ABUNDANCE, POPULATION STRUCTURE AND FIDELITY OF HUMPBACK WHALE IN THE STRAIT OF MAGELLAN, CHILE.

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Abstract

We describe abundance and population characteristics of humpback whales from a feeding area in the Strait of Magellan, Chile. Dedicated field work was conducted during a total of 969 days (533 vessel-days) between December and May, from 1999 to 2011. The cumulative number of identified whales increased from 18 in 1999 to a total of 126 individuals in the 13 years period. All 126 sighting history profiles used in the analysis were for post-yearlings, comprising 36 juveniles and 90 adults. The population size estimated by capture – recapture methods was 92 in 2011 [86 – 98] and 132 [125 – 138] for 1999-2011 period, with an annual increase rate of 0.095 (SD= 0.069) [0.007 – 0.206] and a crude birth rate of 0.094 (SD = 0.039, range 0 - 0.122). Average calving rate was 0.33 (SD= 0.03) and calving interval of two years was the most frequent with 58.3% followed by three years with 16.7%. Age of first parturition was established at 5 and 6 years old for two females re-sighted. We found high site fidelity: a mean recapture rate of 82 % (SD= 10, range 66.7 – 92.5), with 16 individual whales recaptured over a period of nine years or longer. Return by gender was similar: a mean of 77.4% (SD= 5) for males and 80.3% (SD= 2.1) for females. Humpback whales were resident in the area during summer-fall period; we determined a mean occupancy of 54.9 d (SD = 37.4, range 1-156), a mean presence of 11 d (SD = 9, range 2-46) and 73.2% of the individual were observed between 2 and 20 different days/season. The sex ratio, with 91% of the identified animals sexed, is near parity (1.08:1 males/females). The small size of the population, the high site fidelity and occupancy of humpback whales in the SM, maximizes vulnerability to human activities. At present, vessel traffic by the area is mostly composed of large container ships which directly overlap with one sector of higher presence of humpback whales. In the coming years will be added the high traffic of large ships (one vessel every two days at least) regarding the development and transportation of a large scale coal mining project to be located nearby. It will concentrate possible impacts on resident humpback whales, particularly because it raises the probability of collisions with whales.

Introduction

Humpback whale is a cosmopolitan species, found in all oceans except the Arctic. As many other large whale species, humpback whale was heavily hunted by commercial whaling between XIX and XX century (Clapham & Mead 1999). After the cessation of whaling operations, some populations have shown a slow recovery (Fleming & Jackson 2011). Despite humpback is one of the most studied baleen whale species in the world, many aspects of demography and life history remain poorly understood in the Southern Hemisphere where it form relatively discrete populations and segregate into seven Breeding Stocks (A-G) (Olavarría *et al*. 2007) and six management areas recognized by the International Whaling Commission (IWC 1998). One of such breeding ground is found off the western coasts of Central and South America, (Flórez-González et al. 2007). Given the scarcity of long-term studies at the summer feeding areas in the Southern Oceans, it remains debatable whether the knowledge from the northern hemisphere feeding grounds can be generalized to worldwide populations.

The waters of Chilean Patagonian fjords and the Strait of Magellan (SM) remain today as the only one recorded Southern Hemisphere feeding area for humpback whales of the stock G outside the Antarctic waters (Gibbons *et al*. 2003, Capella *et al.* 2008). There is evidence of the summer presence of whales (supposed humpbacks) in the SM since 16th century provided by explorers, sailors and discovery expeditions (compiled in Gibbons *et al*. 2003). A shore-based whaling station located in El Aguila Bay (70°58'S, 53°48'W) on the middle North coast of the SM, operated between 1905 and 1906. Its hunting operations extended during two seasons and resulted in the capture of 129 and 106 whales respectively (mostly humpbacks as is confirmed from historic pictures) (Martinic 1977). A Massive removal of whales by these catches probably took place and reported sightings of humpback whales for the SM subsequently disappeared for decades. Just in the late 1970s and early 80s a few sightings began to appear in SM an adjacent fjords (Oporto 1986). Since the middle 90s a growing number of records of humpback whales accumulated from dedicated surveys conducted along waters of the southern Patagonian fjords (Gibbons *et al.* 1998) and especially in the SM, where humpback sightings were concentrated in the waters surrounding Isla Carlos III (Gibbons *et al.* 2003).

