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Monitoring Seasonal Abundance of Indian River Lagoon Bottlenose Dolphins (*Tursiops truncatus*) Using Aerial Surveys

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Abstract

Systematic long-term monitoring of abundance and distribution is essential to management and conservation and necessary to assess mortality trends and anthropogenic impacts for cetacean stock assessment. Line-transect aerial surveys (*n* = 42) were conducted to assess bottlenose dolphin (*Tursiops truncatus*) abundance, distribution, and group composition in the Indian River Lagoon (IRL) estuary system, Florida, from 2005 to 2011. Multiple covariate distance sampling was used to estimate abundance, and experimental trials were utilized to estimate dolphin availability. Abundance estimates varied seasonally, ranging between 483 (95% CI = 345 to 672; summer 2008) and 1,947 dolphins (95% CI = 1,198 to 2,590; winter 2009-2010), with a mean abundance of 1,032 dolphins (95% CI = 809 to 1,255). The largest abundance estimates for IRL dolphins occurred during extremely cold winter events, suggesting seasonal changes may influence dolphin movements. Mean visibility depth (125.14 ± 38.29 cm) suggested the availability bias did not largely influence estimates of dolphins in this shallow estuary when surveys are conducted under optimal sighting conditions. However, there was some evidence of seasonal changes in availability that may influence abundance estimation, and this should be further investigated. Seasonal trends and corresponding genetic and movement data suggest Mosquito Lagoon may be a disjunct community from the IRL proper. This study provides abundance data to assess the IRL bottlenose dolphin stock prior to the largest Unusual Mortality Event on record for this population, which occurred in 2013.

Key Words: abundance, aerial survey, availability bias, bottlenose dolphin, *Tursiops truncatus*, multiple covariate distance sampling, distribution, Indian River Lagoon, line transect, trend analyses

Introduction

The common bottlenose dolphin (*Tursiops truncatus*; Montagu, 1821) is widely distributed throughout temperate and tropical waters worldwide where the species inhabits open oceans and coastal waters, including shallow lagoons, estuaries, and rivers (Leatherwood & Reeves, 1983). Stock assessment of this species relies on accurate, current population estimates, which allow managers to make informed decisions regarding takes and threats to dolphin stocks. Along the east coast of central Florida, several stocks of bottlenose dolphins occur, including the Indian River Lagoon (IRL) estuarine system stock (National Oceanic and Atmospheric Administration [NOAA] Fisheries, 2009).

The bottlenose dolphins that inhabit the IRL estuarine system are considered year-round residents, which exhibit high site fidelity (Odell & Asper, 1990; Mazzoil et al., 2005). These animals are impacted by several factors that warrant an improved understanding of their population biology. IRL dolphins may be directly (e.g., boat strikes and fishing gear entanglement) (Noke & Odell, 2002; Durden, 2005; Stolen et al., 2007; Bechdel et al., 2009; Stolen et al., 2013) and indirectly (e.g., introduction of marine contaminants) (Durden et al., 2007; Fair et al., 2010) impacted by human activities. As a long-lived top-level predator, IRL dolphins are exposed to and accumulate persistent pollutants (Durden et al., 2007) that may increase their susceptibility to disease (Fair & Becker, 2000). IRL dolphins are known to exhibit skin disease (Caldwell et al., 1975; Bossart et al., 2003; Reif et al., 2006; Durden et al., 2009) and are described as an immune-compromised population (Bossart et al., 2003). Likewise, the IRL dolphin population has experienced unexplained die-offs that have been declared Unusual Mortality Events (UMEs) by the National Marine Fisheries Service (NMFS) in 2001 (*n* = 41 mortalities), 2008 (*n* = 48 mortalities), and in 2013 (*n* = 77 mortalities) (Stolen et al., 2007; NOAA Fisheries, 2014). A fourth UME, the Mid Atlantic UME, with a suspected cause of morbillivirus, also impacted dolphins inhabiting the northern portion of the IRL from 2013 through 2015. These reoccurring mortality events of increasing magnitude could indicate serious ecological pressures that may lead to the decline of this strategic stock. Currently, there is a critical need for information on population abundance and distribution trends to evaluate the impact of the most recent mortality events on the population.

Several aspects of the IRL make vessel-based mark-recapture surveys impractical. The IRL encompasses 902 km^2 of habitat, the majority of which is suitable for bottlenose dolphins (Odell & Asper, 1990). Large sections of the northern IRL are restricted to nonmotorized boats or to government authorized personnel; portions of the lagoon are extremely wide (9.3 km) (Leatherwood, 1979); and large areas present extreme vessel navigation difficulties. Further complicating the use of traditional mark-recapture surveys, covering the expansive size of the estuary by vessel requires numerous days, making it difficult to conduct several complete surveys within a short period of time. Thus, aerial surveys are a practical method to estimate the abundance of the population throughout its range. For decades, aerial surveys have been routinely utilized for wildlife management (Caughley, 1977), and line-transect surveys that incorporate distance sampling to adjust for detectability (Thomas et al., 2006) are widely applicable to estimate the abundance of marine mammal populations (Carretta et al., 1998; Buckland et al., 2001). The objectives of this study were to conduct long-term aerial surveys of the IRL bottlenose dolphin population; to estimate abundance by separate geographic sub-basins; and to examine seasonal changes and trends in abundance, distribution, and group composition.

Methods

Study Area

The IRL is a shallow estuarine system located along the east coast of central Florida that is open to the Atlantic Ocean at four inlets and consists of three interconnected basins: the Indian River, Banana River and Mosquito Lagoon (Mulligan & Snelson, 1983; Environmental Protection Agency [EPA], 1996) (Figure 1). While recent studies have defined the IRL to extend from Ponce Inlet to Jupiter Inlet (EPA, 1996; Mazzoil et al., 2008; NOAA Fisheries, 2013), this study defined the system more narrowly, extending from Ponce de Leon Inlet to St. Lucie Inlet, 25 km north of Jupiter Inlet, to better correspond with historical studies (Leatherwood, 1979; Mulligan & Snelson, 1983; Odell & Asper, 1990; Stolen et al., 2007; Durden et al., 2011). The 902 km^2 estuary spans 220 km with a width of 0.93 to 9.30 km (Leatherwood, 1979). Although most of the area is shallow (<1 m at high tide), depths of greater than 5 m occur in the dredged basins and channels of the Intracoastal Waterway (ICW) (Gilmore, 1977), which encompass approximately 2.2% of the lagoon (W. N. Durden, unpub. data, 2010). The IRL is a diverse estuary with high seagrass coverage and more than 400 fish species (Gilmore, 1977; Mulligan & Snelson, 1983).

To investigate geographical differences in density and group composition and to reduce heterogeneity in detection probability, the three basins of the IRL were divided into four regions (hereafter termed sub-basins) which present different abiotic and biotic characteristics that could indirectly influence dolphin abundance (Smith, 1993; Sigua et al., 2000; Sigua & Tweedale, 2003). The Banana River (BR) (202 km^2) and the Mosquito Lagoon (ML) (140 km^2) included each water basin in its entirety (Figure 1). Because of its large north to south extent, the Indian River basin was divided into two sub-basins: (1) the Northern Indian River (NIR) (378 km^2, previously defined as north of Eau Gallie Causeway), with little tidal and nontidal flushing (Smith, 1993); and (2) the Southern Indian River (SIR) (182 km^2) (Figure 1). The SIR includes the north central, south central, and southern Indian River, previously defined management units, and three of the four inlets (Woodward-Clyde, 1994). The BR and NIR present decreased water quality compared to the majority of ML and SIR (Smith, 1993; Sigua et al., 2000; Sigua & Tweedale, 2003). Partitioning the lagoon into the geographically isolated basins also allowed inferences to be made regarding the communities inhabiting the sub-basins. A prior study defined six dolphin communities occurring in the IRL—two in ML, one occupying a portion of the NIR and BR, and three occurring in the SIR, as defined above, all with some overlap in adjacent basins (Titcomb et al., 2015). Providing abundance estimates for each community was not possible due to sample size constraints and the associated bias of assigning aerial sightings to a particular community. However, the average abundance for the NIR and BR combined was presented as a single community of dolphins that inhabits a large portion of these basins, and dolphins in this area have been subjected repeatedly to UMEs (2001, 2008, and 2013).

Aerial Surveys

Aerial surveys were flown monthly (except when airspace restrictions, weather, or plane availability prevented flights) from 27 September 2005 to 9 August 2007 and seasonally (three winter flights and four summer flights) from 24 June

