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On the spatial-temporal distribution of the minke whales (Balaenoptera acutorostrata and B. bonaerensis) in the Wider Caribbean Region and adjacent western tropical North Atlantic

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Abstract

Until recently, minke whale sightings in the northern Atlantic Ocean (NA) were thought to belong exclusively to the common species *Balaenoptera acutorostrata* (CMW). Historical records confirm the presence of the CMW in the north-eastern Caribbean Sea during the winter months. However, the Antarctic minke whale (*B. bonaerensis*) (AMW) has been recently confirmed in the NA and Gulf of Mexico. We review and summarize the available records of both species to shed light on their spatial–temporal occurrence in the Wider Caribbean Region and adjacent NA (WCR-NA). We revised the literature, searched the internet (social networks and video-hosting websites), downloaded records available in biodiversity platforms, and added visual and acoustical records from the authors' files. Finally, we used oceanographic model databases to search for patterns in spatial–temporal distribution. We collected 130 records, where 128 (98.4%) were classified as CMW, and 2 (1.6%) as AMW. One-hundred (76.9 %) records came from scientific accounts and 30 (23.1%) from citizen-science based contributions. Records included sightings (71.5%), acoustic detections (16.2%), strandings (11.5%), and takes (0.8%). Most records belong to the northern Caribbean (50.0%), eastern Caribbean north of Martinique (30.8%), the Gulf of Mexico (10.0%), and the NA (9.2%), and were acquired during the winter (66.2%) and (early) spring (28.5%) months, especially over the Caribbean upwelling season (December-March, 83.8%). Most of the CMW records correspond to three types of water masses, and also seemed to associate with extreme climatic events such as El Niño/La Niña. Calves/juveniles were recorded only on 6 occasions (4.6%). Low primary productivity during migration may limit feeding opportunities for these whales. Increases in large-scale visual and acoustical surveys, and citizen-based initiatives has resulted in better availability of minke whale records within the study area. Our review confirms the WCR-NA as a wintering ground of the CMW from the North Atlantic.

Introduction

The term minke whales refers to two currently recognized species of the Balaenopteridae that includes the common (*Balaenoptera acutorostrata*) and Antarctic (*B. bonaerensis*) minke whales (Rice, 1998; Cooke, 2018; Cooke et al., 2018). The recognition of these two species is recent and, until the end of the XX century, all minke whales were referred to a single species: *B. acutorostrata* (Jefferson et al., 2015; Perrin et al., 2018). Among these, the common minke whale includes three sub-species: The North Atlantic (*B. a. acutorostrata*), the North Pacific (*B. a. scammoni*) minkes and a dwarf unnamed form what is believed to be endemic to the Antarctic (Rice, 1998; Jefferson et al., 2015).

At a global scale, the common minke whale is widely distributed from the pack ice to subtropical and tropical waters in both northern and southern hemispheres (Cooke, 2018; Jefferson et al., 2015; Perrin et al., 2018). The presence of the Antarctic minke whale north of the Equator has recently been confirmed based on sightings, strandings, entanglements, and captures by whaling ships (Glover et al., 2010, 2013; Segniagbeto et al., 2014; Rosel et al., 2016), but most of these records are considered extralimital (Jefferson et al., 2015). Interestingly, at least one fertile hybrid female between these two species in the eastern North Atlantic has also been documented (Glover et al., 2013).

The presence of minke whales in the northern Caribbean has been historically documented due to occasional accounts as well visual (i.e., Moore and Palmer, 1955; Winn and Perkins, 1976; Mitchell, 1991) and acoustic (v.gr. Mellinger et al., 2000; Clark and Gagnon, 2004; Risch et al., 2014; Risch and de Haan, 2016; Heenehan et al., 2019) surveys. Nevertheless, most of the available records were published during the second half of the XX century and all of them referred to *B. acutorostrata*.

According to Slijper et al. (1964), the majority of these animals apparently live in tropical and subtropical waters during the winter and -during the spring and autumn- they showed the usual migratory pattern of other balaenopterids. Furthermore, Slijper et al. (1964) stated that -during the winter- some animals stayed in northern waters, whereas during the summer there were some stragglers in warm waters.

