Common bottlenose dolphin (*Tursiops truncatus*) abundance and distribution patterns in St Andrew Bay, Florida, USA

Brian Balmer[1,2,3] | Stephanie Watwood[4] | Brian Quigley[1,2,3] | Todd Speakman[2,3] | Kevin Barry[5] | Keith Mullin[5] | Patricia Rosel[6] | Carrie Sinclair[5] | Eric Zolman[1,2,3] | Lori Schwacke[1,3]

[1] National Marine Mammal Foundation, San Diego, California

[2] JHT Incorporated, Orlando, Florida

[3] National Oceanic and Atmospheric Administration, National Centers for Coastal Ocean Science, Charleston, South Carolina

[4] Naval Undersea Warfare Center Division, Newport, Environmental Branch, Newport, Rhode Island

[5] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Pascagoula, Mississippi

[6] National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, Lafayette, Louisiana

Correspondence

Brian Balmer, National Marine Mammal Foundation, San Diego, CA, USA. Email: brian.balmer@nmmf.org

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Abstract

1. Common bottlenose dolphins (*Tursiops truncatus*) are found in temperate and tropical waters of the world across a wide range of habitats. Along Florida's north- western coast, this species resides in the bays, sounds, and estuaries (BSE) and coastal (CST) waters of the northern Gulf of Mexico. The National Marine Fisheries Service has identified one CST (Northern Coastal Stock) and seven adjacent BSE dolphin stocks, including the St Andrew Bay BSE Stock.
2. Baseline data are critical to assess the impacts of ongoing and future anthropogenic stressors on these stocks. Currently, there is no comprehensive abundance estimate for the St Andrew Bay BSE Stock, and there are limited data on distribution patterns and site fidelity for this stock. In addition, little is known about the Northern Coastal Stock hypothesized to range from the Big Bend of Florida to the Mississippi River Delta, inclusive of the CST waters adjacent to St Andrew Bay.
3. The goals of this study were to conduct photographic-identification surveys during 2015 and 2016 to determine abundance, distribution, and site fidelity of common bottlenose

dolphins in the St Andrew Bay BSE Stock over four primary periods (July and October 2015, and April and October 2016).

4. St Andrew Bay BSE dolphin abundance was lowest in April 2016 (199, 95% confidence interval [CI] 173–246), followed by July 2015 (249, 95% CI 199–338), and highest in October 2015 (299, 95% CI 259–361) and October 2016 (315, 95% CI 274–378). Few individuals were sighted in both BSE and CST waters (N = 25/ 353; 7%), and this fact, taken in tandem with limited connections between the BSE and CST environments, suggests that there may be minimal overlap between the St Andrew Bay BSE and Northern Coastal Stocks.

KEYWORDS

coastal, distribution, estuary, mammals, protected species

INTRODUCTION

Common bottlenose dolphins (*Tursiops truncatus*) reside within temperate and tropical bays, sounds, and estuaries (BSE) and coastal (CST) waters throughout the world (Wells & Scott, 1999). Although several populations have been the focus of long-term research, such as Sarasota Bay, Florida, and Shark Bay, Australia, the ubiquitous nature of this species, found across a wide range of habitats, can make the applicability of comparisons across populations particularly difficult (Vollmer & Rosel, 2013). Ranging patterns of BSE and CST common bottlenose dolphins are also highly variable: CST animals can have extended movements over several hundred kilometres (e.g. Defran, Weller, Kelly, & Espinosa, 1999), whereas BSE animals typically have much smaller ranges (e.g. Wells et al., 2017). The differences in these ranges present additional challenges for identifying threats and implementing effective management strategies for common bottlenose dolphin populations. Developing standardized sampling methodologies that efficiently and effectively collect baseline data is essential to assess the impacts of current and future stressors on BSE and CST dolphin populations.

In north-west Florida, along the north-eastern shore of the Gulf of Mexico, also known as the Florida Panhandle, the National Marine Fisheries Service (NMFS) has delineated one CST (Northern Coastal Stock) and seven adjacent BSE dolphin stocks (Hayes, Josephson, Maze-Foley, & Rosel, 2017) (Figure 1). These stocks continue to be impacted by numerous stressors, resulting in unusual mortality events (UMEs) that are caused by harmful algal blooms, infectious disease epizootics, and pollutants (Litz et al., 2014). Two of these BSE stocks, Choctawhatchee Bay and Apalachicola Bay, have been the focus of short 1–2 year studies using photographic-identification (photo-ID) surveys to estimate seasonal dolphin abundance (Conn, Gorgone, Jugovich, Byrd, & Hansen, 2011; Tyson, Nowacek, & Nowacek, 2011). The St Joseph Bay BSE Stock, subject of the only long-term study of dolphins in the Florida Panhandle, has been studied intermittently since 2004 to determine seasonal abundance and distribution patterns (Balmer et al., 2008, 2018), assess dolphin health (Schwacke et al., 2010), and identify contaminant levels (Balmer et al., 2015; Wilson et al., 2012).

These studies have provided valuable information for BSE stock assessment in the Florida Panhandle, but have done little to elucidate the distribution patterns of putative members of the Northern Coastal Stock, boundaries of which stretch from the Big Bend region of Florida (84°W longitude) to the Mississippi River Delta (Hayes et al., 2017) (Figure 1). During spring and autumn, seasonal influxes of dolphins into the St Joseph Bay study area, wherein abundance increased two- to three-fold, have been documented (Balmer et al., 2008). Additionally, extended movements of several individuals along the coast have been recorded—St Joseph Bay to Destin, Florida, ~100 km; and Mississippi Sound, ~300 km; Balmer et al., 2016)—suggesting that the Northern Coastal Stock may seasonally overlap with BSE stocks, and that CST dolphins potentially have ranging patterns significantly greater than BSE dolphins.

Dolphins within St Andrew Bay (SAB) are additionally exposed to unique site-specific stressors, including chronic harassment from swim-with and vessel activities, depredation and illegal feeding. Since 1998, quantification of risk and prevalence of these human interac tions have been a high priority for management agencies (Powell, Machernis, Engleby, Farmer, & Spradlin, 2018; Samuels & Bejder, 2004). However, limited baseline data on abundance, distribution, and site fidelity exist for the SAB BSE Stock and adjacent Northern Coastal Stock. Blaylock and Hoggard (1994) conducted aerial line transect surveys in the autumn of 1992 and 1993 and estimated the abundance of the SAB BSE Stock to be 124 (95% confidence interval [CI] 59–259). Bouveroux, Tyson, and Nowacek (2014) conducted vessel-based, photo-ID surveys in a limited portion of the SAB BSE Stock's boundaries and estimated abundance from 89 (95% CI 71–161) in March–May 2004 to 183 (95% CI 169–208) in June–July 2007. There is no up-to-date abundance estimate encompassing the entire SAB BSE Stock. Furthermore, it is unknown whether SAB seasonally hosts some portion of the Northern Coastal Stock in a pattern similar to what is observed in St Joseph Bay.

