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Haria, Sahya N.

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Estimating Population Abundance of Atlantic Bottlenose Dolphins (*Tursiops truncatus*) in the Coastal Waters of Palm Beach County, Southeastern Florida

Sahya N. Haria,[1] Ian C. W. Hardy,[1,2,3] Stefan Harzen,[4] and Barbara J. Brunnick[4]

[1]*School of Biosciences, University of Nottingham, Sutton Bonington Campus, Loughborough, LE12 5RD, UK*
E-mail: s.haria@hotmail.com
[2]*School of Veterinary Medicine and Science, University of Nottingham, Sutton Bonington Campus, Loughborough, LE12 5RD, UK*
[3]*Department of Agricultural Sciences, PO Box 27, FI-00014, University of Helsinki, Finland*
[4]*Taras Oceanographic Foundation, West Palm Beach, FL 33407, USA*

Abstract

Atlantic bottlenose dolphins (*Tursiops truncatus*) are frequently observed in the coastal waters of Palm Beach County, Florida. In this study, mark-recapture surveys using photo-identification techniques were used to estimate population abundance of Atlantic bottlenose dolphins in this area for the first time. Surveys were conducted for 11 years, between 2005 and 2016, during which 384 individuals were identified and catalogued from distinctive nicks and notches on their dorsal fins. Each marked individual was documented an average of 2.4 times (range 1 to 19). Low resighting rates and a constant rate of encounter with previously unmarked individuals suggest that the population is open, comprising both residents and transients. The Jolly-Seber method was used to estimate population abundance. Estimates of abundance varied greatly in time with an overall average of 264 individuals and a 95% confidence interval of 162 to 366 (SE = 51.3), indicating a variable population size. As threats in the region continue to rise, such as overfishing, toxic algae blooms, and environmental pollutants, this understudied population may be vulnerable to decline. A better understanding of the population dynamics could facilitate more effective conservation action.

Key Words: abundance, mark-recapture, photo-identification, transients, residents, open population, southeast Florida, bottlenose dolphins, *Tursiops truncatus*

Introduction

Atlantic bottlenose dolphins (*Tursiops truncatus*) are mammals with complex social and population structures (Wells et al., 1987). They exhibit significant variation in movement patterns of individuals (home range), pods (distribution range), and seasonality (Berghan et al., 2008). There are two ecotypes, coastal and offshore, which, despite their difference in depth preferences, may frequently overlap and temporarily form mixed pods (Rossbach, 1997; Torres et al., 2003). Further research suggests that these two ecotypes may even represent two distinct subspecies or species in some parts of their range (Wickert et al., 2016; Costa et al., 2021, 2022).

Atlantic bottlenose dolphins frequent the coastal waters of Palm Beach County (PBC), Florida, in the United States, but little is known about the abundance, distribution, and natural history of this species in the region (Read et al., 2003). Lack of information on the population dynamics, population structure, distribution, genetic diversity, health, and habitat use of dolphins in this particular study area hampers the assessment of impacts of numerous direct and indirect anthropogenic threats, including persistent organic pollutants (POPs) and subsequent bioaccumulation of contaminants, reduction in prey availability due to overfishing, bycatch, exposure and ingestion of microplastics, toxic algal blooms, and habitat degradation (Balmer et al., 2011; Nery & Simão, 2012; Vollmer & Rosel, 2013; Wells et al., 2019; McHugh et al., 2021).

Atlantic bottlenose dolphins are subject to management under the 1972 Marine Mammal Protection Act (MMPA) as part of the National Marine Fisheries Service (NMFS) Western North Atlantic Central Florida Coastal Stock, which,

at present, is one of the five stocks considered depleted and presumed to be below its optimum sustainable level (Arrieta et al., 2015; National Marine Fisheries Service [NMFS], 2016). Coastal populations are at a higher risk due to the anthropogenic nature of most threats (Morteo et al., 2017). Thus, long-term monitoring of bottlenose dolphins is essential to understand the population dynamics and to identify potential harmful effects of anthropogenic activities and, subsequently, to develop more effective conservation action (Thompson et al., 2016).

The objective of this study was to estimate, for the first time, population abundance of Atlantic bottlenose dolphins found within the nearshore coastal waters of PBC. These estimates can serve as a data baseline for future assessments in this region and represent a potential bridge between studies conducted towards the North and South.

