Abundance and residency patterns of common bottlenose dolphins (*Tursiops truncatus*) in freshwater-influenced estuaries of the northern Gulf of Mexico

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Abstract

1. Multiple stressors are affecting common bottlenose dolphins in the northern Gulf of Mexico, including two embayments in Alabama, Mobile Bay (MOB) and Perdido Bay (PER), where no comprehensive abundance estimates and residency data are currently available.
2. This study provides the first seasonal abundance estimates and residency patterns for bottlenose dolphins in MOB and PER and discusses the effects of seasonal entry of large volumes of freshwater on dolphin abundance.
3. In MOB, abundance estimates were larger in summer, with the highest abundance recorded in summer 2022 (1,712 dolphins, 95% CI: 1,520-1,928) and the lowest in winter 2019-2020 (518 dolphins, 95% CI: 260-1,032). The opposite pattern was found in PER, where abundances were larger in winter, with the highest abundance in winter 2021-2022 (191 dolphins, 95% CI: 157-232) and the lowest in summer 2020 (100 dolphins, 95% CI: 81-122).
4. Stronger residency patterns were found in PER, with 28% (n = 52) encountered in more than three seasons compared to MOB where only 9% (n = 57) were encountered in more than three seasons, and considered resident dolphins.
5. The two studied embayments support a larger number of dolphins than previously documented and likely provide seasonally different resources, indicating high and potentially complex use of these estuaries. Combined with other data concurrently collected in this area, this study will inform conservation management and strategies for these highly impacted dolphin stocks.

1. INTRODUCTION

The common bottlenose dolphin, *Tursiops truncatus* (hereafter referred as bottlenose dolphin), is the most abundant delphinid species in coastal waters of the northern Gulf of Mexico (GOMx) and the only cetacean species inhabiting bays, sounds and estuaries (BSEs) along this coastline (Garrison et al., 2021; Mullin et al., 1990). For management purposes in the northern GOMx, the species is divided into 32 distinct BSE stocks from Texas to the Florida Keys, and several of these are poorly monitored, with no recent abundance estimates available (Hayes et al., 2023). In particular, bottlenose dolphin populations inhabiting Mobile Bay and Perdido Bay (Alabama, USA) have received very little research attention. The last abundance estimate available in this area was conducted in 1993 using aerial surveys and estimated 122 dolphins in Mobile Bay only (Hayes et al., 2023). Nevertheless, estimation of species abundance is fundamental to monitoring populations through time and informing conservation assessments and strategies (Hammond et al., 2021). This population metric is particularly essential when studying apex predators that have top-down control on ecosystem structure and function and often serve as sentinels of ecosystem health (Baum & Worm, 2009; Wells, et al., 2004). Abundance assessments are also notably important in areas heavily impacted by anthropogenic activities, where multiple stressors may have negative effects on population demographics and survival (Baum & Worm, 2009; Hammond et al., 2021).

In the northern GOMx, multiple stressors affect bottlenose dolphin populations (e.g., Bloodgood et al., 2023; Carmichael et al., 2012). These stressors include infectious diseases (Bloodgood et al., 2023; Cloyed et al., 2021a; Fauquier et al., 2017), harmful algal blooms (Fire et al., 2007; Litz et al., 2014; Twiner et al., 2012), negative human interactions (Carmichael et al., 2022; Collins et al., 2020; Powell et al., 2018; Samuels & Bejder, 2004), pollutant exposure (e.g., *Deepwater Horizon* oil spill; J. Balmer et al., 2018; Schwacke et al., 2014, 2017, 2022; Takeshita et al., 2017), and perennial freshwater inputs (e.g., Carmichael et al., 2012, Takeshita et al., 2021). The northern GOMx, is characterised by rapid and large seasonal volumes of cold freshwater discharge that can drastically change the marine ecosystem and the suitability of habitat for dolphins (Alexander et al., 2001; Carmichael et al., 2012). Bottlenose dolphins typically tolerate seasonal changes in their habitat (e.g., water temperature and/or salinity), but they cannot physiologically support prolonged exposure to low salinity water (< 10 parts per thousand, ppt; Bloodgood et al., 2023; Deming et al., 2020) or temperatures outside their thermoneutral zone (Carmichael et al., 2012; Colbert et al., 1999; Yeates & Houser, 2008). When environmental conditions become unsuitable, dolphin health can be impacted and lead to changes in abundance and residency patterns through movements (Fazioli & Mintzer, 2020; McBride-Kebert & Toms, 2021) or direct mortalities (Deming et al., 2020; Ewing et al., 2017; Ridgway & Venn-Watson, 2010). From 1978 to 2019, environmental and human stressors have resulted in three unusual mortality events (UMEs) of bottlenose dolphins in the northcentral GOMx (Louisiana, Mississippi and Alabama) with several thousand dolphin mortalities (e.g., Carmichael et al., 2012; Colegrove et al., 2016; Litz et al., 2014). Recent mortality events were mostly attributed to the *Deepwater Horizon* oil spill in April 2010, which was the largest marine oil spill that occurred in the United States (USA) (Beyer et al., 2016), and exposure to low salinity waters (Litz et al., 2014; NOAA NMFS, 2022). Consequently, assessing the impact of mortality and developing long-term monitoring programs will be crucial to the conservation of dolphin stocks in this region and, in particular, in Alabama waters where abundance and residency estimates are not available.

The goal of this study is to inform understanding of abundance and residency patterns of bottlenose dolphin populations in Alabama waters that are needed for understanding local ecosystem functions as well as management and conservation actions under the Marine Mammal Protection Act (MMPA; 50 CFR 216). To estimate abundance and define residency patterns for bottlenose dolphins in Alabama waters, we conducted dedicated seasonal capture-mark-recapture (CMR) photo-identification (photo-ID) surveys across three years (three summer and three winter seasons). Surveys were conducted in two adjacent estuaries, Mobile Bay and Perdido Bay, to address the crucial lack of information on abundance and demographic parameters for bottlenose dolphins in the region. We also discussed the relevance of established methods (i.e., Pollock's Robust Design models and standardised CMR photo-ID surveys) in these two embayments with very different characteristics, such as embayment size, level of openness and connectedness with adjacent coastal waters, and volumes of freshwater discharge that affect salinity regimes through time.

2. METHODS

2.1) Study areas

2.1.1) Mobile Bay (MOB)

The MOB estuary, Alabama (30°27'30.3" N, 87°59'44.3" W; Figure 1) is a large (1,070 km^2) semi-open embayment that is the sixth largest estuary in the USA, draining the fourth largest volume of freshwater discharge (mean annual discharge = 1,840 $m^3 s^{-1}$) from watersheds contained in the USA, usually peaking in winter and spring (Alexander et al., 2001; Schroeder et al., 1990; Valentine et al., 2013). This influx of freshwater can drastically change the salinity of the water in MOB and adjacent waters (Carmichael et al., 2012; Schroeder et al., 1990), with a low salinity regime during times of high freshwater flow and a higher salinity regime during periods of lower discharge (Orlando & Klein, 1989). The bay is mostly shallow with an average water depth of 3 m but has a deeper ship channel of approximately 23 m, which runs primarily north-south and connects MOB to the intracoastal waterway and the GOMx at its southernmost extent (Schroeder et al., 1990; Valentine et al., 2013). Seasonal sea surface temperatures range on average between ~ 13 °C in winter and ~ 30 °C in summer (Orlando & Klein, 1989). The Port of Mobile, located in the northern reaches of MOB, has been the second fastest growing port in the USA during the past decade (Roberts, 2023). Expansion plans are ongoing and include deepening and widening of the Mobile Ship Channel to make it the largest harbour on the GOMx coast (USACE, 2023). As a result, MOB is utilised by a range of vessels from small recreational boats to large commercial ships that access resources in the bay and its tributaries and support significant recreational (e.g., fishing, boating) and industrial activities (e.g., metallurgy, aviation, chemicals; USACE, 2023; Valentine et al., 2013).

2.1.2) Perdido Bay (PER)

The PER estuary (30°18'37.1" N, 87°30'25.0" W; Figure 1) is a small (130 km^2) enclosed bay located on the Alabama-Florida border with an average water depth of approximately 2.6 m (Livingston, 2001; Xia et al., 2011). The PER estuary is composed of several smaller lagoons and bayous that are connected to the GOMx in the south through a narrow channel (Perdido Pass). This embayment receives freshwater inflow primarily from the Perdido River in the north (mean daily discharge = 62 $m^3 s^{-1}$), and the water quality can rapidly change in response to rainfall, wind, and tides due to its small size (PERG, 1998). Seasonal sea surface temperatures range on average between ~ 15 °C in winter and ~ 30 °C in summer (Orlando & Klein, 1989). The watershed surrounding PER is characterised by an urbanisation gradient, where areas to the north near Perdido River are largely vegetated and agriculture and residential development increases down bay, with the highest tourism and urbanisation in the southern parts of the bay (PPBEP, 2022). Human activities are primarily residential, recreational, and tourism-related, with smaller-scale commercial activities than MOB.

2.2) Field sampling and data collection

Dedicated boat-based surveys following systematic transect and contour lines were conducted in winter (December - February) and summer (June - July) from January 2020 to June 2022 in the MOB and PER estuaries (Figure 1, Table 1). In each embayment, we conducted CMR photo-ID surveys following standardised methodologies specifically designed to derive dolphin abundance and population demographics (Rosel et al., 2011). A CMR photo-ID survey was typically a day at sea partially or completely following either a transect or a contour line searching for dolphins on effort.

2.2.1) Capture-mark-recapture

Photo-ID data of individual dolphins were collected following Pollock's Robust Design (RD) (Pollock, 1982), with six primary sampling periods (i.e., seasons) between which dolphin populations were considered open to births, deaths, immigration, and emigration. Within primary sampling periods, the crew surveyed each embayment three times (i.e., secondary sampling occasions) in a short period of time to allow for closed population assumptions, such that no demographic changes would be expected (Kendall et al., 1995, 1997; Otis et al., 1978; Pollock, 1982). Once surveys were completed three times in one embayment, the crew immediately started sampling the second embayment. By the end of the study period, all transects and contour lines were completely surveyed 18 times in each embayment, and thus a total of 18 second sampling occasions were successfully completed in each location during the course of the survey period. One secondary sampling occasion took approximately three to six days of survey effort in MOB and two to three days in PER. Under the RD models, abundance estimates and dolphin survival (S) were generated within each season (primary sampling period) by collapsing data from the secondary sampling occasions into a single instance of being encountered or not encountered (Pollock, 1982). Finally, temporary emigration between seasons was estimated as the probability of being a temporary migrant (γ'') between primary sampling periods, and the probability of remaining a temporary migrant (γ') between primary sampling periods (Kendall et al., 1997).

During surveys in MOB, two outboard engine boats (6 m and 7 m length) were usually used to simultaneously survey the embayment, following roughly parallel transect lines within the bay and the entire perimeter of the bay along the contour of the shoreline (Figure 1). In PER, due to the smaller and narrower size of the study area, surveys were conducted using only the 6 m outboard engine boat, following the contour of the shoreline (Figure 1). Perimeter contour lines in each embayment were approximately ranging between 0.2 and 2.0 km distance from shore in ~ 2 m of water depth. At least three crew members (maximum five) were present onboard each vessel, including a captain, one photographer, and data recorder. All crew members searched for dolphins with the naked eye and scanned an estimated area of 500 m, 180° ahead of the research vessel. To maximize the likelihood of detecting dolphin groups, surveys were conducted under favourable weather conditions: wind speeds ≤ Beaufort Sea State 4, clear visibility (no fog or haze), and a swell height of ≤ 1 m. All transect and contour lines were surveyed at a consistent speed of approximately 14 - 16 knots.

Sightings began when a dolphin group was encountered; the vessel was slowed and the dolphins were approached. A group of dolphins was defined as several dolphins usually swimming within a distance of 10 m of any other individuals (i.e., 10 m "chain" rule), moving in the same direction and engaged in similar behavioural activities (Smolker et al., 1992; Syme et al., 2022). The crew attempted to photograph the left and right sides of the dorsal fins of every dolphin in the group for individual identification (Würsig & Würsig, 1977), using a Canon EOS 7D digital camera equipped with a 100 - 400 mm telephoto zoom lens (Canon USA, Inc.). For each dolphin sighting, the minimum (lowest value), maximum (highest value), and best number of dolphins, calves and neonates were estimated through a consensus decision among team members onboard. Daily effort was logged to keep track of the surveyed transects, the number of km surveyed on and off effort, and changes in weather conditions. In both embayments, the total number of km surveyed on effort (i.e., distance on effort) was calculated for each season and was used to generate the seasonal encounter rates (number of sightings per surveyed km) and relative abundances (number of individuals encountered per surveyed km).

