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Population dynamics of southern right whales at Península Valdés and Golfo San Matías, Argentina: rates of increase and changes in distribution

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Summary

The recent mortality of southern right whales at Península Valdés, Argentina is the highest ever recorded for the species. Understanding the causes is critical to propose management and mitigation actions. Preliminary results from glucocorticoids in baleen from stranded calves show that stress from injuries due to Kelp Gull attacks negatively affects their physiological homeostasis, potentially leading to death. Also, aerial counts show an important reduction in population rate of increase as a whole (from 7% in the past to 0.5% at present), and changes in distribution (mainly of adults) and density along the Argentine coast. The expected outcomes of this project include (1) necropsies of stranded whales during the 2018 season (June-December), (2) the collection and analysis of baleen plates to evaluate stress hormones and (3) eight aerial surveys to count whales and record their distribution in Península Valdés and in their expanded range in Golfo San Matías in 2018.

Objectives

To continue investigations of right whale health and mortality at Península Valdés

1. Perform 4 complete flights during the season from April to December in the Penìnsula Valdès area.
2. Perform 4 complete flights during the season from July to December in Golfo San Matìas.
3. Train at least two new observers
4. Produce a new set of records of the flights performed in the both areas that can be integrated into a single database.
5. Set the basis for new models that give us an insight of the within-year dynamics.
6. Integrate the record in both areas in a preliminary model to estimate trend of the population including both surveyed areas.

Materials and methods

Study area and aerial surveys

A monitoring area was defined from the mouth of the Chubut River (42°30´S) to Puerto Lobos (42°00'S), totalling a coastal strip 620 km long (Fig. 1). The area was consistently flown at an altitude of 500 feet (152.4 m) while average speed of the aircraft remained constant at 90 kn (Crespo *et al.* 2011, 2014, 2015) from south to north, taking off at approximately 1000 to avoid variation due to the time of the day. Flights were only carried out if the Beaufort Sea State was between 0 and 3 (Crespo *et al.* 2011, 2014). The period between surveys ranged from 45-50 days, depending on weather conditions. Ideally, 7 to 8 flights were done in a given year but the actual number each year depended on weather conditions and financial support.

The surveys were carried out using high-wing, single-engine aircraft (Cessna B-182). Each survey involved a crew of four: the pilot, one recorder, and one observer on each side of the plane. Flight path was maintained at approximately 500 m from the coastline on the left (onshore) side of the plane. From measurements carried out with a clinometer, the effectively covered strip to the right (offshore) side of the plane (deeper water) was about 1,000 m.

The sea depth in the monitoring area under the plane was less than 20 m. Abundance was estimated by counting the total number of whales within the monitoring area, which gives a relative measure of abundance. A total of 79 flights were carried out between May 1999 and October 2019. Due to financial support, not every year had the same number of flights, and hence effort differed by year.

The study area also encompasses 345 km of Golfo San Matías (GSM) coast and adjacent waters from Puerto Lobos (42˚ 00´S/ 65˚ 04´W) to the mouth of the Río Negro river (41˚ 02´S / 62˚ 47´W), in Río Negro province, Argentina. The study area is adjacent to the main SRW nursery ground in South America; Península Valdés (Payne, 1986; Payne et al., 1990; Rowntree et al., 2001, Arias et al., 2018; Sueyro et al. 2018).

Particularly, during 2020 the flights were not performed because of the restrictions imposed by the national government to cope with the COVID-19 pandemic. During 2021 three complete flights were done in each survey area. The reason for not being able to complete four fights is tht the weather conditions were not good during the moment the flights were planned and also a technical problem with the plane that preclude us to flight at the beginning of the season.

Age and sex classes

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 sub-adult individuals

c) Breeding Groups (BG), which are assumed to be formed by one adult female and several males.

