Modelling a projection for the potential extinction of the African penguin

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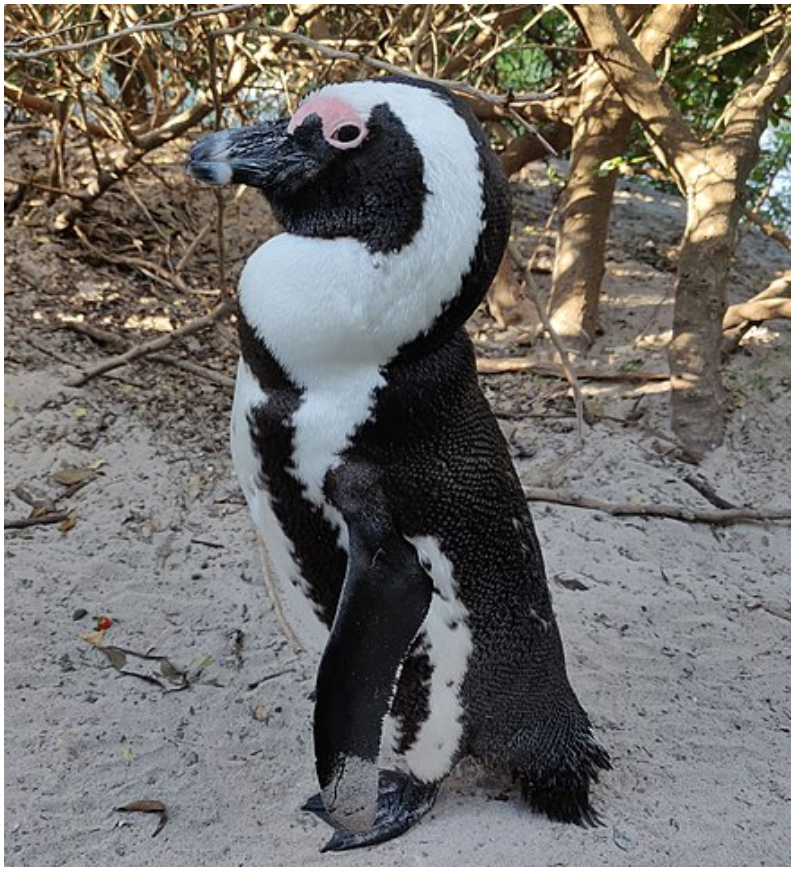
The African Penguin

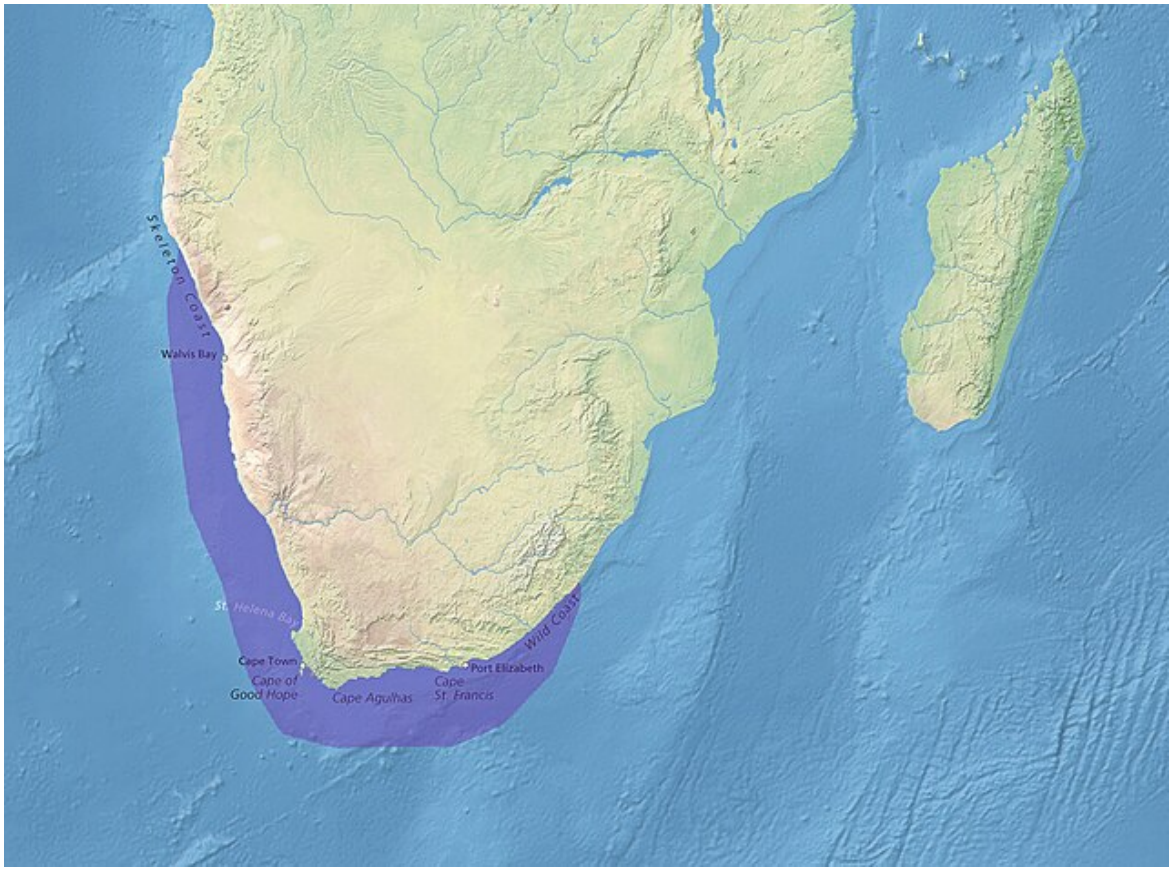


Source:
`https://en.wikipedia.org/wiki/File:African_penguin_side_profile.jpg`

- *Spheniscus demersus*
- Also known as
  - *Cape penguin*
  - *South Africa penguin*
  - *black-footed penguin*
  - *jackass penguin*

