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PROJECTING DEMOGRAPHIC SCENARIOS FOR A SOUTHERN ELEPHANT SEAL POPULATION

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A standard age-structured model was used to model and project population growth, for the expanding southern elephant seal, *Mirounga leonina*, population at Península Valdés (PV, Argentina), considering alternative environmental scenarios.

1. Introduction

Southern elephant seals, *Mirounga leonina,* are distributed mostly in subantarctic environments [8]. One colony, Península Valdés (PV), in coastal Patagonia (Argentina), is exceptional. The number of seals on the Patagonian coast has been increasing for decades. This unique trend in the species is supported by detailed censuses of the PV colony conducted annually during the last 25 years [9].

Despite the positive trend in PV seals, the precedent of several populations of southern elephant seals declining for decades [6, 12] suggests that timely conservation action may benefit from long-term time series in demographic data.

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Indeed, the main purpose of achieving long-term data on population numbers, particularly pup production, at PV was to detect eventual declines.

We applied theoretical demographic and environmental parameters to analyze trend scenarios for PV and discuss quantitative results relative to adopting simple precautionary decisions in the absence of data. The unique characteristic of PV as the only growing colony for a widely distributed species allows comparisons with shrinking populations that may help determine which life history stages are most relevant in explaining present trends.

2. Methods

2.1. *Demographic model*

We used a standard age-structured model (Table 1). Juvenile females were seals up to age 4 and adults were older than 4. We assume an equal fertility parameter (α) for all reproductive females (juvenile females at age 3 and adult females). The mean vital rates were gathered from different sources (see Table 1). First year survival (c) was taken from a life table of South Georgia elephant seals [10]. The sex ratio at birth (ρ) and adult survival (p) were taken from previous mark-recapture estimates for this population [1, 12]. Juvenile survival (s) and fertility (α) were estimated by a standard maximum likelihood approach [5] using census counts of pups and females from 1995 to 2006.

2.2. *Environmental stochasticity*

We assumed the environment, thus the vital rates, varying randomly over time [3] and this environmental variation was assumed to affect juvenile and adult survival (s, p). Year-to-year variations of s and p are likely to be correlated, and this correlation can have significant impact on population growth [13]. To include correlation effects in our projections, we considered two environmental factors, A and B, which were related to s and p. This follows [4] in that the correlations between vital rates are related to a shared dependence of each demographic rate on an environmental factor. An attempt was made to associate environmental factors with foraging success. Female foraging trips were categorized as: (a) to the Patagonian Basin and the edge of the continental shelf (Basin) and (b) to the continental shelf (Shelf), according to the time spent foraging on each region of the SW Atlantic, e.g. [2] and unpublished data. A was assumed as an environmental factor that determines the mortality of Basin seals and B as an environmental factor, independent of A, which determines the mortality of Shelf seals. All adult females and a proportion δ of juvenile females follow a Basin-strategy whereas the rest of juvenile females follow a Shelf-strategy. Thus adult survival *p* was determined directly by *A* and juvenile survival *s* was determined by $\delta A' + (1-\delta)B$, where A' is an environmental factor completely correlated with *A*. We used an estimation of $\delta = 0.5$ according to our records of juvenile foraging trips to project scenarios. On the other hand, we varied δ as a free parameter in a second analysis, this allowed considering several alternatives of correlation between *s* and *p* (in a simple way) to project population numbers.

Table 1. Matrix population model and alternative projected scenarios. Environmental factor A determines the mortality (survival) of Basin seals (see Methods) whereas the independent environmental factor B determines the mortality (survival) of Shelf seals.

Current demographic parameter estimates

Parameter	**Mean value**	**Source**
First year survival (c)	0.6	South Georgia (McCann 1985)
Proportion of females at birth (ρ)	0.5	Península Valdés (Unpublished)
Adult survival, 4 years old and older (p)	0.842	P.V. (Pistorius et al. 2004)
Juvenile survival, 1 to 3 years old (s)	0.804	P.V., Maximum likelihood
Fertility (α)	0.94	P.V., Maximum likelihood

Population projection matrix

$$\begin{pmatrix} 0 & 0 & 0 & \alpha & \alpha \\ \rho.c & 0 & 0 & 0 & 0 \\ 0 & s & 0 & 0 & 0 \\ 0 & 0 & s & 0 & 0 \\ 0 & 0 & 0 & s & p \end{pmatrix}$$

Projected scenarios

Scenario	**Parameter values**			
	Mean value of factor *A* ($\bar{a}$)	Mean value of factor *B* ($\bar{b}$)	Environmental variance (*var*)	Juveniles affected by *A* (δ)
1. Current conditions	0.842	0.804	0.0003	0.5
2. Moderate decrease of *A*	0.830	0.804	0.0003	0.5
3. Strong decrease of *A*	0.818	0.804	0.0003	0.5

To determine the environmental variance (*var*) we consider the adult survival mark-recapture estimates [12]. The observed variance of these estimates includes variance due to demographic stochasticity and measurement error [7].