Marine mammal photo-ID surveys have been used to estimate abundance via capture–recapture (CR), closed, and robust population models (Thompson, White, & Gowan, 1998). When photo-ID CR methods are used, the assumptions of closed CR models (Seber, 1982) can be reasonably met if each primary period is completed in a short period of time, dorsal fin markings are not lost on recapture, and full survey coverage of the study area allows for capture homogeneity (Read, Urian, Wilson, & Waples, 2003). The robust design model uses characteristics of closed population models to estimate abundance and of open population models to calculate survival and emigration (Kendall, Nichols, & Hines, 1997; Pollock, 1982). This model has been applied to nearshore common bottlenose dolphins to estimate seasonal abundance (primary periods) in a study area by conducting multiple, short-term photo-ID surveys (secondary sessions) and accounting for variations in capture probabilities using aspects of an open population model (e.g. Balmer et al., 2013; Smith, Pollock, Waples, Bradley, & Bejder, 2013; Speakman, Lane, Schwacke, Fair, & Zolman, 2010). Photo-ID surveys have also been used to identify distribution patterns (e.g. Ingram & Rogan, 2002;

Williams, Dawson, & Slooten, 1993) and site fidelity (Hubard, Maze-Foley, Mullin, & Schroeder, 2004; Toth, Hohn, Able, & Gorgone, 2011) of common bottlenose dolphins.

The goals of this study were to provide the first comprehensive abundance estimates for the SAB BSE Stock and identify if there is a seasonal component to the Northern Coastal Stock using the adjacent CST waters, similar to what has been observed in St Joseph Bay. The focus of the 2015 SAB photo-ID surveys was to target two seasons based upon the observations in St Joseph Bay: autumn (October), when both the Northern Coastal Stock and SAB BSE Stock are hypothesized to be in the study area; and summer (July), when only the SAB BSE Stock is hypothesized to be in the study area. For the 2016 surveys, the focus was to survey in spring (April) to determine if there was an influx of dolphins into the SAB study area during this season, and autumn (October) to provide a comparison with the 2015 autumn surveys and determine if animals that were sighted in spring and autumn were the same individuals. Distribution patterns of dolphins were identified to assess if animals used the BSE, CST waters, or both within the study area. Short-term site fidelity, across the two years of the study, was determined to provide limited insight into residency patterns. Photo-ID sighting histories from the current study and previous catalogues in SAB and from St Joseph Bay were used to assess long-term site fidelity and identify localized movement patterns of individuals across adjacent stock boundaries.

MATERIALS AND METHODS

Study area

SAB is a shallow estuarine tidal embayment (Grady, 1981) consisting of four bays—East Bay (EAB), North Bay (NOB), SAB proper and West Bay (WEB)—located in the Florida Panhandle (Figure 2). This embayment is unique among Gulf of Mexico coast estuaries, in that the waters are relatively deep and clear as it receives little freshwater input and sedimentation (Brim & Handley, 2002). Mean depth in SAB is approximately 5 m, whereas WEB, NOB, and EAB are generally shallower (2 m) (Ichiye & Jones, 1961). Salinity is approximately 30 parts per thousand (ppt) but can occasionally drop below 10 ppt in locations closest to freshwater input and farthest from the Gulf of Mexico (Ichiye & Jones, 1961). The primary source of fresh water, with an average discharge of 15.3 $m^3 s^{-1}$, is Econfina Creek (reviewed in Brim & Handley, 2002) that flows into Deer Point Lake and empties into NOB at Deer Point Dam (Figure 2). SAB is characterized by a diurnal tidal cycle with a mean range of 0.4 m (Salsman, Tolbert, & Villars, 1966). Seagrasses, primarily shoal grass (*Halodule wrightii*) and turtle grass (*Thalassia testudinum*), are found throughout SAB (Grady, 1981).

The SAB photo-ID study area was divided into two subareas (BSE and CST), with the entrance to SAB as the geographic delineation between subareas. The BSE subarea was further divided into four primary bays: EAB, NOB, SAB, and WEB (Figure 2). The CST subarea included the waters directly adjacent to the estuary (CSTC) and extending approximately 3 km offshore (CST3K) from west of Crooked Island Sound (northern boundary of the St Joseph Bay BSE Stock) to the Gulf of Mexico south-west of WEB and Panama City Beach.

Survey effort

CR photo-ID surveys were conducted during summer (July) and autumn (October) of 2015, and spring (April) and autumn (October) of 2016. For the BSE subarea, contour transects (i.e. transects following a particular geographic feature) were followed either 500 m from the shoreline or along the 1 m depth contour (Figure 2). For the CST subarea, contour transects were followed at 500 m and 3 km from shoreline. The distance offshore for the CST subarea transects was selected based upon the survey design and subsequent photo-ID and telemetry data collected in adjacent St Joseph Bay. For the most part, the St Joseph Bay BSE Stock was sighted in close vicinity to the coast when observed in Gulf of Mexico waters, whereas individuals, presumed to be members of the Northern Coastal Stock, were sighted up to 3 km from shore (Balmer et al., 2008, 2018). The total distances of all survey transects for the BSE and CST subareas were 200 km and 52 km respectively.

Following the robust design (Pollock, 1982), survey effort was temporally divided into primary periods. Within each of the four primary periods, three secondary sessions were completed, in which all transects were surveyed. Once a secondary session was completed, survey effort was halted for ≥1 day to allow for population mixing (reviewed in Rosel et al., 2011). The BSE and CST subarea transects were separated to optimize survey effort and allow for calculation of separate abundance estimates. All transects were surveyed 12 times (12 secondary sessions) across all primary periods. Abundance estimates were determined for all four primary periods. Surveys were conducted in a Beaufort sea state of ≤3 to optimize sighting conditions.

The survey vessel was a 6.3 m, centre-console, Zodiac (ZodiacMilpro International, Paris, France) rigid-hulled inflatable boat with twin 90 hp Yamaha four-stroke outboard engines. Survey speed was maintained at approximately 30 km h^{-1} while searching for dolphins. At least three observers, including the operator, were required, with each observer covering 60° of the 180° forward of the vessel beam. A sighting was recorded any time a dolphin was encountered (on- and off-effort). Sighting data were recorded onto a data sheet and included time, location (GPS coordinates), total number of dolphins, group behaviour(s), and various observational and environmental parameters (reviewed in Melancon et al., 2011). A Canon EOS-1Dx (Canon USA Inc., Melville, New York, NY, USA) with a 100–400 mm telephoto lens (or comparable digital camera and lens) was used to capture dorsal fin images of each individual in the group. Effort was made to photograph all dolphins within a sighting (full photographic coverage) regardless of distinctiveness. Circumstances that could preclude full coverage included prolonged adverse reactions by one or more dolphins in a group, sighting duration >45 min, and inclement weather conditions.

