First aerial surveys to estimate abundance of blue whales off southern Chile

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ABSTRACT

Blue whales (*Balaenoptera musculus*) were heavily exploited in the southern Hemisphere during commercial whaling with about 3,000 blue whale catches reported off Chile. Although recent surveys have documented the presence of blue whales in waters off southern Chile, abundance estimates of blue whales in this feeding area, necessary to provide baseline information for the development and monitoring of future conservation measures, are lacking. Here we present the results of two aerial surveys using standard distance sampling techniques conducted in 2007 and 2009. Abundance estimates using uncorrected data were 44 (CV=0.62) individuals in 2007 and 50 (CV=0.32) individuals in 2009. An estimate for g(0) was made based on the proportion of time blue whales are at the surface. Abundance estimates with correction factor for g(0) increased to 96 (CV=0.65) individuals in 2007 and 110 (CV=0.38) individuals in 2009. The increase in abundance estimate from 2007 to 2009 does not reflect necessarily an increase on abundance but rather differences in the surveys coverage area. Blue whale abundance is considered to be low and therefore any lethal, anthropogenic impact needs to be avoided.

INTRODUCTION

Two subspecies of blue whales are currently accepted in the southern hemisphere: the pygmy blue whale (*Balaenoptera musculus brevicauda)* in the Subantarctic zone; and the Antarctic or true blue whale (*B. m. intermedia*) that summers in the Antarctic Zone (Rice, 1998). Blue whales in Chilean waters have been classified as either Antarctic blue whales or pygmy blue whales (Aguayo L. 1974). However Branch *et al.* (2007a) have shown, based on the length frequency of adult females, that blue whales captured off Chile fall between the two described Southern Hemisphere subspecies and therefore may represent a unique population or a different subspecies. Although more data are needed to resolve this question, the IWC (2006) agreed that the blue whales off Isla de Chiloe differ from Antarctic blue whales.

During the 20th century, blue whales became a principal target of the whaling industry, notably following the opening in 1904 of the rich whaling grounds in the Southern Ocean. Knowledge of blue whale populations is limited and few data are available to assess the status of the different populations, particularly in the Southern Hemisphere (Clapham *et al.*, 1999). In Chile, catches of approximately 3,000 blue whales were reported between 1926 and 1971 (Aguayo *et al.* 1998).

Recent surveys have documented the presence of blue whales in the waters of the northern Los Lagos region (Galletti Vernazzani *et al*., 2006), the outer coast of Isla de Chiloe (Cabrera *et al*., 2005), the Golfo de Corcovado, and the Chonos Archipelago, Chile (Hucke-Gaete *et al*. 2004). Systematic research conducted by Centro de Conservación Cetacea (CCC) highlights the northwestern of Isla de Chiloe to be an important feeding area for blue whales (Cabrera *et al*., 2006; Galletti Vernazzani *et al*, 2005, 2006, 2007, 2008) with sighting rates among the highest in the Southern Hemisphere (Branch *et al.,* 2007b).

Despite this new information, there is a paucity of data on blue whale distribution and density for a large proportion of the Chilean coast. In particular, abundance estimates for the feeding ground off southern Chile are lacking and therefore management efforts may be delayed. With the conservation status of this species uncertain, it is critical to conduct studies to fill in these data gaps. Based on data obtained from the 1997/98 SOWER survey that searched the region from 18°30′S to 38°S, a first approximation of blue whales abundance off Chile for 1997 was estimated to be 452 (CV = 0.56, 95% CI: 160–1300) (Branch *et al.,* 2007c). Although valuable, the survey was designed primarily to maximize blue whale encounters and therefore, there was not equal coverage probability design. In addition, the survey did not cover the territorial waters off Chile (up to 12 n.miles) or the region south of 38°S, compromising the robustness of the abundance estimate.

Surveys using fixed-wing aircraft and distance sampling methodology have been extensively used to study distribution and to estimate abundance of cetaceans. In aerial surveys, the detection probability of individual animals is likely to be lower than ship based surveys due to diving behaviour. Although a correction factor for missed animals has to be included, this method does not require any correction for responsive movement and allows a large area to be covered within a short window of good weather (Slooten *et al*., 2002).

The weather conditions off southern Chile are very unstable and justify the use of aerial surveys to monitor extensive areas in a short period of time. The possible increase of vessel collision on blue whales off southern Chile highlights (Galletti Vernazzani *et al*. 2008) the need to determine blue whale abundance on the southern Chile feeding ground to provide baseline information for the development and monitoring of future conservation measures. Here we present results of the first aerial surveys designed to estimate the abundance of blue whales in the feeding ground off southern Chile.