The recent confirmation of the presence of the Antarctic minke in the northern Gulf of Mexico, as well as the scarcity of information on minkes' winter habitat, emphasizes the importance of rethinking the spatial-temporal distribution pattern of minke whales in the Wider Caribbean Region (WCR). In this paper, we present a review and summarize the available records of both minke species in the WCR, to shed light on their spatial and temporal occurrence in this region.

Methods

Study area

The study area is the Wider Caribbean Region (WCR), as defined by the International "Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region" or "Cartagena Convention". This, the WCR includes "*the marine environment of the Gulf of Mexico, the Caribbean Sea and the areas of the Atlantic Ocean adjacent thereto, south of 30 deg north latitude and within 200 nautical miles of the Atlantic coasts of the States referred to in article 25 of the Convention*". For this review and, because of the scarcity of records, we also included information of opportunistic sightings in the adjacent waters of the western tropical North Atlantic Ocean (Figure 1).

Records

Following Van Waerebeek et al. (1999), Jefferson et al. (2009), and Bolaños-Jiménez et al. (2014), minke whale records were extracted from both the published and unpublished literature and combined with original records collected by the authors or provided by colleagues working in the area (see Acknowledgements). We searched the Internet as well as video-hosting websites and social networks for pictures and video footage of minke whales and reviewed the digital versions of regional newspapers (see Acknowledgements). Whenever possible, we interviewed the journalists or original observers for raw material as well as confirmation and additional information. Records examined included sighting or stranding accounts, museum specimens as well as acoustic detections by one of us (LB, OMMAG), and reports by citizen-based initiatives for the recording of marine mega vertebrate sightings. We also included records from the OBIS SEAMAP platform (Halpin et al., 2006; Fujioka et al., 2014), as well as OBSENMER (www.obsenmer.org) and OBSERVATION (www.observation.org).

Figure 1. Study area, including the Wider Caribbean Region and adjacent waters of the western Atlantic.

Following Jefferson et al. (2009), we scrutinized each record for information on diagnostic character as follows: (1) photos or video documentation showing diagnostic characters (2) voucher specimens that confirmed identification (3) sufficiently-detailed drawings or descriptions of observed animals that showed or mentioned diagnostic characters, leaving no doubt as to the identification, or (4) observations made by marine mammal scientists known to be familiar with the species diagnostic characters (Jefferson et al., 2009). Records were then either coded as (1) confirmed, (2) accepted, (3) Rejected, or (4) misidentified (*sensu* Jefferson et al., 2009).

Records were divided into four categories: captures or takes, strandings, sightings, and acoustical detections. Following Bolaños-Jiménez et al. (2014), spatial-temporal distribution of the records was assessed in terms of the following variables: (i) spatial distribution (Gulf of Mexico, Greater Antilles, eastern Caribbean, southern Caribbean, western Caribbean, and Atlantic), and (ii) seasonal distribution (spring: 1 March–31 May, summer: 1 June–31 August, autumn: 1 September–30 November, and winter: 1 December–28 February).

Oceanographic variables

Mean annual composites of 14 oceanographic variables were obtained from models and databases (MARSPEC, http://marspec.weebly.com/modern-data.html and Bio-Oracle database, https://www.bio-oracle.org/) as shown in table 1, and values were extracted for each sighting using its position with the function "Extract Multi Values to Points" in ArcGis 10.3 (ESRI, 2014). We identified the water masses involved in the encounters using salinity-temperature (S-T) plots (Correa-Ramírez *et al*., 2020). Whenever possible, CMW records were classified according to their date (month/year) to have occurred during average years or else, weak, moderate, strong, or very strong El Niño/La Niña events, using three oceanographic indices 1) the Southern Oscillation (SOi) (NOAA https://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/), 2) the June-August Atlantic Niño (JJANi) (Tokinaga *et al*., 2019) and 3) the North Atlantic Oscillation (NAOi) (Greatbach, 2000). Finally, we searched for correspondence among the CMW sighting records and their prevailing oceanographic conditions using a non-metric multidimensional scaling analysis and permutational analysis of variance; as most of the 18 variables were skewed, we applied a square root transformation and Euclidian distances.

Results and discussion

We collected 130 records, spanning from 1935 through 2021. Out of the 130 records, 100 (76.9 %) came from scientific accounts and 30 (23.1 %) came from citizen-science based contributions.