Between 2005 and 2016, boat surveys and photo-identification techniques were used to determine the occurrence of individual bottlenose dolphins. The Palm Beach Dolphin Project (PBDP) digital database catalogue of the Taras Oceanographic Foundation was created using data collected from these survey efforts, and the data were used to estimate dolphin abundance. This research is a critical first step for the understanding, development, and implementation of effective conservation and management measures and policies, as well as for predicting the long-term impact of anthropogenic activities and disturbances on bottlenose dolphins (Darling & Morowitz, 1986).

Methods

Study Area

The study area comprises the nearshore (< 3 km from land) coastal waters of PBC (Figure 1), situated in the central region of South Florida's Atlantic coastal zone under the Carolinian Atlantic Ecoregion. PBC is endowed with biologically rich coastal and marine ecosystems, with over 177 fish species found on the reefs in this region (Arena et al., 2007). A string of natural and man-made reefs and ledges align the eastern edge of the study area between the nearshore habitat and the Deep Florida Current, making it a well-established SCUBA diving site and tourist destination (Wilkinson et al., 2009). The study area is not protected by a bay or estuary and consists of a narrow coastal sandbank (42 km strip of open coastline) with shallow depths (< 13 m). This region is subject to occasional strong oceanic conditions, including heavy winds, ocean swells, and severe hurricanes (Irvine et al., 1981). During the study, sea surface temperatures ranged from 22.2 to 29.7°C.

Marine Surveys

Non-systematic boat-based photo-identification surveys were conducted aboard a 7.62-m Edgewater open fisherman (Arrieta et al., 2015). This vessel provided a low platform, avoiding distortion of dorsal fin images (Davies et al., 2001). To maximise spatial distribution of survey effort, the research vessel proceeded along a designated survey route between the Palm Beach and Jupiter (north) or Boynton (south) Inlets at a speed of 9 to 19 km/h^{-1}. Surveys were conducted parallel to the shoreline at a depth range of 6 to 10 m due to geographical limits of shallow depths.

Surveys were not conducted on consecutive days and were ultimately controlled by the oceanic conditions which governed the time, frequency, direction, and duration of the surveys. All surveys were conducted in Beaufort Scale ≤ 3 and under visibility conditions adequate for sighting and photographing dolphins, helping to reduce detection favourability bias.

Sighting cues used to detect Atlantic bottlenose dolphins included water disturbance from surface activity of the dolphins, silhouettes of animals rising above the water surface, and splashing (Berghan et al., 2008). Dolphin pods were defined as aggregations of dolphins in close (< 100 m) proximity to one another, engaged in similar behavioural activities, and, if moving, heading in the same direction (Urian & Wells, 1996; Quintana-Rizzo & Wells, 2001). An "encounter" was defined as an observation of one or more dolphins during a survey. Every attempt was made to photograph each dolphin encountered for identification purposes (Urian et al., 2013), regardless of the presence of visible markings, using two Nikon DSLR cameras equipped with 80-400 mm telephoto zoom lenses.

Sampling Frequency

From April 2005 to December 2016, 109 photo-identification surveys, totalling 83 discrete survey days (Figure 2), were conducted throughout the study area. Figure 2a shows the total hours of surveys carried out per year, and Figure 2b shows the sampling intensity at a finer time scale. Both figures illustrate that intervals between surveys were unequal over the 11-y period.

Photo-Identification

Standard photo-identification techniques, as described by Urian & Wells (1996), were used to identify each individual Atlantic bottlenose dolphin using the distinctive features and long-term, recognisable markings found on the dorsal fin, including pigmentation. To maximise the probability of recognising marked

