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Abundance, Distribution, and Group Composition of Indian River Lagoon Bottlenose Dolphins (*Tursiops truncatus*)

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Abstract

Information on the abundance and distribution of cetaceans is essential to management and conservation and necessary to assess mortality trends and anthropogenic impacts for stock assessment. Line-transect aerial surveys (n = 45) were conducted to assess bottlenose dolphin (*Tursiops truncatus*) abundance, distribution, and group composition in the Indian River Lagoon (IRL) estuary system, Florida, from 2002 to 2004. Calves composed 9.41% of all known age class animals sighted. Multiple covariate distance sampling was used to estimate abundance. Abundance estimates varied seasonally, ranging between 362 (95% CI = 192 to 622; summer 2003) and 1,316 dolphins (95% CI = 795 to 2,061; winter 2002-2003), with a mean abundance of 662 dolphins (95% CI = 544 to 842). Abundance estimates for the Mosquito Lagoon sub-basin exhibited the greatest seasonal variability. Seasonal differences in abundance within strata suggest seasonal movement patterns. This study provides the first abundance estimate for IRL dolphins in over 30 y. Further studies that investigate evidence of influx/efflux are needed to better understand the population biology of IRL dolphins.

Key Words: abundance, aerial survey, bottlenose dolphin, *Tursiops truncatus*, distance sampling, distribution, Indian River Lagoon, line transect

Introduction

Bottlenose dolphins (*Tursiops truncatus*) (Montagu, 1821) are widely distributed throughout temperate and tropical waters worldwide and inhabit open oceans and coastal waters, including shallow lagoons, estuaries, and rivers (Leatherwood & Reeves, 1983). Along the east coast of central Florida, several stocks of bottlenose dolphins occur, including the Western North Atlantic coastal morphotype that includes the Northern Florida, central Florida, and southern migratory stocks (National Oceanic and Atmospheric Administration [NOAA] Fisheries, 2008a); the Western Northern Atlantic offshore stock (NOAA Fisheries, 2008b); and the Indian River Lagoon (IRL) estuarine system stock (NOAA Fisheries, 2009). While genetic and morphological differences have been described among some of the ocean stocks (Hersh & Duffield, 1990), relationships between IRL and coastal dolphins are not well understood.

IRL dolphins have an average linear home range of 32 to 84 km and at least a portion of the population is comprised of year-round residents (Odell & Asper, 1990). Dolphins residing in the IRL have been found to exhibit strong site fidelity (Odell & Asper, 1990; Mazzoil et al., 2005). While the degree of influx/efflux of individuals between estuary and the ocean is not well understood, Mazzoil et al. (2011) found only a small amount of movement between estuarine and oceanic dolphins in a portion of the southern Indian River. These and other findings have led to the declaration of IRL dolphins as a separate stock of bottlenose dolphins with an unknown current population size (NOAA Fisheries, 2009). Previous aerial surveys of portions of the IRL suggested a summer influx and autumnal efflux of dolphins (see review in Scott, 1990), a finding inconsistent with a population of exclusively resident dolphins. However, prior aerial surveys that occurred decades ago covered small portions of the IRL (i.e., portions of the Indian and Banana Rivers) and produced small abundance estimates ranging from 101 (95% CI = 65 to 137; Griffin & Patton, 1990) to 438 (95% CI = 311 to 565; Leatherwood, 1979) animals. These results are largely not available in peer-reviewed literature (Leatherwood, 1979) and are insufficient to detect a seasonal influx/efflux of animals. Therefore, there is a need for recent, accurate seasonal abundance estimates, as well as an evaluation of abundance trends in individual water basins that comprise the IRL.

Bottlenose dolphins inhabiting the IRL estuarine system are impacted by several factors that warrant an improved understanding of the population. 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) 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). However, the effect of these impacts on population health are difficult to assess without an accurate estimate of abundance.

Sound management of wildlife populations is dependent upon information about abundance, population structure, and demography (birth, mortality, immigration, and emigration). Because bottlenose dolphins are long-lived with a low reproductive rate, monitoring the population biology of these animals is essential for detecting changes in population size on a timescale at which effective management actions can occur (Wilson et al., 1999). The lack of a current, reliable abundance estimate has hampered the management and understanding of the IRL dolphin population; for example, in recent years, the large number of dolphin mortalities per year (i.e., 2002 to 2005; mean = 36 ± 2.74 SE; Stolen et al., 2007) has raised questions about previous estimates that indicated a small population (100 to 200 dolphins; Scott, 1990) that could not remain stable under such high mortality (Stolen & Barlow, 2003; Stolen et al., 2007). Similarly, in 2001, the IRL population experienced an unexplained die-off (n = 41 mortalities) that was declared an Unusual Mortality Event (UME) by the National Marine Fisheries Service (NMFS) (Stolen et al., 2007). More recently (2008), the population exhibited another UME (n = 48 mortalities; Stolen et al., unpub. data), highlighting the need for information on population abundance and distribution to inform management decisions. While mortality patterns have been investigated, the magnitude of impact to the population is difficult to address due to the lack of abundance data.

