

# Forty-year historical analysis of marine mammal strandings in Texas, from 1980–2019

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## ABSTRACT

Long-term trends in marine mammal stranding patterns can provide useful information on basic life history parameters, spatiotemporal distribution, natural and human-related mortality events, and potentially vulnerable populations. Between 1980 and 2019, a total of 5,303 marine mammal strandings were recorded in Texas, USA. In total, 23 species were identified, including 19 odontocete species (toothed whales and dolphins), 3 mysticete species (baleen whales), and 1 sirenian species (manatee). Common bottlenose dolphins (*Tursiops truncatus*) stranded most frequently (94%). Common bottlenose dolphin stranding events increased significantly from late winter to mid-spring, with an early onset in southern Texas, and had a consistent peak in March involving primarily calves and adults. Spatial analyses using kernel density estimation within seven coastal Texas stock management areas, delineated by the National Marine Fisheries Service, identified potential hotspots for common bottlenose dolphin strandings near higher human population density and deep water channels. Peak stranding density estimates in each stock area ranged from 0.32–4.6km<sup>-2</sup> for presumed bay, sound and estuarine (BSE) stocks and 0.82km<sup>-2</sup> for the presumed Western Gulf of Mexico Coastal Stock. Common bottlenose dolphin stranding events were positively male-biased, including a significantly higher number of stranded male fetuses and neonates, and sexual dimorphism was observed in total body length of adults, with significantly greater length in males. For all records where human interaction (HI) could be determined as ‘yes’ or ‘no’, 30% were positive for HI, with the highest proportion of HI events occurring in the central and southernmost BSE stock areas; however, it is unknown how many HI cases contributed to mortality. This longitudinal study provides a comprehensive overview of marine mammal stranding patterns in Texas and serves as a useful resource for stranding investigators and Gulf-wide natural resource managers.

**KEYWORDS:** STRANDING TRENDS, MARINE MAMMAL, COMMON BOTTLENOSE DOLPHIN, *TURSIOPS TRUNCATUS*, TEXAS BAY, SOUND, AND ESTUARINE STOCKS, WESTERN GULF OF MEXICO COASTAL STOCK, HUMAN INTERACTION

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## INTRODUCTION

Marine mammal distribution and abundance can affect ecosystem structure and function (Bowen, 1997). However, free-ranging marine mammals are inherently challenging to study, given that they are highly mobile, spend significant time underwater, may occur in remote offshore locations and experimental study designs are difficult to implement. Studying wild populations can also be logistically challenging due to unpredictable weather, and costly sampling methods such as large ship or aerial surveys. Stranded, or beach-cast, marine mammals offer an opportunity that provides researchers valuable data that might not otherwise be attainable. Stranding

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event response and research provides a mechanism whereby basic life history, including species distribution, demographic data (e.g., age structure, sex composition, morphometrics), foraging ecology, disease and infection, and morbidity and mortality, can be evaluated to contribute to our knowledge of the biology of marine mammal species and their role within ecosystems. It is also a source for identifying evidence of human interaction (HI), such as fishery gear entanglement (Leeney, R.H. *et al.*, 2008). Stranding data can also be integrated with free-ranging marine mammal population data to assess mortality rate and life expectancy of a population (McGuire *et al.*, 2020), and serve as an early indicator of localised infectious disease or ecosystem anomalies to better inform conservation management.

Legal authority for most marine mammal stranding response in the US is managed by the National Marine Fisheries Service (NMFS). Operating under a letter of authorisation from the NMFS Southeastern Regional Office, the Texas Marine Mammal Stranding Network (TMMSN) was established in 1980 for the systematic collection of cetacean (dolphins, porpoises, and whales) stranding data along the Texas coast (Tarpley, 1987). The TMMSN is the only organisation in Texas that operates under a Stranding Agreement with the NMFS to respond to stranded cetaceans. The TMMSN also responds to stranded West Indian manatees (*Trichechus manatus*) in coordination with the US Fish and Wildlife Service (USFWS), the governing body that has jurisdiction over sirenians. In 1989, the TMMSN was formally incorporated as a non-profit 501(c)(3) organisation (Wilkinson and Worthy, 1999). In 1990, the TMMSN diversified its operation to include live animal rehabilitation and in 2014 implemented formal wild population photo-identification research. The present mission of the TMMSN is to further the understanding and conservation of marine mammals through rescue and rehabilitation, research and education.

At least 29 marine mammals occur in the Gulf of Mexico (GoM), 22 of which occur regularly in the northern GoM, including 1 baleen whale species (mysticete), 20 toothed whale and dolphin species (odontocetes) and 1 coastal manatee (sirenian) (reviewed in Würsig, 2017). Common bottlenose dolphins (*Tursiops truncatus*; hereafter ‘bottlenose dolphin’) are the most abundant and widely distributed marine mammal in near-shore coastal waters including bays, sounds and estuaries (BSEs) (reviewed in Würsig, 2017). Eight bottlenose dolphin stocks (seven BSE stocks and one coastal stock) have been delineated in Texas waters by the NMFS for management purposes (NMFS, 2005; Phillips and Rosel, 2014), though research shows at least some mixing occurs between bay systems (Maze and Würsig, 1999; Ronje *et al.*, 2020; Lynn and Würsig, 2002). The objectives of this study were to provide a comprehensive review and summary of marine mammal stranding data in Texas from 1980 through 2019 by examining stranded species composition, spatiotemporal distribution and frequencies, age class and sex-specific mortality patterns, and human-related incidents to contribute to our understanding of stranding events in Texas.

## METHODS

### Study area

The Texas coast includes 5,406km of tidal shoreline along the northwestern GoM, including sounds, bays, rivers, creeks and offshore islands (NOAA, 1975). The coast extends nearly four degrees latitude (approximately 25°57′N to 29°59′N) and longitude (approximately –97°45′W to –93°50′W), with a broad and flat continental shelf (Davis, 2017) and a subtropical environment ranging from humid to semi-arid (TWDB, 2012). The seaward boundary varies in composition including sand and shell beaches, mud-rich and marsh-dominated shoreline, sandy barrier islands and peninsulas, and human-engineered features such as dredged channels, jetties, seawalls and rock groins (Paine, *et al.*, 2017).

The TMMSN response area is logistically separated into six geographic regions in Texas, including designated counties (in parentheses) as follows, from north to south: Sabine Pass (Jefferson, Chambers), Galveston (Galveston, Harris, Brazoria), Port O’Connor (Matagorda, Jackson, Calhoun), Port Aransas (Refugio, Aransas, San Patricio, Nueces), Corpus Christi (Kleberg, Kenedy) and South Padre Island (Willacy, Cameron). The TMMSN headquarters is located on Galveston Island and over the course of this study Regional Coordinators facilitated coverage and reduced response time to live and dead stranded marine mammals along the coast.

## Data collection and preparation

As defined by the Marine Mammal Protection Act of 1972, marine mammals were considered ‘stranded’ if they were dead on shore, or in waters under US jurisdiction (including navigable waters), or alive and on shore and unable to return to water, on shore and in apparent need of medical attention, or in waters under US jurisdiction (including navigable waters) but unable to return to natural habitat without assistance (MMC, 2018). For analyses herein, the definition of ‘stranded’ also included marine mammals in waters under US jurisdiction (including navigable waters) in their natural habitat but in need of apparent medical attention (e.g., entangled in fishing gear). These cases, as well as out-of-habitat cases, required separate intervention authorisation from NMFS. Stranding events included single individuals, cow-calf pairs, mass stranding events and unusual mortality events (UMEs). Mass stranding events involved 2 or more cetaceans that stranded together, other than cow-calf pairs (NOAA, 2020). Unusual mortality events differed from mass stranding events and were defined under the Marine Mammal Protection Act of 1972 as a stranding event that ‘is unexpected; involves a significant die-off of any marine mammal population; and demands immediate response’ (MMC, 2018).

Stranded marine mammals were reported to the TMMSN by means of a 24-hour reporting hotline that has been in place over 30 years, or more recently through the TMMSN website ([www.tmmsn.org](http://www.tmmsn.org)). Most beaches were visited opportunistically by the public, in which there were strong geographical and seasonal biases (e.g., increased visitation during ‘spring break’ and summer months), and/or routinely surveyed by local agencies (e.g. wildlife enforcement officers, city and county park services, conservation organisations) from which the TMMSN received reports. Survey effort by the TMMSN was intermittent in each region, as resources allowed. Reporting improved over time, due in part to increased public awareness, relationships fostered with local agencies and technological advances that facilitated report submission [e.g., social media and cellular phones with cameras and global positioning system (GPS) capabilities]. For each stranding event, basic ‘Level A’ data (NOAA, 2020), including date, location, species, condition of individual, body length, sex and human interaction, were collected by TMMSN staff or trained personnel *in situ* when possible. Data were later standardised based on a national template created by the NMFS for cetaceans. Manatee condition and HI designations were not consistent with NMFS cetacean designations and were excluded from condition code and HI analyses. If direct observations by TMMSN personnel were not possible (approximately 7% of reports), data were estimated based on photographic evidence or reporter feedback when possible (e.g., sex and age class). Additional data and biological specimens were collected from suitable carcasses for analyses; however, results from biological samples are not discussed here.

Records of stranded marine mammals in the US, from 1989 to the present, were maintained in a centralised online database managed by the NMFS Marine Mammal Health and Stranding Response Program (MMHSRP). Data collected prior to 1989, from 1980 to 1988, were maintained by the TMMSN. The MMHSRP records for Texas were amalgamated with data maintained by the TMMSN. Records for manatees in the TMMSN database and the NMFS MMHSRP reflected manatee stranding events documented by the TMMSN, in coordination with USFWS. Data were validated and formatting was standardised for consistency across years (e.g., geographic coordinates were converted to decimal degrees).

Stranded marine mammal species identification was primarily determined by examining external morphological features or through genetic analysis of skin or bone samples through the National Oceanic and Atmospheric Administration (NOAA) Southeast Fisheries Science Center in Lafayette, Louisiana, U.S.A. (results obtained from P. Rosel, pers. comm.). A condition code was assigned to each stranded cetacean, indicating the state of decomposition at initial observation or report, based on *Marine Mammals Ashore: A Field Guide for Strandings* (Geraci, J.R. and Lounsbury, V.J., 2005) and the NOAA Marine Mammal Examiners Guide (NOAA, 2020). The NOAA Marine Mammal Examiners Guide has been modified throughout the years, with the most current iteration cited for reference. A stranded cetacean assigned code 1 was alive, code 2 was fresh-dead and in good condition, code 3 was in fair condition – moderately decomposed, but organs intact, code 4 was in poor condition with advanced decomposition and code 5 was mummified or skeletal remains. Sex of stranded animals was determined by external examination of the anogenital region, probing the genital region, and/or internal examination of the reproductive organs. Age class of stranded animals was recorded *in situ*, or estimated from

photographs or reporter feedback, based on physical features including body length, odontocete tooth condition (e.g., based on wear, if emerged), fetal folds and rostral hair. Total length of stranded cetaceans was determined by taking the straight-line measurement of whole intact bodies from the tip of the upper rostrum to the medial notch in the tail flukes. In 2007, a new morphological designation was added to distinguish ‘whole animal’ from ‘partial animal.’ A partial animal was defined as a stranded carcass that was not sufficiently intact for level A morphometric data (NOAA, 2020), and may have been missing significant portions of the body (e.g., head, tail flukes). Prior to 2007, most data records lacked the whole/partial animal designation. Stranded individuals lacking whole/partial designation, partial bodies and individuals with estimated lengths were excluded from body length analyses. Body length analyses were conducted for stranded bottlenose dolphins with known length of the confirmed full body. For body length analyses herein, we used the following established criteria to estimate age class for bottlenose dolphins in the GoM, calf: < 200cm (estimated < 2 years of age); subadult: ≥ 200cm to < 240cm (estimated ≥2 and < 10 years of age); adult: ≥240cm (estimated ≥ 10 years of age) (Herrman *et al.*, 2020; Schwacke *et al.*, 2009). We further classified fetuses and neonates as < 130cm. These parameters are considered estimates, rather than a precise index, due to variation in the literature and because growth rates can be influenced by several factors such as geographic location and sex (McFee *et al.*, 2012; McFee *et al.*, 2009; Read *et al.*, 1993).

