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INTRODUCTION

The IWC conducted its last major review of the status of southern right whales (*Eubalaena australis*) in 1998 (IWC 2001) and more recently in 2010 (IWC 2010) and 2011 (IWC 2011). Following severe historical depletion by commercial whaling, several breeding populations (Argentina/Brazil, South Africa, and Australia) of southern right whales have shown evidence of strong recovery, with a doubling time of 10-12 years (Bannister 2001, Best *et al*. 2001, Cooke *et al*. 2001). The other breeding populations are still very small, and data are insufficient to determine whether they are recovering. Estimated total size for the species in the Southern Hemisphere in 1997 was 7,500 animals (of which 1,600 were mature females, including 547 from Argentina and 659 from South Africa), and the three main populations have continued to increase at a similar rate since then. Illegal Soviet catches (mainly in the 1960s) temporarily inhibited recovery, but overall the population appears to have grown strongly since then (Tormosov et al. 1998).

Payne and colleagues carried out long term studies in southern right whales around Península Valdés (Argentina) since the early 70´s and estimated population size and other parameters derived from sighting data based on individual pattern of callosities. The rate of increase r was estimated close to 8% (Payne 1986; Payne et al., 1983, 1990; Whitehead et al., 1986). Those estimations were obtained from a mark-recapture model based on individual recognition of whales. Whereas in 1998 the assumed average growth rate for all populations of southern right whales throughout the Southern Hemisphere was 7.5%, during the 2011 meeting it was agreed to use 6% and 7%. However, Cooke suggested that there has been a substantial decline in the long-term rate of increase for this population in recent years, around 5.0% over the last 10 years (Cooke, per. comm. to the Workshop on SRW).

However, the process of gathering the information from photo-id data bases is time consuming, and there is a need from the local management officers to have a quick and relatively cheap methodology to estimate the abundance and population trend. This is the main reason why we developed a method based on direct counts of whales on the coastal zone from aerial surveys. Nevertheless, some whales are found in deeper waters at least in Golfo Nuevo (Fig 1). This area cannot be surveyed by plane, and hence, estimations using boat based methodology is needed.

With regards to the Península Valdés stock, in the last years the population has experienced an enhanced mortality of calves that has raised concern to the scientific community, national and provincial authorities and local people.

Therefore, the objectives of this work were: 1) to estimate the relative abundance in the monitoring zone every year and the rate of increase, 2) to estimate density in deeper waters, 3) to estimate the number of whales moving around PV and calves born throughout the year, and 4) to analyse the mortality trend of calves through time.

Phylosophy of the method

During the last fifteen years we developed a method for monitoring the population, which could lead to study seasonal changes within and between years. The method is based on the assumption that around 95% of the whales will be found within a coastal strip (Payne 1986; Payne et al., 1983, 1990) and the number of whales in the strip can be considered a measure of relative abundance in the whole PV area. However, an unknown number of whales is in transit in deeper waters in the gulfs and need to be estimated by other methods.

Study area and aerial surveys

A monitoring area was defined from the mouth of Chubut River (42°30´) to Puerto Lobos (42°) totalling a coastal strip of 350 nm long (620km) (Fig. 1) flying the coastal zone parallel to the coastline at an altitude of 500 feet (Crespo et al., 2011, 2014). The area was consistently flown from south to north always taking off around 10:00am in order to avoid any variation in the numbers/visibility due to the time of the day.

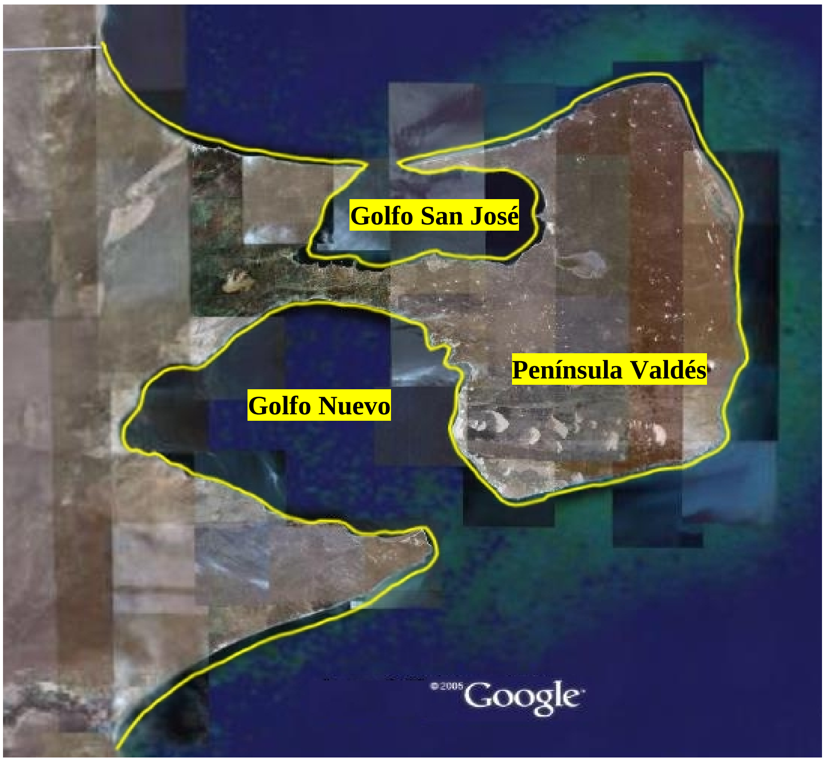

Figure 1: Monitoring area designed for counting SRW

Aerial surveys were selected to be the best method to count whales in the monitoring area. The period between flights ranged from 45-50 days, a similar period of the average residence of whales in the area. Ideally, during each census new individuals were being counted. However, this permanence period was reviewed to be around 70 days (Rowntree et al., 2010, IWC report on SRW). Flights were carried out if the Beaufort Sea State was between 0 and 3 (Crespo et al., 2011, 2014).

The surveys were carried out using high-wing single-engine aircrafts Cessna B-182. A crew of four flew in every survey: the pilot, one recorder and one observer on each side of the plane. Distance to the coast (on the left side of the plane) was held fairly constant at 500 m, and was controlled several times during the flight. From measures carried out with a clinometer, the effectively covered strip to the right side of the plane (deeper waters) was about 1000m. Then the monitoring zone covers the coastal waters from the mouth of Chubut River to Puerto Lobos, in a water strip of about 1500m from the shore.

Average speed of the aircraft remains fairly constant around 90 kn and height remains within 500 ft (≈ 152.4 m). The depth under the plane is less than 20m. Abundance was estimated by counting the total number of whales within the monitoring area which gives a relative measure of abundance. A total of 58 flights were carried out between May 1999 and December 2000 and June 2005 and October 2014. Not every year had the same number of flights, and hence effort differs yearly.

Age and sex classes to be count

Whales from the air can be distinguished in three groups.

a) Mother-calf pairs (MC) which are one adult female and a calf

b) Solitary individuals (SI) which can be either adult males or females or subadult individuals

c) Breeding groups (BG) which is usually formed by one adult female and several males.

The groups and the number of whales in each group were recorded. For analysis purposes, mother-calf pairs and total number of whales were used as response variable. Total number of whales includes the mother-calf pairs.

