DECREASE IN THE OCCURRENCE OF THE SOUTH AMERICAN FUR SEAL (*Arctocephalus australis*) IN SAN MATÍAS GULF AFTER A SUDDEN EPISODE OF REOCCUPATION

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ABSTRACT. The colonies of South American fur seals, *Arctocephalus australis* (SAFS), are currently experiencing population recovery, and as a consequence many coastal areas have been reoccupied. These areas are often haul-out sites used by SAFS for resting during the post-reproductive (winterly) season, and may be playing a key role in the population recovery process since they seem to be located close to winter feeding areas that are far from the breeding colonies. This study reports on the trend in abundance of SAFS in a recently reoccupied winter area, the San Matías Gulf (SMG). The trend was evaluated with generalized linear models between 2007 and 2017 in two sectors of the SMG, Islote Lobos, the only rookery of this species in the area, and the northwest marine area of the gulf. Both sectors showed a negative trend. For Islote Lobos, the best selected models estimated a mean annual rate between -12.2% and -17.6%, and for the northwest area, between -19.02% and -29.9%. The population context suggests that most SAFS observed in 2007 may have been selecting other habitats over the following years; however, simultaneous censuses throughout their distribution range are needed in order to understand the redistribution and recolonization processes.

RESUMEN. Disminución en la ocurrencia del lobo marino sudamericano *Arctocephalus australis* en el Golfo San Matías después de un episodio repentino de recupercación. Las colonias del lobo marino de dos pelos sudamericano, *Arctocephalus australis* (SAFS), están experimentando una recuperación poblacional y como consecuencia muchas áreas costeras han sido reocupadas nuevamente. Muchas de estas áreas son apostaderos utilizados por los SAFS para descansar durante la temporada post-reproductiva (invernal). Las mismas pueden estar jugando un papel clave en el proceso de recuperación ya que estarían ubicadas cerca de áreas de alimentación invernales que se encuentran distantes de las colonias reproductivas. El presente estudio reporta la tendencia en la abundancia de SAFS en un área invernal recientemente ocupada, el Golfo San Matías (GSM). La tendencia se evaluó con modelos lineales generalizados entre los años 2007 y 2017 para dos sectores del golfo: el Islote Lobos, el único apostadero de esta especie, y el área marina del noroeste del golfo. Ambos sectores mostraron una tendencia negativa. Para el Islote Lobos, los modelos seleccionados estimaron una tasa promedio anual entre -12.2% y -17.6%, y para el área marina noroeste entre -19.02% y -29.9%. El contexto a nivel poblacional sugiere que la mayoría de los SAFS observados en 2007 pueden haber seleccionado otros hábitats durante los siguientes años. Sin embargo, para comprender los procesos de redistribución y recolonización se necesitan censos simultáneos en todo su rango de distribución.

Key words: abundance, haul-out sites, recolonization, trend.
The South American fur seal *Arctocephalus australis* (Zimmermann 1783), hereinafter SAFS, is distributed along the Atlantic and Pacific coasts of South America (Cárdenas-Alayza & Oliveira 2016). Since the cessation of commercial hunting, most colonies of SAFS are experiencing a population recovery throughout the entire distribution range (Vaz-Ferreira 1982; Venegas et al. 2002; Oliva et al. 2012; Crespo et al. 2015; Baylis et al. 2019; Franco-Trecu et al. 2019; Milano et al. 2020). As a consequence of this recovery, many coastal areas have been re-occupied during the last three decades (Bastida & Rodríguez 1994; Svendsen et al. 2013; Crespo et al. 2015; Mandiola 2015; Baylis et al. 2019; Cárcamo et al. 2019). Most of these areas are haul-out habitats used by SAFS for resting during the post-reproductive season (i.e., from March to November; Bastida & Rodríguez 1994; Cárcamo et al. 2019). These habitats may be playing a key role in the population recovery process since they seem to be located in strategic places, close to winter feeding areas that are far from the breeding colonies (Fig. 1a; Bastida & Rodríguez 1994; Túnez et al. 2008; Svendsen et al. 2013).