All digital photographs were downloaded and sorted using protocols discussed in Speakman et al. (2010). A standardized approach was used to grade photographic quality and dorsal fin distinctiveness (Urian, Waples, Tyson, Hodge, & Read, 2014). Photographic quality of the best left- and/or right-side dorsal fin image was graded based upon the focus, contrast, angle, dorsal fin visibility, and proportion of the dorsal fin within the image frame. Digital dorsal fin images with a Q-1 (excellent) or Q-2 (good) quality grade were included in data analyses; images with a Q-3 (poor) grade were excluded. A distinctiveness rating (D1: very distinctive; D2: moderately distinctive; D3: not distinctive) was given to each identified individual, as agreed upon by two experienced researchers (BQ and TS). The same two experienced researchers matched and verified all individual dorsal fins. This standardized methodology, discussed in detail in Urian et al. (2014), has been used across multiple photo-ID studies to ensure correct identification of individuals and minimize mismatches. Photographs and associated sighting data were entered into FinBase (Adams, Speakman, Zolman, & Schwacke, 2006), a customized Microsoft Access (Microsoft Corporation, Redmond, WA, USA) database.

Data analyses

Survey summary

Data were compiled to provide a summary of the 2015 and 2016 fieldwork within each primary period (July and October 2015, April and October 2016), subarea (BSE and CST), across primary periods and subareas, and cumulatively. Survey metadata included total hours and total kilometres, which were the amount of time on-water, including both on-effort (active dolphin surveying) and off-effort (transit from the dock and between transects). Sighting data included total number of sightings, dolphins, calves, neonates, mean group size, dolphins photographed, and proportion of dolphins photographed. Calves were defined as dolphins without fetal folds, <75% of the mother's length, and surfacing in ‘echelon’ position; neonates were defined as dolphins with fetal folds and darker coloration, and an irregular surfacing pattern (reviewed in Melancon et al., 2011). The total number of sightings was a sum of all sightings for a given primary period, subarea, or cumulatively. The total number of dolphins, calves and neonates, mean group size, and number of dolphins photographed were determined through subsequent lab-based photo-analysis (PA). The proportion of dolphins photographed was determined by dividing the number of dolphins identified using PA by the best field estimate (FE) of dolphins sighted. Overall number of dolphins identified, as well as the rate at which they were identified, was visualized via a discovery curve. A discovery curve displays the number of new, distinctive individuals identified during a primary period or another defined period of time as well as the total running catalogue size. These data can be used to provide insight into immigration/emigration, appropriate study area boundaries, and the total photo-ID catalogue size (reviewed in Wilson, Hammond, & Thompson, 1999). The number of previously identified individuals, number of new individuals, and total number of individualswere determined for each primary period and secondary session.

|Abundance estimates

Robust-design CR models with variations in Markovian, random movement, and no temporary emigration, and constant (.) or time-varying (t) survival (S) and recapture (p) were used to estimate abundance of distinctive animals (D-1 and D-2) in program MARK (Rexstad & Burnham, 1992; White, Anderson, Burnham, & Otis, 1982) across all effort (on and off) for each of the four primary periods. Markovian models allow for different immigration and emigration probabilities across primary periods, in which individuals return to the study area based upon time-dependent functions, whereas random movement models allow for equal immigration and emigration probabilities, wherein individuals can leave the study area and return randomly during other primary periods (Kendall et al., 1997). The final model was selected as based on the lowest Akaike information criterion (AIC) values (Burnham & Anderson, 1992) out of the subset of models believed to be biologically plausible for BSE dolphins based on previous photo-ID studies (e.g. Balmer et al., 2008, 2018).

MARK-produced abundance estimates from the CR population models were based solely on the number of distinctive animals (D-1 and D-2) sighted during a primary period. To account for non-distinctive dolphins, the total population size (distinctive and non-distinctive individuals) was estimated as

$$N_{total} = N_{distinct} / \theta \qquad (1)$$

where Ntotal = estimated total population size, Ndistinct = MARK estimate of distinctive individuals, and ϴ = estimated proportion of distinctive individuals, which was the mean distinctiveness proportion across all sightings in a given primary period (Wilson et al., 1999). The delta method was used to extrapolate the robust-design population model abundance and 95% confidence interval (CI) to that of the total abundance and 95% CI (Wilson et al., 1999).

Distribution patterns

To identify distribution patterns within the St. Andrew Bay study area, the number of distinctive animals sighted solely in the BSE subarea, solely in the CST subarea, and in both subareas were determined for each primary period. Subsequently, all individuals in the St. Andrew Bay photo-ID catalogue (2015 – 2016) were classified by their presence/absence in BSE and/or CST subareas to provide a cumulative assessment of dolphin distribution.

To assess distribution patterns and stock overlap of individual dolphins outside of the St. Andrew Bay study area, a semi-automated dorsal fin matching software program, FinFindR, was used to compare the St. Andrew Bay to the existing common bottlenose dolphin photo-ID catalogue for adjacent St. Joseph Bay (Balmer et al. 2018). FinFindR is an open source R package (https://github.com/haimeh/finFindR), developed by Western EcoSystems Technology (Laramie, Wyoming, USA) and the National Marine Mammal Foundation, capable of cropping raw field images to isolate dorsal fins, tracing the outline of the trailing edge, and matching individuals within/across study area catalogues. Any matches identified by FinFindR were verified by the same two, experienced researchers (BQ and TS) that graded photographic quality, dorsal fin distinctiveness rating, and dorsal fin matches across the entire study. All sighting locations for individuals matched across the St. Andrew Bay and St. Joseph Bay catalogues were plotted in ArcMap 10.4.1 (ESRI, Redlands, California, USA). A kernel density estimates (KDE) was used as a quantitative method to determine 95% and 50% utilization distributions (UDs) for cumulative sighting locations of all individuals sighted in both study areas (Worton, 1989). For UD calculations, a KDE method for an environment with barriers to movement in Geostatistical Analyst and Spatial Analyst Tools (ESRI, Redlands, California, USA) was used. All spatial analyses were calculated in the Universal Transverse Mercator (UTM) Zone 17 North projection and the World Geodetic System (WGS) 1984 datum. The output grid cell size was 250 m x 250 m. The selection of bandwidth, or the smoothing parameter (h), is an important decision in which KDE distributions can be overor under-estimated depending on this value (Horne & Garton, 2006;

Kie et al., 2010). The methodology for bandwidth selection is dependent on the goals of the project, ranging patterns of the target species, and amount 320 of data available for spatial analyses (Gitzen, Millspaugh, & Kernohan, 2006; Rayment et al., 2009). A rule-based ad hoc method (Kie, 2013) and Home Range Tools (HRT) for ArcGIS (Rodgers et al., 2015) were used to determine the appropriate bandwidth for the cumulative KDE and subsequent 95% and 50% UDs for individuals matched across the St. Andrew Bay and St. Joseph Bay catalogues.

