Chilean blue whales off Isla Grande de Chiloe, 2004-2010: distribution, site-fidelity and behaviour

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ABSTRACT

A collaborative research program (the Alfaguara Project) has collected information on Chilean blue whales (*Balaenoptera musculus*) off Isla Grande de Chiloe, in southern Chile, through eight aerial and 85 marine surveys. A total of 363 individual blue whales was photo-identified from 2004 to 2010. Approximately 20% of all catalogued individuals were resighted within the same season and 31% were resighted between years. Recaptures of photo-identified individuals from other areas to the north and south of the main study area support the hypothesis that the feeding ground off southern Chile is extensive and dynamic. The high overall annual return and sighting rates highlight the waters off northwestern Isla de Chiloe and northern Los Lagos as the most important aggregation areas currently known for this species in Chile and one of the largest in the Southern Hemisphere. Observations on feeding and social behaviour also were recorded. These results provide important information on the conservation status of Chilean blue whales and highlight the necessity that long-term photographic identification research and line-transect surveys to monitor health conditions and population trends be continued off northwestern Isla de Chiloe. The high frequency of large vessels in the mouth of the Chacao Channel (along the north side of Isla de Chiloe) and the high number of blue whales in the area raises the possibility of vessel collisions. Therefore, it is necessary to develop and implement a conservation plan for these whales to address this and other potential threats.

KEYWORDS: DISTRIBUTION; INDEX OF ABUNDANCE; PHOTO-ID; SITE FIDELITY; FEEDING; SOCIAL; BLUE WHALE; PACIFIC OCEAN; SOUTH AMERICA

INTRODUCTION

During the 20th century, blue whales (*Balaenoptera musculus*) became a principal target of the whaling industry worldwide (Clapham *et al.*, 1999). Off Chile, the first commercial catches occurred in 1908 from a land station in San Carlos, Corral (Pastene and Quiroz, 2010). Between 1926 and 1971, catches of almost 3,000 blue whales were taken off Chile, including 1,129 taken in the 1960's (Aguayo-Lobo *et al.*, 1998).

Until recently, only two subspecies of blue whale have been recognised in the Southern Hemisphere: the pygmy blue whale (*Balaenoptera musculus brevicauda*) in the sub-Antarctic zone and the Antarctic 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, 1974). Branch *et al.* (2007a) reported that adult female blue whales taken off Chile are intermediate in length between the total lengths of the two subspecies recognised in the Southern Hemisphere and may represent a unique population or a different subspecies. In addition, LeDuc *et al.* (2007) analysed genetic samples from 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 Scientific Committee of the International Whaling Commission (2007) agreed that the blue whales off Isla Grande de Chiloe (= Isla de Chiloe) differ from Antarctic blue whales and therefore need to be managed as a separate population.

Outside Antarctic waters, aggregation areas used by blue whales are poorly known (Branch *et al.*, 2007b) and few specific feeding areas are known (Cabrera *et al.*, 2005; Gill, 2002; Hucke-Gaete *et al.*, 2004). Recently, blue whales have been reported in the waters of the northern Los Lagos region (Galletti Vernazzani *et al.*, 2005; 2006; 2008), off the west coast of Isla de Chiloe (Cabrera *et al.*, 2005), extending south to the Corcovado Gulf, and the Chonos Archipelago (Hucke-Gaete *et al.*, 2004). Additionally, only two sightings have been reported during winter in the inlet waters east of Chiloe near the mainland (Abramson and Gibbons, 2010). Our systematic research highlighted the northwestern coast of Isla de Chiloe as an important feeding area in the austral summer and early fall (Cabrera *et al.*, 2006; Galletti Vernazzani *et al.*, 2005; 2006; 2007a; 2008). These studies also indicated that the sighting rate of blue whales off northwestern Isla de Chiloe is among the highest in the Southern Hemisphere (Branch *et al.*, 2007b).

This paper presents summary results of the Alfaguara (Chilean blue whale) Project conducted by the Centro de Conservacion Cetacea (CCC) from 2004 to 2010. Information on group size, behaviour, distribution, relative abundance, residency time and site fidelity is analysed. Potential threats and conservation implications for the Chilean blue whale population are discussed.