The San Matías Gulf (SMG; Fig. 1b) is one of the habitats that has recently been reoccupied by juvenile and adult SAFS during the non-reproductive season (Svendsen et al. 2013). Fur seals were a source of food for hunter–gatherers who lived on these coasts between 4 000 and 700 years ago (Borella & Dubois 2007; Gómez Otero 2007; Borella et al. 2011; Borella & Cruz 2012), and although there is a gap in the available information on the presence of SAFS between that period and the second half of the 20th century, it is known that the absence of fur seals continued for longer (Svendsen et al. 2013). The reoccupation process in this gulf started in the 1990s with around twenty fur seals settling at Islote Lobos (ILOB; Fig. 1c; Svendsen et al. 2013). Throughout the 2007 winter season, 1,525 SAFS were counted at ILOB, suggesting a sudden massive reoccupation of this habitat (Table 1; Svendsen et al. 2013). During the period 2006–2011, Svendsen et al. (2013) also registered many groups of fur seals resting at sea between May and October each year, mainly concentrated in the northwest sector of the gulf, between the coast and the 50 m isobath. Since their results suggested that the San Matías Gulf is an important winter habitat for many SAFS, in order to corroborate whether the number of individuals observed in 2007 continued selecting the gulf, opportunistic surveys of this species were carried out until recently. The aim of our study is to report on the number of SAFS recorded in those surveys, and to estimate the trend in relative abundance between 2007 (the last census reported for ILOB) and 2017 (the most recent census conducted in ILOB).

The trend of SAFS in the SMG was analyzed on two different data sets, one for each of the two main areas of concentration of SAFS identified in the SMG (Svendsen et al. 2013). The first data set consisted of a census carried out on aerial photos of the ILOB rookery. A total of 900 opportunistic photographs were taken during 12 aerial surveys of southern right whales (*Eubalaena australis*; Table 1) from a high-wing aircraft (Cessna B 182; see details in Arias et al. 2018). In each of these surveys, the entire shoreline of the Rio Negro province was covered (around 70% of the total SMG shoreline; Fig. 1) during daylight hours (9:42 am to 5:49 pm), coinciding with medium to high tides. In each flight, a loop was flown around ILOB at an altitude of between 150 and 100 m, at a speed of 80 knots and with a bank angle of 50°. During this loop, photographs of SAFS were taken using a NIKON D7000 digital camera with a zoom of 80–200 mm. There was no detectible disturbance to SAFS during flights. The best shots were then selected in terms of clarity, contrast, brightness and angle (i.e., the most perpendicular to the rookery surface). Two observers independently counted the total number of hauling-out individuals on each photo using OTARIIDAE 1.0 software (Barthel et al. 2006), and their counts were used as replicates for each census. There is a marked seasonal variation in the abundance of fur seals in the SMG, reaching a maximum in August and then gradually decreasing until there are no individuals by the end of October (Svendsen et al. 2013). The inter-annual variation in the number of SAFS present in ILOB was therefore analyzed for three different months (August, September and October).

The second data set consisted of 36 nautical surveys of marine mammals conducted in the northwest of the SMG (Fig. 1; Table 3). These surveys comprised random transects over a maritime area of 1077.38 km² during daylight hours (9:30 am to 7:00 pm), traveling at an average speed of 9 kn on board research and opportunistic vessels of 4 to 20 m long (Svendsen et al. 2015). In each survey, two experienced observers equipped with binoculars (Bushnell 7x50 mm) searched for marine mammals in a strip

**Palabras clave:** abundancia, apostadero no reproductivo, recolonización, tendencia.
Fig. 1. a) Distribution of South American fur seal Arctocephalus australis colonies (rookeries and haul-outs) on the Southwest Atlantic coast (Crespo et al. 2015; Baylis et al. 2019; Cárcamo et al. 2019; Milano et al. 2020); b) The study area, the San Matías Gulf with both survey sites Islote Lobos and the northwest area with nautical tracks above; c) Islote Lobos.