1) Rate of increase estimated using Generalized Linear Models procedures

The full data set was analysed using a GLM framework, which extends the standard linear regression model by assuming a non-Normal error structure and using a “link” function (McCullagh and Nelder, 1989; Zuur et al., 2009). The GLM framework has been applied successfully in ecology because some of the exponential family distribution can cope with the problems associated to count data (Zuur et al., 2009). The simplest GLM for count data assumes a Poisson error distribution, and a logarithmic link function. This model is usually called a log-linear regression, because the logarithm of the Poisson parameter (u) is taken to be a linear function of the parameters and data (Zuur et al. 2009). One of the problems of assuming that the errors are Poisson distributed is that the error variance is constrained to be equal to the mean (u).

An alternative to the Poisson model that also can be used for count data is the negative binomial model. The negative binomial model is more flexible because it allows the variance to be a function of the mean and an additional parameter called the overdispersion parameter (McCullagh and Nelder, 1989). The negative binomial regression can be considered as an extension of the Poisson regression model when the overdispersion parameter is known. This parameter allows the variance to be larger than the mean, estimating more accurate standard errors for the parameters. The failure to detect overdispersion and correct it by using a negative binomial error could lead to mistakenly small standard error of the estimated parameter (Ward et al 2011). The Poisson distribution assumes that data are randomly distributed, while the negative binomial can estimate the parameters for aggregated data such as the censuses for the southern right whale.

Both Poisson and negative binomial models were applied to data of censuses of southern right whales in Península Valdés Area. As predictor variables we included the Year and the Month, considered as continuous variables (Month 1-12; Year 1999-2014). Monthly variation in number of whales was modelled using also the Month^2, allowing the models to explore a non-linear relationship between numbers of whales and temporal variables. Another set of models included as predictor variables the Year and the Julian Day, using also Julian Day^2. Models were selected using Akaike Information Criteria (AIC), allowing evaluating which error structures and predictors are best supported by the data. We modelled four response variables: a) the total number of whales; b) the number of calves; c) the number of solitary individuals and c) the number of mating groups. All of the response variables were modelled within the same frame using the package MASS in R software (R Core Team, 2013).

Many more models were evaluated for the full data set, including models that treated the predictor Month as a categorical variable, models estimating the parameters using a quasi-Poisson distribution and models using a normal distribution, but only the best fitting model and several related models are presented. Table 1 shows the models selected using the total of censused animals as a response variable, while Table 2 shows the same models for the calves.

The results for other models (Table 1 and 2) are presented in terms of ΔAIC, and as a rule of thumb values that are less than two should be given consideration in addition to the selected model, while models with ΔAICc values that are more than ten should receive little consideration (Burnham and Anderson, 2002).

Table 1: Poisson and Negative binomial models for southern right whales censuses, using year (Y) and month (M) and year and Julian day (JD) as predictor variables. For each model, the effect of the variable Year is expressed as an annual increase rate and its associated 95% confidence interval (CI). The models are ordered according to the support given by the data assessed by the AIC.

Model	Predictors	Error distribution	Effect of the Year	95 % CI	AIC	ΔAIC
1	Y + JD +JD2	Negative binomial	3.23%	0.13-6.31%	545.62	
2	Y+ M + M2	Negative binomial	3.83%	-0.29-7.90%	572.46	26.84
3	Y + JD	Negative Binomial	5.98%	-1.91-12.1%	640.6	94.98

4	Y + M	Negative binomial	5.50%	-2.38-13.00%	640.79	95.17
5	Y	Negative binomial	4.05%	-4.36-12.10%	647.63	102.01
6	Y + JD +JD2	Poisson	3.25%	2.91-3.58%	2180.1	1634.48
7	Y+ M + M2	Poisson	4.81%	4.47-5.14%	2887.3	2341.68
8	Y + M	Poisson	4.97%	4.64-5.30%	14363	13817.4
9	Y + JD	Poisson	5.15%	4.47-5.49%	14450	13904.4
10	Y	Poisson	3.64%	3.31-3.96%	16291	15745.4

The selected model for the census of all of southern right whales in Península Valdés from 1999 to 2014 indicates that population has increased in 3.23% annually (95% IC= 0.13 – 6.31%), being selected model the lowest estimated increased rate.

Table 2: Poisson and negative binomial models for southern right whales calves censuses, using year (Y), month (M) and Julian day (JD) as predictor variables. For each model, the effect of the variable Year is expressed as an annual increase rate and its associated 95% confidence interval (CI). The models are ordered according to the support given by the data assessed by the AIC.

Model	Variables	Error distribution	Effect of the Year	95 % CI	AIC	ΔAIC
1	Y + JD +JD2	Negative binomial	5.54%	2.27-8.79%	413.48	
2	Y+ M + M2	Negative binomial	6.60%	2.43-10.75%	436.64	23.16
3	Y + JD +JD2	Poisson	6.05%	5.38-6.73%	861.69	448.21
4	Y+ M + M2	Poisson	7.48%	6.81-8.15%	1,057.70	644.22
5	Y + M	Poisson	8.09%	7.44-8.75%	4,301.60	3888.12
6	Y + M	Negative binomial	8.09%	7.44-8.75%	4,303.00	3889.52
7	Y + JD	Poisson	8.38%	7.72-9.04%	4,360.50	3947.02

8	Y + JD	Negative binomial	8.38%	7.72-9.04%	4,361.80	3948.32
9	Y	Poisson	6.21%	5.56-6.86%	5,325.70	4912.22
10	Y	Negative binomial	6.21%	5.56-6.86%	5,326.90	4913.42

The selected model suggests the number of calves of southern right whales born in Península Valdés increased by 5.54% per year (95% CI = 2.27 – 8.79% per year) from 1999 to 2014. Even though the other models are not supported by data, the estimated increased rate is the lowest estimation among all of the models.

For both response variables (whole population and calves), no other model presents a ΔAIC less than 10, hence no other model, but the selected one, was supported by data. All of the models that performed the best presented a negative binomial distribution, with at least 448 AIC units less than their Poisson distribution counterparts, indicating that overdispersion is present in data. The Julian day is the predictive variable that presented the most influence on the number of censused whales (data not shown), and also, the Julian Day^2 has an important influence, suggesting that the temporal relationship with the number of counted whales is not linear. The later can be deduced from the fact that the best fitting model irrespectively of the error distribution includes this term.

The supported model of these GLM analyses of southern right whales censuses was a negative binomial GLM that assumed linear dependence on Year and quadratic dependence on Julian day for both of the used (Model 1, Tables 1 and 2). The estimated Year coefficient was 0.03234 (SE = 0.00132) for the total of counted whales, indicating that the southern right whales increased at a 3.23% annually. For the calves in the same period, the coefficient of Year was 0.05539 (SE = 0.01629), indicating a higher annually increased rate for the same period.

The negative binomial model with the lowest AIC score for both response variable treated Julian day dependence as quadratic. For the whole population the sightings increase from June to September, reaching approximately the same expected number of whales for August and September (Fig. 2). The number of whales lately starts to decrease from September to December, reaching it minimum in January. The model predicts the presence of whales in the area during December. This behaviour of the model is consistent on with the previous published information, but it predicts that the maximum number of whales could be reached from August to September, not during September as it always was assumed (Rowntree et al., 2001). The model shows that depending upon the Year, the bulk of whales can arrive early or later during the season. The model that uses as response variable the number of calves shows a similar pattern, increasing from July onwards. The maximum number of calves in the area is attained during September, and decreases abruptly until December (Fig. 3). The proposed models are not able to cope with the year-related variation in the arrival of the whales to Península Valdés area. The information required for doing so is not available at the moment, but mean monthly STT in South Georgia Islands area, or productivity are candidate variables to model this temporal variation.