METHODS

Study area

The study covers an area of approximately 33,259km^2, from about 39°S to 44°S within 20 n.miles of the coastline (Fig. 1). In 2005 and 2006, the area of coverage was from 40°S to 42.5°S and it was extended from 36°S to 44°S in 2007 and 2008, and in 2009 and 2010 it covered from 40°S to 44°S.

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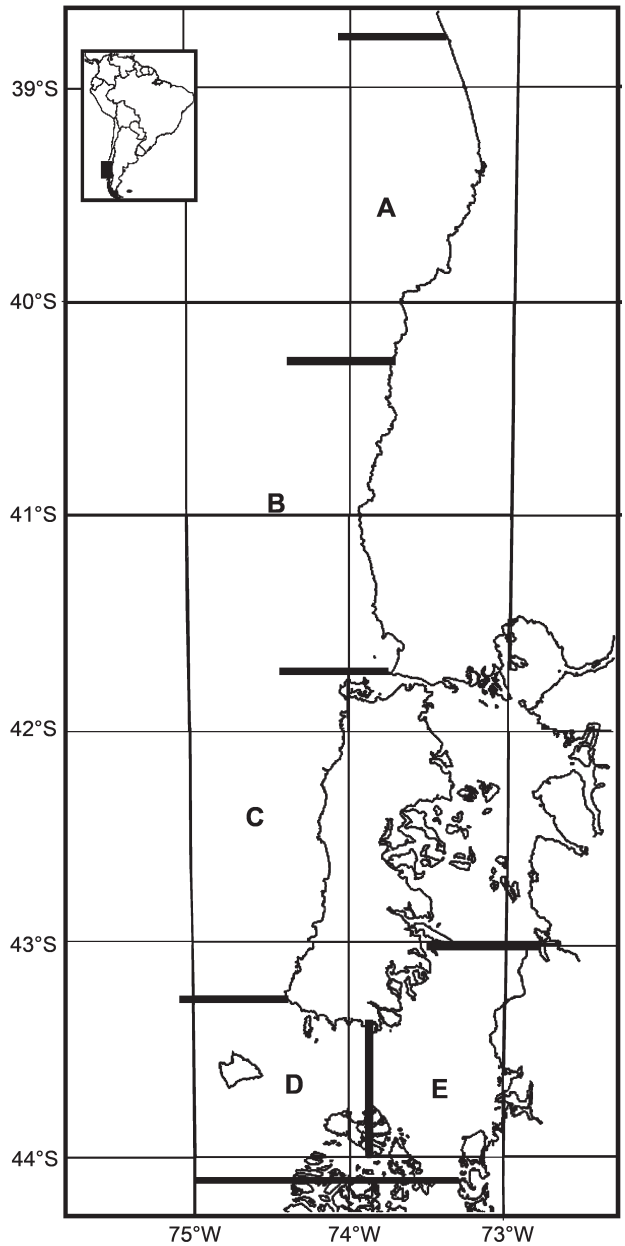

Fig. 1. Study area showing the five sub-areas: A = south Araucania and Los Rios; B = northern Los Lagos; C = west Isla de Chiloe; D = west Corcovado Gulf; E = east Corcovado Gulf.

Dedicated marine surveys for photo-identification and other research activities were conducted primarily off northwestern Isla de Chiloe, between 41°45'S and 42°12'S within 12 n.miles of the coastline, on board the 7m *Alfaguara* research vessel. 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.

Aerial surveys and spatial analyses

In December 2003, an aerial survey was conducted off Isla de Chiloe with no sightings of baleen whales. From 2004 to 2010, nine aerial surveys were undertaken on 15 March 2004, 23 February and 12 April 2005, 1 March 2006, 12 March 2007, 25 and 26 March 2008, 17 April 2009 and 13 April 2010. These nine aerial surveys were conducted to monitor blue whale distribution and relative abundance off southern Chile (39°–44°S) thanks to the support of the Chilean Navy (DIRECTEMAR). Three of these aerial surveys were conducted using standard line transect methods to estimate abundance (Buckland *et al.*, 1993) and will be reported on in future publications. In 2004, visibility was too poor to allow completion of the aerial survey so only eight aerial surveys from 2005 to 2010 are used in our spatial analyses using sighting per unit effort techniques and kernel density estimators.