This long-term study begun in 1999, based on sightings, photo-identification and molecular analysis, presents information about abundance, population structure, demographic and reproductive trends of humpback whales from the SM feeding area, Chile.

Materials and Methods

Study Area

Covered fjords, channels and sounds of central sector of the Strait of Magellan, a long V-shaped channel that connects the Pacific and the Atlantic Oceans at the southern tip of South America. Encompassed an area of *c.* 800 km^2 centered around Carlos III island (53º37'S, 72º21'W) and includes the "Francisco Coloane Coastal Marine Protected Area" (53°33' S to 53°46' S - 72°25' W to 72°54' W). It is characterized by marine waters up to 600 m in depth, an average surface temperature ranging between 5°C and 8°C along year, and strong daily currents due to a semi-diurnal tidal regime.

Fieldwork

The study area was systematically surveyed from marine-based platforms, from 1999 to 2011, between late spring (December) and fall (May). Marine surveys were conducted on small vessels (two outboard powered boats 5 and 9 m in length and one diesel powered 13 m in length), during a total of 533 vessel-days when the weather conditions permitted (sea state below Beaufort 4) covering 14,616 km of navigation. Land-based observations also were carried out with 10x40 Leica binoculars and theodolite NIKON NE-205 on a cliff at 50 masl located on eastern Carlos III Island. We accumulated a total of 969 days of observation effort during 13 consecutive years, increased from less than 37 days/season until 2003 to an annual average of 111 d (SD = 12, range = 95–124) from 2004 to 2011. There was significant difference in survey effort between 1999-2003 and 2004-2011 period (Mann-Whitney, U= 0, P= 0.004). In the period 2004-11 effort was homogeneous (T = 0.08, P = 0.93, n = 8, Student t test) and number of photo identifications was not correlated with effort among years (Spearman correlation: rs = 0.265, df = 7, P = 0.51).

Photographic data Collection

We established sighting histories for individual whales using identification photographs of the natural markings both on the ventral surfaces of the flukes and on the shape of their dorsal fins (Katona and Whitehead, 1981). Individuals were photographed, using 35 mm film cameras with telephoto lens and since 2006 with digital SLR cameras with telephoto lens.

Categories of individuals

Each individual whale was assigned into one of three age classes:

Adult*:* Whale of 12 m in length or more (in a close visual estimation) or over 4.5 years old when we know its life histories of sightings since calf. This identification does not imply sexual maturity.

Juvenile*:* Whale between 1.5 to 4.5 years old, or between 9 to < 12 m in length. One and a half year old would be the age of the first independent return for a whale to the study area. Individuals are likely to be immature whales.

Calf: An individual whale was considered to be a calf if it appeared to be less than half the length of a particular adult with whom it maintained a constant and close relationship. The adult in the dyad was assumed to be its mother.

Molecular Sexing and sex ratio
Humpback whale skin samples (n = 104) from photo-identified individuals were obtained using a biopsy dart and from sloughed skin. Gender of whales was identified via the polymerase chain reaction (PCR) and subsequent Taq I digestion of the ZFX/ZFY region of the sex chromosomes (Palsbøll *et al*. 1992). An adult whale observed in close association with a calf was assumed to be a female also.

