program. Final Technical Report. Project Number: 92F274C, Melbourne, FL
- Zolman E (2002) Residence patterns of bottlenose dolphins (*Tursiops truncatus*) in the Stono River Estuary, Charleston County, South Carolina, USA. *Marine Mammal Science* 18:879–892