MATERIAL AND METHODS

Survey design and protocol

Since December 2003 to April 2009, nine aerial surveys to monitor blue whale distribution and relative abundance have been conducted in southern Chile (39^{o}S-44^{o}S) thanks to the support of the Chilean Navy (DIRECTEMAR). In addition, six additional aerial surveys were conducted in central-southern Chile (36-39^{o}S). Sightings distribution has been used to define the survey coverage area and the time when the population density was expected to be at its highest.

All aerial surveys were conducted from shore up to a maximum of 20nm. As no blue whale sightings were recorded from 36^{o}S to 40^{o}S, the coverage area to conduct line transect surveys was define from 39.8^{o}S to 44.1^{o}S to ensure that sample density is representative of the entire study area. Two aerial surveys using line-transect methods were conducted in March 2007 and April 2009. In 2007, the maximum distance from shore varied from 10 to 20 nm and in 2009, the maximum distance from shore was 15nm and the area covered was reduced because of aircraft availability (Figure 1).

Surveys were carried out using a four-seat, twin engine Cessna Skymaster aircraft with flat windows. The aircraft, provided by the Chilean Navy, was flown at an average altitude of 900 feet and an average airspeed of 120 knots. The transect lines and location of whales were recorded using a Garmin e-trex Global Positioning System (GPS). The survey in 2007 was conducted with a sea state of Beaufort 0-1 and in sea state of Beaufort 1-3 in 2009. Weather and sea conditions were recorded at the start of each transect or whenever weather conditions changed.

When a group of whales was sighted, trained observers measured the downward angle to the group perpendicular to the aircraft's track (at 90^{o}) using a hand-held clinometer (Suunto PM5/360PC). Species, location, time, group size, behaviour and vertical angle were recorded by each observer.

Since blue whales are highly visible from the air, surveys were conducted in 'passing mode' (i.e. the aircraft did not leave the trackline to investigate a sighting) (Buckland *et al*., 1993), except when species identification or group size were uncertain and close to the trackline. In these cases, survey effort was broken off to circle the animals and then the trackline was resumed at the break point. Additional sightings off record are not included in the analyses.

Data Analyses

Abundance estimates were obtained using the standard line transect formula (Buckland *et al.* 1993) and program DISTANCE 5.0 (Thomas *et al.* 2006).

Initially, the area was divided into two strata: the west coast off southern Chile to conduct zig-zag tracklines; and the Corcovado Gulf to conduct parallel tracklines. The coastal start point of one transect within each section was chosen randomly. However, due to logistics restrictions during both aerial surveys, tracklines were modified in the field. Therefore in 2007 no stratum was used in analyses. In 2009, the Corcovado Gulf could not be flown to ensure equally coverage probability and therefore we conduct two different analyses without stratification: one utilizing the entire survey; and the other, excluding the Corcovado Gulf.

Perpendicular distances were calculated using the aircraft's altitude and the declination angle to the sighting. Flat windows do not allow observers to see animals at declination angle between 60° to 90° and this limitation can cause poor fit of the detection curve at the origin. No monotone constraint was used to fit the model. Perpendicular distances were also right-truncated at 5km (i.e. 5% to 10% of the observations as recommended by Buckland *et al*. 1993) to improve the fit of the detection function near the origin. Expected group size was estimated as a simple mean of observed group size since the regression of log school size against the detection function g(x) was not significant at the 0.15 level.

Various models were then tested to distances, including the uniform function, half-normal function, the hazard rate function and the negative exponential with cosine or simple polynomial adjustments. The model that best fit the data was selected according to the Akaike Information Criterion (AIC, Akaike 1973).

Some "unidentified rorqual" observations (n=7) were recorded during the 2009 survey. However, considering that more than 91% of confirmed sightings were blue whales, almost all "unidentified rorqual" groups (n=6.4) could be considered as blue whales.

Finally, since the detection probability on the trackline, *g*(0), is not equal to 1 in aerial surveys (availability bias), the probability of detecting a blue whales was estimated following the approach of Barlow *et al.* (1988):

$$g(0) = (s+t)/(s+d)$$

where *s* is the average time a blue whale group is at the surface (i.e. time animals remain on the surface of the water for a blow series before diving), *d* is the time the whale is submerged and *t* is the time the whale is within the visual range of an observer.