Stranded cetaceans were examined for the presence or absence of potential HI, including healed and fresh injuries. Details surrounding stranding events were also evaluated to determine if HI potentially contributed to, or was involved in, the stranding (e.g., observed boat strike). Findings of HI were classified according to the NOAA Marine Mammal Examiners Guide as ‘yes’ if there were any signs or evidence of HI, ‘no’ if a stranded animal was examined and there was no indication of HI, and ‘could not be determined’ (CBD) if the stranded animal was not thoroughly examined, the stranded animal was too decomposed to make a determination, or the examiner did not feel confident in making a determination (NOAA, 2020). Prior to 1996, HI evaluation was not included on the standardised Level A datasheet and was not consistently recorded. Cases classified as ‘yes’ were further categorised based on HI type including ‘boat’, ‘shot’, ‘fishery’, and/or ‘other’. ‘Boat’ included collision with a marine vessel, blunt trauma from a boat hull and propeller and/or skeg wounds. ‘Shot’ included gunshot wounds and/or bullets. ‘Fishery’ included wounds indicative of fishing gear, fishing gear attached to the animal (e.g., net, line, pot, buoy, line with hook), or fishing gear ingested by the animal. ‘Other’ included mutilation, such as removal of the head or appendages with an instrument (excluding removal due to apparent scavenging), body sliced with an instrument such as a knife or other blade, entanglement in human-made debris (e.g., packing strap, steel cable), plastic ingestion, incidental take related to authorised activities (e.g., scientific research) and wounds from weapons other than firearms (e.g., arrow, harpoon).

## Data analysis

Statistical analyses focused primarily on bottlenose dolphin stranding events because other species did not individually yield sufficient sample sizes (< 40). In some instances, stranded species other than bottlenose dolphins were pooled together representing species that occur farther offshore than bottlenose dolphins. Odontocetes that could not be identified to at least the genus level were excluded from the pooled sample of other species because they could potentially have been bottlenose dolphins and skewed the data output. Sample size varied per statistical test due to incomplete records in some cases (e.g., unknown date, unknown sex, unknown length).

Pearson chi-square and Freeman-Tukey Deviate *post-hoc* tests were conducted for stranded bottlenose dolphins, and separately for other stranded species pooled together, for stranding event count data (Conover, 1980) including season, condition code and sex. Pearson chi-square and Freeman-Tukey Deviate *post-hoc* tests were conducted to analyse stranded bottlenose dolphin age class and HI classification. Pearson chi-square and Freeman-Tukey Deviate *post-hoc* tests were also conducted to analyse the seasonal timing of strandings, including all species combined, across TMMSN regions. The Freeman-Tukey Deviate z score decision rule was based on the critical value 0.95 and results were compared to an expected even distribution. A student’s two-sample t-test was conducted to examine full body length distribution by sex for bottlenose dolphins (McDonald,

J.H., 2014). Pearson chi-square tests, Freeman-Tukey Deviate tests, and the student's two-sample t-test were conducted in Microsoft Excel (2013).

Non-parametric probability density functions were plotted to illustrate the underlying distribution of continuous numeric variables. These density distribution plots, which are smoothed versions of histograms, were created using the ggplot2 package in R statistical software v. 4.0.5 (The R Foundation for Statistical Computing, 2019). Density plots were created to show temporal stranding trends across season, month and day of year for stranded bottlenose dolphins, and separately for other stranded species pooled together. Density plots were also created to show bottlenose dolphin temporal stranding trends based on TMMSN region, age class and body length relative to sex.

## Spatial analysis

To quantify spatial clustering of stranded bottlenose dolphin events, we followed the stock boundaries delineated by Maze-Foley *et al.* (2019) for use in quantifying human impacts to NMFS bottlenose dolphin stocks. The spatial boundaries for Texas bottlenose dolphin stocks consisted of eight polygons – 7 polygons represented bottlenose dolphin BSE stocks (Sabine Lake, Galveston Bay/East Bay/Trinity Bay, West Bay, Matagorda Bay/Tres Palacios Bay/Lavaca Bay, Copano Bay/Aransas Bay/San Antonio Bay/Redfish Bay/Espiritu Santo Bay, Nueces Bay/Corpus Christi Bay, and Laguna Madre) and 1 polygon represented the Western GoM Coastal Stock (Fig. 1). Due to a lack of long-term photo-identification and site fidelity data for bottlenose dolphins in Texas waters, we avoided the assumption that stranded individuals were members of the population NMFS assigned to specific stock management areas and considered the stock area of stranding location only as 'potential stock of origin'. Spatial analyses were conducted for stranded bottlenose dolphins only, due to the low sample size of other stranded species. However, geographic coordinates of other stranded species were plotted on individual maps for each family (excluding bottlenose dolphins) to explore spatial distribution trends (see Supplemental Information Fig. 2).

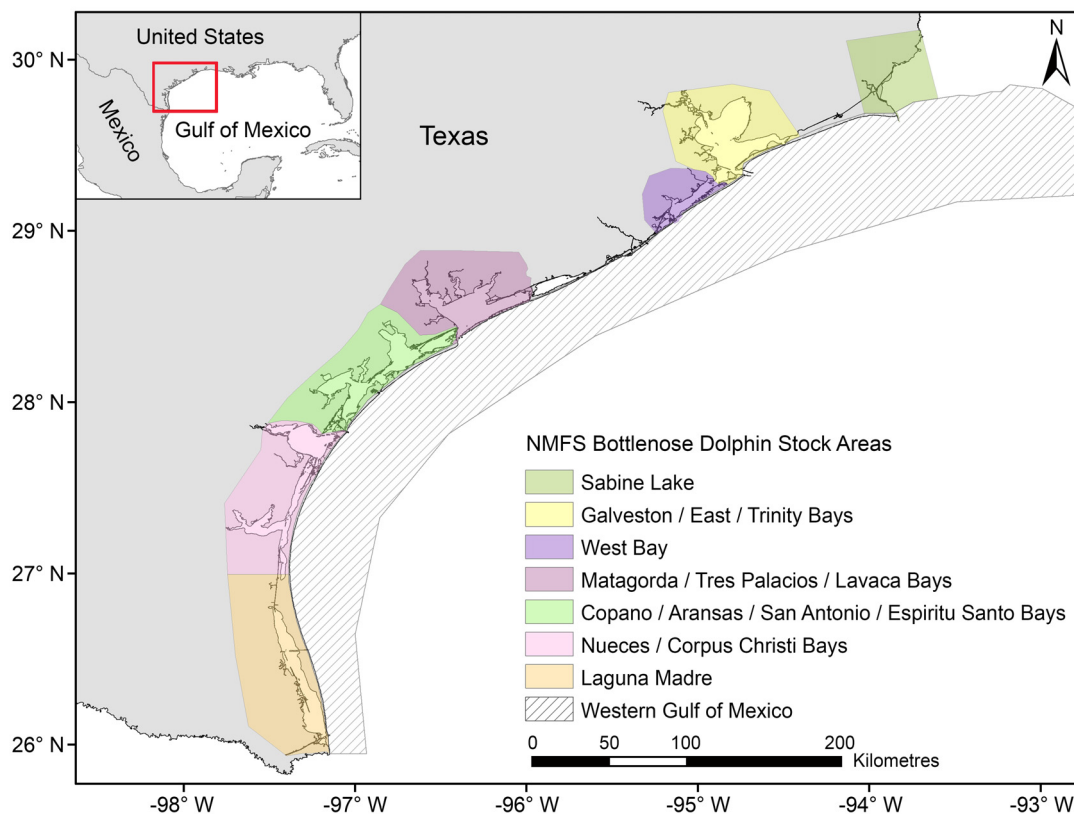


Fig. 1. Map of coastal Texas showing polygon areas for common bottlenose dolphin (*Tursiops truncatus*) bay, sound and estuary stocks and the Western Gulf of Mexico Coastal Stock delineated by the National Marine Fisheries Service (Maze-Foley *et al.*, 2019).



Spatial analyses were completed in the NAD 1983 (2011) Texas Centric Mapping System, Albers equal area projected coordinate system (ESRI, 2020). Bottlenose dolphin stranding location points were spatially joined to their respective NMFS stock polygons. The resulting groups of points associated with each stock polygon were subsequently used in the distance-weighted kernel density estimation (KDE) tool in the Spatial Analyst Package of ESRI ArcGIS Pro 2.7.1 (ESRI, 2020). Spatial KDE measures local spatial intensity (or clustering) of a point pattern, visualised by a continuous estimated surface density layer distributed through and between all points, modulated by a bandwidth (search radius) specified by the analyst. The bandwidth is a critical parameter of KDE; a bandwidth too large may overestimate the density, providing a generally uniform and uninformative visualisation, whereas a bandwidth too small may identify many individual events as peaks with no clear pattern of intensity (O’Sullivan and Unwin, 2010). Optimum bandwidth selection began with the computation of the ‘standard distance’ using the ESRI Standard Distance tool in the Spatial Statistics Package (ESRI, 2020). The standard distance (in meters) is a measure of point dispersion (ESRI, 2020). The optimum bandwidth was calculated following Fotheringham *et al.* (2000):

$$h_{opt} = [2/3n]^{1/4} \sigma$$

Where,

$h_{opt}$  = the optimal bandwidth

$n$  = the number of strandings in a given stock polygon

$\sigma$  = the standard distance described above

The KDE output cell size was set to 250m, and the area units were in km<sup>2</sup>. The KDE tool uses distance in a line-of-sight method to estimate density between points, so it is important to account for environmental barriers (e.g., a peninsula separating a point distribution) that would naturally influence point distribution; therefore, a detailed boundary shapefile for coastal Texas (TXDOT, 2018) was selected as a barrier to simulate the natural topographical features found in each stock polygon. Kernel density estimation surface rasters were created with heterogeneous values specific to the spatial join of each individual bottlenose dolphin stock polygon. Therefore, legend value classes are not uniform among stock polygon maps. The resulting surface density map units were classified into 4 breaks, and density estimates equal to zero were not visually represented with map symbology.

## RESULTS

### Species diversity

A total of 5,303 stranded marine mammals, including 19 odontocete species, 3 mysticete species and 1 sirenian species, were reported off the coast of Texas from 1980 through 2019 (Table 1). There were 5,281 single-stranding events involving one individual, 5 cow-calf events and 5 single-species mass-stranding events involving two to five individuals. Stranded species included 6 taxonomic families, including mysticetes from the balaenopterid family, odontocetes from the delphinid, kogiid, physeterid and ziphiid families, and sirenians from the trichechid family. Cow-calf strandings involved *T. truncatus* and *Kogia* species and mass stranding events involved *T. truncatus*, *Peponocephala electra* and *Mesoplodon* species. Most identified species were bottlenose dolphins, comprising nearly 94% ( $n = 4,976$ ) of all stranded individuals. The second most abundant species to strand was the pygmy sperm whale (*Kogia breviceps*) at just 0.7% ( $n = 36$ ). Species that stranded the least, with only one record per species, were the minke whale (*Balaenoptera acutorostrata*), short-finned pilot whale (*Globicephala macrorhynchus*), Fraser’s dolphin (*Lagenodelphis hosei*) and Blainville’s beaked whale (*Mesoplodon densirostris*).

### Temporal trends

Marine mammals stranded every year in Texas from 1980 through 2019 (Fig. 2 and Supplemental Information Fig. 1). Annual stranding events varied significantly, ranging from a minimum of 2 individuals in 1980 to a maximum of 297 individuals in 1994. Excluding years with outliers, based on the interquartile range (IQR) rule

Table 1

Species (grouped by taxonomic family), sex and age class of individual marine mammals stranded in Texas from 1980 through 2019. 'F' indicates female, 'M' indicates male, 'U' indicates unknown, 'C' indicates calf, 'S' indicates subadult, 'A' indicates adult and '-' indicates no record.