Regarding the models supported for the other two additional response variables (Solitary individuals and Mating groups), the results are summarized in Table 3. Both observed response variables are best supported by the same model structure as the Total number of whales and the Calves (data not shown), but the estimates for the effect of the year is non-significant.

Table 3: Negative binomial models for southern right whales censuses, using year (Y), month (M) and Julian day (JD) as predictor variables. For each model, the effect of the variable Year is expressed as an annual increase rate and its associated 95% confidence interval (CI). SI model uses as a response variable the Solitary individuals and MG model uses as response variable the individuals counted in Mating Groups.

Response variable	Variables	Error distribution	Effect of the Year	95 % CI
SI	Y + JD +JD2	Negative binomial	-0.21%	-4.30 – 4.63%
MG	Y+ M + M2	Negative binomial	-0.74%	-6.61- 4.94%

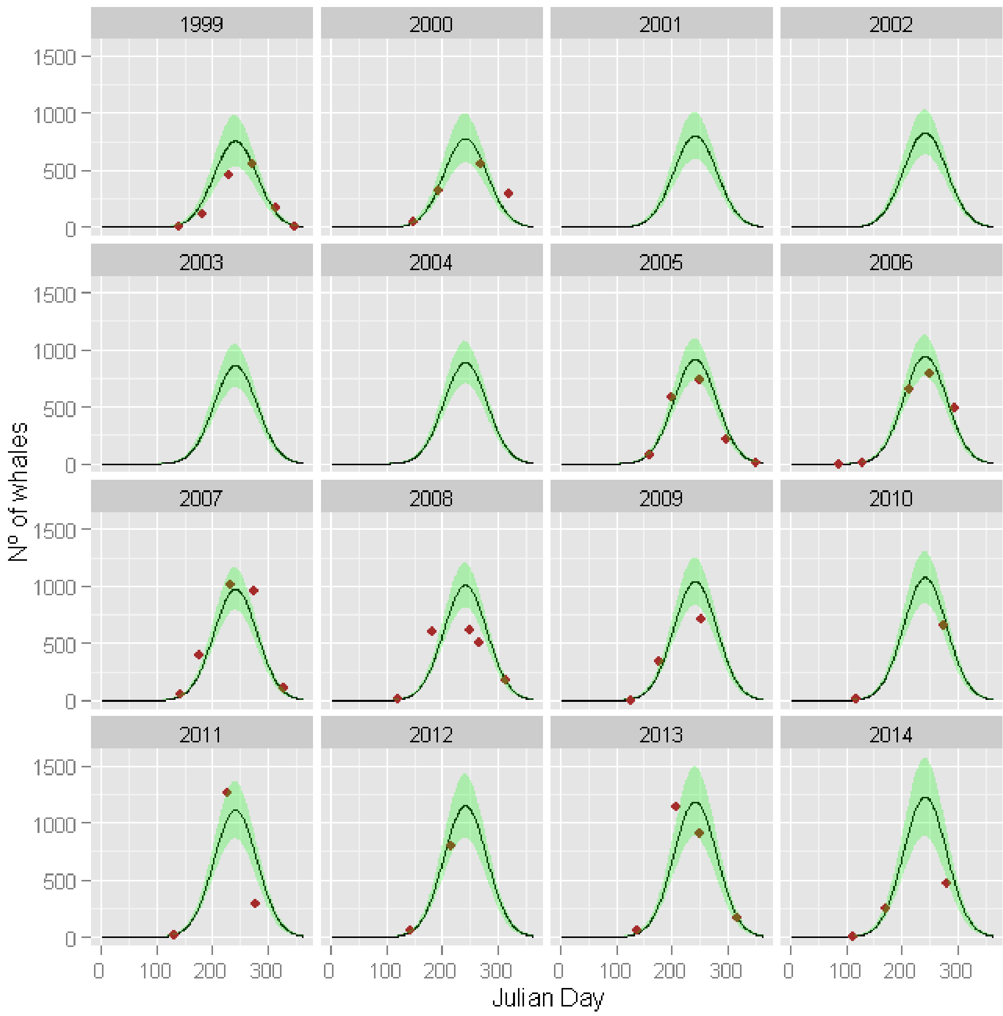

Figure 2: Total Number of whales predicted by best fitted model. Red dots are actual observations and green shadow area represents IC 95% for the estimates.

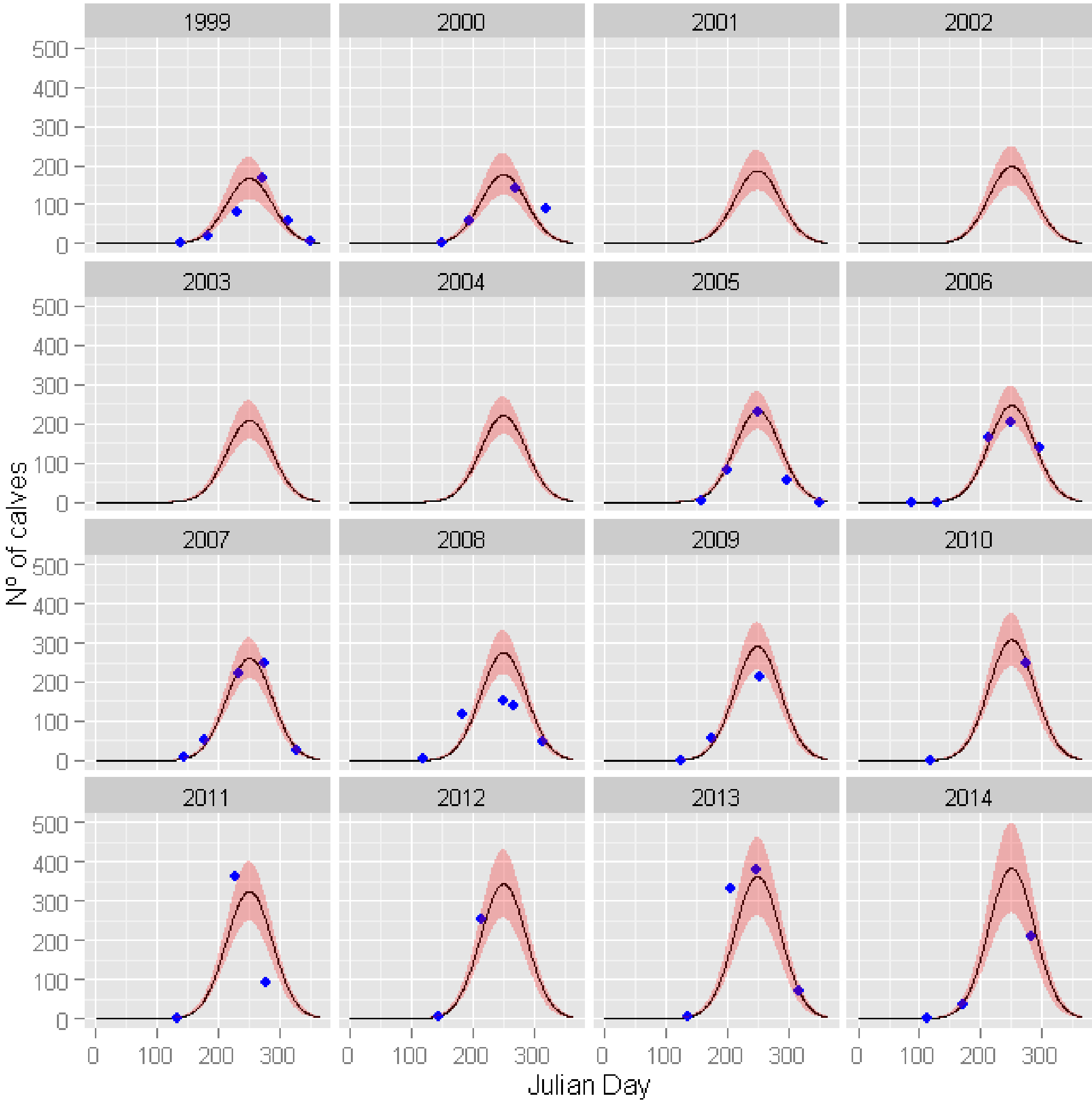

Figure 3: Total Number of calves predicted by best fitted model. Blue dots are actual observations and red shadow area represents IC 95% for the estimates.

