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Introduction

The humpback whale (*Megaptera novaeangliae*) population that breeds in Brazil (Breeding Stock A - BSA) is recovering from depletion caused by whaling. This stock was heavily hunted in the last century, reaching an estimated low abundance of 450 in mid-1950s (Zerbini *et al*., 2019). Recently, the population reached growth rates of 12% per year (Wedekin *et al*., 2017), having increased from 3,396 (CV = 14.15%; CI 95% = 2562-4501) in 2002 (Andriolo *et al*., 2010) to 24,900 (95% PI = 22,400–27,000) in 2019 (Zerbini *et al*., 2019).

Humpback whales distribute across the whole Brazilian coast, from the temperate southern coast to the northeast and northern tropical coasts. However, the main breeding concentration of humpback whales is the Abrolhos Bank (16° 40' to 19°30' S, 37°25' to 39°45'W), an extension of the continental shelf located in the south of the state of Bahia and the north of Espírito Santo state with an area of 882 km² (Andriolo *et al*., 2010; Martins *et.al*., 2013). The humpback whales are found in this region from July to November for the breeding season, with the peak of the season between late August and early September (Morete *et al*., 2008).

Whales usually leave from the Brazilian coast from late October to late December between 20° and 25°S, gradually moving away from the South American coast as they travel towards high latitudes to the feeding area around the South Sandwich Islands (Zerbini *et al*., 2011).

Long term datasets are invaluable to study the population dynamics of endangered populations and their recovery, such as is the case of humpback whale populations. The humpback whales that breed in Brazil recovered from the whaling depletion and now are closer to an equilibrium state, where fluctuations may be governed by climate and availability of their main prey (krill) in the Southern Ocean. Studying the mortality spatial and temporal patterns, and what age classes are more affected, may help to understand this species demography (and a possible transition to a lower growth phase) and its vulnerability to modern human threats.

In this paper we present data on stranding records of humpback whales in Brazil during 20 years (2002 to 2021), correlate these data with population growth and discuss on possible causes for the unusually high mortalities, especially that occurred in 2021.

Methodology

At least 44 institutions are part of the Brazilian Aquatic Mammals Stranding Network (R*ede de Encalhes e Informação de Mamíferos Aquáticos do Brasil* - REMAB) and monitor marine mammal strandings along the coast of Brazil. These institutions are spread along the entire coast (7,491 km long) and in the Amazon basin. The effort to locate the strandings varies along the coast and over time, due to logistic and financial reasons.

In the early 2010s different beach monitoring projects (‘*Projetos de Monitoramento de Praia*’ - PMP) started along the Brazilian coast, aimed at evaluating the potential impacts of oil and gas production in offshore waters on the environment, but focusing on marine tetrapods (sea turtles, seabirds, and marine mammals). The first one began in Rio Grande do Norte and Ceará states (330 km, 03°49’20.9”S to 05°05’28.6”S) in 2009, followed in 2010 by two other PMPs along the coasts of Sergipe and Alagoas (275 km, 10°29'36.6"S to 11°57'56.7"S) and from Espírito Santo to northern Rio de Janeiro states (763 km, 18°19'23.8"S to 22°58'33.8"S). By middle 2015 the largest PMP started along the coasts of Rio de Janeiro, São Paulo, Paraná and Santa Catarina states (2013 km, 22°57'22.6"S to 28°16'48"S). These areas are systematically monitored, with daily, weekly or monthly periodicity, depending on local conditions.

The Humpback Whale Institute (*Instituto Baleia Jubarte* - IBJ) is the REMAB member that collects data on strandings of humpback whales in Abrolhos Bank. The dataset analyzed here is a compilation that includes information of humpback whale stranding reported to REMAB by member institutions distributed along the entire Brazilian coast and IBJ's Abrolhos Bank data. The dataset contains location and date of stranding, sex, total length, state of decomposition of the carcass and suspected cause of death. The IBJ and PMP databases were crosschecked to avoid duplicate information.

Humpback whales were classified into age groups based on the measurement of their total length, that is, the distance from the tip of the maxilla to the notch of fluke tail, taken parallel to the body axis. Animals smaller than 8 meters in length were considered to be calves, between 8 and 11.6 m, juveniles and larger than 11.6 m long, adults (e.g. Wiley *et al*., 1995; Mazzuca *et al*., 1998; Alzueta *et al*., 2001).

Whenever possible necropsies were conducted to establish the cause of death. Carcass decomposition degree was classified from code 1 to 5 following Geraci and Lounsbury (2005) (1 = Live animals; 2 = Carcass in good conditions; 3 = Fair (Decomposed, but organs basically intact); 4 = Poor (advanced decomposition); 5 = Mummified or skeletal remains).