Species by family	Common Name	Sex				Age Class			Total	
		F	M	U	C	S	A	U	Count	%
<b>Balaenopteridae (0.09%)</b>										
<i>Balaenoptera acutorostrata</i>	Minke whale	1	–	–	–	–	–	1	1	0.02%
<i>Balaenoptera borealis</i>	Sei whale	–	1	1	–	–	–	2	2	0.04%
<i>Balaenoptera physalus</i>	Fin whale	1	1	–	–	–	–	2	2	0.04%
<b>Delphinidae (96.78%)</b>										
<i>Feresa attenuata</i>	Pygmy killer whale	4	2	2	–	1	1	6	8	0.15%
<i>Globicephala macrorhynchus</i>	Short-finned pilot whale	–	1	–	–	–	–	1	1	0.02%
<i>Grampus griseus</i>	Risso's dolphin	5	2	–	2	–	2	3	7	0.13%
<i>Lagenodelphis hosei</i>	Fraser's dolphin	1	–	–	–	–	–	1	1	0.02%
<i>Peponocephala electra</i>	Melon-headed whale	6	15	1	1	3	10	8	22	0.41%
<i>Pseudorca crassidens</i>	False killer whale	2	1	–	–	–	–	3	3	0.06%
<i>Stenella attenuata</i>	Pantropical spotted dolphin	7	7	–	1	–	2	11	14	0.26%
<i>Stenella clymene</i>	Clymene dolphin	8	10	1	–	1	3	15	19	0.36%
<i>Stenella coeruleoalba</i>	Striped dolphin	2	3	–	–	–	–	5	5	0.09%
<i>Stenella frontalis</i>	Atlantic spotted dolphin	2	6	3	–	–	–	11	11	0.21%
<i>Stenella longirostris</i>	Spinner dolphin	7	5	1	–	2	4	7	13	0.25%
<i>Steno bredanensis</i>	Rough-toothed dolphin	2	4	–	–	1	3	2	6	0.11%
<i>Tursiops truncatus</i>	Common bottlenose dolphin	1326	2185	1465	1013	282	975	2706	4976	93.83%
Unidentified Delphinid	Delphinid spp.	1	–	24	4	–	4	17	25	0.47%
Unidentified Stenella	Stenella spp.	6	7	8	–	–	1	20	21	0.40%
<b>Kogiidae (1.43%)</b>										
<i>Kogia breviceps</i>	Pygmy sperm whale	7	19	10	4	3	18	11	36	0.68%
<i>Kogia sima</i>	Dwarf sperm whale	9	12	1	3	4	6	9	22	0.41%
Unidentified Kogia	Kogia spp.	9	2	7	2	–	3	13	18	0.34%
<b>Physeteridae (0.21%)</b>										
<i>Physeter macrocephalus</i>	Sperm whale	4	3	4	1	3	1	6	11	0.21%
<b>Ziphiidae (0.19%)</b>										
<i>Mesoplodon densirostris</i>	Blainville's beaked whale	1	–	–	–	–	–	1	1	0.02%
<i>Mesoplodon europaeus</i>	Gervais' beaked whale	3	–	1	–	–	1	3	4	0.08%
<i>Ziphius cavirostris</i>	Cuvier's beaked whale	3	1	0	–	1	1	2	4	0.08%
Unidentified Mesoplodon	Mesoplodon spp.	–	–	1	–	–	–	1	1	0.02%
<b>Trichechidae (0.21%)</b>										
<i>Trichechus manatus</i>	West Indian manatee	2	8	1	–	–	1	10	11	0.21%
<b>Unknown (1.09%)</b>										
Unidentified mysticete		–	–	3	–	–	–	3	3	0.06%
Unidentified odontocete		–	–	2	–	–	–	2	2	0.04%
Unidentified		1	1	51	1	–	8	44	53	1.00%
<b>Total</b>		<b>1420</b>	<b>2296</b>	<b>1587</b>	<b>1032</b>	<b>301</b>	<b>1044</b>	<b>2926</b>	<b>5303</b>	<b>100%</b>

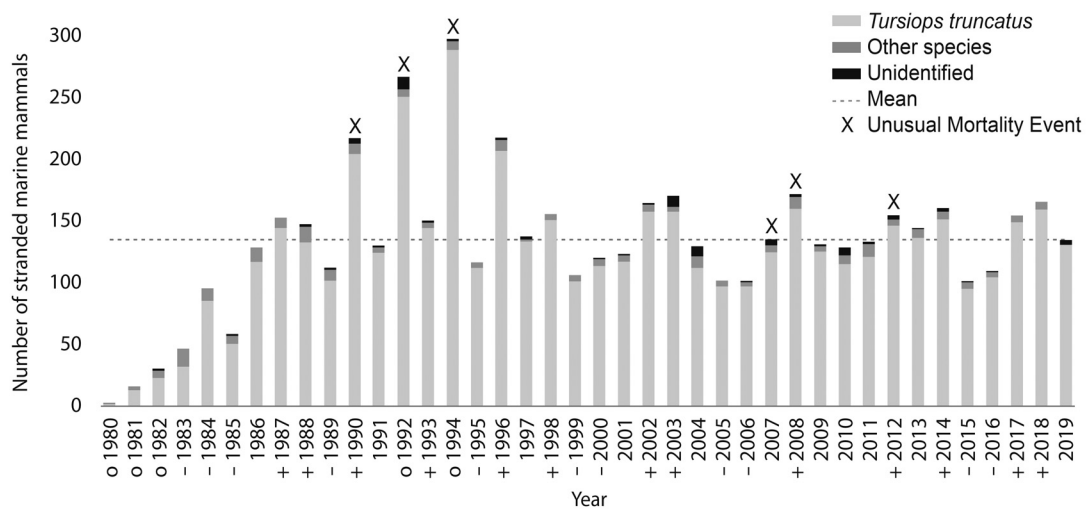


Fig. 2. Annual distribution of stranded common bottlenose dolphins (*Tursiops truncatus*), other species pooled together and unidentified species, reported in Texas from 1980 through 2019 ( $n = 5,303$ ). The mean line calculation excludes outliers. An 'o' symbol next to the year indicates an outlier. A '-' symbol next to the year indicates significantly fewer overall strandings than expected, and a '+' symbol indicates significantly more strandings than expected based on even distribution from Chi-square and Freeman-Tukey Deviate *post-hoc* tests.

(Tukey, J.W., 1977), the mean was 134 (SD  $\pm$  35.08) strandings per year. Marine mammal strandings occurred throughout the year, with seasonal variation in frequency. Analysis of bottlenose dolphins showed a clear peak in strandings from late winter to mid-spring with significantly more strandings reported in January, February, March and April (74% of bottlenose dolphin strandings) than expected ( $\chi^2 = 5,369.49$ ,  $n = 4,973$ ,  $df = 11$ ,  $p < 0.001$ ; Fig. 3A). Analysis of all other species pooled together (excluding bottlenose dolphins) showed significantly more strandings reported in the month of March, and significantly fewer strandings in the months of January, February and August than expected ( $\chi^2 = 8.98$ ,  $n = 244$ ,  $df = 11$ ,  $p < 0.01$ ). Strandings of species other than bottlenose dolphins had a more uniform distribution throughout the year and lacked the extreme multi-month seasonal peak observed in bottlenose dolphin stranding events (Fig. 3A).

All stranded species were combined to analyse broad seasonal distribution across TMMSN designated regions; results indicated a seasonal stranding peak during late winter to mid-spring across all regions with some variation (Fig. 3B). The southernmost region, Padre Island, had significantly higher stranding peaks than expected in November, February and March ( $\chi^2 = 134.74$ ,  $n = 294$ ,  $df = 11$ ,  $p < 0.001$ ). The Corpus Christi region had significantly higher stranding peaks in January, February and March ( $\chi^2 = 395.80$ ,  $n = 371$ ,  $df = 11$ ,  $p < 0.001$ ). The Port Aransas, Port O'Connor, and Galveston regions had higher stranding peaks in January, February, March and April (PA  $\chi^2 = 656.98$ ,  $n = 1199$ ,  $df = 11$ ,  $p < 0.001$ ; PO  $\chi^2 = 638.44$ ,  $n = 552$ ,  $df = 11$ ,  $p < 0.001$ ; GA  $\chi^2 = 2991.22$ ,  $n = 2309$ ,  $df = 11$ ,  $p < 0.001$ ). The Galveston region also had a peak in December. The northernmost region, Sabine Pass, had significantly higher stranding peaks in February, March and April ( $\chi^2 = 843.14$ ,  $n = 569$ ,  $df = 11$ ,  $p < 0.001$ ).

## Spatial trends

Analyses were not performed on the Sabine Lake Stock polygon due to the low number of strandings (Table 2). Estimated stranding density in the Western GoM Coastal Stock polygon was highest near Galveston Island, Port Aransas and Port Arthur (Fig. 4). The KDE surface density map for the Galveston Bay/East Bay/Trinity Bay Stock polygon indicated the highest estimated stranding density in the Galveston Ship Channel, and extending out into Bolivar Roads and toward the busy intersection of navigational waterways known as the Texas City Y. Smaller peaks of stranding point intensity were observed along the northern side of the Texas City Dike and near Kemah in upper Galveston Bay (Fig. 5A). Estimated stranding density in the West Bay Stock polygon was highest adjacent to San Luis Pass (Fig. 5B). Stranding density in the Matagorda Bay/Tres Palacios Bay/Lavaca Bay Stock polygon



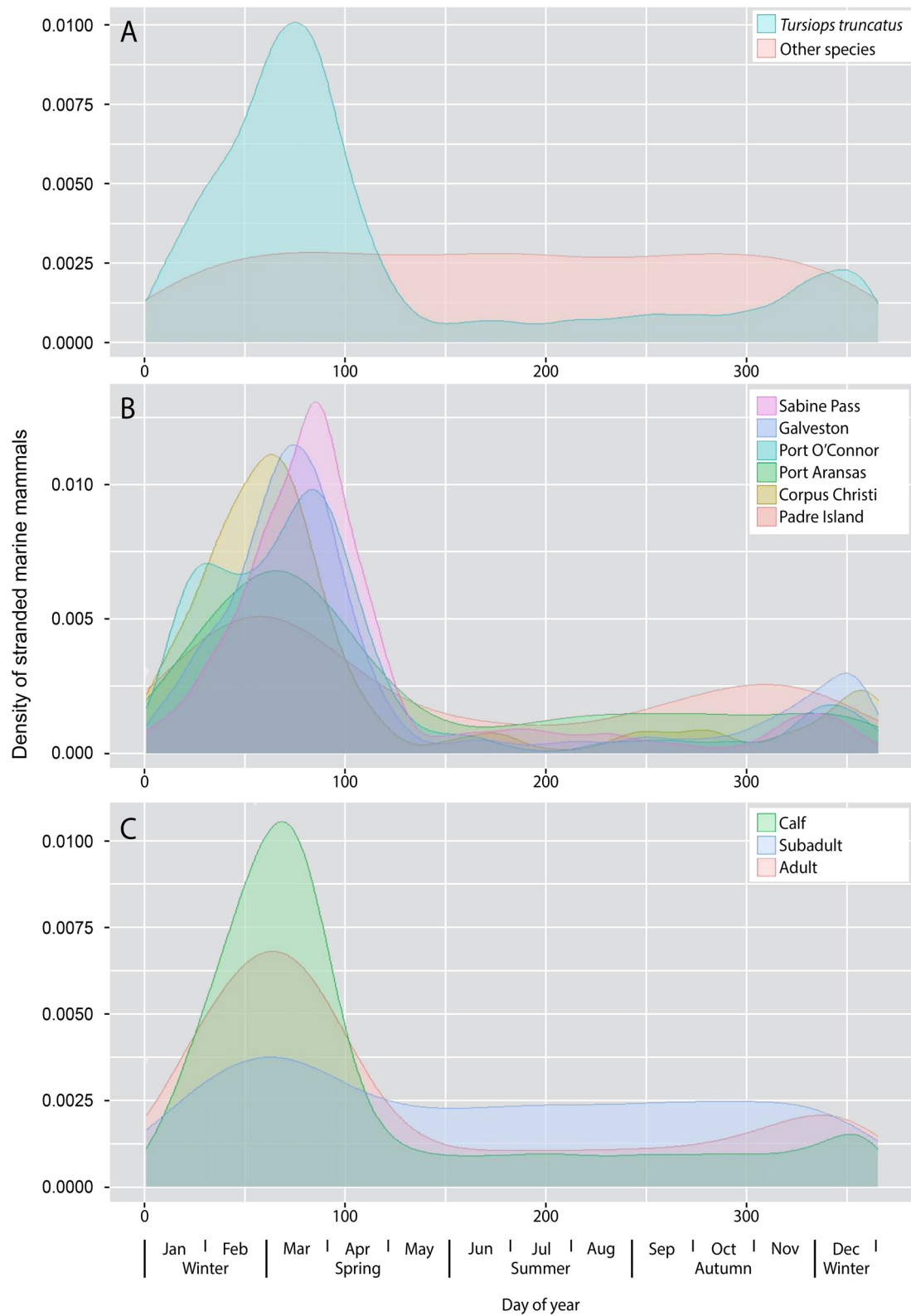


Fig. 3. Probability density functions of marine mammal strandings reported in Texas per season, month and day of year from 1980-2019 ( $n = 5,217$ ) (A). Probability density functions of stranded marine mammals per Texas Marine Mammal Stranding Network designated region based on season, month and day of year from 1980-2019 ( $n = 5,294$ ) (B). Probability density functions of stranded common bottlenose dolphin (*Tursiops truncatus*) age class reported in Texas per season, month and day of year from 1980-2019 ( $n = 2,270$ ) (C).

