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# Blue whales of the Chiloé-Corcovado region, Chile: Potential for anthropogenic noise impacts

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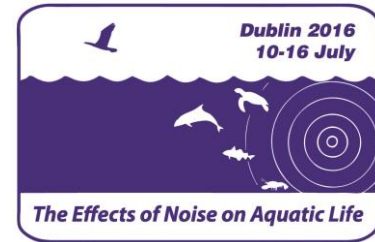
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## Fourth International Conference on the Effects of Noise on Aquatic Life

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## Blue whales of the Chiloé-Corcovado region, Chile: Potential for anthropogenic noise impacts

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Blue whales (*Balaenoptera musculus* spp.) were once abundant in the Southern Hemisphere, but commercial whaling hunted them to near extinction in the previous century. The species is currently listed as endangered on the IUCN Red List of Threatened Species. The Chiloé-Corcovado region in Chile is one of the most important areas in the Southern Hemisphere for blue whales since it functions as a feeding and nursing ground. In recent years, ship traffic has increased considerably in the area and noise pollution is a major concern. We review what is known about blue whales in this area, and also about potential effects of noise on their communication and behavior. Since we still know so little about the functions of blue whale vocalizations, and since reactions to various kinds of anthropogenic noise can be so variable, further research is required to understand the biological implications of the effects of ship noise on blue whale communication and overall fitness in the Chiloé-Corcovado region.



## 1. INTRODUCTION

Blue whales (*Balaenoptera musculus* spp.), the largest animals on Earth, were the principal target of the whaling industry in the early 20th century. After the whaling grounds in the Southern Ocean were opened in 1904, they were hunted to the brink of extinction. Since the 1960s, blue whales have been legally protected by the International Whaling Commission (IWC), although illegal whaling continued into the early 1970s (Laws, 1977; Yablokov, 1994; Clapham et al., 1999; Thomas et al., 2015). Approximately 360,000 blue whales were killed in the Antarctic alone, reducing the population size to less than 1% (Thomas et al., 2015). In the Southeast Pacific, blue whales were primarily taken off Chile, but some were also caught off Peru and Ecuador (Clarke et al., 1978; Ramírez, 1983; Van Waerebeek et al., 1997). The first commercial catches off Chile occurred in 1908 from a land station in San Carlos, Corral (Pastene and Quiroz, 2010), and between 1926 and 1971 ca. 3,000 catches were reported in southern Chile (Aguayo-Lobo et al., 1998). Williams et al. (2011) estimated that the population was reduced to 7.2-9.5% of its original size.

Despite having complete global protection for several decades, overall blue whale population size remains low and their recovery seems slow (Branch et al., 2004; Branch and Mikhalev, 2008). Indeed, the current global status for blue whales is 'Endangered' according to the IUCN red list (IUCN, 2016), and their recovery is now a key international conservation goal (Roman et al., 2014).

Outside Antarctic waters, aggregations of blue whales in the Southern Hemisphere are poorly understood (Branch et al., 2007a) and only a few feeding areas are known (Gill, 2002; Cabrera et al., 2005; Huckle-Gaete et al., 2004; Galletti Vernazzani et al., 2012). Discovery and scientific monitoring of readily accessible aggregations is therefore of utmost importance to conserve the species. Today, one of the main concerns for coastal marine mammals is the loss of critical habitat due to an increase in human activities. Animals need these critical areas to perform essential biological activities such as feeding, calving or socializing (Huckle-Gaete et al., 2004; Galletti Vernazzani et al., 2012).