Rate of increase estimated using Generalized Linear Models procedures

The full data set was analysed using a Generalized Linear Model (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 with count data (Zuur *et al.* 2009). We used a negative binomial regression, which can be considered an extension of the Poisson regression model when the over dispersion parameter is known. This parameter allows the variance to be larger than the mean, estimating more accurate standard errors for the parameters (Ward *et al.* 2011). While the Poisson distribution assumes that data are randomly distributed, the negative binomial can estimate the parameters for aggregated data, such as the censuses for the SRW.

As predictor variables, we included Year and Month as continuous variables (Month 1-12; Year 1999-2019). Monthly variation in number of whales was also modelled using Month^2, allowing the models to explore a nonlinear relationship between numbers of whales and temporal variables. Another set of models included the Year, the Julian day, and Julian day^2 as predictor variables. Models were selected using Akaike Information Criteria (AIC). We modelled four response variables: a) the total number of whales; b) the number of calves; c) the number of Solitary Individuals and d) the number of individuals in the Breeding Groups. All the response variables were modeled within the same frame using the package MASS in R software (R Core Team 2013).

Fig. 1. Monitoring area for southern right whales around the breeding ground of Península Valdés and Golfo San Matías

Other 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 related models are presented.

Aerial surveys in Golfo San Matías (GSM)

Aerial surveys were carried out in GSM during 2021 to evaluate the distribution and the relative abundance of Southern Right Whales (SRW) in the GSM coastal aerial. Permissions to perform these aerial surveys were issued by the *Secretaría de Medio Ambiente y Cambio Climático* of Río Negro province. The timing of these surveys was planned for the period in which it is most likely to find right whales on the GSM coast, between August and October (Failla et al., 2008; Arias et al., 2018).

Surveys aim to record the position (lat, long) and group composition (the number of animals and the type of group) of SRW. Three group categories were identified: mother-calf pairs, one adult female with a calf; solitary individuals, adult or sub-adult males or females; breeding group, two or more individuals socializing (Crespo et al., 2019); and additional category was considered: the non-social active group, composed by adults or sub-adults whales not showing courtship behaviour (Best et al., 2003), but for the analysis they were included in SI groups. The same plane and methods were used also in GSM.

Results

Relative abundance of whales

Whales arrive at PV early in April or later in May and remain in the area up to November or later in December. The length of the season varies from year to year. Some years a few whales are still seen in January. The peak of the season is usually at the end of August or in mid-September, but it has occurred at the end of July as well. In the earlier years of the survey (1999-2000) the total number of whales counted during a flight reached around 400 adult and sub-adult whales and around 150 new-born calves. In later years (2005-2017), the number of whales in the peak of the breeding season reached 1,200 adult and sub-adult individuals and 500 new-born calves. The number of whales peaked during 2018, with a total count of 1605 whales and 710 new-born calves. Numbers were lower in 2019. In the 2021 censuses a peak of 1139 was recorded including 448 calves (Fig. 2 and 3). These figures correspond to an instantaneous count and thus are not the number of whales that pass through the area given that the residence time of individual whales is always less than the length of the breeding season. In addition, some whales are found in deeper waters far from the coastal zone, which remain to be estimated.

Estimated rate of increase

The set of models built using the total number of whales including calves as a response variable is shown in Table 1, while Table 2 shows the same models for the number of calves. Table 3 considers the number of Solitary Individuals and Breeding Groups. 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).

The selected model for the census of SRW in PV indicates that there is no influence of the Year (Table 1). The second-best model includes the Year, the estimated rate of increase is 0.58% (95% IC= -1.28% – 2.45 %), and the ΔAIC between both models is less than 2. The weight of these two models combined is 0.999.

When analysing the number of calves of SRW born in PV, the results are consistent with those obtained for the census counting the total number of whales. The selected model includes the Year yielding an increasing rate of 2.91% (95%CI = 0.71% - 5.12%). Nevertheless, the second best does not include the Year as a predictor variable. The ΔAIC between the two first models is 4.38, well above the threshold of 2. The combined weight of both models is more than 0.99, but the best-fitted model has an AIC weight of 0.88.

