Abundance estimates of Chilean blue whales by mark-recapture techniques

Barbara Galletti Vernazzani[1]

[1] Centro de Conservación Cetacea - Casilla 19178 Correo 19, Santiago, Chile – barbara@ccc-chile.org

ABSTRACT

From 2004 to 2010, 334 individual Chilean blue whales were photo-identified off northwestern Isla de Chiloe with quality sufficient to perform mark-recapture analyses. Seventy-four individuals were sighted in different years, including 13 sighted in three years and three in four years. High annual return rates suggest a degree of site-fidelity and therefore, heterogeneity may be introduced. Re-sightings in other areas in southern and northern Chile suggest that abundance estimates should applied to the entire Chilean population. A POPAN open population model estimated a super-population size to be between 682 and 1,151 individuals. A closed population model, time-dependent, estimated a population between 598 to 817 individuals. About ½ to 1/3 of the total population estimates used the waters off northwestern Isla de Chiloe and this further strengthens the importance of these waters for the conservation of the species in Chilean waters. In spite of the high concentration of blue whales off Isla de Chiloe, the Chilean blue whale population appears to be smaller than other populations of blue whales around Antarctica and off western Australia.

KEYWORDS

Abundance estimates, mark-recapture, blue whale, *Balaenoptera musculus*, eastern South Pacific Ocean, Chile

INTRODUCTION

Two subspecies of blue whales are 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 in size and may represent a unique population or a different subspecies. In addition, LeDuc *et al*. (2007) analyzed genetic samples taken off southwestern Australia, the southeastern Pacific (Chile), and the Antarctic and found that the genetic differentiation between Antarctic blue whales and pygmy blue whales was not markedly greater than between Australian and Chilean blue whales. Although more data are needed to resolve this question, the IWC (2006) agreed that blue whales off Isla de Chiloe differ from Antarctic blue whales and therefore need to be managed as a separate population.

Based on surveys conducted from the IWC-SOWER 1997/98 blue whale cruise off central Chile (Findlay *et al*., 1998), Branch *et al*. (2007b) used line-transect methods to estimate a population abundance of 452 individuals. However, the survey was designed primarily to maximize blue whale encounters and thus had not an equal coverage probability design. Williams *et al*., (2011) reanalyzed these data using spatial modeling methods and obtained a new abundance estimate of 303 whales. Both estimates are lower than the 363 blue whales identified by photographs between 2004-2010 off Isla de Chiloe, southern Chile (Galletti Vernazzani *et al.,* 2011). However, both the Branch *et al*. (2007b) and Williams *et al*. (2011) are for 1998 and the population may be increasing.

Capture-recapture techniques using photographically identified individuals increasingly have been used to estimate the population size of large whales, including blue whales in eastern North Pacific and western Australia (Hammond, 1986; Calambokidis and Barlow, 2004; Jenner *et al.*, 2008). In 2009, the Scientific Committee encouraged providing abundance estimates from mark-recaptures for Australia and Chile (IWC, 2010).

The waters off northwestern Isla de Chiloe and northern Los Lagos represent the most important aggregation areas known for this species in Chile and the Southern Hemisphere (Galletti Vernazzani *et al.*, 2011). This paper presents the first mark-recapture abundance estimates of Chilean blue whale population, primarily off northwestern Isla de Chiloe, based on photo-identification data collected from 2004 to 2010.

METHODS

Blue whales are individually identifiable from the unique pattern of mottling on both sides of the body near the dorsal fin (Sears *et al.*, 1990) and in some cases permanent scars can be used to identify or confirm individuals.

From 2004 to 2010, 85 dedicated marine surveys for photo-identification and other research activities were conducted under Beaufort Sea State three or less, totaling 453 hours of observation. The survey area primarily was off northwestern Isla de Chiloe, between 41º45'S and 42º12'S within 12nm from the coastline, on board the 7m *Alfaguara* research vessel. However, one marine survey was conducted off northern Los Lagos in 2008 and one around the Corcovado Gulf in 2004 on board a 30m Chilean Navy surveillance vessel. Clear, well-focused photographs of individual blue whales were compared within season to determine the number of individuals sighted and resighting matches. All individual whales then were compared to the master catalogue of Centro de Conservacion Cetacea (CCC) to determine if they were new or unknown. Photographs of low quality or whales only partially photographed were not included in the catalogue. Separate photographic catalogues for the left and right sides are maintained. One opportunistic sighting of blue whales from northern Chile (29^{o}S) is also included on the CCC catalogue (Galletti Vernazzani *et al.*, 2011).

For mark-recapture analyses, photographs need to have an acceptable quality to assure recognition in the future (Hammond, 1986). Left side catalogue, comprised of 363 individual blue whales, was reviewed and poor and medium quality records removed.

Estimates of abundance were calculated using the software MARK, assuming both closed and open population models. Time dependent and heterogeneity models were tested with closed population models. The closed models estimates the probability of first seeing an individual (p_c), the probability of resighting an individual (c) and population size (N_c). With the open population model, the Jolly-Seber model did not converge with our data so we applied the 'super-population' model POPAN. This model allows for temporary movement to and from a larger super-population. It provides apparent survival (φ), probability of resighting (p_P), probability of entry into the population (β) and the total super-population size (N_P).