The African Penguin

Distribution



Source:
https://en.wikipedia.org/wiki/File:African_penguin_distribution_en.jpg

The African Penguin

Breeding and lifecycle

Stage	**Length (in days)**
Egg	≈ 40
Fledgeling	≈ 100
Juvenile	≈ 730 (2 years)
Adult	$\approx$ 3650–7300 (10–20 years)

The African Penguin

Breeding and lifecycle

- Social animals, seen in groups (both on land and at sea)
- Monogamous
- Females lay two eggs, incubation period of 40 days
- Chicks are guarded and fed by both parents for 2–3 weeks, after which parents alternate between foraging and guarding the chicks
- Chicks develop their wing feathers at ≈60 days old, leave the nest after 60–90 days (depending on food availability)
- **Breeding is largely dependent on local food supply abundance.**

The African Penguin

Breeding and lifecycle

- During the juvenile stage, the penguins spend 1–2 years away from the colony.
- Juveniles return when they become sexually mature, approximately 4 years of age.
- Some adults start breeding earlier, approximately 2–3 years
- Average lifespan in the wild of 15–20 years.

The African Penguin

Impacts on survival

Some factors which might impact the survival rate of the penguins:

- Commercial fishing (and food competition)
- Food supply
- Habitat degradation
- Heat stress

The African penguin is sensitive to climate change and the associated impacts.

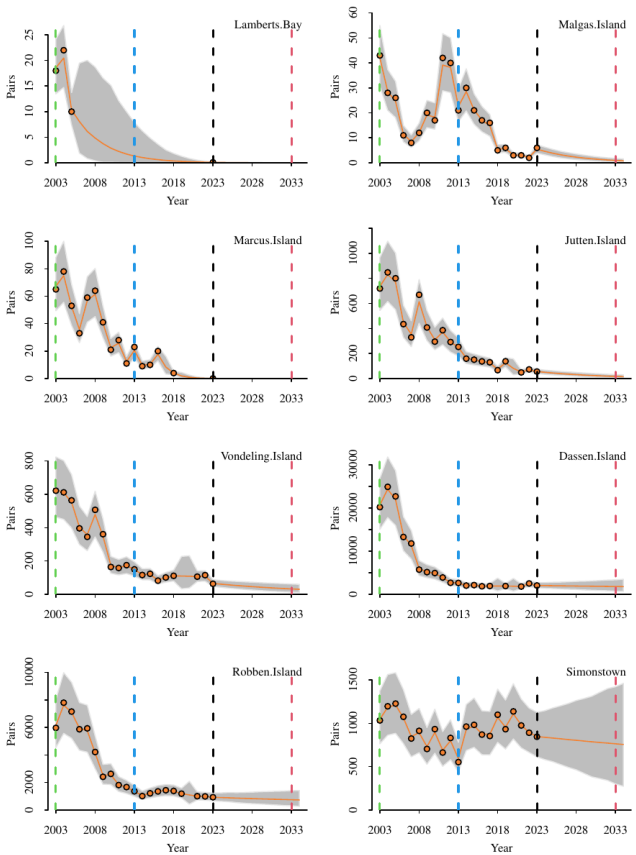
The African Penguin

Potential extinction

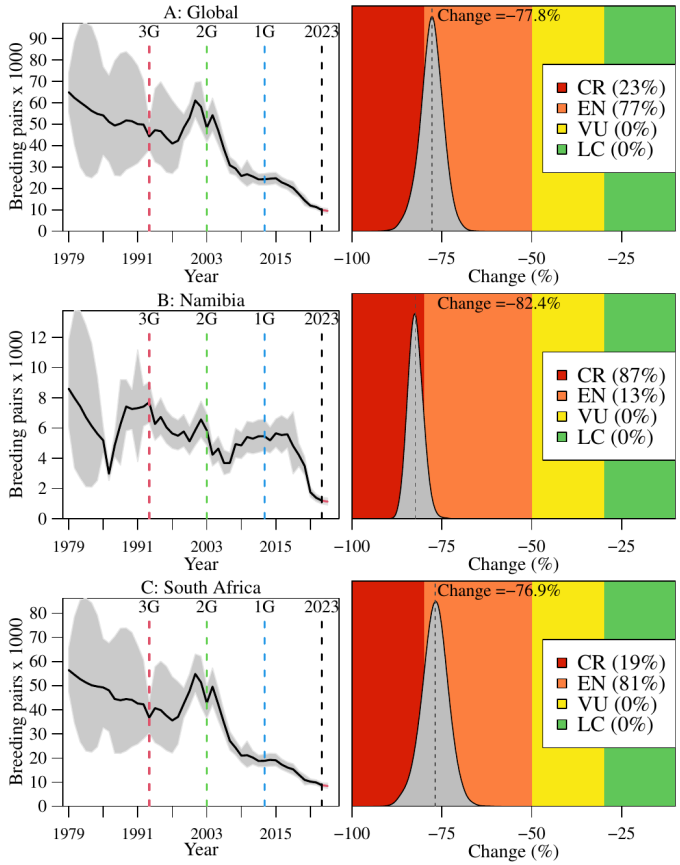
- The African penguin is considered *critically endangered*.
- Within the context of climate change, the African penguin will face significant threats to its survival.
- Without targeted conservation efforts, the African penguin will face extinction.
- Climate change may adversely affect the species' access to food and/or habitation, expose the penguins to more heat stress, and potentially disrupts the breeding cycles and patterns