The cumulative curve of new records indicated two periods (Figure 1). A first period from 1935 through 1970, with a low, gradual discovery rate of new records, and a second period from 1971 through 2020, with greater, steeper discovery rate (Figure 2). The first period included information from occasional sighting and stranding accounts. The second period mostly included records from strandings, museum specimens, large scale visual and/or acoustical surveys, as well as citizen-based contributions. We believe that the increased availability of minke whale records of the second period is related to a variety of reasons, including a greater interest by the scientific community after research and conservation initiatives generated under the framework of the United

States´ Marine Mammal Protection Act and the Specially Protected Areas and Wildlife (SPAW) Protocol of the Cartagena Convention, as well as the technological advances in digital imagery and citizen-based initiatives to record and disseminate biodiversity observations in social networks and public repositories.

Table 1. Oceanographic variables extracted from model databases (MARSPEC and Bio-Oracle databases) for coordinates of CMW sighting at the Wider Caribbean region from 1935 to 2021 (the spatial resolution of the oceanographic variables -pixel- is of 2.5 arc-minute, approximately 5 km grid cell sizes at the equator).

Variable	Code	Units
Depth of the seafloor	Bathy	m
Mean Chlorophyll	Chl	$mg.m^{-3}$
Mean Currents velocity	CV	m^{-1}
Mean Diffuse attenuation	DAtt	m^{-1}
Mean Light at bottom	Light	
Mean Annual Sea Surface Salinity (SSS)	MASSS	psu
Mean Annual Sea Surface Temperature (SST)	MASST	°C
Mean Primary productivity	PProd	$g.m^{-3}.day^{-1}$
Distance to Shore	Shore	km
Bathymetric Slope	Slope	degrees
SSS of the saltiest month	SSalt	psu
SSS of the freshest month	SSFre	psu
SST of the coldest month	STColS	°C
SST of the warmest month	STWar	°C

Species composition included 128 records (98.5 %) of the common and two (1.5 %) of the Antarctic minke whale (Figure 3); the latter corresponded to strandings in Surinam and the northern Gulf of México, respectively. For the CMW, the number of individuals per sighting ranged from 1 to 7 individuals (mean = 2.0 ± 1.3, n = 67), and calves/juveniles were recorded only in 6 occasions (4.6%).

Most of the records have been documented on the northern Caribbean (50.0 %), eastern Caribbean north of Martinique (30.8 %), the Gulf of Mexico (10.0 %), and the North Atlantic Ocean (9.2 %), respectively (Figure 2). No records were documented in the western Caribbean or the southern Caribbean. The high proportion of records in the Eastern and Northern Caribbean, and the western

Atlantic confirm the use of the region as part of the wintering grounds of common minke whales from the northern hemisphere.