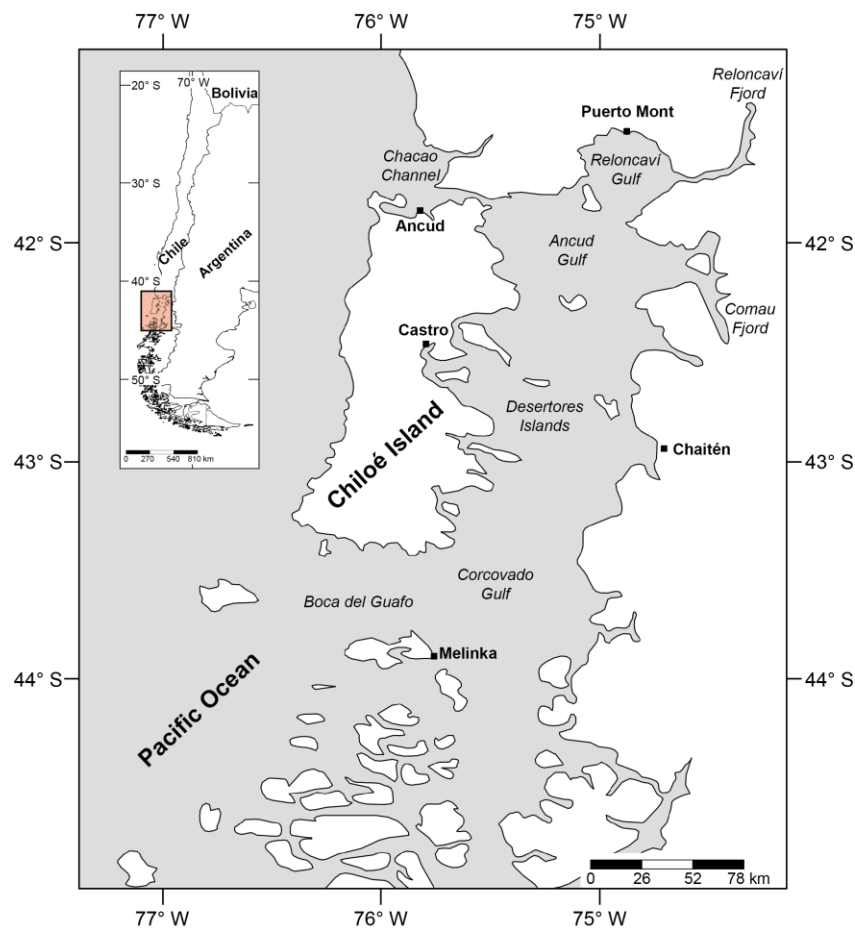
Recently, one of the most important feeding and nursing areas for blue whales in the Southern Hemisphere was discovered in the Chiloé-Corcovado region in Chilean Patagonia (Huckle-Gaete et al., 2004). The combination of astounding landscapes, clean semi-enclosed water bodies and significant bodies of freshwater is increasingly attracting the attention of new stakeholders to this area, including developers associated with hydroelectricity, tourism and aquaculture. While the increase in economic development is beneficial to the local community, due to new infrastructure and jobs, these activities also pose serious challenges to the natural heritage of the area (Pantoja et al., 2011). The increase in human activity has led to a considerable increase of ship traffic during the last decade as a result of more cargo and supply shipping for the salmon industry as well as public transportation, tour boats and fishing. The main threats originating from shipping traffic are collisions (Huckle-Gaete et al., 2005), accidents (e.g. oil spills) and noise pollution (Huckle-Gaete et al., 2013). The latter is a major concern because the use of sound for communication and acquisition of information about the environment is a very important aspect of the lives of baleen whales and marine mammals in general (Tyack and Miller, 2002).

In this review paper, we summarize what is known about the Chiloé-Corcovado region and its population of blue whales. We also describe several threats posed to blue whale conservation, with a focus on the potential impacts of anthropogenic noise.