The African Penguin

Decline in breeding pairs



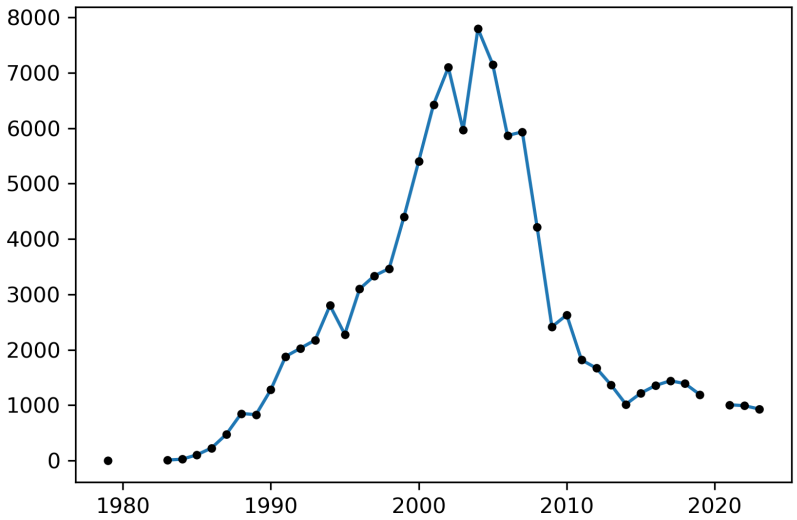
Source: [Sherley et al., 2024]



Source: [Sherley et al., 2024]

The African Penguin

Decline in breeding pairs



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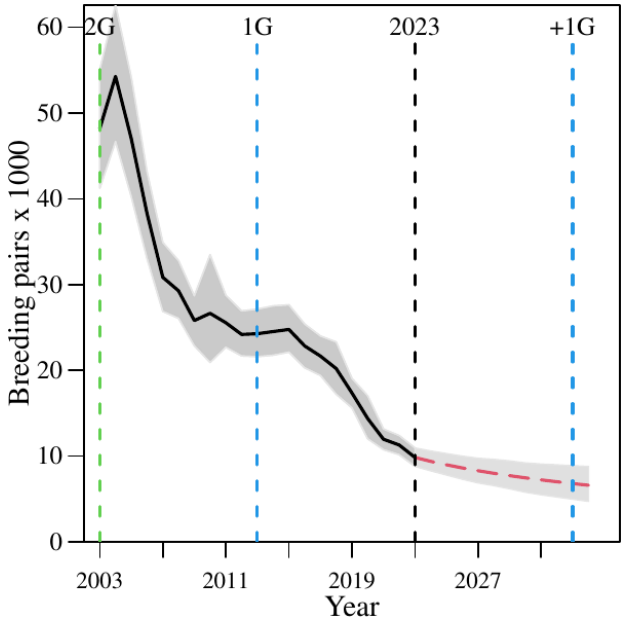


Source: [Sherley et al., 2024]

Problem Statement

Two main problems:

- Investigate projections for the potential extinction of the African penguin due to climate change or other reasons.
- Find alternate projections and scenarios based on modifications of the mathematical models.

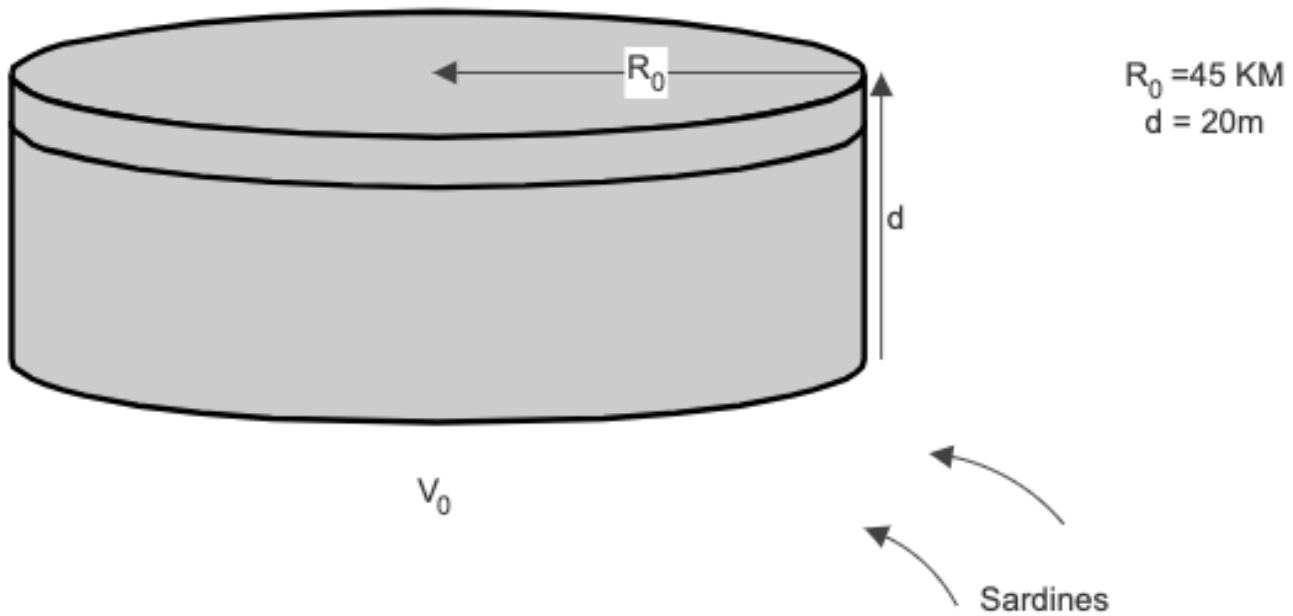
Approaches

Consider how changes and other factors (climate or otherwise) affects

- the lifecycle of an individual penguin, or
- colonies of penguins.