2.2.2) *Photo-identification and photo analyses*

Each individual encountered and captured in photos was identified using natural and long-lasting nicks and notches present on the dorsal fin (Würsig & Jefferson, 1990). A standardised protocol was used to rate photographic quality and dorsal fin distinctiveness as described in Melancon et al. (2011). Briefly, overall photographic quality of dorsal fins was graded as Q1 (excellent), Q2 (good) or Q3 (poor) based on the focus and clarity, contrast, angle, dorsal fin visibility, and proportion of the fin within the photo frame. A distinctiveness rating was also attributed to each individual dorsal fin as very distinctive (D1), moderately distinctive (D2), marginally distinct (D3) or not distinctive (D4) (Melancon et al., 2011; Urian et al., 2015). Once dorsal fin photographs were sorted and individuals identified, images were stored in *FinBase* (Microsoft Corporation, Redmond, WA, USA; Adams et al., 2006). In the subsequent analyses, only excellent and good quality dorsal fin images (Q1, Q2) of very and moderately distinct individuals (D1, D2) were used to avoid misidentification while still achieving high match rates (Tyson et al., 2022). This threshold used for distinctiveness also allowed exclusion of calves and neonates from analyses because of their dependence on their mothers (i.e., photographic captures must be independent; Pollock et al., 1990).

Finally, recent development of computer vision applications using artificial intelligence algorithms have proven their performance in assisting with dorsal fin matching (Tyson et al., 2022). Therefore, we used the semi-automated dorsal fin matching software *finFindR* (Thompson et al., 2022) to compare dorsal fin images collected during surveys with the photo-ID catalogue in development in Alabama waters which contained images of individuals previously identified during the project. Dorsal fin matching was performed in the laboratory by experienced researchers and each match was verified by a second, independent researcher not involved in the original matching (Urian et al., 2015). A third opinion was sought in cases of disagreement.

2.2.3) *Environmental data collection*

In both embayments, from summer 2020 through summer 2022, at least one boat was equipped with a Dataflow data logging system, including a Manta multiprobe sonde (© Eureka Water Probes) to continuously collect environmental data on salinity, water temperature (°C), dissolved oxygen (mg/l) and pH at the water surface (~ 50 cm depth) while underway during surveys and sightings. To obtain environmental data of homogenous resolution throughout the study areas, the Dataflow system was programmed to collect data every 5 seconds while on transect and cruising at higher speeds, and every 30 seconds during focal observations of dolphins at lower speeds. During the first season of sampling (winter 2019-20), the Dataflow system was not available and salinity and water temperature were recorded manually using a handheld data sonde (YSI® Professional Series Pro30) at gridded waypoints located at 9 km intervals in MOB and 7 km in PER along the survey transects.

2.3) Data analyses

2.3.1) Abundance estimates

As a first step in calculating abundance estimates, we tested the robustness of the photo-ID catalogue and the assumption of population closure for each embayment by computing discovery curves based on the cumulative counts of distinct individuals (D1, D2) in each embayment during the study period (Wilson et al., 1999). To compute the abundance estimates, we tested 16 full-likelihood parameterization RD models with temporary emigration constraints (e.g., Markovian and random movement), with constant (.) or time-varying (t) survival (S) and recapture probability (p). For each of these 16 models, we set up recapture probabilities equal to capture probabilities ($p = c$) because dolphin photo-ID is a non-invasive method that should not change the behaviour of dolphins within a primary sampling period (Hammond, 2010). Markovian models allow for different immigration and emigration probabilities between primary sampling periods, while random movement models require equal probabilities between immigration and emigration (Kendall et al., 1997). Preliminary analyses investigating movement patterns of dolphins between embayments found that some individuals regularly move in and out of the two embayments (Bouveroux, pers. com.; Clance, 2022), hence, the “no movement” models were not computed.

Abundance estimates for each primary sampling period were produced solely from encounter histories of distinctive animals (D1, D2). To consider the number of unmarked individuals that do not have distinct dorsal fins in the population, we divided the abundance estimates based on distinct individuals by the proportion of distinct individuals encountered during each primary sampling period $N_{total} = N_{distinct}/\theta$, where N_{total} is the estimated total population size, $N_{distinct}$ is the estimate of distinct individuals derived by the models, and θ is the estimated proportion of distinct individuals encountered within each primary sampling period (Wilson et al., 1999). We followed the delta method to extrapolate the 95% Confidence Interval (95% CI) of the total abundance (Wilson et al., 1999). The Akaike Information Criterion (AIC) was used to evaluate the best fitting model, by selecting the model having the lowest AIC value (Burnham & Anderson, 2004). Models were built in R (R Development Core Team, 2023) using the package *RMark* (Laake, 2013). Finally, the mean seasonal abundances were calculated by averaging the estimated total abundance derived within winter or summer seasons for each embayment. Potential effects of seasonal mean salinity and water temperature on seasonal abundance estimates of dolphins in both study areas were tested using a General Linear Model (GLM) in R (R Development Core Team, 2023) using the package *MASS* (Venables & Ripley, 2022). Environmental analyses were limited to comparisons for salinity and water temperature, including their interactions because these were the dynamic variables for which data were available for the duration of the study period in both embayments. A backward selection was used to identify the most important variables predicting seasonal abundance, starting with all variables, and systematically removing variables one at a time with a null model run last. At each step, the variable that contributes the least to the model fit was removed, and the model was refitted. Models were ranked depending on the support of each variable using the AIC and Akaike weights (w) values (Burnham & Anderson, 2004).

2.3.2) Resighting and residency pattern

We characterised the resighting patterns of distinct individuals encountered during the study period in each embayment by determining the total number of times each individual was encountered among the 18 potential secondary sampling occasions. Residency patterns were determined as the total number of distinctive animals encountered within the six primary sampling periods that represent seasons. Individual dolphins that were encountered in more than three primary sampling periods in a given estuary were considered resident animals (adapted from Rosel et al., 2011).

3. RESULTS

3.1) Survey summaries

In MOB, a total of 85 surveys were conducted, representing 6,599 km of survey effort and resulting in 309 dolphin sightings during which 2,845 animals were encountered, including 263 calves and 23 neonates. In PER, a total of 38 surveys were conducted representing 2,412 km of survey effort, with 301 dolphin sightings and 1,523 animals encountered, including 216 calves and 42 neonates. In both embayments, neonates were only observed in summer (Table 1).

While the total number of dolphin sightings was similar between embayments, the encounter rates differed significantly. In MOB, the encounter rates were approximately 2 to 6 times lower than in PER (0.02 - 0.07 sightings km^{-1} and 0.12 - 0.14 sightings km^{-1}, respectively; Kruskal-Wallis $X^2 = 8.61$, df = 1, p-value = 0.003; Table 1). The relative abundances were up to 4 times lower in MOB (0.15 - 0.68 dolphins km^{-1} and 0.54 - 0.80 dolphins km^{-1}) compared to PER, but were overall not significantly different (Kruskal-Wallis $X^2 = 3.70$, df = 1, p-value = 0.05; Table 1). The greatest difference in encounter rates and relative abundances between embayments occurred during the first season of sampling in winter 2019-20. In MOB, highest encounter rates occurred in winter 2020-21 and 2021-22 (Table 1). In contrast, in PER, encounter rates were similar between seasons, with the highest encounter rate recorded in summer 2021. In both embayments, the highest relative abundance occurred during summer 2022 (0.68 dolphins km^{-1} and 0.80 dolphins km^{-1}, respectively, for MOB and PER; Table 1). Finally, no seasonal difference was observed within embayments in dolphin encounter rates (MOB: Kruskal-Wallis $X^2 = 0.07$, df = 1, p-value = 0.796; PER: Kruskal-Wallis $X^2 = 0.43$, df = 1, p-value = 0.512) and relative abundances (MOB: Kruskal-Wallis $X^2 = 0.05$, df = 1, p-value = 0.827; PER: Kruskal-Wallis $X^2 = 0.44$, df = 1, p-value = 0.506).

3.2) Discovery curves and abundance estimates

During the study period, a total of 673 distinctly marked individuals (D1, D2) were identified in MOB, and 189 distinctly marked individuals were identified in PER (Figure 2). The discovery curve, indicating the number of newly identified individuals encountered during each seasonal period, increased during the study for both MOB and PER, with the highest number of new animals documented through the first three seasons in MOB (through winter 2020-21) and only during the first season in PER (winter 2019-20) (Figure 2). After these peak periods, the number of newly identified animals each season remained near 100 for MOB (ranging 79 to 112) and 20 for PER (ranging 11 to 31).

Among the 16 RD models we tested, random movement in MOB and Markovian movement in PER, with constant survival over time and time-varying recapture probability in both areas had the lowest corrected AIC (Tables S1 and S2). Based on encounter histories, we estimated a mean seasonal abundance of 738 ± 112.67 dolphins in winter and 1,469 ± 152.99 dolphins in summer in MOB (Table 2). In PER, the mean seasonal abundance varied between 179 ± 6.09 in winter and 130 ± 16.39 in summer. The abundance of bottlenose dolphins in each embayment varied with season, but in opposite directions. Depending on the seasons, the total abundance of dolphins in MOB was three to ten times higher than the abundance estimated in PER (Table 2). The lowest abundance in either embayment was found during the 2019-2020 survey year (MOB winter: n = 518; 95% CI: 260-1,032; PER summer: n = 100; 95% CI: 81-122, Figure 3), and the highest abundances were found during the 2022 survey year (MOB summer: n = 1,712; 95% CI: 1,520-1,928; PER winter: n = 191; 95% CI: 157-232; Figure 3, Table 2). In both areas, survival estimates were constant through time and estimated at 0.93 ± 0.02 (95% CI = 0.89-0.95) in MOB and 0.92 ± 0.02 (95% CI = 0.88-0.95) in PER.

3.2.1) Effects of environmental attributes on abundances

In all, we collected 127,126 environmental data points in MOB and 88,760 in PER between the winter 2019-20 and summer 2022. The mean surface salinity was generally low in both embayments during the study periods (< 19 ppt; Table 3) and was significantly lower in MOB compared to PER (*one-way ANOVA*: *F* = 10.80; df = 1; p-value = 0.0082). Salinity in MOB varied significantly between seasons, ranging from 3.53 ± 3.51 in summer 2021 to 14.76 ± 4.79 in winter 2021-22 (*one-way ANOVA*: *F* = 11,705; df = 5; p-value < 0.001; Table 3; Figure S1). The mean salinity recorded in PER was also significantly different between seasonal periods (*one-way ANOVA*: *F* = 4,493; df: 5; p-value < 0.001), ranging between 17.04 ± 6.12 in winter 2021-22 and 18.39 ± 5.67 in winter 2020-21, but decreased to 10.10 ± 7.14 in summer 2022 (Table 3, Figure S1). The mean sea surface temperatures did not vary between embayments (*one-way ANOVA*: *F* = 0.04; df = 1; p-value = 0.85). In MOB, water temperature was significantly colder in winter compared to summer (*one-way ANOVA*: *F* = 699,509; df: 5; p-value < 0.001) and ranged from 12.23°C ± 1.24 in winter 2019-20 and 31.76 ± 1.03 °C in summer 2022. In

PER, water temperature was also significantly colder in winter compared to summer (*one-way ANOVA*: *F* = 896,123; df: 5; p-value < 0.001) and ranged from 11.32 ± 1.30 °C in winter 2020-21 and 29.81 ± 1.08°C in summer 2022 (Figure S1). Among the models testing the effects of salinity and water temperature on dolphin abundance, only water temperature was driving the seasonal abundance within each embayment (MOB: AIC weight = 0.44, t value = 5.23, p-value < 0.001; PER: AIC weight = 0.78, t value = -2.98, p-value = 0.04). In MOB, the increase in water temperature had a positive influence on the abundance of dolphins, while the opposite was observed in PER (Table S3).

3.3) Resighting and residency patterns

During the 18 possible resighting occasions, the maximum number of sightings of individual dolphins was 8 in MOB (n = 2 dolphins) and 13 in PER (n = 1 dolphin). The number of dolphins seen once was high in both areas (Figure 4A), with about 40% of the dolphins in MOB (n = 266 of 673) and 32% of the dolphins in PER (n = 61 of 189) sighted only once. Almost 40% of dolphins in MOB (n = 265) and 50% of those in PER (n = 94) were encountered at least three times (Figure 4A).