This rate of increase for the total of whales in the area is relatively low when compared with the previous published information (Cooke et al., 2001; Rowntree et al., 2013; Crespo et al., 2014). In order to detect a trend in the rate of increase, estimates using the same model selection procedure were performed, using the information available. The best fit model for every data set was the same as the selected for the whole set (Table 1), including the year, the Julian day and the Julian Day^2 and a negative binomial error distribution. The first estimate is for the year 2007 (from 1999), and sequentially models including the year 2008-2014 were adjusted (Figure 4). For 2007 the r= 6.22% [CI 0.44 - 11.25%], and decreased at a rate of -0,45% annually (Linear regression, p< 0.001).

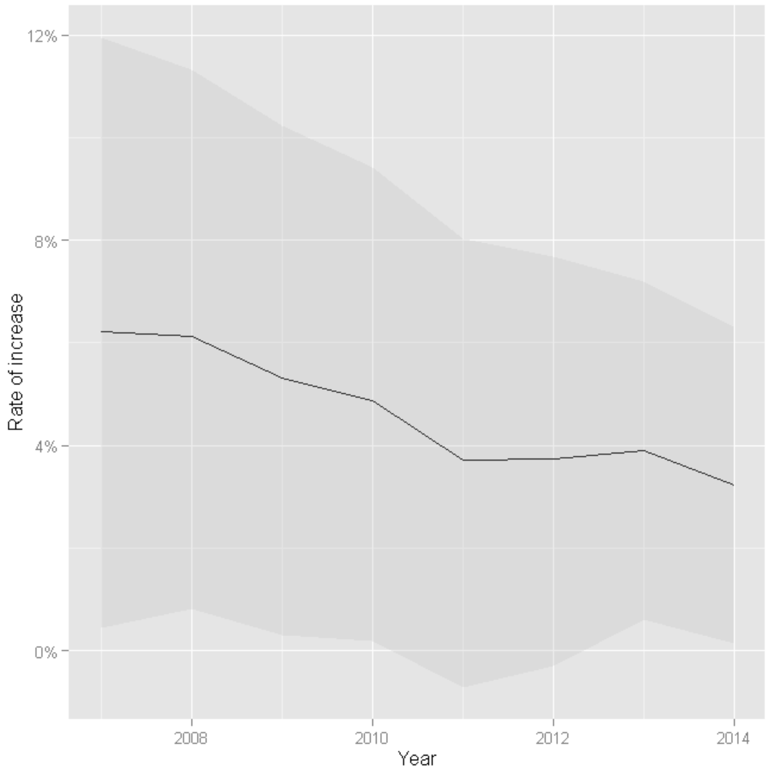

Figure 4: Rate of increase from the best fit models adding sequentially data from years 2007-2014. Grey shadow area indicates the CI 95% for the estimates.

Considering that the general trend of the population in the surveyed area is increasing, although the rate is steadily decreasing, that the calves are increasing at a rate close to the previously reported and that the Solitary Individual and the Mating Groups are no longer growing, the most likely scenario includes a relocation of the whale in the Península Valdés area. Mother-calf pairs are occupying the coastal zone (*ie*: the optimal habitat), while Solitary Individuals and Mating groups are forced to use suboptimal habitats. The trend found could be an indication that the area is getting close to it carrying capacity for the optimal habitat. This coupled with the fact that more whales are sighted each year outside the surveyed area, lead us to propose that the south Atlantic population still grows at a high rate. Whales are recolonizing pre-depletion areas, both along the argentine coasts as in south Brazil and Uruguay. For the surveyed area, we propose that in the next few years the Solitary Individuals and the Mating Groups will be found in deeper waters inside both gulfs and the outer ridge of Península Valdés. Also, in the surveyed area, we can expect observe to density-dependent effects on population parameters, including perinatal and calf mortality.

2) Estimation of the number of whales in deeper waters

Given also that there is an unknown number of whales out of the monitoring zone in the coastal area, it was decided to estimate this figure by means of several nautical surveys in deeper areas of Golfo Nuevo and Golfo San José. Random transects were carried out by a research boat from January 2001 to August 2012 on both gulfs during a study focused on the behaviour and ecology of dusky dolphins (*Lagenorhynchus obscurus*). This allowed gathering information on southern right whales in deeper areas. However, it was observed that density was not homogeneous in the gulfs. A high variability of density was observed within years, between years and between zones. Therefore, a specific distance sampling survey for counting whales was carried out in 2014 choosing one area close to Puerto Madryn. Transects were disposed with a zig-zag pattern in an area of 112.55 km^2 (shaded area in Fig. 5). The chosen area is close to one called El Doradillo, which has been reported as a high density area (Crespo et al., 2014). Southern right whales groups were recorded with geographical location and perpendicular distance estimated by eye.

Right whale density was estimated in deeper areas using the standard distance sampling methods (Buckland et al. 1993, 2001). Data were analysed using the program DISTANCE 6.2 (Thomas et al. 2010). Data were pooled in intervals to allow a monotonically decreasing frequency distribution of animals. Distance larger than 1000, were truncated. Model selection for detection probability was performed using information criterion (AIC). Essentially, the program fits a detection function to the distribution of perpendicular distances and this function is used to estimate the effective strip half-width (ESW). Then, the density is given in the following equation:

$$\hat{D} = \frac{n}{2L * \hat{\mu}}$$

where n is the number of sightings on effort, *L* is the total search effort, $\hat{\mu} = \int_0^w g(x)$ and *g(x)* is the detection function. The quantity n/*L* is referred to as the encounter rate that is the number of sightings per km surveyed.

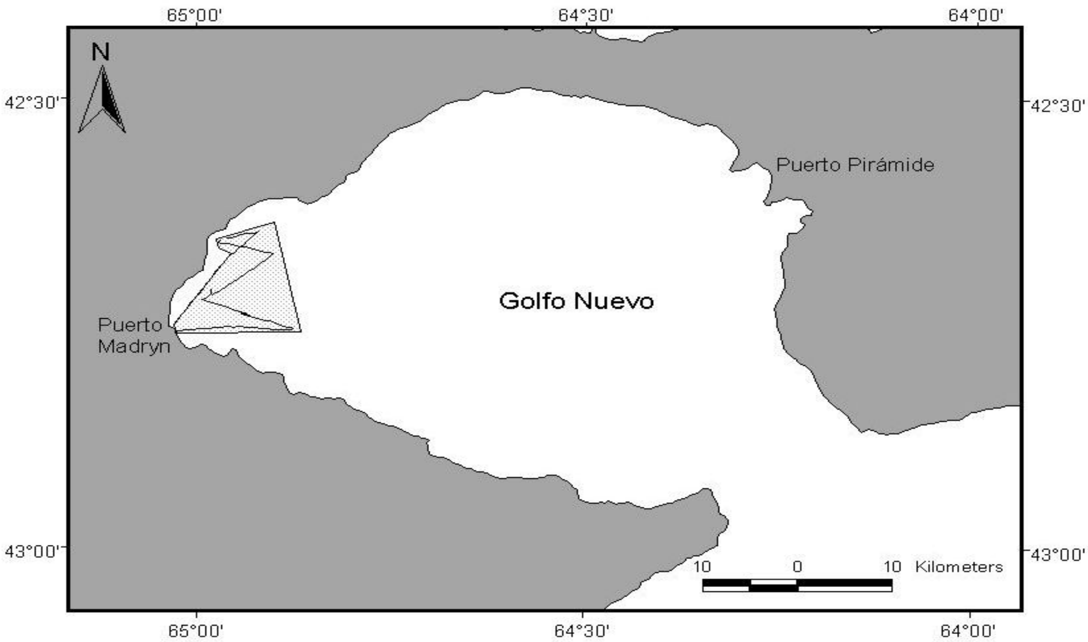

Figure 5: Nautical surveys in deeper waters for dusky dolphins and southern right whales

