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System dynamics modelling of the *Endangered* African penguin populations on Dyer and Robben islands, South Africa

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ABSTRACT

African penguins (*Spheniscus demersus*) in South Africa have been subject to rapid decline in the 20th century and are currently listed as "endangered" on the IUCN Red List. A stochastic, stage-specific system dynamics model with spatial components was developed to investigate the interaction of multiple pressures on penguin population development, and originally applied to study conservation management options for the penguin colony at Robben Island, Table Bay, South Africa. We here present an extension of the model to the nearby colony at Dyer Island. The modelled population was found to be strongly dominated by the effects of Cape fur seal (*Arctocephalus pusillus pusillus*) predation and immature emigration, which appear to be key drivers behind current declines in population numbers at this colony. Chronic low-level oiling also had a consistent impact despite ongoing mitigation measures, while kelp gull predation had a lower effect than expected. At current low population size, the pressure from either seal predation *or* immature emigration seems sufficient to mask any beneficial effects to penguins from possible improvements in available food biomass (e.g., from fishery restrictions). Results suggest that conservation management at this colony should focus on regular culling of predating seals combined with improving availability of prey (thus discouraging emigration) both in the foraging range of breeding penguins and in their general foraging area. Our findings demonstrate the use of site-specific scenario tools to explore conservation strategies in data-poor management situations.

1. Introduction

Biodiversity in the world's oceans is coming under increasing pressure from a suite of anthropogenic pressures (Halpern et al., 2008; McCauley et al., 2015). Many of the most threatened marine animals are those that interact with land during some parts of their life cycle (McCauley et al., 2015), because they face compounding threats in both the marine and terrestrial environments (Croxall et al., 2012; Trathan et al., 2015). Seabirds are amongst the most threatened of marine species that have been assessed (McCauley et al., 2015), having deteriorated in their conservation status faster over the last 20 years than other similarly specious groups of birds (Croxall et al., 2012). After the albatrosses (Diomedeidae), the penguins (Spheniscidae) are the most threatened seabird family, highlighting the need for targeted and rapid conservation action for this taxon (Trathan et al., 2015).

When a species or population faces multiple concurrent threats, conservation may require managers to consider complex trade-offs between the feasibility of improving different components of demographic performance and the sensitivity of populations to changes in these demographic rates (Finkelstein et al., 2010). Effective conservation also requires targeted action, particularly when species are declining rapidly. This may necessitate having specific knowledge of how each component pressure acts upon a population. However, good demographic data on threatened species are often scarce and pressures may exert themselves differently on distinct sub-populations (Nichols and Williams, 2006). This can make it difficult to know where to focus conservation efforts. In such circumstances, decision analysis tools, such as computer models can help prioritize management actions (Grantham et al., 2010)

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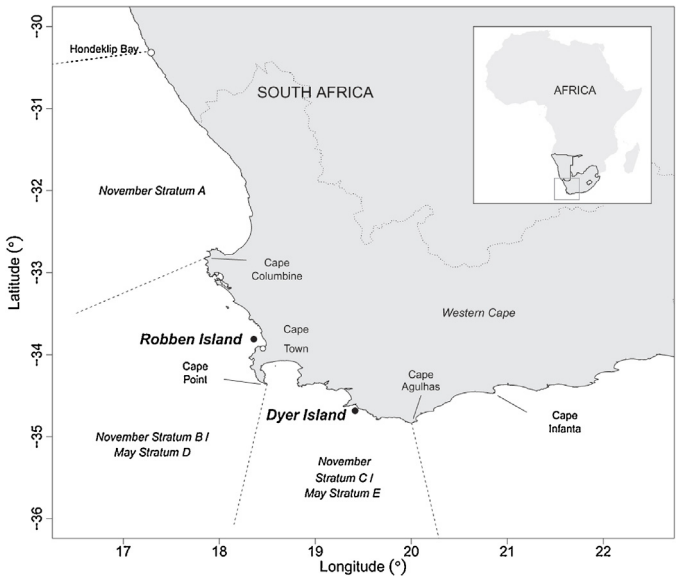

Fig. 1. Location of Robben Island and Dyer Island African penguin colonies on the coast of South Africa. The approximate stratum boundaries used in the DAFF biomass surveys (sardines and anchovy) are shown by dotted lines.