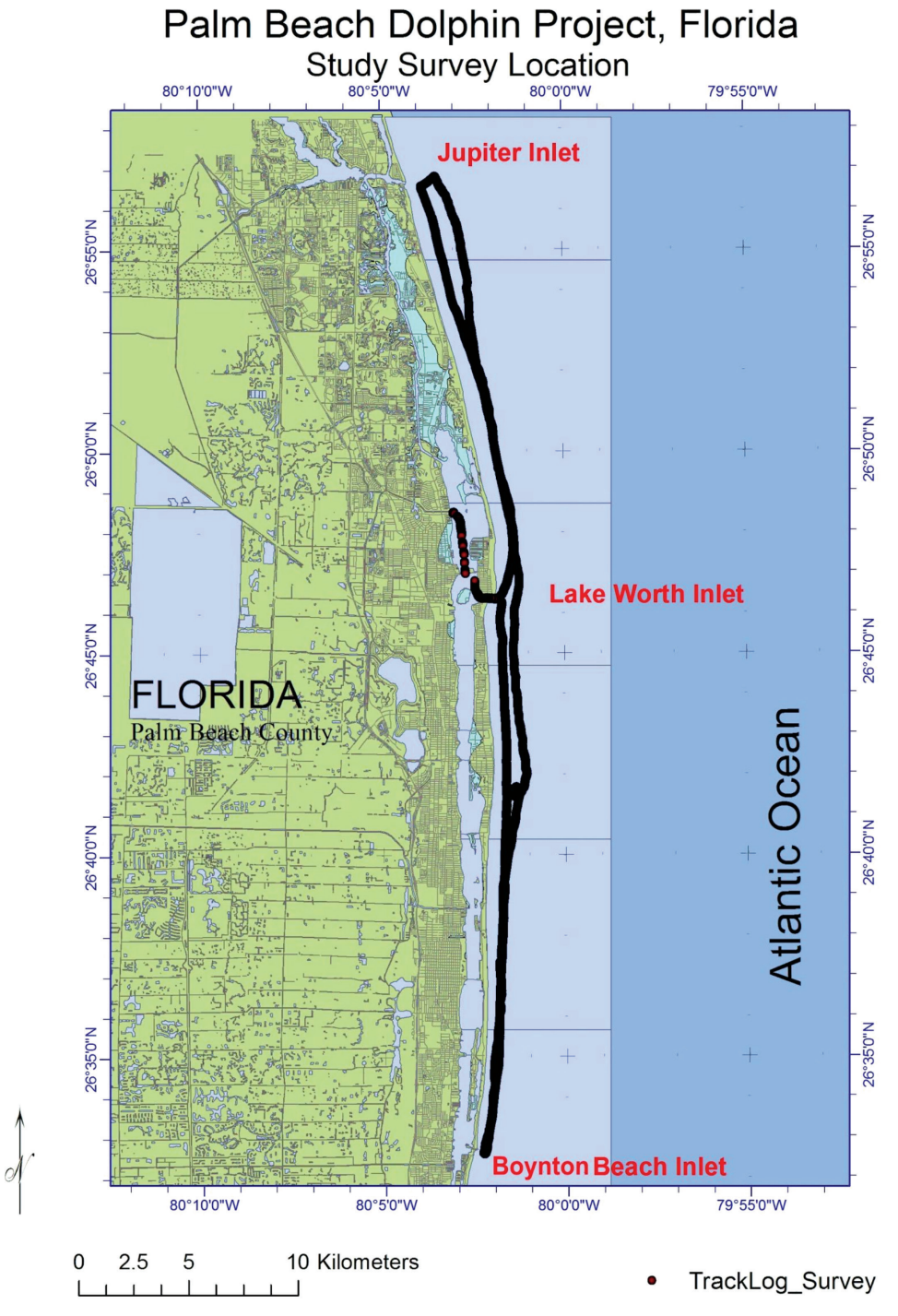

Figure 1. GIS map of survey location. The black "line" consists of a series of bullets that represent the location of all sightings of Atlantic bottlenose dolphin (*Tursiops truncatus*) pods (track log survey). The study area includes three passages (inlets) between the Atlantic Ocean and the Intracoastal Waterway (ICW): Jupiter Inlet, Lake Worth (Palm Beach) Inlet, and Boynton (South Lake Worth) Inlet. The study area extends alongshore from Jupiter Inlet (26° 58' 15" N, 80° 04' W) to Boynton Inlet (26° 31' 50" N, 80° 02' W).