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, and considerable areas present extreme vessel navigation difficulties; thus, aerial surveys are a practical method to study the population throughout its range. For decades, aerial surveys have been routinely utilized for wildlife management (Caughley, 1977). Line-transect surveys that incorporate distance sampling to adjust for detectability (Thomas et al., 2006) are considered one of the best methods to estimate the abundance of marine mammal populations (Carretta et al., 1998; Buckland et al., 2001). The objective of this study was to conduct the first comprehensive aerial survey of the IRL bottlenose dolphin population; to estimate abundance by separate geographic sub-basins; and to examine seasonal changes in abundance, distribution, and group composition.

Materials and 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: (1) the Indian River, (2) Banana River, and (3) Mosquito Lagoon (Mulligan & Snelson, 1983; U.S. Environmental Protection Agency [EPA], 1996) (Figure 1). While recent studies have defined the IRL to extend from Ponce Inlet to Jupiter Inlet (U.S. EPA, 1996; Mazzoil et al., 2008; NOAA Fisheries, 2009), most historical studies have defined the system as extending from Ponce de Leon Inlet to St. Lucie Inlet (Leatherwood, 1979; Mulligan & Snelson, 1983; Odell & Asper, 1990; Stolen et al., 2007). 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 > 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, the IRL was divided into four regions (hereafter termed sub-basins). 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/central Indian River (NIR) (378 km^2) and (2) the southern Indian River (SIR) (182 km^2) (Figure 1).

Aerial Surveys

Aerial surveys were flown twice monthly from 7 June 2002 to 7 May 2004 following line-transect distance sampling methodology (Buckland et al., 2001). Surveys were conducted from a high-wing Cessna 172 aircraft that was 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

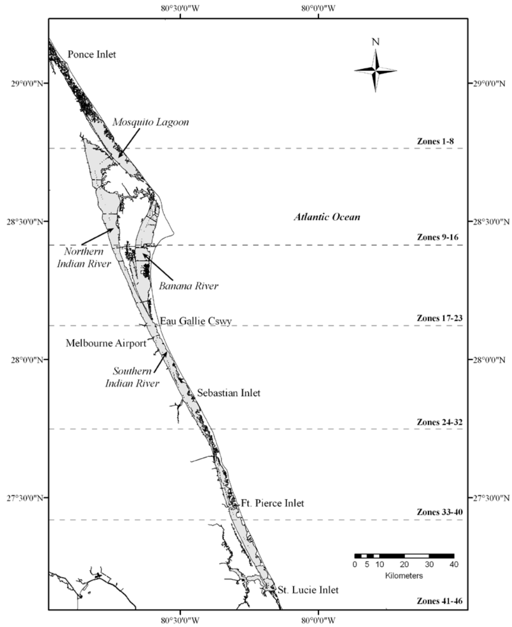

Figure 1. The study area, Indian River Lagoon (IRL), Florida, covered by aerial surveys; the study area was divided into 46 zones that were further subdivided into five parallel (east-west) transects (one transect from each zone was flown during each survey). The lagoon was divided into four sub-basins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

Inlet (29° 04' 30" N) to St. Lucie Inlet (27° 10' 0" N). The study area was divided into 46 equal zones, 2.5 nmi apart (Figure 1). Each zone was further subdivided into five east-west parallel transects, 0.5 nmi apart. During each survey, one randomly selected transect was flown from each zone. Surveys were conducted from approximately 0730 to 1300 h, under strict environmental conditions (Beaufort sea states ≤ 2; wind speed ≤ 16 km/h). Personnel consisted of a pilot; a data recorder, who occupied the 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 hand-held 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 federal airspace access restrictions, all surveys were conducted following the same flight path. The aircraft began at Zone 23; continued north to Zone 1; then returned to the starting location, 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 transect was resumed from the point at which it 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 or when a change occurred. Habitat description was recorded for each sighting and was grouped into two categories: (1) shallow water (where we could readily see the bottom) or (2) the channel (designated by markers) and adjacent deep water. Group size, composition (adults and calves), and behavior (when apparent; Wells, 1996) were recorded for each sighting. An animal was considered to be a calf if it was approximately half the size of the associated adults. Adults were determined based on physical size (i.e., not sexual maturity). Flight path data from the GPS were later imported into *Arc GIS 9.1*, and distance over water (m) for each transect was determined.