Table 1

| Month   | 2007 | 2008 | 2013 | 2014 | 2015 | 2016 | 2017 | N° surveys |
|---------|------|------|------|------|------|------|------|------------|
| August  | 1525 (23) | 977 (9) | 1035 (21) | 856 (23) | 448 (25) | 5    |
| September | 595 (24) | 777 (18) | 136 (23) | 136 (23) | 4    |
| October | 662 (5) | 242 (11) | 102 (9) | 65 (5) | 4    |

of 300 m of sea on each side of the boat. For each sighting, the species and the number of individuals were registered without approaching the group (i.e., avoiding any possible disturbance to the animals). For each daily survey, a SAFS encounter rate was calculated as the relationship between the number of fur seals sighted at sea and the distance traveled each day looking for seals (a measurement of the observation effort for each survey). This rate allows a repeated measurement of the relative abundance of fur seals in the study area for each month.

Each data set was analyzed separately using a generalized linear model (GLM) framework (McCullagh & Nelder 1989; Zuur et al. 2009). For the first data set, the dependent variable was the number of SAFS present in ILOB on each date, and for the second data set the dependent variable was the SAFS encounter rate for each survey. Count data such as SAFS abundances generally follow a Poisson distribution; however, over-dispersion can invalidate the Poisson assumption that variance equals mean (Zuur et al. 2009). A negative binomial (NB) regression model was used to accommodate the over-dispersion of ILOB data (dispersion parameter > 5). NB distribution allows the error distribution to vary independently of the mean by including an overdispersion parameter k (Zuur et al. 2009). Data from the northwest SMG region was not normally distributed because of a high number of zero values. Therefore, the Tweedie compound Poisson GLM (cpglm) as implemented with library compound Poisson linear mixed models (library Cpm; Zhang 2013) was used...
Table 2
Negative binomial models for fur seal *Arctocephalus australis* censuses in Islote Lobos rookery, using year (Y), and month (M) as predictor variables. For each model, the effect of the variable year is expressed as an annual rate and its associated 95% confidence interval (CI). LogLik: log-likelihood; AICc: Akaike Information Criterion corrected for small sample size; DeltaAICc: delta AICc, the difference from the best model; W: relative weight.

| Variables | Effect of year | 95%CI   | LogLik  | AICc  | DeltaAICc | W     |
|-----------|---------------|---------|---------|-------|-----------|-------|
| Y+M       | -17.6 %       | -27.7; -8.3 % | -80.860 | 181.7 | 0.00      | 0.427 |
| Y         | -12.2 %       | -27.8; 0.9 %   | -87.087 | 183.2 | 1.45      | 0.206 |

...to determine the relationship between the dependent variable (SAFS encounter rate) and the predictors (year and month). For each study area, a full model with the fixed (and additive) effects of the year and month was constructed. Both models treated month and year as predictors. They were ranked according to the Akaike Information Criterion adjusted for small samples (AICc). All statistical tests were performed in R (R Core Team 2019) and utilized the Modern Applied Statistics with S package (library MASS; Venables & Ripley 2002).

In all surveyed years, most SAFS settled in ILOB formed a large, crowded group along a crack in the substrate about 50 m long and 2 m high. This positioning of the fur seals prevented the age and sex of the majority from being accurately identified. On the periphery of this group, males (adults and subadults), juveniles and indeterminate individuals (females and/or juveniles of both sexes) could be identified. The total counts per date of both observers showed negligible differences (mean difference ± SD= 2.8 ± 2.6 individuals). The maximum number of SAFS counted on ILOB was 1,525 (August 2007; Table 1).