These components must be removed to estimate environmental variance, otherwise, the environmental variability may be considerably overestimated. We do not have an estimate of measurement error and demographic stochasticity for the current survival mark-recapture estimates. Thus, to get an acceptable value of environmental variance, we rejected three extreme values and calculated observed variance.

2.3. *Projected scenarios*

When we ran a simulation in a specific scenario, we first selected a value for each environmental factor A and B from a beta distribution with mean $\overline{a}$ and $\overline{b}$ respectively, and variance *var*, according to Table 1. We assumed that the mean value of A' and B coincides under current conditions. Then we directly calculated $A' = c_1 A + c_2$, with $c_1 = \sqrt{2}$ and $c_2 = \overline{b} - c_1(0.842)$, and the population projection parameters: $p = A$, $s = \delta A' + (1 - \delta) B$. In this way, when we varied δ in the following analysis, p and s have a correlation of $\delta \big/ \sqrt{\delta^2 + (1-\delta)^2}$, and the variance of s is greater than *var*, regardless of the δ value.

Assuming an initial population corresponding to the number of pups estimates (directly from census data) prior to 2006, the population was projected for 50 years, and we performed 1000 replicate runs for each scenario. We assumed that environmental states (annual values of A and B) were independent and identically distributed. We excluded density dependence and demographic stochasticity from our model since it was a first approximation to modeling this southern elephant seals population.

2.4. *Stochastic population dynamics*

Two metrics are commonly used to summarize the stochastic population dynamics: the growth rate of mean population size (r), and the stochastic growth rate (r_s). The former corresponds to the deterministic growth rate of mean population parameters and it is not influenced by environmental variability. The latter correspond to the average of growth rates of many replicate simulations. It is particularly important because it depends of environmental variability [3]. We used the Tuljapurkar's approximation of the stochastic growth rate [13, 14] to calculate r_s as an explicit function of three parameters: adult mortality, proportion of juveniles affected by factor A (δ, which determines the correlation between adult and juvenile mortality) and the environmental variance (*var*). Then, for different values of δ and *var*, we calculated how much should increase adult mortality so that $r_s = 0$, which allow us to distinguish between an increasing and a decreasing population in a variable environment.

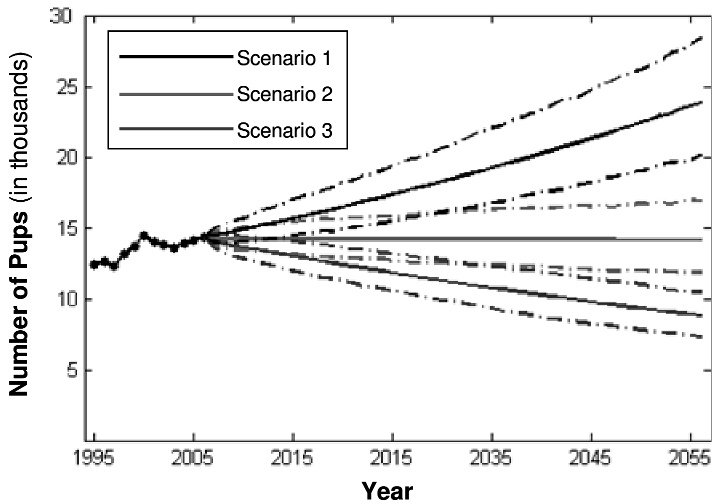

Figure 1. Projections of the number of pups for the three scenarios described in Table 1. Solid lines are mean population projections. Dotted lines are 90% confidence limits from 1000 simulations.