## 2. SOUTHEAST PACIFIC BLUE WHALES

### A. Chiloé-Corcovado region

Corcovado Bay (Figure 1) is part of the Los Lagos administrative region (region X; Molinet et al., 2014), and according to the classification of Marine Ecosystems of the World (MEOW), defined by Spalding et al. (2007), it belongs to the Chiloense Ecoregion (CER). It is situated in the southeastern border of the Pacific Ocean in Chilean Patagonia, one of the most important and extensive fjord regions in the world. Patagonia extends from the Reloncaví Fjord ( $41^{\circ}31'S$ ) to Cape Horn ( $55^{\circ}S$ ), covering almost 240,000 km<sup>2</sup>. This zone is characterized by a highly fragmented coastline and is composed of many islands, peninsulas, channels and fjords (Silva and Palma, 2008). The general oceanographic conditions affecting this area are under the direct influence of the West Wind Drift (WWD) or the Antarctic Circumpolar Current (Viddi et al., 2010).



**Figure 1:** Map of the Chiloé-Corcovado region (map created with Shorthouse (2016)).

The bulk of the oceanic west-driven currents encounter the South American continent around  $42-48^{\circ}S$ , splitting into a northern component, the Humboldt Current (HC), and a southern component, the Cape Horn Current (CHC). These currents transport Subantarctic Surface Water (SASW) north, towards the Equator, and south, along the contour of the South American coast. The SASW also enters the southern Chilean channels and fjords, where it mixes with fresh water from rain, rivers, coastal runoff and glacial melting, generating one of the largest estuarine

systems of the planet (Longhurst, 1998; Palma and Silva, 2004; Silva et al., 2009). The interaction of the WWD, SASW, tidal currents and fjord freshwater (glacier melt, river drainage and copious precipitation) defines a strong vertical and horizontal salinity gradient (Palma and Silva, 2004; Viddi et al., 2010), conditions that are favorable to high productivity.

Primary production in the CER is high and strongly seasonal, peaking in spring/summer (Gonzalez et al. 2010), when it exceeds 10 mg Chl-a/m<sup>3</sup> (Hucke-Gaete, 2004, Montecino and Pizarro 2006). Not surprisingly, the CER is a hotspot of terrestrial and marine biodiversity (Catalan et al., 2011). The Chiloé Interior Sea is home to a wide range of marine species such as cold-water corals (Försterra and Häussermann, 2003), penguins, marine and freshwater otters, many migratory bird species, Chilean and Peale's dolphins, and humpback and blue whales (Hucke-Gaete et al., 2004; 2010, 2013; Häussermann et al., 2012; Viddi et al., 2010).

Blue whale foraging success depends not only on the abundance of euphausiid aggregations, but also on their density (Goldbogen et al., 2011). An individual blue whale requires  $1120 \pm 359$  kg of euphausiids per day in order to meet its energetic demands. Individuals concentrate foraging within relatively small areas, usually under 1 km<sup>2</sup> (Acevedo-Gutierrez et al., 2002). Blue whale distribution is therefore driven by the attraction of whales to areas where high euphausiid densities are predictable as a result of high levels of primary productivity caused by upwelling, topographic breaks, and/or frontal regions (e.g. Croll et al., 1998, 2005; Branch et al., 2007a; Gill et al., 2011), such as occur in the CER. The dominant mesozooplankton species in this area, the euphausiid *Euphausia vallentini* (Antezana 1976), doubles in abundance between winter and spring (Gonzalez et al. 2010) and probably peaks in late summer (Croll et al. 2005).

The CER supports a robust population of blue whales; based on line-transect surveys conducted from the IWC-SOWER 1997/98 blue whale cruise off central Chile (Findlay et al., 1998), Williams et al. (2011) estimated 303 animals (95% Confidence Interval = 176-625) between north (18° S) and central Chile (38° S). Galletti-Vernazzani et al., (2012) photo-identified 363 individuals between 2004 and 2010 off Isla Grande de Chiloé in the CER. They had an overall annual return rate of 31%, which shows high site fidelity. Between-year resightings of blue whales that matched individuals identified in east Corcovado Gulf and northern Los Lagos support the idea that the blue whale feeding grounds in the CER is large and dynamic. The high sighting rate, number of identified individuals and the degree of site fidelity shows that the waters off Isla de Chiloé and northern Los Lagos contain the largest aggregation known for this species in Chile and one of the largest currently known in the Southern Hemisphere (Galletti-Vernazzani et al., 2012).