All aerial surveys were conducted with Beaufort Sea State <4 and covered an area from shore up to a maximum of 20 n.miles. Most surveys were conducted from a four-seat, twin engine Cessna Skymaster aircraft with flat windows flown at an altitude of 900ft and an average airspeed of 120kn. Helicopters were used only in February 2005 and March 2008. Two dedicated observers, one seated on each side of the aircraft, recorded sighting data and weather conditions. The pilot and co-pilot from the Chilean Navy also contributed to the sighting effort. The transect lines and locations of whales were recorded using a Global Positioning System (GPS). Weather and sea conditions were recorded at the start of each transect or whenever weather conditions changed.

When a group of whales was sighted, species, location, time, group size, behaviour and other species present were recorded by each observer. While conducting aerial line-transect surveys to estimate abundance, the vertical angle from the horizon to the group perpendicular to the aircraft's track (at 90°) was also measured using a hand-held clinometer (Suunto PM5/360PC). 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 was 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.

Based on data collected from aerial surveys, blue whale distribution off southern Chile was assessed and relative abundance, using sighting per unit effort (SPUE in groups of blue whales per km) and kernel density estimators, was calculated. Density kernels (Silverman, 1986) have been used to graphically represent blue whale density distribution in southern Australia (Gill *et al.*, 2011). Comparisons of SPUE were performed within five sub-areas, varying from 6,407km^2 to 6,877km^2 each (Fig. 1) and at a smaller scale using a 10km^2 grid. Sighting data were weighted by survey effort (km) to correct biases.

Marine surveys

Eighty-five boat-based photo-identification surveys were conducted during Beaufort Sea State 3 or less. Sound recordings and faecal and plankton samples also were collected with associated data on group composition, location and behaviour of whales as well as weather, sea conditions, sea surface temperature and association with other marine fauna such as birds or marine mammals.

Photo-identification analyses

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. We maintain separate photographic catalogues for the left and right sides of the head region, dorsal fin, flank and caudal peduncles, but here we only used the left-side flank with dorsal fin catalogue. Left side was chosen arbitrarily before analyses were performed. The overall consistency in research design, data collection techniques and data analysis allowed between-year comparisons to be made (Cabrera *et al.*, 2006).

Clear, well-focused photographs of individual blue whales were compared within season to determine the number of individuals sighted, resighting matches and residency time (number of days between first and last sightings within the same season). All individual whales were then compared to the master CCC catalogue to determine if they were new or unknown. The overall annual return rate was calculated as the proportion of individuals resighted in later years. Photographs of low quality or whales only partially photographed were not included in the catalogue.

Group size and behavioural analyses

Group size was calculated using all data obtained during marine and aerial surveys. Behavioural analyses were performed using data from marine surveys conducted from 2006 to 2010 to ensure overall consistency in research design and data collection.

The following behavioural patterns were established following terms used previously (Gill, 2002; Sears *et al.*, 1999) and personal observations made by us off southern Chile: (1) 'side-fluking' – the whale rolled on one side and exposed one tip of the fluke, sometimes exposing the distended throat pleats; (2) 'fluking-up' – the fluke is raised out of the water; (3) 'circling movements' – the whale made continual changes in swim direction over a radius of 1km; (4) 'social behaviour' – chasing, partial breaches, high-speed swimming and forceful blows are observed while two or more whales are interacting; (5) 'head out of the water' – the whale lifts its head out of the water; (6) 'fast swimming' – swimming at more than about 12 knots; (7) 'prolonged dive times' – dives are longer than 10 minutes; (8) 'sub-surface travel' – whales swim just below the surface; (9) and 'stationary' – whales do not move at the surface. The presence of light reddish-brown faeces was also recorded. Contingency tables show the frequency distribution of variables and are widely applied to investigate relations among variables (Sokal and Rohlf, 1995). Here, chi-square tests were used to investigate if there was an association between any behaviour and observations of faeces.

RESULTS

Distribution and relative abundance

Eight aerial surveys were conducted between February and April 2005 to 2010, with a total on-effort distance of 4,352km; 203 blue whales in 138 groups were recorded. The northernmost blue whale sighting was at 40°23'S and 73°48'W and the southernmost sighting was at 43°48'S and 73°23'W (Fig. 2). No mother-calf pairs were observed.

Differences in effort across the study area and between years were due to logistical constraints and/or weather conditions. Therefore sightings have been weighted by effort to perform spatial analyses.