Results

There were 1,260 strandings of humpback whales on the Brazilian coast from 2002 to 2021 (Figure 1). Males (n=437) were more frequent than females (n=296), though sex could not be determined for 527 specimens. Considering the whole period, 106 whales stranded alive while 1,145 were dead and for 9 animals this information is not available. There is a positive exponential trend in the number of strandings (R^2=0.5936) over time, with peaks recorded in 2010, 2017/2018 and 2021. The latter stands out as the number of stranded whales nearly tripled the previous year (Figure 1). The exponential curve resulted in a positive trend of 9.7% increase of strandings per year ($t = 7.001$; $p < 0.05$; R^2 adjusted = 71.7%).

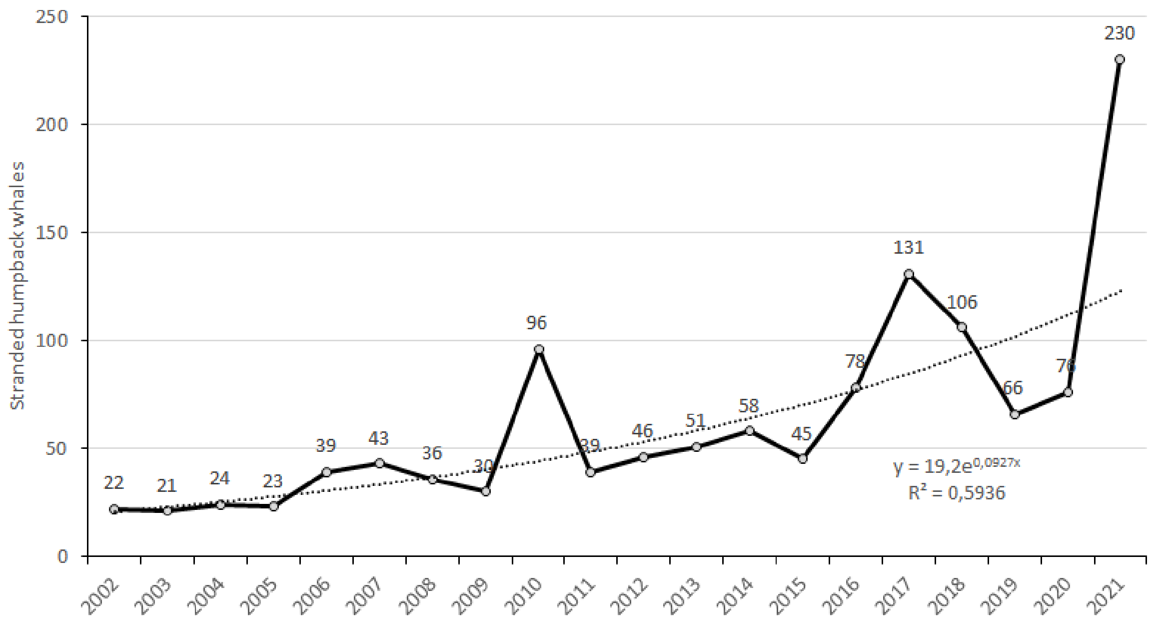

Figure 1 – – Absolute number of humpback whales stranded along the Brazilian coast, from 2002 to 2021. Exponential tendency is shown with the dotted curve.

From the total number of strandings in the Brazilian coast, the majority (52.4%) occurred in August (30.2%) and September (22.1%). Moreover, 82.6% of the strandings happened from July to October. The peak of strandings occurred predominantly in August (10 seasons), September (7 seasons), August/September (2 seasons) and only once the peak of the season occurred in July (in 2015). Apparently, the peak of mortality is getting earlier in the breeding seasons throughout the years of monitoring, with 60% of the years peaking the mortality in September from 2002-2011, while 80% peaked the mortality in August from 2011-2021. Despite being a migratory species, humpback whale strandings have been recorded every month of the year, with a sequence of 20 consecutive months (from May 2018 to December 2019) with strandings (Figure 2).

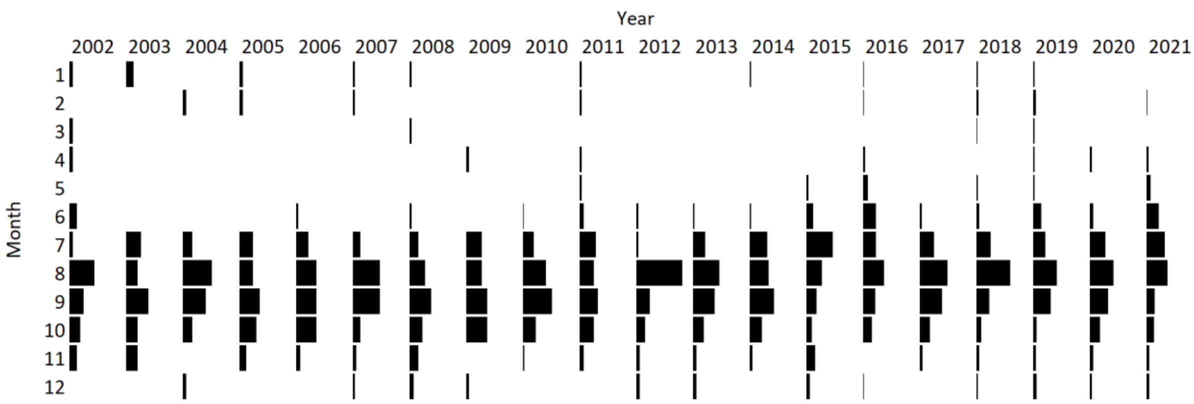

Figure 2 - Humpback whale strandings frequency along the Brazilian coast by month and year.