Distance Sampling

Dolphin density ($\hat{D}$) and abundance ($\hat{N}$) were estimated using multiple covariate distance sampling methods applied to clusters of animals (Marques & Buckland, 2004). Multiple covariate distance sampling is similar to conventional distance sampling (Buckland et al., 2001) except that covariates are included in the 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 and abundance were estimated as

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

where A is the area of the covered region; 2L is two times the length of the surveyed strips; $\hat{E}(s)$ is the expected cluster size (see below); n is the number of clusters seen; and $\hat{f}\,(0|z_i)$ 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 5.0* (Thomas et al., 2006) 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 5.0* to obtain CIs on abundance estimates for each stratum with 2,000 replicates. Because *Distance 5.0* 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 the *R* program (R Development Core Team, 2008), using parameter estimates from *Distance 5.0*, following methods described in Buckland et al. (2001).

Covariates considered were season-year (SY; 8 levels), sub-basin (SB; 4 levels) and observer (OBS; 2 levels). Models of the detection function were considered without covariates and in combinations of one, two, or three covariates. For each combination of covariates, the half-normal key function with hermite polynomial or cosine adjustment terms and the hazard rate key function with hermite or simple polynomial adjustment terms were considered. The number of adjustment terms was limited to two to prevent problems with convergence of the detection function in *Distance 5.0* (Marques et al., 2007). For each combination of detection function, adjustment term, and covariates, two forms of the scale parameter were considered: the observed distance divided by the truncation distance, or 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), and the model that had the lowest AIC was chosen for inference. Following selection of the best model for the detection function, abundance was estimated for each of 32 strata determined as combinations of the eight SY time periods and the four SBs. SY combinations were based on the following seasons: winter = December-February, spring = March-May, summer = June-August, and fall = September-November (Shane, 1990). There were eight SY combinations that combined with four SBs to produce 32 strata for estimation.

Data were pooled over 3-mo periods—winter (December-February), spring (March-May), summer (June-August), and fall (September-November)—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). Because of aircraft design, area directly beneath the plane was not visible to observers. Based on ground and survey measurements, we determined that objects > 50° from the horizon were not consistently visible 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; the null hypothesis was that the proportion of calves did not vary by season. All statistical comparisons were calculated using the *R* program (R Development Core team, 2008).

Results

Field Effort

A total of 45 surveys, corresponding to a total linear transect distance of 8,524 km, were flown. Survey duration ranged from 4.75 to 6.22 h (mean = 5.5 ± 0.60 SE). A total of 961 groups, comprised of 2,549 dolphins, were recorded (2,282 adults, 237 calves, and 30 animals of unknown age class). The number of dolphins sighted per survey ranged from 7 to 123 animals (mean = 56.6 ± 4.49 SE). Calves represented 9.41% (237/2,519) of the known age class animals observed (Table 1). Calf sightings varied seasonally, with more calves than expected in the winter season and less calves than expected in the summer ($\chi^2 = 53.61$, $df = 3$, $p < 0.0005$).

Modeling the Detection Function

Following the initial data screening, a right-truncation distance of 270 m was chosen, resulting in

Table 1. Number of Indian River Lagoon (IRL) dolphins by age class (adult/calf) sighted per season and year (summer 2002, 2003 = June-August; fall 2002, 2003 = September-November; winter 2002-2003, 2003-2004 = December-February; spring 2003, 2004 = March-May) and the percentage of animals that were calves. The number of adults, calves, and percent of calves are also given for season combined by year (in italics).

Season	Adults	Calves	% Calves
Summer 2002	152	7	4.40
Summer 2003	178	21	10.55
Summer 2002, 2003	330	28	7.82
Fall 2002	172	22	11.34
Fall 2003	236	29	10.94
Fall 2002, 2003	408	51	11.11
Winter 2002-2003	431	63	12.75
Winter 2003-2004	480	42	8.04
Winter 2002, 2003, 2004	911	105	10.33
Spring 2003	245	16	6.13
Spring 2004	388	37	8.75
Spring 2003, 2004	633	53	7.72
Total	2,282	237	9.41