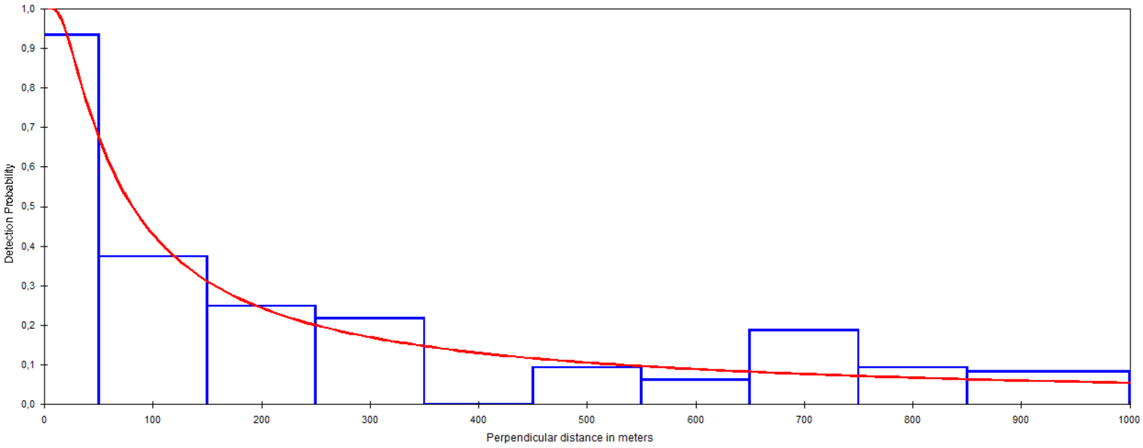

Figure 6: Detection probability function of southern right whale sightings in nautical surveys

Table 4: Parameter estimation for offshore areas. ESW: effective search width. n/L: encounter rate. D: density

Parameter	Point Estimate	Percent Coef. of Variation	95% Percent Confidence Interval
ESW (m)	186.8	42.7	82.3 - 424.0
n/L (individuals/km)	1.07	19.7	0.65 - 1.77
D (individuals/km^2)	4.1	47.5	1.6 - 10.2

We recorded 60 whale groups of size one or two. The model selected was the Hazart Rate (Fig. 6). The CV% for density was rather high (Table 4). Detection probability, encounter rate and group size contributed to the variance with 81%, 17% and 2% respectively. Density (D) obtained in this area was 4.1 whales/km^2. A rough estimation of abundance in this area is 470 whales (CI95% 191; 1159). However, the surveyed area is only a small part of the gulf. It is remarkable that the density in offshore areas is very similar to the high density areas inside the monitoring zone. Therefore, the total number of whales in the monitoring zone is underestimating the real number of whales that could be circulating in the area.

3) *Estimation of the number of whales passing through and number of calves born in PV area*

The number of whales estimated by GLM presented in the previous section for the coastal zone is an instantaneous count of whales encountered at any given Julian day. However, given that the whales remain in the area for specific periods, the whales counted early in the season, are not the same to the whales present in the middle or at the end of the season.

According to Rowntree et al., (2001), females with calves remain significantly longer on the nursery ground than other whales. In 1973, females with calves stayed on average 77 days (SD = 36.4, n = 36, range 15-170 days) while other whales stayed 52 days (SD = 34.4, n = 57, range 8-145 days).

Based on this fact, and as a conservative measure, we decided to develop a cumulative function model to estimate the total number of whales moving around Península Valdés area each year considering the residence times estimated for females with calves.

We developed this model based on the following premises: 1) the number of days a whale remains in the area is a sample from a normal distribution; 2) we can estimate accurately the number of whales present in the coastal area for each Julian day. The model is based on a cumulative function that takes into account the variation on the number of days an individual whale remains in the area and the number of whales estimated for each day of the year.

The cumulative function was built using the best fitted model from section 1. The model can estimate the number of whales for a given Julian day t in the year y:

$$B_{(t,y)} = e^{-a+by+ct-dt^2} \qquad 1 \le t \le 365$$

$$1999 \le y \le 2014$$

Where the parameters a, b, c and d are

$$a = 77,41 = 7,741 \times 10^{1}$$

$$b = 0,03234 = 3,234 \times 10^{-2}$$

$$c = 0,1605 = 1,605 \times 10^{-1}$$

$$d = 0,0003323 = 3,323 \times 10^{-4}$$

The cumulative model is presented for the all group types combined, without discriminating among solitary individuals, mating groups or mother calf pairs. For every whale the time spent in the area is drawn from a normal distribution with mean $\mu = 77$ and deviation $\sigma = 36$. (Rowntree et al, 2001). This model and the probabilistic distribution of the permanence of one whale in the surveyed area allow us to estimate the total number of whales $A(x, y)$ that came to the study area the first day of the year ***y***, until the Julian day x of the same year. We obtained the $A(x, y)$ estimation in terms of $B(t, y)$ and the unitary normal distribution $\frac{1}{\sqrt{2\pi}} N(t) = e^{-\frac{1}{2}t^2}$ by the Fourier Transform. This Transform is used in ecology in spectral analysis (Legendre and Legendre, 1998). In Appendix 1 is proved that

$$A(x,y) = B(x,y) + \frac{1}{\sigma}\sum_{k=1}^{\infty}\frac{1}{\sqrt{k}}\left(\int_{-\infty}^{x} N\left(\frac{t-k\mu}{\sigma\sqrt{k}}\right)B(x-t,y)\,dt - \int_{0}^{+\infty} N\left(\frac{t+k\mu}{\sigma\sqrt{k}}\right)B(t,y)dt\right)$$

According to our model x is the maximum Julian day in which the last whale arrived to the area, and hence writing $x = n\mu$ and using the integer part of $n = \frac{365}{u}$, we can estimate the total number whales that used the area during the year y.

For the last surveyed year, the estimated number of whales that used the Península Valdés coastal area is 1556.

