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Dolphin Sightings in the Vicinity of Land/Ocean Biogeochemical Observatories: Relationships with Weather and Water Quality

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Abstract

The objective of this study was to test the potential influence of short-term changes in water quality on the frequency of sightings of common dolphins (*Tursiops truncatus*) in the Indian River Lagoon, Florida. The study was based on two data sources: (1) Land/Ocean Biogeochemical Observatories (LOBOs) that provided real-time monitoring of multiple water quality and weather parameters, and (2) standardized methods for identifying and counting individual dolphins using photo-identification techniques. Water quality parameters included salinity, water color (chromophoric dissolved organic matter), conductivity, dissolved oxygen concentration, oxygen saturation, chlorophyll, nitrate and phosphate concentrations, temperature, and turbidity. Weather was assessed using data for air temperature, barometric pressure, humidity, light, and wind speed and direction. Variables were measured continuously over a one-year period and analyzed as the mean for each parameter the hour before, during, and after each dolphin sighting period. Short-term variations in sightings within 0.5 km of the LOBO were measured using previously established photo-identification techniques on a weekly basis. In multivariable regression analyses, statistically significant inverse associations were found between air temperature and the frequency of dolphin sightings for all three time periods. The results demonstrate the feasibility of integrating variation in weather and water chemistry data with dolphin movements as potential indicators of ecosystem quality and climate change.

Key Words: common bottlenose dolphins, *Tursiops truncatus*, water quality, photo-identification, Land/Ocean Biogeochemical Observatories, weather, Indian River Lagoon

Introduction

The Indian River Lagoon (IRL) is a unique shallow water coastal ecosystem, which extends 250 km along 40% of the east coast of Florida. From north to south, this linear estuary is comprised of three distinct, interconnected water bodies, the Mosquito Lagoon, Indian River, and Banana River and the St. Lucie estuary, that constitute the major dolphin habitats. With the exception of the dredged Intracoastal Waterway and channels, the average depth of the IRL is approximately 1.5 m (Woodward-Clyde Consultants, 1994). Due to its shallow depth and the limited tidal exchange between it and the Atlantic Ocean, the lagoon has minimal flushing and, thus, chemical and microbiological agents may become concentrated (Smith, 1993). Dense human development along the eastern coast of Florida and intense agricultural activity have resulted in increased freshwater inputs and altered water quality characterized by chemical contamination, high nutrient input, decreased salinity, decreased seagrass habitat, and eutrophication (Sigua et al., 2000; Sime, 2005).

The IRL was declared an Estuary of National Significance in 1990 by the U.S. Environmental Protection Agency (U.S. EPA) (1996) as a result of expansive human population growth; habitat, fisheries, and species loss; invasive species; excessive freshwater inflows; nutrient loading and eutrophication; pollutants; and algal toxins negatively impacting this biodiverse estuary. Key biological indicators, including common bottlenose dolphins (*Tursiops truncatus*), were identified for implementation of research, management, and protection actions in the federal National Estuary Program Comprehensive Conservation and Management Plan and the Comprehensive Everglades Restoration Program. Dolphins in this ecosystem are exposed to marked variation in water quality and localized pollution, primarily from non-point sources. Previous studies have documented the exposures of IRL dolphins to persistent organic and inorganic anthropogenic pollutants, which have been associated with a variety of health effects in this population (Reif et al., 2017).

As long-lived apex predators, dolphins in the IRL exhibit regional site fidelity and, therefore, serve as important indicators for the effects of water quality in the local marine environment (Mazzoil et al., 2005). In previous work, dolphins were found to inhabit segments of the IRL that are characterized by incursions of fresh water, nitrates, and phosphates (Mazzoil et al., 2008). However, there has been no work published to date to explore the potential effects of changes in water quality on short-term movements of dolphins in a limited geographic area using real-time data.

The current investigation was enabled by the placement of Land/Ocean Biogeochemical Observatories (LOBOs) (Sea-Bird Scientific, Bellevue, WA, USA) at key locations in the IRL as part of the Indian River Lagoon Observatory Network of Environmental Sensors (IRLON) (Hanisak et al., 2015). LOBOs provide intensive, real-time measurements of multiple indicators of water quality and the environment (Harbor Branch Oceanographic Institute [HBOI] at Florida Atlantic University; http://fau.loboviz.com). The objective of this study was to determine whether dolphin sighting frequency in the vicinity of IRLON stations was influenced by temporal changes in weather parameters or water quality. The over-arching hypothesis for the study was that dolphins were less likely to be sighted during periods of reduced water quality.