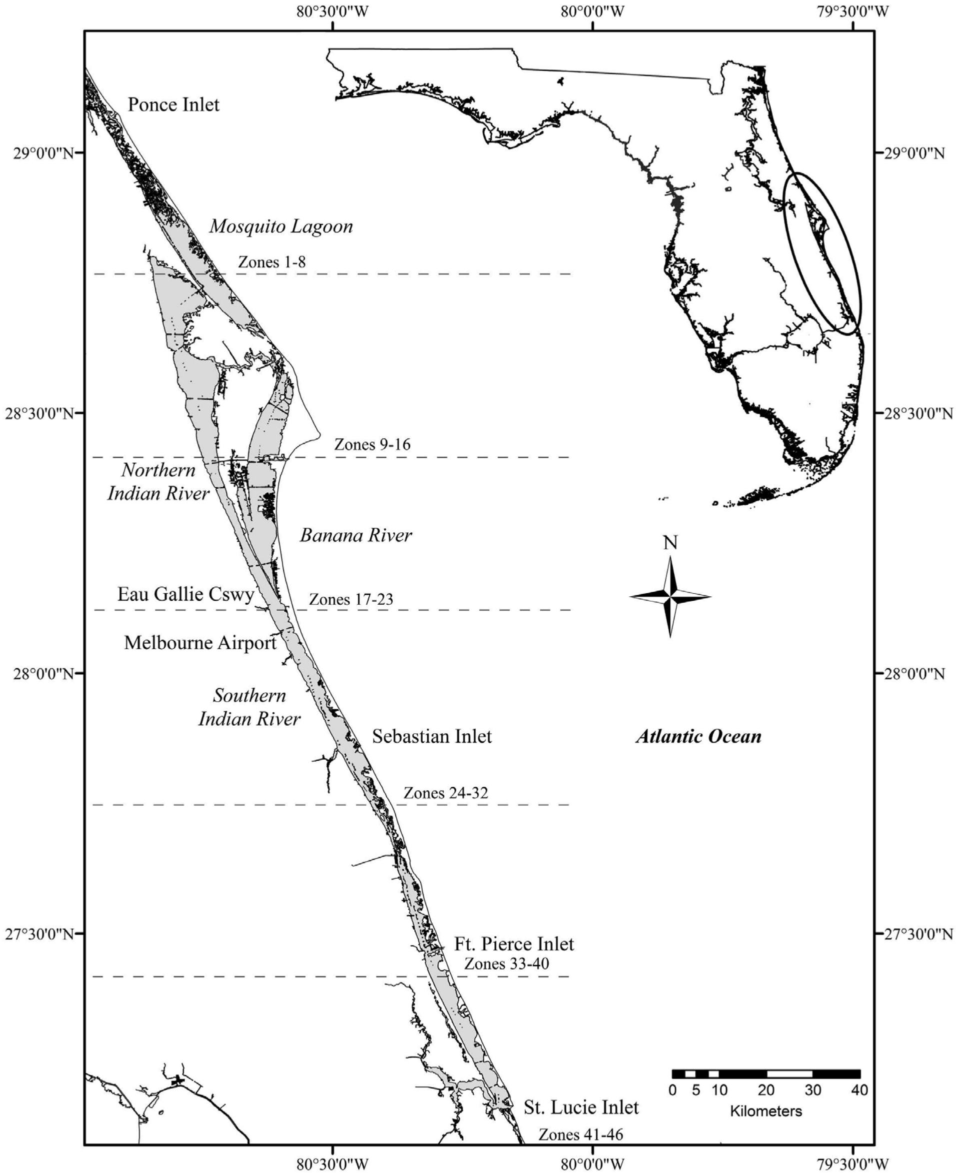

Figure 1. The study area (Indian River Lagoon [IRL], Florida) covered by aerial surveys. The study area was divided into 46 zones that were further subdivided into five parallel (east-west) transects (one transect from each zone was flown during each survey); the lagoon was divided into four sub-basins to examine abundance and distribution trends: (1) Mosquito Lagoon, (2) Northern Indian River (from Eau Gallie Causeway north), (3) Banana River, and (4) Southern Indian River (from Eau Gallie Causeway south).

2008 to 30 January 2011, following line-transect distance sampling methodology (Buckland et al., 2001). Surveys were conducted from a high-wing Cessna 172 aircraft flown at a fixed altitude of 152 m and a ground speed of 167 km/h. During each survey, the IRL was surveyed from Ponce de Leon Inlet (29° 4' 30" N) to St. Lucie Inlet (27° 10' 0" N). The study area was divided into 46 equal 4.63 km zones (Figure 1). Each zone was further subdivided into five east-west parallel transects, 0.93 km apart. One transect was selected randomly from each zone prior to flights and remained fixed throughout the study. Following IRL dolphin stock declaration, surveys (summer 2010; winter 2011) were extended southward to Jupiter Inlet (26° 56' 40" N) to correspond with the stock's range (NOAA, 2009). Five additional transects were added to evaluate the potential impact of the exclusion of this portion of the IRL but were not included in further analyses as the area was not assessed during prior surveys (Durden et al., 2011) or during most surveys in this study. Surveys were conducted from approximately 0730 to 1300 h, corresponding with optimal environmental conditions (Beaufort sea states ≤ 2; wind speed ≤ 16 km/h) for detection of dolphins. Personnel consisted of a pilot, a data recorder (right rear seat), and two observers (seated in the right front and left rear seat); all personnel communicated via headsets. A Garmin GPS 12 CX handheld Global Positioning System (GPS) with an external antenna was used in combination with nautical charts to navigate transects and to record dolphin locations.

Due to the necessity of coordinating permission to access federally restricted airspace, all surveys were conducted following the same flight path. The aircraft began at Zone 23 and continued north to Zone 1, then returned to the starting location (off effort), refueled, and resumed the survey southbound covering Zones 24 to 46 (Figure 1). The aircraft circled animals when necessary to obtain an accurate count of group size and composition (variable effort recount method; Lefebvre & Kochman, 1991). Following circling, the survey was resumed from the point at which the transect was departed. Declination angles (θ) from the flight line were measured when dolphins were perpendicular to the aircraft using a self-damping clinometer. Subsequently, distances were calculated as perpendicular distance (m) = tan (90 - θ) * 152.4 (152.4 m = the distance above water).

Environmental Conditions

Beaufort sea state, percent cloud cover, visibility (an overall assessment of sighting conditions), and relevant weather conditions were recorded every half hour and when a change occurred. To account for variable sighting conditions, each observer reported the following for each transect and/or each water basin along the transect to the data recorder: glare (none, little = present but noninterfering; some = avoidable by looking forward or backward; a lot = entire transect with unavoidable glare resulting in difficult sighting conditions), sea state (0 = glassy, 1 = rippled water, 2 = scattered white caps), turbidity conditions (cannot see the substrate, can see the substrate across less than half of the transect, can see the substrate across greater than half of the transect), and sighting conditions (observer's estimate of overall sightability based on glare, sea state, and turbidity at sighting and binned as excellent, good, fair, and poor). To investigate the possibility of availability bias (Marsh & Sinclair, 1989), sighting cues (e.g., surfacing, splashing, and associated birds) also were recorded. A habitat description was recorded for each sighting and was grouped into two categories: (1) shallow water (the substrate readily visible) or (2) the channel (designated by markers) and adjacent deep water where the substrate was not visible. Group size and composition (adults and calves) and behavior (when apparent; Wells, 1996) were recorded for each sighting. A group was defined as a cluster of dolphins sighted by either observer that were typically engaged in the same behavior and were in close proximity. An animal was considered a calf if it was approximately half the size of the associated adults. Flight path data from the GPS were later imported into *Arc GIS 9.1*, and distance over water (m) for each transect was determined.

Estimating Availability Bias

Aerial surveys were designed to meet the assumptions of line-transect theory (Buckland et al., 2001), and biases could have been introduced if the assumptions were not met (Burnham et al., 1980; Hammond & Laake, 1983). The most important assumption was that all of the animals on the track line were detected (i.e., the probability that a group on the transect line was seen, g(0) = 1). When conducting aerial surveys of cetaceans, it is often impossible to meet this assumption since these animals spend a large amount of time under water (Hiby & Hammond, 1989; Buckland et al., 1993), and availability bias occurs when animals are submerged (unavailable) as the survey platform passes over a given area. In the IRL, however, much of the area is shallow, allowing observers to see the bottom of the lagoon throughout much of the estuary. While aerial surveys for dolphins in a shallow estuary system create an ideal situation to meet the assumptions of the theory, the deeper dredged channels of the system and poor water clarity could make animals unavailable for detection. To estimate availability bias, two experiments were conducted—one to measure visibility depth (cm) and the second to measure the observation window time (s).

A dolphin decoy was deployed to determine the distance through the water which dolphins could be reliably observed. A stranded IRL dolphin carcass of average adult size (243 cm) was positioned on its ventrum and traced onto paper. The outline was then cut from wood, and three small circular holes were cut to insert screw eyes to thread rope through (for deployment) and to attach weights to the ventral side. The decoy was then painted to mimic the coloration of a dolphin. During aerial surveys, the decoy was deployed from a vessel at various transect locations throughout the lagoon. Once the aircraft team had completed the transect, the aircraft circled back and directly overflew the decoy. When the decoy was in sight, the aerial team instructed the deployment team (via cell phone) to slowly lower the dolphin. Multiple passes were made until the greatest depth was determined at which the dolphin was still visible and identifiable. The deployment team then marked the rope at the water's surface and recorded the straight-line distance from the marked area of the rope to the dolphin, along with deployment location and water depth.

To estimate availability bias under occasionally less than optimal conditions (e.g., deep/dredged channel, and poor water quality resulting in reduced visibility), we estimated the maximum time period that an object at or near the surface could be observed during the passage of the aircraft. Experimental trials were set up by the front observer who sighted stationary objects on the water's surface (e.g., pole, buoy, and channel marker) ahead of the right rear "observer." When the object came in view for the right rear "observer," a stopwatch was started and subsequently stopped when the object went out of view. The observation time window was measured with precision to 0.01 s.

Distance Sampling

Dolphin density ($\widehat{D}$) and abundance ($\widehat{N}$) were estimated using multiple covariate distance sampling (MCDS) methods applied to clusters of animals (Marques & Buckland, 2004). MCDS is similar to conventional distance sampling (Buckland et al., 2001) except that covariates are included in estimation of the detection function via the scale parameter of the key function (Marques & Buckland, 2004). Although conventional distance sampling is thought to be robust to the effect of covariates on the estimated detection function, the use of such covariates allows pooling of sighting data across strata while still obtaining abundance estimates at the level of the stratum (Marques et al., 2007). Density ($\widehat{D}$) and abundance ($\widehat{N}$) were estimated as

$$\widehat{D} = \frac{1}{2L}\hat{E}(s)\sum_{i=1}^{n}\hat{f}\,(0|z_i) \qquad \widehat{N} = A * \widehat{D}$$

where A is the area of the covered region, 2L is two times the length of the surveyed strips, ($\widehat{E}$) *(s)* is the expected cluster size, *n* is the number of clusters seen, and $\widehat{f}(0/z_i)$ is the estimated probability of detecting a cluster at zero distance given it has the covariate values designated in the vector z_i. Expected cluster size was estimated using a regression of ln (group size) on the estimated detection probability as a function of distance for each group, calculated separately within each stratum (Buckland et al., 2001). The program *Distance 6.0* (Thomas et al., 2009) was used to model the detection functions and obtain estimates of abundance and group size within the strata. A bootstrap resampling procedure was run within *Distance 6.0* to obtain confidence intervals (CIs) on abundance estimates for each stratum. Because *Distance 6.0* has a limited ability to pool across multiple layers of stratification (i.e., temporal strata and geographic strata), the final estimates for combinations of strata were calculated in program *R*, Version 2.14.1 (R Development Core Team, 2011) using parameter estimates from *Distance 6.0*, following methods described in Buckland et al. (2001).