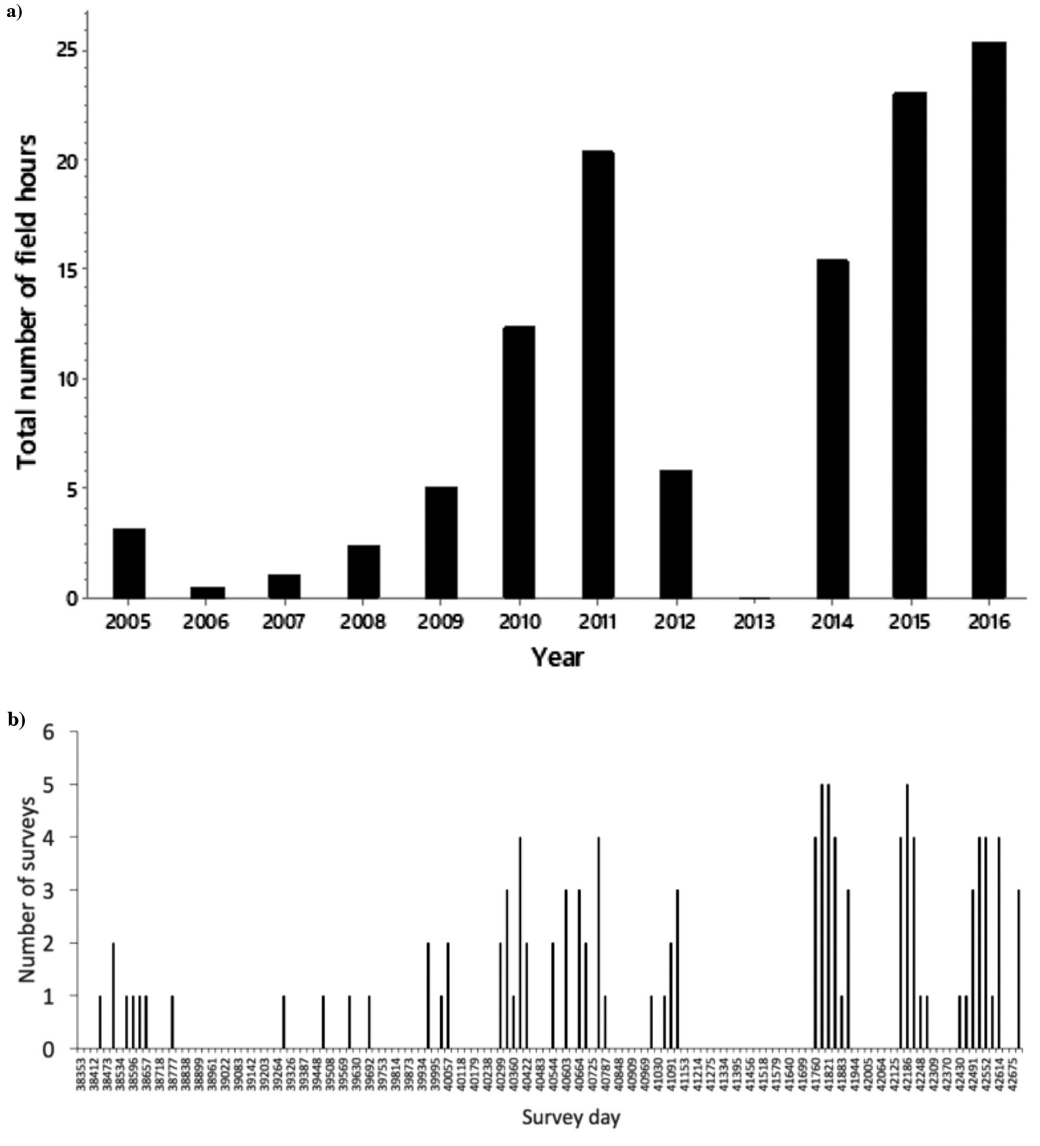

Figure 2. Sampling intensity throughout the study, from 2005 to 2016: (a) total hours of surveying carried out per year—a total of 114.34 daylight hours were spent in direct observation of dolphins; and (b) the number of surveys conducted on each survey day. Seventeen surveys were conducted from 2005 to 2009; 34 surveys were conducted from 2010 to 2012; and no surveys were conducted in 2013 due to a lack of personnel. Fifty-eight surveys were conducted from 2014 to 2016.

individuals and to enable accurate re-identification, mark-recapture analysis was restricted to the highest quality images with the full dorsal fin in focus (Scott et al., 1990; Urian et al., 2013). The photos were scored with a systematic method adapted from Defran et al. (1990). The identified individuals were then included in the PBDP catalogue.