Methods

The study was based on two data sources: (1) IRLON (LOBO) units that provide real-time monitoring of multiple water quality parameters and weather data, and (2) standardized methods for identifying and counting individual dolphins by photo-identification techniques. Water quality and weather data were collected at two IRLON stations in the IRL. The Link Port station (IRL-LP) was located at the mouth of the Harbor Branch canal (Figure 1). This monitoring station was placed into operation on 1 March 2013. The instrument's probe was located at a depth of ~2.5 m where the water depth was ~3.5 m. The second station was located at the St. Lucie River Middle Estuary (SLE-ME) and was placed in operation on 9 September 2015. The SLE-ME observatory was located in an area of lower salinity due to the influx of fresh water from Lake

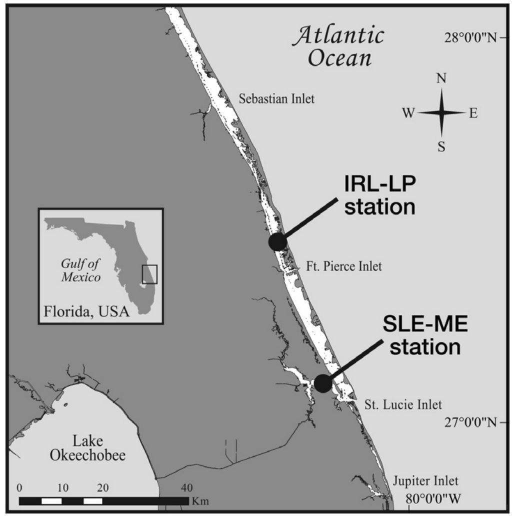

Figure 1. Map showing locations of Indian River Lagoon-Link Port (IRL-LP) and St. Lucie River Middle Estuary (SLE-ME) IRLON stations, Indian River Lagoon, Florida, 2016

Okeechobee, which empties into the St. Lucie River. Both the IRL-LP and SLE-ME stations also have weather stations.

The weather station at each IRLON site provided real-time monitoring of air temperature, barometric pressure, humidity, solar radiation (photosynthetically active radiation [PAR]), and wind speed and direction. Water quality data included chlorophyll, nitrate and phosphate concentrations, chromophoric dissolved organic matter (CDOM), conductivity, dissolved oxygen concentration, oxygen saturation, salinity, turbidity, and water temperature. Water quality and weather data (hourly readings) were downloaded from the HBOI website (http://fau.loboviz.com) and used in the analyses of each parameter. Units of measurement for each parameter are provided in Table 1.

Dolphin sightings were counted using standardized methods of photo-identification as previously described (Würsig & Würsig, 1977; Mazzoil et al., 2005, 2008). Boat-based surveys were conducted twice daily at a 4- to 6-h interval on a weekly basis. The boat maintained a continuous circular pathway around the monitoring station at a radius of 0.5 km from the IRLON station for 1 h. Observations, counts, and individual identification of dolphins were recorded by trained observers.

Data for each water quality and environmental parameter were downloaded for the hour prior (HP), the hour during (HO), and the hour after (HA) each dolphin survey. The data were evaluated for normality using the Kolmogorov Smirnov

Table 1. Weather and water quality variables measured at the Indian River Lagoon-Link Port (IRL-LP) IRLON station for the hour of, hour before, and hour after dolphin observations, Indian River Lagoon, Florida, 2016