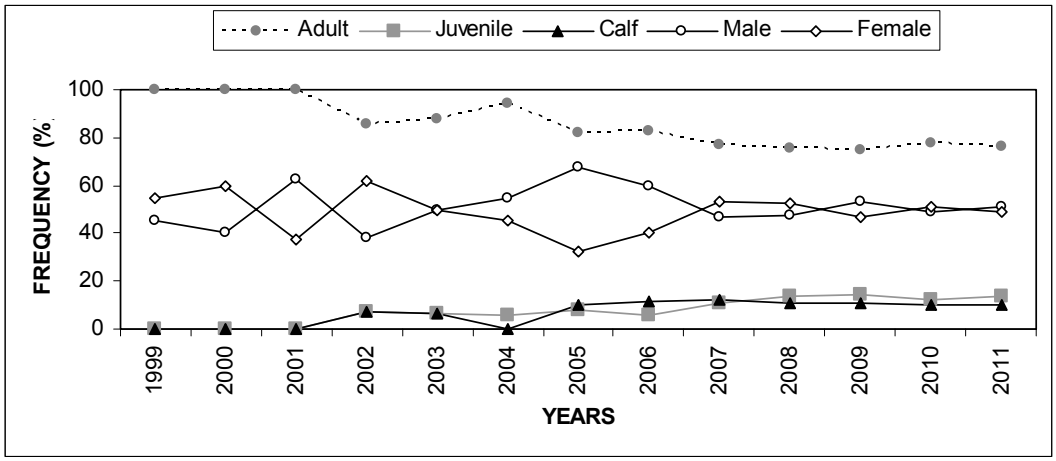
Analysis
Occupancy - period of days between the first and last sightings of an individual whale within a season (sensu Clapham *et al*., 1993). It was not assumed that whales remained the whole period in the study area.
Presence - number of sighting days of an individual whale within a season.
Site Fidelity - number of years an individual whale was sighted in the study area during the 13 years period (1999 - 2011) expressed as a recapture rate. A frequency of annual return was calculated for individuals and for population (*e.g.*, Clapham *et al.* 1993). We distinguished among female and male recapture rate.
Crude birth rate – proportion of the number of offspring to the total identified individuals in a given year (including calves) (Clapham & Mayo 1987).
Calving interval – interval in years between successive calves of an individually identified female.
Calving rate – number of photo-identified females with calves observed in a year divided by the total number of photo-identified mature females with or without calves (Perry et al. 1990). Mature females were assumed when females were older than 4.5 years old or larger than 12 m in length.
Age of first parturition – Estimated age at which female gives birth to her first calf, assuming a gestation period of nearly one year.
Abundance- We used two presence-absence mark and recapture models: The Chapman form of the Petersen estimator for closed populations with two time periods (years) and the Jolly-Seber estimator for populations repeatedly sampled and opened to mortality, birth and immigration (Seber 1982). We used pairs of adjacent years taken from an eight-year period of more consistent and homogeneous effort, from 2004 to 2011, to generate Petersen capture-recapture estimates. We established 99% confident interval for estimation.
Population Increase rate – Determined by the difference between the population estimated by the Chapman model of two successive years with respect to the most recent estimated value.

Results

Sample and Catalogue
From 1999 to 2011, 5303 whale groups were sighted in the SM with an annual mean of 5.2 groups/day (SD = 1.6, range = 2.1 to 7.5). The number of identified unique whales by season progressively increased from 18 at the beginning of the study in 1999 up to 73 in 2011, with a cumulative total of 126 humpback whales. All 126 sighting history profiles used in the analysis were for post-yearlings, comprising 36 juveniles (13 of which became adults during the study) and 90 adults. The rate of new adults (not identified previously) fell steadily in the period down to 1.4% in 2011.

Population structure and sex ratio
Adults represented 100% of individuals recorded at the beginning of the period but fell steadily since 2001 to stabilizing close to 75% from 2005 (Figure 1), while juveniles were recorded since 2002 to the present, representing 13.6% of individuals identified at the end of the period (Figure 1). Calves represent between 10-12% of individual whales each year since 2005. Between 1999 and 2011, 75.4% (95) of the 126 humpback whales identified were sexed, with 48.4% males and 51.6% females (Figure 1). Since 2003 a mean of 94.1% of the identified whales were sexed (SD= 7.7, range 78.1-100), with an annual mean of 91.1% (SD= 11.9). The sex ratio is near parity for the period (1.08:1 male/females), but in 2005 and 2006 we found 2.09: 1 and 1.46: 1 males/females respectively (Figure 1).