Population Abundance Estimation

The data were analysed using mark-recapture models, which are widely used in ecological studies to estimate the number of marked individuals in a population (Otis et al., 1978), with different models employing different assumptions about sampling procedures (Williams et al., 1993; Read et al., 2003). Here, the Jolly-Seber

approach was used as it was the most appropriate method for the dolphin dataset which satisfied the assumptions of the model, including random sampling, an open population, and requiring ≥ 3 occasions of sampling (Begon, 1979; Seber, 1982; Krebs, 1999). Further, this model is suitable when there are series of data collected over multiple years with unequal intervals between surveys (Krebs, 1999). Data on individuals with no identification marks, calves, and dolphins identified from secondary characteristics alone were excluded from the dataset. The Method-B Table in Krebs (1999), which is derived from the Jolly-Seber model, was used to analyse the remaining mark-recapture data and calculate independent population abundance estimates for each of the 109 surveys.

Results

Palm Beach Dolphin Project Catalogue

There was an 87% Atlantic bottlenose dolphin encounter rate. During the 11-y study, 384 unique individual bottlenose dolphins were identified. The number of sightings for individual dolphins ranged from 1 to 19, with the majority (62.5%) being sighted only once (Figure 3). However, some individuals were resighted multiple times and in multiple years. On average, 88.6% (n = 885) of dolphins encountered were considered to be marked individuals.

Population Abundance

Independently calculated population abundance estimates for each of the 109 surveys are presented in Figure 4. The average abundance estimate was 264.6 (95% CI = 162.8 to 366.3; SE = 51.3), but there was a large range ($12.75 < \hat{N} < 4{,}464$) with many fluctuations between surveys. The size of the marked population was 98.4 ($7.5 < \hat{M} < 453$).

During some months, the total abundance, extrapolated from independent estimates from the surveys, yielded exceptionally high population estimates resulting in large variance. In particular, in survey 44 ($\hat{N}$ = 2,484; residual = 4.2), all the Atlantic bottlenose dolphins encountered were unmarked individuals; and in survey 89 ($\hat{N}$ = 4,464; residual = 7.93), there was a high proportion of marked but not resighted individual dolphins, suggesting transience. As a result, most estimates of population size were generally below the estimated overall mean. The modal population size was estimated as 720, and the median population size was 131.6.