removal of 11.3% of detections. The number of detections within the 32 pooled strata ranged from 50 to 141, and the encounter rates ranged from 0.14 to 0.18 (clusters observed/km of transect surveyed). The total number of observations used to fit the detection function was 762. The best-supported model (g_1) for the detection function included a half-normal key function with a Hermite polynomial adjustment of order 1, and SY and OBS as covariates (Table 2). The next best-supported model (g_2) had the same covariates but used a cosine adjustment term of order 2 (Table 2). The third best-supported model (g_3) had the same key function and series adjustment as the best-supported model, but added the covariate SB (Table 2). The global density estimates for all the top models were similar and ranged from 0.71 to 0.76; thus, the best supported model (g_1) was used for all subsequent inference. The fit of this model was explored using qq-plots and goodness-of-fit diagnostic tests in *Distance 5.0* (Thomas et al., 2006). The qq-plot suggested a slight heaping at zero distance, but otherwise showed no departure from model assumptions. The Kolmogorov-Smirnov goodness-of-fit tests indicated a lack of fit ($p = 0.0077$). This diagnostic test is based on the largest discrepancy between observed and predicted values and thus was most likely indicating the heaping near zero distance. The Cramer-von Mises tests, which are based on the overall differences between the observed and predicted values, showed no evidence for lack of fit (Cramer-von Mises test with uniform weighting $0.2 < p \leq 0.3$; Cramer-von Mises test with cosine weighting $0.15 < p \leq 0.2$). 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); no estimated detection probability was less than 0.39 for the best-supported model. The fitted detection function averaged over the observed covariate levels for the best-supported model (g_1) is illustrated in Figure 2.

Following the selection of a model for the detection function, estimates of density and abundance were produced for each of the eight levels of SY within each of the four SBs (32 total strata). *Distance 5.0* was used to obtain point estimates of density and abundance for each strata, and a bootstrap procedure (n = 2,000 replicates) was used to obtain the CIs on density and abundance within each strata, with the final estimates for combinations of strata calculated in *R* using parameter estimates from the program. Occasionally during the bootstrap, within a stratum, the regression of ln (group size) on the estimated detection probability produced unreasonably large cluster size estimates, which then resulted in unreasonable density and abundance estimates. These replicates were removed before calculating the bootstrap CIs of density and abundance (n = 13 replicates removed).

Abundance Estimation

Expected cluster size within strata ranged from 1.36 to 8.31 individuals. The largest group sizes were

Table 2. Comparison of AIC (Akaike's Information Criterion) values of multivariate detection function models; covariates considered included season-year (SY; 8 levels), sub-basin (SB; 4 levels), and observer (OBS; 2 levels). Model g_1 was found to have the lowest AIC and was used for all subsequent inference; % CV = % coefficient of variation.

Model/ Key function	Adjustment term	Covariates	Parameters	Distance scaling	Order of adjustment terms	ΔAIC	Density (dolphins/ km^2)	% CV
g_1 Half-normal	Hermite	SY-OBS2	10	y/w	1	0.00	0.0071	7.40
g_2 Half-normal	Cosine	SY-OBS2	11	y/w	2	2.44	0.0076	7.55
g_3 Half-normal	Hermite	SY-SB-OBS2	13	y/w	1	2.86	0.0071	7.40
g_4 Half-normal	Cosine	SY-SB-OBS2	14	y/w	2	5.94	0.0076	7.60
g_5 Half-normal	Cosine	SY-OBS2	9	y/σ	0	7.25	0.0080	7.74
g_6 Half-normal	Hermite	SY-OBS2	9	y/σ	0	7.25	0.0080	7.74
g_7 Hazard rate	Simple	SY-OBS2	11	y/w	2	7.66	0.0069	7.12
g_8 Hazard rate	Simple	SY-OBS2	10	y/σ	1	9.91	0.0069	7.16
g_9 Hazard rate	Cosine	SY-OBS2	10	y/σ	1	9.91	0.0069	7.16
g_{10} Hazard rate	Cosine	SY-OBS2	10	y/w	1	9.91	0.0069	7.16
g_{11} Half-normal	Cosine	SY-SB-OBS2	12	y/σ	0	10.96	0.0080	7.84
g_{12} Half-normal	Hermite	SY-SB-OBS2	12	y/σ	0	10.96	0.0080	7.84
g_{13} Hazard rate	Simple	SY-SB-OBS2	14	y/w	2	11.93	0.0071	7.23
g_{14} Hazard rate	Cosine	SY-SB-OBS2	13	y/σ	1	15.54	0.0071	7.28
g_{15} Hazard rate	Simple	SY-SB-OBS2	13	y/σ	1	15.54	0.0071	7.28
g_{16} Hazard rate	Cosine	SY-SB-OBS2	13	y/w	1	15.54	0.0071	7.28