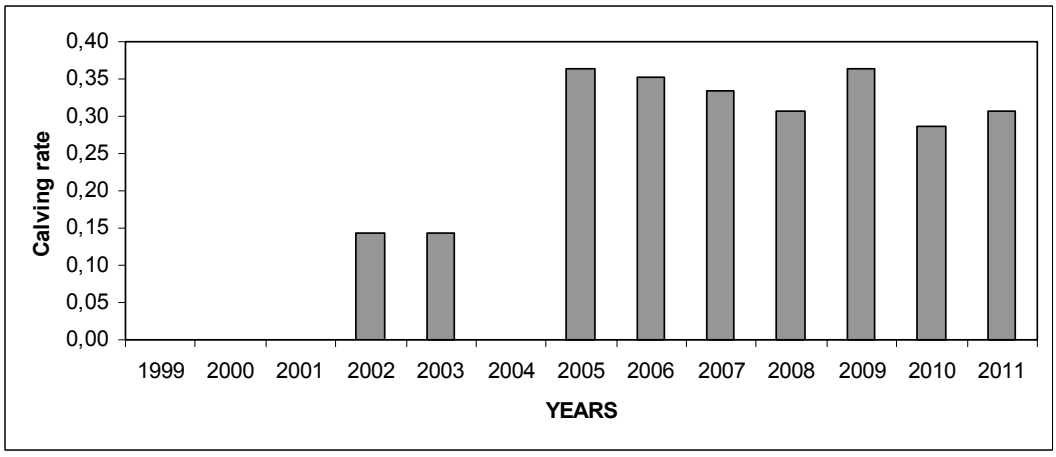
Figure 1. Frequency by categories of individuals and by gender in humpback whales along the study period.



Reproductive rates

1757 total sightings of 30 individual females across the period included records of 24 calving intervals, being two years the most frequent interval with 58.3% followed by three years interval with 16.7%. Intervals of one, four and five years showed 8.3% each one. The average calving rate had considerable year to year variation, ranging from 0 in 2004 to a rise higher of 0.36 in 2009 (Figure 2). Overall differences across the 2005-2011 period (Figure 2) were not statistically significant (t test, t= 0, p= 1), with an average calving rate of 0.33 (SD= 0.03). Age of first parturition was established at 5 and 6 years old for two females re-sighted.

Figure 2. Calving rate of humpback whales in the Strait of Magellan, Chile.



Occupancy and Presence

Humpback whales were resident in the area during summer-fall study period. Occupancy ranged from 1 to 156 d, with a mean of 54.9 d (SD = 37.4, n = 376). 60% of individuals remained in the area over 41 d and only 12.3% one day (Figure 3). Along season, the presence ranged from 1 to 46 different days. For individuals observed more than one day, mean presence was 11 d (SD = 9, range 2-46). 73.2% of the individuals were observed between 2 and 20 different days per season, and frequency gradually decreased for more than 20 days of presence (Figure 4).

Figure 3. Frequency of occupancy of humpback whales in the Strait of Magellan, Chile.