The residency pattern of dolphins revealed that MOB had fewer resident animals (~ 28% of the distinct individuals) compared to PER (~ 40%) (Figure 4B). In MOB, these residents were comprised of 188 distinctive dolphins that were resighted during three seasons or more and 57 individuals (9%) that were encountered during four seasons or more. In PER, residents included 76 individuals resighted during at least three seasons and 52 dolphins (28%) resighted during four seasons or more. About 45% of the distinct individuals in MOB (n = 301) and 35% of those in PER (n = 67) were encountered in only one season. One dolphin was encountered during every season in MOB, and five dolphins were encountered in every season in PER (Figure 4B). Finally, out of a total of 862 distinctive dolphins identified in MOB (n = 673) and PER (n = 189), 15 individuals (1.74 %) were occasionally encountered in both areas during the study period.

4. DISCUSSION

CMR photo-ID surveys were conducted in two embayments along the Alabama coastline, MOB and PER, providing the first estimates of bottlenose dolphin abundance and survival rates as well as a quantification of residency patterns for these two stocks. This study also provided an opportunity to assess RD modelling techniques in two embayments characterised by different physical and chemical attributes. Our study revealed that the number of dolphins inhabiting MOB is larger than PER and much larger than historically documented (1993 aerial surveys; Blaylock & Hoggard, 1994). Among the 32 recognized BSE dolphin stocks of the northern GOMx, only 11 have recent (since 2016) abundance estimates (Hayes et al., 2023). When comparing the abundances of these dolphin stocks and their respective waterbody surface area, MOB contains one of the largest populations (e.g., Hayes et al., 2023). We also provided the first abundance estimate of bottlenose dolphins in PER and revealed that it has similar (or slightly higher) abundances than similar sized bays along the northern GOMx, such as St. Andrew Bay and Sarasota Bay (e.g., B. Balmer et al., 2018; Tyson & Well, 2016). The estimated survival rates of dolphins in the study areas were similar to those reported for other bottlenose dolphin populations. Specifically, they were consistent or slightly lower than survival rates observed in Charleston, SC (S = 0.95, Speakman et al., 2010), Sarasota Bay, FL (S = 0.96, Wells & Scott, 1990), and Barataria Bay, LA (S = 0.97, McDonald et al., 2017) within the Gulf of Mexico. Overall, the higher abundance estimates observed in MOB and the significant seasonal increase in abundance during summer, as well as the residency patterns of dolphins characterized in both areas, highlight a greater importance than previously expected of these Alabama embayments to BSE dolphin stocks in the northern GOMx.

Abundance and residency patterns of bottlenose dolphin populations are usually influenced by their habitats, where smaller populations typically have a higher degree of residency in protected and enclosed habitats (Irwin & Würsig, 2004; Shane et al., 1986; Wells et al., 1987) compared to semi-open or open habitats (Ballance, 1992; Mullin et al., 2017; Zanardo et al., 2016). Accordingly, the two studied embayments had distinctly different seasonal abundances and residency patterns. MOB, which is a large, semi-open and highly dynamic embayment with several connections to surrounding dolphin stocks, had a higher estimated abundance of dolphins but fewer resident individuals. In contrast, the smaller semi-enclosed bay of PER, with smaller connections to surrounding stocks and relatively stable marine environment throughout seasons, had lower abundances and higher residency. Interestingly, the seasonal residency patterns were also opposing in these embayments, with the abundance of dolphins higher in summers in MOB and higher during winters in PER. Even with high interannual variation (e.g., 95% CI, winter 2019-20), this pattern was strongly persistent. The recruitment rates of newly identified dolphins entering these two embayments showed similar seasonal trends, with a larger number of new individuals encountered during summers in MOB and winters in PER. In MOB, the non-asymptotic discovery curve and the higher proportion of distinct animals seen once, coupled with the low proportion of animals resighted among seasons, indicates a higher percentage of transient dolphins are likely mixing with resident dolphins in this more open embayment compared to PER. Such co-occurrence between transient and resident dolphins have been previously reported in many areas along the Florida coastline (Wells et al., 1987; Quintana-Rizzo & Wells, 2001; Shane, 2004) and in San Luis Pass, Texas (Maze & Würsig, 1999). This co-occurrence observed in MOB is likely promoted by the large pass connecting with the GOMx on the southern end of the estuary, where larger number of individual transient dolphins were probably encountered, such as documented in Galveston Bay and Aransas Pass in Texas (Bräger, 1993; Weller, 1998).

Seasonal variation in dolphin abundance has been described in other BSE dolphin stocks along the northern GOMx as well (Balmer et al., 2008, 2019; Fazioli et al., 2006; Mullin et al., 2017; Toms, 2019). These variations were related to non-resident visitors from neighbouring systems, including the adjacent Northern Coastal Stock, which occasionally or seasonally utilises inshore embayments (B. Balmer et al., 2018; Conn et al., 2011; Fazioli et al., 2006; Irvine et al., 1981). The large increase of abundance in the MOB estuary during summer is likely associated with temporary immigration of dolphins from adjacent waters moving into the area, rather than by unmarked individuals (i.e., subadults and calves) becoming marked throughout the study period. MOB has close connections with neighbouring dolphin stocks (Hayes et al., 2023), such as the Mississippi Sound/Lake Borgne/Bay Boudreau Stock (3,469 dolphins, 95% CI: 3,113 - 3,725; Mullin et al., 2017), and the Northern Coastal Stock (11,543 dolphins, CV = 0.19; Garrison et al., 2021). Preliminary results from intensive biopsy sampling surveys conducted concurrently with this study in the eastern part of Mississippi Sound, MOB, PER and in the GOMx off the coast of Alabama, found evidence of movements among these areas (Bouveroux, pers. com; Clance, 2022). Additionally, movement patterns of tagged dolphins in the eastern part of MSS revealed that some individuals travel widely throughout the southwestern portion of MOB, where it also connects with the coastal water of the GOMx (Cloyed et al., 2021b). These combined results indicate connectivity among embayments and potential for frequent interactions among dolphin stocks in this region.

Seasonal movements into embayments have been previously described in eastern regions of the northern GOMx (e.g., St. Andrew Bay and St. Joseph Bay: Balmer et al., 2008, 2018; Bouveroux et al., 2014), but the specific drivers of these movements are not well understood. During this study, water temperature was the major environmental parameter related to seasonal abundances of dolphins in Alabama waters. Because the seasonal abundance patterns were opposite relative to temperature between embayments, however, it is likely that temperature alone is not the primary driver but may be a covariate or proxy for another as yet unidentified factor or combination of factors affecting dolphin movements in the area. A common theory is that seasonal variation in dolphin abundance could follow seasonal prey movements and variation in local resource availability. We do not have embayment-specific data on seasonal variation in prey abundance to test this theory in our study embayments. In MOB, however, the shrimp fishery is one of the most important commercial fisheries and most active in summer (GULF, 2021; Loesch, 1976). Bottlenose dolphins are often associated with shrimp boats and other fishing vessels, and they take advantage of the lower energy cost of feeding activities from depredation in trawling gears or discarded prey items (Genov et al., 2019; Greenman & Mcfee, 2023; Lorenz, 2015; Shane et al., 1986). Shrimp are found in the stomachs of dolphins stranded in MOB (Russell pers. com., Alabama Marine Mammal Stranding Network), and fishery-associated feeding behaviours were frequently recorded during our surveys in MOB (authors pers. obs.). In contrast, shrimping is limited year-round in PER due to tighter restrictions on shrimping activities in Florida waters, which make up about half of PER. Therefore, animals from the Northern Coastal Stock and MSS might benefit from the seasonal increase of available resources and move into MOB during summer, which can partially explain differences in abundance observed between the two study areas during this time.

Because our study was concurrently conducted in two adjacent areas under otherwise similar conditions, we were also able to further test relationships to environmental attributes. The large volumes of cold and freshwater discharge that seasonally drain into MOB can dominate the system during certain years (e.g., Carmichael et al., 2012; NOAA NMFS, 2022). During this study salinity at the surface in both embayments did not appear to influence the abundance of dolphins. It is important to note, however, that the salinity during this study was recorded at the surface and not in the water column. MOB can have a strong vertical salinity stratification, with twice the surface values at the bottom, especially in the low-wind conditions required during our surveys (Kim & Park, 2012). Therefore, it is likely that our data do not fully capture the effects of salinity on dolphin abundance; for example, animals may have benefited from higher salinity water at depth as a refuge, particularly in the deep MOB ship channel. During winter 2019-20, however, almost all of MOB had an extremely low surface salinity regime, which combined with colder winter temperatures (the coldest documented during this study) could explain the low number of sightings and animals encountered, as well as their greater southern distribution (Bouveroux et al., in prep.). As described in other areas, these poor ecological conditions for dolphins likely promoted temporary dolphin movements out of the study area (Fazioli & Mintzer, 2020; McBride-Kebert & Toms, 2021). In Barataria Bay (Louisiana), a salinity threshold of ~ 8 ppt was identified as a critical area of preferred dolphin habitat, and animals were rarely seen in salinity waters below that isohaline (Hornsby et al., 2017). Dolphins can tolerate low salinity waters (< 10 ppt) for short periods of time (Takeshita et al., 2021), but longer or chronic exposure can dramatically impact dolphins' health (from generalised skin pallor to ulcerative lesions, corneal oedema, electrolyte imbalance) and contribute to mortality (Deming et al., 2020; Ewing et al., 2017). From February to November 2019, between Louisiana and the Florida Panhandle, 337 bottlenose dolphins died stranded on beaches, and an UME was declared in this region. Most of the investigated carcasses exhibited skin lesions consistent with freshwater exposure; 10% of these strandings occurred in Alabama waters (NOAA NMFS, 2022). Therefore, the combined effect of low salinity water, low water temperatures, and higher mortality rates in the region likely resulted in the lowest abundance of dolphins recorded in MOB in winter 2019-20. In contrast, temporal fluctuations of salinity were less pronounced and mostly limited to the north easternmost part of PER. The stability of dolphin habitat in PER may have contributed to the smaller seasonal variation in abundance and higher residency patterns for this population. Long-term monitoring and higher resolution of environmental sampling will help better resolve the drivers of seasonal habitat use and residency patterns for these dolphin stocks.

Comparing dolphin abundance and residency patterns on a regional scale, across embayments with different environmental and geomorphic features, presents methodological and analytical challenges. To compare results between embayments and potentially reveal seasonal patterns of dolphin abundance along the northern GOMx, it is essential to follow the same or very similar methodologies among sites. Most of the research conducted in this region used CMR photo-ID surveys and RD modelling methods (Balmer et al., 2008, 2019; Bouveroux et al., 2014; Litz et al., 2019; Tyson et al., 2011) and this study followed that approach. This study achieved high capture probabilities > 0.10, which indicates limited bias in the estimates (Otis et al., 1978). There was one exception to these capture probabilities, the MOB sampling period during winter 2019-20 (probabilities 0.05-0.10), when environmental conditions were poor. Refinements to develop more complex models that include spatial information on detections to estimate abundance, survival, and recruitment through time and consider individual heterogeneity in capture probabilities and mortality, would be an important step for future research. Such methodologies will help refine abundance and survival estimates, particularly for large and open areas with dynamic habitats. Despite these challenges, the approach used for this study appears robust.

This study provides much needed baseline data on abundance and residency patterns for bottlenose dolphins in Alabama waters. The two studied embayments support a large number of dolphins, in particular MOB, and likely provide seasonally different resources, indicating high and potentially complex use of these estuaries. Although survival rates were sufficient for sustainable population growth, but lower than estimated in other BSE stocks (e.g., McDonald et al., 2017; Speakman et al., 2010; Wells & Scott, 1990), these two populations should be closely monitored because the region is subject to high human activities and environmental variation. Further research is ongoing in both embayments to characterise dolphin distribution and habitat selection and define dolphin hotspots. Biopsy samples that were collected after each season of CMR surveys are being used to analyse genetic stock structure, assess dolphin health through contaminant levels and investigate dolphin diet from stable isotope analyses. These combined data will provide comprehensive information to complement ongoing photo-ID and abundance surveys in these embayments and others in support of effective conservation plans for bottlenose dolphins throughout their range.

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6. DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found online at Dauphin Island Sea Lab data center: https://doi.org/10.57778/fsqw-pj98

7. ETHICS AND PERMIT APPROVAL STATEMENT

This study was conducted under National Marine Fisheries Service (NMFS) Scientific Research Permit No. 23772 issued to Dauphin Island Sea Lab (DISL), and No. 21938 issued to SEFSC-NOAA. Research protocols used were approved by the Institutional Animal Care and Use Committee (IACUC) prior to data collection: NMFS Atlantic IACUC 2020-002.

