Cetacean Strandings in Chile between 2015 and 2020

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Strandings caused by anthropogenic factors are one of the most worrying threats in relation to the conservation of cetacean species, and in the case of Chile, due to its geography and large extension of the coastline, monitoring and access to these events is difficult, making their study more complex. According to the Chilean government official database, researchers described that the main causes of unusual mortality events (UME) and mass strandings from 2015 and 2016 were acute poisoning by biotoxins and strandings by multiple possible causes, respectively, while individual strandings would have their causes in anthropogenic activities, such as entanglements in fishing and aquaculture gears and collisions with vessels. The predominant species in mass strandings was the sei whale (*Balaenoptera borealis*). The geographical area of greatest prominence in mass strandings was the Aysén Region in the Central Patagonia of Chile, while the species mostly involved in individual strandings along the south-central, central, and northern coasts of Chile was the small porpoise (*Phocoena spinipinnis*). The most common gross pathological findings were advance decay of the carcasses and non-specific wounds of different natures.

Keywords: cetaceans ; strandings ; Chile

1. Introduction

Interest in researching cetaceans as conservation targets has increased markedly due to their particular features and charisma [1], their fundamental role in the context of oceanic food chains as top predators and fertilizers of the sea [2], as providers of ecosystem services [3], as bio-indicators of the ocean's health due to their great longevity, and the relevance of their population abundance as a biological tool in carbon sequestration to face climate change [4]. Strandings are undoubtedly one of the best sources to generate data for forensic studies of marine animals [5]. However, years of investigation of these events have led to a broader and more detailed understanding that includes animals found dead on shore, cetaceans found alive on shore, pinnipeds found sick or injured on shore, and animals that are "out of habitat". In some cases, marine mammals found entangled in fishing gear or debris and carcasses found floating in the sea are also considered strandings [6]. There are basically four types of stranding events: According to the number of individuals involved: (1) individual stranding (of a single individual or a mother with a calf, alive or dead), (2) mass stranding (more than one individual, alive or dead), (3) mass mortality and unusual mortality events (UMEs), and (4) out-of-habitat situations [7]. And according to the nature of the event, all four types can fit into two categories: (a) natural strandings (old age, malnutrition, abandonment of offspring, diseases of various etiologies, poisoning by biotoxins, and scape from predators), environmental causes (tides, volcanic eruptions, and earthquakes), and geographical causes (coast with low slope and local anomalies of the earth's magnetic field), and (b) anthropogenic strandings (noise pollution, plastic pollution, hydrocarbon spills, climate change, entanglements in fishing and aquaculture gear, and collisions with boats) [8]. With increasing stress and anthropogenic pressures on the marine environment, the impacts on marine mammals are growing. The sustained expansion in the number of annual cases, whether entangled in fishing gear or victims of collisions with large vessels because of intense maritime traffic [9], added to the inherent difficulties for the implementation of mitigation measures in highly migratory populations, making it imperative to quantify and understand the mechanisms by which these interactions occur. The objective, systematic, and coherent examination of stranded specimens, dead or alive, offers the only and opportune instance to carry out different studies; however, a combination of medical–forensic training and field experience is necessary to reliably evaluate the specimens and search for signs that guide the diagnosis towards its causality [10]. Added to the above, in the Chilean case, due to the geography and great extension of its coastline, monitoring and access to these events is even more complex, hindering the timely arrival of scientific research that helps to clarify the possible causes that generate these events [11]. In Chile, the diversity of cetacean species is abundant; a total of 8 species of mysticetes and 32 species of toothed whales have been recorded [12], reaching 43% of the global number of species described [13]. All cetacean species were declared a natural monument by Chilean regulation (Decree 230/2008); apart from that, the maritime areas of national sovereignty and jurisdiction have been declared a free zone for cetacean hunting (Law 20.293). Despite all the regulations and instruments designed to protect this group of species, there are still threats that affect them (MERI Foundation, undated).

In the case of cetaceans, low adult survival or massive mortality events can have negative consequences for their population abundance. Cetacean mass strandings cause the deaths of up to hundreds of individuals in a single event. They occur in species of mysticetes and odontocetes; however, mass strandings of odontocetes occur more often than those of mysticetes, in part because of pod sizes and social interactions of odontocetes [14]. Recent research suggests that environmental factors, such as seasonal fluctuations or geographic location, would influence the increase in mass

strandings. Despite this, while there have been numerous advanced theories, a few are backed by concrete evidence. There is no single conclusive explanation for all individual and mass strandings around the world [15]. According to a study of 50 years of cetacean strandings in Chile, which used the spatiotemporal permutation model using the space–time scan statistic for the cetacean strandings between January 1968 and August 2018, in Chile, the occurrence of these events is estimated to be 80% more than the global average [16]. Some authors point out that there is a trend towards an increase in these events since 2015 on the country's coasts, plus the difficulty in collecting data in Chile and the dispersion of the information obtained. Various agencies, both state and private institutions, that have registered strandings [16] provide the appropriate context for the generation of improvement initiatives in the collection and review of data and information, as well as the need to develop histopathological diagnostic techniques that will help to clarify the causes responsible for the current state of the strandings in Chile.