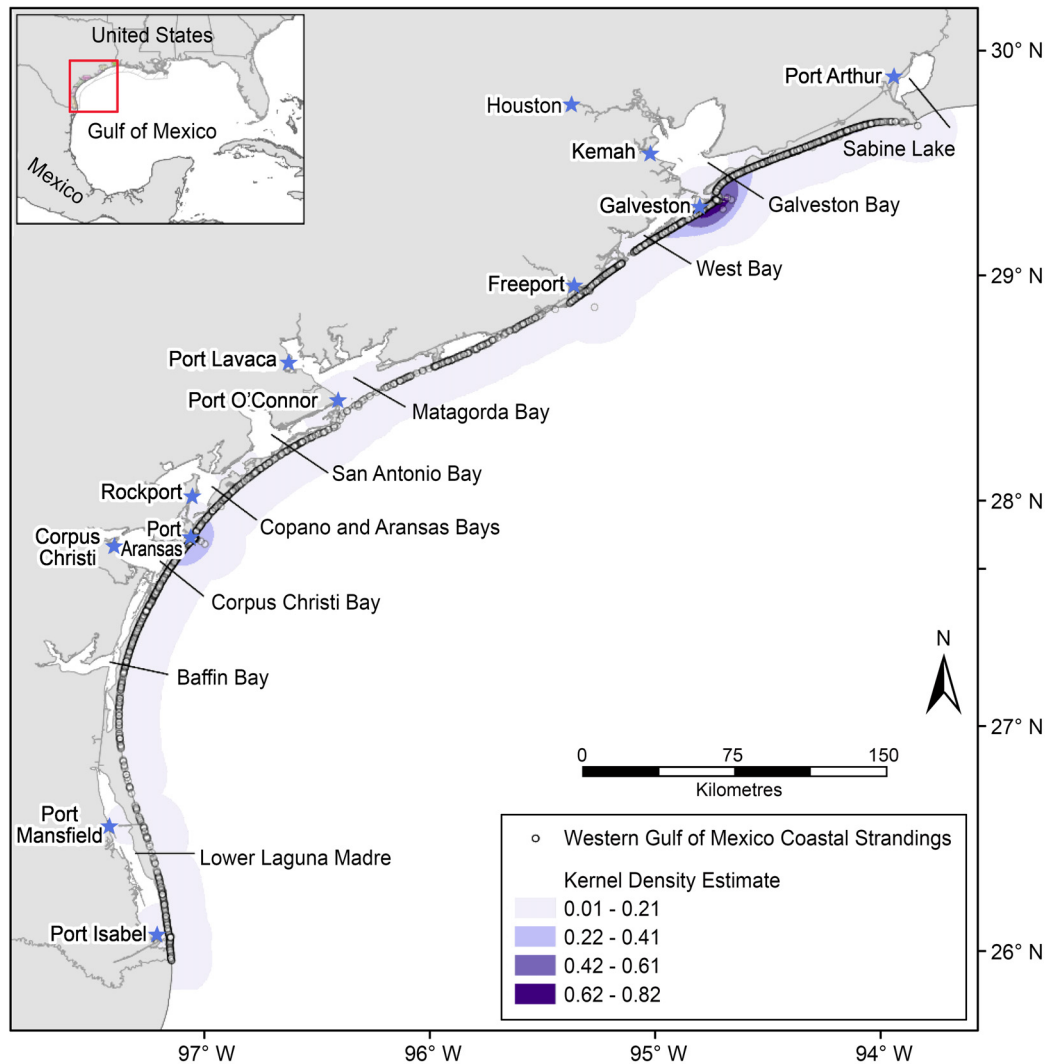


Fig. 4. Kernel density estimation of common bottlenose dolphin (*Tursiops truncatus*) strandings in Texas, within the National Marine Fisheries Service designated Western Gulf of Mexico Coastal Stock, from 1980–2019.

was estimated higher near the towns of Port O'Connor, Port Lavaca, Palacios and within the Pass Cavallo channel (Fig. 5C). Stranding density in the Copano Bay/Aransas Bay/San Antonio Bay/Redfish Bay/Espiritu Santo Bay Stock polygon was highest near Rockport and Fulton (Fig. 5D). The Nueces Bay/Corpus Christi Bay Stock polygon stranding density was highest near Port Aransas and moderate near Corpus Christi and Portland (Fig. 5E). The estimated stranding density for the Laguna Madre Stock polygon was highest near Port Isabel (Fig. 5F). The bottlenose dolphin stranding count, standard distance, optimum bandwidth, and peak estimated stranding density for each stock polygon are summarised in Table 2.

Although KDE analysis was not suitable for stranded species other than bottlenose dolphins, due to low sample size, a potential pattern emerged for the taxonomic families Physteridae and Ziphiidae. These deep diving species (Tyack *et al.*, 2006; Watkins *et al.*, 1993) appeared to strand more frequently in the southern portion of Texas where the continental shelf, and therefore deeper water, is closer to the barrier island shoreline (Supplemental Information Fig. 2).

### Condition code

Analysis of stranded bottlenose dolphins showed that moderate (code 3) to advanced (code 4) decomposition states were reported significantly more than expected ( $\chi^2 = 5,042.25$ ,  $n = 4,976$ ,  $df = 5$ ,  $p < 0.001$ ; Fig. 6). Live, fresh dead and skeletal remains of stranded bottlenose dolphins were reported significantly less than expected

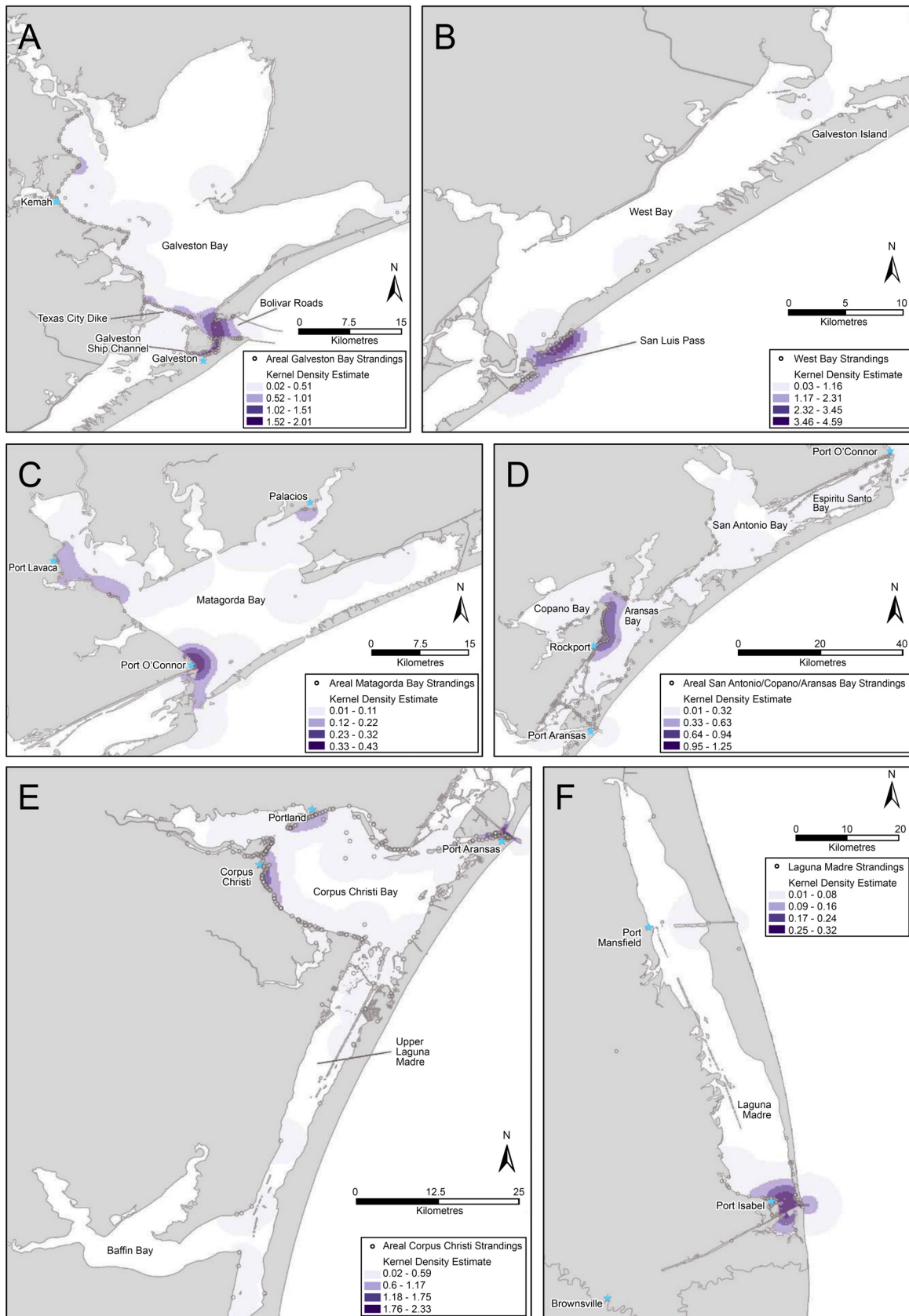


Fig. 5. Kernel density estimation of common bottlenose dolphin (*Tursiops truncatus*) strandings in Texas, within the National Marine Fisheries Service designated bay, sound and estuary stock polygons, from 1980-2019. Common bottlenose dolphin stock areas include Galveston Bay, East Bay and Trinity Bay (A), West Bay (B), Matagorda Bay, Tres Palacios Bay and Lavaca Bay (C), Copano Bay, Aransas Bay, San Antonio Bay, Redfish Bay and Espiritu Santo Bay (D), Nueces Bay and Corpus Christi Bay (E), and Laguna Madre (F). Legend value classes are not uniform among stock polygon maps.

Table 2

Summary of common bottlenose dolphin (*Tursiops truncatus*) stranding count, standard distance, optimum bandwidth, and peak density per National Marine Fisheries Service (NMFS) defined stock polygons in Texas. KDE indicates kernel density estimation.

NMFS Stock Polygon	Strandings (n)	Standard Distance ( $\sigma$ )	Optimum Bandwidth ( $h_{opt}$ )	Peak KDE ( $km^{-2}$ )
Sabine Lake	11	NA	NA	NA
Galveston Bay/East Bay/Trinity Bay	304	15,973.82	3,457	2.01
West Bay	99	7,783.19	2,230	4.59
Matagorda Bay/Tres Palacios Bay/Lavaca Bay	87	16,754.19	4,957	0.43
Copano Bay/Aransas Bay/San Antonio Bay/Redfish Bay/Espiritu Santo Bay	379	25,943.91	5,313	1.25
Nueces Bay/Corpus Christi Bay	329	17,013.87	3610	2.33
Laguna Madre	72	22,932.84	7,114	0.32
Western Gulf of Mexico Coastal Stock	3,625	155,813.00	18,145	0.82
No Stock Assignment	48	NA	NA	NA
Total	4,954			

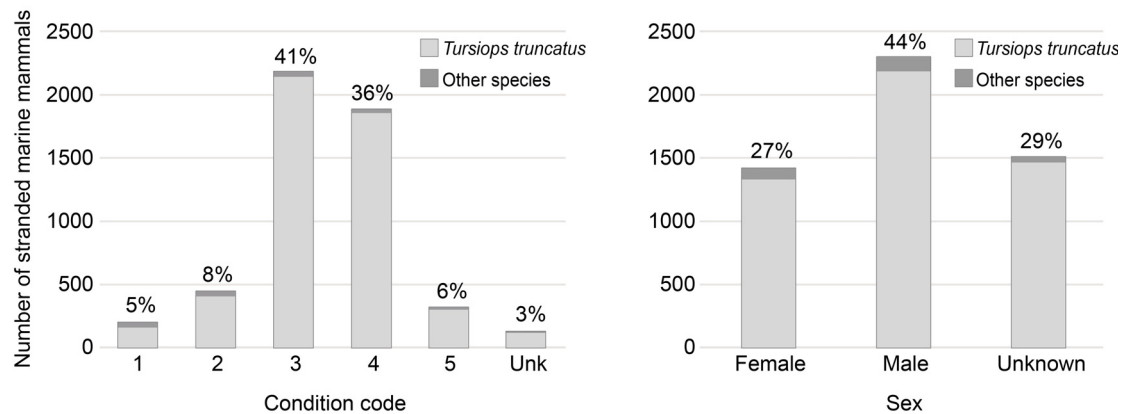


Fig. 6. Condition code (left) and sex (right) distribution of stranded common bottlenose dolphins (*Tursiops truncatus*), and other stranded marine mammal species pooled together (excluding unidentified species), reported in Texas from 1980 through 2019 ( $n = 5,222$ ).