Relative abundance is expressed as sighting per unit effort in groups and individual blue whales per 1,000km for the five sub-areas (Table 1). Overall sighting rates including all regions were 31.7 groups of blue whales per 1,000km and 46.7 individuals per 1,000km. Sighting rates ranged from 169.4 groups of whales per 1,000km to zero, depending on the area. Relative abundance of blue whales in northern Los Lagos (B) and west Isla de Chiloe (C) was one order of magnitude higher than in other areas. No correlation has been found between SPUE and the sighting conditions on the days of surveys.

All aerial survey track lines and sighting locations of each group from 2005–2010 are shown in Fig. 2. The relative abundance (SPUE within each 10km^2) and kernel density using effort-weighted data from the 2005 – 2010 aerial surveys are shown in Fig. 3. SPUE indicates relative abundance in discrete 10km^2 grid cells, while the kernel density shows probability contours produced by smoothing the data over a surface. During February – April, the highest probability of occurrence is off the northwestern coast of Isla de Chiloe and north of the Chacao Channel when blue whales are aggregated in this southern austral summer-autumn feeding ground.

Photo-identification

Eighty-five photo-identification surveys totaling 453hr were conducted. A total of 621 blue whale groups was encountered comprising 937 individuals. The number of groups and individual whales encountered does not include animals resighted on the same day. The 2004–2010 CCC catalogue consists of 363 individual blue whales photographed on the left side. Eighty-four individuals have been resighted during the same season, including 20 individuals that have been sighted on several occasions. Seventy four individuals were sighted in different years, including 13 sighted in three different years and three in four years (Table 2).

From 2005 to 2010, the proportion of individuals observed on multiple days during a season ranged from 8.6% to 37.5% (CI 95% = 8.5%–31.0%); most of the individuals were resighted one (34.9%) or two times (8.5%). Minimum residency time ranged from 2 to 71 days, with a mean of 17 days (SD = 19 days). In 2008 and 2010, an individual was observed on five occasions over a period of 25 days and 55 days respectively. In 2008, 37.5% of all documented individuals in this season were observed on multiple occasions, the highest residency rate documented to date. By contrast, the lowest residency rate of 8.6% was obtained in 2009.

From 2005 to 2009, the site fidelity to northwestern Isla de Chiloe, expressed as overall annual return rate of individuals, was 31.2% (SD = 18.0%; Range = 7.4% to 50.0%). Most between-year sightings occurred off northwestern Isla de Chiloe and corresponded to animals previously sighted in close proximity to the same area. However, one individual first photo-identified in east Corcovado Gulf (43°43'S/73°6'W) on 13 March 2004 was resighted off northwestern Isla de Chiloe (41°44'S/74°5'W) on 20 April 2007. Another individual previously photo-identified on 21 December 2006 off Atacama Region (29°2'S/71°33'W) by Carlos Aguilar, a member of the CCC National Marine Mammal Sighting Network,