## B. Chilean blue whales

### i. Unnamed subspecies

Within the Southern Hemisphere, two different subspecies of blue whales have been recognized (Ichihara, 1966; Branch et al., 2007a, b): the true or Antarctic blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*Balaenoptera musculus brevicauda*). Both subspecies were caught off the coast of Chile (Aguayo, 1974). However, later evidence suggests that the blue whales present off the Chilean coast are actually a separate subspecies, as originally proposed by Clarke et al. (1978). This is supported by their discrete summertime distribution, as well as body length data (Branch et al., 2007b; Gilpatrick and Perryman, 2008), genetic analyses (Conway, 2005; LeDuc et al., 2007; Torres-Florez et al., 2014), (Branch et al., 2007a) and a distinct acoustic repertoire (Cummings and Thompson, 1971; Buchan et al., 2010, 2014). Adult female blue whales caught off Chile were reported to have an intermediate length, between the total lengths of the two subspecies (Branch et al., 2007b). In



terms of genetic differences, a recent study (LeDuc et al., 2007) identified mitochondrial and nuclear differences, using molecular markers, between blue whales from the Indian Ocean, the Antarctic and from the eastern south Pacific. Torres-Florez et al. (2014) also found the three blue whale populations to be genetically different. Finally, blue whale songs recorded in the waters of southern Chile are different from those of pygmy and Antarctic blue whales (McDonald et al., 2006; Buchan et al., 2010; 2014).

It is generally thought that southern hemisphere blue whales undergo north-south migrations, between high-latitude summer feeding grounds and low-latitude calving grounds (Mackintosh and Wheeler, 1929). During austral summer, pygmy blue whales and Antarctic blue whales are believed to remain largely segregated, with Antarctic blue whales feeding south of the Antarctic convergence and pygmy blue whales feeding north of the convergence (Kato et al., 1995; Branch et al., 2007a, b; Attard et al., 2012; Torres-Florez et al., 2014).

In contrast to the feeding areas, little is known about the location of breeding ground(s) used by any of the blue whale subspecies (Torres-Florez et al., 2014). It is believed that the Eastern Tropical Pacific (ETP) might be a breeding area for many blue whales from Chilean feeding aggregation areas (Mackintosh, 1942; Reilly & Thayer, 1990; Torres-Florez et al., 2014). Chilean blue whales are believed to follow a north-south migration route based on satellite tracking data from the CER feeding ground (Hucke-Gaete et al., 2004) and an acoustic link (the same song type) between the CER and the Eastern Tropical Pacific (ETP; Stafford et al., 1999b; Buchan et al., 2014). Recently, a match (both photographic and genetic) was made for a female sampled first near the Galapagos and then in the Gulf of Corcovado, Chile, just south of Chiloe (Torres-Florez et al., 2015). This is the first solid link between the feeding area and a likely breeding area for this population (Thomas et al., 2015). However, it has also been suggested that blue whales off the north coast of South America are part of a resident ETP population (or ‘Galapagos biostock’; Berzin, 1978; Donovan, 1984; Palacios, 1999; Gilpatrick and Perryman, 2008). Sighting data (Findlay et al. 1998), as well as some recent records (Abramson & Gibbons 2010, Försterra & Häussermann 2012), have documented the presence of blue whales in the Chiloense Ecoregion until the beginning of July (austral winter; Buchan et al., 2014). Based on molecular techniques, Torres-Florez et al. (2014) suggest that Chilean blue whales from the CER could be part of a large Southeast Pacific population, which separates into smaller subgroups during the austral summer feeding season. It is therefore possible that there might be a constant flow of animals between the two sites whereby animals are not resident in one particular site, but each area is occupied year-round (Buchan et al., 2015).