Calves were the category that most stranded in 15 of the 20 seasons, with 432 specimens (34.3%), with juveniles being the second most abundant age class (473 specimens, 37.5%), predominating in only five seasons (2011, 2016, 2018, 2019 and 2021). Adults were the less abundant category (212 specimens, 16.8%). In 2021 there was an absolute predominance of juveniles, corresponding to 94.9% of the stranded animals that had the age group determined (n=187; Figure 3). Removing strandings from 2021, juveniles account for only 26.7% of all stranded whales.

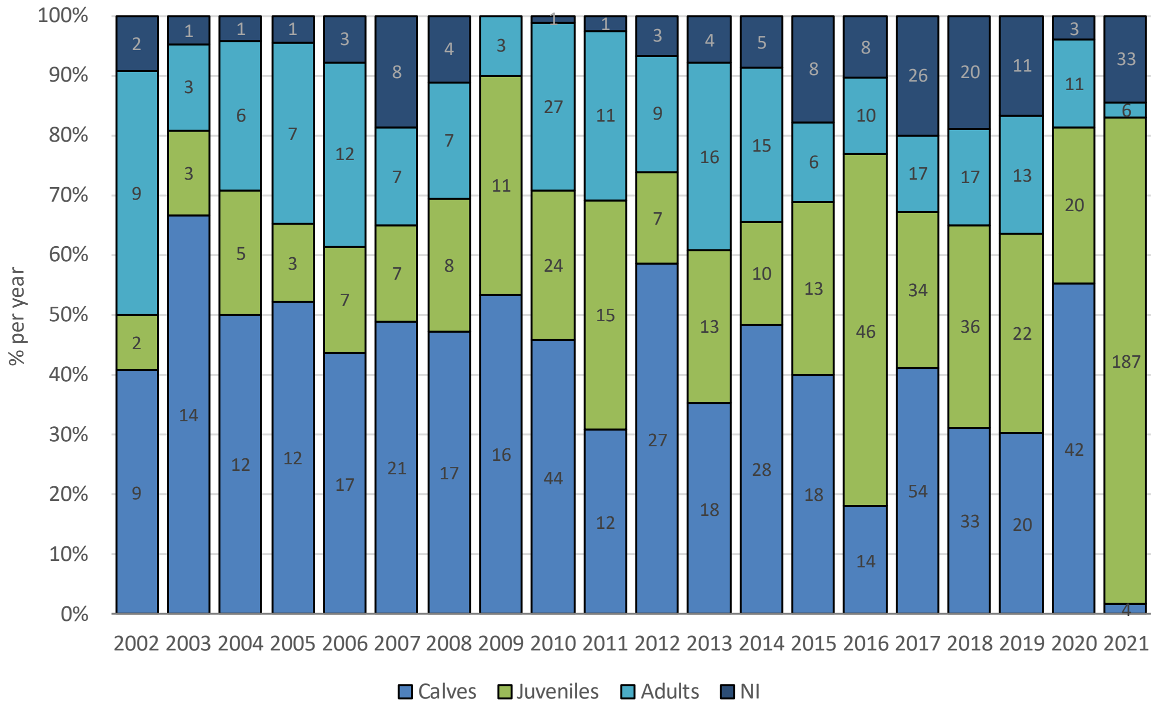

Figure 3 – Yearly relative occurrence of age classes of humpback whales stranded along the Brazilian coast. NI – Not determined.

Humpback whale strandings have already been recorded in all states along the Brazilian coast. Bahia (from 11°26' to 18°20'S) was the state with the highest number of strandings in 16 seasons, followed by the Espírito Santo state (18°20' to 21°18'S) with two seasons (2011 and 2012). In 2016 for the first time the strandings were concentrated further south with 1/3 of the strandings occurring in São Paulo state (23°22' to 25°18'S) and in 2021 the strandings were concentrated even further south, with the state of Santa Catarina (25°58' to 29°19'S) concentrating 28.3% of all strandings (Figure 4). Even though strandings are spread along much of the Brazilian coast, a Kruskal-Wallis test comparing stranding latitudes among years revealed a significant difference [H(20, N= 1,137) = 343.5652 p = 0.000]. A pairwise comparison showed that the strandings' latitudes in 2021 and 2016 were significantly different to all other years (Table 1). Spatial differences in the strandings were also found when the three different age groups were compared (Figure 5).