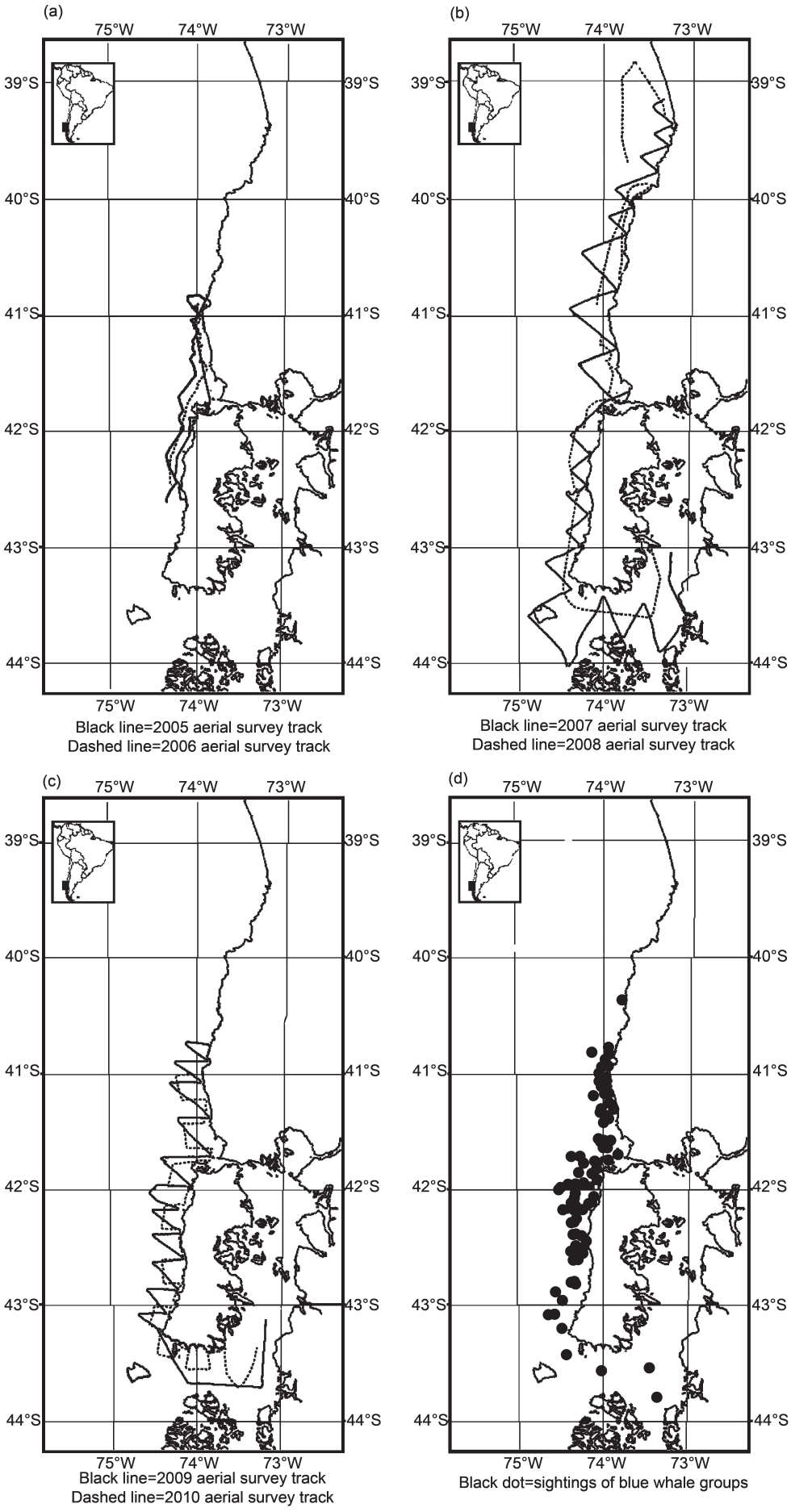

Fig. 2. Aerial surveys: (a) tracks 2005 and 2006; (b) tracks 2007 and 2008; (c) tracks 2009 and 2010; and (d) sightings of blue whale groups from 2005 to 2010.

Table 1

Summary of aerial surveys from 2005 to 2010 for each sub-area and all areas combined.

	Effort (km)					Number of groups/individual blue whales					SPUE (groups of whales 1,000 km^{-1})				
Year	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
2005	0	227.8	220.4	0	0	–	9/12	11/22	–	–	–	39.5	49.9	–	–
2006	0	94.4	85.2	0	0	–	16/27	4/5	–	–	–	169.4	46.9	–	–
2007	223.0	255.0	255.6	225.9	225.9	0/0	8/11	4/4	0/0	2/3	0	31.4	15.6	0	8.8
2008	155.6	192.6	229.6	70.38	111.1	0/0	4/6	20/31	1/1	0/0	0	20.8	87.1	14.2	0
2009	0	275.9	490.8	107.8	112.2	–	4/5	22/32	0/0	0/0	–	14.5	44.8	0	0
2010	0	202.8	339.3	133.3	118.3	–	8/10	24/32	1/1	0/0	–	39.6	70.7	7.5	0
All years	**378.6**	**1,247.6**	**1,620.8**	**537.5**	**567.6**	**0**	**49/71**	**85/126**	**2/2**	**2/3**	**0**	**39.3**	**52.4**	**3.7**	**5.3**
Overall			**4,352**					**138/203**					**31.7**		

was resighted off northwestern Isla de Chiloe on 22 February 2007 (41°58'S/74°13'W) and 26 April 2007 (41°53'S/74°10'W) (Galletti Vernazzani *et al.*, 2007b). Finally, an individual first photo-identified at northwestern Isla de Chiloe on 26 April 2007 (41°54'S/74° 11'W) was resighted on 27 April 2007 (41°52'S/74°16'W) and again photo-identified on 17 March 2008 off northern Los Lagos (41°7'S/74°2'W)(Galletti Vernazzani *et al.*, 2008).