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9. CONFLICT OF INTEREST DISCLOSURE

The authors declare they are not aware of any conflict of interest.

10. REFERENCES

Adams, J.D., Speakman, T., Zolman, E., Schwacke, L.H., 2006. Automating image matching, cataloging, and analysis for photo-identification research. Aquatic Mammals 32, 374–384. https://doi.org/10.1578/AM.32.3.2006.374

Alexander, R., Smith, R., Schwarz, G., Preston, S., Brakebill, J., Srinivasan, R., Pacheco, P.A., 2001. Atmospheric Nitrogen flux from the watersheds of major estuaries of the Unites States: An application of the SPARROW watershed model. In: Valigura, R.A., Alexander, R., Castro, M., Meyers, T., Paerl, H., Stacey, P.E., turner, E., editors. Nitrogen loading in Coastal Water Bodies: An Atmospheric Perspective. Coastal and Estuarine Studies. Washington DC: American Geophysical Union. 119–170.

Ballance, L.T., 1992. Habitat use patterns and ranges of the bottlenose dolphin in the Gulf of California, Mexico. Marine Mammal Science 8, 262–274. https://doi.org/10.1111/j.1748-7692.1992.tb00408.x

Balmer, B.C., Wells, R.S., Nowacek, S.M., Nowacek, D.P., Schwacke, L.H., Mclellan, D.A., Scharf, F.S., Rowles, T.K., Hansen, L.J., Spradlin, T.R., Pabst, D.A., 2008. Seasonal abundance and distribution patterns of common bottlenose dolphins (*Tursiops truncatus*) near St. Joseph Bay, Florida, USA. Journal of Cetacean Research and Management 10, 157–167. https://doi.org/10.47536/jcrm.v10i2.650

Balmer, B., Mcdonald, T., Hornsby, F., Allen, J., Barleycorn, A., Clarke, P., Cush, C., Honaker, A., Mchugh, K., Speakman, T., Wells, R., Schwacke, L., 2018. Long-term trends in a northern Gulf of Mexico common bottlenose dolphin (*Tursiops truncatus*) population in the wake of the *Deepwater Horizon* oil spill. Journal of Cetacean Research and Management 18, 1–9. https://doi.org/10.47536/jcrm.v18i1.409

Balmer, B., Watwood, S., Quigley, B., Speakman, T., Barry, K., Mullin, K., Rosel, P., Sinclair, C., Zolman, E., Schwacke, L., 2019. Common bottlenose dolphin (*Tursiops truncatus*) abundance and distribution patterns in St Andrew Bay, Florida, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 29, 486–498. https://doi.org/10.1002/aqc.3001

Balmer, J.E., Ylitalo, G.M., Rowles, T.K., Mullin, K.D., Wells, R.S., Townsend, F.I., Pearce, R. W., Bolton J.L., Zolman, E.S., Balmer, B.C., Schwacke, L.H., 2018. Persistent organic pollutants (POPs) in blood and blubber of common bottlenose dolphins (*Tursiops* *truncatus*) at three northern Gulf of Mexico sites following the *Deepwater Horizon* oil spill. Science of the Total Environment 621, 130-137 https://doi.org/10.1016/j.scitotenv.2017.11.209.

Baum, J.K., Worm, B., 2009. Cascading top-down effects of changing oceanic predator abundances. Journal of Animal Ecology 78, 699–714. https://doi.org/10.1111/j.1365-2656.2009.01531.x

Beyer, J., Trannum, H.C., Bakke, T., Hodson, P.V., Collier, T.K., 2016. Environmental effects of the *Deepwater Horizon* oil spill: a review. Marine Pollution Bulletin, 110(1): 28–51. https://doi.org/10.1016/j.marpolbul.2016.06. 027 PMID: 27301686

Blaylock, R.A., Hoggard, W., 1994. Preliminary estimates of bottlenose dolphin abundance in southern U.S. Atlantic and Gulf of Mexico continental shelf waters. NOAA Tech. Memo. NMFS-SEFSC-356. 10 pp.

Bloodgood, J., Deming, A., Colegrove, K., Russell, M., Díaz Clark, C., Carmichael, R., 2023. Causes of death and pathogen prevalence in bottlenose dolphins *Tursiops truncatus* stranded in Alabama, USA, between 2015 and 2020, following the *Deepwater Horizon* oil spill. Diseases of Aquatic Organisms 155, 87–102. https://doi.org/10.3354/dao03746

Bouveroux, T., Tyson, R.B., Nowacek, D.P., 2014. Abundance and site fidelity of bottlenose dolphins in coastal waters near Panama City, Florida. Journal of Cetacean Research and Management 14 (1), 37-42.

Bräger, S., 1993. Diurnal and seasonal behavior patterns of bottlenose dolphins (*Tursiops truncatus*). Marine Mammal Science. 9: 434-440.

Burnham, K.P., Anderson, D.R., 2004. Multimodel Inference: Understanding AIC and BIC in Model Selection. Sociological Methods and Research 261–304.

Carmichael, R.H., Graham, W.M., Aven, A., Worthy, G., Howden, S., 2012. Were multiple stressors a ‘perfect storm’ for northern Gulf of Mexico bottlenose dolphins (*Tursiops truncatus*) in 2011? PLoS ONE 7, e41155. https://doi.org/10.1371/journal.pone.0041155

Carmichael, R.H., Hodanbosi, M.R., Russell, M.L, Wingers, N.L., 2022. Human influence on bottlenose dolphin (*Tursiops truncatus*) strandings in the northern Gulf of Mexico. Frontiers in Environmental Science, 10: https://doi.org/10.3389/fenvs.2022.951329

Clance, L., 2022. Site fidelity of bottlenose dolphins (*Tursiops truncatus*) using elemental analyses and photo-identification. Theses and Dissertations, University of South Alabama, pp. 49. Available: https://jagworks.southalabama.edu/theses_diss/49

Cloyed, C.S., Balmer, B.C., Schwacke, L.H., Takeshita, R., Hohn, A., Wells, R.S., Rowles, T.K., Saliki, J.T., Smith, C.R., Tumlin, M.C., Zolman, E.S., Fauquier, D.A., Carmichael, R.H., 2021a. Linking morbillivirus exposure to individual habitat use of common bottlenose dolphins (*Tursiops truncatus*) between geographically different sites. Journal of Animal Ecology 90, 1191–1204. https://doi.org/10.1111/1365-2656.13446

Cloyed, C.S., Balmer, B.C., Schwacke, L.H., Wells, R.S., Berens McCabe, E.J., Barleycorn, A.A., Allen, J.B., Rowles, T.K., Smith, C.R., Takeshita, R., Townsend, F.I., Tumlin, M.C., Zolman, E.S., Carmichael, R.H., 2021b. Interaction between dietary and habitat niche breadth influences cetacean vulnerability to environmental disturbance. Ecosphere 12, e03759. https://doi.org/10.1002/ecs2.3759

Colbert, A.A., Scott, G.I., Fulton, M.H., Wirth, E.F., Daugomah, J.W., Key, P.B., Strozier, E.D., 1999. Investigation of Unusual Mortalities of Bottlenose Dolphins along the Mid-Texas Coastal Bay Ecosystem during 1992 (NOAA Tech Rep NMFS 147).

Colegrove, K., Venn-Watson, S., Litz, J., Kinsel, M., Terio, K., Fougeres, E., Ewing, R., Pabst, D., McLellan, W., Raverty, S., Saliki, J., Fire, S., Rappucci, G., Bowen-Stevens, S., Noble, L., Costidis, A., Barbieri, M., Field, C., Smith, S., Carmichael, R., Chevis, C., Hatchett, W., Shannon, D., Tumlin, M., Lovewell, G., McFee, W., Rowles, T., 2016. Fetal distress and in utero pneumonia in perinatal dolphins during the Northern Gulf of Mexico unusual mortality event. Diseases of Aquatic Organisms 119, 1–16. https://doi.org/10.3354/dao02969

Collins, M.K., Carmichael, R.H., Rotstein, D.S., Byrd, J.H., Deming, A.C., 2020. Suspected broadhead arrow injuries in two common bottlenose dolphins (*Tursiops truncatus*) along the Alabama Coast. Marine Mammal Science 36, 721–727. https://doi.org/10.1111/mms.12667

Conn, P.B., Gorgone, A.M., Jugovich, A.R., Byrd, B.L., Hansen, L.J., 2011. Accounting for transients when estimating abundance of bottlenose dolphins in Choctawhatchee Bay, Florida. Journal of Wildlife Management 75, 569–579. https://doi.org/10.1002/jwmg.94

Deming, A.C., Wingers, N.L., Moore, D.P., Rotstein, D., Wells, R.S., Ewing, R., Hodanbosi, M.R., Carmichael, R.H., 2020. Health impacts and recovery from prolonged freshwater exposure in a common bottlenose dolphin (*Tursiops truncatus*). Frontiers in Veterinary Science 7, 235. https://doi.org/10.3389/fvets.2020.00235

Ewing, R.Y., Mase-Guthrie, B., McFee, W., Townsend, F., Manire, C.A., Walsh, M., Borkowski, R., Bossart, G.D., Schaefer, A.M., 2017. Evaluation of serum for pathophysiological effects of prolonged low salinity water exposure in displaced bottlenose dolphins (*Tursiops truncatus*). Frontiers in Veterinary Science 4, 80. https://doi.org/10.3389/fvets.2017.00080

Fauquier, D., Litz, J., Sanchez, S., Colegrove, K., Schwacke, L., Hart, L., Saliki, J., Smith, C., Goldstein, T., Bowen-Stevens, S., McFee, W., Fougeres, E., Mase-Guthrie, B., Stratton, E., Ewing, R., Venn-Watson, S., Carmichael, R., Clemons-Chevis, C., Hatchett, W., Shannon, D., Shippee, S., Smith, S., Staggs, L., Tumlin, M., Wingers, N., Rowles, T., 2017. Evaluation of morbillivirus exposure in cetaceans from the northern Gulf of Mexico 2010-2014. Endangered Species Research 33, 211–220. https://doi.org/10.3354/esr00772

Fazioli, K.L., Hofmann, S., Wells, R.S., 2006. Use of Gulf of Mexico coastal waters by distinct assemblages of bottlenose dolphins (*Tursiops truncatus*). Aquatic Mammals 32, 212.

Fazioli, K., Mintzer, V., 2020. Short-term Effects of Hurricane Harvey on Bottlenose Dolphins (*Tursiops truncatus*) in Upper Galveston Bay, TX. Estuaries and Coasts 43, 1013–1031. https://doi.org/10.1007/s12237-020-00751-y

Fire, S.E., Fauquier, D., Flewelling, L.J., Henry, M., Naar, J., Pierce, R., Wells, R.S., 2007. Brevetoxin exposure in bottlenose dolphins (*Tursiops truncatus*) associated with *Karenia brevis* blooms in Sarasota Bay, Florida. Marine Biology 152, 827–834.

Garrison, L.P., Ortega-Ortiz, J., Rappucci, G., 2021. Abundance of Coastal and Continental Shelf Stocks of Common Bottlenose and Atlantic Spotted Dolphins in the Northern Gulf of Mexico: 2017-2018. National Marine Fisheries Service; Southeast Fisheries Science Center (U.S.), pp. 25. https://doi.org/10.25923/3px6-9v48.

Genov, T., Centrih, T., Kotnjek, P., Hace, A., 2019. Behavioural and temporal partitioning of dolphin social groups in the northern Adriatic Sea. Marine Biology 166, 11. https://doi.org/10.1007/s00227-018-3450-8

Greenman, J.T., Mcfee, W.E., 2023. A characterisation of common bottlenose dolphin (*Tursiops truncatus*) interactions with the commercial shrimp trawl fishery of South Carolina, USA. Journal Of Cetacean Research and Management 14, 69–79. https://doi.org/10.47536/jcrm.v14i1.525

GULF, 2021. G.U.L.F. Alabama Shrimp Summary Action Plan. Audubon Nature Institute Gulf United for Lasting Fisheries (G.U.L.F.).

Hammond, P., 2010. Estimating the abundance of marine mammals, in: Marine Mammal Ecology and Conservation: A Handbook of Techniques. Oxford University Press, New York, pp. 42–67.