( $\chi^2 = 5,042.25$ ,  $n = 4,976$ ,  $df = 5$ ,  $p < 0.001$ ; Fig. 6). Other species (excluding manatees), analysed separately from bottlenose dolphins, stranded alive significantly more than expected and with advanced decomposition or skeletal remains significantly less than expected ( $\chi^2 = 196.30$ ,  $n = 233$ ,  $df = 5$ ,  $p < 0.001$ ; Fig. 6).

### Sex, body length and age class

Sex was determined for 70% ( $n = 3,716$ ) of all stranded marine mammal individuals, and 30% ( $n = 1,587$ ) were undetermined due to advanced decomposition, scavenging or anthropogenic-related damage to the anogenital region, or inability to examine the carcass. Analysis of stranded bottlenose dolphin sex ratio showed a significant positive bias toward males, with 44% ( $n = 2,185$ ) males, 27% ( $n = 1,326$ ) females and 29% ( $n = 1,465$ ) categorised as unknown ( $\chi^2 = 256.35$ ,  $n = 4,976$ ,  $df = 2$ ,  $p < 0.001$ ; Fig. 6). Analysis of other stranded species, excluding bottlenose dolphins, showed no significant difference in sex ratio, with 45% ( $n = 110$ ) males and 37% ( $n = 92$ ) females ( $\chi^2 = 1.61$ ,  $n = 202$ ,  $df = 1$ ,  $p = 0.90$ ). However, there were significantly fewer cases of other stranded species categorised as unknown (18%,  $n = 44$ ) ( $\chi^2 = 28.39$ ,  $n = 246$ ,  $df = 2$ ,  $p < 0.001$ ; Fig. 6).

Age classification was made for 46% ( $n = 2,270$ ) of stranded bottlenose dolphins, and 54% ( $n = 2,706$ ) were unclassified. Calves (45%,  $n = 1,013$ ) and adults (43%,  $n = 975$ ) stranded significantly more than expected based on even distribution, and subadults (12%,  $n = 282$ ) stranded significantly less than expected ( $\chi^2 = 447.60$ ,  $n = 2,270$ ,  $df = 2$ ,  $p < 0.001$ ; Fig. 3C).

A total of 1,332 stranded bottlenose dolphins fit the criterion for body length analysis and ranged from 61cm to 326cm in length. From that sample, the total with known sex was 1,133, ranging from 61cm to 299cm. The combined mean length did not differ significantly based on sex alone (t-value = 1.34,  $n = 1,133$ ,  $df = 1,131$ ,  $p = 0.182$ ). When sex was tested per stranded bottlenose dolphin age class cohort, length did not vary significantly for calves (t-value = 1.49,  $n = 568$ ,  $df = 566$ ,  $p = 0.137$ ) or subadults (t-value = 0.65,  $n = 201$ ,  $df = 199$ ,  $p = 0.516$ ). However, stranded male adult mean length was significantly greater than stranded female adult mean length (t-value = 5.39,  $n = 364$ ,  $df = 362$ ,  $p = 1.29e-7$ ; Fig. 7). The sex to length ratio of stranded bottlenose dolphins had a bi-modal distribution, with two relatively similar peaks for both sexes (calf and adult cohorts), but with higher peaks for males – one peak at ~105cm and another peak at ~255cm length, and females with a consistent sex-bias in strandings from ~120-245cm length (Fig. 7). We further explored trends for very young stranded bottlenose dolphins, including fetuses and neonates ( $\leq 130$ cm,  $n = 366$ ), from the sample with known length and sex. There was a strong male bias with 66% ( $n = 242$ ) stranded young males and 34% ( $n = 124$ ) stranded young females ( $\chi^2 = 38.05$ ,  $n = 366$ ,  $df = 1$ ,  $p < 0.001$ ), with no significant variation in body length based on sex (t-value = 0.61,  $n = 366$ ,  $df = 364$ ,  $p = 0.542$ ).

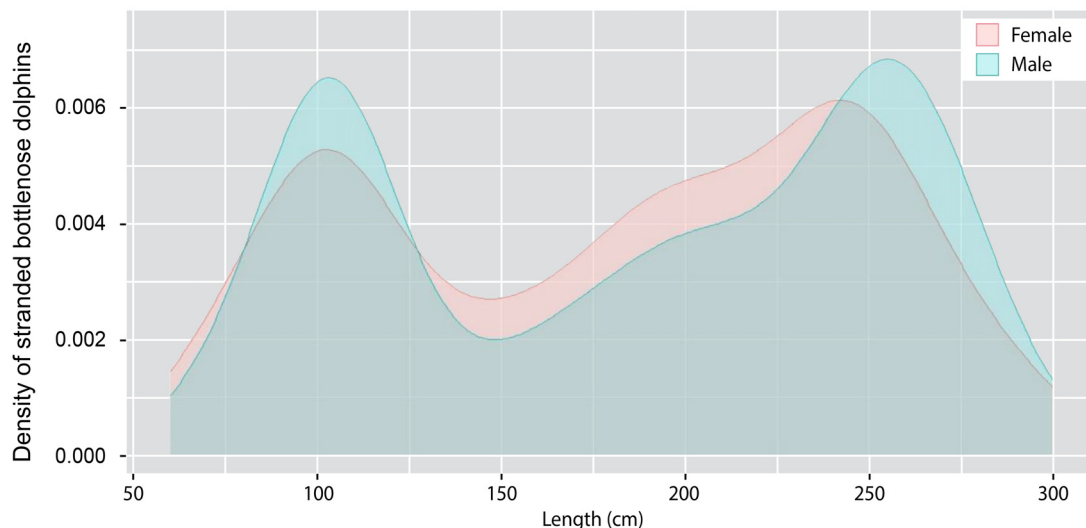


Fig. 7. Probability density functions of total body length by sex of stranded common bottlenose dolphins (*Tursiops truncatus*) reported in Texas from 2007 through 2019 ( $n = 1,133$ ).

## Human interaction

For all species combined (excluding manatees), HI categorisation of ‘yes’, ‘no’ or ‘CBD’ was made for 66% ( $n = 3,480$ ) of stranded marine mammals. Of the cases that included categorisation, 9% ( $n = 321$ ) were categorised as ‘yes’, 22% ( $n = 748$ ) as ‘no’, and 69% ( $n = 2,411$ ) as CBD. Thirty percent of cases, in which presence or absence of HI could be determined, were classified as ‘yes’ and involved six identified stranded species, including *B. acutorostrata* ( $n = 1$ ), *Feresa attenuata* ( $n = 1$ ), *K. breviceps* ( $n = 1$ ), *S. frontalis* ( $n = 1$ ), *S. longirostris* ( $n = 1$ ) and *T. truncatus* ( $n = 308$ ) as well as eight cases of unidentified stranded species. The documented HI cases included ‘boat’ (17%,  $n = 55$ ), ‘shot’ (5%,  $n = 17$ ), ‘fishery’ (29%,  $n = 95$ ) and ‘other’ (50%,  $n = 164$ ). Ten of these cases involved two different HI classifications for a single individual. The HI classification ‘other’ primarily included mutilation, straight line cuts and debris entanglement. One ‘other’ HI incident involved the intentional shooting, and subsequent death, of a free-swimming bottlenose dolphin by compound bow and arrow.

For bottlenose dolphins, HI categorisation of ‘yes’, ‘no’ or ‘CBD’ was made for 66% of stranding cases (Table 3). Stranded bottlenose dolphin HI cases were analysed within each NMFS delineated ( $\chi^2 = 21.70$ ,  $n = 8$ ,  $df = 7$ ,  $p < 0.001$ ; Table 3). There was a significantly higher proportion of HI cases (standardised by total number of regional bottlenose dolphin strandings inspected for HI) within the Matagorda Bay/Tres Palacios Bay/Lavaca Bay, Copano Bay/Aransas Bay/San Antonio Bay/Redfish Bay/Espiritu Santo Bay, and Laguna Madre Stock areas



Table 3  
Summary of stranded common bottlenose dolphin (*Tursiops truncatus*) human interaction (HI) cases within the National Marine Fisheries Service (NMFS) defined stock polygons in Texas.

NMFS Stock Polygon	Number of Bottlenose Dolphin HI Cases					Total Bottlenose Dolphin Strandings with HI Inspection	Proportion with HI
	Boat	Shot	Fishery	Other	Total		
Sabine Lake	0	0	0	1	1	7	14%
Galveston Bay/East Bay/Trinity Bay	10	0	11	11	32	237	14%
West Bay	0	0	1	3	4	67	6%
Matagorda Bay/Tres Palacios Bay/Lavaca Bay	1	0	2	4	7	34	21%
Copano Bay/Aransas Bay/San Antonio Bay/Redfish Bay/Espiritu Santo Bay	12	2	16	11	41	196	21%
Nueces Bay/Corpus Christi Bay	8	1	13	10	32	247	13%
Laguna Madre	1	2	7	4	14	54	26%
Western Gulf of Mexico Coastal	21	11	41	110	183	2,437	8%
No Stock Assignment	1	0	0	2	3	14	21%
Total	54	16	91	156	317	3,293	10%

and a significantly lower proportion of HI cases in the West Bay Stock area and Western GoM Coastal Stock. Fisheries interactions, including nets and monofilament line, accounted for 50% of HI cases recorded in Laguna Madre, the southernmost NMFS stock area in Texas.

## DISCUSSION

### Species diversity

The forty-year marine mammal stranding history on the Texas coast broadly reflects the biodiversity of free-ranging marine mammals in the northern GoM, with a few exceptions. Although Rice's (*Balaenoptera ricei*, Rosel *et al.*, 2021) and killer whales (*Orca orcinus*) occur in the GoM (Mullin and Fulling, 2004; Rosel and Wilcox, 2014; Soldevilla *et al.*, 2017), they are not represented in the 40-year TMMSN stranding record. Several baleen whales that are rarely observed in the GoM – the fin whale, minke whale and sei whale – have stranded in Texas, two of which stranded alive. The abundant representation of bottlenose dolphin strandings was expected considering that bottlenose dolphins are the most commonly occurring free-ranging marine mammal in shallow coastal Texas waters and BSEs (Würsig, 2017). Free-ranging Atlantic spotted dolphins occur primarily within the 200m isobath, along the upper slope and shallow offshore waters and are also represented in the stranding records. Although free-ranging manatees are not frequently reported in Texas waters, they do occur (Fertl, *et al.*, 2005; Hieb *et al.*, 2017), inhabiting shallow coastal areas where carcasses are more likely to reach shore. All other species reflected in the TMMSN records typically occur from the continental slope to deep oceanic water (> 200m deep) in the northern GoM (Würsig, 2017), where carcasses are less likely to be driven to shore by wind or surface water currents before sinking or being scavenged.

### Temporal trends

A number of factors potentially contributed to the annual variation of strandings observed in Texas. The increase in strandings after 1982 likely reflects improved survey effort and reporting awareness rather than an actual shift in strandings or mortality rates. This trend is reflected in other studies and corresponds with the establishment of marine mammal stranding networks in response to the United States Marine Mammal Protection Act of 1972 (Danil, *et al.*, 2010; Maldini *et al.*, 2005). Six separate UMEs occurred in Texas during the study period (1990, 1992, 1993–94, 2007, 2008 and 2011–12). Potential contributing factors in the 1990 UME included an unusual confluence of weather and anthropogenic habitat modifications that may have trapped the bottlenose dolphins in an inhospitable environment (Miller, 1992; Ronje *et al.*, 2018). Potential contributing factors in the 1992 UME

included low salinity, pesticide runoff and morbillivirus (Colbert *et al.*, 1999). The 1993–94 UME was attributed to morbillivirus (Lipscomb *et al.*, 1996; Litz *et al.*, 2014). Infectious disease may have contributed to the 2007 UME but could not be confirmed due to the advanced state of decomposition of carcasses (Litz *et al.*, 2014; Litz *et al.*, 2019). The 2008 UME co-occurred temporally and spatially with multiple harmful algal blooms (HABs) and low concentrations of toxins were detected in stranded bottlenose dolphin stomach contents, but etiology could not be confirmed (Fire *et al.*, 2011; Litz *et al.*, 2014). An infectious agent, such as the bacterium *Brucella*, was also suspected, given the high proportion of stranded perinate dolphins involved. The 2011–12 UME was attributed to biotoxin exposure (NOAA, 2012). The longitudinal record of stranding data reported here established an important baseline for GoM marine mammal stranding that improved NMFS capacity to detect UMEs and compare UME events to other areas of the GoM (e.g., Venn-Watson *et al.*, 2015). The frequency of strandings have remained relatively stable over the past 20 years with minor fluctuations that may reflect a natural cyclical pattern in mortality.