In situ measurements from boat-based surveys were taken in 2009 to estimate the proportion of time each group of whales spent at the surface by dividing the amount of time the group was at the surface by the total amount of observation time. Each observation period consisted of a sequence of times at which the whales became visible as they surfaced and disappeared again to dive. During the 2009 aerial survey, the duration of visibility of any object at the surface of the sea, using a chronometer, was recorded to estimate the time that an animal was visible from the aircraft's window (*t*). The estimate of g(0) as a correction factor was then calculate as the mean of the proportions obtained for each group.

RESULTS

The total number of blue whale sightings and effort considered in the analyses are presented in Table 1. As expected, the greatest numbers of sightings were made in northern Los Lagos and west Isla de Chiloe (Figure 1). These areas have been reported to have the highest sighting rates of blue whales in southern Chile (Galletti Vernazzani *et al*., 2008).

Table 1 – Components considered in different analyses

Survey	Groups	Individuals	Area (km^2)	# of Transect	Effort (km)	Sighting rate (groups/km)
2007	14	18	19,700	26	1020.3	0.0137
2009	24	33	16,500	25	895.6	0.0268
2009 – excluding Corcovado Gulf	24	33	8,500	22	720.3	0.0333

Truncation at distances beyond 5km excluded one sighting in 2007 and two sightings in 2009 from analyses (i.e. between 5-10%). The models that best fit the detection function based on its minimum AIC value were the hazard-rate function with cosine adjustment in 2007 (Figure 2) and the uniform function with simple polynomial adjustment in 2009 (Figure 3).

Mean school size was 1.30 (SE=0.13) in 2007 and 1.40 (SE=0.12) in 2009. Estimated search half width was 3,751.9m (CV=0.35) in 2007 and 3,662.5m (CV=0.14) in 2009.

Estimated abundance was 44 (CV=0.62) in 2007 and 70 (CV=0.35) in 2009 or 50 (CV=0.32) excluding Corcovado Gulf.

Based on 26 observations from boat-based surveys, the time spent by each group of whales at the surface varied from 60s to 192s while the time each group was submerged (d) varied from 210s to 487s. The time animals were visible from the aircraft window (t) varied from 50s to 70s depending on declination angle. The estimate for *g* (0) as a correction factor was 0.4546. Abundance estimates increased with correction factor to 96 (CV=0.62) in 2007 and 172 (CV=0.35) in 2009 or 110 (CV=0.32) excluding Corcovado Gulf (Table 2).

Table 2 – Estimated abundances for each survey analyses with and without correction factor for g(0)

Survey	Without correction factor for g(0)			With correction factor for g(0)		
	N	**CV**	**95% CI**	**N**	**CV**	**95% CI**
2007	44	0.62	14 - 138	96	0.62	30 - 304
2009	70	0.35	35 - 140	172	0.35	86 - 342
2009 – excluding Corcovado Gulf	50	0.32	26 - 95	110	0.38	58 - 209

DISCUSSION AND CONCLUSIONS

Line-transect abundance estimates can be biased by failure to meet a variety of assumptions. In this case, the exclusion of individuals in the population outside of the study area limits the scope of the abundance estimate. Therefore, these estimates should be considered as abundance estimates of blue whales in the known feeding ground off southern Chile rather than abundance estimates for the blue whale population in Chilean waters.

The main disadvantage of the aerial surveys conducted was the absence of bubble windows preventing observations directly below the plane. Perception bias can introduce a negative bias, but this may be considered to be negligible in the detection area (between vertical angle 0^{o} to 60^{o}), as blue whales are highly visible and therefore easy to detect, and no correction is necessary for responsive movement. Availability bias, when animals are missed because they are beneath the surface, has been corrected by estimating g(0) according to in-situ records of the proportion of time blue whales were at surface in northwestern Isla de Chiloe. Although this technique reduces negative bias present in the analyses with no correction factor, it might introduce a positive or negative bias because a greater sample size over longer periods is needed to better asses the correction factor. Passing mode may also introduce a negative bias as some individuals in a group are not seen.

We consider that the best abundance estimates in 2009 is represented by the analyses that excludes Corcovado Gulf since the survey did not ensure an equal coverage probability in that area and therefore an important assumption is violated.

Nevertheless, the higher abundance estimate in 2009 than in 2007 does not necessarily reflect an increase in the blue whale population present in southern Chile. We believe this increase is due to the survey area coverage and animal density, since 2007 and 2009 were the two years of the six-years study under the Alfaguara Project that whales were located further offshore, and in 2007 the area covered in west Isla de Chiloe during the line-transect survey was from shore to only 10nm and several animals might been missed.

Considering that this is the first study based on aerial surveys to estimate blue whales abundance in southern Chile and that weather conditions make it difficult to conduct complete area coverage from marine surveys, we believe that aerial surveys with distance sampling techniques can be a successful method to monitor blue whale abundance and population trends, as long as consistent data collection and survey area coverage are used throughout the years.