Models were fitted using a logit link function for survival φ and resighting probability p_p, a log link for N_p, and the multinomial logit link function to constrain entry probabilities to ≤ 1 for the POPAN model. With the closed models, the sin link function was used for p_c and c and log link function for N_c (Cooch & White, 2009).

Data from 2004 and 2005 was pooled since only four and 11 individuals were photo-identified in 2004 and 2005, respectively. To account for time between sampling occasions with the 2004/2005 pooled data, the first time interval was set to 1.5 in the open population model.

RESULTS

The total left side catalogue consisted of 363 individuals photographed between 2004-2010. Seventy-four individuals were sighted in different years, including thirteen sighted in three years and three in four year. After a more stringent quality photograph selection, 29 individuals were discarded, all of them sighted in only one season and consisting of mostly medium quality left side photos that have a good quality right side identification associated. A total of 334 sighting histories were used to perform the analyses.

The closed capture model (M_0t), time depended with equal captures and sighting rates (p=c) best fit the data. However, the full closed captures with heterogeneity model (Mth), also time dependent and with equal captures and sighting rates (p=c), had a small difference in AIC (0.9) with previous model. These models provided population size estimates of 691 individuals (SD=55, $CI_{95\%}$=[598; 817]), and 714 individuals (SD=77, $CI_{95\%}$=[590; 898]), respectively.

Closed population models using seven years of data violate no birth-death assumptions, and therefore, our estimates might be negatively biased if the population is increasing or positively biased if it is decreasing. The model with full closed captures with heterogeneity takes into account that all animals have not an equal chance of being captured in each sampling occasion.

Under the open population assumption, the POPAN model had a significantly smaller AIC when apparent survival rate was constant through time. The abundance estimate for the super-population was 917 individuals (SD=119, $CI_{95\%}$=[682; 1151]).

The estimated super-population size is interpreted as the total number of animals ever present during the study period and does not represent the number present at any particular point in time (Cooch & White, 2009), therefore it may be positively biased.

DISCUSSION

Study areas are almost always smaller than the area inhabited by the target population and so some aggregations of animals may not have been seen and the whole population does not have an equal chance of being captured (Hammond, P., 2010). Capture heterogeneity tends to produce negatively biased estimates of population size.

Waters off northwestern Isla de Chiloe show a 31% overall annual return rate and some resighted animals are from off Atacama (29^{o}S), northern Los Lagos (40^{o}S) and the Corcovado Gulf (43^{o}S) (Galletti Vernazzani *et al.*, 2011). This is a high resighting probability for blue whales but shows that those animals use other areas in Chilean waters in addition to Chiloe. Therefore, these mark-recaptures abundance estimates may be for the entire Chilean blue whale population although there must be some resighting heterogeneity and consequently, our estimates may be negatively biased.

The locations of 363 individuals photographed over seven years also indicate that ½ to 1/3 of the estimated population have used the waters off northwestern Isla de Chile. This further strengthens the importance of these waters for the conservation of the species in Chilean waters.

Our estimates are larger than the abundance estimate of 452 using line-transect data (Branch *et al.*, 2007b) and 303 obtained using a combined standard line-transect and spatial density models with data from a survey conducted Chile in December 1997 (Williams *et al*., 2011). However, it is likely that animals at least in coastal waters off northern and central Chile were missed during 1997/98 survey cruise (Galletti Vernazzani *at al*., 2011).

Line transect aerial surveys conducted in 2007, 2009 and 2010 over the southern Chile feeding ground produced abundance estimates of 97, 154 and 163 blue whales with CVs of 0.51, 0.32 and 0.39, respectively (IWC, 2011). Although these survey data provide an estimate of the density of whales and inter-annual variability of whale numbers in the southern feeding ground, they cannot be used to estimate the total size of the Chilean blue whale population. The animals present in any one year on the southern Chile feeding ground are six to ten times fewer than the abundance estimates obtained for Chilean population through mark-recapture techniques. Therefore, there must be one or more additional areas where Chilean blue whales are found during the austral summer-autumn.

Antarctic blue whales have a current (1991-2004) population estimate of 2,280 (95% CI=1,160-4,500) the population is believed to be increasing at a rate of 8.2% per year (Branch, 2008). In Perth Canyon, western Australia, 569 to 1,147 blue whales individuals have been estimated using the POPAN model and 712 to 1,754 individuals with a closed, time-dependent, model with individual heterogeneity (Jenner *et al*., 2008). Abundance estimates for Perth Canyon are not likely to represent abundance estimates for the whole Australia region because of the low resighting rates and the difficulty of distinguishing between pygmy blue whales and Antarctic blue whales.

Although more data are needed, our abundance estimates suggest that Chilean blue whales are the smallest population of blue whales in the Southern Hemisphere, despite the high concentration of whales off Isla de Chiloe.

Comparisons of Southern Hemisphere blue whales now underway by several researchers in a collaborative effort will improve our knowledge of the distribution, boundaries and abundance estimates for the different populations and subspecies in this area.

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