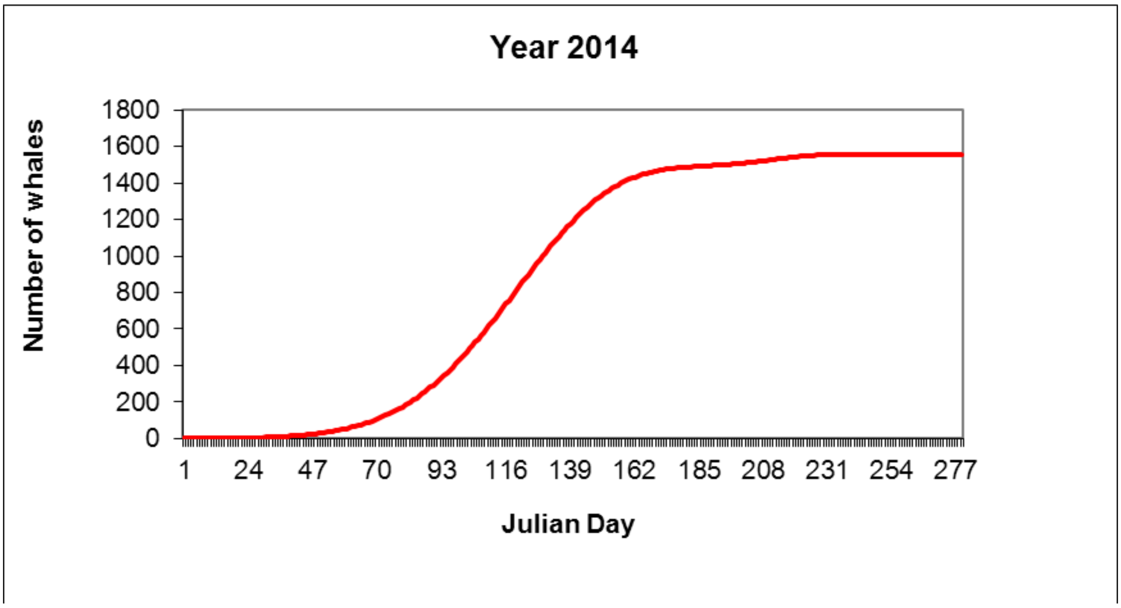

Figure 7: Estimated number of whales that circulated in the Península Valdés coastal area during the year 2014.

Using the same cumulative function we were able to estimate the number of calves born in Península Valdés each year. The model holds using the appropriate parameter set as follows for the number of calves:

$$a = 128 = 1.28\text{x}10^{2}$$
$$b = 0.05539 = 5.539\text{x}10^{-2}$$
$$c = 0.1792 = 1.792\text{x}10^{-1}$$
$$d = 0.0003588 = 3.588\text{x}10^{-4}$$

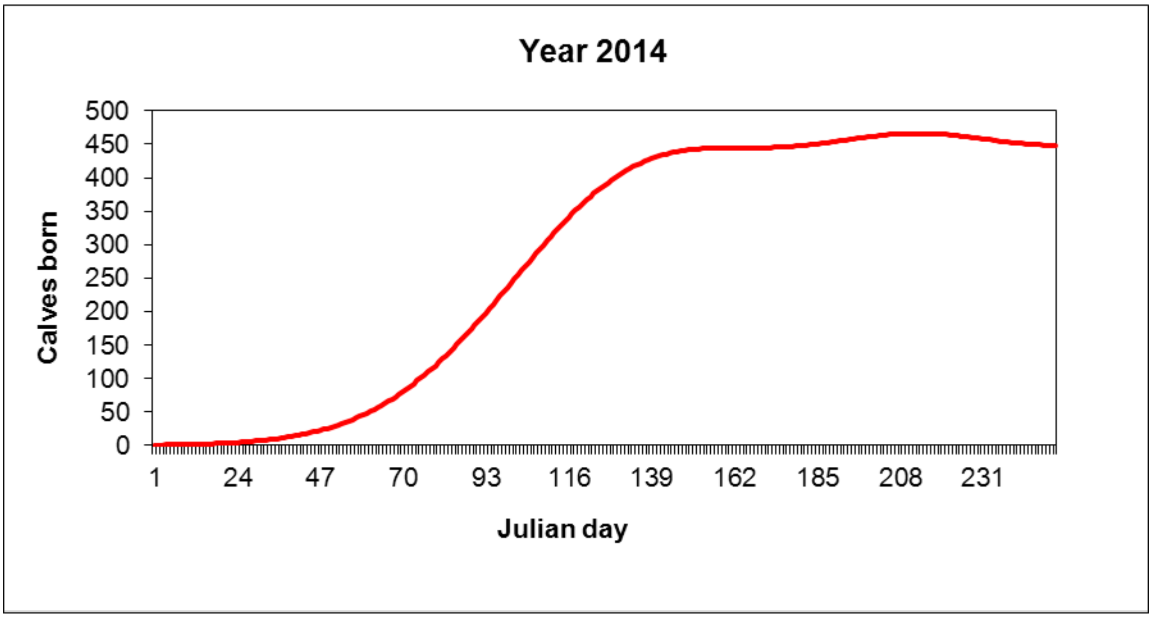

Figure 8: Estimated number of calves born in in the Península Valdés coastal area during the year 2014.

The model estimates presented in the Fig.7 are to be taken as the minimum number of whales transiting the coastal area of Península Valdés, since a key parameter of the model (i.e.: μ) is taken to be 77 days, and it was applied to every whale without discriminating into groups. Seventy seven days is the mean time spent by mothers with calves, the group with the longest permanence time (Burnel and Bryden, 1996; Rowntree et al., 2001). Other whales stayed 52 days (Rowntree et al., 2001) or even shorter periods when they are solitary individuals (Burnel and Bryden, 1996). Decreasing the mean time of residence in the study area will increase the total number of whales using Península Valdés.

The model estimates presented in the Fig.8 are the number of calves born. This model should be further examined in order to get the minimum and the maximum number of calves born in the area, using several scenarios including a shorter and longer residence time and the lower and upper limit estimation for the increasing rate model. This cumulative model shows a slightly fluctuation near it maximum because the model was constrained to be 0 in the last part of the year (December). This model allows us to estimate the number of calves born from 2003 and on. The estimations are presented in the next section along with an analysis of the death rate of the calves in the area.

4) *Analysis of mortality rates of calves around Península Valdés*

During the last decade many southern right whale calves died on their calving ground at Península Valdés (Rowntree et al., 2013) calling the attention and concern of scientists and conservation organisations. Once estimated the number of calves born around Península Valdés, the objective of this section was to analyse the trend of mortality rates trough time. Data of live and dead calves was obtained from Brownell Jr. (1986) for the period 1971-1973 and 1981-1982 and data on dead calves for the period 2003-2014 was obtained from Di Martino et al., (2013) (Table 5). The number of estimated calves born each year was obtained by means of the cumulative function developed in section 3. Calf mortality rate was calculated as the proportion of calves found dead with respect to the total born each year (Table 5).

Table 5: Mortality rates of calves

Year	Estimated calves born	Calf mortality rate
1971	21	9,52
1972	28	3,57
1973	38	2,63
1981	37	5,41
1982	40	7,50
2003	253	12,25
2004	268	4,85
2005	283	16,61
2006	299	6,02
2007	316	26,27
2008	334	29,94
2009	353	22,95
2010	373	14,75
2011	395	15,44
2012	417	27,82
2013	441	15,19
2014	466	3,43

A linear regression was fitted to the calf mortality rate showing a significant slope 0.315 (CI 0.053-0.58) (F=6.55; DF: 1, 15) (Fig. 9). It is clear that mortality rates are variable between years. Maximum rates were observed in 2007, 2008 and 2009, being the highest rate in 2008 reaching almost 30%. However, minimum rates were as low as those observed in 2004 and 2014. The rates observed in the former years, (1971-1973; 1981-1982) show the same pattern of variability with ranges from 2 or 3 to 10%. Nevertheless the significant regression indicates probably density-dependence in the mortality rates. This is coherent with the decline in the rate of increase of the population and the occupation of deeper areas during the last decade (Crespo et al., 2014).