The consistent and marked seasonal peak in bottlenose dolphin stranding events each year in Texas from January through April is colloquially referred to as the ‘stranding season’. The reason for this seasonality is not well understood but may relate to calving season, given the significant number of calves that strand, colder ocean temperatures in winter, and/or seasonal fluctuations in oceanographic features (e.g., currents, upwelling/downwelling). Calf survival rates are not known for bottlenose dolphin populations in Texas waters. However, a study of the Indian River Lagoon (IRL) dolphin population, on the east coast of Florida, U.S.A., showed a high rate of mortality among young dolphins <5 years of age (Stolen and Barlow, 2003). Another study in Doubtful Sound, New Zealand estimated 33% of common bottlenose dolphin calves did not survive their first year, with most dying within the first month of life (Henderson *et al.*, 2014). Similarly, a study involving bottlenose dolphins in a captive setting showed that 21.6% of newborns similarly died within 30 days after birth (Venn-Watson *et al.*, 2011). Peak calf strandings in Texas during March may be consistent with a spring calving season in Texas, although bottlenose dolphins exhibit year-round calving cycles. This timing is slightly earlier than what Shane (1977) observed in wild populations that suggested calving season peaks during the late spring in the Aransas Pass area of Texas. However, those findings were based on a live population study and likely do not account for stranded neonates that died earlier in the year. The peak in stranding reports during March of the present study coincides with increased public attendance on Texas beaches during school-designated spring break vacation (typically in March). However, the seasonal stranding peaks were observed in all regions, even those with more remote beaches that are not common spring break destinations. Furthermore, significant peaks for bottlenose dolphin strandings were not observed during summer months when public attendance on beaches also increases relative to cooler months. Seasonal peaks in bottlenose dolphin strandings have been observed in other areas of the US, including the Mississippi Sound during spring (March–May), the IRL Estuary system during spring (March–May) and summer (June–August) and off South Carolina during spring (April–June) and autumn (October–December) (Mattson, *et al.*, 2006; McFee *et al.*, 2006; Pitchford *et al.*, 2013; Stolen *et al.*, 2007). The peak in Mississippi strandings, including perinates, during a single season more closely reflects the unimodal stranding distribution observed in Texas. The bi-seasonal stranding trends observed in South Carolina and the IRL, both on the Atlantic Coast, included a significant number of neonates, supporting a bi-modal reproductive cycle that is not observed in Texas (McFee *et al.*, 2006). These diverse breeding cycles and seasons among similar latitudes, but within different ocean basins, warrants more investigation.

The southernmost region, Padre Island, had an early initial-onset of strandings in November and the northernmost region, Sabine Pass, had a late initial-onset of strandings in February. These findings support a northerly progression of a spatiotemporal stranding peak with an early onset in southern Texas during November that tapers off in April at the Texas/Louisiana border.

## Spatial trends

Signals of spatial clustering may be useful to conservation managers interested in identifying mortality risk to protected populations, for studying the potential reasons for increased stranding occurrence in certain areas, and for assessing where scarce resources should be directed. While marine mammals stranded along the entire

coast of Texas, some spatial patterns emerged for bottlenose dolphins that may be important indicators for conservation and management. It is possible that higher reports of strandings in discrete areas may signal higher mortality rates. However, the spatial clustering of stranded bottlenose dolphins is likely a function of 1) free-ranging bottlenose dolphin abundance and distribution, 2) human population density in associated counties, 3) physical oceanographic and environmental features (e.g., currents, wind) that influence drift, or more likely, 4) a combination of factors.

In the absence of long-term photo-identification data confirming the site fidelity of stranded bottlenose dolphins, our confidence in assigning stranded bottlenose dolphins to a specific NMFS stock remains guarded. There is evidence that some dolphins on the Texas Gulf coast exhibit transient behaviour (Gruber 1981; Maze and Würsig 1999; Ronje *et al.*, 2020). It is possible some dolphin strandings that were joined to the NMFS stock polygons in this study were migrating from some other area, were transients, or were part of an adjacent stock population. However, estuarine bottlenose dolphins have limited home ranges and show high site fidelity to specific embayments (Maze and Würsig 1999; Shane 1980; Wells *et al.*, 2017; Würsig and Lynn 1996). Kernel density estimates for stranded bottlenose dolphins in all stock polygons were higher near areas of concentrated human population in coastal Texas. Greater human population density may be responsible for some of the higher reporting rates in those areas because more people frequent the beaches where strandings may occur. However, areas with high human population density are also thought to contain features that may attract dolphins. For example, deep navigational channels are often characterised by stratified salinity, steep sides and narrow egress points, all of which likely serve as prey funnels for dolphins and such areas are well known for having high concentrations of bottlenose dolphins in coastal Texas (Leatherwood and Reeves, 1983; Maze and Würsig, 1999; Moreno and Mathews, 2018); such areas may therefore have a higher number of corresponding mortality events due to natural causes, or other factors associated with coastal cities such as anthropogenic disturbance from recreational and commercial fisheries, ship strikes, habitat modification, destruction, or pollution (e.g., oil spills). Texas refineries have the largest operable capacity of crude oil in the U.S. (EIA, 2021), and localised chemical spills occur periodically into coastal waters (NOAA, 2021). Additionally, seafood consumption advisories are regularly posted by the Texas Department of State Health Services, indicating the potential for toxic bioaccumulation in fishes (TDSHS, 2021), a primary prey resource for bottlenose dolphins.

### Condition code

The majority of bottlenose dolphin stranding events involved carcasses with moderate to advanced decomposition that likely reflects the amount of time between death and stranding on shore, the amount of time between stranding and detection of the carcass, and/or environmental conditions that can accelerate decomposition (e.g., water and air temperature, cloud cover). Although sample collection for some analyses were still possible in some cases, determining cause of death and identifying potential HI becomes more difficult when a carcass decomposes. The TMMSN has initiated several improved reporting and response measures for live animal response and dead animal recovery, including city- and state-wide educational outreach. It is unclear why the statistical analysis indicated pelagic species were reported alive more than expected. One potential explanation is that distant offshore marine mammal carcasses may be more likely to sink or be preyed upon before reaching shore, whereas a live animal closer to shore may strand before it dies or is preyed upon.

### Sex, body length and age class

The male sex bias observed in the present study has also been documented in stranded bottlenose dolphins in the Mississippi Sound region (Mattson *et al.*, 2006), and *Tursiops* sp. in Western Australia (Groom and Coughran, 2012). Male sex bias was also observed in stranded Indo-Pacific humpback dolphins (*Sousa chinensis*) off Hong Kong, however, male carcasses tested several times higher than females for concentrations of organochlorine that may have contributed to the higher number of male strandings (Jefferson *et al.*, 2006). In Texas, the significant number of young stranded bottlenose dolphin males suggests a greater number of males were born in our sample, which contributes to the overall male-bias of strandings (assuming equal survivability of males and females at birth). Sex ratios at birth in certain populations of animals may fluctuate in response to different

selection pressures (Gellatly, 2019), which may explain why more fetal and neonate males stranded. Positive male bias of stranded bottlenose dolphins may also potentially reflect differences in sex-based ranging patterns (Scott *et al.*, 1990), inter-sex competition, sex-biased mortality, physiological characteristics or drift characteristics.

Sexual dimorphism was observed in stranded bottlenose dolphin adult body lengths, but not in calf or subadult body lengths. The observed sexual dimorphism, in which adult males were longer than adult females, has also been described in bottlenose dolphins on the west coast of Florida (Read *et al.*, 1993) and in southern Brazil (Venuto *et al.*, 2020). Read *et al.* (1993) found that free-ranging male bottlenose dolphins in Sarasota Bay continued to grow after female dolphins had generally reached asymptotic length, and hypothesised that the additional investment of energy in male dolphins was likely a reproductive strategy, but with a potential trade-off in longevity. Stolen, M.K. and Barlow (2003) estimated lower survival rates for male bottlenose dolphins in the IRL, based on stranding data, with the largest difference relative to females at the age of 15 years. Females may be able to offload accumulated contaminants to their offspring (Wells *et al.*, 2005, Yordy *et al.*, 2010), potentially increasing female probability of survival after reaching sexual maturity. Stranded female bottlenose dolphins in Texas waters have also demonstrated a higher rate of growth decay than males (Neuenhoff *et al.*, 2011) and growth rate differences between the sexes may reflect divergent reproductive strategies, which may drive sexual dimorphism in adulthood (Read *et al.*, 1993).

## Human interaction

Evidence of HI in 30% of stranded marine mammal cases, in which presence or absence of HI could be determined, is consistent with research in South Carolina showing approximately 25% of stranded bottlenose dolphins exhibited signs of HI, primarily attributed to crab pot entanglement (McFee *et al.*, 2006). Understanding the prevalence, locations, and nature of HI can provide a solid foundation for mitigation efforts. Data can guide regional educational outreach and broader development of response techniques for live animals. For example, the high incidence of fisheries-related HI cases in the Laguna Madre Stock area may benefit from increased localised public outreach efforts relating to derelict fishing gear. In general, HI is likely underestimated given the cryptic nature of the evidence in some cases (e.g., fishing line impressions may go undetected), and the high rate of moderate to advanced decomposition making detection difficult. However, HI data should also be interpreted with caution because recording methods have varied over time and evidence of HI does not necessarily represent the cause of, or contribution to, stranding or mortality.

Documentation of marine mammal mortality, both naturally occurring and human-related, is negatively biased due to a number of potential contributing factors including drift, sinking, scavenging at sea and natural removal from beaches due to tide and wave action (Moore *et al.*, 2020). One study of a well-known population of bottlenose dolphins in Sarasota Bay, Florida estimated carcass recovery rate at 33% (Wells *et al.*, 2015). Another study of inshore bottlenose dolphins in California estimated that 25% of carcasses were recovered (Carretta *et al.*, 2016) and rates are likely lower for pelagic marine mammal species that occur offshore. A drift study off the coast of France showed that only 8% of cetacean carcasses, released from vessels at a mean of 41km ( $\pm$  31.5km) from shore, were later found stranded on beaches (Peltier *et al.*, 2012). Stranding location of dead marine mammals may not always reflect the area of origin, due to the physical influences of currents and wind, and therefore may not serve as reliable proxies of nearby source populations. Additionally, survey effort may strongly influence detection probability of stranded carcasses, particularly in areas where human density is typically sparse (Pitchford *et al.*, 2018). Although we do not know the full extent of marine mammal mortality in Texas waters, it is clear that marine mammals consistently strand every year, with a seasonal peak, from late winter to mid-spring, and involve primarily bottlenose dolphin single-individual stranding events.

## CONCLUSIONS

This longitudinal study provides a comprehensive overview of marine mammal stranding patterns in Texas and serves as a resource for stranding investigators and Gulf-wide natural resource managers. These results contribute to our knowledge of marine mammal species, especially regarding common bottlenose dolphins, that occur off Texas in the GoM. Potential state-wide and regional bottlenose dolphin stranding distribution hotspots were

identified near areas of high human density and deep channels and passes, likely due to a combination of improved reporting and human-engineered features that attract free-ranging bottlenose dolphins. Data substantiated a peak bottlenose dolphin stranding season during the late winter to mid-spring. These findings are useful for determining when and where to divert limited resources for stranding surveys and response, wild population photo-identification monitoring surveys, and public education and outreach efforts. Rapid response to live stranded marine mammals may improve survival probabilities for ill, injured or out of habitat cases and timely response to dead stranded marine mammals may increase viable tissue collection for improved diagnostic capabilities. At a minimum, the spatiotemporal analyses provide insight to narrow research foci into potential factors affecting stranding distribution, and these results warrant further investigation by focusing on statistical modeling of environmental, anthropogenic, physiographic, and biological factors. Modelling ecosystem effects on carcass drift may also help estimate origin of death, to relate back to source populations. Bottlenose dolphin free-ranging population and photo-identification surveys will build capacity for long-term comparisons and provide a contextual framework for interpreting morbidity and mortality data obtained during stranding response, particularly relating to NMFS bottlenose dolphin stock assignment. Individual sighting histories can be paired with dead dolphin data for a better understanding of population level effects in a fluctuating environment, especially useful during die-off and catastrophic events. The human interaction analysis highlighted areas of particular concern and the Laguna Madre area may benefit from increased localised mitigation and outreach efforts relating to derelict fishing gear. Further investigation is needed to better understand contributing factors to the stranded bottlenose dolphin male-bias, and how disease, environmental perturbations, and HI relate to mortality. This work highlights the value of data garnered through consistent, long-term stranding response and the importance of continued funding support for marine mammal stranding networks.