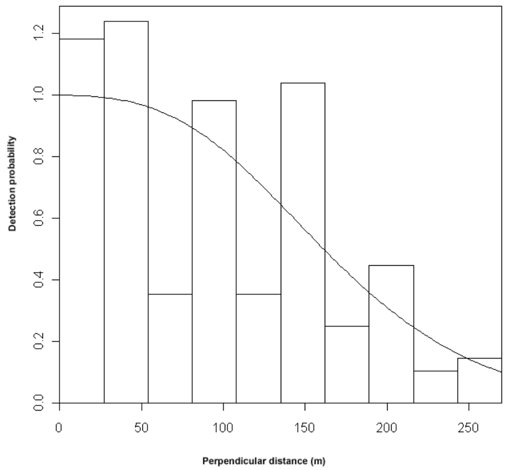

Figure 2. Fitted detection function (half-normal key function with hermite polynomial of order 1) of bottlenose dolphin sighting data (smooth curve) and the frequency of observed sightings by perpendicular distance (m) (histogram)

found in Mosquito Lagoon (ML) during winter (winter 2002-2003 = 8.31 [95% CI = 5.46 to 12.66]; winter 2003-2004 = 4.16 [95% CI = 2.39 to 7.23]). Mean group size for the IRL was 1.11 (95% CI = 2.83 to 8.53). Abundance estimates for the IRL system ranged from 362 to 1,316 and were greatest during winter and lowest during summer (Table 3; Figure 3). Abundance estimates for ML exhibited the greatest seasonal variability, ranging from 53 (summer 2002) to 604 dolphins (winter 2002-2003) (Table 3; Figure 4d). Abundance also varied in the SIR, ranging from 55 (summer 2003) to 370 dolphins (winter 2002-2003) (Table 3; Figure 4c); however, less variability occurred in the Banana River (BR) (66 to 160

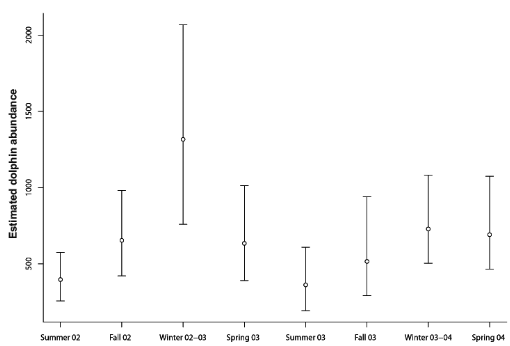

Figure 3. IRL abundance estimates by season (winter = December-February, spring = March-April, summer = June-August, and fall = September-November); mean values and 95% CIs were obtained for each stratum using a bootstrap resampling procedure in *Distance 5.0* (with 2,000 replicates).

dolphins) (Table 3; Figure 4a) and NIR (142 to 279 dolphins) (Table 3; Figure 4b). Mean abundance for IRL dolphins during the survey period was 662 (95% CI = 544 to 842). IRL dolphin density ranged from 0.387 dolphins/km^2 (summer 2003) to 1.406 dolphins/km^2 (winter 2002-2003) (Table 3). Density varied by sub-basin and was greatest in the winter months in ML and SIR, with the greatest overall density of animals being 4.118 dolphins/km^2 in ML during winter 2002-2003 (Table 3).

Discussion

Calves were found to compose 7.7 to 11.1% of all known age class animals sighted. These results directly correspond with previous Indian River Lagoon (IRL) aerial survey data that indicated that calf percentage ranged between 8.1 to 10.1% (Leatherwood, 1979). Our data found that calves were more abundant during fall and winter. While not identical, these results are similar to those found from studies on free-ranging IRL dolphins that indicated calving peaks in September (fall) and April (spring) (Howells et al., 2008). IRL dolphin stranding data (1977 to 2005) (Stolen et al., 2007) suggest calving peaks in spring and late summer/early fall. Small discrepancies in seasonal estimates of calf prevalence may be related to differences among the classification protocols for stranded calves (≤ 160 cm; Stolen et al., 2007), calves sighted during aerial surveys (half of adult body length), and estimated birth month for young of the year (Howells et al., 2008). Alternatively, the difference may indicate minor temporal changes in calving trends.

We found a marked difference in bottlenose dolphin abundance between winter and summer, with larger winter estimates. This pattern occurred in both years of the study and was pronounced in the two water bodies with direct access to the ocean inlets (Mosquito Lagoon [ML], southern Indian River [SIR]), with smaller fluctuations observed in the water bodies that were removed from inlets (Banana River [BR], northern/central Indian River [NIR]). Seasonal fluctuations in abundance are contrary to what would be expected of an exclusively resident population with little influx or efflux. Previous studies on IRL dolphin abundance reported seasonal fluctuation but, in contrast, found a summer increase in dolphin abundance in the IRL (Scott, 1990). These findings were based on a low sample size (e.g., *n* = 3 surveys), however, and a limited temporal and geographic (i.e., did not include ML) scope and, thus, were inconclusive (see review in Scott, 1990). The seasonal fluctuations in abundance observed during this study are consistent with movements of IRL dolphins between adjacent estuarine and/or oceanic areas since the areas with large shifts in abundance are those with direct ocean access and also represent

Table 3. 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 ($\hat{D}$ = number of dolphins/km^2), abundance ($\hat{N}$ = number of dolphins), percentage of coefficient of variation (% CV), and 95% confidence interval (CI).