Chilean blue whales are currently recognized as a separate unnamed subspecies (Committee on Taxonomy, 2016) and are managed as a separate population. However, they still remain one of the least understood populations of blue whales worldwide (Thomas et al., 2015).

## ii. Vocalizations

Blue whale vocalizations have a frequency range of 16-100 Hz and documented source levels of 188 dB re 1 uPa (Cummings and Thompson, 1971; Stafford et al., 1998; McDonald et al., 2001; Širovic et al., 2007). The biological functions of blue whale vocalizations, as with other mysticetes, are not well understood. Social functions proposed for these sounds include: foraging, mating and parental behavior, long range contact, assembly, sexual advertisement, greeting, spacing, threat, individual identification and sensing of the environment (Tyack, 1999, 2000; Clark and Ellison, 2004; McDonald et al., 2006). The acoustic behavior of mysticetes known as singing is defined as the production of a limited number of stereotypic sound types in regular succession that form a recognizable pattern in time (McDonald et al., 2006). A song sequence is made up of individual sounds or ‘units’ which occur in repeated ‘phrases’. Blue

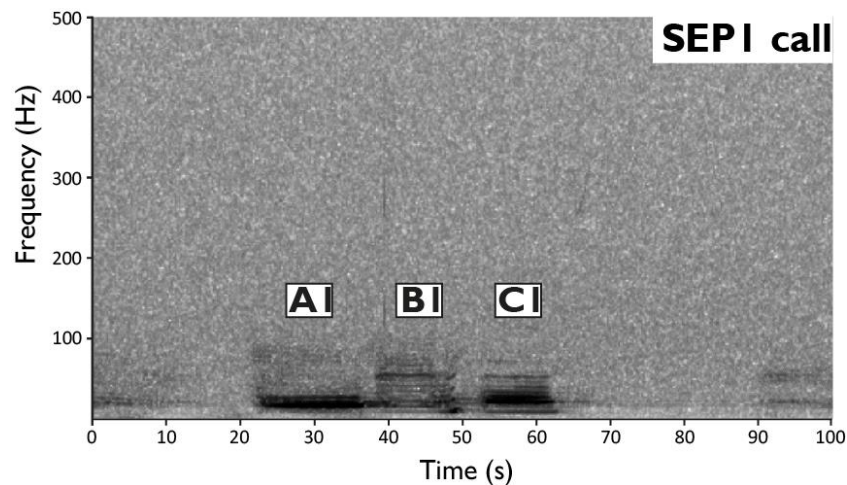
whale song types have been characterized based on differences in some or all of the following criteria: song phrasing (e.g. ABABAB or ABCABC, where A, B and C represent different song units); inter-unit time interval; total phrase duration; and unit characteristics (e.g. frequency, duration) (Buchan et al., 2014). Variability within song types is found to be minimal relative to the variation among song types, and song characteristics are believed to remain relatively stable over a forty-year period (McDonald et al., 2006). Blue whales worldwide have acoustically distinct populations, or acoustic groups, each with distinct song types, geographic ranges, migration routes and seasonal residencies (e.g. Stafford et al., 1999a, b, 2001, 2011; Mellinger and Clark, 2003; McDonald et al., 2006; Samaran et al., 2013). Distinct song types consist of entirely different units characterized by peak frequency, duration and modulation characteristics. Song types can therefore be used to examine recent distribution changes that are relevant for conservation management (McDonald et al., 2006; Buchan et al., 2014).

Chilean blue whales have two distinct song types (Buchan et al., 2014). The first ever recorded song of a blue whale was of the SEP1 song type, obtained in May 1970 near Guafo Island (Cummings and Thompson, 1971). The same song type (SEP1) was recorded again in 1996 from a fixed hydrophone in the ETP (Stafford et al., 1999b). The second song type (SEP2), recorded along with SEP1 calls in the ETP, was first described as a variant (the same units of a given song type, but in different proportions or temporal sequences) by Stafford et al. (1999b), but was later defined by Buchan et al. (2014) as a new song type.