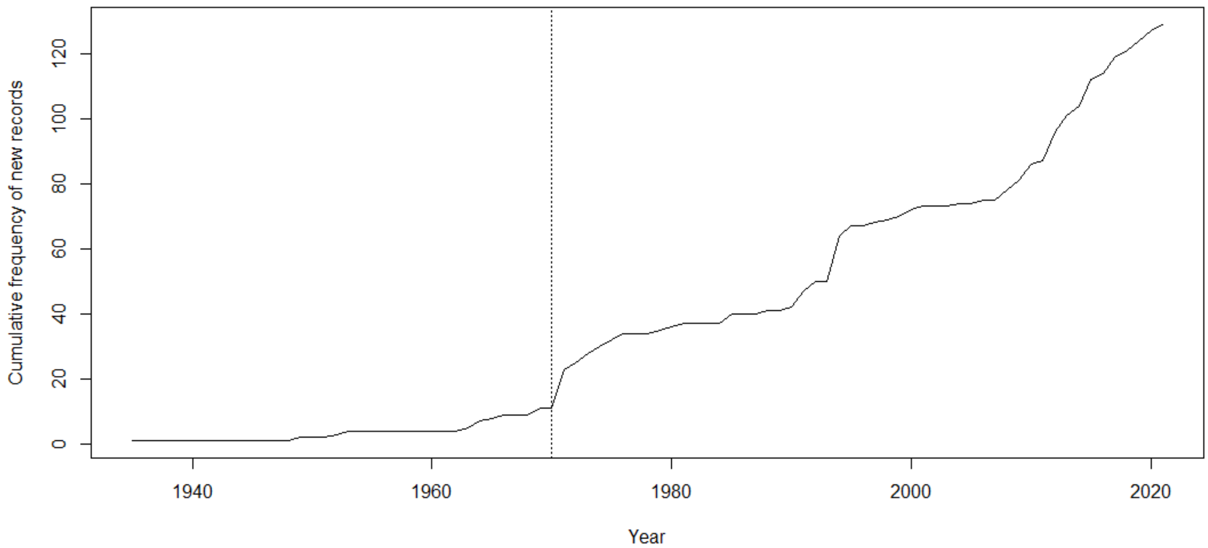

Figure 2. Cumulative discovery curve of new records of the minke whale in the Wider Caribbean Region and adjacent western tropical Atlantic. The dotted line indicates the separation between periods 1 and 2.

Most of the records (94.7 %) were detected during winter (66.2 %) and (early) spring (28.5 %) (Figures 3). When stratified by month, 83.8 % of the records concentrated over the December-March period (Figure 4). It is noteworthy that during this period, the southward migration of the inter Tropical Convergence Zone intensifies the trade winds, causing nutrient-rich sub-superficial water inputs (upwellings) in the southeastern Caribbean (Correa-Ramírez *et al*., 2020).

Records included sightings (71.5 %), acoustic detections (16.2 %), strandings (11.5 %) and takes (0.8 %) (Figure 4); about 27 % of the records counted on photographic or video material, recordings or stranding material that helped get a secure identification.