Site fidelity

The St. Andrew Bay study included four primary periods across a 2-year time span. This design enabled short-term assessment of seasonal and yearly site fidelity. The total number of distinctive dolphins sighted in one, through all four primary periods, was determined. For individuals sighted in only one primary period, the season/year sighted was used to identify potential seasonal trends in the Northern Coastal Stock. These data also provided a framework to more fully assess site fidelity of dolphins in the St. Andrew Bay study area through comparison with previous but more limited photo-ID surveys in St. Andrew Bay (2004 – 2007 and 2012) (Bouveroux et al., 2014; Powell et al., 2018, respectively) and adjacent, St. Joseph Bay (Balmer et al., 2018) using the Gulf of Mexico Dolphin Identification System (GoMDIS) (Cush & Wells, 2015). Comparisons across these catalogues were used to determine long-term site fidelity in the study area

Proportion of dolphins with distinctive dorsal fins

In the south-eastern USA, photo-ID surveys have identified seasonal variations in distinctiveness rate suggestive of higher numbers of distinctive dolphins from CST waters entering a given BSE (Balmer et al., 2008, 2018; Speakman et al., 2010). The SAB study area provides a unique opportunity to compare distinctive proportion across interior bays (EAB, WEB, and NOB), bays adjacent to the coast (SAB), and CST waters (CST) to better assess if dorsal fin distinctiveness differs across estuarine and CST habitats. The mean proportion of distinctive dorsal fins for each subarea (CST, EAB, NOB, SAB, and WEB) was calculated for all survey effort. An ANOVA (JMP 11; SAS Institute, Cary, NC, USA) was performed to compare this proportion (arcsine transformed) across subareas. If the ANOVA showed a significant effect, a Tukey's honestly significant difference test for unequal sample size was used to identify pairwise statistical differences between distinctiveness proportion and subarea.

RESULTS

Survey summary

CR photo-ID survey effort was conducted in the SAB study area during 14–21, 27 July and 12–18 October 2015, and 18–21, 23–27 April and 13–20 October 2016. All BSE and CST transects were completed three times in each primary period, totalling 12 times over the course of 2015–2016. During 2015 and 2016, 2,050 km and 1,943 km were surveyed during 116 and 117 on-water hours respectively (Table 1). Total number of sightings was highest in October 2016, followed by July and October 2015, and lowest in April 2016. However, total number of dolphins, mean group size, and total number of neonates was highest during April 2016. Total number of dolphins was higher across all primary periods in the BSE than the CST subareas. Percentage of dolphins photographed was generally comparable across all primary periods (range: 92–96%). During 2016, two sightings, totalling six Atlantic spotted dolphins (*Stenella frontalis*) were observed (April, N = 2; October, N = 4) along the CST3K transect. Data for these six individuals were excluded from abundance estimates and subsequent analyses.

The SAB photo-ID study area comprises 353 distinctive individuals (Figure 3). Within secondary sessions (s), the number of new individuals was highest during s1 and s2 in July 2015 (N = 49 and N = 46 respectively), followed by s8 in April 2016 (N = 45) (Figure 3a). Within primary periods, the number of new individuals was highest in July 2015 (N = 131), followed by October 2015 and April 2016 (N = 96 and N = 95 respectively), and lowest in October 2016 (N = 31) (Figure 3b). The discovery curve increased similarly throughout the first three primary periods (July and October 2015, April 2016), but the identification rate of new, distinctive individuals decreased in October 2016 (Figure 3).

Abundance estimates

Twelve robust-design CR models with variations in Markovian, random movement, and no temporary emigration, and constant (.) or time-varying (t) survival (S) and recapture (p) were used to estimate abundance for each of the four primary periods. The models were applied separately for BSE and CST survey data. In the BSE subarea, the S(.)p(t) random emigration model had the lowest corrected AIC for all 12 CR models (Table 2), and the results from this model were used to estimate total abundance in the BSE subarea (Table 3). Total BSE abundance was lowest in April 2016 (199, 95% CI 173–246), followed by July 2015 (249, 95% CI 199–338), and highest in October 2015 (299, 95% CI 259–361) and October 2016 (315, 95% CI 274–378) (Table 3, Figure 4). Robust-design CR models were used in an attempt to estimate abundance in the CST subarea. However, these estimates were not included as a result of extremely large 95% CIs, likely attributed to relatively limited CST subarea size and immigration/emigration violations in CR model assumptions.

Distribution patterns

Across all primary periods, the majority of dolphins were sighted exclusively in the BSE subarea (Table 4). During April 2016 and October 2016, a higher percentage of animals than in 2015 were sighted exclusively with the CST subarea. Across the entire SAB photo-ID catalogue (N = 353), only 25 individuals (7%) were sighted in both BSE and CST waters.

The SAB catalogue was compared with the St Joseph Bay catalogue (2004–2013, N = 726) to assess extended movement patterns and stock overlap between these adjacent study areas. Twenty-seven matches were made between the SAB (8%) and St Joseph Bay (4%) catalogues. These 27 matches included 179 sightings and a range of 3–21 sightings per individual. The 50% UD was primarily in and around the waters of the entrances to SAB and Crooked Island Sound (Figure 5.). The 95% UD included portions within each of the SAB subareas as well as waters within St Joseph Bay and the adjacent CST waters.

Site fidelity

Of the 353 catalogued individuals, 139 were sighted in only one primary period, 97 in two primary periods, 81 in three primary periods, and 36 in all four primary periods (Figure 6a). Of the 139 individuals only sighted during one primary period, 67 were sighted in April 2016, 31 in October 2016, 25 in October 2015, and 16 in July 2015 (Figure 6b). The SAB catalogue developed by this study was compared with two catalogues that were developed from previous survey efforts (2004–2007, N = 263; and 2012, N = 57) to assess long-term site fidelity. Thirty-nine matches across SAB catalogues were identified, with some animals dating to 2004.

Proportion of dolphins with distinctive dorsal fins

The proportion of dolphins with distinctive dorsal fins was significantly different across subareas ($P < 0.0001$) (Figure 7). The CST subarea had the highest mean distinctiveness (0.86, 95% CI 0.81–0.91), followed by SAB (0.78, 95% CI 0.73–0.83), WEB (0.72, 95% CI 0.64–0.80), EAB (0.68, 95% CI 0.61–0.75), and NOB (0.66, 95% CI 0.58–0.72).

DISCUSSION

Common bottlenose dolphins in the northern Gulf of Mexico continue to be exposed to cumulative stressors, including biotoxins (e.g. Twiner et al., 2012), contaminants (e.g. Balmer et al., 2015), disease (e.g. Venn-Watson et al., 2015), and human interactions (e.g. Samuels & Bejder, 2004). The collection of baseline data for these stocks is essential to provide the information necessary to make informed management decisions (Lotze & Worm, 2009). The SAB BSE abundance estimates across all four primary periods were generally similar and comparable to other northern Gulf of Mexico BSEs (Hayes et al., 2017). Rosel et al. (2011) defined a resident dolphin as an individual that spends greater than 50% of its time within a given BSE. A total of 117 distinctive individuals were sighted in three or four of the primary periods within the SAB study area, providing a minimum estimate of resident dolphins (Figure 6a). Photo-ID catalogues from the current SAB project (Bouveroux et al., 2014), SAB (2004–2007 and 2012) (Powell et al., 2018), and adjacent St Joseph Bay (2004–2013) (Balmer et al., 2018) are available in GoMDIS, and comparisons between these catalogues provided insight into long-term site fidelity. Thirty-nine matches were identified within SAB catalogues and 27 matches between the SAB and St Joseph Bay study areas, with many individual sighting histories extending over ≥10 years. For example, X02, a 43-year-old male dolphin radio-tagged during a 2005 health assessment in St Joseph Bay (Balmer et al., 2008; Schwacke et al., 2010), was a 2014 focal follow animal in SAB to assess chronic human interactions (Powell et al., 2018) and then was resighted in the SAB study area during 2015–2016.