For both response variables (whole population and calves), no other model presents a ΔAIC less than 2, hence no other model but the selected one was supported by the data (Table 1 and 2).

For the whole population models the Julian day is the predictive variable that presents the main influence on the number of whales counted (Coef. Est. = 0.161, $p<0.001$) and the Julian day^2 also has an important influence (Coef. Est. = 0.004, $p<0.001$), indicating that the temporal relationship with the number of counted whales is not linear. The sightings increase from June to September, reaching approximately the same expected number of whales for August and September (Fig. 2). In recent years, the number of whales, starts to decrease from September to December, reaching it minimum in January. The model for the number of calves shows a similar pattern, increasing from July onwards, and also the Julian day is the most influential variable. The maximum number of calves in the area is attained during September and decreases abruptly until December (Fig. 3).

Regarding the models for the other two response variables (Solitary Individuals and Breeding Groups), the results are summarized in Table 3; and models presented a combined weight of 0.99. Both observed response variables are best supported by the same model structure as the Total number of whales and the Calves (data not shown). Nevertheless, a marked decrease in the number of breeding groups is observed with a rate of -10.19% (95%CI = -15.20 - -5.19%). For the solitary individuals the decreasing rate is less steeped, being estimated in -1.43% (95%CI = -3.780 - 0.10%). Breeding groups and Solitary individuals are becoming less common in PV.

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 that 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 2008-2021 were adjusted (Fig. 4). For 2007, the rate of increase was 8.20% and decrease at a rate of -0.705% annually (Linear regression, $P < 0.001$). For the calves, the rate of increase fluctuated from 7.45% to a 3.01% during the same period. The regression model shows a milder decrease in the trend for the calves increasing rate (-0.339% annually; Linear regression, $P = 0.009$).

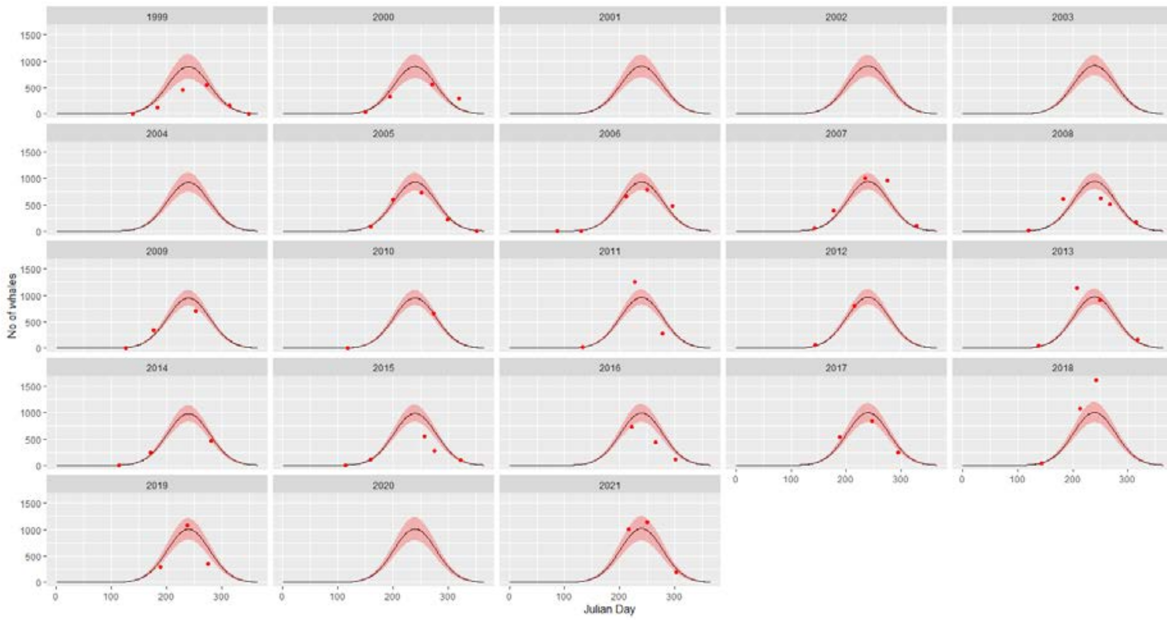

Fig. 2. Total Number of whales predicted by the best-fitted model 1999-2021. Red dots are actual observations and pink shadow area represents IC 95% for the estimates.