We decided to focus on the latter.

Population/Predator-prey Model



Population/Predator-prey Model

Unscaled model

$$\underbrace{\frac{\mathrm{d}N_p}{\mathrm{d}t}}_{\text{penguin population}} = \underbrace{\beta_p S N_p}_{\text{food supply}} - \underbrace{\gamma N_p}_{\text{natural death}} ,$$

$$\underbrace{\frac{\mathrm{d}S}{\mathrm{d}t}}_{\text{sardine biomass}} = \underbrace{R(t) + \alpha S}_{\text{sardine supply}} - \underbrace{\beta_s S N_p}_{\text{eaten by penguins}} - \underbrace{(F(t) + L(t))S}_{\text{sardine death rate}}$$

Predator-prey Model

Unscaled model

N_p = population of penguins

S = population of sardine biomass

$R(t)$ = function describing external sardine influx

$F(t)$ = function describing sardine death due to fishing

$L(t)$ = function describing sardine death due to other reasons

Predator-prey Model

Scaled model

Scaled parameters and variables:

$$N_p = N_p^0 N_p', \qquad S = S^0 S', \qquad t = t^0 t',$$
$$R = R^0 R', \qquad F = F^0 F', \text{ and} \qquad L = L^0 L'.$$

Scaled model:

$$\frac{\mathrm{d}N_p'}{\mathrm{d}t'} = S' N_p' - \xi_p N_p',$$
$$\frac{\mathrm{d}S'}{\mathrm{d}t'} = R^* R'(t') + \alpha_s^* S' - \beta_s^* S' N_p' - (F^* F'(t') + L^* L'(t'))S.$$

Predator-prey Model

Scaled model

where

$$t^0 = \frac{1}{\beta_p S^0}, \qquad \xi_p = \frac{\gamma}{\beta_p S^0}, \qquad R^* = \frac{R^0}{\beta_p {S^0}^2}, \qquad \alpha_s^* = \frac{\alpha_s}{\beta_p S^0},$$

$$\beta_s^* = \frac{\beta_s N_p^*}{\beta_p S^0}, \qquad F^* = \frac{F^0}{\beta_p S^0}, \qquad L^* = \frac{L^0}{\beta_p S^0}.$$

We drop primes from our variables for the remainder.

Constant Sardine Supply Model

Simplification

For our simulations, we simplified to model further by assuming:

- no sardine loss due to other factors, i.e., $L(t) = 0$;
- sardine loss due to fishing happens at a constant rate, i.e., $F(t) = F$.

These assumptions yield the model

$$\frac{\mathrm{d}N_p}{\mathrm{d}t} = SN_p - \xi_p N_p,$$
$$\frac{\mathrm{d}S}{\mathrm{d}t} = R + \alpha_s^* S - \beta_s^* SN_p - FS,$$

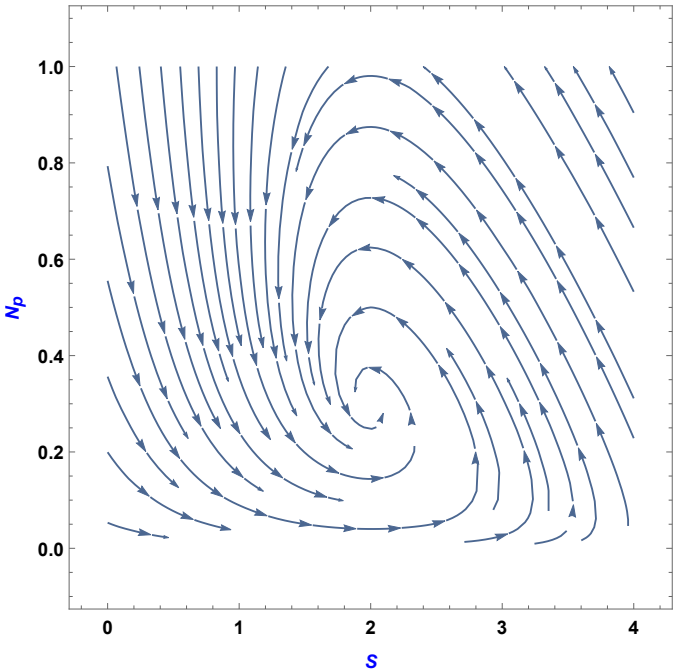
Constant Sardine Supply Model

Equilibrium solution

Equilibrium solution:

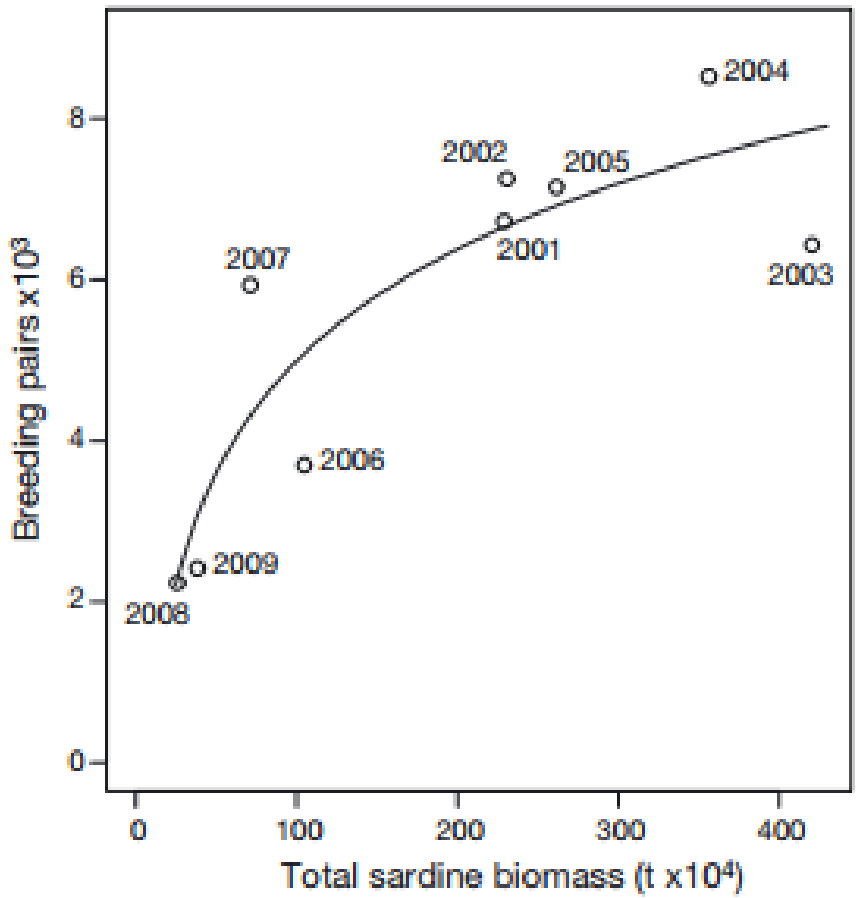
$$(N_p^*, S^*) = \left(\frac{R + (\alpha_s^* - F)\xi_p}{\beta_s^* \xi_p}, \xi_p \right)$$

If $\alpha_s^* = 0$ and $R < F\xi_P$, then we shall have penguin extinction (negative equilibrium population).



Constant Sardine Supply Model

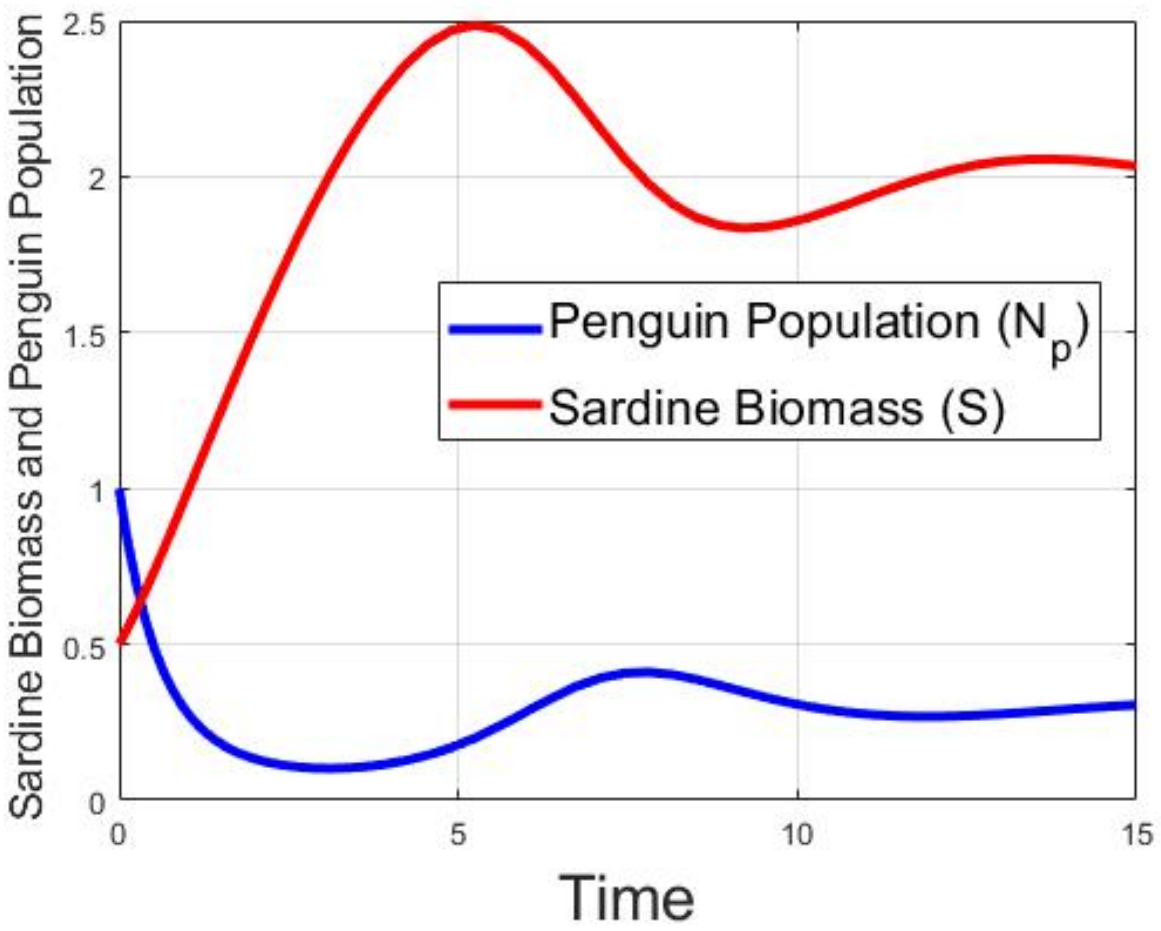
Data and parameter values



- Using this data, we made an educated guess toward reasonable parameter values.
- Better, and more, data will allow us to attempt to find parameter values by appropriate fitting techniques.