The NMFS Southeast Fisheries Science Center conducted aerial surveys during 2011–2012 to estimate abundance for the Northern Coastal Stock (N = 7,185; CV = 0.21) (Hayes et al., 2017). Although this abundance estimate is useful for stock assessment, the large geographic extent of this stock's boundaries (four states and >600 km of coastline) creates logistical challenges in developing an appropriate survey design to determine seasonal shifts in abundance, distribution, and stock overlap across the Northern Coastal Stock's range and additional data are needed. The SAB study area's two CST transects, totalling 52 km in length, were likely too small to be used for determining CST dolphin abundance and distribution. This was particularly evident in the large 95% CIs, attributed to model violations in immigration/ emigration that in turn likely confounded assessment of abundance and seasonal trends. However, during October 2015 and April 2016, there was a large number of new individuals sighted (Figures 3, 6), primarily in the CST subarea, suggesting that there may be a seasonal influx of CST dolphins as observed in St Joseph Bay (Balmer et al., 2008, 2018). Balmer et al. (2016) identified three individuals that had extended movements up to 300 km from St Joseph Bay and suggested that these animals may be part of the Northern Coastal Stock with ranges overlapping numerous northern Gulf of Mexico BSE study areas. Additional CST survey effort (farther offshore and along the coast) was conducted in 2017 to better assess seasonal abundance and distribution patterns of the Northern Coastal Stock in the SAB study area. Data analyses for these surveys, including distance sampling (e.g. Miller, Burt, Rexstad, & Thomas, 2013) and open population modelling (Fearnbach, Durban, Parsons, & Claridge, 2012), are currently under way to provide insight into the existence of potential seasonal movements of the Northern Coastal Stock and better characterize ranging of CST animals across multiple northern Gulf of Mexico study areas.

Study area size and sampling methodology can greatly influence our understanding of ranging patterns and site fidelity. For example, Nekolny et al. (2017) identified that ranging patterns can be significantly underestimated when animals have movements outside a study area's boundaries. Similarly, Balmer et al. (2014) determined that ranging patterns and site fidelity classifications can vary greatly across different sampling methodologies (photo-ID, radio tracking, and satellite telemetry). Based upon the photo-ID data collected in SAB during 2015–2016, there was minimal overlap of animals between the BSE and CST subareas (Table 4). These results were corroborated when comparing the SAB and St Joseph Bay photo- ID catalogues, in which there was minimal overlap (8% and 4% respectively). Although caution should be used with these photo- ID results, the SAB BSE subarea is likely representative of a semi- closed population, and the current boundary (north-west corner of Crooked Island Sound) delineating the SAB and St Joseph Bay Stocks appears to be appropriate. The 50% UD for the 27 overlap animals was at the entrances to SAB and Crooked Island Sound, suggesting that these locations may be mixing areas for the SAB, St Joseph Bay, and/or Northern Coastal Stocks (Figure 5). Although the 95% UD for the overlap animals did extend into the BSE waters of both study areas, based upon the current photo-ID results, it appears to be a relatively minimal overlap between the SAB and St. Joseph Bay Stocks. Additional studies that include satellite telemetry (Mullin et al., 2017; Wells et al., 2017) would greatly enhance our knowledge of ranging patterns, site fidelity, and stock overlap of the SAB, St Joseph Bay, and Northern Coastal Stocks.

The geography of the SAB study area, with enclosed interior bays, waters adjacent to the Gulf of Mexico proper, and CST waters allowed for an assessment of dorsal fin distinctiveness between subareas. CST dolphin groups had significantly higher distinctiveness than BSE groups in interior bays (Figure 7), suggesting that the distinctiveness between BSE and CST waters may differ as a result of different levels of interspecific, intraspecific, abiotic, and human interactions. Future research investigating distinctiveness in other study areas with similar geography will provide additional insight into the differences observed between BSE and CST subareas in the SAB study area.

Over the past >20 years, SAB has been identified as a hot spot for chronic harassment and interactions between humans and dolphins. Samuels and Bejder (2004) identified a minimum of seven distinctive dolphins in SAB engaged in human interaction behaviours during a 6-day study in August 1998. During 2014, Powell et al. (2018) found a threefold increase in the number of dolphins associated with human interactions ($N = 21$), suggesting that human interactions are increasing in SAB. Although the survey design for the 2015–2016 project was not appropriate for a comprehensive assessment of the number of conditioned individuals and scale of human interactions, 12 conditioned individuals were observed, with many of these also identified by Powell et al. (2018). The previous studies primarily conducted focal follows in a limited study area to assess fine-scale behavioural changes as a result of human interactions. The extended survey coverage for the 2015–2016 project included all of the BSE waters within SAB and the adjacent CST waters, which could be used to compare ranging patterns of both individual dolphins that are associated with human interactions and those that are not.

The Northern Gulf of Mexico Stock of Atlantic spotted dolphins includes all continental shelf (10–200 m deep) and slope (<500 m deep) waters in the northern Gulf of Mexico (Hayes et al., 2017). Viricel and Rosel (2014) also suggest that there may be two demographically independent east–west populations that overlap between Mobile Bay (Alabama) and Cape San Blas (Florida), and, based upon limited data, may move inshore seasonally during spring (Caldwell & Caldwell, 1966). During 2016, six juvenile (speckled) to young adult (mottled) spotted dolphins were sighted across two sightings, approximately 3 km from shore. Preliminary results from the CST survey effort in 2017 identified an additional 48 individuals of all age classes, across five sightings. Currently, little is known about spotted dolphins in this study area, and future research needs to assess abundance, distribution, and ranging patterns of this species in the CST waters off SAB.