## ACKNOWLEDGMENTS

This work would not have been possible without the dedication of TMMSN staff and volunteers over the past 40 years. We thank the TMMSN co-founders and board of directors for their guidance and support of the organisation throughout the years. We thank the many state and regional coordinators, with special recognition of Tony Amos and Lea Walker, both of whom devoted decades of service to the TMMSN. We are incredibly grateful for the time and effort put forth by TMMSN veterinary consultants. We thank the countless local, state and federal agencies and conservation organisations that have assisted with reporting and response of both dead and live marine mammal stranding events. We thank the NOAA MMHSRP Southeast Regional Office administrators, regional coordinators and response coordinators for their contributions to response and processing of stranding data. Thanks to the NMFS Southeast Fisheries Science Center for providing the GoM bottlenose dolphin stock polygons for spatial analyses. As a non-profit, the stranding program at TMMSN has remained active for over 40 years due to the financial support from generous donors as well as the John H. Prescott Marine Mammal Rescue Assistance Grant Program (since 2001). We also thank SeaWorld of Texas and the SeaWorld & Busch Gardens Conservation Fund for financial support.

## REFERENCES

- Bowen, W.D. 1997. Role of marine mammals in aquatic ecosystems. *Mar. Ecol. Prog. Ser.* 158: 267–74. [Available at: <https://doi.org/10.3354/meps158267>].
- Colbert, A.A., Scott, G., Fulton, M., Wirth, E., Daugomah, J., Key, P., Strozier, E. and Galloway, S. 1999. Investigation of unusual mortalities of bottlenose dolphins along the mid-Texas coastal bay ecosystem during 1992. NOAA Technical Report NMFS 147. Charleston, SC. 23pp.
- Conover, W.J. *Practical Nonparametric Statistics*. 2 ed. Vol. 94. Wiley. 512pp.
- Dani, K., Chivers, S.J., Henshaw, M.D., Thieleking, J.L., Daniels, R. and St Leger, J.A. 2010. Cetacean strandings in San Diego County, California, USA: 1851–2008. *J. Cetacean Res. Manage.* 11(2): 163–84.
- Davis, R.A. 2017. Sediments of the Gulf of Mexico. pp.165–215. *In*: Ward, C.H. (eds). *Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill*. Springer Open, New York.
- EIA. 2021. U.S. Energy Information Administration. Oil and petroleum products explained. [<https://www.eia.gov/energyexplained/oil-and-petroleum-products/refining-crude-oil-refinery-rankings.php>, accessed 30 August 2021].
- ESRI. 2020. Environmental Research Systems Institute. ArcGIS Pro 2.7.1. Redlands, CA, USA.
- Fernandez, S. and Hohn, A.A. 1998. Age, growth and calving season of bottlenose dolphins (*Tursiops truncatus*) off coastal Texas. *Fish. Bull.* 96(2): 357–65.



- Fertl, D., Schiro, A., Regan, G., Beck, C.A., Adimey, N., Price-May, L., Amos, A., Worthy, G.A. and Crossland, R. 2005. 2005. Manatee occurrence in the northern Gulf of Mexico, west of Florida. *Gulf. Caribb. Res* 17(1): 69–94.
- Fire, S.E., Wang, Z., Byrd, M., Whitehead, H.R., Paternoster, J. and Morton, S.L. 2011. Co-occurrence of multiple classes of harmful algal toxins in bottlenose dolphins (*Tursiops truncatus*) stranding during an unusual mortality event in Texas, USA. *Harmful. Algae* 10: 330–6. [Available at: <https://doi.org/10.1016/j.hal.2010.12.001>].
- Fotheringham, A.S., Brunson, C. and Charlton, M. 2000. *Quantitative geography: perspectives on spatial data analysis*. Sage, London.
- Gedamke, J. and Robinson, S.M. 2010. Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30–80°E) in January–February 2006. *Deep-Sea Res. II* 57: 968–81.
- Gellatly, C. 2019. The global male-bias in sex ratio at birth is sustained by the sex ratio genotypes of replacement offspring. *Genetica* 147(3): 249–58. [Available at: <https://doi.org/10.1007/s10709-019-00074-2>].
- Geraci, J.R. and Lounsbury, V.J. 2005. *Marine Mammals Ashore: a Field Guide for Strandings*. 2nd ed. National Aquarium in Baltimore, Baltimore, MD. 371pp.
- Groom, C.J. and Coughran, D.K. 2012. Three decades of cetacean strandings in Western Australia: 1981 to 2010. *J. Roy. Soc. Western Australia* 95: 63–76.
- Gruber, J.A. 1981. Ecology of the Atlantic bottlenose dolphin *Tursiops truncatus* in the Pass Cavalla area of Matagorda Bay. Master's thesis. Texas A&M University. 182pp.
- Henderson, S.D., Dawson, S.M., Currey, R.J., Lusseau, D. and Schneider, K. 2014. Reproduction, birth seasonality, and calf survival of bottlenose dolphins in Doubtful Sound, New Zealand. *Mar. Mamm. Sci.* 30(3): 1067–80. [Available at: <https://doi.org/10.1111/mms.12109>].
- Herrman, J.M., Morey, J.S., Takeshita, R., De Guise, S., Wells, R.S., McFee, W., Speakman, T., Townsend, F., Smith, C.R. and Rowles, T. 2020. Age determination of common bottlenose dolphins (*Tursiops truncatus*) using dental radiography pulp: tooth area ratio measurements. *PLoS One* 15(11): e0242273. [Available at: <https://doi.org/10.1371/journal.pone.0242273>].
- Hieb, E.E., Carmichael, R.H., Aven, A., Nelson-Seely, C. and Taylor, N. 2017. Sighting demographics of the West Indian manatee *Trichechus manatus* in the north-central Gulf of Mexico supported by citizen-sourced data. *Endanger. Species Res.* 32: 321–32. [Available at: <https://doi.org/10.3354/esr00817>].
- Jefferson, T.A., Hung, S.K. and Lam, P.K.S. 2006. Strandings, mortality and morbidity of Indo-Pacific humpback dolphins in Hong Kong, with emphasis on the role of organochlorine contaminants. *J. Cetacean Res. Manage.* 8(2): 181–93.
- Leatherwood, S. and Reeves, R.R. 1983. Abundance of bottlenose dolphins in Corpus Christi Bay and coastal southern Texas. *Con. Mar. Sci.* 26: 179–99.
- Leeney, R.H., Amies, R., Broderick, A.C., Witt, M.J., Loveridge, J. and Doyle, J. 2008. Spatio-temporal analysis of cetacean strandings and bycatch in a UK fisheries hotspot. *Biodiv. Conserv.* 17: 2,323–38. [Available at: <https://doi.org/10.1007/s10531-008-9377-5>].
- Lipscomb, T.P., Kennedy, S., Moffett, D., Krafft, A., Klauberg, B.A., Lichy, J.H., Regan, G.T., Worthy, G.A.J. and Taubenberger, J.K. 1996. Morbilliviral epizootic in bottlenose dolphins of the Gulf of Mexico. *J. Vet. Diag. Invest.* 8: 283–90. [Available at: <https://doi.org/10.1177/104063879600800302>].
- Litz, J.A., Baran, M.A., Bowen-Stevens, S.R., Carmichael, R.H., Colegrove, K.M., Garrison, L.P., Fire, S.E., Fougères, E.M., Hardy, R., Holmes, S., Jones, W., Mase-Guthrie, B.E., Odell, D.K., Rosel, P.E., Saliki, J.T., Shannon, D.K., Shippee, S.F., Smith, S.M., Stratton, E.M., Tumlin, M.C., Whitehead, H.R., Worthy, G.A.J. and Rowles, T.K. 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. *Dis. Aquat. Organ.* 112(2): 161–75. [Available at: <https://doi.org/10.3354/dao02807>].
- Litz, J.A., Ronje, E.I., Whitehead, H.R. and Garrison, L.P. 2019. Updated abundance estimates for common bottlenose dolphins (*Tursiops truncatus*) inhabiting West Bay, Texas. *Aquat. Conserv.* 29(11): 1959–70.
- Lynn, S.K. and Würsig, B. 2002. Summer movement patterns of bottlenose dolphins in a Texas Bay. *Gulf of Mexico Science* 20(1): 25–37. [Available at: <https://aquila.usm.edu/goms/vol20/iss1/3/>].
- Maldini, D., Mazzucca, L. and Atkinson, S. 2005. Odontocete stranding patterns in the main Hawaiian islands (1937–2002): how do they compare with live animal surveys? *Pacific Science* 59(1): 55–67. [Available at: <https://doi.org/10.1353/psc.2005.0009>].
- Mattson, M., Mullin, K., Ingram, G. and Hoggard, W. 2006. Age structure and growth of the bottlenose dolphin (*Tursiops truncatus*) from strandings in the Mississippi Sound region of the north-central Gulf of Mexico from 1986 to 2003. *Mar. Mamm. Sci.* 22: 654–66. [Available at: <https://doi.org/10.1111/j.1748-7692.2006.00057.x>].
- Maze-Foley, K., Byrd, B.L., Horstman, S.C. and Powell, J.R. 2019. Analysis of stranding data to support estimates of mortality and serious injury in common bottlenose dolphin (*Tursiops truncatus truncatus*) stock assessments for the Atlantic Ocean and Gulf of Mexico. 51. [Available at: <https://doi.org/10.25923/jt1x-jv75>].
- Maze, K.S. and Würsig, B. 1999. Bottlenose dolphins of San Luis Pass, Texas: occurrence patterns, site fidelity, and habitat use. *Aquat. Mamm.* 25(2): 91–103.
- McDonald, J.H. 2014. Handbook of Biological Statistics (3rd ed.). <http://www.biostathandbook.com/chiind.html>, Updated March 15, 2018, accessed 3 November 2020.
- McFee, W.E., Adams, J.D., Fair, P.A. and Bossart, G.D. 2012. Age Distribution and Growth of Two Bottlenose Dolphin (*Tursiops truncatus*) Populations from Capture-Release Studies in the Southeastern United States. *Aquat. Mamm.* 38(1): 17–30. [Available at: <https://doi.org/10.1578/AM.38.1.2012.17>].
- McFee, W.E., Hopkins-Murphy, S.R. and Schwacke, L.H. 2006. Trends in bottlenose dolphin (*Tursiops truncatus*) strandings in South Carolina, USA, 1997-2003: implications for the Southern North Carolina and South Carolina Management Units. *J. Cetacean Res. Manage.* 8(2): 195–201.
- McFee, W.E., Schwacke, J.H., Stolen, M.K., Mullin, K.D. and Schwacke, L.H. 2009. Investigation of growth phases for bottlenose dolphins using a Bayesian modeling approach. *Mar. Mamm. Sci.* 26(1): 67–85. [Available at: <https://doi.org/10.1111/j.1748-7692.2009.00306.x>].