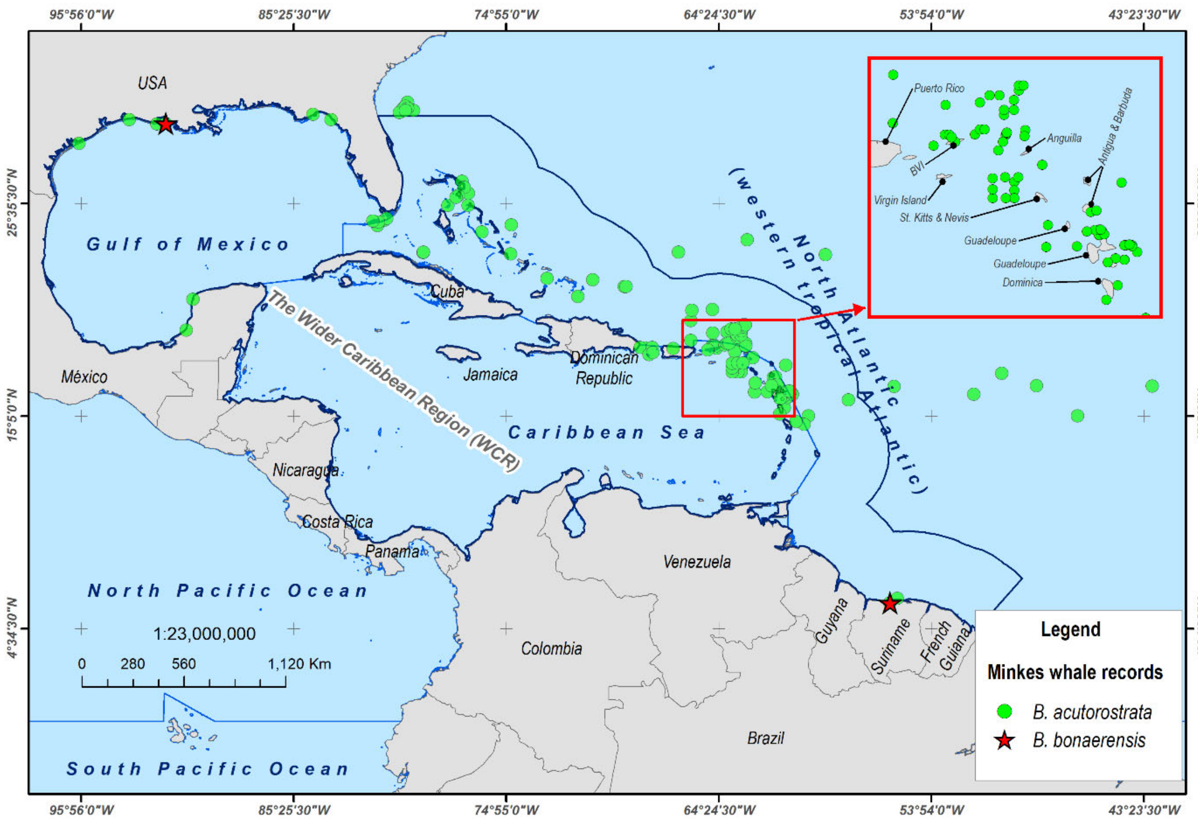

Figure 3. Minke whale records in the Wider Caribbean Region and adjacent western tropical Atlantic, 1935-2021.

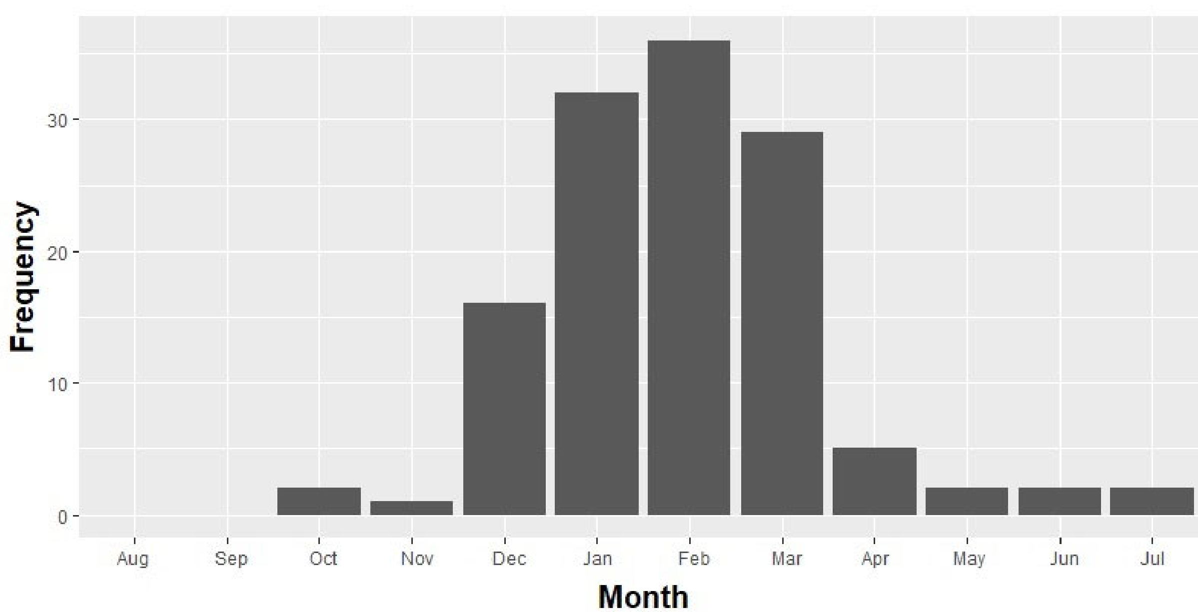

Figure 4. Monthly distribution of minke whale records in the Wider Caribbean Region.