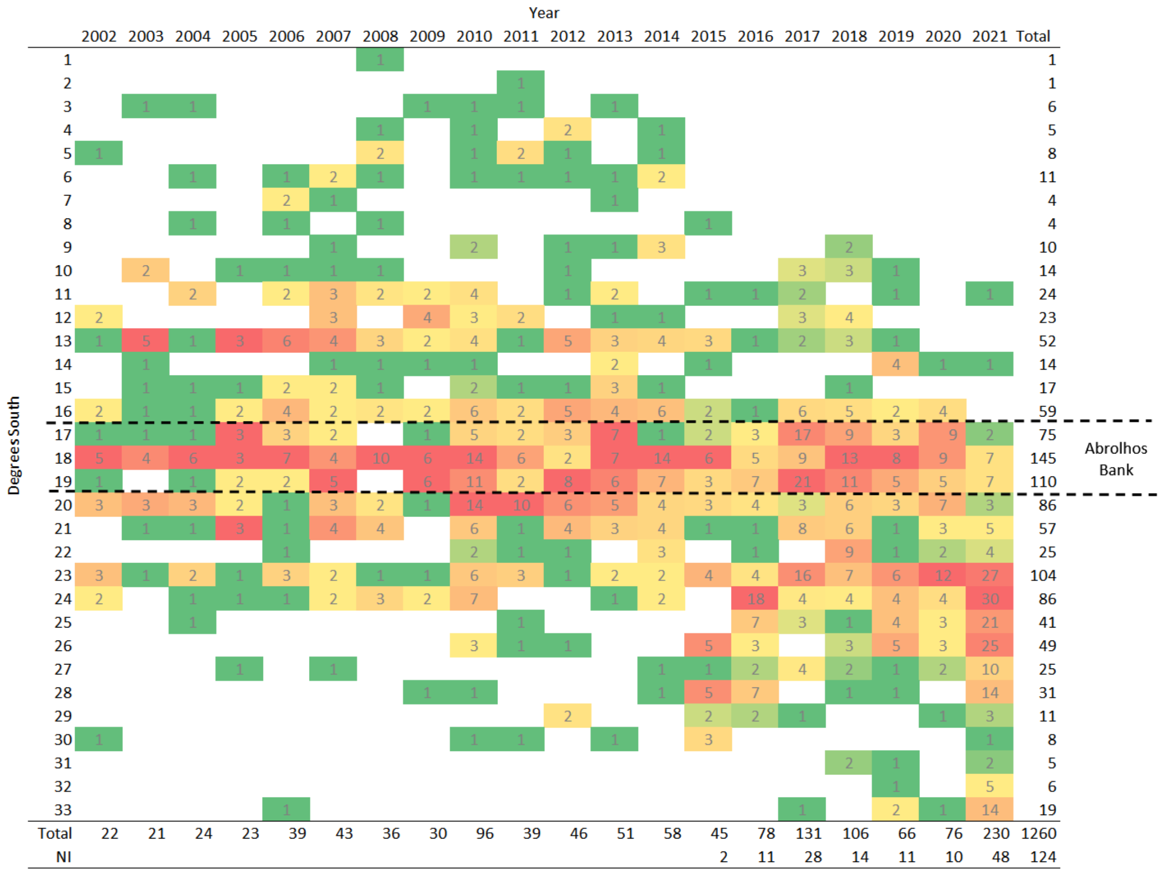

Figure 4 – Absolute number of humpback whales stranded along the Brazilian coast, grouped by latitudinal degree and year. The Abrolhos Bank approximate position is indicated. Color indicates the relative amount for each year, with red indicating the highest value and green the lowest, white indicates no animals. "NI" – records with only approximate geographical position.

Table 1 – Pairwise comparison (Kruskal-Wallis test) of stranding latitudes among years. Values above the diagonal are H, below the diagonal are p-values. Values of p<0.05 are indicated in bold.