3. Results

Projecting population trends for the period 2006-2056 yielded three theoretical scenarios (Figure 1), none of them conducting to extinction in 50 years. Scenario 1 reflected the continuity of present conditions for an annual mean population growth of 1.04% (Tuljapurkar approximation of the stochastic growth rate was r_s = 0.0101 and the growth rate of mean population r = 0.0103). The 90% confidence interval after 1,000 simulations projected a range in the number of pups born for 2056 of 20,110 – 28,360 individuals.

Scenario 2 simulated a worsening of environmental conditions that caused 1.4% decrease of the mean value of factor A, corresponding to an increase of 8% in adult female mortality and of 4.5% in mean mortality of juvenile females. The stochastic growth rate estimate was $r_s = -0.0002$, and the growth rate of mean population $r = -0.0001$ (stable population). The projected range of pups born in 50 years from 2006 ranged 11,830 – 16,870 animals.

Scenario 3 illustrated an important environmental deterioration with a decrease of 2.9% in the mean value of factor A, with a 15% increase in adult female mortality and an 8.6% increase in juvenile female mortality. The stochastic growth rate estimate was $r_s = -0.0096$, and the growth rate of mean population $r = -0.0094$, corresponding to a 1% annual decrease in mean population size. The 90% confidence interval for the number of pups born ranged 7,290 – 10,466 seals.

Table 2. Percent of increase in adult female mortality that will explain a decrease in number of pups born ($r_s < 0$) as a function of the effect of environmental factor *A* on juveniles. Four cases are tested with different environmental variance: *var* = 0 represents the mean population behavior, *var* = 0.0003 is the value assumed as current environmental variance, *var* = 0.006 is the observed variance of adult survival mark-recapture estimates [12] and *var* = 0.01 is a speculative increase in environmental variance proposed as a worse case.

Environmental variance (*var*)	**Proportion of juveniles affected by environmental factor *A* (δ)**				
	0	0.25	0.5	0.75	1
0	11.9 %	9.45 %	7.83 %	6.69 %	5.84 %
0.0003	11.8 %	9.36 %	7.74 %	6.59 %	5.74 %
0.006	9.79 %	7.65 %	6.07 %	4.81 %	3.74 %
0.01	8.35 %	6.45 %	4.91 %	3.56 %	2.35 %

On the other hand, a potentially decreasing population (in a stochastic environment) will result from small changes in the mean of environmental factor *A*, by considering a combined increase of environmental variance and the proportion of juveniles affected by *A* (Table 2).

4. Discussion

4.1. *General conclusions*

Expectations are that a PV elephant seal colony will continue to exist in the next 50 years with a number of pups born that range from over 7,000 (the colony size in the late 1960s) to close to 30,000 individuals, depending on the scenario.

A deterioration of environmental factor *A* would be the equivalent of a worsening of the environmental conditions that today support the population. Two kinds of environmental modifications: a decrease in the *A* mean and an increase in the environmental variance were analyzed in the present work. However, the impact of *A* was restricted to adult and juvenile females, which is a strong simplification. Moreover, projections could certainly be improved by a better understanding of environmental variance.

4.2. *The practical conservation value of estimating future scenarios*

One motivation to conduct detailed counts during decades is the early detection of population changes to advice management accordingly and to contribute to species conservation. However, in an eventual decrease in pup production we would not be able to determine with certainty if the trend represents a shift from scenario 1 to scenarios 2 or 3. Moreover, the causes of a shift in scenarios may also be difficult, if not impossible, to tackle. A decrease in numbers may reflect either a large scale environmental change or a negative interaction with humans.

Therefore, chances are that a decrease in numbers will only serve for the record. Elephant seals suggest that our best chance to protect them is the precautionary alleviation of actual and potential threats. We know that seals forage on the Argentine continental Basin. Therefore, the developing of deep sea fishery in the Basin is likely to be a potential source of interaction. If the interaction occurs and causes population impacts, we will most likely be unable to document the direct cause, although we will be accurately documenting the demise.

The constrains that our data may have for conservation beyond the Precautionary Principle find a counterpart in their potential for comparing growing and shrinking populations and determine which life history stages are most relevant to explain present trends. The demographic model presented here (Table 1) implies that adult female survival is the vital variable with greatest impact on population growth, followed by juvenile survival, first year survival and fertility. This can be made explicit by performing a standard elasticity analysis [3], the respective elasticity values for p, s, c and α are: 0.46, 0.32, 0.11 and 0.11. This elasticity distribution is different from populations that were decreasing, such as Macquarie Island or Marion Island, where juvenile survival seems to be the vital rate of greatest impact on population growth [11].

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