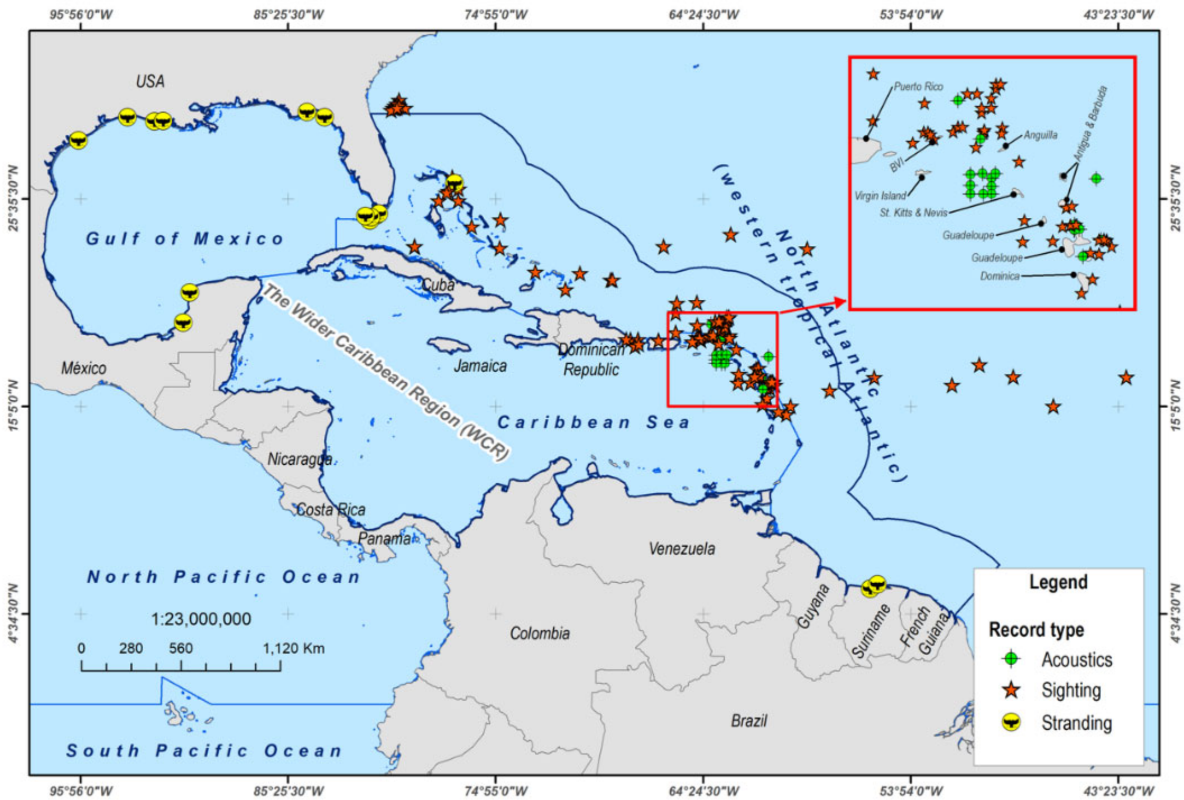

Figure 5. Classification of type of records of minke whales in the Wider Caribbean Region and adjacent western tropical Atlantic.

Our 1935 to 2021 query retrieved sufficient data for many of the oceanographic variables from the model data bases. Variables with over 30% of null values were discarded; furthermore, those that were derived from, or presented known correlations with other variables were also eliminated from the analyses (e.g., SSS and SST provided water mass type classification, also slope is commonly associated to depth and distance from shore, etc.). The descriptive statistics of environmental variables for all CMW sightings are provided in table 2, and to the best of our knowledge, this is the first report on oceanographic variables associated to sightings of the species in this region. Details on the statistical distribution of these variables are available in supplemental materials (see file “Sup_Mat_1_Oceanographic_Variables.jpg).

Table 2. Descriptive statistics for relevant oceanographic variables (see codes in table 1) at sighting locations for CMW from 1935 to 2021.

Variable code	Mean	S.D.	Md	Mode	Asimetry	CV
Bathy	-1737.89	2137.01	-612.00	-7.00	-1.19	-1.23
Chl	0.06	0.08	0.04	0.00	3.48	1.35
CV	0.14	0.18	0.09	0.00	2.88	1.27
DAtt	0.02	1.58	-0.46	-0.40	3.36	78.98
Light	2.69	7.29	0.00	0.00	3.36	2.71
MASSS	34.06	7.54	35.67	0.00	-4.34	0.22
MASST	25.04	2.22	25.86	25.91	-3.51	0.09
PProd	0.00	0.00	0.00	0.00	5.68	2.43
Shore	111.35	255.45	30.00	4.00	4.02	2.29
Slope	28.57	32.82	21.50	0.00	2.19	1.15
SSalt	3464.83	765.52	3634.00	3638.00	-4.37	0.22
SSFre	3338.63	744.11	3480.00	0.00	-4.25	0.22
STColS	2764.53	611.84	2890.50	2887.00	-4.34	0.22
STWar	375.74	254.88	304.50	308.00	2.84	0.68