Parameter	Unit of measurement	Mean	Standard deviation	Minimum	Maximum
Weather					
Air temperature	°C	24.71	5.02	9.80	31.70
Humidity	%	68.62	10.18	45.00	92.50
Barometric pressure	in Hg	30.16	0.29	29.10	30.70
PAR (light)	µmol/m^2/s	1,282.51	490.57	104.90	1,967.00
Wind direction	Degree	178.82	112.28	17.70	355.50
Wind speed	Mph	8.07	3.53	1.60	14.70
Water quality					
Chlorophyll concentration	µg/L	5.04	6.37	1.50	41.88
Dissolved oxygen	mg/l	6.46	1.85	0.02	10.14
Oxygen saturation	%	92.19	23.99	0.27	145.75
Salinity	PSU	27.32	6.72	0.01	34.13
Water temperature	°C	26.07	4.86	13.42	32.96
Turbidity	NTU	6.17	4.73	1.78	32.13
Water color CDOM	QSDE	28.54	12.44	12.49	64.78
Conductivity	S/m	4.03	1.30	0.00	5.75
Nitrate concentration	mg/L	0.03	0.05	-0.05	0.13
Phosphate concentration	mg/L	0.02	0.01	0.01	0.06

procedure. Environmental variables were log transformed as necessary to meet test assumptions. Pearson correlation coefficients were calculated initially for each water quality parameter at each time interval with the number of dolphins sighted. A stepwise, forward selection multivariate linear model was constructed for each time period (HP, HO, HA) with weather and water quality variables as covariates and the number of dolphins sighted during each survey as the dependent variable. All environmental variables were included in the analysis. The statistical criterion for retention in each step of the modelling process was $p < 0.25$. The models were also evaluated using goodness of fit and a change in R^2 of > 20% for selection. The final models contained only variables that were statistically significant at $p < 0.05$. Statistical analyses were conducted using *SPSS*, Version 23 (IBM, Armonk, NY, USA).

Results

A total of 82 boat-based surveys were conducted at the IRL-LP site between 1 January and 31 December 2016. A total of 266 dolphins were sighted during 48 surveys; no dolphins were sighted in the remaining 34 surveys. The 266 dolphins sighted comprised 173 sightings of photographically distinct individuals (65%) and 93 sightings of unmarked individuals. During the course of the study period, 107 individual dolphins were identified, all of which had been sighted during previous photo-identification surveys. Matching pre- and post-survey water quality measures were available for 72 of the 82 surveys and formed the basis for data analysis.

A total of 85 boat-based surveys were conducted at the SLE-ME site between 1 December 2015 and 9 May 2017. No dolphins were encountered during 80 of the 85 observation periods. A total of 31 dolphins were observed on the five occasions when animals were sighted. The number of sightings at this site was inadequate for statistical analysis.

In multivariable models, statistically significant inverse associations were found between air temperature and the frequency of dolphin sightings for each of the three time intervals: prior to, during, and after the survey (Table 2). Dolphins were more likely to be sighted when air temperature was lower over the 1-y observation period. Water temperature was significantly correlated with air temperature during each measurement period (r = 0.930 to 0.938, $p < 0.01$) but did not enter the final model. Humidity was a statistically significant predictor of the number of dolphin sightings only for the hour after the survey. *A priori* hypotheses developed to predict associations between dolphin sighting frequency and water quality included negative relationships with indicators of poor habitat quality, including high turbidity, low salinity, low concentrations of dissolved oxygen, and high concentrations of nitrates and phosphates. However, none of the water quality variables were significantly associated with the frequency of dolphin sightings in the vicinity of the IRL-LP LOBO.

Since the timeframe for the analysis encompassed a 1-y period, the inverse association between air temperature and the frequency of dolphin sightings suggests a seasonal rather than a short-term effect. The monthly frequency of dolphin sightings confirms the existence of a distinct seasonal pattern, with the preponderance of sightings during the winter months of December, January, and February of 2016 (Figure 2).

Table 2. Results of multivariable linear regression analyses showing statistically significant associations between total dolphins sighted during surveys and weather parameters from the IRL-LP IRLON station

Parameter	R^2	F	Beta	p value
Hour before				
Air temperature	0.167	7.434	- 0.409	0.010
Hour of				
Air temperature	0.146	6.175	-0.383	0.018
Hour after				
Humidity	0.125	6.267	0.325	0.017
Humidity, air temperature	0.196	4.212	-0.317	0.048