Eight to ten covariates were considered in MCDS models for the monthly and seasonal surveys (Table 1). When modeling covariates in MCDS, it is important to carefully monitor convergence of the maximum likelihood estimation procedure; thus, Marques et al. (2007) recommend an approach in which covariates are evaluated individually followed by a limited amount of model building with the best performing covariates. Following these recommendations, a set of MCDS detection function models with only single covariates were first evaluated to determine which had the best ability to explain variation in the detection function. For each covariate, models with the half-normal key function, with either hermite polynomial or cosine adjustment terms, and the hazard rate key function, with hermite, simple polynomial, or cosine adjustment terms, were considered. The number of adjustment terms included in each model was determined using a likelihood ratio test, and the maximum number of terms considered was limited to two to prevent problems with convergence of the detection function in the *Distance 6.0* program. For each combination of detection function, adjustment term, and covariate, two forms of the scale parameter were considered: (1) the observed distance divided by the truncation distance or (2) the observed distance divided by sigma, which is the scale parameter in the estimated detection function (Marques & Buckland, 2004). The models were evaluated based on the relative Akaike's Information Criterion (AIC) value (Burnham & Anderson, 1998). The covariate that had the most support in the univariate MCDS model was next combined with other covariates that had some support to attempt to build a better detection function model. Throughout the model

Table 1. The covariates considered in multiple covariate distance sampling (MCDS) models for monthly surveys conducted between 2005 and 2007 and seasonal surveys from 2008 to 2011. Where two level numbers are given, the covariate was included in separate models with each level of categorization. Note that season was only evaluated at two levels for seasonal surveys (winter/summer).

Covariate	Levels	Description
Season	4/2	Winter, spring, summer, fall; winter/summer
Sub-basin	4	Banana River, Mosquito Lagoon, Northern Indian River, Southern Indian River
Glare	4/2	Observer's recorded glare on water surface at sighting; glare presence or absence
Observer	3/2	Coded for observer
Sighting conditions	4/2	Observer's estimate of sighting conditions: excellent, good, fair, poor; excellent or not excellent
At surface	2	Dolphin(s) at surface or submerged when sighted
Sea state	5/continuous	Beaufort sea state
Cluster size	Continuous	Number of dolphins in group
Turbidity	3/2	Observer's recorded clarity of water at sighting—can see the substrate across less than half of the transect or can see the substrate across greater than half of the transect
Habitat	2	Observer's description of habitat bathymetry at sighting (can see the substrate/cannot see substrate)

selection procedure, the fit of all models was evaluated based on recommendations in Marques et al. (2007), and only models without evidence for lack of fit were considered for inference. Once the final model for the detection function was determined, the variance of estimators was calculated using the bootstrap procedure with 5,000 replications. Following selection of the best model for the detection function, abundance was estimated for each of the strata determined as combinations of the season-year time periods and the four sub-basins. Season-year combinations were based on the following seasons: winter = December-February, spring = March-May, summer = June-August, and fall = September-November (Shane, 1990), which were chosen to enable comparisons with prior studies (Stolen et al., 2007; Durden et al., 2011)

Data were pooled over 3-mo periods (seasons) to meet minimum data requirements and to examine seasonal patterns in abundance and group size. Following data screening, detection distances were right truncated to allow better estimation of detection functions (Buckland et al., 2001). Due to aircraft design, an area directly beneath the plane was not visible to observers. Based on ground and survey measurements, objects > 50° from the horizon were determined to be inconsistently visible beneath the plane during flight. As with other studies that utilized similar aircraft (Buckland et al., 2001; Borchers et al., 2006; Gómez de Segura et al., 2006), a distance of 128 m (corresponding to a clinometer angle of 50º) was subtracted from all the perpendicular distances during analysis, thereby moving the centerline to the closest area clearly visible beneath the plane.

Seasonal changes in calf presence (as a percentage of adults) were evaluated using contingency table analysis, and differences in group size by season and sub-basin were evaluated using an analysis of variance (ANOVA). A *t*-test was used to evaluate seasonal differences in the mean percentage of the water column that was visible during dolphin decoy deployments. All statistical comparisons were calculated using the program *R* (R Development Core Team, 2011).

Trend Analyses

Bootstrap analysis was used to assess trends in abundance during the study period and between seasons. To extend the temporal coverage, data from this study were combined with data from Durden et al. (2011), which used similar methods to estimate abundance. Analysis was limited to summer and winter seasons to enable comparisons between datasets. Survey periods spanned from summer 2002 through winter 2011 and included 2002 to 2004 (two winters and two summers; Durden et al. 2011), 2005 to 2007 (two winters and two summers), and 2008 to 2011 (three winters and three summers). To assess trends in abundance, the following procedure was conducted. A random bootstrap replicate abundance estimate was obtained from the *Distance 6.0* analysis for each survey period, and these were combined to produce a time series of estimates. Next, the slope of the regression of abundance on year was calculated within each season for each water basin and for all basins combined (IRL). Finally, the difference in mean abundance between seasons within each sub-basin and the combined basins was calculated. A total of 5,000 iterations of this procedure were conducted. The distribution of the resulting bootstrap estimates for all parameters within each sub-basin were used to examine evidence for linear temporal trends in abundance and abundance differences between winter and summer. Evidence for trends or differences was considered to be supported if the interval containing the 2.5 and 97.5% quantiles of the bootstrap estimates for the quantity did not overlap zero. Given the increase in IRL dolphin mortality during the study period (the 2008 UME), a null-hypothesis test for a negative linear trend was utilized as a conservative test for a decline in abundance.

Results

Field Effort

A total of 42 surveys were flown, corresponding to a total line-transect distance of 7,875 km. Survey duration was 4.46 to 7.42 h (mean = 5.4 ± 0.5 SD). No dolphins were sighted on the additional transects south of St. Lucie Inlet (summer 2010/winter 2011), which were excluded from analyses. A total of 1,322 groups, comprised of 3,245 dolphins (3,069 adults, 176 calves), was recorded. The number of dolphins sighted per survey was 18 to 179 (mean = 77.3 ± 35.08 SD). Calf sightings did not vary significantly by individual season-year ($\chi^2 = 11.35$, $df = 13$, $p = 0.581$) (Table 2). Fewer calves were sighted in spring than in other seasons (pooled) but did not differ significantly between seasons ($\chi^2 = 3.32$, $df = 3$, $p = 0.346$) (Table 2). Calves represented 5.42% of the animals observed with little variation between water basins (range: 4.9 to 5.9%). Group size ranged from 1 to 25 (mean: 2.45 ± 2.70) and varied significantly between pooled seasons (ANOVA, F = 3.87, $df = 3$, $p = 0.009$), with significantly larger group sizes in winter compared to summer (Tukey's HSD test, $p < 0.05$). The largest mean group size per season occurred in the winter of 2007 (3.30 ± 4.32), while the smallest group size was in the summer of 2007 (1.78 ± 1.28). Mean group size by pooled sub-basin was largest in Mosquito Lagoon (ML) (2.84 ± 3.31), followed by the Southern Indian River (SIR) (2.51 ± 2.77), Northern Indian River (NIR) (2.39 ± 2.48), and the Banana River (BR) (2.20 ± 2.39); however, differences were not significant (ANOVA, F = 2.43, $df = 3$, $p = 0.064$). Surfacing data were recorded for all sightings. A total of 527 (40%) groups were sighted while submerged, while 795 (60%) dolphin groups were surfacing when sighted. Surfacing data were similar between winter and summer seasons, with 41% of summer sightings submerged and 59% at the surface, while 40% of winter sightings were submerged vs 60% at the surface.

Table 2. Total number of bottlenose dolphin (*Tursiops truncatus*) sightings (adults and calves) and the percent of calves by season

Season	Total	Adults	Calves	% calves
Fall 2005	138	130	8	5.8
Fall 2006	183	172	11	6.01
Fall combined	321	302	19	5.92
Winter 2005-2006	290	273	17	5.86
Winter 2006-2007	349	327	22	6.3
Winter 2008-2009	323	299	24	7.43
Winter 2009-2010	328	314	14	4.27
Winter 2010-2011	339	322	17	5.01
Winter combined	1,629	1,535	94	5.77
Spring 2006	159	154	5	3.14
Spring 2007	100	97	3	3
Spring combined	259	251	8	3.09
Summer 2006	201	189	12	5.97
Summer 2007	125	119	6	4.8
Summer 2008	208	197	11	5.29
Summer 2009	289	269	20	6.92
Summer 2010	213	207	6	2.82
Summer combined	1,036	981	55	5.31
Total	3,245	3,069	176	5.42

Estimating Availability

A total of 14 dolphin decoy trials were conducted during 12 surveys between 2008 and 2011 (Table 3). Trials were conducted in the NIR (n = 3), BR (n = 2), ML (n = 3), and SIR (n = 6) during winter (n = 7) and summer (n = 7) months. The visibility depth ranged from 81 to 204 cm (mean 125.14 ± 38.29). Mean visibility depth across all locations varied little between summer (126.38 ± 39.56) and winter (130.50 ± 42.35). During some winter trials, the decoy was clearly visible while resting on the bottom of the estuary; therefore, mean visibility in the winter season may have been greater than the mean presented as trials in deeper waters may have yielded an even larger depth visibility. The greatest visibility (204 cm) was in ML, Zone 6, in winter, while the least visibility (81 cm) was in ML, Zone 8, in the summer. On average, 70% of the water column was available during deployment trials. The mean percent of water column available varied seasonally with a significantly larger portion available during winter trials (88.14% ± 18.76) than summer (51.45% ± 15.18) (t = 4.02, df =12, p = 0.0017).