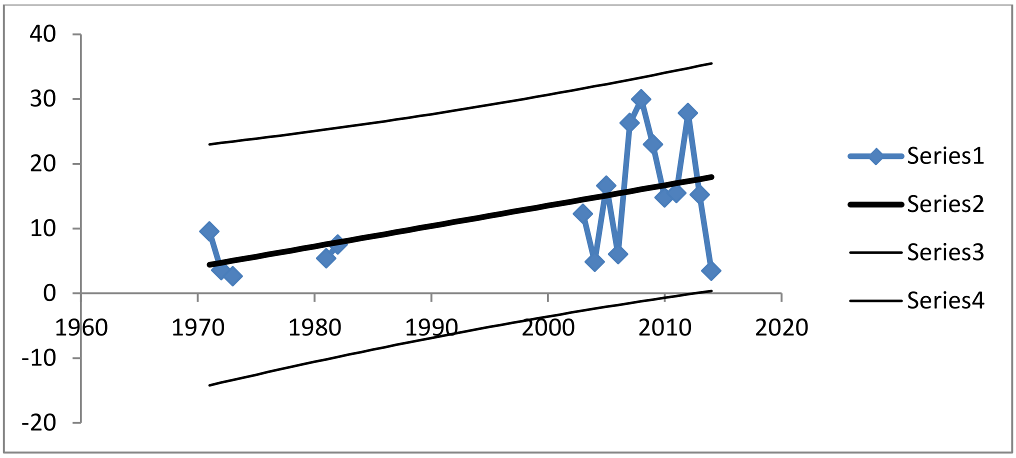

Figure 9: trend of the mortality rate of calves' trough time

DISCUSSION

The analysis of the information presented in this paper supports that the Southern Right Whale population is increasing in the nursing area around Península Valdés. In spite that the number of whales in the surveyed area is increasing, the rate is steadily decreasing. Density has been also increasing and whales have been expanding their distribution to deeper waters during the last decade (Crespo et al., 2014). The analysis of mortality rates since the early 70´s show an increase. All these facts together are coherent with a density-dependence response. The same effect was also shown by Rowntree et al., (2013) when they compared the increase in calf mortality with the increase of living calves.

With regards to the rate of increase, the calves increasing at a higher rate than the Solitary Individuals and the Mating Groups, which almost show no increase. These differences could also be explained by the fact that some adult whales could be moving to other peripheral areas as shown by the number of breeding groups and solitary individuals sighted in Golfo San Matías. This could be due to a non-stable age structure within this population (Caughley, 1977).

It should be considered that the analysis of GLM models and the estimation of the total whales and calves born with the cumulative function only considered the coastal strip. However, in section 2 it was demonstrated that many whales are off the coastal zone in deeper waters. Previously we have reported a shift in the proportion of the different groups type recorded from each side of the plane, and the proportion of mother-calf pairs is higher than expected on the coastal side (Crespo et al., 2014). The estimates of the number of whales in the deeper waters of Golfo Nuevo are a clear indication that the 5m corridor or "whale road" proposed by R. Payne is no longer the only place where southern right whales are to be found in large numbers (Payne, 1986). One thing we need to clarify is the proportion of whales that can be found in deeper waters. Also, is clear for us that whales are not evenly distributed in deeper waters, with more whales surrounding the areas of high density in the coastal zone. An extensive boat based survey must be undertaken in the next seasons, including both high and low density areas inside the gulfs, for us to be able to make accurate estimates of the population size.

The surveyed area for the southern right whale includes most of the population off the coast of Argentina, and could be considered as the optimum habitat for the species on its breeding grounds. Considering that Península Valdés as the optimum habitat, once it becomes saturated, the rate of growth in the area should decrease, and the whales should start to move to other regions, less dense and in which the rate of growth could be higher. There are clues that indicate that this could be the case, as shown by the number of whales occupying deeper waters in Península Valdés, the increasing number of whales spotted in Golfo San Matías, Buenos Aires, Uruguay and Santa Catarina in southern Brazil (Groch, et al 2005, IWC. 2010). The actual population rate of increase would be a combination of the growth in the optimal habitat and the rate of expansion to more peripheral areas.

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LITERATURE CITED

Bannister, J.L. 2001.Status of southern right whales (Eubalaenaaustralis) off Australia. Report of the International Whaling Commission (Special Issue) 2, 103-110.

Best, P.B., Brandão, A., and Butterworth, D.S. 2001.Demographic parameters of southern right whales off South Africa. Report of the International Whaling Commission (Special Issue) 2, 161-169.

Brownell Jr., R.L. 1986. Right whale survivorship around Peninsula Valdes, Argentina. App. 9 to the Report of the Workshop: Right whales: Past and Present Status

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1993. Distance sampling. Estimating abundance of biological populations. Chapman and Hall, London.

Buckland, S.T., D.R. Anderson, K.P. Burnham, J.L. Laake, D.L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. OxfordUniversity Press, Oxford.

Burnell S (2001) Aspects of the reproductive biology and behavioural ecology of right whales off Australia. J Cetacean Res Manag (Spec Issue) 2:89−102

Burnham, K. P. and D.R. Anderson. 2002. Model selection and multimodel inference. Springer,488pp.
Caughley, G. 1977. Analysis of vertebrates populations. John Wiley & sons, 234pp
Cooke, J.C., Rowntree, V.J., and Payne, R. 2001. Estimates of demographic parameters for southern right whales (*Eubalaena australis*) observed off Península Valdés, Argentina. Report of the International Whaling Commission (Special Issue) 2, 125-132.
Crespo, E.A., Pedraza, S.N., Dans, S.L., Coscarella, M., Svendsen, G. and Degrati, M. 2011. Number of southern right whales *Eubalaena australis* and population trend in the neighbourhood of Peninsula Valdes during the period 1999-2011 by means of aerial and boat surveys. Paper SC/S11/RW4 presented to the Southern Right Whale Assessment Workshop, 13-16 September 2011, Buenos Aires, Argentina (unpublished). 15pp.
Crespo, E.A., S. N. Pedraza, S. L. Dans, M.A. Coscarella, G.M. Svendsen & M. Degrati. 2014. Number of southern right whales *Eubalaena australis* and population trend in the neighbourhood of Península Valdés during the period 1999-2013 by means of aerial and boat surveys. Scientific Committee of the International Whaling Commission SC65B, Bled, Slovenia, 12-24 May 2014.
Di Martino, M., L. Beltramino, V. Rago, M. Sironi, V. Rowntree & M. Uhart. Informe Temporada 2013. Programa de Monitoreo Sanitario Ballena Franca Austral.
Groch, K. R., Pallazzo, J. T., Flores, P. A., Adler, F. and M. E. Fabian. 2005. Recent rapid increases inthe right whale (*Eubalaenaaustralis*) population off southern Brazil. LAJAM 4(1): 41-47.
Hildebrand, F.B. 1976. Advanced Calculus for Applications.2ndEdition.Prentice – Hall, Inc.
IWC. 2001. Report of the workshop on the comprehensive assessment of right whales: a worldwide comparison. Journal of Cetacean Research and Management (Special Issue) 2, 1-60.
IWC. 2010. Report of the Southern Right Whale Die-Off Workshop. R. Reeves, P. Thomas & R.L. Brownell (Eds.) 15-18 March 2010, Centro NacionalPatagónico, Puerto Madryn, Argentina. SC/62/Rep1.
IWC. 2011. Report of the Workshop on the Southern Right Whale Assessment at Buenos Aires, Argentina.
Legendre, P. and Legendre L. 1998. Numerical Ecology. 2ndEdition. Elsevier.
McCullagh, P., & Nelder, J. A. (1989). Generalized Linear Models (Second ed.). London: Springer-Science+Business Media, B.V., 511 pp.
Payne, R. 1986. Long Term Studies of the Southern Right Whale (*Eubalaenaaustralis*).pág. 161-168. En: R.L. Brownell Jr., P.B. Best y J.H. Prescott (eds.): Right Whales: Past and Present Status. Rep. Int. Whal. Commn.(Special Issue 10), 289 pág.
Payne, R. , Brazier, O., Dorsey, E., Perkins, J., Rowntree, V. y Titus, A. 1983. External features in southern right whales (*Eubalaenaaustralis*) and their use in identifynigindividuals.pág. 371-445. En: R. Payne (ed) Communication and Behavior of Whales. AAAS Selected Symposia Series 76. Westview Press Boulder.Colorado.643 pág.
Payne, R., Rowntree, V., Perkins, J.S., Cooke, J.G. and Lankester, K. 1990. Population Size, Trends and Reproductive Parameters of Right Whales (Eubalaenaaustralis) off Peninsula Valdes, Argentina.pág. 271:278. En: P.S. Hammond., S.A. Mizroch y G.P. Donovan (eds.): Individual Recognition of Cetaceans: Use of Photo-Identification and Other Techniques to Estimates Population Parameters. Rep. Int. Whal. Commn.(Special Issue 12), 440 pág.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.URL http://www.R-project.org/.