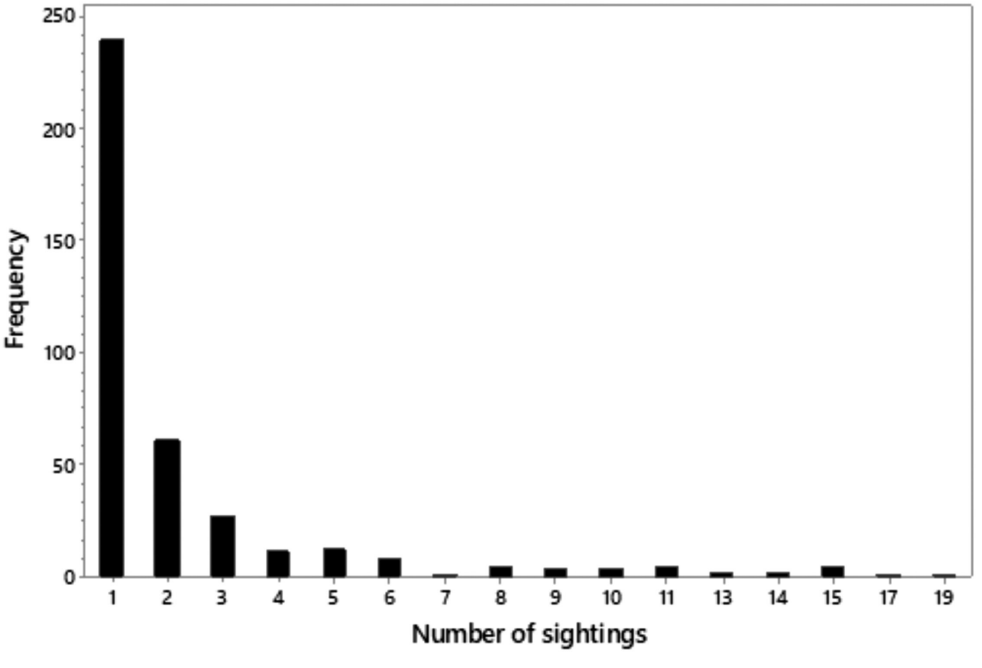

Figure 3. Sighting frequency of marked individuals: 384 Atlantic bottlenose dolphins were identified of which 240 (62.5%) were only sighted once. Out of the 144 (37.5% of the total catalogue) resighted individuals, 111 (28.9%) were resighted between 2 to 5 times, and 33 (8.6%) were resighted ≥ 6 times.

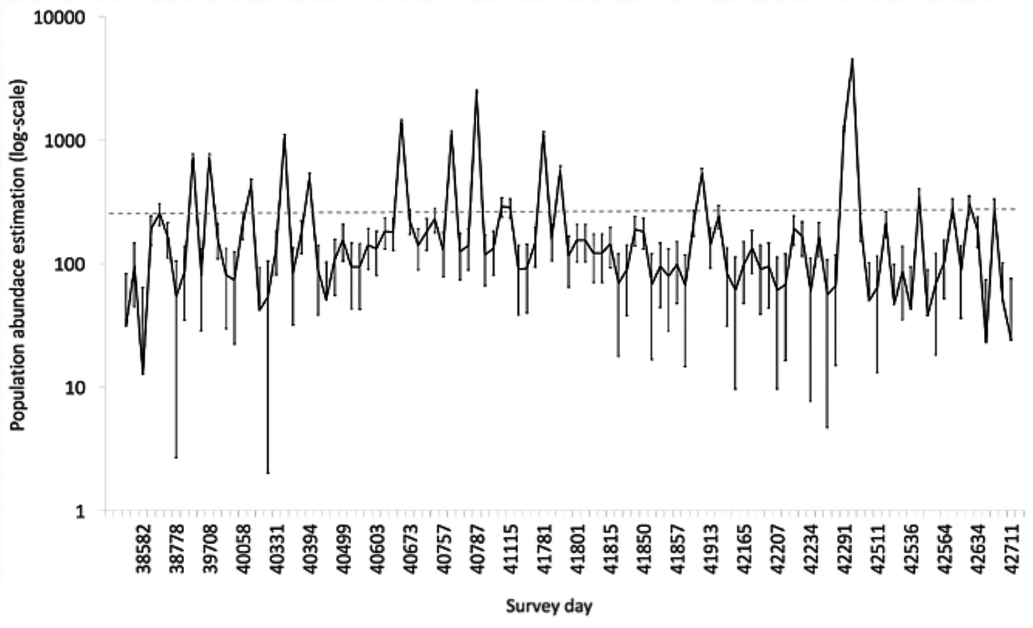

Figure 4. Population abundance estimates across 109 surveys. The abundance scale is log-transformed. Error bars represent one standard error around each mean, and the dotted line indicates the overall mean.