Multiple stressors, including CST pollution, harmful algal blooms, freshwater discharge, and extreme weather events, affect the inshore and nearshore habitats of the northern Gulf of Mexico. Common bottlenose dolphins are particularly vulnerable to such stressors due to their trophic position and slow recovery time for populations of this long-lived species with extended generation times. Therefore, early detection of impacts is essential for effective management intervention. Baseline data are necessary to assess the long-term effects of cumulative stressors and to develop restoration strategies for impacted populations. Currently, there are 31 BSE and three CST stocks of common bottlenose dolphins in the northern Gulf of Mexico (Hayes et al., 2017). The high number of BSE stocks, overlapping ranges between BSE and CST stock, and extended movements of CST stocks create logistical and economic challenges for the collection of data necessary to evaluate long-term trends. This 2-year project effectively collected data on seasonal abundance, site fidelity, and distribution patterns of the SAB BSE Stock. The survey design implemented in the BSE waters of SAB has applicability across other northern Gulf of Mexico BSE stocks in which data are currently insufficient. Although the survey methodology in the CST waters was not conducive for abundance estimation, the data collected did provide insights into potential overlap between BSE and CST stocks of common bottlenose dolphins, as well as additional overlap with the Northern Gulf of Mexico Stock of Atlantic spotted dolphins.

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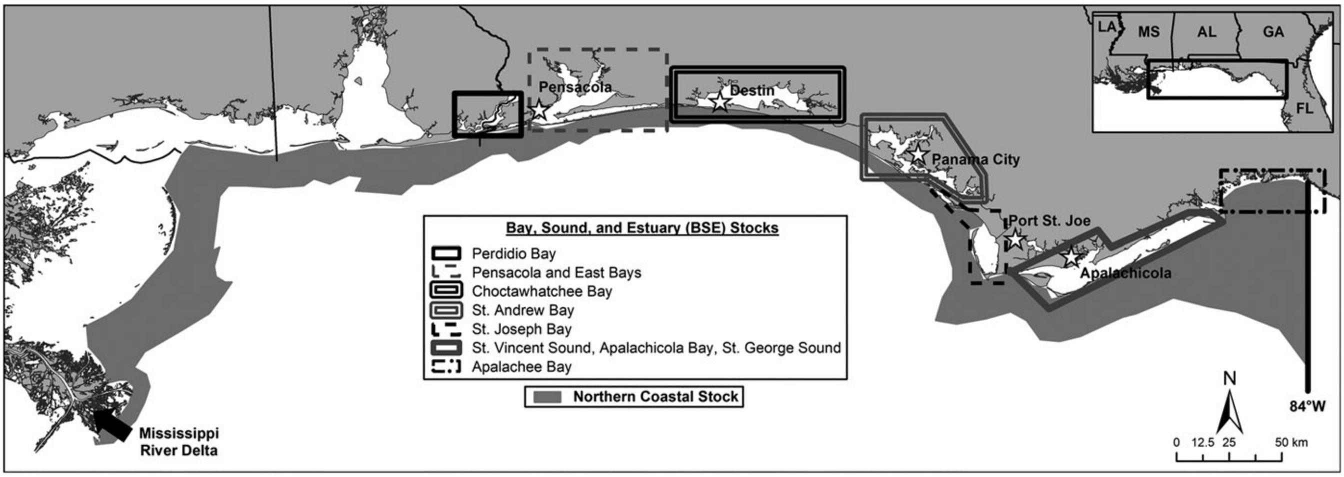

Figure 1. Common bottlenose dolphin bay, sound, and estuary (BSE), and coastal stock structure along Florida's north-western coast

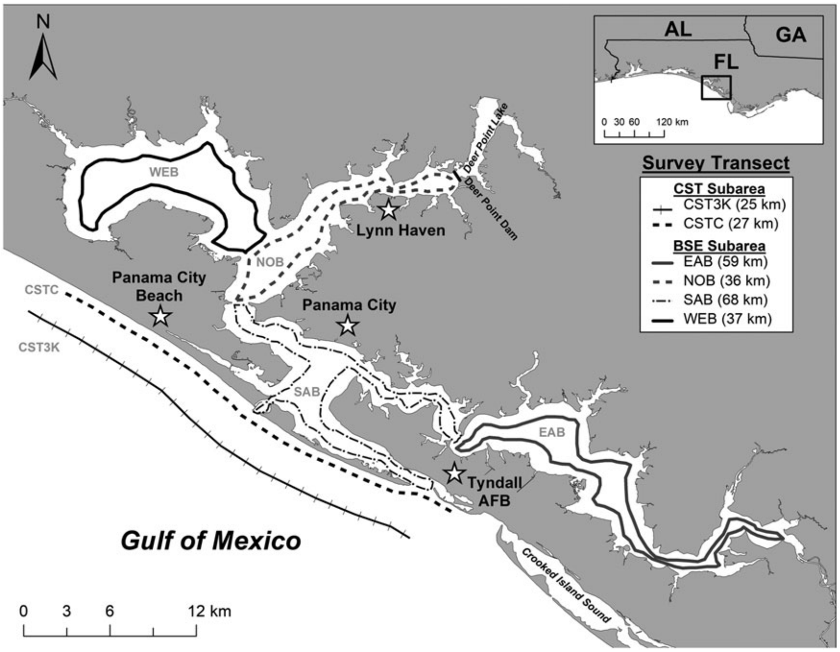

Figure 2. St. Andrew Bay photographic-identification (photo-ID) study area, divided by subarea (Bay, Sound, and Estuary (BSE), and coastal (CST)) with survey transects and survey distance (km) [Coastal 3 km offshore (CST3K), Coastal 0.5 km offshore (CSTC), East Bay (EAB), North Bay (NOB), St. Andrew Bay (SAB), and West Bay (WEB)].