R:	645.43	816.48	723.38	698.28	784.67	761.87	770.65	751.03	651.01	663.86	713.93	758.59	703.44	476.56	368.27	602.84	602.85	505.60	514.71	238.09
Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
2002	-	1.707	0.804	0.540	1.590	1.353	1.409	1.146	0.072	0.210	0.805	1.351	0.706	1.962	3.435	0.552	0.546	1.688	1.617	5.496
2003	1.000	-	0.949	1.193	0.358	0.625	0.508	0.700	2.092	1.717	1.186	0.680	1.352	3.888	5.458	2.717	2.690	3.691	3.668	7.643
2004	1.000	1.000	-	0.262	0.719	0.460	0.546	0.308	0.966	0.699	0.114	0.433	0.250	2.950	4.546	1.619	1.601	2.711	2.666	6.805
2005	1.000	1.000	1.000	-	1.001	0.750	0.826	0.580	0.620	0.399	0.187	0.731	0.064	2.614	4.159	1.260	1.247	2.363	2.309	6.333
2006	1.000	1.000	1.000	1.000	-	0.314	0.185	0.422	2.144	1.625	0.990	0.373	1.195	4.243	6.296	2.945	2.898	4.060	4.070	9.433
2007	1.000	1.000	1.000	1.000	1.000	-	0.118	0.139	1.840	1.350	0.688	0.048	0.884	4.029	6.134	2.667	2.622	3.834	3.841	9.407
2008	1.000	1.000	1.000	1.000	1.000	1.000	-	0.242	1.864	1.407	0.776	0.169	0.965	3.965	5.930	2.639	2.599	3.765	3.762	8.891
2009	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	1.456	1.093	0.481	0.100	0.644	3.514	5.306	2.175	2.146	3.293	3.268	7.928
2010	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	0.206	1.069	1.891	0.960	2.895	5.409	1.034	1.005	2.619	2.596	9.969
2011	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	0.701	1.356	0.582	2.580	4.469	0.988	0.972	2.302	2.249	7.348
2012	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	0.669	0.162	3.408	5.498	1.908	1.873	3.175	3.159	8.781
2013	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	0.875	4.148	6.396	2.770	2.717	3.963	3.984	10.005
2014	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	-	3.433	5.691	1.866	1.827	3.201	3.193	9.399
2015	1.000	**0.021**	0.667	1.000	**0.005**	**0.012**	**0.015**	0.093	0.796	1.000	0.137	**0.007**	0.125	-	1.688	2.118	2.082	0.434	0.593	4.283
2016	0.124	**0.000**	**0.001**	**0.007**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.002**	**0.000**	**0.000**	**0.000**	1.000	-	4.551	4.448	2.299	2.572	2.774
2017	1.000	1.000	1.000	1.000	0.678	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.001**	-	**0.000**	1.773	1.702	9.009
2018	1.000	1.000	1.000	1.000	0.789	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**0.002**	1.000	-	1.738	1.664	8.684
2019	1.000	**0.047**	1.000	1.000	**0.010**	**0.026**	**0.035**	0.208	1.000	1.000	0.314	**0.016**	0.287	1.000	1.000	1.000	1.000	-	0.152	5.295
2020	1.000	0.051	1.000	1.000	**0.010**	**0.026**	**0.035**	0.227	1.000	1.000	0.333	**0.014**	0.295	1.000	1.000	1.000	1.000	1.000	-	5.863
2021	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.004**	1.000	**0.000**	**0.000**	**0.000**	**0.000**	-

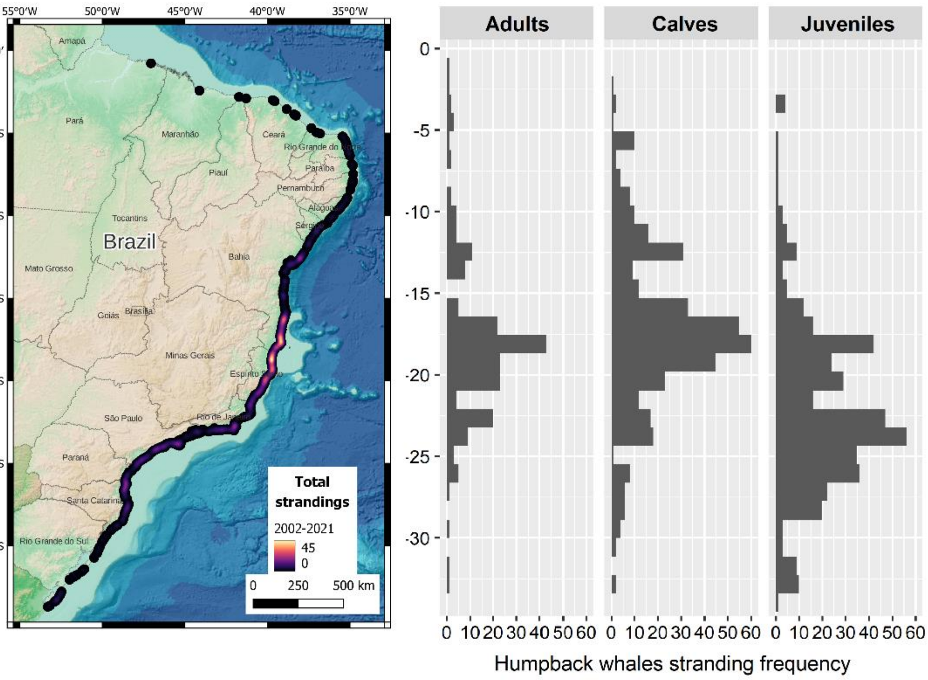

Figure 5 – Density of humpback whale strandings along the coast of Brazil between 2002 and 2021, separated by age classes.

Necropsies were conducted by PMP in 146 whales stranded from 2015 to 2021 from Espírito Santo to Santa Catarina State. Most of them were in advanced state of decomposition (N=124, code 4), followed by carcasses in fair condition (N=17, code 3) and fresh carcasses (N=5, code 2). In most cases (77.4%) the cause of death could not be determined, anthropogenic interaction such as entanglement in fishing gear and ship trike were responsible for19.2%, followed by and natural causes (3.4%) including parasitism, infectious diseases, and neonatal mortality. Regarding to body condition, 2.7% were considered as cachectic, 24.2% thin, 24,2% had good body condition and for 48.9% it could not be evaluated.