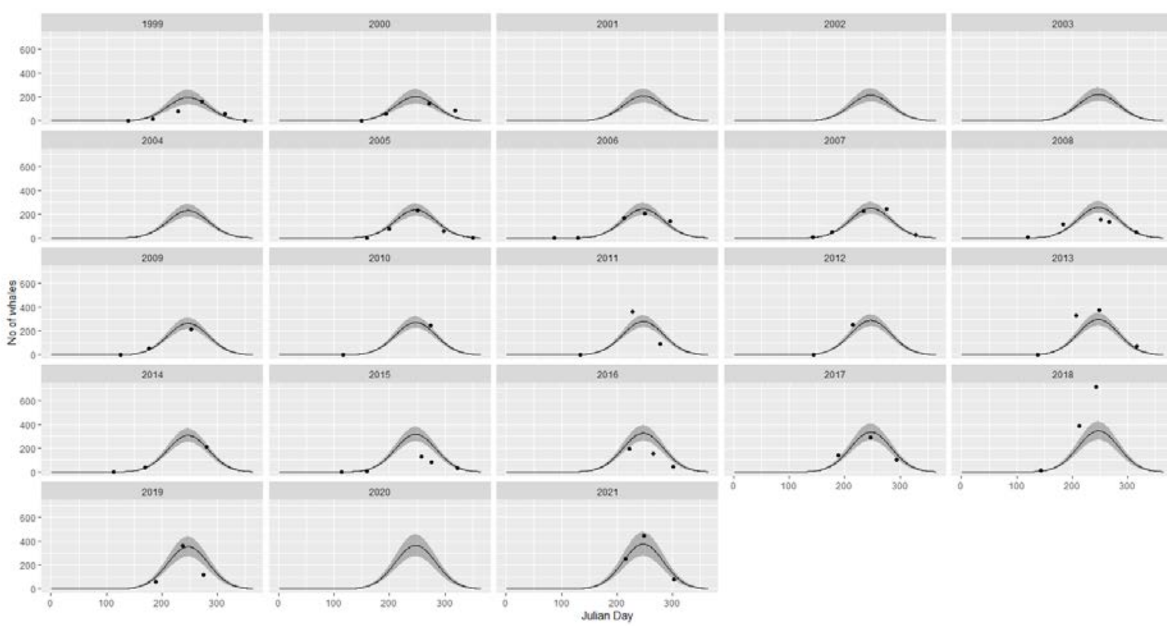

Fig. 3. Total Number of calves predicted by the best-fitted model 1999-2021. Black dots are actual observations and gray shadow area represents IC 95% for the estimates.

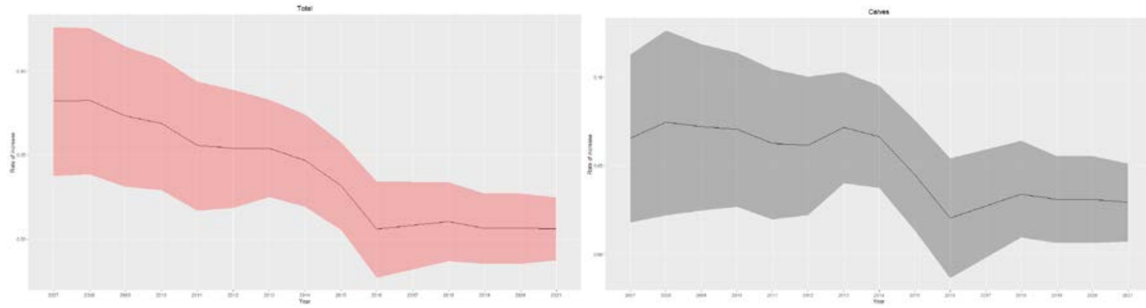

Fig. 4. Declining rate of increase from the best-fitted models adding data from years 2007-2021 sequentially. a) Total population. b) Calves. Pink and gray shadow areas indicate the CI 95% for the estimates.