A total of 31 trials were conducted to estimate observation window time. The observation window ranged from 13.35 to 25.78 s (mean 20.26 ± 3.19).

Modeling the Detection Function

Monthly Surveys (2005-2007)—Following initial data screening, a right-truncation distance of 400 m was chosen, resulting in removal of 1.2% of detections. The number of detections within the 32 pooled strata were 1 to 39, and the encounter rates were 0.040 to 0.26 (clusters observed/km of transect surveyed). The total number of observations used to fit the detection function was 515. The best-supported univariate model for the detection function included a half-normal key function with no adjustment terms and "at the surface" as the covariate (Table 4). The next best supported univariate model included a half-normal key function with no adjustment terms and "season" as the covariate, but this model had ΔAIC = 10.1 relative to the best univariate model. Global density estimates for all the top models were similar and ranged from 0.0087 to 0.0098 dolphins/km^2. Following evaluation of the univariate detection function models, a limited number of models were evaluated, with "surface" combined with "season" or "observer" (Table 4). This resulted in a model which included a half-normal key function

Table 3. Maximum dolphin visibility depth (cm) as estimated from dolphin decoy trials; sub-basins included the Northern Indian River (NIR), Southern Indian River (SIR), Banana River (BR), and Mosquito Lagoon (ML). The percent of the water column visible was calculated based on the water depth at deployment and the decoy depth recorded. Note that in four winter cases (*), the bottom of the lagoon was visible; therefore, these depths may not represent the depth of maximum visibility (i.e., trials conducted at greater depths may have yielded a greater visibility depth).

Trial no.	Date (d/mo/y)	Season	Latitude	Longitude	Zone #	Water depth (cm)	Decoy depth (cm)	% of water column visible	Sub-basin	Comments
1	22/7/2008	Summer	28.2621167	-80.6779167	20	366	102	27.87	NIR	
2	22/7/2008	Summer	27.9709667	-80.5357000	27	183	137	74.86	SIR	
3	25/7/2008	Summer	28.6109667	-80.7965167	12	274	127	46.35	NIR	
4	7/8/2008	Summer	28.7605100	-80.7614600	8	168	81	48.21	ML	
5	17/12/2008/*	Winter	28.8374500	-80.8098666	6	204	204	100.00	ML	Can see to the bottom
6	5/1/2009	Winter	28.7595333	-80.7625833	8	326	164	50.31	ML	
7	23/1/2009	Winter	28.6107500	-80.7966500	12	247	191	77.33	NIR	
8	23/1/2009*	Winter	27.8995000	-80.4745000	29	141	141	100.00	SIR	Can see to the bottom
9	21/8/2009	Summer	28.3300400	-80.6547100	17	155	98	63.23	BR	
10	14/12/2009*	Winter	28.0101883	-80.5363333	26	115	115	100.00	SIR	Can see to the bottom
11	20/1/2010*	Winter	28.0682750	-80.5675060	25	93	93	100.00	SIR	Can see to the bottom
12	9/7/2010	Summer	28.3793000	-80.6468100	17	183	104	56.83	BR	
13	13/7/2010	Summer	27.8990470	-80.4797860	29	201	86	42.79	SIR	
14	30/1/2011	Winter	27.9231860	-80.5170940	28	122	109	89.34	SIR	
					Mean ± SD	198.43 ± 79.89	125.14 ± 38.29	69.79 ± 25.13		

Table 4. Comparison of Akaike's Information Criterion (AIC) values of multivariate detection function models for monthly surveys conducted between 2005 and 2007; model g1 was found to have the lowest AIC (5,813.58) and was used for all subsequent inference. %CV = % coefficient of variation.

Model/key function	Adjustment term	Covariates	Parameters/ # adjustment terms	ΔAIC	ESW	GOF CvM (cos) p	GOF CvM (unif) p	GOF K-S p	Density (dolphins/ km²)	% CV
g1 Half-normal		At surface, season	9/0	0.00	169.6598	0.60	0.60	0.71	0.0098	7.2
g2 Hazard-rate		At surface, season	10/0	7.69	173.1794	0.90	0.70	0.57	0.0096	7.3
g3 Half-normal		At surface, observer	4/0	10.74	175.0153	0.90	0.90	0.58	0.0092	7.1
g4 Half-normal		At surface	2/0	15.30	176.8544	0.60	0.60	0.37	0.0092	7.1
g5 Hazard-rate	Cosine	At surface, observer	6/1	19.19	188.3735	0.40	0.40	0.34	0.0087	7.2
g6 Hazard-rate		At surface, observer	5/0	20.42	170.3051	0.50	0.40	0.12	0.0096	7.2
g7 Half-normal		Season	8/0	25.39	176.2146	0.40	0.40	0.16	0.0093	7.1
g8 Hazard-rate		At surface	3/0	27.39	169.4914	0.50	0.40	0.07	0.0096	7.2
g9 Half-normal		Observer	3/0	31.22	180.0871	0.50	0.60	0.15	0.0090	7.1
g10 Half-normal		Glare	4/0	32.58	180.109	0.50	0.50	0.20	0.0089	7.1
g11 Hazard-rate	Simple		3/1	33.65	175.4637	0.50	0.60	0.53	0.0092	9.2
g12 Half-normal			1/0	37.58	182.1567	0.30	0.30	0.11	0.0088	7.1
g13 Half-normal		Sighting conditions	4/0	37.61	181.0538	0.40	0.40	0.17	0.0089	7.2
g14 Half-normal		Sea state (continuous)	2/0	38.02	181.8404	0.40	0.40	0.32	0.0088	7.0
g15 Half-normal		Sub-basin	4/0	38.07	181.0213	0.40	0.40	0.23	0.0090	7.1
g16 Half-normal		Sea state (factor)	5/0	38.77	180.6583	0.50	0.50	0.36	0.0089	7.1
g17 Half-normal		Cluster size	2/0	39.15	182.0905	0.30	0.40	0.19	0.0094	0.0
g18 Half-normal		Turbidity	3/0	39.38	181.7169	0.40	0.40	0.11	0.0089	7.1

with no adjustment terms and "at surface" and "season" as covariates; this model was superior to the best univariate model by ΔAIC > 15 and was also unambiguously superior to the next best model. Because it was so highly supported relative to other models considered, all further inference was based on this model alone. The fit of this model was explored using qq-plots and goodness-of-fit diagnostic tests in *Distance 6.0* (Thomas et al., 2006). The qq-plot showed no departure from model assumptions, and the Kolmogorov-Smirnov goodness-of-fit tests indicated no lack of fit ($p = 0.71$). The Cramer-von Mises tests, which are based on the overall differences between the observed and predicted values, also showed no evidence for lack of fit (Cramer-von Mises test with uniform weighting $0.5 < p \leq 0.6$; Cramer-von Mises test with cosine weighting $0.5 < p \leq 0.6$).

Another diagnostic measure useful for assessing multiple covariate distance models is the distribution of the estimated detection probabilities given the covariates (Marques et al., 2007); only 5.8% of the observations had estimated detection probability that was < 0.3 for the best-supported model. Figure 2 shows the fitted detection function averaged over the observed covariate levels for the best-supported model. Following selection of a model for the detection function, estimates of density and abundance were produced for each of the eight levels of season-year within each of the four sub-basins (32 total strata).

Seasonal Surveys (2008-2011)—Following initial data screening, a right-truncation distance of 290 m was chosen, resulting in removal of 6.9% of detections. The number of detections within the 24 pooled strata was 13 to 51, and encounter rates were 0.088 to 0.31 (clusters observed/km of transect surveyed). The total number of observations used to fit the detection function was 620. The best-supported univariate model for the detection function included a half-normal key function with a second order cosine adjustment term and "at