Discussion

The increase on the number of strandings of humpback whales along the coast of Brazil over time during the period from 2002 and 2021, with the three peaks identified, might be a result of a combination of different factors. We acknowledge that the population increase seems to have reflected in an increased number of strandings along the coast from 2002 to 2021. The growing number of whales frequenting the coast of Brazil increases the likelihood of interactions with human activities such as entanglements in fishing gear and ship strikes, hence increasing non-natural mortality and the number of strandings.

Due to the state of decomposition of most of the carcasses, conclusive diagnosis on the cause of death of most individuals could not be established. Groch *et al*. (2012) examined skeletal tissues from 49 humpback whales stranded between 2002 to 2011 along the Abrolhos Bank seashore and found that 24.5% of the animals presented pathological changes in one or more bones. Degenerative changes and developmental malformations were most frequent (10.2% each), followed by inflammatory/infectious and traumatic lesions (8.2% each).

In another study the pathologies of 24 humpback whales stranded along the Brazilian coast from 2004 to 2016 were described (Groch *et al.*,2018). The most probable cause of stranding and/or death (CSD) in 19 calves were neonatal respiratory distress (68.4%), infectious disease (septicemia, omphaloarteritis and urachocystitis; 15.8%), trauma of unknown origin (10.5%) and ship strike (5.3%). In 4 juveniles and 1 adult the CSD were emaciation (40%), sunlight-thermal burn shock (20%); and discospondylitis (20%) and in one juvenile the CSD was undetermined. The nutritional status of each animal was classified as good, moderate, poor, or emaciated based on the degree of atrophy of the epaxial musculature, prominence of ribs, scapula or axial skeleton, and amount of subcutaneous, intrathoracic and abdominal fat. Most of the whales were in good conditions (54.2%), followed by moderate (25%), poor (12.5%), emaciated (4.2%) and unknown (4.2%).

Samples collected from the whales that stranded in 2021 are still being examined. However, from macroscopic evaluations we found human induced mortality causes in at least 19.2% of whales stranded from 2016 to 2021. Another possible factor influencing on the number of strandings observed can be the nutritional condition of the individuals, which relates to food availability in higher latitudes, with consequences for the energy reserves to sustain the individuals during the breeding season. An analysis carried out in the period 2001-2016 seems to indicate a relationship between variations in the occurrence of krill in the South Georgia Islands area and the strandings of humpback whales (Marcondes *et al*., 2017). That work has shown that a decline in krill would lead to an increase in strandings in Brazil and this relationship would be stronger when the decline continued for two or three years. Animals with nutritional deficit are more subject to a decrease in the immune system, decrease in fertility and, in the case of lactating females, lower milk production. A relationship has also been found between the number of calves observed on the coast of Ecuador (Breeding Stock G - BSG) and food availability (krill density) in the feeding area around the Antarctic Peninsula (Seyboth *et al*., 2021). Also, Gabriele *et al*. (2022) observed a decline in survival and reproductive success in humpback whales during a Northeast Pacific marine heatwave which affected the food supply. The influence of higher sea surface temperatures and the consequent decrease of the sea ice on the development of krill is well known (e.g. Moline *et al*., 2004; Schofield *et al*., 2017), and can be of concern for humpback whales and other whale species in the current scenario of climate changes.

Considering our results, the influence of food availability seems to mainly affect juvenile individuals, prompting them to seek other sources of food. This hypothesis is supported by the necropsies done by the PMP in whales stranded south of 22°57'S. There were presence of food remains in gastrointestinal tracts of 44.3% whales in 2021 and 42.8% in 2016, compared to 31.6% in other years. In 2016 and 2021 there were records of humpback whale sightings on São Paulo and Santa Catarina states, close to the coast, and feeding behavior was recorded in these two states (LLW personnel observation). This corroborates that eventually humpback whales feed in their breeding grounds, including prey from more temperate and subtropical regions (Alves *et al.*, 2009; Danilewicz *et al.*, 2009; Bortolotto *et al.*, 2016).

Another possible evidence of a reduced food supply for whales of this breeding stock was recently reported for photo-identified whales switching feeding grounds. Humpback whales from Brazil were observed in the Antarctic Peninsula, in the feeding area of the humpback whales of the eastern Pacific (BSG), suggesting that some individuals may be looking for other feeding areas. However, it is not known whether this could be an effect of population growth, variations in food supply or even a bias caused by a greater effort and more efficient photoidentification data process (Marcondes *et al*., 2021).