Table 1. Models for SRW 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	AICw
1	JD+JD2	Negative binomial	-	-	797.04	0	0.69
2	Y + JD +JD2	Negative binomial	0.58 %	-1.28 – 2.45 %	798.66	1.62	0.31
3	Y+ M + M2	Negative binomial	0.58 %	- 1.87 – 3.25 %	833.13	36.09	0.00
4	Y +M	Negative binomial	4.25 %	-0.02 – 5.75 %	933.12	136.08	0.00
5	Y + JD	Negative binomial	4.635 %	-0.03 – 9.01 %	933.57	136.53	0.00
6	Y	Negative binomial	4.04 %	-1.65 – 15.82 %	940.49	143.45	0.00

Table 2. The best fitted models for SRW 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	Predictors	Error distribution	Effect of the Year	95 % CI	AIC	ΔAIC	AICw
1	Y + JD +JD2	Negative binomial	2.91%	0.71% - 5.12%	630.00	0.00	0.90
2	JD+JD2	Negative binomial	-	-	634.39	4.38	0.10
3	Y+ M + M2	Negative binomial	3.02%	0.25% - 5.77%	658.83	28.83	0.00
4	Y + JD	Negative binomial	7.63%	2.73% - 12.49%	743.66	113.65	0.00
5	Y +M	Negative binomial	7.11%	2.24% - 11.91%	743.70	113.70	0.00
6	Y	Negative binomial	6.23%	1.02% - 11.40%	757.75	127.74	0.00

Table 3. Negative binomial models for SRW 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 Breeding Groups.

Response variable	Variables	Error distribution	Effect of the Year	95 % CI	AIC
SI	JD +JD2	Negative binomial	-	-	695.42
SI	Y + JD +JD2	Negative binomial	-1.43%	-3.78% – 0.1%	696.05
MG	Y + JD +JD2	Negative binomial	-10.19%	-15.20% – 5.29%	501.26
MG	JD +JD2	Negative binomial	-		514.25

Golfo San Matías

Whales were recorded on every flight undertaken between August and October (Table 4). The highest number of whales was recorded in early September, with a maximum of 252 individuals recorded. In August and September, the breeding groups were the predominant group type. However, in October the predominant group was de solitary individual and breeding groups were not observed (Fig. 5). Finally, most of the whales were concentrated on the north coast of the gulf. In addition, the areas in which the whales concentrate have changed and expanded, with an increase in the presence of whales between Caleta de los Loros towards to Punta Bermeja (Fig. 6).

Table 4. Details of the aerial surveys, and the maximum number of whales registered on each flight.

Year	Date	Maximun N° whales
2021	6/8	102
2021	4/9	252
2021	7/10	12

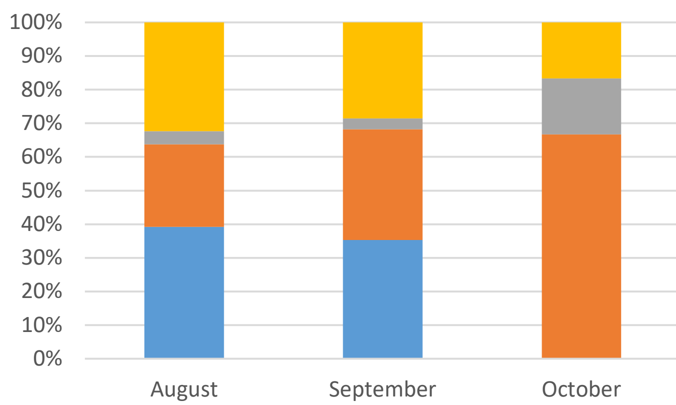

Figure 5. Proportion of group types registered on each flight (Grey mother calf pairs, orange solitary individuals, blue breeding group, yellow non-social active groups)