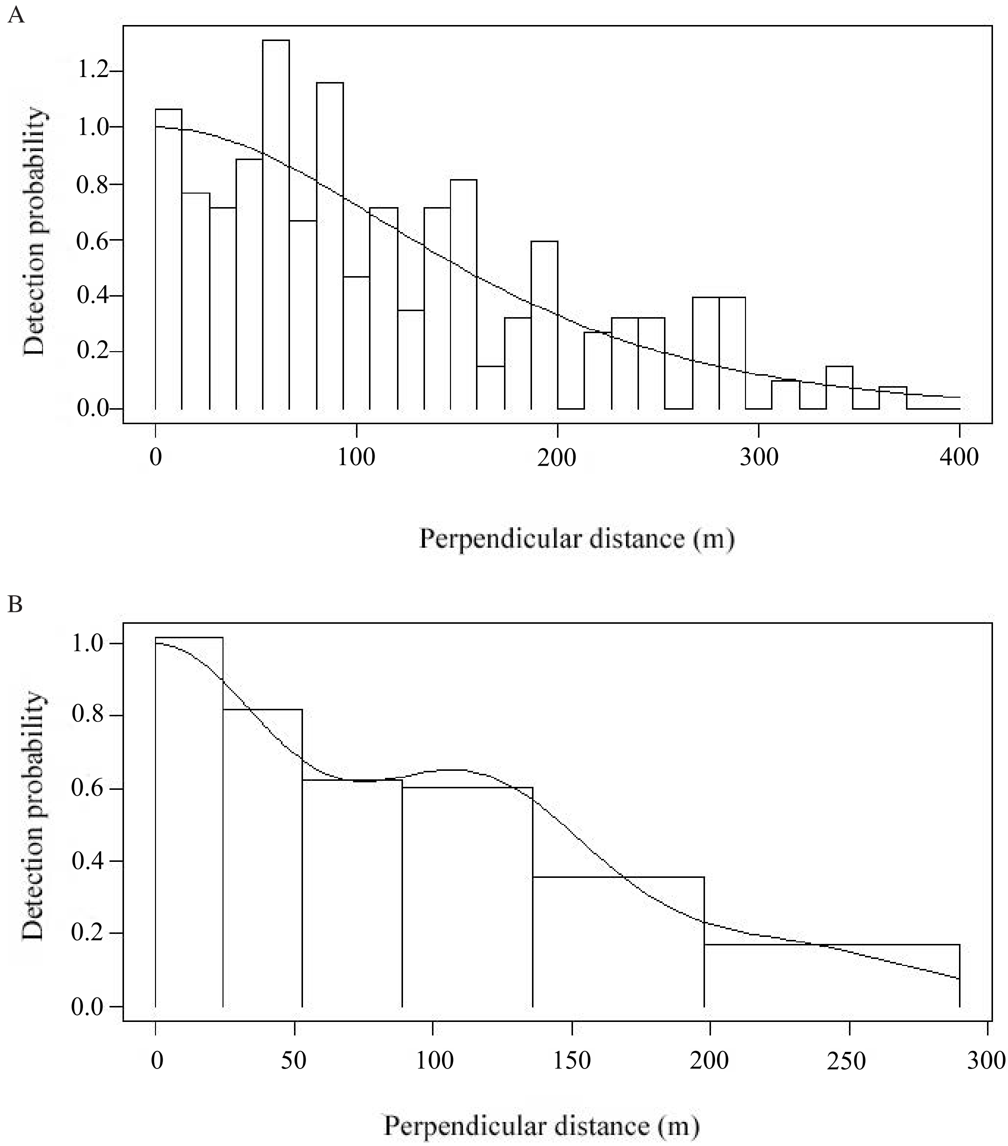

Figure 2. Fitted detection function of bottlenose dolphin (*Tursiops truncatus*) sighting data (smooth curve) and the frequency of observed sightings by perpendicular distance (m) (histogram) for (A) monthly surveys (2005 to 2007) and (B) seasonal surveys (2008 to 2011)

the surface" as the covariate with sigma scaling (Table 5). The univariate models with sea state, season, glare, observer, and turbidity all had some support with ΔAIC within 2.0 of the best univariate model. All of these models had very similar predictions of density to that of the best univariate model (range: 0.0095 to 0.0118 dolphins/km^2), so the consideration of multiple covariate models was limited to the covariate "at the surface" combined with the other candidate covariates. None of these models were better supported than the best univariate model; therefore, all further inference was based on this model alone. The fit of this model was explored using goodness-of-fit diagnostic tests in *Distance 6.0* (Thomas et al., 2006), which showed no departure from model assumptions ($\chi^2 = 1.62$, $df = 2$, $p = 0.45$). None of the observations had estimated detection probability < 0.40

Table 5. Comparison of AIC values of multivariate detection function models for seasonal (winter/summer) surveys conducted between 2008 and 2011. Model g1 was found to have the lowest AIC (2,208.34) and was used for all subsequent inference. %CV = % coefficient of variation; * = too few *df* to perform automated GOF test.

Model/key function	Adjustment term	Covariates	Parameters/# adjustment terms	Δ AIC	ESW	GOF Chi-P	Density (dolphins/ km²)	%CV
g1 Half-normal	Cosine	At surface	3/1	0.00	136.08	0.45	0.0108	6.2
g2 Half-normal	Cosine	At surface, observer	4/1	0.50	140.86	0.15	0.0105	6.2
g3 Half-normal	Cosine	At surface, sea state	4/1	1.28	136.81	0.20	0.0107	6.2
g4 Half-normal	Cosine	Sea state	3/1	1.45	136.55	0.45	0.0107	6.2
g5 Half-normal	Cosine	At surface, season	4/1	1.61	139.73	0.17	0.0106	6.2
g6 Half-normal	Cosine	Season	3/1	1.65	140.08	0.39	0.0105	6.2
g7 Half-normal	Cosine	Glare	3/1	1.76	135.27	0.45	0.0108	6.2
g8 Half-normal	Cosine	Observer	3/1	1.82	140.34	0.38	0.0105	6.2
g9 Half-normal	Cosine	Turbidity	3/1	1.82	135.42	0.45	0.0108	6.2
g10 Half-normal	Cosine	Season, observer	3/0	1.85	158.60	0.03	0.0096	6.1
g11 Half-normal	Cosine	At surface, glare	4/1	1.99	136.20	0.20	0.0108	6.2
g12 Hazard-rate	Cosine	Observer	4/1	2.01	123.17	0.01	0.0118	6.3
g13 Half-normal	Cosine	At surface, turbidity	4/1	2.16	136.50	0.20	0.0107	6.2
g14 Half-normal	Cosine	At surface, observer	6/1	2.65	142.58	*	0.0104	6.2
g15 Half-normal	Cosine	Sub-basin	5/1	2.89	142.90	*	0.0103	6.2
g16 Half-normal	Cosine	Sea state, season	4/1	2.96	139.97	0.17	0.0105	6.2
g17 Half-normal	Cosine	Sea state, glare	4/1	3.07	136.20	0.21	0.0107	6.2
g18 Half-normal	Hermite	Observer	2/0	3.16	158.98	0.07	0.0095	6.1

for the best-supported model. The fitted detection function averaged over the observed covariate levels for the best-supported model is illustrated in Figure 2. Following selection of a model for the detection function, estimates of density and abundance were produced for each of the six levels of season-year within each of the four sub-basins (24 total strata).

Abundance Estimation

Abundance estimates for the IRL system ranged from 483 to 1,947, with a mean abundance of 1,032 dolphins (95% CI = 809 to 1,255) (Table 6; Figure 3). Abundance estimates within the individual sub-basins varied seasonally with the greatest variance seen in ML and the SIR (Figure 4). The average abundance estimate was greatest in the SIR (347; 95% CI = 202 to 492), followed by the NIR (299; 95% CI = 239 to 359), ML (206; 95% CI = 126 to 286), and BR (193; 95% CI = 153 to 233). The average combined abundance estimate for the NIR and BR was 492 (95% CI = 402 to 581). Estimated abundance for the IRL was greatest in the winter of 2009-2010 and lowest during the summer of 2008. Expected cluster size within strata ranged from 0.92 to 7.50 individuals. Mean expected cluster size for IRL dolphins was 2.31 ± 1.01. Dolphin density was greatest in ML during the winter of 2010-2011 and lowest in ML in spring 2007 (Table 6). Pooled seasons indicated the lowest mean density during the fall (0.85 ± 0.224) and largest mean density during the winter (1.13 ± 0.462).

Trend Analyses

Bootstrap analysis of trends in abundance over time indicated increasing or nonsignificant changes (neutral) for dolphin abundance in the

Table 6. Estimated abundance for IRL bottlenose dolphins and related statistics by season and water body; effort is equivalent to linear water distance (km) covered per season. Density, $\widehat{D}$ = number of dolphins/km^2; abundance, $\widehat{N}$ = number of dolphins; %CV = percent of coefficient of variation; and 95% CI = 95% confidence interval.

Season	Sub-basin	Effort (km)	No. observations	Parameter	Estimate	%CV	95% CI
Fall 2005	Banana River	130	10	$\widehat{D}$	0.544	57.55	0.111-1.305
				$\widehat{N}$	106		22-254
	Mosquito Lagoon	88	8	$\widehat{D}$	0.638	48.88	0.208-1.346
				$\widehat{N}$	94		31-197
	Northern Indian River	171	19	$\widehat{D}$	1.211	35.40	0.484-2.183
				$\widehat{N}$	350		140-631
	Southern Indian River	182	18	$\widehat{D}$	0.495	34.78	0.215-0.870
				$\widehat{N}$	151		66-266
	Combined estimate	570	55	$\widehat{D}$	0.749		0.425-1.185
				$\widehat{N}$	701		398-1,109
Winter 2005-2006	Banana River	129	20	$\widehat{D}$	1.017	53.18	0.279-2.197
				$\widehat{N}$	198		54-427
	Mosquito Lagoon	84	17	$\widehat{D}$	1.383	38.69	0.419-3.212
				$\widehat{N}$	203		61-471
	Northern Indian River	170	31	$\widehat{D}$	1.087	30.71	0.514-1.824
				$\widehat{N}$	314		149-527
	Southern Indian River	177	33	$\widehat{D}$	1.024	28.34	0.568-1.661
				$\widehat{N}$	313		174-508
	Combined estimate	560	101	$\widehat{D}$	1.098		0.722-1.588
				$\widehat{N}$	1,028		676-1,486
Spring 2006	Banana River	128	14	$\widehat{D}$	0.671	40.06	0.260-1.217
				$\widehat{N}$	130		51-237
	Mosquito Lagoon	82	6	$\widehat{D}$	0.621	59.75	0.085-1.1177
				$\widehat{N}$	91		12-173
	Northern Indian River	173	21	$\widehat{D}$	0.745	32.77	0.338-1.337
				$\widehat{N}$	215		98-387
	Southern Indian River	181	24	$\widehat{D}$	0.939	36.25	0.442-1.568
				$\widehat{N}$	287		135-479
	Combined estimate	563	65	$\widehat{D}$	0.772		0.502-1.083
				$\widehat{N}$	723		470-1,014
Summer 2006	Banana River	127	14	$\widehat{D}$	0.860	35.41	0.356-1.532
				$\widehat{N}$	167		69-298
	Mosquito Lagoon	88	7	$\widehat{D}$	0.524	79.15	0.074-1.507
				$\widehat{N}$	77		11-221
	Northern Indian River	170	17	$\widehat{D}$	0.696	40.83	0.246-1.374
				$\widehat{N}$	201		71-397
	Southern Indian River	182	11	$\widehat{D}$	0.275	48.67	0.063-0.678
				$\widehat{N}$	84		19-207
	Combined estimate	567	49	$\widehat{D}$	0.565		0.315-0.918
				$\widehat{N}$	529		295-859
Fall 2006	Banana River	84	13	$\widehat{D}$	1.595	49.98	0.345-3.258
				$\widehat{N}$	310		67-633
	Mosquito Lagoon	55	17	$\widehat{D}$	0.862	60.23	0.190-1.938
				$\widehat{N}$	126		28-284
	Northern Indian River	112	20	$\widehat{D}$	1.090	35.19	0.415-2.441
				$\widehat{N}$	315		120-706