The areas with more strandings also varied over the period investigated. In 2010 there was a higher percentage of juvenile deaths, with strandings concentrated in the Abrolhos Bank region. In 2016, there was again a predominance of juveniles but the concentration of strandings were in São Paulo State, further south. In the following year we had the second mortality peak with a predominance of calves and concentration in the Abrolhos bank. Strandings remained high during 2018. In 2021 during the largest event of humpback whales strandings recorded in Brazil, the usual pattern of more strandings in the Abrolhos region and of calves changed again. There was a high concentration of strandings in the southern region of Brazil and being almost entirely of juveniles. Necropsies revealed that some whales were in very poor body condition. The occupation and consequent increased mortality of these juveniles in southern Brazilian waters may be related to the higher productivity of the South Brazil Bight - SBB (the shelf waters of southeastern Brazil), than more tropical and oligotrophic waters of the northern and more dense breeding grounds, such as the Abrolhos Bank. The SBB waters are influenced by upwelling of bottom waters and the coastal freshwater inputs carried along the coast from the south (Brandini *et al.*, 2018), which may propitiate more opportunistic feeding for whales following bad years in the feeding grounds.

The proximity of the humpback whales to shore in more southern areas of Brazil, where the species is not observed so often, caused an increase in records of entanglements in fishing gears. From 2002 to 2020, 57 entanglements were recorded, with a peak of 16 in 2016. At least 60 animals recorded in 2021 had fishing gear attached to their bodies, of which at least 23 were found stranded. It was not possible to establish how many whales died because of entanglement.

Although the frequency of strandings' data may be biased due to a large fraction of whales that die does not end washed ashore, remaining undetected, and also because stranding monitoring effort is not evenly distributed along the coast, the data presented here shed light on the demography of humpback whales after recovery from depletion. Further analyses are underway, focusing on the effect of changes in krill biomass and climate variability on humpback whales mortality and stranding rates.

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References

ALVES, L.C.P.S.; ANDRIOLO, A.; ZERBINI, A.N.; PIZZORNO, J.L.P. & CLAPHAM, P.J. 2009. Record of feeding by humpback whales (*Megaptera novaeangliae*) in tropical waters off Brazil. **Marine Mammal Science**, 25(2): 416-419.

ALZUETA, J.C.; FLÓREZ-GONZALEZ, L. & FERNÁNDEZ, P.F. 2001. Mortality and anthropogenic harassment of humpback whales along the Pacific coast of Colombia. **Memoirs of the Queensland Museum**, 47(2): 547-553.

ANDRIOLO, A.; KINAS, P.G.; ENGEL, M.H.; MARTINS, C.C.A. & RUFINO, A.M. 2010. Humpback whales within the Brazilian breeding ground: distribution and population size estimate. **Endangered Species Research,** 11: 233–243.

BORTOLOTTO, G.A.; KOLESNIKOVAS, C.K.M.; FREIRE, A.S. 7 SIMÕES-LOPES, P.C. 2016. Young humpback whale *Megaptera novaeangliae* feeding in Santa Catarina coastal waters, Southern Brazil, and a ship strike report. **Marine Biodiversity Record**, 9: 29.

BRANDINI, F.P.; TURA, P.M. & SANTOS, P.P.G.M. 2018. Ecosystem responses to biogeochemical fronts in the South Brazil Bight. **Progress in Oceanography**, 164: 52-62.

DANILEWICZ, D., TAVARES, M., MORENO, I.B., OTT, P.H. & TRIGO, C.C. 2009. Evidence of feeding by the humpback whale (Megaptera novaeangliae) in mid-latitude waters of the western South Atlantic. Journal of the Marine Biological Association of the U.K. 2 – Biodiversity Records.

GABRIELE, C.M.; AMUNDSON, C.L.; NEILSON, J.L.; STRALEY, J.M.; BAKER, C.S. & DANIELSON, S.L. 2022. Sharp decline in humpback whale (*Megaptera novaeangliae*) survival and reproductive success in southeastern Alaska during and after the 2014–2016 Northeast Pacific marine heatwave. **Mammalian Biology**, https://doi.org/10.1007/s42991-021-00187-2.

GERACI, J.R. & LOUNSBURY, V.J. 2005. **Marine Mammals Ashore: a field guide for strandings**. 2 ed. Baltimore, MD: National Aquarium in Baltimore, 371 pp.

GROCH, K.R.; MARCONDES, M.C.C.; COLOSIO, A.C. & CATÃO-DIAS, J. L. 2012. Skeletal abnormalities in humpback whales *Megaptera novaeangliae* stranded in the Brazilian breeding ground. **Diseases of Aquatic Organisms**. 101, 145-158 doi: 10.3354/dao02518

GROCH, K.R.; DIAZ-DELGADO, J.; MARCONDES, M.C.C.; COLOSIO, A.C.; SANTOS-NETO, E. B.; CARVALHO, V.L.; BOOS, G.S.; MEIRELLES, A.C.O.; RAMOS, H.G.C.; GUIMARÃES, J.P.; BORGES, J.C.G.; VERGARA-PARENTE, J.E.; LEGER, J. A. St.; FERNANDEZ, A; CATÃO-DIAS, J.L. 2018. Pathology and causes of death in stranded humpback whales (*Megaptera novaeangliae*) from Brazil. **PLoS ONE** 13(5) 1-19 e0194872. .pone.0194872

MARCONDES, M.C.C.; COLÓSIO, A.C.; RAMOS, H.G.C. & COELHO, I.P. 2017. Krill decreasing in South Georgia could explain humpback whale strandings in Brazil? VIII ENCOPEMAQ, Natal-RN 22 a 25 de Agosto de 2017.