Rowntree, V., Payne, R., Schell, D.M. 2001. Changing patterns of habitat use by southern right whales (*Eubalaena australis*) on their nursery ground at Península Valdés, Argentina, and in their long-range movements. J. Cetacean Research and Management (Special Issue) 2, 133-143.

Rowntree, V., M. Uhart, M. Sironi1, A. Chirife, M. Di Martino, L. La Sala, L. Musmeci, N. Mohamed, J. Andrejuk, D. McAloose, J.A. Sala, A. Carribero, H. Rally, M. Franco, F. R. Adler, R. L. Brownell Jr., J. Seger, T. Rowles. 2013. Unexplained recurring high mortality of southern right whale *Eubalaena australis* calves at Península Valdés, Argentina. Marine Ecology Progress Series, 493: 275–289.

Stein, E.M. and Weiss, G.L.1971, Introduction to Fourier Analysis on Euclidean Spaces. Princeton University Press.

Thomas, L., S.T. Buckland, E.A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47: 5-14. DOI: 10.1111/j.1365-2664.2009.01737.x

Tormosov, D.D., Mikhaliev, Y.A., Best, P.B., Zemsky V.A., Sekiguchi ,K. and Brownell, R.L.. 1998. Soviet catches of southern right whales *Eubalaena australis*, 1951-1971. Biological data and conservation implications. Biological Conservation, 86: 185-197.

Ward, E., Zerbini, A., Kinas, P.G., Engel, M.H. and Adriolo, A. 2011. Estimates of growth rates of humbpback whales (*Megapteranovaeanglie*) in the wintering grounds off the coast of Brazil (Breeding Stock A). J. Cetacean. Res. Manage. (Special Issue) 3: 145-149.

Whitehead, H., Payne, R. and Payne, M. 1986. Population Estimate for the Right Whales off Peninsula Valdes, Argentina, 1971-1976. pág. 169-176. En: R.L. Brownell Jr., P.B. Best y J.H. Prescott (eds.): Right Whales: Past and Present Status. Rep. Int. Whal. Commn.(Special Issue 10), 289 pág.

Zar J.H. 1996. Biostatistical Analysis, 3rd Edition. Prentice Hall Inc., New Jersey.

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A. andG.M. Smith. 2009. Mixed effects model and extension in ecology with R. Springer. 574pp.

Appendix 1

$A(x,y)$ Estimation

If we denote $E(t,y)$ as the number of individuals that came into the Golfo Nuevo from the beginning of the year until the Julian day *t*, then

$$A(x,y)=\int_0^x E(t,y)dt$$

We suppose that the time a particular whale remains in the surveyed area has a Normal distribution with mean μ and standard deviation σ. We denote the density function of this distribution as $p(t)$.

$$p(t)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2}=\frac{1}{\sigma}N\left(\frac{t-\mu}{\sigma}\right)$$

if $N(t)=\frac{1}{\sqrt{2\pi}}e^{-\frac{1}{2}t^2}$.

We also can assume that $S(t,y)$ is the number of whales that leave the study area the Julian day *t* of year *y*, therefor

$$S(t,y)=\int_{-\infty}^{+\infty} p(t-x)E(x,y)dx=(p*E)(t,y)$$

Where the convolution operation, denoted as * with respect to *t*. The former functions namely "number of whales entering" $E(t,y)$ and "number of whales leaving" $S(t,y)$ the study area are connected to the number of estimated whales $B(t,y)$ by the following equality:

$$E(t,y)-S(t,y)=B(t,y)-B(t-1,y)\cong B'(t,y)$$

that is

$$E(t,y)=B'(t,y)+(p*E)(t,y)\ \text{(a)}$$

The Fourier Transform (Stein et al., 1971; Hildebrand, 1976; Legendre and Legendre, 1998) is frequently used in problems related with harmonic analysis and differential equations. It is a useful tool for calculation the unknown function $E(t,y)$ in terms of the known function $B(t,y)$. If we use the Fourier Transform to (a), we obtain the Transform of $E(t,y)$, then we applicate the inverse Transform and obtain

$$E(t,y)=B'(t,y)+(Q*B')(t,y)$$

Where $Q(t)$ only depends of the density function $p(t)$. In this way we obtain

$$A(x,y)=B(x,y)+(Q*B)(x,y)-(Q*B)(0,y)=$$

$$=B(x,y)+\int_{-\infty}^{x} Q(t)B(x-t,y)-\int_{-\infty}^{0} Q(-t)B(t,y)dt$$

In numerical terms is possible to obtain a simpler expression of $Q(t,y)$, if $N(t) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}t^2}$ and using the Fourier Transform´s elemental properties, we obtain

$$Q(t) = \frac{1}{\sigma} \sum_{k=1}^{\infty} \frac{1}{\sqrt{k}} N\left(\frac{t - k\mu}{\sqrt{k}\sigma} \right)$$

Hence, the number of whales that came into the surveyed area by day x of the year y is given by

$$A(x,y) = B(x,y) + \frac{1}{\sigma} \sum_{k=1}^{\infty} \frac{1}{\sqrt{k}} \left(\int_{-\infty}^{x} N\left(\frac{t - k\mu}{\sigma\sqrt{k}} \right) B(x-t,y)\, dt - \int_{0}^{+\infty} N\left(\frac{t + k\mu}{\sigma\sqrt{k}} \right) B(t,y) dt \right)$$

In terms of $p(t)$ we get

$$A(x,y) = B(x,y) + \sum_{k=1}^{\infty} \frac{1}{\sqrt{k}} \left(\int_{-\infty}^{x} p\left(\frac{t - k\mu + \mu}{\sqrt{k}} \right) B(x-t,y)\, dt - \int_{0}^{+\infty} p\left(\frac{t + k\mu + \mu}{\sqrt{k}} \right) B(t,y) dt \right)$$