2. Probable Causes of Strandings in Chile

2.1. Anthropogenic Factors

(a) Fishing and aquaculture activities. There are mainly two types of interactions with marine mammals associated with fishing and aquaculture activities. On the one hand, those of the direct type (also known as operational or technical) in which the animals usually come into physical contact with the fishing gear or fish-capturing devices generate negative effects for both cetaceans and the targeted species of the fishery. On the other hand, indirect interactions (also known as biological or ecological) are those in which both marine mammals and the fishing industry compete for fish species [17] (Obusan et al., 2016). In Chile, bycatch of dolphins, killer whales, and sperm whales has been reported. Due to these rooted habits, these species currently suffer a deplorable reputation in most fisheries, and in response, they generate very drastic solutions or measures to repel mammals, threatening their survival, not only with those species that interact with fishing activity but also with those that do not, generally due to ignorance [18] (Arata and Hucke-Gaete, 2005). The most common form of anthropogenic trauma for small cetaceans is death by submersion due to bycatch. According to a study through pathological findings at necropsy carried out in 2020, most small and medium-sized cetacean species were affected by drowning when interacting with fishing activity [11] (Alvarado-Rybak et al., 2020a). Diagnosis of this condition is difficult in carcasses with moderate or advanced autolysis; therefore, the real magnitude of this problem is difficult to assess when access to fresh-stranded carcasses is limited. However, another in situ study carried out in south-central and southern Chile highlighted that the most common species affected by bycatch are Commerson's dolphin (*Cephalorhynchus commersonii*), Chilean dolphin (*Cephalorhynchus eutropia*), bottlenose dolphin (*Tursiops truncatus*), and Burmeister's porpoise (*Phocoena spinipinnis*) [16] (Alvarado-Rybak et al., 2019). On the other hand, based on an offshore stranding investigation by the Fisheries Development Institute (IFOP), during 2018 and 2019, small cetaceans of the Delphinidae family were incidentally caught (killer whale, bottlenose dolphin, dusky dolphin, common dolphin, and an unidentified dolphin). The total number of small cetaceans captured was 102, and 39 of them were killed. The species with the highest capture was the common dolphin, with 56 individuals, while the dusky dolphin was the species with the highest mortality, registering 19 dead individuals (IFOP, 2020). Regarding aquaculture, the interaction of marine mammals with this activity is usually negative; animals are affected by the loss of habitat and by the application of erratic mitigation measures, such as nets and acoustic artifacts that prevent the approach but cause the abandonment of the areas or even the death of the animals. Although there are no empirical data on whether the presence of salmon cages directly influences or alters movement patterns or habitat use by dolphins, Chilean dolphins have been observed avoiding salmon farms in fjords [19] (Hucke-Gaete, 2006).

(b) Whale-watching tourism. Whale watching can provide many socioeconomic benefits and could also aid conservation. However, this has many direct and indirect impacts on this group of species [20] (Parsons, 2012). In the short term, drastic changes in immersion times, group cohesion, or changes in speed and direction of movement can be observed in mysticetes [21] (Christiansen et al., 2013). Various behavioral changes were observed in humpback whales in Peru. While groups with calves avoid boats by increasing immersion time, course changes, and decreasing their number of breaths, groups without calves increase travel speed, time on the surface, and the number of breaths [22] (Garcia-Cegarra et al., 2020)

Chile has not been immune to this phenomenon either, due to the great diversity of species that visit the Chilean Sea. Although there are "General Regulations for the Observation of Hydrobiological Mammals, Reptiles, and Birds and the Cetacean Watching Registry" (D.S. No 38-2011), this is little known by tourists and the public. According to an investigation in the Isla Chañaral Marine Reserve, by observing whales through a theodolite, an alteration in the behavior of the fin whale was observed during tourist activity, particularly in reorientation (greater during post-tourism) and linearity (lower with and post-tourism), and in resting behavior (higher during post-tourism). These changes would be related to an evasive response in the presence of tourist boats; however, it is important to note that the intensity of tourism in the study area is moderate, since most of the observations had between one and two boats of tourism and, in a smaller proportion, more than three boats, with a maximum of five [23] (Sepulveda et al., 2017). Despite the latter, there is no record that proves any stranding event in Chile due to this cause.