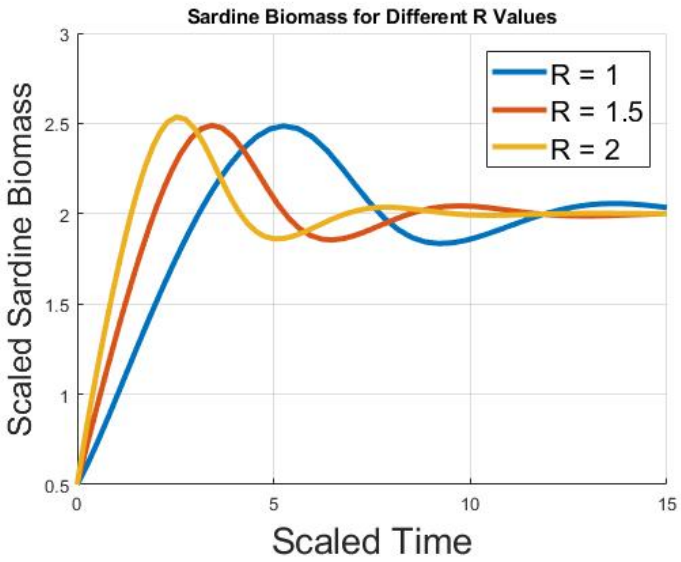
Constant Sardine Supply Model

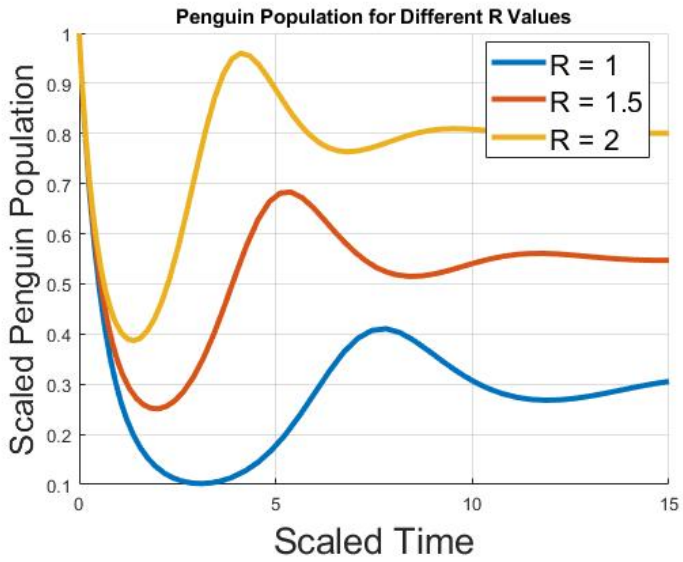
Numerical simulations



Constant Sardine Supply Model

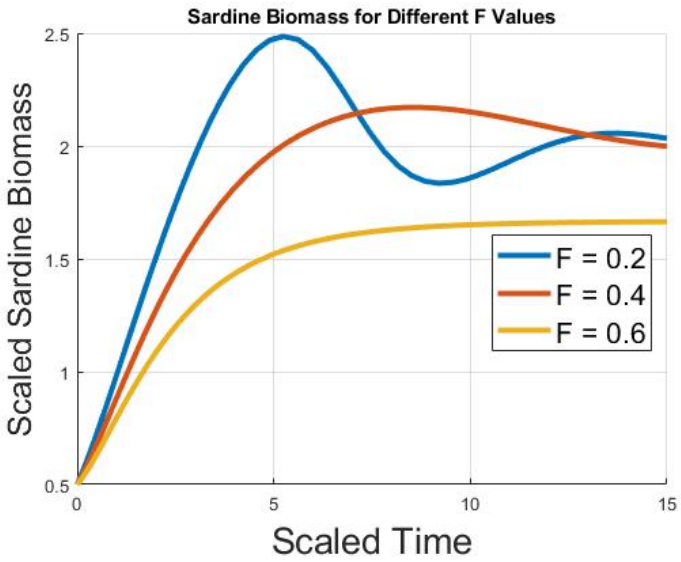
Numerical simulations

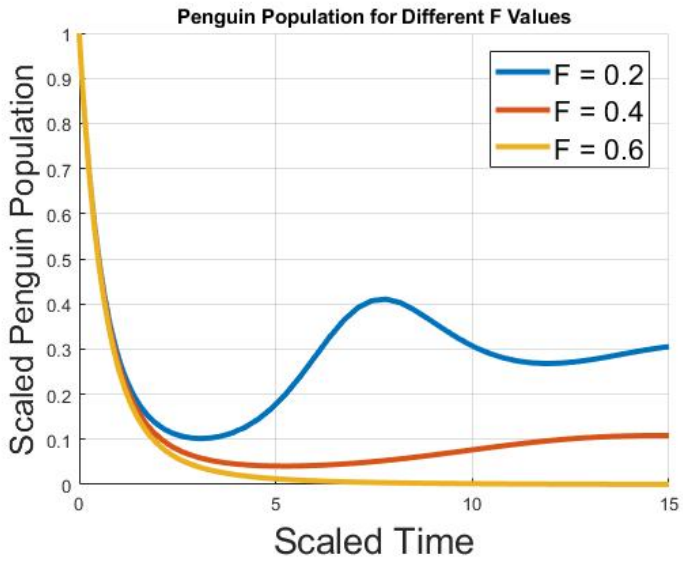




Constant Sardine Supply Model

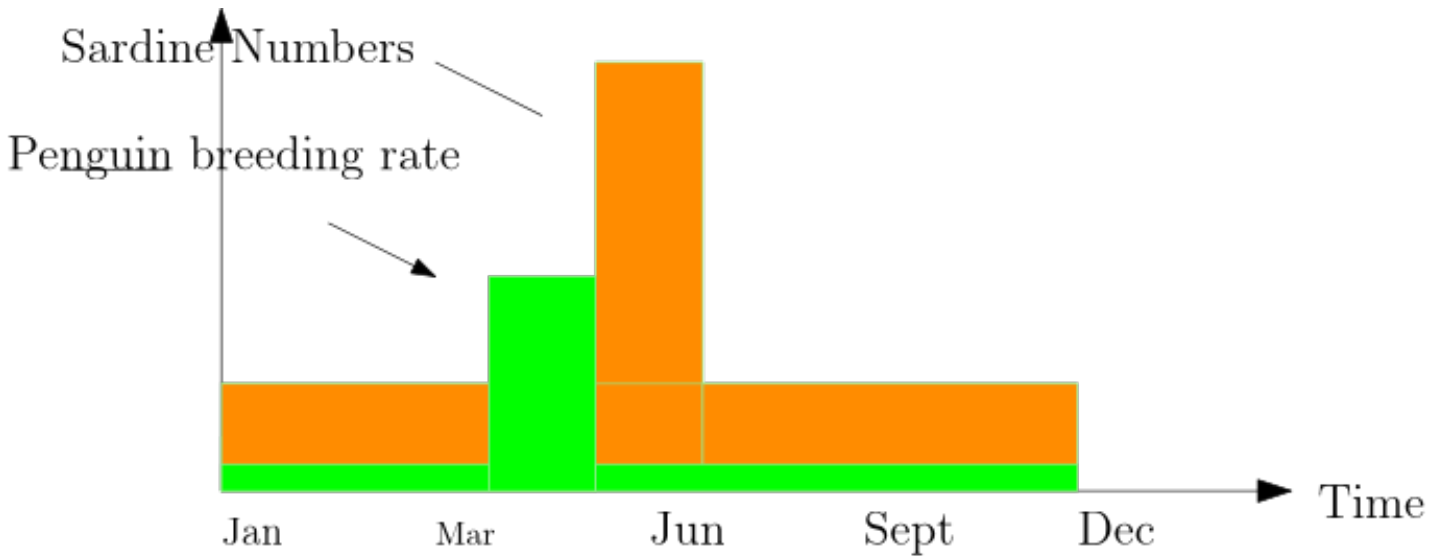
Numerical simulations





Variable Sardine Supply Model

- From common knowledge, there is a sardine run approximately between May and July every year.