Based on the S-T plot from mean annual sea surface salinity (MASSS) and temperature (MAST) (Fig. 6), from the 121 records with available data, 21% occurred under prevailing subtropical underwater (SUW) conditions, whereas 62% were related to Caribbean Surface Water (CSW), 15% were Gulf Common Water (GCW), and the remaining could not be assigned to a particular water mass (Portela *et al*., 2018). The SUW is considered the main source of upwelled waters in the Caribbean, but it is diluted by vertical mixing processes during the transport by the Caribbean Coastal Undercurrent (Correa-Ramírez *et al*., 2020); however, such a tropical upwelling system is considered to have low biological productivity, thus as happens with other balaenopterids during their migration, feeding activities for CMW might be limited in this region. This is particularly relevant since upwellings in this region have been significantly reduced due to intensified stratification of the water column by a net SST rise of 1.0 (± 0.14 °C) during the past decade, leading to overall declines in primary production (Taylor *et al.*, 2012).

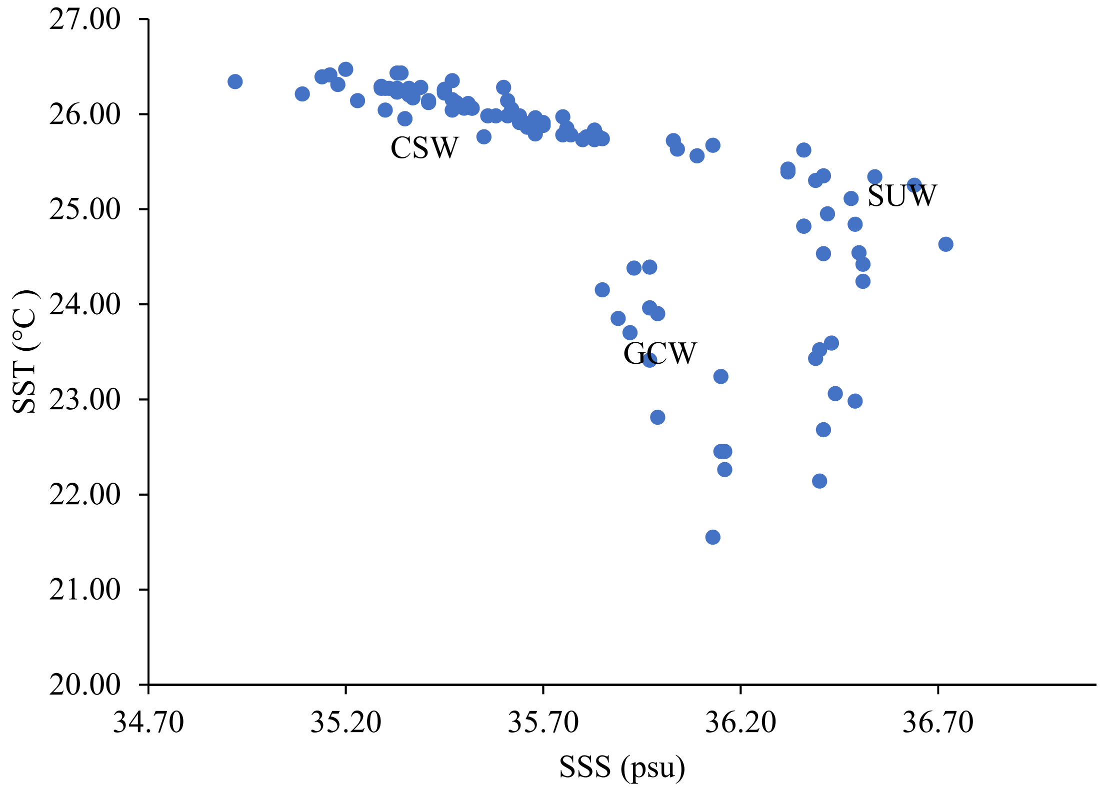

Figure 6. Mean annual sea surface salinity (MASSS) and temperature (MASST) conditions for sighting records (n=121) of common Minke whales from model databases for the Wider Caribbean region from 1935 to 2021. Identified water masses are labeled as subtropical underwater (SUW), Caribbean Surface Water (CSW), and Gulf Common Water (GCW).