	Southern Indian River	118	12	$\hat{D}$	0.764	48.02	0.252-1.613
				$\hat{N}$	234		77-493
	Combined estimate	370	62	$\hat{D}$	1.052		0.591-1.749
				$\hat{N}$	985		553-1,637
Winter 2007-2008	Banana River	126	16	$\hat{D}$	0.616	35.87	0.273-1.013
				$\hat{N}$	120		53-197
	Mosquito Lagoon	78	8	$\hat{D}$	1.936	57.60	0.131-4.094
				$\hat{N}$	284		19-601
	Northern Indian River	172	28	$\hat{D}$	1.069	36.83	0.508-1.873
				$\hat{N}$	309		147-541
	Southern Indian River	184	39	$\hat{D}$	1.615	31.29	0.692-2.945
				$\hat{N}$	494		212-901
	Combined estimate	560	91	$\hat{D}$	1.290		0.762-1.922
				$\hat{N}$	1,207		713-1,799
Spring 2007	Banana River	42	10	$\hat{D}$	1.500	58.79	0.125-3.211
				$\hat{N}$	292		24-624
	Mosquito Lagoon	25	1	$\hat{D}$	0.101	122.64	0.000.0.344
				$\hat{N}$	15		0-50
	Northern Indian River	57	10	$\hat{D}$	2.015	47.86	0.620-3.192
				$\hat{N}$	582		179-923
	Southern Indian River	61	16	$\hat{D}$	1.548	51.25	0.446-2.938
				$\hat{N}$	473		136-899
	Combined estimate	185	37	$\hat{D}$	1.455		0.723-2.086
				$\hat{N}$	1,362		677-1,952
Summer 2007	Banana River	126	19	$\hat{D}$	1.232	35.84	0.556-2.245
				$\hat{N}$	239		108-436
	Mosquito Lagoon	82	10	$\hat{D}$	0.995	47.61	0.308-1.599
				$\hat{N}$	146		45-235
	Northern Indian River	165	23	$\hat{D}$	1.181	31.69	0.587-2.021
				$\hat{N}$	341		170-584
	Southern Indian River	183	14	$\hat{D}$	0.524	38.78	0.227-0.894
				$\hat{N}$	160		69-273
	Combined estimate	556	66	$\hat{D}$	0.947		0.615-1.339
				$\hat{N}$	886		576-1,253
Summer 2008	Banana River	170	19	$\hat{D}$	0.476	35.51	0.210-0.827
				$\hat{N}$	92		41-161
	Mosquito Lagoon	111	13	$\hat{D}$	0.557	45.60	0.209-1.489
				$\hat{N}$	82		31-218
	Northern Indian River	231	38	$\hat{D}$	0.564	21.33	0.373-0.825
				$\hat{N}$	163		108-238
	Southern Indian River	252	25	$\hat{D}$	0.476	26.05	0.262-0.679
				$\hat{N}$	146		80-208
	Combined estimate	764	95	$\hat{D}$	0.516		0.369-0.718
				$\hat{N}$	483		345-672
Winter 2008-2009	Banana River	128	23	$\hat{D}$	1.089	30.73	0.477-2.120
				$\hat{N}$	212		93-412
	Mosquito Lagoon	82	19	$\hat{D}$	2.148	38.31	0.755-3.059
				$\hat{N}$	315		111-449
	Northern Indian River	173	26	$\hat{D}$	0.928	31.89	0.454-1.461
				$\hat{N}$	268		131-422

	Southern Indian River	189	38	$\hat{D}$	1.436	26.12	0.671-2.899
				$\hat{N}$	439		205-886
	Combined estimate	571	106	$\hat{D}$	1.318		0.840-1.842
				$\hat{N}$	1,234		786-1,724
Summer 2009	Banana River	170	15	$\hat{D}$	0.736	35.43	0.280-1.203
				$\hat{N}$	143		55-234
	Mosquito Lagoon	108	23	$\hat{D}$	2.274	31.23	0.891-3.373
				$\hat{N}$	334		131-495
	Northern Indian River	229	25	$\hat{D}$	0.510	30.81	0.255-1.087
				$\hat{N}$	147		74-314
	Southern Indian River	249	22	$\hat{D}$	0.873	29.18	0.361-1.311
				$\hat{N}$	267		110-401
	Combined estimate	757	85	$\hat{D}$	0.952		0.631-1.228
				$\hat{N}$	891		591-1,149
Winter 2009-2010	Banana River	130	27	$\hat{D}$	1.187	25.47	0.600-1.837
				$\hat{N}$	231		117-357
	Mosquito Lagoon	54	17	$\hat{D}$	3.166	35.53	1.446-5.726
				$\hat{N}$	464		212-840
	Northern Indian River	151	19	$\hat{D}$	0.796	39.78	0.251-2.067
				$\hat{N}$	230		73-598
	Southern Indian River	183	51	$\hat{D}$	3.341	24.18	1.558-4.672
				$\hat{N}$	1,022		476-1,429
	Combined estimate	518	114	$\hat{D}$	2.080		1.280-2.767
				$\hat{N}$	1,947		1,198-2,590
Summer 2010	Banana River	171	20	$\hat{D}$	0.759	32.61	0.275-1.086
				$\hat{N}$	148		54-211
	Mosquito Lagoon	108	18	$\hat{D}$	0.902	37.33	0.305-1.522
				$\hat{N}$	132		45-223
	Northern Indian River	228	34	$\hat{D}$	1.058	28.01	0.490-1.602
				$\hat{N}$	306		142-463
	Southern Indian River	253	27	$\hat{D}$	0.554	30.10	0.285-1.021
				$\hat{N}$	170		87-312
	Combined estimate	762	99	$\hat{D}$	0.808		0.522-1.060
				$\hat{N}$	756		489-992
Winter 2010-2011	Banana River	128	30	$\hat{D}$	1.626	29.18	0.685-2.639
				$\hat{N}$	316		133-513
	Mosquito Lagoon	78	23	$\hat{D}$	3.447	37.96	0.981-6.508
				$\hat{N}$	506		144-955
	Northern Indian River	172	38	$\hat{D}$	1.514	28.27	0.833-2.135
				$\hat{N}$	438		241-617
	Southern Indian River	193	30	$\hat{D}$	1.488	31.77	0.603-2.281
				$\hat{N}$	455		184-698
	Combined estimate	572	121	$\hat{D}$	1.832		1.119-2.378
				$\hat{N}$	1,715		1,047-2,226

IRL (all basins combined) and the individual water basins (Table 7; Figures 5 & 6). A significant positive trend in dolphin abundance was indicated for the IRL (all basins combined), ML, and the SIR for the summer season over time, while a significant positive trend was also indicated across winter seasons in the BR. Only the SIR indicated a significantly positive trend over time for both seasons ($p \geq 0.05$). Bootstrap analysis of the difference in abundance between winter and summer indicated increased winter abundance for the IRL (all basins combined) and

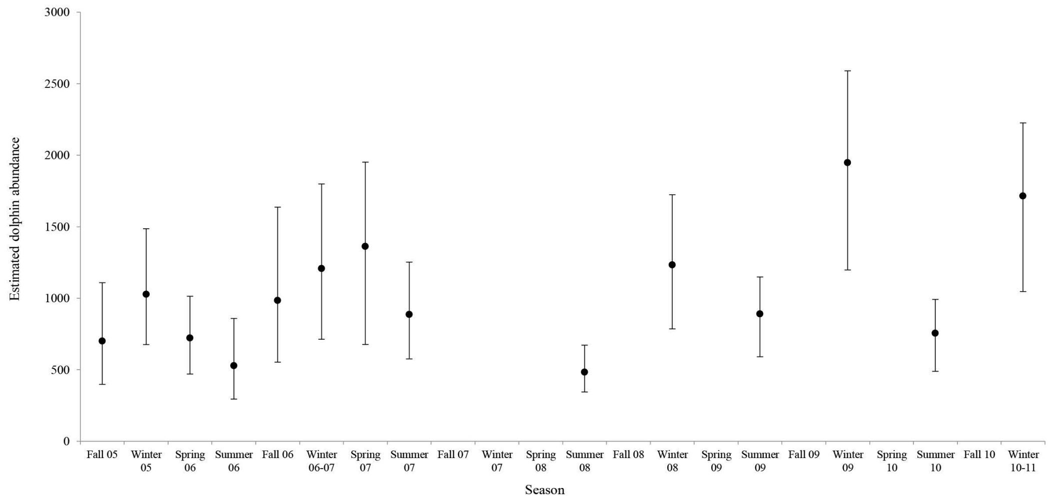

Figure 3. IRL abundance estimates by season (winter = December-February, spring = March-April, summer = June-August, and fall = September-November); mean values and 95% CIs were obtained for each stratum using a bootstrap resampling procedure in *Distance 6.0* (with 5,000 replicates).

for the individual water basins (Table 7). These differences were significant for the IRL and for the ML and SIR sub-basins.

Discussion

The largest dolphin abundance estimates for the IRL estuary corresponded with unprecedented cold temperatures and hard-freeze events occurring in the winters of 2009-2010 and 2010-2011, which may have yielded atypical dolphin movements from surrounding areas. Likewise, temporary seasonal movements surrounding the northern- and southernmost boundaries may contribute to abundance fluctuation. The lowest abundance estimate corresponded with a UME which occurred in the summer of 2008. Experimental results indicated that availability (visibility depth experiments) varied significantly between seasons and likely resulted in a marginal, negatively biased summer abundance estimate. This study provides an abundance estimate prior to mortality events occurring in 2013 and is currently required for IRL dolphin stock assessment.