Season	Body of water	Effort (km)	No. observations	Parameter	Estimate	% CV	95% CI
Summer 2002	Banana River	236	23	$\hat{D}$	0.581	38.15	0.0024 - 0.0111
				$\hat{N}$	113		46-216
	Mosquito Lagoon	170	10	$\hat{D}$	0.361	44.39	0.0010 - 0.0071
				$\hat{N}$	53		14-104
	Northern Indian River	357	26	$\hat{D}$	0.491	31.38	0.0024 - 0.0086
				$\hat{N}$	142		70-248
	Southern Indian River	377	22	$\hat{D}$	0.291	27.36	0.0015 - 0.0046
				$\hat{N}$	89		47-140
	Combined estimate	1,140	81	$\hat{D}$	0.424	20.43	0.0027 - 0.0061
				$\hat{N}$	397		257-574
Fall 2002	Banana River	201	22	$\hat{D}$	0.823	29.25	0.0044 - 0.0139
				$\hat{N}$	160		86-270
	Mosquito Lagoon	135	16	$\hat{D}$	0.845	55.17	0.0022 - 0.0202
				$\hat{N}$	124		32-297
	Northern Indian River	305	17	$\hat{D}$	0.540	37.28	0.0021 - 0.0102
				$\hat{N}$	156		61-294
	Southern Indian River	304	23	$\hat{D}$	0.700	26.74	0.0037 - 0.0111
				$\hat{N}$	214		114-340
	Combined estimate	945	78	$\hat{D}$	0.700	20.92	0.0045 - 0.0105
				$\hat{N}$	654		421-982
Winter 2002-2003	Banana River	235	21	$\hat{D}$	0.643	37.04	0.0023 - 0.0116
				$\hat{N}$	125		44-225
	Mosquito Lagoon	162	23	$\hat{D}$	4.118	43.29	0.0123 - 0.0833
				$\hat{N}$	604		180-1,221
	Northern Indian River	338	23	$\hat{D}$	0.751	43.84	0.0027 - 0.0162
				$\hat{N}$	217		78-469
	Southern Indian River	368	51	$\hat{D}$	1.210	24.91	0.0071 - 0.0189
				$\hat{N}$	370		218-577
	Combined estimate	1,103	118	$\hat{D}$	1.406	24.1	0.0085 - 0.0221
				$\hat{N}$	1,316		795-2,068
Spring 2003	Banana River	198	26	$\hat{D}$	0.813	36.01	0.0034 - 0.0153
				$\hat{N}$	158		67-298
	Mosquito Lagoon	132	15	$\hat{D}$	1.132	61.67	0.0022 - 0.0289
				$\hat{N}$	166		32-423
	Northern Indian River	298	41	$\hat{D}$	0.754	25.72	0.0042 - 0.0120
				$\hat{N}$	218		122-348
	Southern Indian River	307	9	$\hat{D}$	0.301	56.6	0.0004 - 0.0073
				$\hat{N}$	92		12-223
	Combined estimate	935	91	$\hat{D}$	0.677	23.9	0.0042 - 0.0108
				$\hat{N}$	634		391-1,013