Hammond, P.S., Francis, T.B., Heinemann, D., Long, K.J., Moore, J.E., Punt, A.E., Reeves, R.R., Sepúlveda, M., Sigurðsson, G.M., Siple, M.C., Víkingsson, G., Wade, P.R., Williams, R., Zerbini, A.N., 2021. Estimating the Abundance of Marine Mammal Populations. Frontiers in Marine Science 8, 735770. https://doi.org/10.3389/fmars.2021.735770

Hayes, S., Josephson, E., Maze-Foley, K., Rosel, P.E., McCordic, J., Wallace, J., 2023. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2022 (NOAA Technical Memorandum NMFS-NE-304).

Hornsby, F., McDonald, T., Balmer, B., Speakman, T., Mullin, K., Rosel, P., Wells, R., Telander, A., Marcy, P., Schwacke, L., 2017. Using salinity to identify common bottlenose dolphin habitat in Barataria Bay, Louisiana, USA. Endangered Species Research 33, 181–192. https://doi.org/10.3354/esr00807

Irvine, A.B., Scott, M.D., Wells, R.S., Kaufmann, J.H., 1981. Movements and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. Fishery Bulletin 79, 671–688.

Irwin, L.-J., Würsig, B., 2004. A Small Resident Community of Bottlenose Dolphins, *Tursiops truncatus*, in Texas: Monitoring Recommendations. Gulf of Mexico Science 22. https://doi.org/10.18785/goms.2201.02

Kendall, W.L., Pollock, K.H., Brownie, C., 1995. A likelihood-based approach to capture–recapture estimation of demographic parameters under the robust design. Biometrics 51, 293. https://doi.org/10.2307/2533335

Kendall, W.L., Nichols, J.D., Hines, J.E., 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. Ecology 78, 563–578.

Kim, Ch-Ki, Park, K., 2012. A modelling study of water and salt exchange for a micro-tidal, stratified northern Gulf of MExico estuary. Journal of Marine Systems: 96-97, 103-115

Laake, J.L., 2013. RMark: An R Interface for analysis of capture-recapture data with MARK (AFSC Processed Rep 2013-01). Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service, Seattle, Washington, USA.

Litz, J., Baran, M., Bowen-Stevens, S., Carmichael, R., Colegrove, K., Garrison, L., Fire, S., Fougeres, E., Hardy, R., Holmes, S., Jones, W., Mase-Guthrie, B., Odell, D., Rosel, P., Saliki, J., Shannon, D., Shippee, S., Smith, S., Stratton, E., Tumlin, M., Whitehead, H., Worthy, G., Rowles, T., 2014. Review of historical unusual mortality events (UMEs) in the Gulf of Mexico (1990-2009): providing context for the multi-year northern Gulf of Mexico cetacean UME declared in 2010. Diseases of Aquatic Organisms 112, 161–175. https://doi.org/10.3354/dao02807

Litz, J.A., Ronje, E.I., Whitehead, H.R., Garrison, L.P., 2019. Updated abundance estimates for common bottlenose dolphins (*Tursiops truncatus*) inhabiting West Bay, Texas. Aquatic Conservation: Marine and Freshwater Ecosystems 29, 1959–1970. https://doi.org/10.1002/aqc.3195

Livingston, R.J., 2001. Eutrophication processes in coastal systems: origin and succession of plankton blooms and effects on secondary production in Gulf Coast estuaries, Boca Raton, Fla. ed. CRC Press.

Loesch, H.C., 1976. Shrimp population densities within Mobile Bay. Gulf and Caribbean Research 5. https://doi.org/10.18785/grr.0502.02

Lorenz, C.M., 2015. Bottlenose dolphin (*Tursiops truncatus*) behaviors in the presence of active and non-active shrimp trawlers in the Mississippi Sound (Honor Thesis). The University of Southern Mississippi.

Maze, K.S., Würsig., B., 1999. Bottlenose dolphins of San Luis Pass, Texas: Occurrence patterns, site fidelity, and habitat use. Aquatic Mammal, 25: 91-103.

McBride-Kebert, S., Toms, C.N., 2021. Common bottlenose dolphin, *Tursiops truncatus*, behavioral response to a record-breaking flood event in Pensacola Bay, Florida. Journal of Zoological and Botanical Gardens 2, 351–369. https://doi.org/10.3390/jzbg2030025

Mcdonald, T.L., Hornsby, F.E., Speakman, T.R., Zolman, E.S., Mullin, K.D., Sinclair, C., Rosel, P.E., Thomas, L., Schwacke, L.H., 2017. Survival, density, and abundance of common bottlenose dolphins in Barataria Bay (USA) following the Deepwater Horizon oil spill. *Endangered Species Research, 33*, 193-209.

Melancon, R.A.S., Lane, S., Speakman, T., Hart, L.B., Sinclair, C., Adams, J., Rosel, P.E., Schwacke, L., 2011. Photo-identification field and laboratory protocols utilizing FinBase version 2. NOAA Technical Memorandum NMFS-SEFSC- 627.

Mullin, K.D., Barry, K., Sinclair, C., Litz, J., Fougeres, E., Mase-Guthrie, B., Ewing, R., Gorgone, A., Adams, J., Tumlin, M., 2007. Common bottlenose dolphins (*Tursiops truncatus*) in Lake Pontchartrain, Louisiana: 2007 to mid-2014. NOAA technical memorandum NMFS-SEFSC, 673. http://doi.org/10.7289/V51C1TT8

Mullin, K.D., McDonald, T., Wells, R.S., Balmer, B.C., Speakman, T., Sinclair, C., Zolman, E.S., Hornsby, F., McBride, S.M., Wilkinson, K.A., Schwacke, L.H., 2017. Density, abundance, survival, and ranging patterns of common bottlenose dolphins (*Tursiops truncatus*) in Mississippi Sound following the *Deepwater Horizon* oil spill. PLoS ONE 12, e0186265. https://doi.org/10.1371/journal.pone.0186265

NOAA NMFS., 2022. Bottlenose dolphin Unusual Mortality Event Along the Northern Gulf of Mexico. Available: https://www.fisheries.noaa.gov/national/marine-life-distress/2019-bottlenose-dolphinunusual-mortality-event-along-northern-gulf.

Orlando, S.P., Klein, C.J., 1989. Characterization of salinity and temperature for Mobile Bay. https://repository.library. noaa.gov/view/noaa/47624.

Otis, D.L., Burnham, K.P., White, G.C., Anderson, D.R., 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs, 62: 3-135

Pollock, K.H., 1982. A capture-recapture design robust to unequal probability of capture. The Journal of Wildlife Management 46, 752–757.

Pollock, K.H., Nichols, J.D., Brownie, C., Hines, J.E., 1990. Statistical inference for capture–recapture experiments. Wildlife Monographs 107, 3–97.

Powell, J.R., Machernis, A.F., Engleby, L.K., Farmer, N.A., Spradlin, T.R., 2018. Sixteen years later: an updated evaluation of the impacts of chronic human interactions with bottlenose dolphins (*Tursiops truncatus truncatus*) at Panama City, Florida, USA. Journal of Cetacean Research and Management 19, 79–93.

PPBEP, 2022. Comprehensive Conservation Management Plan: A Prescription for Healthy Bays. *Pensacola and Perdido Bays Estuary Program*. 220 pages. Available:https://indd.adobe.com/view/c2f4ee73-a2a8-456d-b4bf-75ae16895a87?transition.

PERG, 1998. Perdido ecosystem management strategies: Pensacola, Fla., Florida Department of Environmental Protection. *Perdido Ecosystem Restoration Group.*

Quintana-Rizzo, E., Wells, R.S., 2001. Resighting and association patterns of bottlenose dolphins (*Tursiops truncatus*) in the Cedar Keys, Florida: Insights into social organization. Canadian Journal of Zoology, 79: 447-456.

Ridgway, S., Venn-Watson, S., 2010. Effects of fresh and seawater ingestion on osmoregulation in Atlantic bottlenose dolphins (*Tursiops truncatus*). Journal of Comparative Physiology B 180, 563–576. https://doi.org/10.1007/s00360-009-0439-0

Roberts, K., 2023. Top 10 fastest-growing ports In United States over the last decade. Forbes.https://www.forbes.com/sites/kenroberts/2023/12/30/top-10-fastest-growing-ports-in-united-states-over-the-last-decade/?sh=2d6825d15e92

Rosel, P.E., Mullin, K.D., Garrison, L., Schwacke, L., Adams, J., Balmer, B., Conn, P., Conroy, M.J., Eguchi, T., Gorgone, A., Hohn, A., Mazzoil, M., Schwarz, C., Sinclair, C., Speakman, T., Urian, K., Vollmer, N., Wade, P., Wells, R., Zolman, E., 2011. Photo-identification capture-mark-recapture techniques for estimating abundance of bay, sound and estuary populations of bottlenose dolphins along the U.S. east coast and Gulf of Mexico: a workshop report. NOAA Technical Memorandum NMFS-SEFSC- 621.

Samuels, A., Bejder, L., 2004. Chronic interaction between humans and free-ranging bottlenose dolphins near Panama City Beach, Florida. Journal of Cetacean Research and Management 6, 69–77.

Schroeder, W., Dinnel, S., Wiseman, W., 1990. Salinity stratification in a river dominated estuary. Estuaries, 13: 145–154.

Schwacke, L.H., Smith, C.R., Townsend, F.I., Wells, R.S., Hart, L.B., Balmer, B.C., Collier, T.K., De Guise, S., Fry, M.M., Guillette, L.J., Lamb, S.V., Lane, S.M., McFee, W.E., Place, N.J., Tumlin, M.C., Ylitalo, G.M., Zolman, E.S., Rowles, T.K., 2014. Health of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, Following the *Deepwater Horizon* Oil Spill. Environmental Science and Technology. 48, 93–103. https://doi.org/10.1021/es403610f

Schwacke, L.H., Thomas, L., Wells, R.S., McFee, W.E., Hohn, A.A., Mullin, K.D., Zolman, E.S., Quigley, B.M., Rowles, T.K., Schwacke, J.H., 2017. Quantifying injury to common bottlenose dolphins from the *Deepwater Horizon* oil spill using an age-, sex- and class-structured population model. Endangered Species Research, 33: 265-279. https://doi.org/10.3354/esr00777

Schwacke, L.H., Marques, T.A., Booth, C., Balmer, B., Barratclough, A., Colegrove, K., De Guise, S., Garrison, L., Gomez, F., Morey, J., Mullin, K.D., Quigley, B.M., Rosel, P., Rowles, T., Takeshita, R., Thomas, L., Townsend, F., Speakman, T., Wells, R., Zolman, E., Smith, C., 2022. Modeling population effects of the *Deepwater Horizon* oil spill on a long-lived species. Conservation Biology, e13878. Advance online publication. https://doi.org/10.1111/ cobi.13878

Shane, S.H., Wells, R.S., Würsig, B., 1986. Ecology, behavior and social organization of the bottlenose dolphin: a review. Marine Mammal Science 2, 34–63. https://doi.org/10.1111/j.1748-7692.1986.tb00026.x

Shane, S.H., 2004. Residence patterns, group characteristics, and association patterns of bottlenose dolphins near Sanibel Island, Florida. Gulf Mexico Science, 22(1): 1-12.

Smolker, R.A., Richards, A.F., Connor, R.C., Pepper, J.W., 1992. Sex differences in patterns of association among Indian ocean bottlenose dolphins. Behaviour, 123, 38–69.

Speakman, T.R., Lane, S.M., Schwacke, L.H., Fair, P.A., Zolman, E.S., 2010. Mark-recapture estimates of seasonal abundance and survivorship for bottlenose dolphins (*Tursiops truncatus*) near Charleston, South Carolina, USA. Journal Of Cetacean Research and Management 11, 153–162. https://doi.org/10.47536/jcrm.v11i2.621

Syme, J., Kiszka, J.J., Parra, G.J., 2022. How to define a dolphin “group”? Need for consistency and justification based on objective criteria. Ecology and Evolution, 12, e9513. https://doi.org/10.1002/ece3.9513

Takeshita, R., Sullivan, L., Smith, C., Collier, T., Hall, A., Brosnan, T., Rowles, T., Schwacke, L., 2017. The *Deepwater Horizon* oil spill marine mammal injury assessment. Endangered Species Research 33, 95–106. https://doi.org/10.3354/esr00808

Takeshita, R., Balmer, B.C., Messina, F., Zolman, E.S., Thomas, L, Wells R.S., Smith, C. R., Rowles, T. K., Schwacke, L.H., 2021. High site-fidelity in common bottlenose dolphins despite low salinity exposure and associated indicators of compromised health. PLoS ONE 16(9): e0258031. https://doi.org/10.1371/journal.pone.0258031

Thompson, J.W., Zero, V.H., Schwacke, L.H., Speakman, T.R., Quigley, B.M., Morey, J.S., McDonald, T.L., 2022. *FINFINDR*: Automated recognition and identification of marine mammal dorsal fins using residual convolutional neural networks. Marine Mammal Science 38, 139–150. https://doi.org/10.1111/mms.12849

Toms, C.N., 2019. Filling the gaps: common bottlenose dolphin (*Tursiops truncatus*) population dynamics, structure and connectivity within Florida panhandle bays, sounds, and estuaries. University of Central Florida. Pp 373.