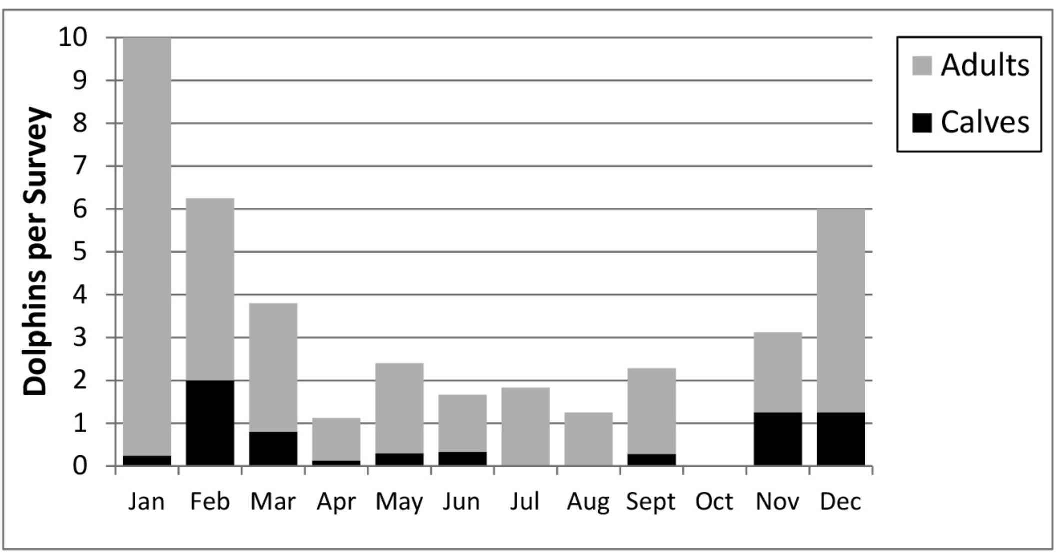

Figure 2. Mean monthly frequency of adult and calf dolphin sightings per survey at the IRL-LP IRLON station, 2016

Discussion

The IRL is a shallow, linear estuary with limited connections to the ocean (U.S. EPA, 1996). Long-term photo-identification studies of the dolphin population suggest a stable pattern of residency. Surveys conducted in the 1980s (Odell & Asper, 1990) as well as more comprehensive surveys carried out between 2002 and 2005 (Mazzoil et al., 2008) showed that IRL dolphins maintain a relatively high degree of site fidelity within the IRL. Movement of dolphins between the six hydrogeographically identified segments is limited, with 33% of dolphins sighted in only one segment and 44% in two segments (Mazzoil et al., 2008). Additionally, all 107 of the individual dolphins that were distinctly marked and identifiable in the current study had a previous sighting history within the IRL, suggesting that it is highly unlikely that these dolphins were transients or seasonal migrants.

Photographic surveys conducted between 2006 and 2008 in the Atlantic Ocean adjacent to the IRL showed an increase in the number of group sightings and group size during the winter months, consistent with the results of the current study (Mazzoil et al., 2011). With few exceptions, there appeared to be a distinct separation between the coastal Atlantic and IRL dolphin populations, suggesting that the higher sighting frequency of IRL dolphins in the vicinity of the IRL-LP LOBO during the winter is not due to movement of Atlantic Ocean dolphins into the IRL.

The IRL is impacted by influxes of fresh water containing high concentrations of nitrates, phosphates, and other chemicals from residential and agricultural applications, storm water events, and septic systems (Sigua et al., 2000; Lapointe et al., 2015). Enriched nutrient conditions have resulted in eutrophication, loss of seagrass beds, and harmful algal blooms (Lapointe et al., 2015). However, in the current study, water quality was not related to the frequency of dolphin sightings in the vicinity of the IRL-LP observatory. No statistically significant associations with nitrate or phosphate concentrations were found after adjustment for other variables. Similarly, in data collected during earlier photographic surveys of IRL dolphins, there were no statistically significant associations between the total number or density per km^2 of dolphins and surface water area, salinity, or contaminant loads within segments of the lagoon (Mazzoil et al., 2008). Further, projected pollutant loading rates were calculated for expected land use in each segment (U.S. EPA, 1996). No statistically significant correlation coefficients were found for biological oxygen demand, total suspended solids, total nitrogen, total phosphorous, lead, or zinc (Mazzoil et al., 2008).