The proportion of records for sightings of CMW varied across the three oceanographic indices used in this study; however, it is important to mention that 80-95% of the records were related to El Niño/La Niña events. For instance, under the Southern Oscillation (SOi) and the North Atlantic Oscilation (NAOi) indices, most records occurred during El Niño years in their different intensities (53 and 62%, respectively) (Table 3). Conversely, the June-August North Atlantic Niño (JJANi) placed a higher proportion of records during La Niña conditions (48%) compared to El Niño (31%). An interesting pattern was noted for the NAOi, in which the proportion of records for CMW seems to increase with the intensity of the climatic anomalies, especially during El Niño conditions, thus being uncommon during average years; this reduction in CMW records during average years was also true for the SOi, but not for the JJANi.

Table 3. Proportion of records for common Minke whales classified by prevalent atmospheric conditions in three relevant oceanographic indices (SOi=Southern Oscillation, JJAN=June-August Atlantic Niño, NAO=North Atlantic Oscillation) according to their sighting date.

	Category	SOi	JJANi	NAOi
El Niño	Very strong	0.09	0.04	0.43
	Strong	0.11	0.03	0.09
	Moderate	0.22	0.21	0.07
	Weak	0.12	0.04	0.03
	Average	0.05	0.21	0.06
La Niña	Weak	0.27	0.04	0.05
	Moderate	0.12	0.09	0.10
	Strong	0.03	0.26	0.02
	Very strong	0.00	0.09	0.15
	Total (N=130)	128	102	125

We only found a low but significant relationship between the water mass types, and El Niño/La Niña events, when sighting classification arose from the regional oceanographic indices (i.e., r^2_{NAOi}=0.17, p=.01880, and r^2_{JJANi}=0.27, p=0.0005), and we also observed that all analyzed variables were skewed towards the component portraying distance from the shore (i.e. Shore_5m_S). Finally, the PermANOVA test also reflected the relationship between water mass types, but only for JJANi (r^2_{JJANi}=0.11, p=0.03). The latter points to possible ecological processes related to climatic extreme events and ocean circulation that may help to explain potential causes and the temporal patterns for the presence of the species in the WCR; but this still remains largely unclear.

The present review contributes to the growing knowledge of the presence of CMW in their wintering grounds in the north-eastern Caribbean Sea and adjacent waters of the tropical western North Atlantic through the mid-Atlantic Ridge. In the absence of large-scale vessel surveys, the contribution from citizen-science based initiatives and passive acoustics monitoring have demonstrated an enormous potential to shed light on the presence of minke whales in the study area in different seasons of the year.

Our findings indicate that during the winter months the CMW utilizes mostly the north-eastern part of the Caribbean (northern of Martinique), the Greater Antilles, and the adjacent central western North Atlantic through the mid-Atlantic Ridge. These findings are in agreement with Risch et al.

(2014), who stated that the minke whale breeding grounds extend eastwards from the Caribbean to at least the Mid-Atlantic Ridge. Similar to the life cycle of other baleen whales, our results are consistent with large-scale seasonal migrations between summer feeding in higher latitudes and winter breeding grounds in lower latitudes (Mitchell, 1991; Van Waerebeek et al., 1999; Risch et al., 2014). The occurrence of a stranding of a common minke whale in the Bahamas during the summer of 2004 supports speculations by Slijper et al. (1964), that -during the winter- some animals stay in northern waters, whereas during the summer there are some stragglers in warm waters.

The presence of both species of the minke whale inside the Gulf of Mexico was confirmed based on strandings; interestingly, we found no evidence of sightings inside the Gulf. The occurrence of strandings of minke whales inside the Gulf of Mexico during different seasons of the year (Figure 3) could be indicating that the whales stay year-round inside the Gulf as it is the case in the Canary Islands (van Waerebeek et al., 1999) and the Azores Archipelago (Visser et al., 2011; Silva et al., 2014; Risch et al., 2014), but this remains to be investigated.

Finally, we are confident that, despite the limitation of the lack of homogeneous effort, our data and distribution map strongly reflect the true distribution of the common minke whale in the Wider Caribbean Region, as other contributions that used the same methodological approach yielded sightings of other long-ranged species, such as the killer whale, Orcinus orca (Bolaños-Jiménez et al, 2014; 2021) in areas with no CMW sightings.

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