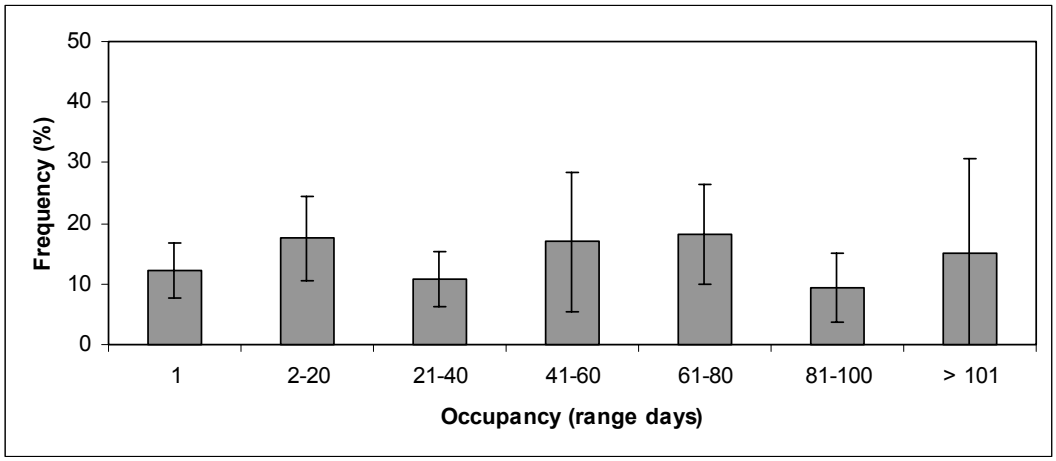
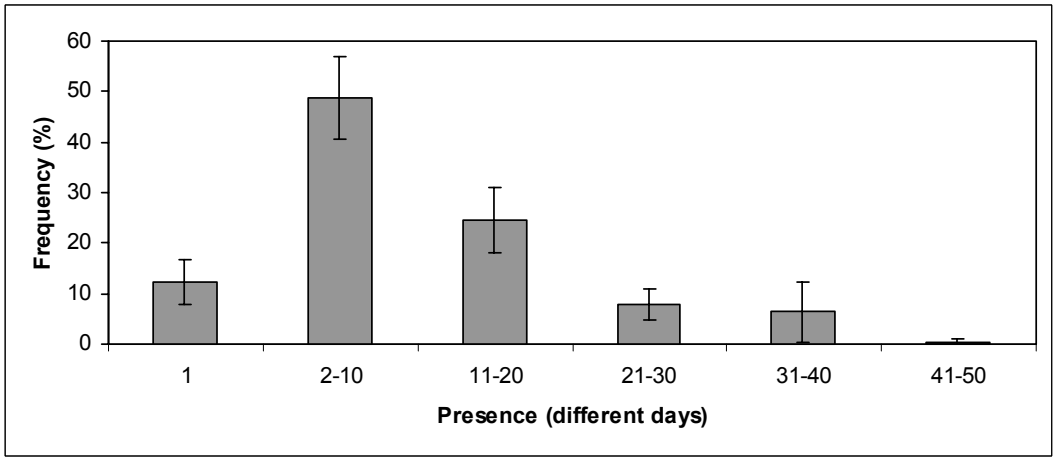


Figure 4. Frequency of presence of humpback whales in the Strait of Magellan, Chile



Site Fidelity

We found high levels of persistent site fidelity with a mean recapture rate of 82% between 2004 and 2011 (SD= 10, range 66.7 – 92.5). The interval between the first and the last sighting ranged from one to a maximum of 12 years, with 16 individual whales recaptured over a period of 9 years or longer. Males and females show similar annual recapture rates (Figure 5). Return for periods between two and nine years were similar by gender (Figure 6) with a mean of 77.4% (SD= 5) for males and 80.3% (SD= 2.1) for females. 40.4% of calves observed returned as juveniles.

Figure 5. Recapture rate of humpback whales in the Strait of Magellan in the period 2004-2011.