Throughout the study, IRL dolphin abundance estimates fluctuated, with the greatest variation observed in the SIR and ML, which represent the southern- and northernmost boundaries of the IRL, respectively. While mean linear home ranges of IRL dolphins have been reported between 22 to 54 km (Mazzoil et al., 2008), estuarine dolphins have been documented ranging over 100 km (Balmer et al., 2008). Therefore, changes in abundance may correspond with an influx/efflux of animals via inlets open to the Atlantic Ocean or movements of animals from dolphin communities inhabiting the intracoastal waterways (ICW) adjacent to the IRL. Supporting these hypotheses, photo-identification studies and stranding response efforts have documented marked dolphins known to inhabit ML traveling well beyond the boundaries of the IRL into the Atlantic Ocean and adjacent northern estuarine waters (Nekolny, 2014; Durden, unpub. data). However, the duration of these excursions beyond the IRL boundaries is not clear and warrants further investigation.

Recent genetic studies have indicated that bottlenose dolphins residing in ML could not be differentiated from those in the southern Jacksonville Estuary community, suggesting genetic exchange along this expansive stretch of estuarine waters (Rodgers, 2013). Similarly, dolphins sampled in ML were determined to be genetically distinct from dolphins sampled in the remainder of the IRL (Richards et al., 2013), and photo-identification studies indicate ML supports a separate community of dolphins (Mazzoil et al., 2008). These lines of evidence provide support for ML dolphins being a disjunct community from the IRL proper (Indian and Banana Rivers) and for movements of these dolphins beyond the IRL boundaries, supporting the variance seen in this stratum. Furthermore, these data highlight the need to further evaluate the affiliation of ML dolphins with IRL estuarine stock.

Variance in abundance within the southern portion of the IRL should also be further investigated. While the northern portion of the lagoon is only open at one inlet (Ponce Inlet, ML), the SIR is open at four inlets, providing opportunities for short-term dolphin influx/efflux beyond

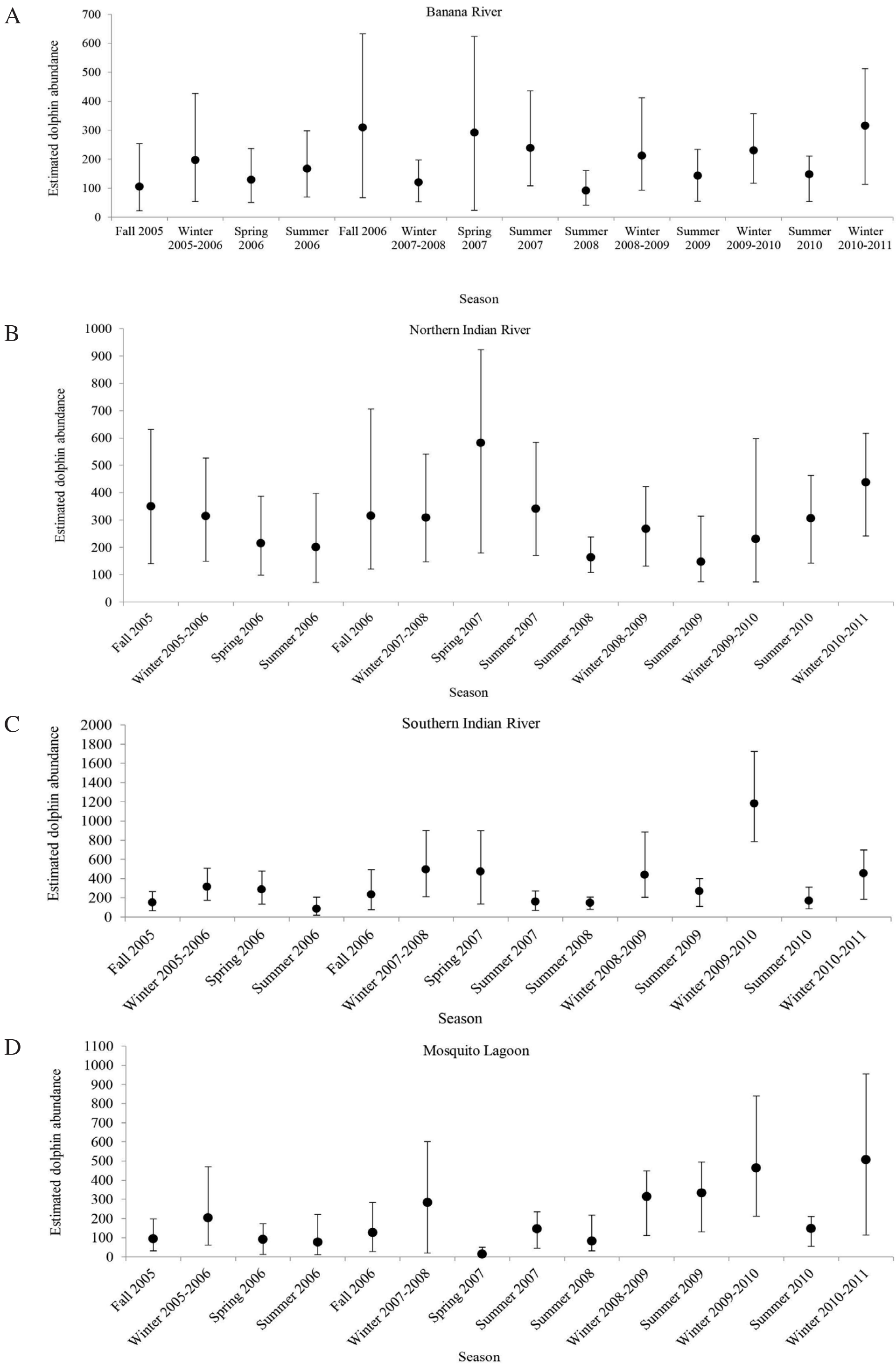

Figure 4. IRL dolphin abundance estimates by season for each sub-basin: (A) Banana River, (B) Northern Indian River, (C) Southern Indian River, and (D) Mosquito Lagoon. Mean values and 95% CIs were obtained for each stratum using a bootstrap resampling procedure in *Distance 6.0* (with 5,000 replicates).

Table 7. Parameter estimates from a bootstrap method of calculating temporal trends and seasonal differences for the IRL (all sub-basins combined) and for each individual water basin (BR = Banana River, ML = Mosquito Lagoon, NIR = Northern Indian River, and SIR = Southern Indian River). Bold type indicates significance ($p \geq 0.05$). β = estimated slopes for the yearly trend in abundance.

Parameter	Mean	95% CI
β All basins, winter	18	(-3, 40)
β All basins, summer	**13**	**(4, 21)**
β ML, winter	6	(-52, 60)
β ML, summer	**17**	**(2, 32)**
β BR, winter	**21**	**(1, 41)**
β BR, summer	2	(-10, 13)
β NIR, winter	8	(-20, 38)
β NIR, summer	12	(-5, 28)
β SIR, winter	**39**	**(2, 79)**
β SIR, summer	**20**	**(7, 33)**
Abundance summer – Abundance winter, all basins	**-136**	**(-199, -75)**
Abundance summer – Abundance winter, BR	-70	(-153, 9)
Abundance summer – Abundance winter, ML	-149	(-289, -30)
Abundance summer – Abundance winter, NIR	-97	(-207, 10)
Abundance summer – Abundance winter, SIR	**-227**	**(-360, -102)**

the boundaries of the IRL. While there are currently no data indicating significant movements of dolphins from the adjacent estuarine communities or via the open inlets in the SIR (Mazzoil et al., 2011), further investigations may be warranted. Fluctuations in abundance seen in this area could be associated with intraregional movements or temporary immigration from surrounding waters, or with potentially decreased availability in some portions of the SIR due to poor water quality (Sime, 2005). Future studies on availability in this area may provide further clarity.

The largest abundance estimates for IRL and water bodies bordering the IRL (ML and the SIR) were seen in the winters of 2009-2010 and 2010-2011. Both of these winters corresponded with unusually cold weather events. During the winter of 2009-2010, Florida experienced record-breaking cold temperatures for an extended duration (Roberts et al., 2014). In early 2010, much of central and northern Florida experienced below freezing temperatures for 12 d, and near-shore water temperatures dropped below 10° C for ten consecutive days (Roberts et al., 2014). Extended periods of below-freezing temperatures also occurred in the winter of 2010-2011 (National Weather Service, 2011). The cold weather events took place during the coldest winter season on record and resulted in record mortality and injury to both manatees and sea turtles and yielded large-scale fish die-offs (Barlas et al., 2011; Roberts et al., 2014). These historic events were the only occurrences of water temperature dropping below 10° C in the study area during this study (data acquired from the U.S. Geological Survey Haulover Canal Station: http://waterdata.usgs.gov/usa/nwis/uv?site_no=02248380).

It is likely that these events caused atypical movements of dolphins in response to prey and/or water temperature. For example, during the winter of 2010, over 100 dolphins were photographed congregating within a 4 km radius of Ponce Inlet (within estuarine waters) and were witnessed foraging on and playing with debilitated fish struggling at the water's surface (W. N. Durden, pers. obs.). Studies of migratory dolphins along the east coast of the U.S. have found dolphin presence to occur between 14.0 to 16.3° C (Toth et al., 2011) and the absence of dolphins at < 9.5° C (Garrison et al., 2003; NOAA Fisheries, 2010). Both direct (thermoregulatory needs) and indirect (prey movements) impacts of cold water temperature have been speculated to influence bottlenose dolphin movement patterns (Kenney, 1990; Barco et al., 1999; Gubbins et al., 2003; Torres et al., 2005). While bottlenose dolphin populations can occur in water temperatures as low as 9 to 10° C (Ross & Cockcroft, 1990), dolphin movement patterns seen along the east coast of the U.S. may be influenced by the movements and temperature tolerance of prey species. Future investigations should explore how extreme weather events and prey abundance and distribution influence temporal shifts in IRL dolphin movements and abundance.