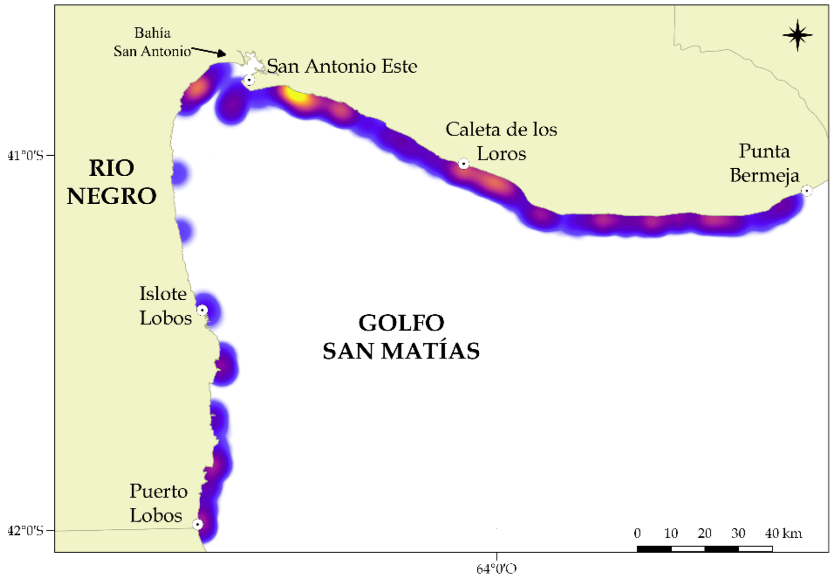

Figure 6. Distribution SRW density maps (Kernel technique) in the coastal strip showing the high aggregation areas (yellow areas) in 2021

Evaluation of the distribution pattern

In the former years of our population monitoring the survey are was restricted to Península Valdés. However, in the last ten years the SRW expanded their territory to Golfo San Matías. While PV retained the area for parturition and nursing calves, in GSM started to increase the number of groups performing mating behaviours.

A change in the spatial distribution through the years along the coast of GSM was recorded (Fig. 7). In 2007, most whales were found around Puerto Lobos, near Península Valdés concentrated in a few segments (segments 1 – 4), and few whales were recorded on the north coast of GSM. In the last years (2013-2021) the areas in which the whales concentrate have changed and expanded. The SRW distribution was mainly confined to the northwest coast of the GSM, particularly in the sector between San Antonio Este and Caleta de los Loros (Fig. 7). However, in 2021 a large number of whales were recorded from Caleta de los Loros up to Punta Bermeja.

The dominant group type in the coastal strip were solitary individuals (Fig. 7). Mother-calf pairs and breeding groups were mainly concentrated in the area around Puerto Lobos, near Península Valdés, and in the sector between San Antonio Este and Caleta de los Loros. Finally, the maximum density of whales was registered in 2007, with 3.06 whales/km2.

Training of new observers

During the year 2021, four new observers were trained, two of them in Chubut province and the other two observers in Rio Negro province. Following the recommendations presented in Sueyro et al. (in press), the observers begun to be trained in the flights carried out in 2019 and 2021. The new observes in Chubut province are part of the *Laboratorio de Mamíferos Marinos* – CESIMAR – CENPAT – CONICET, and the ones in Rio Negro province are part of the *Escuela de Ciencias*

Marinas – UNCO. All these new observers will carry on with the aerial surveys in the next years to complete their 5-flight training.