As the model-building objective was to test whether the number of fur seals recorded in the coastal aerial surveys was affected by the year, only the subset of models that included at least the explanatory variable Year, plus the null model, were considered. The best model supported by our data to account for the number of SAFS in ILOB included Year and Month (Table 2). The goodness of fit test indicates that the negative binomial model fits the data (Chi-square test, df= 8, *p* = 0.13). The annual rate of decline estimated in each model was always significant, with values that ranged between -12% and -17% (Table 2). As both models had a ΔAICc < 2, to consider the variation between models, a multi-model approach was performed. Coefficients once again revealed a negative effect of Year, with an estimated rate of -15.85% (95% CI= -29.1%, -2.6%; Fig. 2).

A total of 2,142 km of nautical transects at sea were performed, with 512 SAFS observed between 2007 and 2017. Table 3 shows the mean encounter rate of SAFS per month in the northwest area of the SMG. In 11 surveys no fur seals were observed. Groups of SAFS sighted at sea were composed of males (adults or subadults) and/or indeterminate individuals (females and/or juveniles of both sexes). When analyzing the encounter rate in the northwest area...
Table 3
Mean encounter rate per month of SAFS sighted at sea during coastal nautical surveys in the northwest area of the San Matías Gulf between 2007 and 2017. Dates on which surveys were conducted are shown in parentheses.

| Month | 2007 | 2008 | 2009 | 2010 | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|------|------|------|------|
| July  | 0.23 (21, 26) | 0.16 (15) | 0.12 (29) | 0.05 (16, 18, 22) | 0.01 (02, 21) | 0.07 (07) | 11 |
| August| 3.49 (12, 14) | 0.01 (25) | 0.82 (06, 07, 21) | 0.42 (23, 17) | 0.13 (01) | 0.01 (25) | 11 |
| September | 2.03 (07, 27) | 0.11 (03, 16) | 0.17 (07) | 0.10 (03, 16) | 0.13 (01) | 0.01 (25) | 11 |
| October | 0.82 (06, 07, 21) | 0.01 (25) | 0.00 (06) | 0.13 (01) | 6 |

Table 4
The Tweedie compound Poisson generalized linear models show the effects of year (Y) and month (M) on the encounter rate of the fur seal Arctocephalus australis in the northwest SMG region. For each model, the effect of the variable year (YE) is expressed as an annual rate. LogLik: log-likelihood; AICc: Akaike Information Criterion corrected for small sample size; ΔAICc: delta AICc, the difference from the best model; W: relative weight.

| Variables | YE  | LogLik | AICc | ΔAICc | W   |
|-----------|-----|--------|------|-------|-----|
| Y+M       | -19.02 % | -8.075 | 28.1 | 0.00  | 0.958 |
| Y         | -29.9 % | -18.20 | 40.8 | 12.62 | 0.002 |

region, the results are consistent with those obtained for the aerial census which counted the total number of SAFS in ILOB. The selected model includes both Month and Year (Table 4). The effect of Year was negative and significant (t-value= -3.206, p < 0.01).

The two data sets analyzed in this study indicate that the occurrence of SAFS in the SMG has dropped considerably since the sudden and massive reoccupation observed in 2007. The causes of this decrease are unknown, although many hypotheses could be proposed. Recent studies have pointed out that SAFS colonies are showing complex patterns of redistribution during the recovery process (Crespo et al. 2015; Mandiola 2015; Baylis et al. 2019; Milano et al. 2020). Some non-reproductive colonies are decreasing in numbers or have been abandoned; new haul-out and breeding colonies have appeared, and some haul-out colonies have become breeding colonies in the last few decades (Crespo et al. 2015; Mandiola 2015; Baylis et al. 2019; Milano et al. 2020). This regional context suggests that most SAFS observed in 2007 in the SMG may have been selecting other habitats during the winter and spring seasons of the following years. The results of our study highlight the need to coordinate regional censuses of SAFS colonies throughout their distribution range in order to understand the redistribution and the recolonization processes.

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