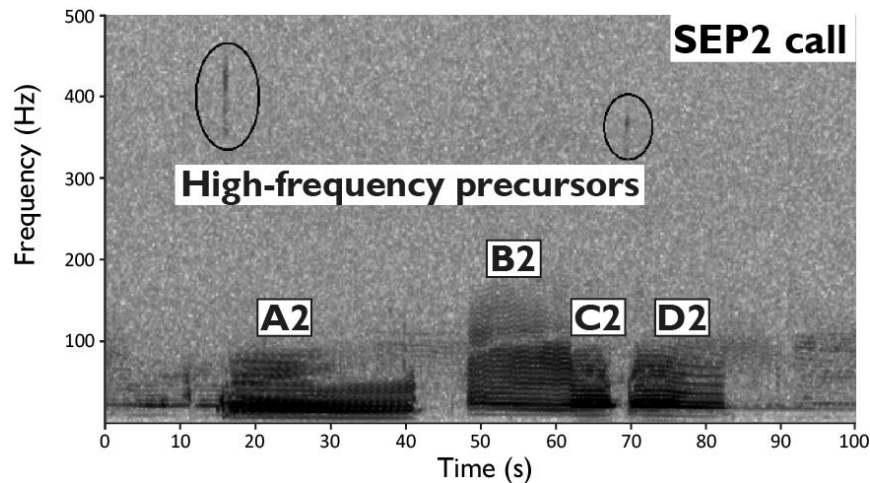
SEP1 calls (Figure 2) are composed of 3 units (A1–B1–C1) and the total call lasts on average 33.9 s according to Buchan et al. (2014), 36.5 s according to Cummings and Thompson (1971) and 38.8 according to Stafford et al. (1999b). There is a gap between units B1 and C1 (2.5 – 5 s) where a short, high-frequency pulse (0.7 s) may occur. Buchan et al. (2014) reported this pulse at 350 Hz and Cummings and Thompson (1971) observed it at 390 Hz. SEP2 calls (Figure 3) are composed of 4 units (A2–B2–C2–D2) and their total duration averages 59.6 s. Units A2 and D2 are preceded by high-frequency pulses of 414 and 356 Hz respectively (Buchan et al., 2014). Most of the energy of both calls occurs below 200 Hz.

The presence of two song types could either indicate two distinct blue whale acoustic groups that exploit the same feeding area during similar times of the year, or it could indicate the presence of a single acoustic group with higher levels of song type variation than previously described for blue whales. The latter could be due to different behavioral contexts or simply individual variation. The similar seasonality of SEP1 and SEP2 in the CER and ETP would suggest common migration and would therefore suggest that both songs stem from the same population. The striking similarity between the two song types could suggest that both evolved from a common ‘stock source’ (Buchan et al., 2014), or that SEP2 song is derived from SEP1.





**Figure 2: Spectrogram of SEP1 call.** Spectrogram was created with RavenPro 1.4 with the following settings: 2000 DFT size, 50% overlap and the Hann window function.



**Figure 3: Spectrogram of SEP2 call.** Spectrogram was created with RavenPro 1.4 with the following settings: 2000 DFT size, 50% overlap and the Hann window function.

### 3. ANTHROPOGENIC IMPACTS

Campbell et al. (1999) and Thomas et al. (2015) provide an overview of the various threats to baleen whales and the status of their populations. Thomas et al. (2015) make a distinction between acute or lethal threats (e.g. whaling, entanglement in fishing gear and ship strikes) and sublethal or chronic threats (e.g. anthropogenic noise, pollution, climate change, ocean acidification).