- This suggests a modification to the (external) sardine supply R'.



Variable Sardine Supply Model

We modify the model accordingly:

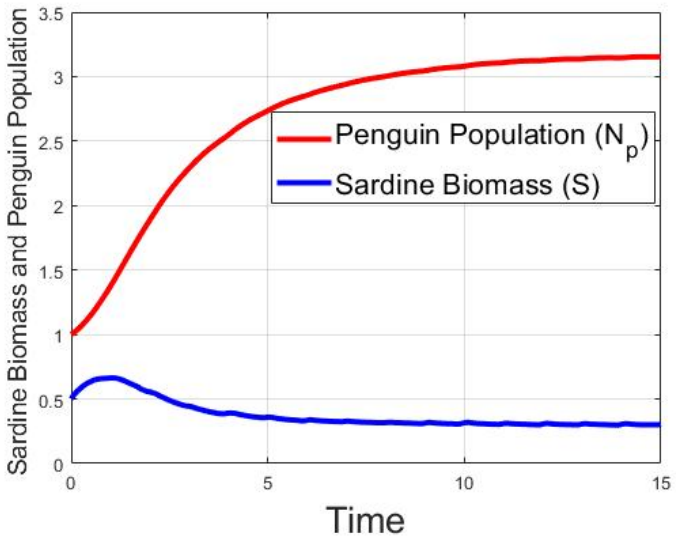
$$\frac{\mathrm{d}N_p}{\mathrm{d}t} = SN_p - \xi_p N_p,$$
$$\frac{\mathrm{d}S}{\mathrm{d}t} = R(t) + \alpha_s^* S - \beta_s^* S N_p - F^* S,$$

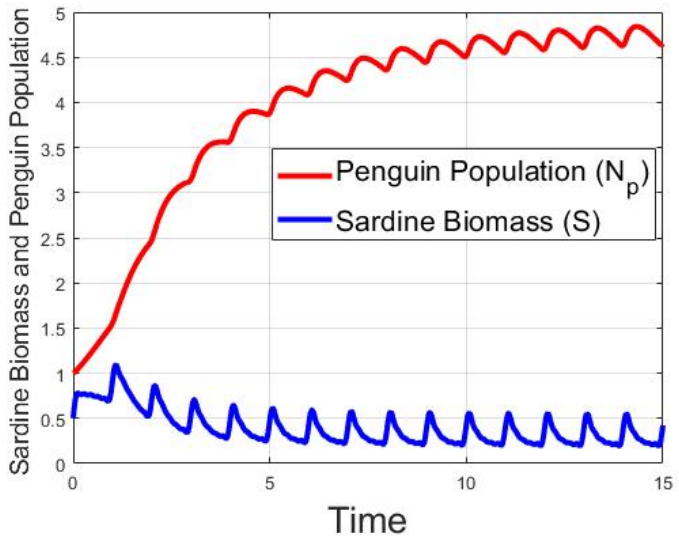
where $R(t) = 1 + \bar{R}\psi(t)$,

$$\psi(t) = \frac{1}{4} + \sum_{i=1}^{4} b_n \cos(2n\pi t), \quad b_n = \frac{2\int_0^{1/8} \cos(2n\pi t)\,\mathrm{d}t}{\int_0^1 \cos^2(2n\pi t)\,\mathrm{d}t}$$