Season	Body of water	Effort (km)	No. observations	Parameter	Estimate	% CV	95% CI
Summer 2003	Banana River	253	8	$\hat{D}$	0.340	52.03	0.0003 - 0.0077
				$\hat{N}$	66		6-149
	Mosquito Lagoon	167	10	$\hat{D}$	0.661	56.82	0.0006 - 0.0160
				$\hat{N}$	97		9-234
	Northern Indian River	374	25	$\hat{D}$	0.498	37.27	0.0020 - 0.0095
				$\hat{N}$	144		58-275
	Southern Indian River	391	7	$\hat{D}$	0.180	69.88	0.0002 - 0.0043
				$\hat{N}$	55		8-133
	Combined estimate	1,185	50	$\hat{D}$	0.387	29.08	0.0021 - 0.0065
				$\hat{N}$	362		193-609
Falll 2003	Banana River	210	17	$\hat{D}$	0.396	37.97	0.0015 - 0.0075
				$\hat{N}$	77		29-146
	Mosquito Lagoon	152	16	$\hat{D}$	0.375	39.42	0.0014 - 0.0074
				$\hat{N}$	55		21-109
	Northern Indian River	301	14	$\hat{D}$	0.744	60.52	0.0014 - 0.0194
				$\hat{N}$	215		40-561
	Southern Indian River	336	26	$\hat{D}$	0.553	36.06	0.0023 - 0.0104
				$\hat{N}$	169		71-319
	Combined estimate	999	73	$\hat{D}$	0.551	31.72	0.0031 - 0.0100
				$\hat{N}$	516		291-939
Winter 2003-2004	Banana River	227	25	$\hat{D}$	0.401	27.09	0.0020 - 0.0064
				$\hat{N}$	78		40-124
	Mosquito Lagoon	172	20	$\hat{D}$	1.248	50.74	0.0024 - 0.0289
				$\hat{N}$	183		35-424
	Northern Indian River	368	48	$\hat{D}$	0.823	25	0.0049 - 0.0133
				$\hat{N}$	238		141-383
	Southern Indian River	358	48	$\hat{D}$	0.752	28.12	0.0041 - 0.0128
				$\hat{N}$	230		125-392
	Combined estimate	1,125	141	$\hat{D}$	0.779	19.35	0.0054 - 0.0116
				$\hat{N}$	729		504-1,081
Spring 2004	Banana River	253	31	$\hat{D}$	0.561	31.94	0.0028 - 0.0099
				$\hat{N}$	109		54-193
	Mosquito Lagoon	175	22	$\hat{D}$	0.927	41.42	0.0035 - 0.0188
				$\hat{N}$	136		51-276
	Northern Indian River	354	40	$\hat{D}$	0.965	33.41	0.0049 - 0.0186
				$\hat{N}$	279		142-539
	Southern Indian River	398	37	$\hat{D}$	0.546	28.4	0.0030 - 0.0093
				$\hat{N}$	167		92-285
	Combined estimate	1,180	130	$\hat{D}$	0.738	20.8	0.0050 - 0.0115
				$\hat{N}$	691		466-1,074

the northern and southernmost geographical limits of the lagoon. The marked increase in mean winter group size in ML could be related to groups of oceanside animals entering the lagoon since group size has been found to be larger for coastal compared to estuarine dolphins (Shane et al., 1986; Scott et al., 1990; Toth et al., 2011). Alternatively, increased group size could be correlated with environmental factors such as prey species aggregation since bottlenose dolphins tend to form larger group sizes when feeding on patchy food resources (Wells et al., 1980). Further studies should examine correlations between prey abundance and distribution and temporal shifts in IRL dolphin abundance.

There is clearly a need to better understand movement patterns in the IRL stock, and the adjacent estuarine and ocean dolphin communities. While IRL bottlenose dolphins are largely resident (Odell