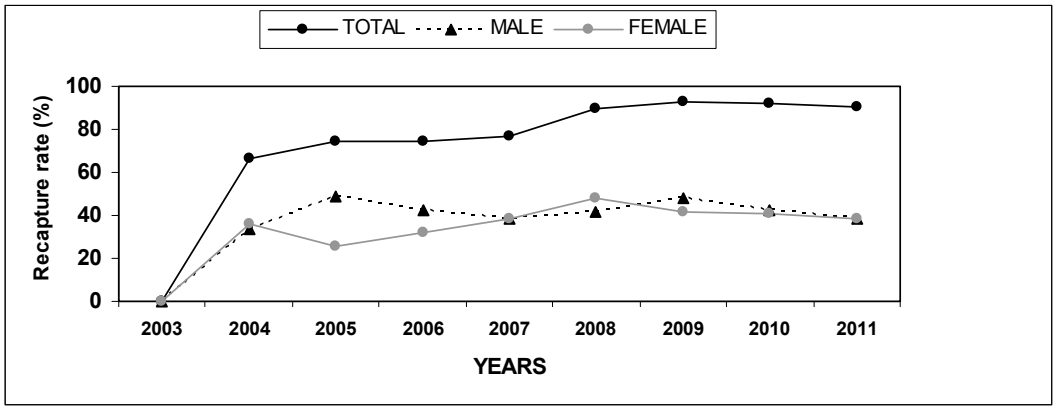
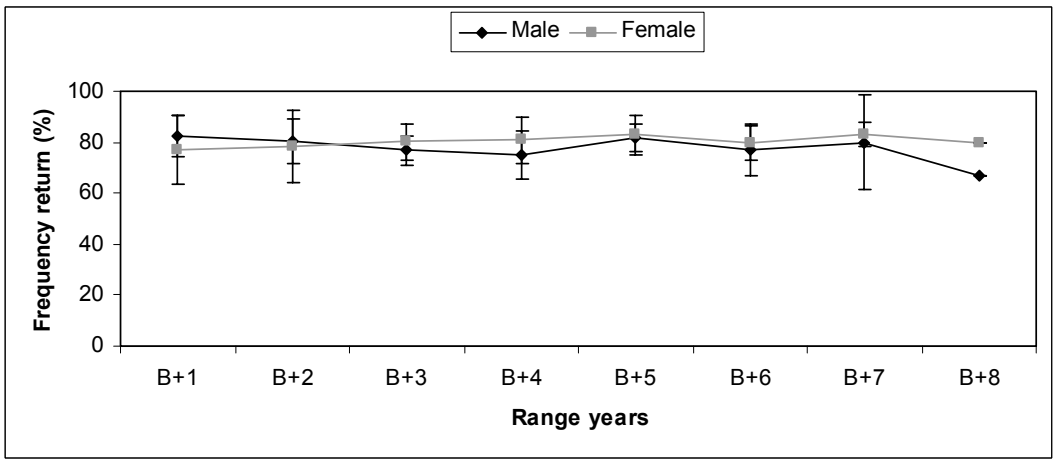


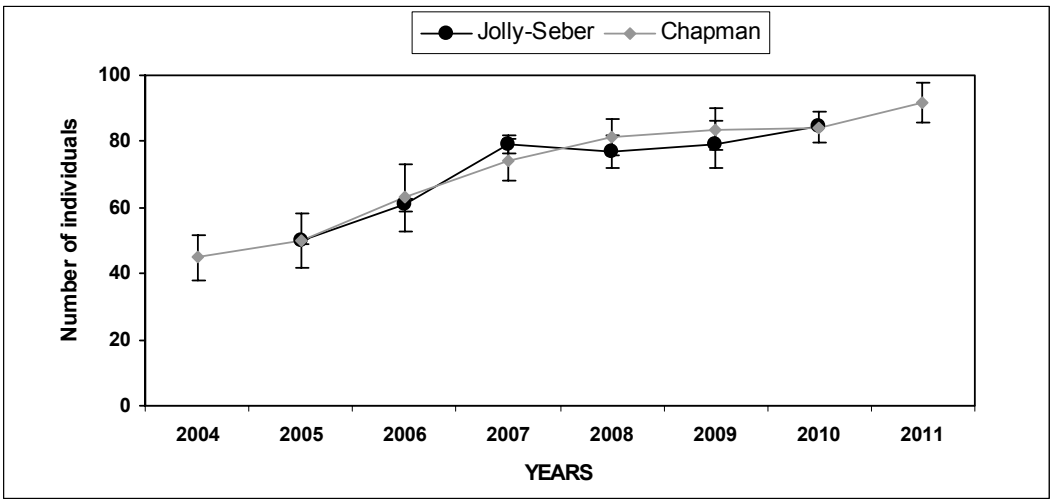
Figure 6. Frequency of return by gender of humpback whales to the Strait of Magellan separated by two to nine years.