(c) Collisions. Ship collisions with cetaceans are a major concern in the context of the conservation of these groups of species, whose incidence has increased rapidly due to the increase in global maritime traffic, speed, and fleet size.

This is particularly serious in populations of mysticetes since the groups facing the greatest risk of collisions were the most hunted during the last century, specifically during the whaling season, due to which several of them still have not been recovered [24] (Jackson et al., 2016). Ship collisions can cause acute trauma, with severe cuts to the skin, often compromising subcutaneous tissue and skeletal musculature, as well as limb amputation and/or evisceration. However, it is difficult to determine the pre- or post-mortem nature of these findings without further histopathological studies.

Regarding marine transit in Chile, according to what was observed in the Mejillones Bay, northern region of Tarapaca, Chile, one of the main whale aggregation areas is very close (less than 1000 m) to one of the main routes used by large cargo ships [25] (Pacheco et al., 2015), and, added to this, the navigation routes of fishing vessels coincide with the distribution of small cetaceans. Another issue in addition to the above is the speed of merchant ships, which usually exceeds the maximum limit [22] (Garcia-Cegarra et al., 2020). In Chile, there are published records of three possible collisions between ships and whales. During 2009, the first confirmed collision of a large whale was reported in Chile, which was identified as a female sei whale [8] (Brownell et al., 2009). The second collision report corresponds to the stranding of a blue whale during the year 2014 in the bay of Puerto Montt, region of Los Lagos, which would have arrived dead or dying a few meters from the waterfront of that city; the specimen had an exposed fracture in its right pectoral fin, which could probably be attributed to a collision with a large vessel [26] (CCC, 2014). Later in 2019, a complaint was registered for a collision of a blue whale specimen in the Tarapacá region through the hot line of the Chilean Fisheries and Aquaculture Service (SERNAPESCA) [27] (SERNAPESCA database 2009–2022). In addition to the three previously described vessel strikes, the review of the pathological findings of strandings between 2010 and 2020 revealed two more likely vessel strikes [11] (Alvarado-Rybak et al., 2020a). These animals were found near two ports with high maritime traffic, which could have increased the chances of collision with a ship [11] (Alvarado-Rybak et al., 2020a).

(d) Contamination. Another anthropogenic threat for these mammals is the exposure to high levels of pollutants, both acoustic and due to pollution from industrial activities or fishing operations [28] (Avila et al., 2018). For cetaceans, the threats posed by marine debris are manifold and range from direct impacts on health and mortality to possible secondary effects because of habitat degradation, the transference of chemical pollutants, and effects on prey populations [29] (Baulch and Perry, 2014). Eighty percent (80%) of marine pollution by plastics derives from terrestrial sources. Even in the case of countries like Chile, far from the large centers of production and consumption, there is evidence of incipient contamination by plastic [30] (Elías, 2015).

Heavy metals and non-essential metals, such as mercury, cadmium, and lead, are very toxic, even in small concentrations. Chronic or subchronic exposure to concentrations lower than those producing toxic effects can alter the composition and/or functionality of the immune system [31] (Cámara et al., 2003). According to studies carried out in Chile, the concentrations of both trace elements and persistent organic pollutants measured in pilot whales stranded on the Chilean coast are lower than those reported for the same species from Australia or New Zealand [22] (García, 2020). However, the presence of thallium ion (Tl+), a residue from the metallurgical industry that can produce toxic effects in mammals due to its competition with potassium ion (K+) in metabolic processes, was detected. Given their characteristic longevity and their quality as predators at the highest levels of the food chain in the marine environment, the order Odontoceti is most exposed, and although researchers are aware of the toxic effects that this trace element can cause, their effects on marine mammals are unknown. However, the fact that it was found in remote ecosystems may indicate its persistence in the environment [22] (Garcia-Cegarra et al., 2020), which opens the spectrum of factors to be considered when analyzing the causative agents that influence mass strandings and/or mortality events in Chile.

Noise pollution, or anthropogenic underwater noise, is currently recognized as a global problem, and studies have shown a wide range of negative effects on a variety of taxa [32] (Williams et al., 2015). It can be generated by a variety of activities, such as commercial transportation, oil and its subsea exploration, pipeline development and construction, naval operations (e.g., military sonars), fishing (e.g., acoustic deterrents and harassment devices), research using air guns, icebreakers, and recreational boating [9] (Colpaert et al., 2016). Although there is no confirmed evidence of these activities causing mortalities or mass strandings in Chile, they could all perfectly be part of the “multiple causality of strandings” in Chile. Further studies should necessarily be implemented to confirm it.