Further supporting temporal shifts, trend analyses found IRL dolphin abundance was significantly larger during the winter compared to

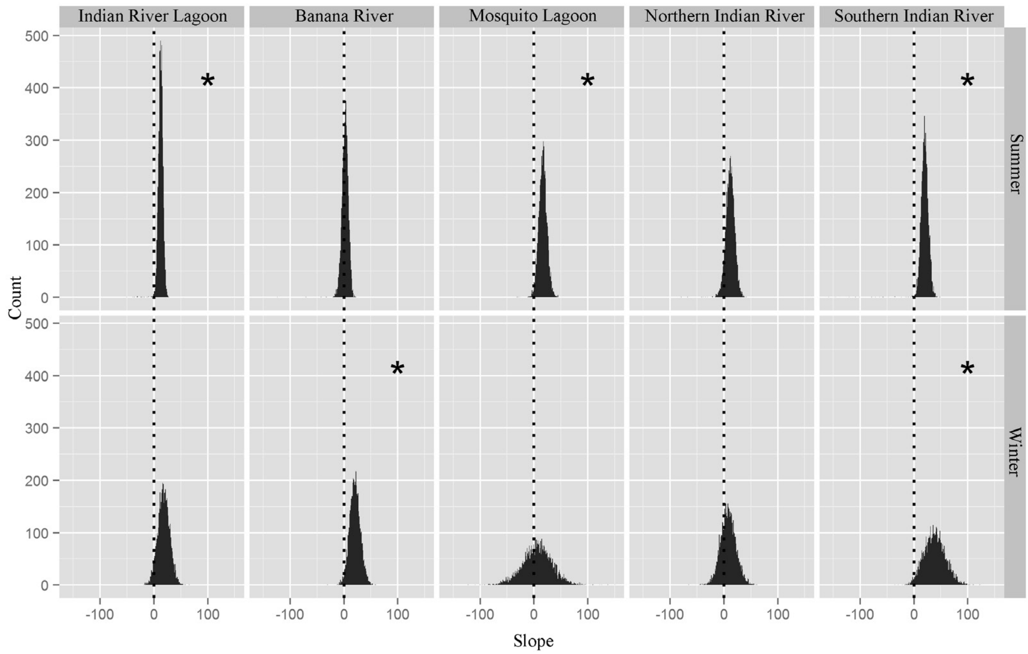

Figure 5. Slopes of the linear yearly trend in abundance were estimated separately within each season and sub-basin (IRL = all basins) using a bootstrap procedure; graphs in which the 95% CI of bootstrap estimates did not overlap zero are indicated with an *. Because all slopes were either neutral or positive, evidence for a decline was not found during the study period.

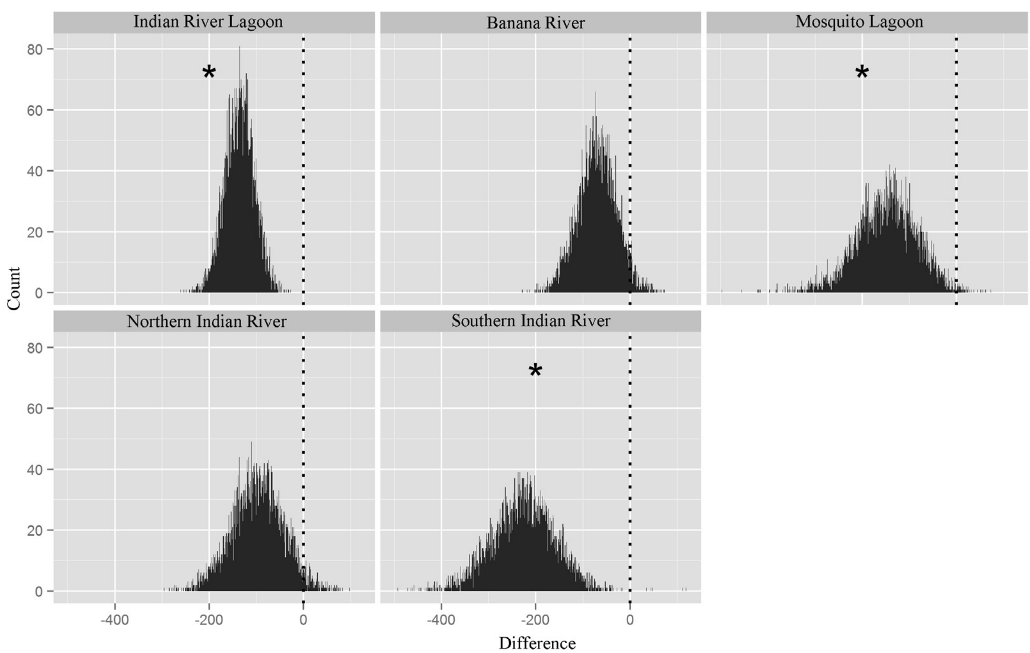

Figure 6. Differences in abundance between summer and winter were estimated within each sub-basin (IRL = all basins) using a bootstrap procedure; graphs in which the 95% CI of bootstrap estimates did not overlap zero are indicated with an *. In all cases, results indicated that abundance was greater in winter than summer.

summer season. However, when individual water basins were examined, only ML and SIR revealed a significant positive trend in winter abundance. Contrary to the other water basins of the lagoon, these basins have direct access to the Atlantic Ocean and represent the southern- and northernmost basins, enabling movements of animals to/from the adjacent estuaries and coastal waters. Seasonal changes in both of these water basins contribute to the overall increase in winter abundance seen in the IRL. Future efforts to determine abundance for stock management should be mindful of seasonal trends and should place an emphasis on summer efforts to ensure transient or nonresident dolphins are not included in estimates.

Aerial surveys of IRL dolphins in a shallow estuary create an ideal situation to meet the assumptions of line-transect theory and to decrease availability bias. Based on experiments to evaluate availability bias, the dolphin decoy could be seen at depths greater than the average depth of the IRL suggesting that dolphins are typically available for detection, provided surveys are conducted under optimal conditions. However, dolphin decoy trials found that while dolphins were available throughout the majority of the water column, more of the water column was available during winter than summer. Even though seasonal differences were not evident for the percent of dolphins sighted at the surface vs submerged, it is possible that seasonal changes in availability may have yielded a negatively biased summer abundance estimate, although any such bias would have been small. Future studies that evaluate water column utilization would provide information regarding availability bias. Furthermore, there are likely numerous factors that contribute to visibility depths, which may vary temporally and spatially even at small scales. Changes in availability and perception bias and the influence of these factors on abundance estimates should be further evaluated.

To put bounds on availability bias, it is also worthwhile to consider the effect of this bias on a survey conducted under the worst possible conditions. Surfacing intervals for estuarine and coastal bottlenose dolphins average between 30 and 40 s (Irvine et al., 1981). Previously, we modified the calculations described by Andriolo et al. (2006) to match our study and estimated the window of observation at 19.3 s (Durden et al., 2011). These results are very similar to our window of observation experiments, which estimated the mean observation time window to be 20.3 s. Using an average surfacing interval of 2/min (Irvine et al., 1981), an animal would be expected to surface every 30 s (2/60 s). Therefore, during a 20.3 s observation window, the probability of sighting a dolphin under adverse conditions (i.e., when submerged in deep water and only available when surfacing) would be 0.68. Therefore, for a survey area with conditions where animals were only available for observation while surfacing, we would expect that abundance would be underestimated by a factor of 1.47. This correction factor is a vast overestimate for the IRL since the correction factor would only apply during extremely poor conditions where the substrate was not visible and in the dredged channel, which represents a very small portion of the IRL (~2%).

Bottlenose dolphins are a long-lived species that mature late and produce few offspring, yielding a slow population growth rate. During the 9-y temporal period that was evaluated, IRL dolphin abundance indicated a neutral or slightly positive trend over time. A significant positive trend was only evident across both seasons for the SIR, a basin with opportunities for intraregional movements and immigration via access to multiple inlets and an adjacent estuary, and which has consistently been excluded from the mortality events seen in the NIR and BR. Trends in abundance should be interpreted with caution as population trends are often impossible to detect with any certainty unless long-term monitoring data are available. One study estimated that a minimum of 8 y were needed to detect trends in a dolphin population (Wilson et al., 1999). Future studies are needed to examine population dynamics, and developing a means to routinely monitor IRL dolphin abundance should be a priority for the management of these animals. Aerial surveys may represent a cost-effective and reliable method to estimate trends in abundance over time for the IRL dolphin population, which inhabits an expansive area and faces numerous threats.

Abundance and habitat usage data are essential to the management and conservation of the dolphins residing in the IRL. Understanding movement patterns and abundance of IRL dolphins has become increasingly important as the stock has been subjected to multiple UMEs (IRL: 2001, 2008, and 2013; Mid Atlantic: 2013), with the largest occurring in 2013. Furthermore, in recent years, the IRL has undergone significant ecological disturbances, yielding a catastrophic loss of nearly 50% of seagrass habitat (Morris et al., 2015). The bulk of these ecological disturbances and the IRL dolphin UMEs have occurred in the NIR and BR. Given that a single community of dolphins occupies a large portion of these two basins (Titcomb et al., 2015), the impacts of both ecological disturbances and reoccurring mortality events on this community warrants further investigation. Furthermore, while the impacts of indirect anthropogenic activities are not well understood, IRL dolphins face significant direct threats from injury and mortality associated with recreational and commercial fishing gear (Noke & Odell, 2002; Stolen et al., 2013). Likewise, high concentrations of mercury, and papilloma and skin disease presence are causes for concern regarding the health of this population (Caldwell et al., 1975; Reif et al., 2006; Durden et al., 2007, 2009; Bossart, 2007; Murdoch et al., 2008). Abundance and distribution data are needed to assess the impacts of recent mortality events and to estimate potential biological removal (human-related mortality), particularly as it relates to commercial fisheries takes. This study provides abundance estimates surrounding recent UMEs, and abundance and distribution data prior to the impacts of several large-scale mortality events and ecosystem changes.

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