Photo-identification studies off northwestern Isla de Chiloe has reported 250 individual collected from 2004 to 2008 (Galletti Vernazzani *et al*., 2008) and abundance estimates for blue whale population off Chile in 1997 could be around 452 (Branch *et al*., 2007c). The relatively low abundance estimates obtained from line-transect surveys in the feeding ground off southern Chile may indicate that blue whales move outside this area and probably have more than one area in inshore and/or offshore waters of Chile and/or Eastern South Pacific yet to be discovered where they concentrate and feed during austral summer and fall.

During the 1997/1998 SOWER cruises, concentrations of blue whales were reported off Chile, off Iquique (18°30′S to 23°S and east of 72°W) and between Valparaiso and Talcahauno (31°S to 40°S and east of 75°W) (Branch *et al*., 2007c). However, these cruises were conducted in December, at a time when no blue whale sightings have been recorded off Isla de Chiloe from marine or aerial surveys (pers.obs. BGV and EC) and therefore those areas are not necessarily used when blue whales are aggregated in southern Chile.

In any case, abundance estimates of blue whales off Chile and on the feeding ground off southern Chile are considered to be low. From a conservation perspective, concerns regarding the high volume of large vessel traffic and high concentration of blue whales in southern Chile, particularly in northern Los Lagos (Galletti Vernazzani *et al*., 2008), as well as the occurrence of skin lesions on individuals of this population (Brownell *et al*., 2008) are further strengthen by this study. Considering the small population estimate, any lethal anthropogenic impact on blue whales must be avoided as well as any impact on the ecosystem processes critical to their summer feeding ground.

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Figure 1 – Survey area and blue whale sightings. a) 2007 Line transect survey. b) 2009 Line transect survey. Dot = sightings of blue whales

a) 2007 line transect survey

b) 2009 line transect survey
(Dashed line to the south indicate Corcovado Gulf area)

Figure 2 – Distribution of perpendicular distances from 2007 aerial survey and the fitted detection function.

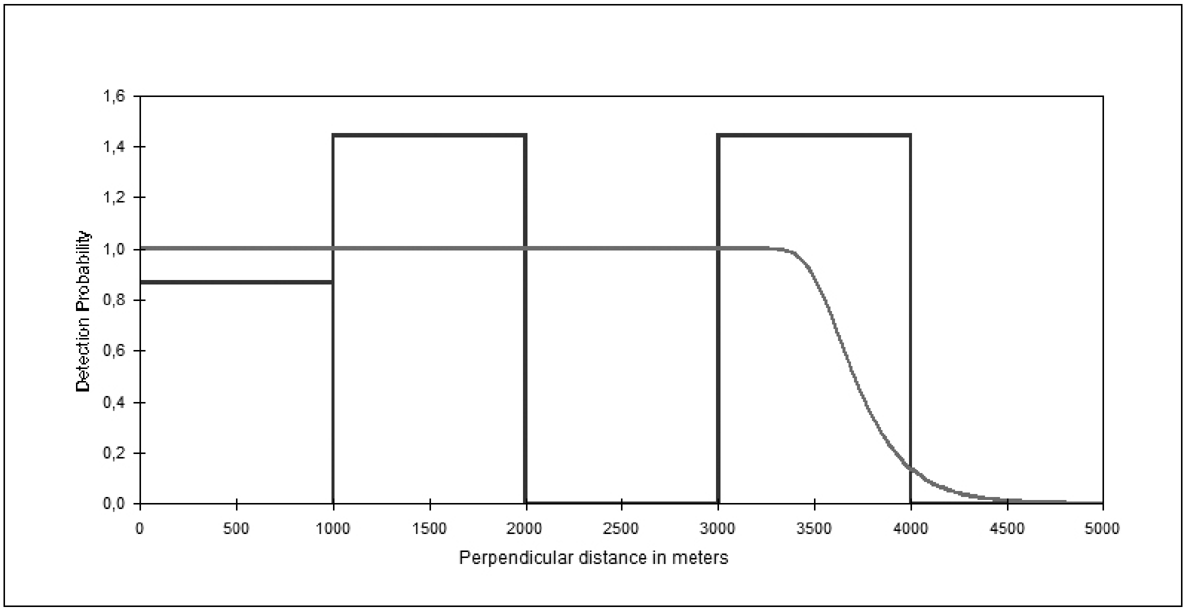

Figure 3 – Distribution of perpendicular distances from 2009 aerial survey and the fitted detection function.