Higher variability in water quality parameters was expected in the vicinity of the SLE-ME LOBO which is located in the St. Lucie River. The St. Lucie River drains Lake Okeechobee, the largest freshwater lake in Florida, through the St. Lucie C-44 canal, which contributes to lower salinity at the mouth of the estuary. The lake and its tributaries receive extensive runoff from agricultural activities in central Florida (Sime, 2005). Unfortunately, the number of sightings at the SLE-ME site was inadequate for statistical analysis.

Although statistically significant associations between water quality parameters and frequency of dolphin sightings were not found at the IRL-LP site in the current study, increases in mortality of inshore dolphins were observed following periods of freshwater discharge and lower air temperature in the northern Gulf of Mexico (Carmichael et al., 2012) and Australia (Meager & Limpus, 2014). Additionally, an increase in the incidence of dolphin pox, a viral disease associated with decreased water quality, habitat degradation, and environmental stress (Geraci et al., 1979), was observed in two estuarine populations in Australia following flooding events characterized by lower levels of salinity and higher turbidity (Fury & Reif, 2012).

Associations between dolphin abundance, migratory movements, and water temperature are well supported by previous investigations but demonstrate substantial variability in seasonal relationships. Patterns of dolphin distribution in coastal waters may depend on species-specific thermoregulatory requirements (Yeates & Houser, 2008) or, alternatively, on local patterns of prey availability. For example, the number of coastal migratory dolphins near Virginia Beach, Virginia, was strongly correlated with water temperature rather than with an estimate of prey availability or photoperiod (Barco et al., 1999). Similarly, changes in residency patterns of bottlenose dolphins occurred following the 1982-1983 El Niño warming along the western coast of North America, with a northward extension of their range into central California (Wells et al., 1990).

In contrast, the sighting frequency of dolphins in the vicinity of the IRL-LP station was highest during December and January as shown in Figure 2 and supported by the association with air temperature in the data analysis. Aerial surveys of the IRL dolphin population conducted between 2005 and 2011 confirm an increase in dolphin abundance during the colder winter months (Durden et al., 2017). In that study, seasonal fluctuations in abundance in the southern lagoon were potentially attributed to intraregional movements, temporary immigration from surrounding habitats, or artefact due to impaired visibility depth resulting from poor water quality during the summer months (Durden et al., 2017). Thus, the associations detected between air temperature and dolphin sightings in the current study may reflect intraregional seasonal movements of dolphins in the IRL. Similarly, aerial surveys of bottlenose dolphin populations along the North Carolina coast demonstrated clear seasonal effects on dolphin abundance in coastal waters, with an increase in the number of coastal sightings during the winter months (Torres et al., 2005). The authors attributed these patterns to changes in water temperature and prey availability.

Seasonal effects have also been demonstrated on dolphin density, measured as the number of dolphins sighted per km^2 during photographic surveys of dolphin communities inhabiting estuarine areas in northeastern Florida (Caldwell, 2016). Dolphin density increased significantly during warm water seasons, defined as water temperature > 16°C, compared to the cold water seasons with temperatures $\leq$ 16° C in the coastal region and two of the three inshore estuarine regions (Caldwell, 2016).

The association with humidity at a single point in time (HA) has no obvious biological explanation. The inconsistency among time points suggests that this association may have been due to chance.

This study was unique in the use of an apex species to assess potential effects of changes in weather and water quality parameters using real-time assessment of population and environmental variables. The results demonstrate the feasibility of monitoring dolphin sighting frequency contemporaneously with measurements of weather and water quality. As a caveat, relatively limited variability in water quality parameters at a single monitoring site reduced the probability of detecting associations with sighting frequency. Further, changes in water temperature and water quality may have had an impact on the movements of fish species that comprise dolphin prey (Alshuth & Gilmore, 1994; Kupschus & Tremain, 2001). Therefore, the relationships identified may have been a response to changes in the availability of prey, which, in turn, drove dolphin movement. Lusseau et al. (2004) stated the importance of studying prey availability and cetacean grouping behavior in conjunction with variation in climate indices. Thus, from a long-range perspective, methods such as those described above may contribute to our understanding of the impacts of climate change on ecosystem health.

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