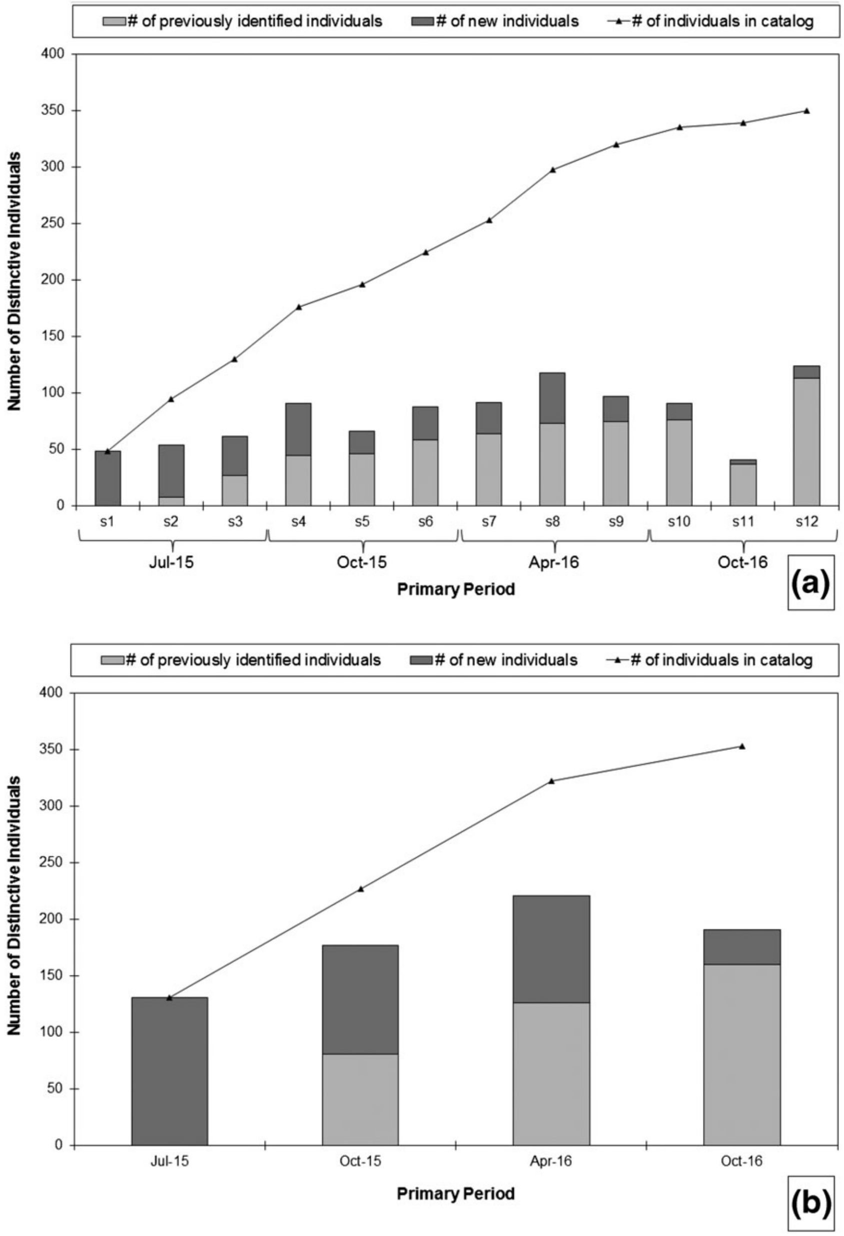

FIGURE 3 Number of distinctive individuals sighted and discovery curve for bottlenose dolphins in the St Andrew Bay study area during capture–recapture photographic identification survey: (a) secondary sessions and (b) primary periods

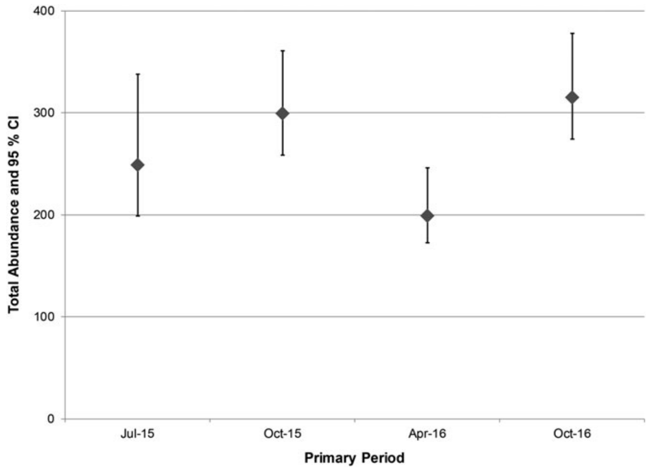

FIGURE 4 Total abundance estimates and 95% confidence intervals (CIs) for dolphins in the bay, sound, and estuary subarea of the St Andrew Bay study area during the four primary periods July 2015, October 2015, April 2016, and October 2016

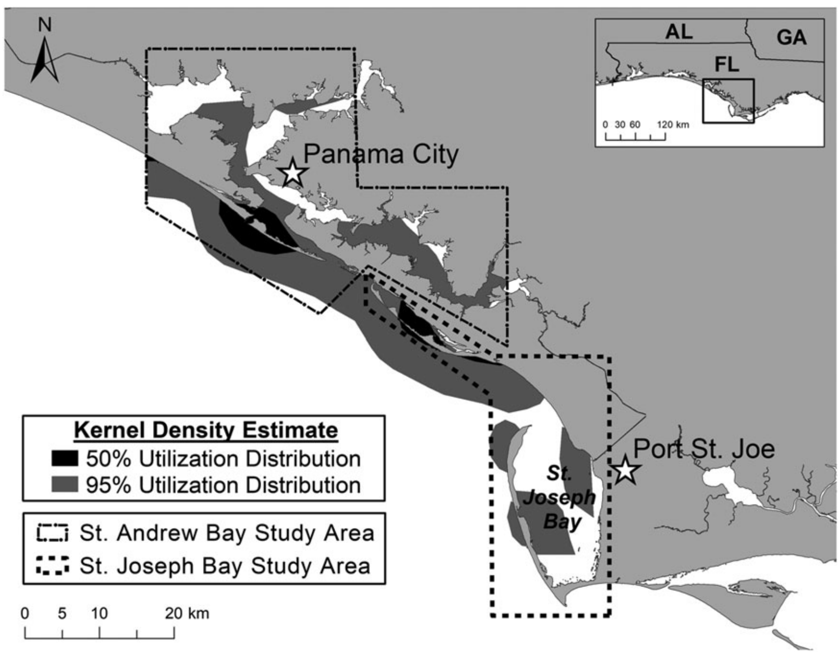

FIGURE 5 The 50% and 95% utilization distributions derived from a cumulative kernel density estimate for the 27 dolphins sighted in both the St Andrew Bay and St Joseph Bay photographic identification catalogues

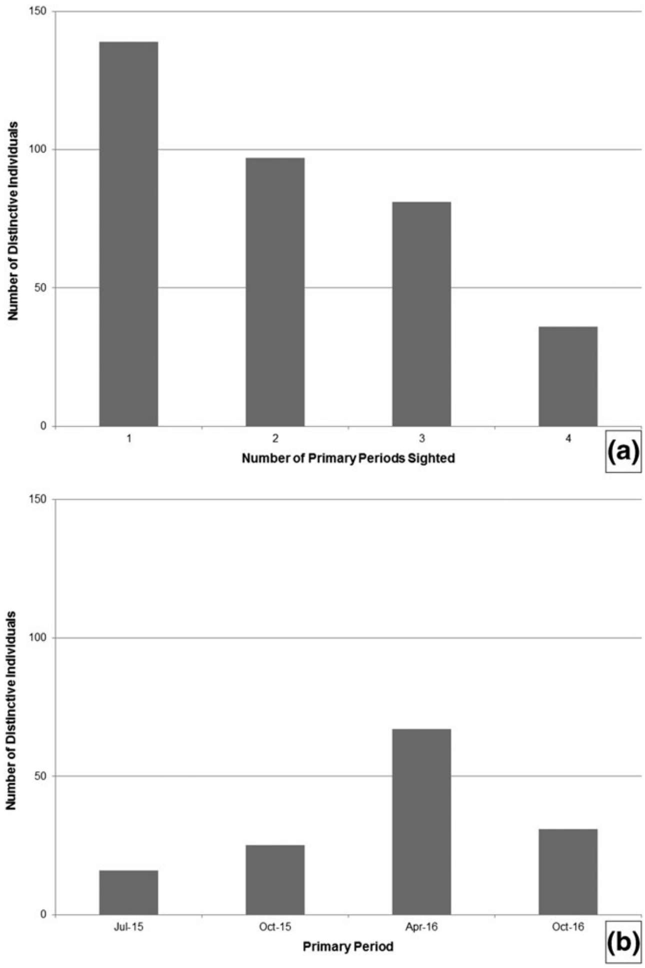

FIGURE 6 (a) Number of distinctive individuals sighted in one, two, three, or all four primary periods (July 2015, October 2015, April 2016, and October 2016). (b) Number of distinctive individuals only sighted in one primary period grouped by primary period (month-year)