Twiner, M.J., Flewelling, L.J., Fire, S.E., Bowen-Stevens, S.R., Gaydos, J.K., Johnson, C.K., Landsberg, J.H., Leighfield, T.A., Mase-Guthrie, B., Schwacke, L., Van Dolah, F.M., Wang, Z., Rowles, T.K., 2012. Comparative Analysis of Three Brevetoxin-Associated Bottlenose Dolphin (*Tursiops truncatus*) Mortality Events in the Florida Panhandle Region (USA). PLoS ONE 7, e42974. https://doi.org/10.1371/journal.pone.0042974

Tyson, R., Nowacek, S., Nowacek, D., 2011. Community structure and abundance of bottlenose dolphins *Tursiops truncatus* in coastal waters of the northeast Gulf of Mexico. Marine Ecology Progress Series 438, 253–265. https://doi.org/10.3354/meps09292

Tyson, R.B., Wells, R.S., 2016. Sarasota Bay/Little Sarasota Bay bottlenose dolphin abundance estimates: 2015. Prepared for National Marine Fisheries Service, northern Gulf of Mexico bay, sound, and estuary bottlenose dolphin stock blocks B20 and B35, combined. Southeast Fisheries Science Center, Protected Resources and Biodiversity Division, 75 Virginia Beach Dr., Miami, FL 33140. PRBD Contribution # PRBD-2016-02, 21 pp. Available from: https://www.sefsc.noaa.gov/P_QryLDS/download/PRB84_PRBD-201602.pdf?id=LDS

Tyson, R.B., Urian, K.W., Allen, J.B., Cush, C., Parham, J.R., Blount, D., Holmberg, J., Thompson, J.W., Wells, R.S., 2022. Rise of the Machines: Best Practices and Experimental Evaluation of Computer-Assisted Dorsal Fin Image Matching Systems for Bottlenose Dolphins. Frontiers in Marine Science 9, 849813. https://doi.org/10.3389/fmars.2022.849813

Urian, K., Gorgone, A., Read, A., Balmer, B., Wells, R.S., Berggren, P., Durban, J., Eguchi, T., Rayment, W., Hammond, P.S., 2015. Recommendations for photo-identification methods used in capture-recapture models with cetaceans. Marine Mammal Science 31, 298–321. https://doi.org/10.1111/mms.12141

USACE, 2023. Supplemental environmental assessment Mobile Harbor Upper Bay channel widening Mobile County, Alabama Federally authorized project Prepared by U.S. Army Corps of Engineers, Mobile District Planning and Environmental Division Environment and Resources Branch Coastal Environment Team September 2023. 36 pages.

Valentine, J.F., Heck, K., Dardeau, M.R., Burch, H., 2013. Ecosystem-based management of Mobile Bay, Alabama, in: Gulf of Mexico Origin, Waters, and Biota. Texas A & M University Press, College Station, TX, pp. 71–92.

Venables, W.N., Ripley, B.D., 2002. Modern Applied Statistics with S (Fourth Edition). Springer, New York, NY.

Weller, D.W., 1998. Global and regional variation in the biology and behavior of bottlenose dolphins. Ph.D. thesis. Texas A&M University, College Station. 142 pp.

Wells, R.S., Scott, M.D., 1990. Estimating Bottlenose Dolphin Population Parameters From Individual Identification and Capture-Release Techniques. Report of the International Whaling Commission. 12, 407 – 415 (SC/A88/P23)

Wells, R.S., Scott, M.D., Irvine, A.B., 1987. The Social Structure of Free-Ranging Bottlenose Dolphins, in: Genoways, H.H. (Ed.), Current Mammalogy. Plenum Press, New York, New York and London, pp. 247–305. https://doi.org/10.1007/978-1-4757-9909-5_7

Wells, R.S., Rhinehart, H.L., Hansen, L.J., Sweeney, J.C., Townsend, F.I., Stone, R., Casper, D.R., Scott, M.D., Hohn, A.A, Rowles, T.K., 2004. Bottlenose Dolphins as Marine Ecosystem Sentinels: Developing a Health Monitoring System. EcoHealth, 1: 246–254. https://doi.org/10.1007/s10393-004-0094-6

Wilson, B., Hammond, P.S., Thompson, P.M., 1999. Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecological Applications 9, 288–300.

Würsig, B., Jefferson, T., 1990. Methods of photo-identification for small cetaceans. Report of the International Whaling Commission Special Issue, 43–52.

Würsig, B., Würsig, M., 1977. The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). Science 755–756.

Xia M., Craig P.M., Wallen C.M., Stoddard A., Mandrup-Poulsen J., Peng M., Schaeffer, B., Liu, Z., 2011. Numerical simulation of salinity and dissolved oxygen at perdido bay and adjacent coastal ocean. Journal of Coastal Research 27 (1), 73–86. doi: 10.2112/JCOASTRES-D-09-00044.1

Yeates, L.C., Houser, D.S., 2008. Thermal tolerance in bottlenose dolphins (*Tursiops truncatus*). Journal of Experimental Biology 211, 3249–3257. https://doi.org/10.1242/jeb.020610

Zanardo, N., Parra, G.J., Möller, L.M., 2016. Site fidelity, residency, and abundance of bottlenose dolphins (*Tursiops* sp.) in Adelaide's coastal waters, South Australia. Marine Mammal Science 32, 1381–1401. https://doi.org/10.1111/mms.12335

Figures

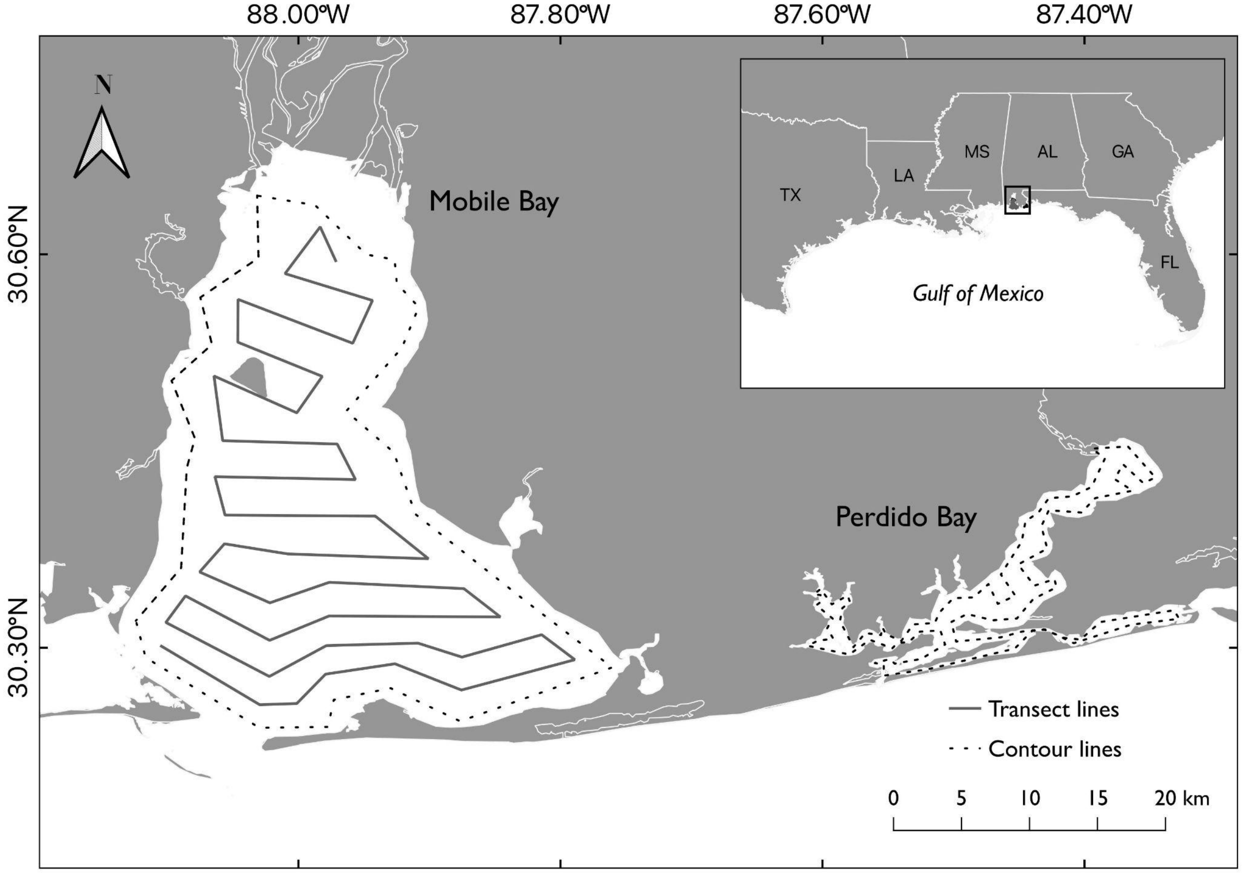

Figure 1. Two adjacent study areas in Alabama waters, Mobile Bay (left) and Perdido Bay (right), that were surveyed to collect mark-recapture photo-identification data on common bottlenose dolphins (*Tursiops truncatus*) following either transect lines (solid black lines) and/or contour lines (dashed black lines).

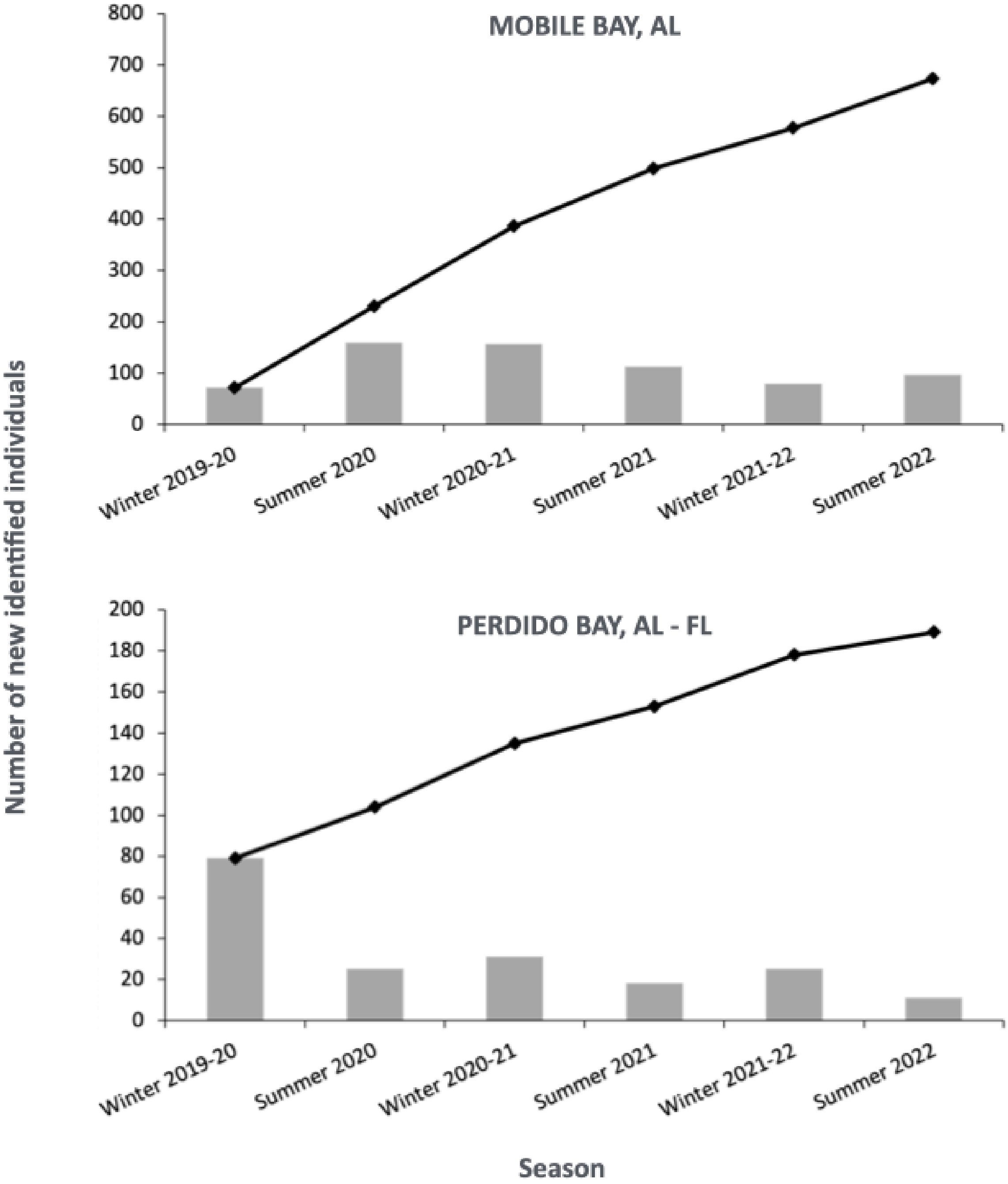

Figure 2. The number of newly identified common bottlenose dolphins in each survey season (primary sampling occasions) in Mobile Bay (N = 673) and Perdido Bay (N = 189), and the resulting discovery curve showing the cumulative number of newly identified distinct individual dolphins (D1, D2), during the study period (winter 2019-20 to summer 2022).