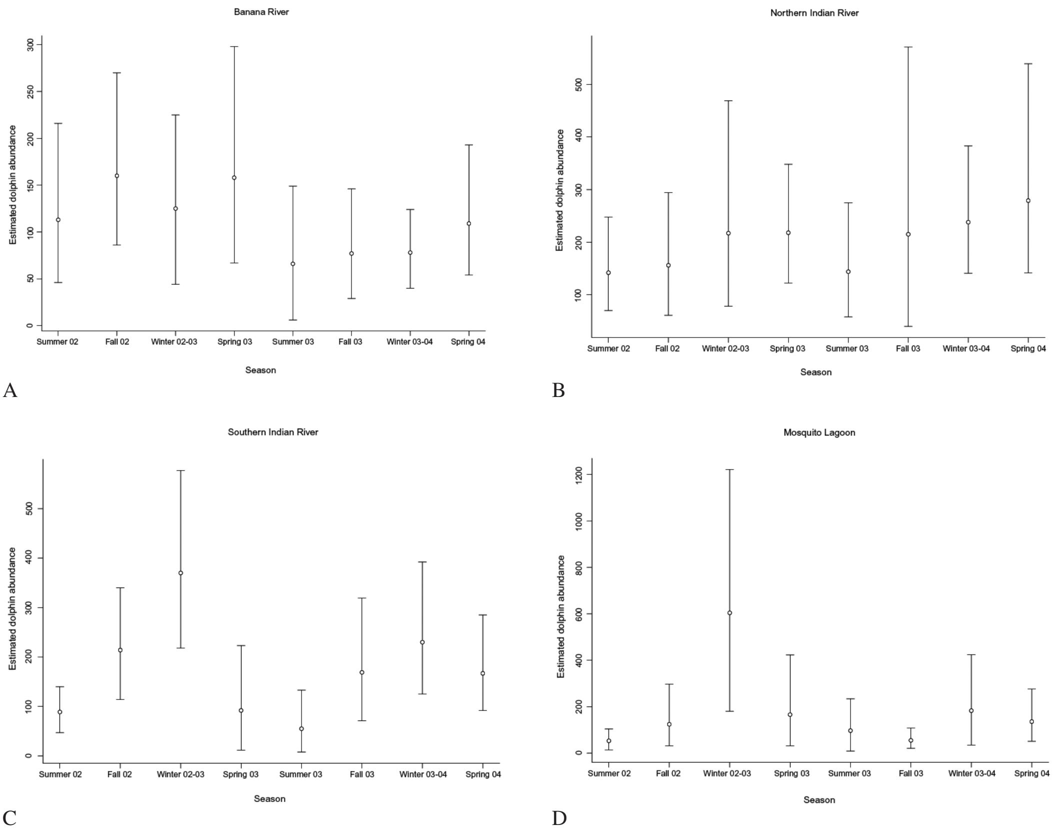

Figure 4. IRL dolphin abundance estimates by season for each sub-basin—A: BR, B: NIR, C: SIR, and D: ML; mean values and 95% CIs were obtained for each stratum using a bootstrap resampling procedure in *Distance 5.0* (with 2,000 replicates).

& Asper, 1990; Mazzoil et al., 2005), little data exist on the dispersal of these animals or the influx/efflux of neighboring populations. For example, a recent boat based photo-identification study documented large groups of dolphins moving from Mosquito Lagoon to the adjacent Atlantic waters (W. N. Durden, unpub. data, 2010). Furthermore, marked IRL dolphins have been recovered stranded outside the lagoon (W. N. Durden, unpub. data), providing additional evidence of dispersal. Further examination of movement and dispersal patterns that utilize photo-identification methods will be essential to understanding this aspect of IRL dolphin biology.

While aerial survey methods are well-suited to count individuals over large areas (Buckland et al., 1993), one inevitable problem is that observers miss individuals in the survey area (visibility bias) (Pollock & Kendall, 1987). Line-transect surveys that incorporate distance sampling adjust for this visibility bias (Burnham et al., 1980; Buckland et al., 2001) but must meet the assumptions of line-transect theory (Buckland et al., 2001) or biases can be introduced (Burnham et al., 1980; Hammond & Laake, 1983). The most important assumption is that all animals on the survey line are detected ($g(0) = 1$) (Buckland et al., 2001). When conducting aerial surveys of cetaceans, it is often difficult to meet this assumption since animals may spend a large amount of time underwater (Hiby & Hammond, 1989; Buckland et al., 1993). Aerial surveys of IRL dolphins create an ideal situation to satisfy these assumptions since the majority of the lagoon (> 90%) is shallow and readily allows visibility to the bottom of the lagoon. Furthermore, conducting flights only under optimal conditions also helps to alleviate potential visibility biases. The deeper dredged channels of the IRL and occasional poor water clarity, however, may produce an availability bias when submerged animals are unavailable for detection.

To put bounds on this bias, it is useful to consider the effect that availability bias would have 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). During an aerial survey, using an aircraft similar to the one used in this study, Andriolo et al. (2006) estimated an available observation window of 14.5 s during which a stationary object on the transect line could be viewed. Using Andriolo et al.'s calculations with modified aircraft velocity to match our study, the estimated window of observation for this study was 19.3 s. Using an average surfacing interval of two/min (Irvine et al., 1981), an animal would be expected to surface every 30 s (2/60 s). Therefore, during a 19.3-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 0.64. Therefore, for a survey flown under conditions during which animals were only available for observation while surfacing, we would expect that abundance would be underestimated by a factor of 1.56. To better understand potential availability bias, future studies should examine the influence of covariates such as water clarity, glare, and sea states on detectability, as well as surfacing rates and surface activity in IRL dolphins.

Developing an accurate and cost-effective means to routinely monitor IRL dolphins is a priority for the conservation of these animals. Aerial surveys may represent a cost-effective and reliable method to estimate trends in abundance over time for this dolphin population that inhabits an expansive area and faces numerous threats. In recent years, the IRL dolphin population has undergone two large mortality events. Studies have found signs of diminished IRL dolphin health, including high concentrations of mercury (Durden et al., 2007), a toxic element that can compromise immune health (Moszczynski, 1997); lingual and genital papillomas that may be related to immune dysfunction (Bossart, 2007); and the presence of the skin disease lacaziosis on dolphins throughout the lagoon (Caldwell et al., 1975; Reif et al., 2006; Murdoch et al., 2008; Durden et al., 2009). Because of the need for a better understanding of IRL dolphin population biology, the National Oceanic and Atmospheric Administration (NOAA)/NMFS proposed that the population be listed as a strategic stock in 2009 (NOAA Fisheries, 2009). Sound, science-based management and conservation of the IRL stock is dependent on a thorough understanding of abundance trends, habitat utilization, and distribution and group composition, especially during large mortality events. This study represents the first and most comprehensive abundance estimate for IRL dolphins in 30 y.

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