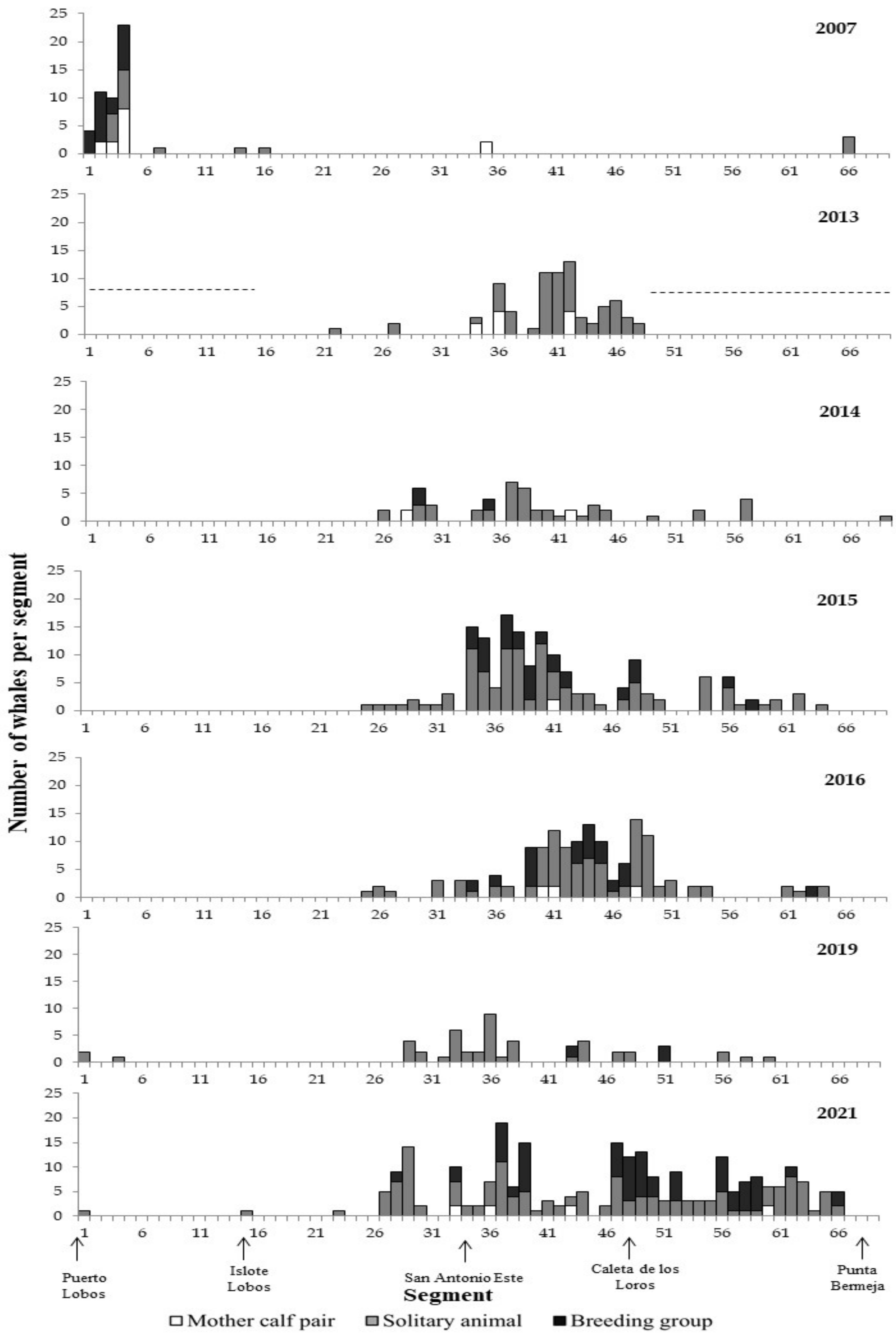

Figure 7. Group types and number of whales per 5 km coast segment recorded on the flight in which the highest number of whales was recorded each year. The dotted line in 2013 indicate the area that was not flown that year.

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