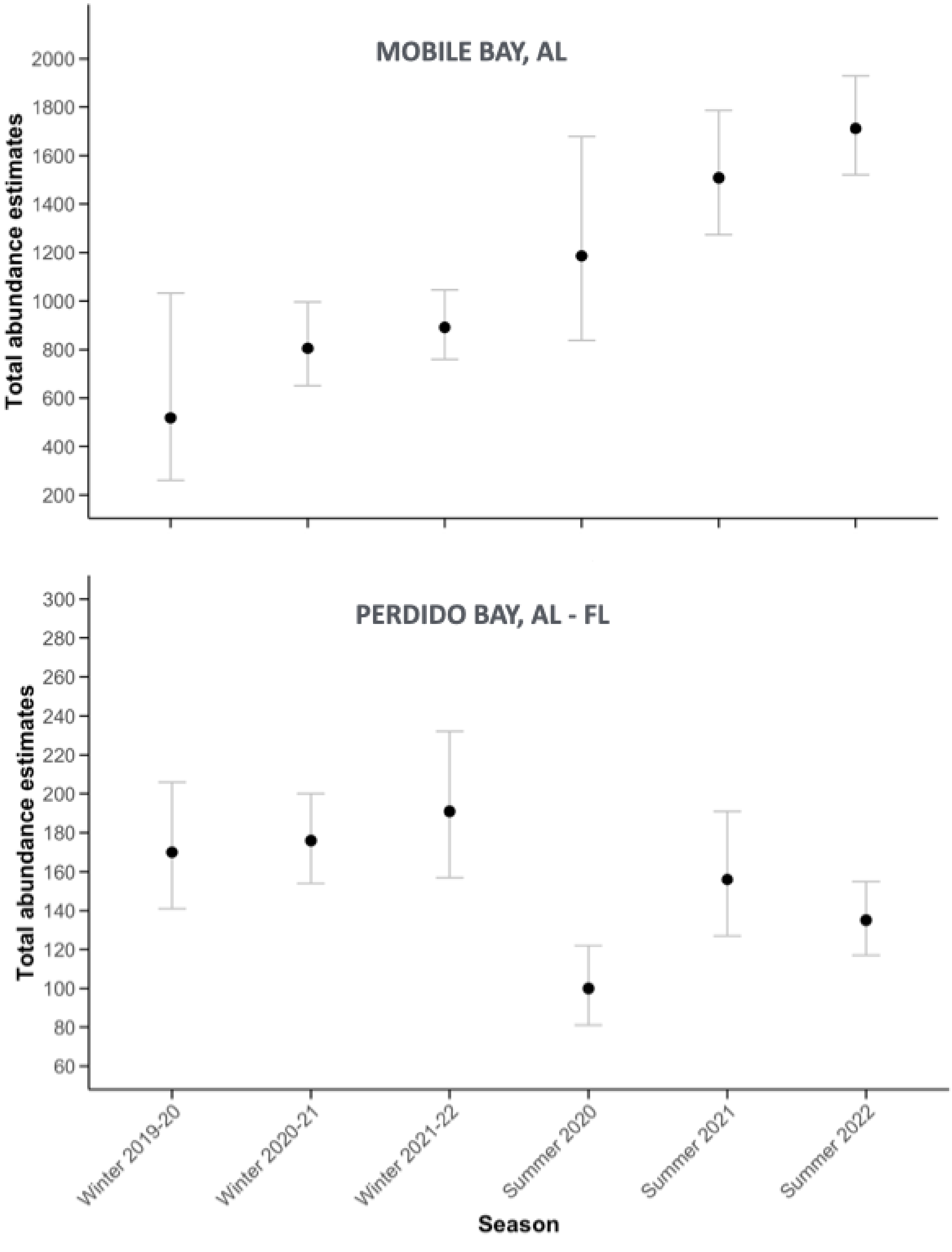

Figure 3. Seasonal abundance estimates of common bottlenose dolphins in in Mobile Bay and Perdido Bay, derived from Pollock's robust design full-likelihood *p* and *c* approach for each season (primary sampling period). Best fitting model for Mobile Bay (MOB) = *{S.) p(t) random emigration}*, best fitting model for Perdido Bay (PER) = *{S(.) p(t) Markovian emigration}*. The estimates include unmarked individuals (N total), and the vertical grey bars represent the 95% confidence interval for each estimate.

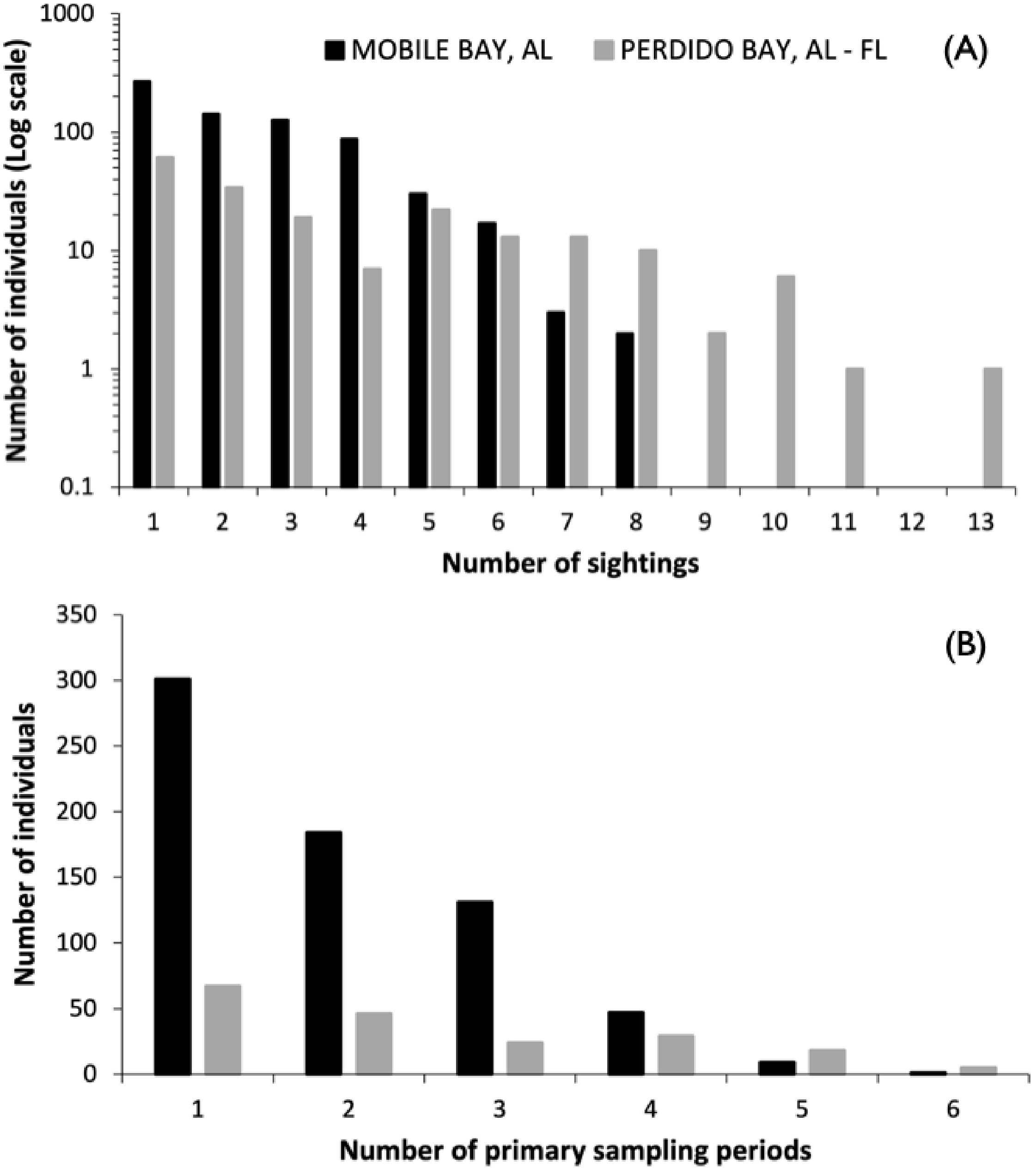

Figure 4. (A) Number of distinct individual common bottlenose dolphins (expressed in log scale) encountered during the study period (winter 2019-20 to summer 2022); (B) number of distinct individuals encountered per number of survey seasons (i.e., number of primary sampling periods) in Mobile Bay and Perdido Bay.

Tables

Table 1. Photo-identification survey effort for each study embayment during the primary sampling periods (seasons) between winter 2019-20 and summer 2022 showing distances on effort, encounter rates (sightings km^{-1}), relative abundance (dolphins km^{-1}), number of surveys and sightings, as well as number of encountered dolphins, calves, and neonates of common bottlenose dolphins. MOB = Mobile Bay, PER = Perdido Bay.

Study area	Season	Distance on effort (km)	Encounter rates	Relative abundance	No. of surveys	No. of sightings	No. of dolphins	No. of calves	No. of neonates
MOB	Winter 2019-20	1,086.4	0.02	0.15	13	26	162	20	0
	Winter 2020-21	1,096.3	0.06	0.47	13	70	519	48	0
	Winter 2021-22	1,047.2	0.07	0.55	14	74	580	74	0
	Summer 2020	1,111.5	0.03	0.36	13	37	404	46	0
	Summer 2021	1,148.8	0.04	0.38	14	41	431	36	9
	Summer 2022	1,109.2	0.05	0.68	18	61	749	39	14
	Sub-total	***6,599.4***	**-**	**-**	***85***	***309***	***2,845***	***263***	***23***
PER	Winter 2019-20	386.4	0.12	0.62	7	48	238	38	0
	Winter 2020-21	394.2	0.13	0.75	6	52	295	44	0
	Winter 2021-22	417.2	0.12	0.56	6	50	232	25	0
	Summer 2020	407.8	0.12	0.54	7	47	221	41	3
	Summer 2021	414.7	0.14	0.54	6	56	224	26	12
	Summer 2022	391.8	0.12	0.80	6	48	313	42	27
	Sub-total	***2,412.1***	**-**	**-**	***38***	***301***	***1,523***	***216***	***42***
TOTAL	**-**	***9,011.5***	**-**	**-**	***123***	***610***	***4,368***	***479***	***65***

Table 2. Abundance estimates (N distinct) of common bottlenose dolphins for Mobile Bay, derived from Pollock's robust design full-likelihood *p* and *c* approach for each season (primary sampling period). Best fitting model for MOB = *{S.) p(t) random emigration}*, best fitting model for PER = *{S(.) p(t) Markovian emigration}*. SE = standard errors, CI = 95% confidence interval. The table gives the proportion of distinct individuals (D1, D2), the total abundance estimate including unmarked individuals (N total), and the overall mean abundance in Winter and Summer.