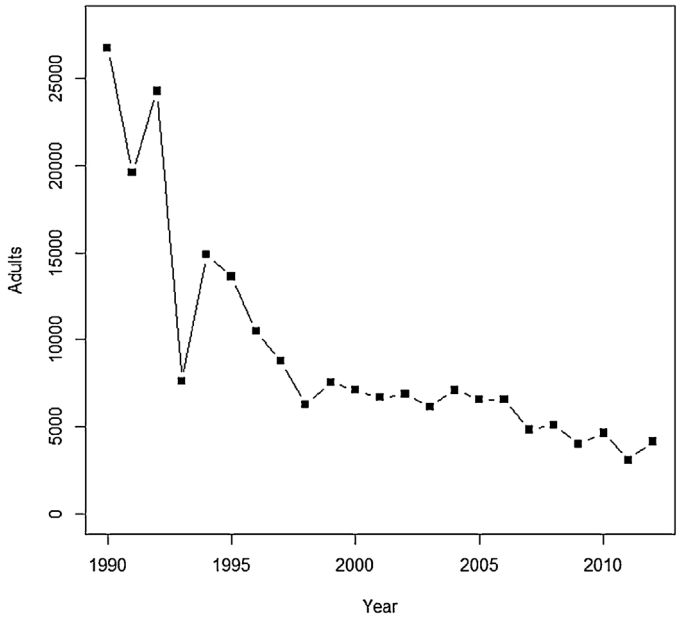

Fig. 2. Numbers of adult African penguins resident on Dyer Island, 1990–2012, estimated from nest counts (Underhill et al., 2006; Makhado et al., 2013b) and a conversion factor of 3.2 (Crawford and Boonstra, 1994).

and future monitoring programmes (Nichols and Williams, 2006). In particular, system dynamics models allow expert opinion to be incorporated to qualitatively define relationships for which underlying data are lacking. This makes them particularly valuable in situations where an urgent need for conservation management is apparent, but the data to inform approaches like MICE (Plagányi et al., 2014) are not available. Weller et al. (2014) recently presented a system dynamics model of the African penguin *Spheniscus demersus* population at Robben Island, South Africa, that was developed to investigate management scenarios under scarce data conditions. Here, we present an extension of that model to another key colony, Dyer Island (Fig. 1), for this species which is classified as *Endangered* on the IUCN Red List.

African penguins are endemic to southern Africa, and depend largely upon sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*) for food (Crawford et al., 2011; Sherley et al., 2013). Egg collection and guano scraping caused dramatic population declines over the last century (Frost et al., 1976; Shannon and Crawford, 1999) but since the 1950s food availability and pollution (from oil spills) have had major influences on the species (Wolfaardt et al., 2009; Crawford et al., 2014). Off western South Africa, the relative abundance of sardine and anchovy along the west and south coasts changed markedly during the last two decades in response to changing environmental conditions and spatially disproportionate fishing pressure (Roy et al., 2007; Coetzee et al., 2008; Van der Lingen et al., 2011). In turn, as the proportions of these species located in the south increased, and thus became difficult to access for seabirds at colonies on the west coast, the South African penguin population declined from ca. 56 000 pairs in 2001 to ca. 17 000 pairs in 2013 (Crawford et al., 2008, 2011, 2014). However, the colony at Dyer Island (Fig. 1), South Africa, once the largest for the species, has decreased from 22 655 pairs in 1979 to fewer than 1500 pairs since (Fig. 2) and did not respond to the apparent increase in the biomass of their main prey (Underhill et al., 2006; Ludynia et al., 2014). The continued decline observed at this colony in recent years is difficult to explain against the background of the higher abundance of prey fish along the south coast and a rapid increase of penguin numbers at another nearby colony (Stony Point). For the conservation of the species, it is therefore essential to understand the processes acting on the Dyer Island colony. Ludynia et al. (2014) recently reviewed the knowledge on processes influencing penguin population dynamics on Dyer Island and outlined the need for a modelling approach to examine the efficacy of potential management interventions at the colony. In this paper, we further develop the approach in Weller et al. (2014) to investigate penguin population dynamics at Dyer Island.

We first explore several prey biomass-related scenarios and contrast results for Robben and Dyer islands to determine the differences in response to food availability changes. We then discuss interactions with predation pressures at Dyer Island. Finally, we discuss the implications for future monitoring and management at this colony.

2. Model structure and parameterization

The Penguin Pressure Model is a colony-specific demographic simulation with configurable environmental pressure modules, built in a system dynamics framework (Vensim, Ventana). It makes extensive use of resampling from recorded databases and of stochastic variability within configurable bounds.

Structured model documentation following the TRACE format (Schmolke et al., 2010; Grimm et al., 2014) is available as an electronic appendix. Readers are referred to this document for details about model processes, parameterization, data sources, verification, and sensitivity tests. Table 1 provides a summary. The model in Vensim .vpm format is available as a supplementary file and can be executed using the free Vensim Model Reader (available at http://vensim.com/vensim-model-reader/).

A notable difference between the Robben Island and Dyer Island models is the presence of two additional strong negative influences on the Dyer population: an annual immature emigration rate possibly in excess of 50%, and annual losses of 7–8% of adults to predation by fur seals. These factors were found to lead to major differences in population response between the two colonies. Details on these pressures can be found in the TRACE appendix in Sections 3.3.1, 6.2.2, 6.3, 7.2.4 (emigration), and 3.3.4, 7.2.9 (seal predation).