Variable Sardine Supply Model

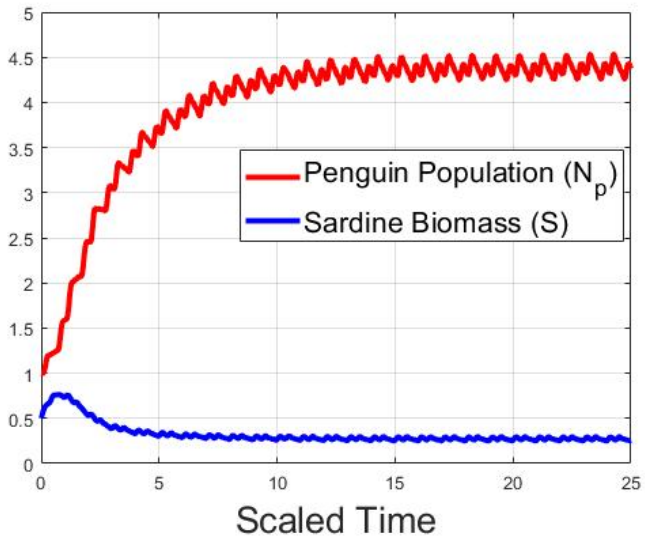
Numerical results

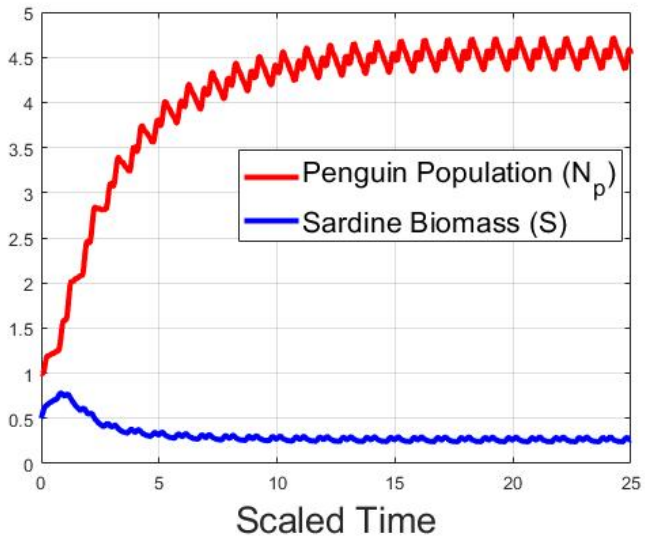




Variable Sardine Supply Model

Numerical results





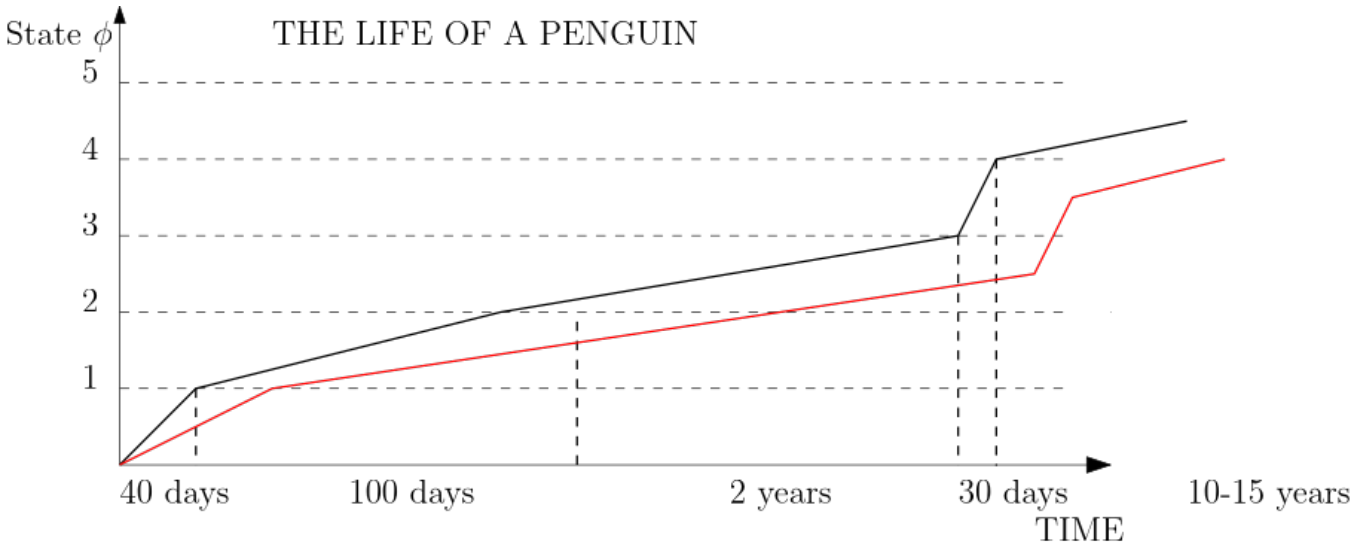
Summary and Conclusions

- Global model (climate change and fishing):
  - Fitting the Robben Island data was *very* crude. More work!
  - Overfishing effects are seen/quantified.
  - The model results suggest that penguin breeding times and the sardine run need to match up to give the required boost in the population; a major worry, since the sardine run "doesn't always occur".

Summary and Conclusions

- Local model: We are developing a experimental/theoretical framework for determining the effect of various disturbances (including temperature change) on individual penguin development. Briefly we use a status function ψ to quantify the level of maturity, and relate this to the various threats.
- A demographic model: It is possible that changes in demography could cause collapse of a colony. The above global model would not be able to describe such a collapse. We therefore need to develop a demographic model that determines $N_p(\phi, t)$.

A Penguin's Lifecycle



The black lies refer to normal development
The red lines refer to development under stress

References

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Thank you for your time.

Any comments, questions or suggestions?