Group size and behaviour

Blue whales generally were observed alone (52%) or in a group of two (43%) individuals. Groups of three whales were sighted on 25 occasions (3%) and larger groups of four or six whales represented less than 1% of all observations. In 2005, 2008 and 2009, the number of pairs of blue whales recorded was greater than the number of solitary individuals. Fifty-eight of the 138 sightings during aerial surveys were groups of two or three whales with similar body size. Almost

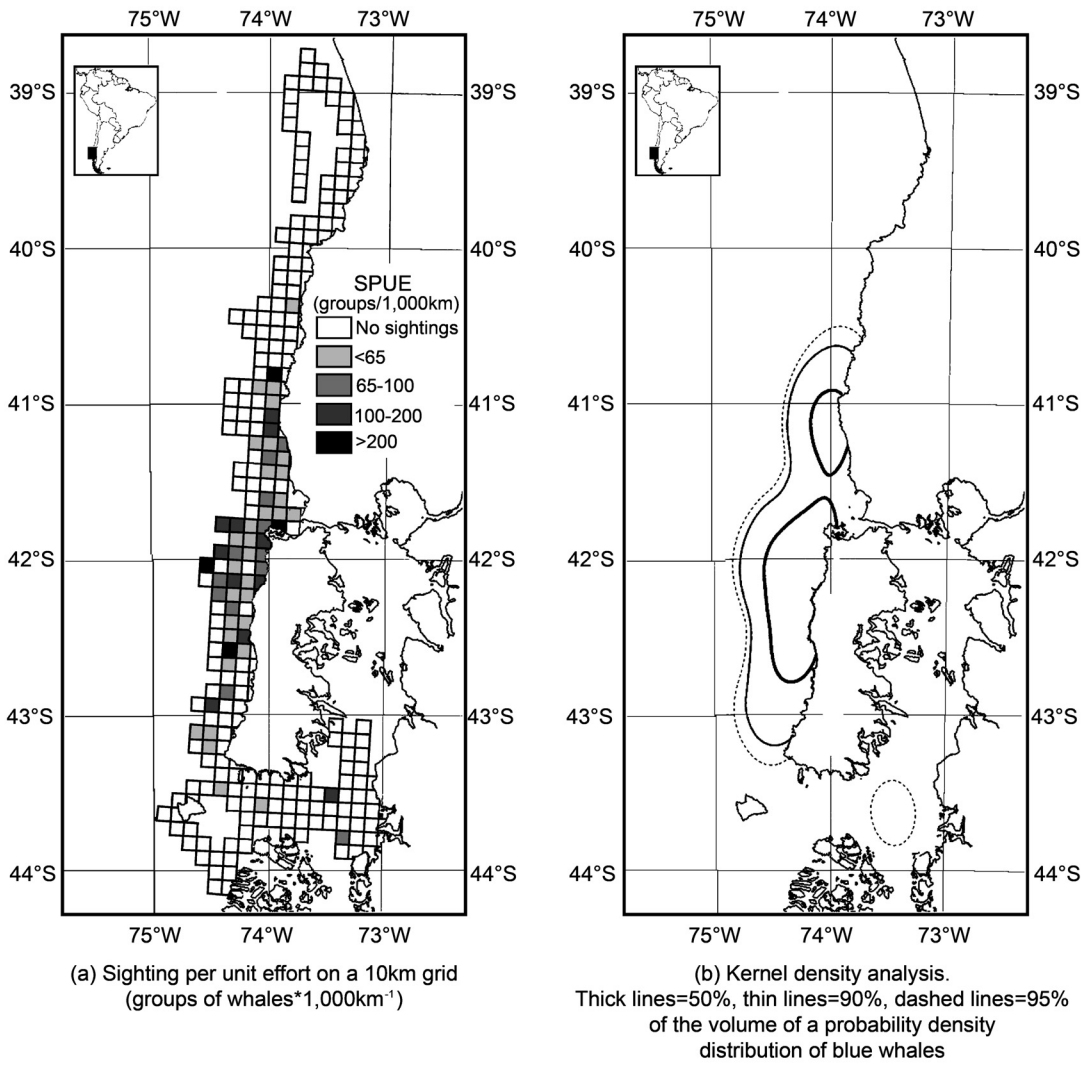

Fig. 3. Blue whale relative abundance and distribution probability expressed as (a) SPUE and (b) kernel density using effort-weighted data from 2005–2010 aerial surveys.