2.2. Natural Factors

(a) Biological agents that can lead to death and/or stranding can be viral, fungal, parasitic, and bacterial infections [33] (Starrantino, 2018). It is also important to include stranding events associated with biotoxin poisoning, as occurred in the mass stranding of Golfo de Penas, Chile, during the summer of 2015 [34]. Although in live specimens the assessment of the health status of wild cetaceans is difficult to carry out without handling and capture, the observation of skin lesions allows the identification of diseases such as lobomycosis caused by *Lacazia loboi*, dermatitis caused by herpesviruses, and rhomboid lesions caused by *Erysipelothrix rhusiopathiae*, a disease potentially lethal [35] (Powell et al., 2018). Even the lesions observed in carcasses could also be a source of data for population extrapolation [5] (Geraci and Lounsbury, 2005). In the case of Chile, around the year 2006, the presence of wounds on the skin of Chilean dolphins (*Cephalorhynchus eutropia*) and bottlenose dolphins (*Tursiops truncatus*) was detected for the first time, which could have been related to environmental degradation as an effect of pollution or exotic diseases probably associated with aquaculture. However, more research is needed to test this hypothesis [19] (Hucke-Gaete, 2006). Regarding parasitic infections, according to necropsies carried out on 15 specimens stranded between 2010 and 2019, parasitism and

diseases derived from these agents were observed in some toothed whales, including verminous pneumonia and vasculitis due to *Pseudalius inflexus* in Burmeister's porpoises. This nematode is a parasite that can cause direct mortality or cause secondary bacterial pneumonia with fatal consequences. In the case of respiratory and periotic sinus nematodes within the genus Stenurus, it has been suggested that they can potentially affect hearing and echolocation, and although lesions observed in the study were significant, there is no evidence that they have complicated the escape from entanglements or increased the risk of stranding due to echolocation failures, since to assess the real impact of parasites of Stenurus spp. in Burmeister's porpoises, a histopathologic examination is needed [36] (Alvarado-Rybak, et al., 2020b).

(b) Climatic and seasonal factors, such as El Niño and Harmful Algal Blooms (HABs), can result in domoic acid (DA) production, a neurotoxin that can cause amnesic shellfish poisoning in humans, with symptoms such as vomiting, seizures, memory loss, and disorientation. In the case of marine mammals, such as sea lions and seals, they have shown neurological dysfunction due to brain lesions, especially in the hippocampus, which could lead to maladaptive navigation behavior and consequent mortality in the wild [37] (Bengston, 2016). Although biotoxin poisoning is a biological agent, the reason why it was decided to address in this item is due to its possible relationship with climate change. During 2015 in Golfo de Penas, Chile, an unusual mass mortality episode (UME) was reported, producing by far the largest ever recorded unusual mortality event of baleen whales at one time and place, with the death of 369 individuals in the span of a few weeks, and most probably the number of individuals killed in that event probably exceeded 400 individuals, since those that die offshore tend to sink and not refloat [38] (Smith et al., 2015). In five of the specimens analyzed by necropsy, no signs of human interaction were determined in the deaths of these animals. Also, due to the position of the whales on shore (skull resting on their dorsal part), it was postulated that the animals apparently died while they were still in the water, and the sea currents and winds dragged them to shore; therefore, some authors referred to this event as mass mortality rather than multiple stranding. Traces of toxin were found in the vectors, *Sprattus fuegensis* and *Munida* spp., and in the stomach contents of two necropsied specimens. Additionally, the remains of *Pseudonitzschia* spp. cells in their intestinal content were also found. This is supported by the higher presence of Pseudonitzschia during February and March 2015, measured at the stations of the Chilean Red Tide Monitoring Program [34]. Due to this and to rule out other natural or anthropogenic causes, the most solid and probable hypothesis was that of poisoning by biotoxins from harmful algae blooms (HABs), and although this would have been possibly related to the phenomenon of El Niño [34] (Häussermann et al., 2017), it is relevant to stress the increase in HABs, whether associated with climatic phenomena or the contribution of nitrogen or other nutrients to the sea, and its impact as a possible cause of mass strandings.

(c) Geographic factors: the hypothesis on coastal morphology indicates that shallow, closed bays with wide intertidal differences act as traps for pelagic cetaceans [4] (Perrin & Geraci, 2009). On the other hand, there is evidence that geomagnetic anomalies of the earth are directly related to stranding zones [39] (Mazzariol et al., 2011), in which animals tend to get disoriented, become stressed, and escape to strand on nearby coasts. Although this factor could perfectly be a common natural cause of live stranding events, so far there is no registered evidence of this phenomenon causing the stranding of cetaceans in Chile.

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