Estimate of abundance and Population growth rate

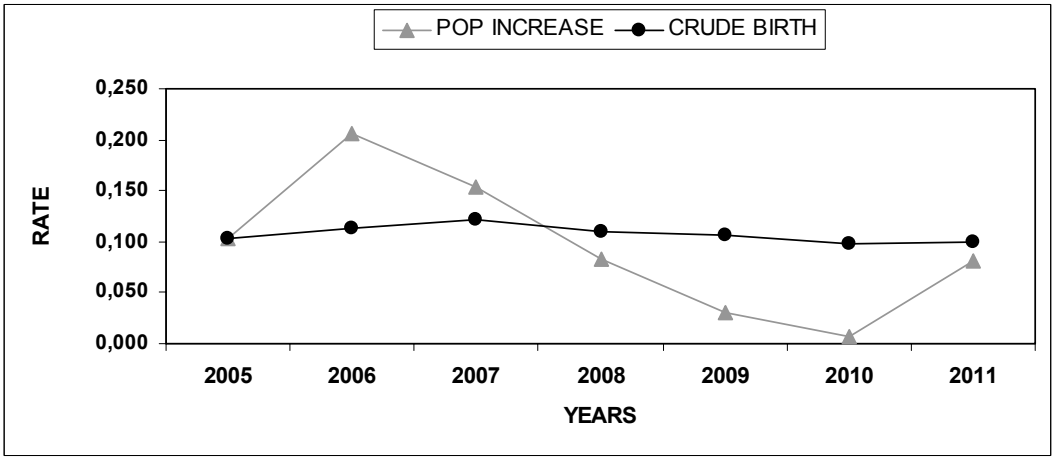
Abundance estimates on the 2004 – 2011 period show a progressive increase, from a mean of 45 individuals in 2005 [37 – 53] to 92 in 2011 [86 – 98]. Closed and opened models show consistent figures and similar tendency of steady growth in abundance (Figure 7). There were no significant differences in abundance estimate with both models (Mann-Whitney, U= 22, *P*= 0.846). The high fidelity and annual rate of return of humpback whales to SM, allow us to estimate an overall abundance of 132 individuals for the whole period (1999-2011) (CV= 2.5%, [125-138]).

Figure 7. Abundance of humpback whales in the Strait of Magellan estimated by two models of capture-recapture.



We estimated a mean annual growth rate of 0.095 whales (SD= 0.069) [0.007 – 0.206] between 2004 and 2011. With the exception of 2004, we found calves in all seasons in the period 2004 – 2011, with a mean crude birth rate of 0.094 (DS= 0.039, range 0 - 0.122) (Figure 8). Also, two unidentified adult humpback whale corpses (*c.* 14 and 12 m) were found in the area at the end of season 2009 and 2010, and one calf corpse at the end of 2011.

Figure 8. Annual population growth rate and crude birth rate for humpback whales in the Strait of Magellan, Chile



Discussion

Sex ratio and life-history parameters

Our estimate of sex ratio is reliable and representative of SM population because or due to we sexed 91% of all whales identified between 1999 and 2011 or an annual average of 91.1% along the period of more

homogeneous effort (2004-2011). The sex ratio near parity in the SM is consistent with most of the feeding aggregations (Clapham *et al*. 1995, Palsbøll *et al*. 1997).

Our estimate of 5-6 years for the mean age of first parturition based in two females is similar to average of 5.9 years (SE= 0.23 years) estimated by Clapham (1992) for the Gulf of Maine, value considered as the most appropriate estimate for the species by Zerbini *et al*. (2010). However, sexual maturity appears to vary both within and among populations in Northern and Southern Hemisphere. (Chittleborough 1965, Gabriele *et al.* 2007).

Although there is some variation across regional populations worldwide in feeding areas, both in calving and crude birth rate (Baker *et al*. 1987, Clapham & Mayo 1990), the average crude birth rate 0.090 (SD = 0,038) for the SM is consistent with the 0.08 (SE=0.01) for the Gulf of Saint Lawrence (Ramp *et al*. 2010) and 0.075 to 0.079 for the Gulf of Maine (Clapham & Mayo 1987, 1990). Our average calving rate (0.33) is smaller than the rate of 0.39 to 0.42 observed in the Gulf of Maine (Clapham & Mayo 1990, Barlow & Clapham 1997, Clapham *et al*. 2003) and the range between 0.37 to 0.44 for southern Alaska and California humpback whales (Baker *et al.* 1992, Straley *et al*. 1994, Steiger & Calambokidis 2000, Zerbini *et al*. 2010). As observed in the SM, calving interval of two years mainly followed by three years appears to be most common worldwide (Steiger & Calambokidis 2000, Wiley & Clapham, 1993, Straley 1994, Barlow & Clapham 1997, Craig & Herman 2000).