Table 2
Photo-id effort, groups and number of blue whales approached.

Year	Sampling period (mo/d)	Number of surveys	Hours of observation	Groups of blue whales encountered	Number of blue whales encountered	Blue whale individuals		
						New photo-id	Re-sightings within season	Re-sightings on later years
2004	02/25–03/15	2[1]	17:35	2	3	4	0	2
2005	02/01–03/15	8	29:13	25	58	11	1	4
2006	02/04–04/15	12	67:15	70	112	54	8	27
2007	02/01–04/29	17	94:54	142	188	89	26	27
2008	02/01–04/30	17	93:33	171	270	76	39	10
2009	02/01–04/30	12	68:55	82	124	54	6	4
2010	01/25–04/30	17	81:39	129	182	75	25	–
Total		**85**	**453:04**	**621**	**937**	**363**	**105[2]**	**74[3]**

[1]One marine survey (10.25hr) in the Corcovado Gulf. [2]Corresponds to 84 individuals catalogued. [3]Thirteen individuals have been seen in three different years and three in four different years.

all individuals seen during the 2004 to 2010 marine surveys were considered non-calves (i.e. adults or sub adults). The first mother-calf pair was recorded during a marine survey off northwestern Isla de Chiloe on 2 February 2008 for 4 minutes and was resighted for 36 minutes on 20 February 2008 close to the previous location. The smaller whale was identified as a calf by its size (half the length of the larger whale) and behaviour (staying close to the other whale and surfacing on alternate sides of it). The mother also was resighted for 4 minutes on 8 February without the calf. On 21 February 2009, a second mother-calf pair was observed.

Within a given observation period, whales exhibited up to six different patterns of behaviour. The time spent in the proximity of a group of whales varied from less than a minute up to 30 minutes. Behaviour was recorded in 321 encounters (67%). The three most frequently observed behaviours were: circling movements (47.0%), fluking up (33.3%), and side-fluking (21.8%). Additional behavioural observations included the whale lifting its head out of the water (10.3%), fast swimming (11.5%), prolonged dive times (8.7%), sub-surface travel (3.4%) and stationary (2.5%). In 25.5% of the cases when behaviour was recorded, light reddish-brown faeces were seen. These data indicate that circling movements, even if whales were not fluking-up, and fluking-up observations, are significantly related to the occurrence of faeces (p-value<0.05) and therefore can be considered feeding behaviour. Social behaviours were recorded on 2.2% of all observations. Similar social behaviour by blue whales has been recorded in the Gulf of St. Lawrence (Sears *et al.*, 1999) and was first reported off northwestern Isla de Chiloe in 2006 (Galletti Vernazzani *et al.*, 2006).

DISCUSSION

Northern Los Lagos seems to represent the northern limit of this austral summer-autumn feeding area, although more systematic effort needs to be made in south Araucania and Los Rios to resolve this question. Sighting rates of blue whales off northwestern Isla de Chiloe have been reported to be among the highest in the Southern Hemisphere along with the Madagascar Plateau, south of Madagascar, and off southwestern Australia (Branch *et al.*, 2007b). Gill *et al*. (2011) recently reported 10 blue whales per 1,000km for the southern Australia coastal upwelling zone. The high sighting rate, number of identified individuals and degree of site fidelity documented here, confirms that the waters off Isla de Chiloe and northern Los Lagos contain the largest aggregation known for this species in Chile and one of the largest aggregations currently known in the Southern Hemisphere.

Over the period of this study, a total of 363 whales was identified by photographs. This number is larger than the abundance estimate of 303 (CI 95% = 176–625) (see discussion below) obtained using a combined standard line-transect and spatial density models with data from a survey conducted in December 1997 (Williams *et al.*, 2011). An overall annual return rate of 31% shows high site fidelity off northwestern Isla de Chiloe and highlights the importance of these waters for this population. Photo-identification data were also used to conduct an in-depth analysis of scars and lesions (Brownell *et al.*, 2007; 2008) and general health condition (Galletti Vernazzani *et al.*, 2007b; 2008).