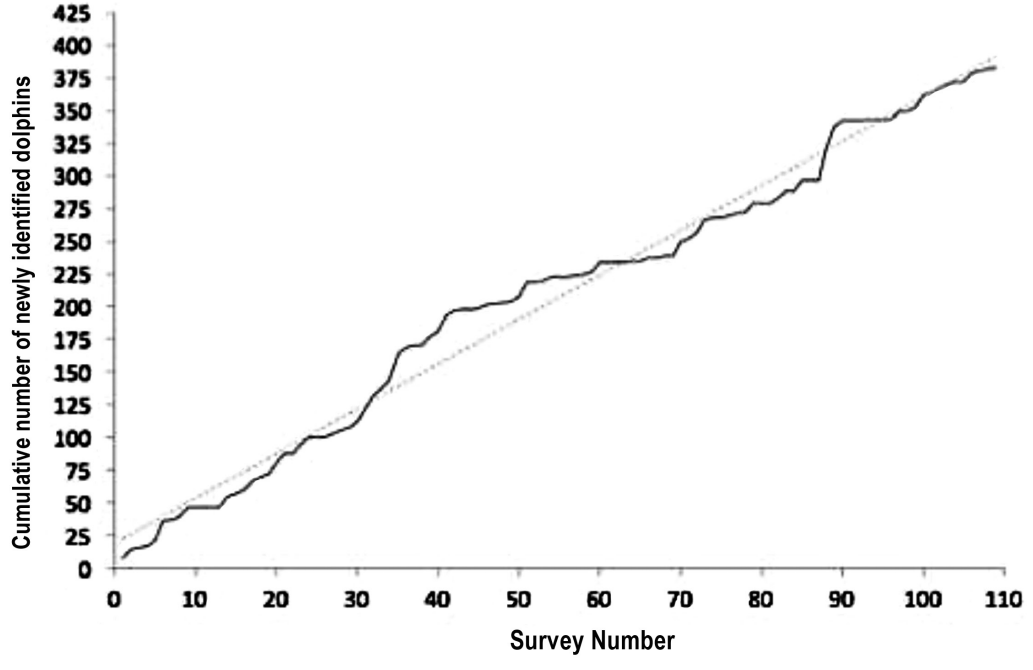

Figure 5. Discovery rate of previously unidentified individual Atlantic bottlenose dolphins from 2005 to 2016. The fitted regression line describes the data better than a curvilinear model, indicating that the rate of encounter with previously unidentified individuals was constant over the study period.

The cumulative number of individuals observed increased with time (standard linear regression: $F_{1,105} = 0.05$, $p = 0.819$; Figure 5), and there was no significant change in the rate of encounter with previously unidentified dolphins (addition of a quadratic term did not significantly improve the fit of the model: $F_{1,104} = 0.45$, $p = 0.502$).

Discussion

Population Abundance and Structure

This study provides the first population abundance estimate of Atlantic bottlenose dolphins in the coastal waters of Palm Beach County. The estimate of 264 individuals, with a 95% CI of 162 to 366, indicates that the population is similar in size to coastal populations of bottlenose dolphins found elsewhere (Williams et al., 1993; Liret et al., 1994; Wilson et al., 1999). There were, however, large fluctuations in estimated abundance, possibly related to the presence of transients or seasonal residents which were new and previously unmarked individuals—an interpretation further supported by the large fluctuations found in the size of observed pods. It should be noted that abundance estimates may be affected by a complex array of interrelated attributes (Ballance & Pitman, 1998; Krebs, 2009). The variable population size, in combination with its coastal distribution, suggests a complex combination of potential residential and seasonal or transient individuals, raising concerns that have been expressed about dolphins' susceptibility to a variety of anthropogenic pressures and impacts, enhanced by ecosystem stresses due to the climate crisis (Wells et al., 2019; McHugh et al., 2021).

As many distinctive features as possible were used to increase the accuracy of re-identification and to minimise any alterations in capture probability which may impact the abundance estimates. The PBDP catalogue was regularly updated to reduce the probability of false positives which would otherwise inflate the estimated population size (Scott et al., 1990; Würsig & Jefferson, 1990). Since surveys were only conducted under weather conditions that provided adequate visibility for sighting and photographing dolphins, the distribution of survey effort was not even throughout the study area or the study period. This may have led to a lower recapture rate for some individuals due to the loss of data on individuals' recapture histories (Baird et al., 2009).

Some individuals were resighted multiple times, and in multiple years, while the majority were sighted only once during the 11-y study. The fact that the cumulative number of marked individuals did not begin to asymptote suggests that many dolphins are transient members of an open population. Bottlenose dolphins display fission-fusion interactions, whereby pod composition changes frequently as individuals leave and join pods, depending on habitat, region, and season (Würsig & Würsig, 1977; Connor et al., 2000).

Large influxes of ≥ 22 unmarked adult individuals were occasionally observed. These individuals seem to undertake seasonal migrations along the coast—north to New Jersey or south to the Gulf of Mexico—and their home range may include the study area (McLellan et al., 2003). Other large pods encountered, consisting of both newly sighted and resighted individuals, may represent convergence on an area of prey abundance. Similar patterns were observed in other bottlenose dolphin studies, including the world's longest-running study of wild dolphins in Sarasota Bay on the west (Gulf of Mexico) coast of Florida (Wells et al., 2017). This supports our initial supposition that the communities are not closed demographic units as individuals may change community membership over time, evident from the gene flow occurring between communities (Shane et al., 1986; Connor et al., 2000).