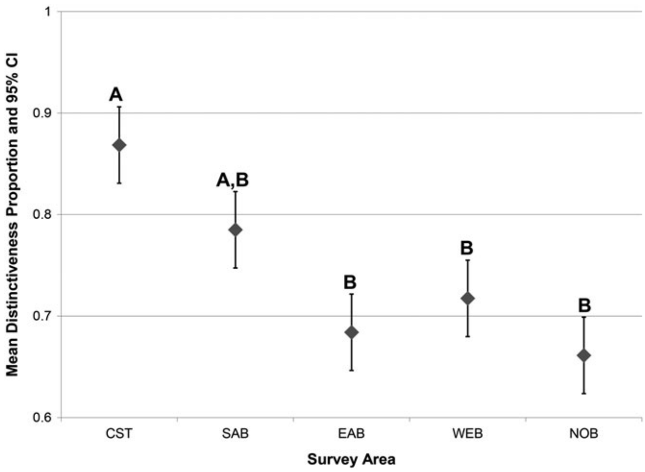

Figure 7. Mean proportion of dolphins with distinctive dorsal fins and 95% CI during 2015 – 2016 photo-ID effort, grouped by subarea [Coast (CST), St. Andrew Bay (SAB), East Bay (EAB), West Bay (WEB) and North Bay (NOB)]. Statistically homogeneous groups are indicated by the same letter subscripts.

TABLE 1 Photographic identification effort for each subarea during the primary periods (July 2015, October 2015, April 2016 and October 2016) and cumulatively (cumulative 2015 and cumulative 2016) in the St. Andrew Bay study area

	Total hours	Total km	Total sightings	Total no. dolphins (FE)	Total no. calves (PA)	Total no. neonates (PA)	Mean group size (PA)	No. dolphins photographed	Dolphins photographed (%)
July 2015									
BSE	48	848	66	213	22	1	3.4	205	0.96
CST	12	208	16	42	9	1	2.6	38	0.90
Total	60	1056	82	255	31	2	3.3	243	0.95
October 2015									
BSE	43	763	64	328	32	1	5.3	314	0.96
CST	13	231	16	68	11	0	4.3	59	0.87
Total	56	994	80	396	43	1	5.1	373	0.94
Cumulative 2015									
BSE	91	1611	130	541	54	2	4.4	519	0.96
CST	25	439	32	110	20	1	3.4	97	0.88
Total	116	2050	162	651	74	3	4.2	616	0.95

April 2016									
BSE	42	714	51	289	27	13	5.7	259	0.90
CST	14	238	22	218	13	14	9.9	209	0.96
Total	56	952	73	507	40	27	6.9	468	0.92
October 2016									
BSE	50	779	90	392	54	0	4.4	378	0.96
CST	11	212	14	65	7	0	4.6	59	0.91
Total	61	991	104	457	61	0	4.4	437	0.96
Cumulative 2016									
BSE	92	1493	141	681	81	13	4.8	637	0.94
CST	25	450	36	283	20	14	7.9	268	0.95
Total	117	1943	177	964	101	27	5.4	905	0.94

BSE: bay, sound, and estuary; CST: coastal.

Total hours and total kilometres (km) are respectively the amount of time and distance on-water. Total sightings are the sum of all sightings for a given primary period, subarea, or cumulatively. The total number of dolphins, calves, and neonates, mean group size, and number of dolphins photographed were determined through subsequent lab-based photo-analysis (PA). The proportion of dolphins photographed was determined by dividing the number of dolphins identified using PA by the best field estimates (FE) of dolphins sighted.

TABLE 2 Robust-design capture–recapture models with variations in Markovian, random and no temporary emigration, and constant (.) or time- varying (t) survival (S) and recapture (p) ranked by lowest corrected Akaike information criterion (AICc), and used to estimate abundance in the bay, sound, and estuary subarea of the St Andrew Bay study area. The proposed best-fit model utilized is in bold

Model	AICc	Delta AICc	AICc weights	Model likelihood	No. parameters	Deviance
{S(.)p(t) Random}	−1584.8646	0	0.85496	1	20	261.9731
{S(t)p(t) Random}	−1581.2269	3.6377	0.13868	0.1622	24	257.0741
{S(.)p(t) Markovian}	−1574.7275	10.1371	0.00538	0.0063	26	259.2674
{S(t)p(t) Markovian}	−1571.1710	13.6936	0.00091	0.0011	29	256.3169
{S(t)p(t) No movement}	−1565.7599	19.1047	0.00006	0.0001	26	268.2351
{S(.)p(t) No movement}	−1562.1454	22.7192	0.00001	0	23	278.2993
{S(t)p(.) Random}	−1547.7014	37.1632	0	0	20	299.1362

{S(.)p(.) Random}	−1546.2056	38.659	0	0	18	304.863
{S(.)p(.) Markovian}	−1542.6317	42.2329	0	0	21	302.0811
{S(t)p(.) No movement}	−1542.1900	42.6746	0	0	19	306.7662
{S(.)p(.) No movement}	−1537.9525	46.9121	0	0	17	315.2225
{S(t)p(.) Markovian}	−1537.0149	47.8497	0	0	25	299.1362

TABLE 3 Total abundance and 95% confidence interval (CI) using robust-design capture–recapture (CR) S(.)p(t) random movement model for bay, sound, and estuary subarea across four primary periods (July 2015, October 2015, April 2016, and October 2016) in the St Andrew Bay study area

Primary period	Ndistinct	θ	Nmodel	SE (Nmodel)	Ntotal	95% CI (N_{total})
July 2015	102	0.69	172	20.71	249	199–338
October 2015	146	0.71	212	14.31	299	259–361
April 2016	113	0.75	149	10.95	199	173–246
October 2016	153	0.65	205	11.60	315	274–378

$N_{distinct}$: MARK estimate of distinctive individuals; N_{model}: model population size; N_{total}: estimated total population size; θ: estimated proportion of distinctive individuals.

TABLE 4 Number and percentage of distinctive individuals in the St Andrew Bay phototographic identification catalogue that were sighted exclusively in the bay, sound, and estuary (BSE) subarea, coastal (CST) subarea, or both (BSE–CST) during each primary period (July 2015, October 2015, April 2016, and October 2016)

Subarea	Distinctive individuals sighted							
	July 2015		October 2015		April 2016		October 2016	
	No.	%	No.	%	No.	%	No.	%
BSE	141	82	146	77	114	52	153	65
CST	28	16	31	16	107	48	82	35
BSE–CST	2	1	12	6	0	0	2	1