Fiedler *et al.* (1998) reported that the dynamics of prey aggregations may be an important factor affecting whale distribution. Between-year resightings of individual blue whales off northwestern Isla de Chiloe that matched individuals identified in east Corcovado Gulf and northern Los Lagos support the idea that the blue whale feeding ground off southern Chile is large and dynamic. However, the physical and ecological processes of 'The Pacific Patagonia cold estuarine front' which extends southward (42°S) from Isla de Chiloe to the tip of South America are poorly known (Acha *et al.*, 2004).

Behavioural analyses indicate that this area is used as a feeding ground for blue whales and that fluking-up and circling movements may also be associated with feeding behaviour. Side-fluking has been considered a feeding behaviour and sub-surface feeding has been inferred from frequent short-duration fluke-up dives, with whales resurfacing near the point of diving (Gill, 2002).

The risk of vessel collision is higher in areas where cetacean concentration and vessel traffic frequency are high (Laist *et al.*, 2001). In recent years, a number of blue whale strandings have occurred in areas with high densities of whales and commercial vessels off southern California. These strandings have been spatially associated with the location of the shipping lanes and the dead whales had wounds typical of ship strikes (Berman-Kowalewski *et al.*,

2010). There is a high frequency of large vessels transiting the northern Los Lagos region and entering the Chacao Channel towards Puerto Montt and other inland water locations. The northern Los Lagos and northwestern Isla de Chiloe, at the west entrance of Chacao Channel, also shows the highest density of blue whales in Chile. Four strandings have been reported for Chile (Branch *et al.*, 2007b), one has been located in northwestern Isla de Chiloe and the other in northern Los Lagos, both near the mouth of the Chacao Channel. In addition, one baleen whale ship-strike is known from Puerto Montt (Brownell *et al.*, 2009).This raises concerns about possible vessel collisions with blue whales in the region. Therefore, it is critical to monitor any cetacean strandings to determine cause of death and develop mitigation measures to address any emerging threat.

Based on the line-transect surveys conducted from the IWC-SOWER 1997/98 blue whale cruise off central Chile (Findlay *et al.*, 1998), Branch *et al.* (2007c) estimated a population abundance of 452 individuals using standard line-transect methods. Williams *et al.* (2011) reanalysed these data using spatial modelling methods and obtained a new abundance estimate of 303 whales. These authors indicated that their estimate was a minimum because the survey, conducted between 18 December 1997 to 1 January 1998, did not cover the waters south of 38°S, north of 18°S, waters outside the Economic Exclusive Zone (EEZ), and the inshore waters (east of 12 n.miles to the coast) in Chile. Williams *et al*. (2011) noted that incidental sightings south and inshore of the SOWER survey area, both before and after SOWER, observed large numbers of blue whales in the inshore waters east of Isla de Chiloe and the Corcovado region (Galletti Vernazzani *et al.*, 2006; Hucke-Gaete *et al.*, 2004). The 1997/98 El Niño event has been considered one of the strongest ever recorded. Therefore, we believe it is unlikely that many, if any blue whales, were west of the SOWER survey area (outside the EEZ) because the vessels travelled south to north, and blue whales had already moved into coastal waters due to the El Nino Event. Therefore, any blue whales missed during the SOWER survey would have been east of the area surveyed (between the coast and out to 12 n.miles). Also, our survey data since 2004 have shown no records of blue whales in the western coastal waters of Isla de Chiloe in December and early January. Therefore, it is unlikely that blue whales were missed in southern Chilean waters or outside the EEZ at the time of the SOWER survey.

CONCLUSIONS

Southern Chile is an important feeding ground for this unique blue whale population in the Southern Hemisphere. Therefore, it is essential that long-term photo-identification research, line-transect surveys, and work to determine the cause of death in stranded individuals be continued in Chilean waters to monitor population trends, the health status of individuals and to understand the overall conservation status of this population. We recommend development of an action plan for the recovery of this species in Chilean waters that includes protection of critical habitats and implementation of effective conservation measures to address potential threats such as vessel collisions and habitat degradation.

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