Anthropogenic noise is of particular concern with respect to baleen whales, because of their reliance on sound for communication and perhaps other functions (Richardson et al., 1995; Nowacek et al., 2007; Southall et al., 2007; Moore et al., 2012). Disturbance by noise has lately become much more apparent due both to greater efforts to monitor and measure underwater noise, and to technological advances in measurement. In addition, activities that generate anthropogenic noise continue to increase (Reeves et al., 2014; Thomas et al., 2015). Anthropogenic noise can be generated by a variety of activities, such as commercial shipping, oil and gas exploration, development and construction, naval operations (e.g. military sonars),

fishing (e.g. acoustic deterrent and harassment devices), research (e.g. air-guns), construction, icebreaking, and recreational boating (Hildebrand, 2009).

A first negative consequence of noise is that it can impede a receiver's ability to understand, recognize or detect sounds of interest, reducing the range of communication; this is referred to as masking (Tyack, 2008; Clark et al., 2009). Masking has been suggested to have the potential to impact individual fitness (Erbe et al., 2016). The definition of masking according to the American National Standards Institute (2008) is the process by which the threshold of hearing for one sound is raised by the presence of another (masking) sound, and the amount by which the threshold of hearing for one sound is raised by the presence of another (masking) sound (in dB). Of all the ways in which noise can affect the lives of marine mammals, masking might be the most pervasive. However, it is very difficult to predict masking levels for any particular combination of sender, environment and receiver characteristics (Erbe et al., 2016).

Early masking studies in humans showed that tonal signals (having discrete frequencies) are most effectively masked by tonal sounds or broadband noise with similar frequencies (Wegel and Lane, 1924; Fletcher, 1940). Further studies revealed that this principle of masking also applies to other mammals (Scharf, 1970; Fay, 1988). Since noise from commercial shipping occurs in the same frequency range as the vocalizations of blue whales (and baleen whales in general), these animals are particularly vulnerable to effects of masking from ever-increasing amounts of ship noise.

Anti-masking compensation strategies used by cetaceans are quite variable among species, populations and different types of noise. Melcón et al. (2012) found that blue whales in the Southern California Bight produced fewer D-calls in the presence of mid-frequency active sonar, and more D-calls in the presence of ship noise. In contrast, McKenna et al. (2009) detected fewer blue whale calls in the presence of commercial ships. While McDonald et al. (1995) and Clark and Gagnon (2006) found that travelling blue and fin whales stopped vocalizing when exposed to seismic airguns, Di Iorio and Clark (2009) found that blue whales in the St. Lawrence Estuary (Canada) vocalized consistently more on seismic exploration days. Besides affecting the communication range, noise can affect animals in a variety of ways. For example, animals may avoid important habitats because of anthropogenic noise (Tyack, 2008).

Preliminary results of an ongoing study by Colpaert et al. (submitted) suggests that ship noise seems to change communication behavior of Chilean blue whales and potentially reduces their communication range. Other ongoing research in the area is focusing on characterizing the vocal repertoire of Chilean blue whales using DTAGs (Bocconcelli et al., current issue). Further steps to understand the vocal behavior of these whales should include linking vocalizations to behavior, perhaps by using a similar method as Oleson et al. (2007): acoustic recording tags and simultaneous visual and acoustic tracking. In order to characterize the anthropogenic noise in the area, AIS (Automatic Identification System) data could be analyzed following the methods described by Hatch et al. (2008; 2012).

## 4. CONCLUSION

The Chiloe-Corcovado region hosts one of the most important aggregations in the Southern hemisphere for the endangered blue whale. Increased interest in the area for aquaculture, fisheries and tourism causes a concomitant increase in threats for cetaceans, such as ship strikes and anthropogenic noise. Since we still know so little about the functions of blue whale vocalizations, and since reactions to various kinds of anthropogenic noise can be so variable, the potential impacts of changing vocal behavior and missing information are unknown. Further

research is required to understand the biological implications of the effects of ship noise on blue whale communication and overall fitness in the Chiloé-Corcovado region.

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