Extensive, long-term sampling suggests that resighted individuals are likely to either be resident dolphins or individuals that return regularly to the study area, resighted in every sampling year after being marked and catalogued. These individuals are likely to be of the coastal ecotype (Rossbach, 1997), which are usually confined to waters within both < 40 m isobath and < 10 km offshore. However, they have also exhibited considerable plasticity in their movement patterns (Feldhamer et al., 2003). The degree of spatial overlap between the two ecotypes remains unclear (NMFS, 2016), which has also hampered attempts to estimate the abundance of coastal bottlenose dolphins in other areas along the East Coast of the U.S. (MacLeod, 2010). It is also unclear whether this stock overlaps with the Southern Migratory Coastal Stock.

The individuals encountered were known to range beyond the study area since they are not geographically isolated with no obvious boundary. This supports the potential that some level of interchange occurs between bottlenose dolphins in the Carolinian Atlantic Ecoregion, especially considering the large-scale movement of individuals relative to small coastal study sites (Fearnbach et al., 2012).

Implications of the Study

Although common bottlenose dolphins are currently classified as of "Least Concern" by the International Union for Conservation of Nature's (IUCN) *Red List* (Wells et al., 2019), they cannot be regarded as a secure population in the long

term. Their habitat is vulnerable to pollution and various impacts from coastal human activities, including commercial fisheries, likely leading to a decline in food availability, immunosuppression, and reproductive impairment.

Long-term photographic records allow the monitoring of changes in individual characteristics that indicate health status as dolphins have a high prevalence of skin lesions and small, sessile barnacles (*Xenobalanus globicipitis*), which use dolphins, among other marine species, as a host (Wilson et al., 1997; Díaz-Aguirre et al., 2012). Photo-identification data can also be used to assess other population parameters, including patterns of association, reproductive success, residency, and range (Davies et al., 2001), which assist in effective conservation and management actions. The PBDP database adds to existing research on populations between the state of Virginia and Jacksonville, Florida, which supports the hypothesis that there are multiple populations of coastal bottlenose dolphins along this coastline, each comprising both residential and migratory coastal individuals (Bills & Keith, 2012). In addition, dolphin identification catalogues, from PBC and adjacent areas, can be compared and collated to assess larger migration patterns. This will help to fill the substantial knowledge gaps that remain in the understanding of bottlenose dolphins, helping future effective conservation and management actions for this species along the Atlantic coast of the U.S. (Read et al., 2003).

Importance of Findings

Low resighting rates and a constant rate of discovery of previously unidentified dolphins were observed over the 11-y study. Of the 384 marked individuals, 240 were sighted only once, and 33 were resighted more than five times. These findings suggest that the studied population is open. The population found in the study area is likely comprised of a combination of both full-time and part-time residents, with relatively restricted home ranges, seasonal coastal migrants, regular visitors with high site fidelity, sporadic visitors, and highly mobile offshore transients, or at least individuals that have a home range larger than the area surveyed. This suggests that the majority of the marked individuals are highly mobile and may spend part of their time outside of the study area. Thus, the study area is likely to be part of a larger home range.

The population size was estimated to be 265 individuals overall, but component estimates varied greatly, and their calculation is known to be sensitive to violations of their assumptions. Thus, further information on factors affecting behaviour, spatial and temporal distribution, patterns of site fidelity, migratory patterns, social structure, food availability, climate, and disease would help to improve the understanding of the dynamics of this dolphin population. Genetic analyses of mitochondrial DNA haplotype frequencies, nuclear microsatellite markers, haematocrit, and Hb levels, obtained from biopsies, would further help determine the population demographic structure and viscosity or natal philopatry within and between different areas, stocks, and ecotypes (Rosel et al., 2009; Rodrigues, 2021).

The presence of Atlantic bottlenose dolphins in the survey area indicates that the site is critical for the maintenance of marine biodiversity and that effective conservation and management measures are required to protect the existing population to prevent any population decline.

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