Primary sampling period	**N distinct**	**SE**	**95% CI (N distinct)**	**Proportion of distinct IDs**	**N total**	**95% CI (N total)**	**Mean abundance ± SE**
MOB - *{S.) p(t) random emigration}*							
Winter 2019-20	306	110.91	168 - 637	0.59	518	260 - 1,032	738 ± 112.67
Winter 2020-21	483	52.63	399 - 608	0.60	805	650 - 996	
Winter 2021-22	535	43.67	461 - 634	0.60	891	759 - 1,045	
Summer 2020	546	97.38	399 - 790	0.46	1,186	838 - 1,678	1,469 ± 152.99
Summer 2021	663	57.41	565 - 791	0.44	1,508	1,273 - 1,786	
Summer 2022	582	35.36	522 - 662	0.34	1,712	1,520 - 1,928	
PER - *{S(.) p(t) Markovian emigration}*							
Winter 2019-20	109	10.72	95 - 139	0.64	170	141 - 206	179 ± 6.09
Winter 2020-21	109	7.36	99 - 129	0.62	176	154 - 200	
Winter 2021-22	149	14.99	126 -187	0.78	191	157 - 232	
Summer 2020	83	8.64	71 - 107	0.83	100	81 - 122	130 ± 16.39
Summer 2021	106	10.95	90 - 135	0.68	156	127 - 191	
Summer 2022	108	7.63	97 - 128	0.80	135	117 - 155	

Table 3. Mean and range (min - max) seasonal variation of the surface salinity (± SD) and water temperature (± SD) for Mobile Bay (MOB) and Perdido Bay (PER) collected on effort during photo-identification surveys between winter 2019-20 and summer 2022.

Study area	Season	Salinity (ppt)	Min - Max (ppt)	Water temp. (°C)	Min - Max (°C)
MOB	Winter 2019-20	3.72 ± 3.19	0.10 - 13.10	12.23 ± 1.24	8.40 - 16.00
	Winter 2020-21	11.51 ± 4.84	0.14 - 25.56	15.07 ± 1.56	12.30 - 20.55
	Winter 2021-22	14.76 ± 4.79	2.15 - 31.00	17.22 ± 1.03	13.92 - 20.14
	Summer 2020	12.01 ± 6.29	0.08 - 31.36	30.30 ± 1.09	23.11 - 33.55
	Summer 2021	3.53 ± 3.51	0.06 - 20.65	29.52 ± 1.46	24.12 - 34.67
	Summer 2022	8.89 ± 3.58	0.51 - 24.25	31.76 ± 1.03	27.74 - 34.71
PER	Winter 2019-20	18.12 ± 5.78	4.30 - 28.00	16.75 ± 1.96	13.80 - 21.20
	Winter 2020-21	18.39 ± 5.67	0.10 - 30.31	11.32 ± 1.30	6.42 - 19.93
	Winter 2021-22	17.04 ± 6.12	0.18 - 30.16	14.33 ± 1.27	9.82 - 18.39
	Summer 2020	18.11 ± 7.07	3.17 - 34.13	29.81 ± 0.89	27.79 - 32.88
	Summer 2021	17.99 ± 6.51	2.23 - 31.22	28.31 ± 0.80	24.82 - 32.53
	Summer 2022	10.10 ± 7.14	0.05 - 28.08	29.81 ± 1.08	25.63 - 34.37

Supplementary Material

Table S1: Model selection details of Robust Design candidate models for Mobile Bay testing for Markovian and random temporary emigration (γ”, γ’) with combined estimated parameters for survival (S) and capture (p) probabilities. Models are ranked by lowest corrected Akaike Information Criterion (AICc). Delta AICc is the difference between a model and the best ranked model. No. parameters = number of estimated parameters.

Model	No. parameters	AICc	ΔAICc
S(.) γ” = γ’ p(time)	29	-5675.301	0.000000
S(t) γ” = γ’ p(time)	33	-5672.253	3.047545
S(.) γ”≠ γ’ p(time)	32	-5672.156	3.144824
S(t) γ”≠ γ’ p(time)	36	-5666.624	8.677216
S(.) γ” = γ’ p(1sess)	17	-5569.585	105.715433
S(t) γ” = γ’ p(1sess)	21	-5566.859	108.441557
S(.) γ”≠ γ’ p(1sess)	20	-5561.964	113.336829
S(t) γ” ≠ γ’ p(1sess)	24	-5561.088	114.212995
S(t) γ” = γ’ p(2sess)	18	-5548.320	126.981172
S(.) γ”≠ γ’ p(2sess)	17	-5547.540	127.760933
S(.) γ” = γ’ p(2sess)	14	-5544.576	130.725117
S(t) γ”≠ γ’ p(2sess)	21	-5544.470	130.831057
S(t) γ” = γ’ p(.)	16	-5535.447	139.853347
S(.) γ” ≠ γ’ p(.)	15	-5534.768	140.533010
S(.) γ” = γ’ p(.)	12	-5531.676	143.624543
S(t) γ”≠ γ’ p(.)	19	-5529.678	145.622369

S denotes survival; p probability of capture and recapture (p = c);
γ” = γ’ random emigration model; γ”≠ γ’ Markovian emigration model;
(.) denotes constancy over time; (t) vary by time;
(1sess) vary by primary sessions (e.g., season); (2sess) vary by secondary sessions but constant between primary sessions.

Table S2: Model selection details of Robust Design candidate models for Perdido Bay, testing for Markovian and random temporary emigration (γ”, γ’) with combined estimated parameters for survival (S) and capture (p) probabilities. Models are ranked by lowest corrected Akaike Information Criterion (AICc). Delta AICc is the difference between a model and the best ranked model. No. parameters = number of estimated parameters.

Model	**No. parameters**	**AICc**	**ΔAICc**
S(.) γ”≠ γ’ p(time)	32	-601.3892	0.000000
S(t) γ”≠ γ’ p(time)	36	-599.7946	1.594558
S(t) γ” = γ’ p(time)	33	-597.6384	3.750829
S(.) γ” = γ’ p(time)	29	-590.2232	11.166009
S(.) γ”≠ γ’ p(1sess)	20	-587.8069	13.582285
S(t) γ” ≠ γ’ p(1sess)	24	-586.6826	14.706555
S(t) γ” = γ’ p(1sess)	21	-584.1481	17.241069
S(.) γ” ≠ γ’ p(.)	15	-583.3657	18.023545
S(t) γ”≠ γ’ p(.)	19	-580.5405	20.848701
S(.) γ”≠ γ’ p(2sess)	17	-579.8266	21.562595
S(t) γ”≠ γ’ p(2sess)	21	-576.9509	24.438339
S(t) γ” = γ’ p(.)	16	-576.4426	24.946575
S(.) γ” = γ’ p(1sess)	17	-576.3465	25.042695
S(.) γ” = γ’ p(.)	12	-573.5119	27.877291
S(t) γ” = γ’ p(2sess)	18	-572.8887	28.500501
S(.) γ” = γ’ p(2sess)	14	-570.0076	31.381615

S denotes survival; p probability of capture and recapture (p = c);
γ” = γ’ random emigration model; γ”≠ γ’ Markovian emigration model;
(.) denotes constancy over time; (t) vary by time;
(1sess) vary by primary sessions (e.g., season); (2sess) vary by secondary sessions but constant between primary sessions.

Table S3. Statistics for the environmental parameters of models for Mobile Bay (MOB) and Perdido Bay (PER). SE = standard error, t = t-values, p = p-values, AIC = Akaike information criterion, and ΔAIC = delta Akaike information criterion, w = Akaike weights.

	Parameters	**Estimate**	**SE**	**t**	**p**	**AIC**	**ΔAIC**	**w**
MOB	(Intercept)	-490.46	500.36	-0.98	0.4303	83.11	0.19	0.39
	Salinity	63.80	54.37	1.17	0.3615			
	Temp	74.68	22.41	3.33	0.0795			
	Salinity:Temp	-3.33	2.53	-1.32	0.3190			
	(Intercept)	48.53	320.11	0.15	0.8890	84.85	1.93	0.17
	Salinity	-3.67	20.09	-0.18	0.8670			
	Temp	47.97	10.57	4.54	0.0200			
	(Intercept)	12.87	221.06	0.06	0.9564	82.92	0.00	0.44
	Temp	48.07	9.19	5.23	0.0064			
	Parameters	**Estimate**	**SE**	**t**	**p**	**AIC**	**ΔAIC**	**w**
PER	(Intercept)	768.84	837.27	0.92	0.4550	59.35	2.53	0.22
	Salinity	-30.24	46.73	-0.65	0.5840			
	Temp	-20.79	28.26	-0.74	0.5380			
	Salinity:Temp	0.97	1.58	0.61	0.6020			
	(Intercept)	257.79	76.41	3.37	0.0433	84.85	28.04	0.00
	Salinity	-1.67	3.52	-0.47	0.6683			
	Temp	-3.48	1.33	-2.61	0.0798			
	(Intercept)	224.06	24.75	9.05	0.0008	56.82	0.00	0.78
	Temp	-3.20	1.07	-2.98	0.0408			

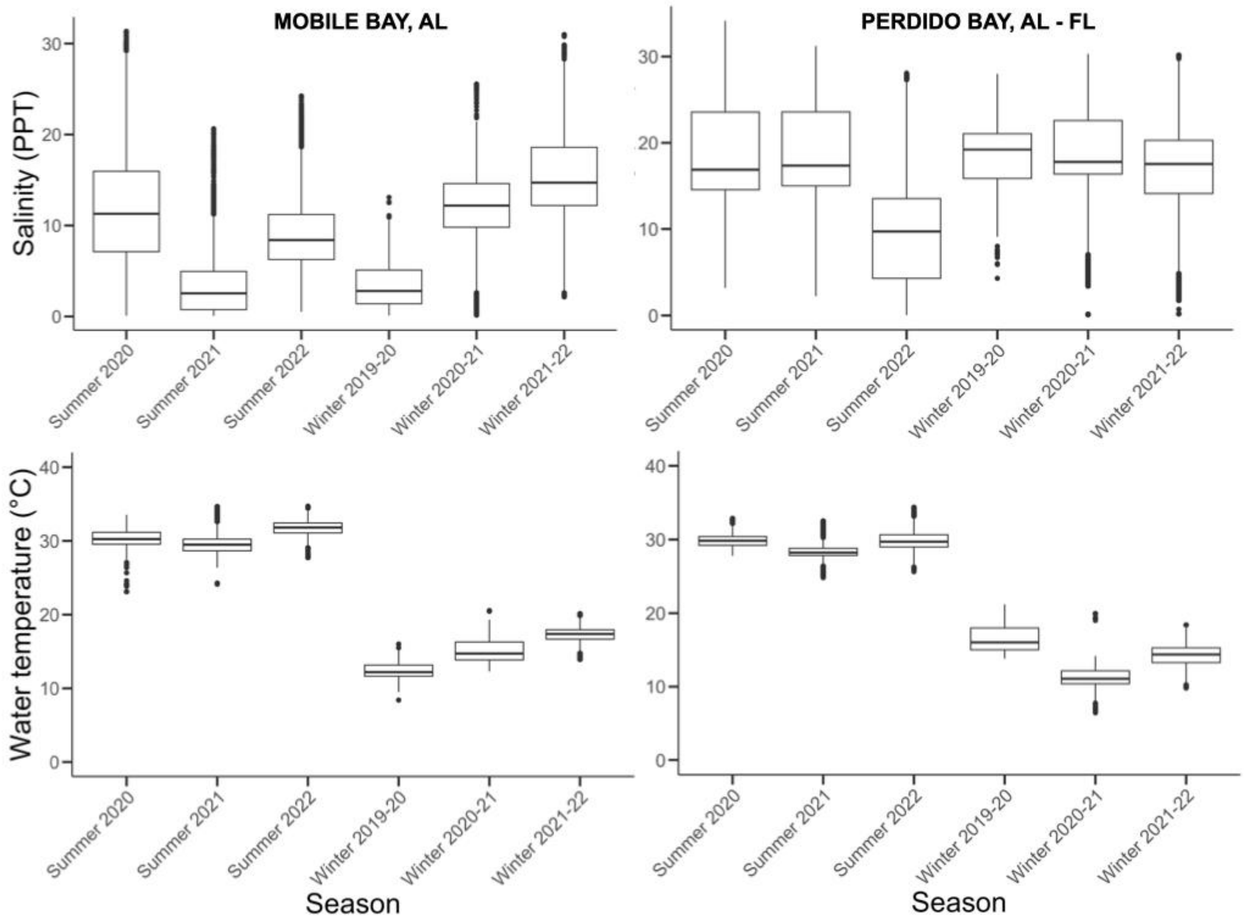

Figure S1: Seasonal variation of salinity (top panels) and water temperature (bottom panels) recorded by the Dataflow continuous data logger (© Eureka Water Probes) during sampling in Mobile Bay (n = 127,126) and Perdido Bay (n = 88,760), including the median (black horizontal lines), lower and upper quartile and outlier (black circles) values.