Abundance and population trends

The population studied is small. Our growing seasonal estimates by the two models are very similar, accurate (with low SD), and indicate a maximum abundance smaller than a hundred for the last season (2011). Across-year estimates seem representative and reliable of the true abundance of humpback whales in the area being always slightly higher than the whales photographically identified each year. Also, parity found in the sex ratio doesn't create a possible bias to our abundance estimate as has been noted in other regions. Abundance estimate of 132 individuals [125 – 138] for the whole period 1999-2011 is also slightly higher but consistent with the cumulative 126 photo-identified whales.

This feeding aggregation is only a small fraction of the primary feeding grounds for the South East Pacific population, being 6,991 humpback whales (CV = 0.32) estimated by visual line transects for the Western Antarctic Peninsula and 2,493 (CV= 0.55) for the Scotia Sea carried out by CCAMLR in January and February 2000 (Fleming &nd Jackson 2011). Consistent with these figures, the most recent estimate of abundance for its breeding area in Ecuador was 6,504 (CV = 0.21) over the survey period 2005-2006 (Félix et al., In Press in Fleming & Jackson 2011). In the mid 1990s, photo-ID based mark recapture estimates of abundance for the Colombian breeding grounds was between 1,120 and 2,120 whales for the whole Colombian Pacific (Flórez-González *et al*. 2007).

Although our study area seems to be small for the home range of humpback whales within feeding areas, it concentrates the species and is representative for regional aggregation. The actual seasonal abundance estimates still appear to be substantially lower than numbers found prior to commercial hunting from coastal whaling station occurred in the 1905-06, when at least over a hundred were taken each year (Martinic 1977). These catches probably encompassed areas larger than our present study area, but waters around Carlos III island show a high density of animals in comparisons to other fjords of the western Patagonian region (Gibbons *et al*. 2003).

Occupancy and site fidelity

Both the presence and the average occupancy of about two months seems representative of the real residence of whales in the study area. No underestimate appears feasible since occupancy estimate is included within the average sampling effort period (111 days per year) carried out during this study. The high annual humpback whale return rates (81.5%) and the longest interval recorded (11 years) in the SM suggest long-term site fidelity at the SM as was suggested by a preliminary report (Acevedo *et al*. 2006).

Conservation and Management Implications

The small size of the humpback whale population in the SM, the high site fidelity and occupancy, certainly maximize vulnerability to human activities, like commercial whale watching operations and vessel traffic. At present vessel traffic is mostly composed of large container ships and oil tankers which directly overlap

along at least one hundred kilometres of narrow marine channels with one sector of higher presence of humpback whales. In the coming years will be added the high traffic of large ships (one vessel every two days at least) regarding the development of a large scale coal mining project to be located nearby Jeronimo Channel and the middle Strait of Magellan. This area, recognized as a critical habitat for a unique population of humpback whale, will be used for the coal transportation. It will concentrate the impacts on resident humpback whales, particularly because it raises the probability of collisions with large vessels. This negative impact has not been appropriately evaluated in the Chilean system of environmental impact assessment.

Acknowledgments

The study was partially funded by grants INV-5-03-01 of the Universidad Santo Tomás, grants N° 021500 of the Universidad de Magallanes, grants D/010828/07 and D/010828/08 from AECID (Agencia Española de Cooperación Internacional y Desarrollo) and grant Fondecyt 029700 from Chile. Authors wish to thank to Ministerio de Bienes Nacionales, Instituto de Fomento Pesquero (IFOP), Direction of Maritime Territory (DIRECTEMAR) and Ministerio del Medio Ambiente, for the facilities. To Derek Corcoran, Frederick Toro, María José Perez for field assistence and Sofia Guerrero, Franco Cruz and Paola Sáez by the laboratory work.

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