- McGuire, T.L., Shelden, K.E., Himes Boor, G.K., Stephens, A.D., McClung, J.R., Garner, C., Goertz, C.E., Burek-Huntington, K.A., O’Corry-Crowe, G. and Wright, B. 2020. Patterns of mortality in endangered Cook Inlet beluga whales: insights from pairing a long-term photo-identification study with stranding records. *Mar. Mamm. Sci.* 37(3). [Available at: <https://doi.org/10.1111/mms.12766>].
- Miller, W.G. 1992. An investigation of bottlenose dolphin (*Tursiops truncatus*) deaths in East Matagorda Bay, Texas, January 1990. *Fish. Bull.* 90(4): 791–97.
- MMC. 2018. The Marine Mammal Protection Act of 1972 as Amended 2018. Marine Mammal Commission. [Available at: [https://www.mmc.gov/wp-content/uploads/MMPA\\_March2019.pdf](https://www.mmc.gov/wp-content/uploads/MMPA_March2019.pdf), accessed 28 April 2022].
- Moore, M.J., Mitchell, G.H., Rowles, T.K. and Early, G. 2020. Dead cetacean? Beach, bloat, float, sink. *Front. Mar. Sci.* 7: 333. [Available at: <https://doi.org/10.3389/fmars.2020.00333>].
- Moreno, P. and Mathews, M. 2018. Identifying foraging hotspots of bottlenose dolphins in a highly dynamic system: a method to enhance conservation in estuaries. *Aquat. Mamm.* 44(6): 694–710. [Available at: <https://doi.org/10.1578/AM.44.6.2018.694>].
- Mullin, K.D. and Fulling, G.L. 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996–2001. *Mar. Mamm. Sci.* 20: 787–807. [Available at: <https://doi.org/10.1111/j.1748-7692.2004.tb01193.x>].
- Neuenhoff, R.D., Cowan, D.F., Whitehead, H. and Marshall, C.D. 2011. Prenatal data impacts common bottlenose dolphin (*Tursiops truncatus*) growth parameters estimated by length-at-age curves. *Mar. Mamm. Sci.* 27(1): 195–216. [Available at: <https://doi.org/10.1111/j.1748-7692.2010.00394.x>].
- NMFS. 2005. Bottlenose dolphin (*Tursiops truncatus*): Northern Gulf of Mexico coastal stocks. National Marine Fisheries Service. [Available at: <http://www.nefsc.noaa.gov/nef...ications/tm/tm201/303-308.pdf>, accessed 28 April 2022].
- NOAA. 1975. The coastline of the United States. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. [Available at: [https://shoreline.noaa.gov/\\_pdf/Coastline\\_of\\_the\\_US\\_1975.pdf](https://shoreline.noaa.gov/_pdf/Coastline_of_the_US_1975.pdf), accessed 10 February 2021].
- NOAA. 2012. 2011–2012 bottlenose dolphin unusual mortality event in Texas. National Oceanic and Atmospheric Administration. [Available at: <https://www.fisheries.noaa.gov/national/marine-life-distress/2011-2012-bottlenose-dolphin-unusual-mortality-event-texas>, accessed 15 December 2020].
- NOAA. 2020. Examiner’s guide, 2020 revision. Marine mammal stranding report – Level A (NOAA Form 89-864, OMB No. 0648-0178). National Oceanic and Atmospheric Administration. [Available at: [https://media.fisheries.noaa.gov/dam-migration/examiners\\_guide\\_2023.pdf](https://media.fisheries.noaa.gov/dam-migration/examiners_guide_2023.pdf)].
- O’Sullivan, D. and Unwin, D. 2010. *Geographic Information Analysis*. John Wiley & Sons, Hoboken, NJ, USA.
- Paine, J.G., Caudle, T.L. and Andrews, J.R. 2017. Shoreline and sand storage dynamics from annual airborne LIDAR surveys, Texas Gulf Coast. *J. Coastal Res.* 33(3): 487–506. [Available at: <https://doi.org/10.2112/JCOASTRES-D-15-00241.1>].
- Peltier, H., Dabin, W., Jepson, P.D., Deaville, R., Van Canneyt, O., Daniel, P. and Ridoux, V. 2012. The significance of stranding data as indicators of cetacean populations at sea: modeling the drift of cetacean carcasses. *Ecological Indicators* 18: 278–93. [Available at: <https://doi.org/10.1016/j.ecolind.2011.11.014>].
- Phillips, N.M. and Rosel, P.E. 2014. A method for prioritizing research on common bottlenose dolphin stocks through evaluating threats and data availability: development and application to bay, sound and estuary stocks in Texas. NMFS-SEFSC-665. 154pp.
- Pitchford, J.L., Garcia, M., Pulis, E.E., Ambert, A.M., Heaton, A.J. and Solangi, M. 2018. Gauging the influence of increased search effort on reporting rates of bottlenose dolphin (*Tursiops truncatus*) strandings following the deepwater horizon oil spill. *PLoS One* 13(6): e0199214. [Available at: <https://doi.org/10.1371/journal.pone.0199214>].
- Pitchford, J.L., Serafin, B.J.S., Shannon, D., Coleman, A.T. and Solangi, M. 2013. An analysis of historical bottlenose dolphin (*Tursiops truncatus*) strandings in the Mississippi sound, USA using classification and regression trees (CART). *J. Cetacean Res. Manage.* 13(3): 201–9.
- Read, A.J., Wells, R.S., Hohn, A.A. and Scott, M.D. 1993. Patterns of growth in wild bottlenose dolphins, (*Tursiops truncatus*). *J. Zool. (Lond.)* 231: 107–23. [Available at: <https://doi.org/10.1111/j.1469-7998.1993.tb05356.x>].
- Ronje, E.I., Whitehead, H.R., Barry, K., Piwetz, S., Struve, J., Lecours, V., Garrison, L., Wells, R.S. and Mullin, K.D. 2020. Abundance and occurrence of common bottlenose dolphins (*Tursiops truncatus*) in three estuaries of the Northwestern Gulf of Mexico. *Gulf. Caribb. Res* 31: 18–34. [Available at: <https://doi.org/10.18785/gcr.3101.09>].
- Ronje, E.I., Whitehead, H.R. and Mullin, K.D. 2018. The 1990 common bottlenose dolphin (*Tursiops truncatus*) mass die-off in East Matagorda Bay, Texas – New insight into a cold case *SouthEast Nat* 17(3): 411–22. [Available at: <https://doi.org/10.1656/058.017.0306>].
- Rosel, P.E. and Wilcox, L.A. 2014. Genetic evidence reveals a unique lineage of Bryde’s whales in the northern Gulf of Mexico. *Endanger. Species Res.* 25(1): 19–34. [Available at: <https://doi.org/10.3354/esr00606>].
- Rosel, P.E., Wilcox, L.A., Yamada, T.K. and Mullin, K.D. 2021. A new species of baleen whale (*Balaenoptera*) from the Gulf of Mexico, with a review of its geographic distribution. *Mar. Mamm. Sci.* 37(2): 1–34. [Available at: <https://doi.org/10.1111/mms.12776>].
- Schwacke, L.H., Hall, A.J., Townsend, F.I., Wells, R.S., Hansen, L.J., Hohn, A.A., Bossart, G.D., Fair, P.A. and Rowles, T.K. 2009. Hematologic and serum biochemical reference intervals for free-ranging common bottlenose dolphins (*Tursiops truncatus*) and variation in the distributions of clinicopathologic values related to geographic sampling site. *Am. J. Vet. Res.* 70(8): 973–85. [Available at: <https://doi.org/10.2460/ajvr.70.8.973>].
- Scott, M.D., Wells, R.S. and Irvine, A.B. 1990. A long-term study of bottlenose dolphins on the west coast of Florida. pp.235–44. In: Leatherwood, S. and Reeves, R.R. (eds). *The Bottlenose Dolphin*. Academic Press, San Diego, California. 653pp.
- Shane, S. 1977. The population biology of the Atlantic bottlenose dolphin *Tursiops truncatus* in the Arkansas Pass area of Texas. MSc thesis. College Station, Texas A&M University. 238pp.
- Shane, S.H. 1980. Occurrence, movements and distribution of bottlenose dolphins, *Tursiops truncatus*, in southern Texas. *Fish. Bull.* 78: 593–601.
- Soldevilla, M.S., Hildebrand, J., Frasier, K., Dias, L., Martinez, A., Mullin, K. and Garrison, L. 2017. Spatial distribution and dive behaviour of Gulf of Mexico Bryde’s whales: Potential risk for vessel strikes and fisheries interactions. *Endanger. Species Res.* 32. [Available at: <https://doi.org/10.3354/esr00834>].

- Stolen, M.K. and Barlow, J. 2003. A model life table for bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon system, Florida, USA. *Mar. Mamm. Sci.* 19(4): 630–49. [Available at: <https://doi.org/10.1111/j.1748-7692.2003.tb01121.x>].
- Stolen, M.K., Durden, W.N. and Odell, D.K. 2007. Historical synthesis of bottlenose dolphin (*Tursiops truncatus*) stranding data in the Indian River Lagoon system, Florida, from 1977–2005. *Fla. Sci.* 70(1): 45–54.
- Tarpley, R. 1987. Texas Marine Mammal Stranding Network. *Southwest. Vet.* 38(2): 51–58.
- TDSHS. 2021. Texas fish consumption advisory viewer. Texas Department of State Health Services, Texas Health and Human Services. <https://www.dshs.texas.gov/seafood/TFCAV.aspx>, accessed 30 August 2021.
- Tukey, J.W. 1977. *Exploratory data analysis* Addison-Wesley Publishing Company, Inc., Reading, Mass.
- TWDB. 2012. Climate of Texas. Texas Water Development Board. [https://www.twdb.texas.gov/publications/state\\_water\\_plan/2012/04.pdf](https://www.twdb.texas.gov/publications/state_water_plan/2012/04.pdf), accessed 1 September 2020.
- TXDOT. 2018. Texas Department of Transportation. Open Data Portal. <https://gis-txdot.opendata.arcgis.com/datasets/>, accessed 8 April 2021.
- Tyack, P.L., Johnson, M., Aguilar Soto, N., Sturlese, A. and Madsen, P.T. 2006. Extreme diving of beaked whales. *Journal of Experimental Biology* 209: 4238–53. [Available at: <https://doi.org/10.1242/jeb.02505>].
- Venn-Watson, S., Colegrove, K.M., Litz, J., Kinsel, M., Terio, K., Saliki, J., Fire, S., Carmichael, R., Chevis, C., Hatchett, W., Pitchford, J., Tumlin, M., Field, C., Smith, S., Ewing, R., Fauquier, D., Lovewell, G., Whitehead, H., Rotstein, D., McFee, W., Fougères, E. and Rowles, T. 2015. Adrenal gland and lung lesions in Gulf of Mexico common bottlenose dolphins (*Tursiops truncatus*) found dead following the Deepwater Horizon oil spill. *PLoS One* 10(5): e0126538. [Available at: <https://doi.org/10.1371/journal.pone.0126538>].
- Venn-Watson, S.K., Jensen, E.D. and Ridgway, S.H. 2011. Evaluation of population health among bottlenose dolphins (*Tursiops truncatus*) at the United States Navy Marine Mammal Program. *J. Am. Vet. Med. Assoc.* 238(3): 356–60. [Available at: <https://doi.org/10.2460/javma.238.3.356>].
- Venuto, R., Botta, S., Barreto, A.S., Secchi, E.R. and Fruet, P.F. 2020. Age structure of strandings and growth of Lahille's bottlenose dolphin (*Tursiops truncatus gephyreus*). *Mar. Mamm. Sci.* 36(3): 813–27. [Available at: <https://doi.org/10.1111/mms.12683>].
- Watkins, W.A., Dahler, M.A., Frstrup, K.M., Howald, T.J. and Notarbartolo-di-Sciara, G. 1993. Sperm whales tagged with transponders and tracked underwater by sonar. *Mar. Mamm. Sci.* 9(1): 55–67. [Available at: <https://doi.org/10.1111/j.1748-7692.1993.tb00426.x>].
- Wells, R.S., Allen, J.B., Lovewell, G., Gorzelany, J., Delynn, R.E., Fauquier, D.A. and Barros, N.B. 2015. Carcass-recovery rates for resident bottlenose dolphins in Sarasota Bay, Florida. *Mar. Mamm. Sci.* 31(1): 355–68. [Available at: <https://doi.org/10.1111/mms.12142>].
- Wells, R.S., Schwacke, L.H., Rowles, T.K., Balmer, B.C., Zolman, E., Speakman, T., Townsend, F.I., Tumlin, M.C., Barleycorn, A. and Wilkinson, K.A. 2017. Ranging patterns of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. *Endanger. Species Res.* 33: 159–80. [Available at: <https://doi.org/10.3354/esr00732>].
- Wells, R.S., Tornero, V., Borrell, A., Aguilar, A., Rowles, T.K., Rhinehart, H.L., Hofmann, S., Jarman, W.M., Hohn, A.A. and Sweeney, J.C. 2005. Integrating life history and reproductive success data to examine potential relationships with organochlorine contaminants for bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Science of the Total Environment* 349(1–3): 106–19. [Available at: <https://doi.org/10.1016/j.scitotenv.2005.01.010>].
- Wilkinson, D. and Worthy, G.A. 1999. Marine mammal stranding networks. pp.396–411. In: Twiss, J.R. and Reeves, R.R. (eds). *Conservation and Management of Marine Mammals*. Smithsonian Institution Press, Washington.
- Würsig, B. 2017. Marine mammals of the Gulf of Mexico. pp.1489–587. In: Ward, C.H. (eds). *Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill*. Springer Open, New York, NY.
- Würsig, B. and Lynn, S. 1996. Movements, site fidelity and respiration rates of bottlenose dolphins on the central Texas coast. *NOAA Technical Memorandum: NMFS-SEFSC-383*. 111pp.
- Yordy, J.E., Wells, R.S., Balmer, B.C., Schwacke, L.H., Rowles, T.K. and Kucklick, J.R. . 2010. Life history as a source of variation for persistent organic pollutant (POP) patterns in a community of common bottlenose dolphins (*Tursiops truncatus*) resident to Sarasota Bay, FL. *Sci. Total Environ.* 408(9): 2163–72. [Available at: <https://doi.org/10.1016/j.scitotenv.2010.01.032>].