MARCONDES, M.C.C.; CHEESEMAN, T.; JACKSON, J.A.; FRIEDLAENDER, A.S.; PALLIN, L.; OLIO, M.; WEDEKIN, L.L.; DAURA-JORGE, F.G.; CARDOSO, J.; SANTOS, J.D.F.; FORTES, R.C.; ARAÚJO, M.F.; BASSOI, M.; BEAVER, V.; BOMBOSCH, A.; CLARK, C. W.; DENKINGER, J; BOYLE, A.; RASMUSSEN, K.; SAVENKO, O.; AVILA, I.C.; PALACIOS, D.M.; KENNEDY, A.S. & SOUSA-LIMA, R.S. 2021. The Southern Ocean Exchange: porous boundaries between humpback whale breeding populations in southern polar Waters. **Scientific Reports,** 11: 23618 https://doi.org/10.1038/s41598-021-02612-5

MARTINS, C.C.A.; ANDRIOLO, A.; ENGEL, M.H.; KINAS, P.G. & SAITO, C.H.2013. Identifying priority areas for humpback whale conservation at Eastern Brazilian Coast. **Ocean & Coastal Management,** 75: 63-71

MAZZUCA, L.; ATKINSON, S. & NITTA, E. 1998. Deaths and entanglements of humpback whales, *Megaptera novaeangliae*, in the main Hawaiian Island, 1972-1996. **Pacific Science**, 52(1): 1-13.

MOLINE, M. A.; CLAUSTRE, H.; FRAZER, T.K.; SCHOFIELD, O. & VERNET, M. 2004. Alternation of the food web along the Antarctic Peninsula in response to a regional warming trend. **Global Change Biology***,* 10: 1973–1980.

MORETE, M.E.; BISI, T.L.; PACE III, R.M. & ROSSO, S. 2008. Fluctuating abundance of humpback whales (*Megaptera novaeangliae*) in a calving ground off coastal Brazil. **Journal of the Marine Biological Association of the United Kingdom**, 88(6): 1229-1235.

SCHOFIELD, O.; SABA, G.; COLEMAN, K.; CARVALHO, F.; COUTO, N.; DUCKLOW, H.; FINKEL, Z.; IRWIN, A.; KAHL, A.; MILES, T.; MONTES-HUGO, M.; STAMMERJHON, S. & WAITE, N. 2017. Decadal variability in coastal phytoplankton community composition in a changing West Antarctic Peninsula. **Deep-Sea Research Part I: Oceanographic Research Papers**, 124: 42–54.

SEYBOTH, E.; FELIX, F.; LEA, M.A.; DALLA ROSA, L.; WATTERS, G.M.; REID, K., & SECCHI, E.R. 2021. Influence of krill (*Euphausia superba*) availability on humpback whale (Megaptera novaeangliae) reproductive rate. **Marine Mammal Science**, 1-9.

WEDEKIN, L.L.; ENGEL, M.H.; ANDRIOLO, A.; PRADO, P.I.; ZERBINI, A.N.; MARCONDES, M.C.C.; KINAS, P.G. & SIMÕES-LOPES, P.C. 2017. Running fast in the slow lane: rapid population growth of humpback whales after exploitation. **Marine Ecology Progress Series**, 575: 195-206.

WILEY, D.N.; ASMUTIS, R.A.; PITCHFORD, T.D. & GANNON, D.P. 1995. Stranding and mortality of humpback whales, *Megaptera novaeangliae*, in the mid-Atlantic and southeast United States, 1985-1992. **Fishery Bulletin**, 93 (1): 196-205.

ZERBINI, A.N.; ANDRIOLO, A.; HEIDE-JØRGENSEN, M.P.; MOREIRA, S.C.; PIZZORNO, J.L.; MAIA, Y.G.; VANBLARICOM, G.R. & DEMASTER, D.P. 2011. Migration and summer destinations of humpback whales (*Megaptera novaeangliae*) in the western South Atlantic Ocean. **Journal of Cetacean Research and Management**, special issue 3: 113–118.

ZERBINI, A.N.; ADAMS, G.; BEST, J.; CLAPHAM, P.J.; JACKSON, J.A. & PUNT, A.E. 2019 Assessing the recovery of an Antarctic predator from historical exploitation. **Royal Society Open Science,** 6: 190368, http://dx.doi.org/10.1098/rsos.190368,.