Chapter 38

Indexing the availability of anchovy and sardine to seabird predators in the southern Benguela ecosystem

LG Underhill[1]* and RJM Crawford[1,2]

[1]Avian Demography Unit, Department of Statistical Sciences, University of Cape Town, Rondebosch 7701, South Africa
[2]Marine and Coastal Management, Department of Environmental Affairs and Tourism, Private Bag X2, Roggebaai 8012, South Africa
** Corresponding author: e-mail: les.underhill@uct.ac.za*

An index of the state of the epipelagic component of the southern Benguela ecosystem was derived for 1978–2006 using information on abundance, breeding success and diet for four seabirds (African Penguin *Spheniscus demersus*, Cape Gannet *Morus capensis*, Cape Cormorant *Phalacrocorax capensis* and Swift Tern *Sterna bergii*) that feed mainly on anchovy *Engraulis capensis* and sardine *Sardinops sagax*. It was significantly correlated with the combined biomass of these two fish species, suggesting the usefulness of seabirds in gauging the state of the epipelagic component of the ecosystem.

Keywords: Benguela ecosystem, index of health, seabirds, South Africa, target population level

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Introduction

This paper extends concepts developed by Underhill & Crawford (2005), in which a prototype index was developed for the health of the environment for seabirds breeding in the southern Benguela ecosystem. That prototype index made use of ideas originally presented by Bibby (1999). The index was illustrated by a dataset which used the population sizes of 10 species of seabird breeding along the coast of South Africa from 1956 to 1999. The key contribution made by Bibby (1999), and followed by Underhill & Crawford (2005), was to develop indices with an upper limit of 100%, which represented complete satisfaction with the state of the ecosystem, in that all component parts of the index were within target levels. In honour of Colin Bibby, who passed away in 2004, we will designate this type of index a Bibby Index.

In this paper, we use information from seabirds other than that relating to population sizes in the construction of a Bibby Index. Our target was to use time series related to those seabirds that feed mainly on anchovy *Engraulis capensis* and sardine *Sardinops sagax* to obtain an index of the health of the epipelagic system in the southern Benguela Current region, off South Africa's Western Cape, in which anchovy and sardine are the dominant forage fish species (Cury *et al.* 2000). There are four species of seabird in this region that feed mainly on anchovy and sardine: African Penguin *Spheniscus demersus*, Cape Gannet *Morus capensis*, Cape Cormorant *Phalacrocorax capensis* and the nominate race of Swift Tern *Sterna b. bergii*, all of which are endemic to the Benguela system (Crawford *et al.* 2006b). Additionally to sizes of populations, some monitoring has been undertaken of reproductive parameters and diet for some of these seabirds. We compared our index with estimates of the biomass of anchovy and sardine.

Material and Methods

Time series of information from the four seabird species which were available for developing an index of health were as follows: estimates of the numbers breeding in the Western Cape for African Penguins (Underhill *et al.* 2006), Swift Terns (Crawford 2003, updated) and, at eight islands in the Western Cape (that in 1977–1981 supported 98% of the number breeding in South Africa; Cooper *et al.* 1982), for Cape Cormorants (Underhill and Crawford 2005, updated); estimates of the area occupied by Cape Gannets breeding in the Western Cape (Crawford *et al.* 2007a); estimates of the number of African Penguins in adult or immature plumage that moulted at Robben Island (Underhill and Crawford 1999, updated), measures of the breeding success of African Penguins at Robben Island (Crawford *et al.* 2006a) and of Cape Gannets at Lambert's Bay and Malgas Island (unpublished information); and information on the contribution by mass of anchovy and sardine to the diet of Cape Gannets at Lambert's Bay and Malgas Island (Berruti *et al.* 1993, Schwartzlose *et al.* 1999, updated). Cape Gannets breed only at Lambert's Bay and Malgas Island in the Western Cape. We combined the information on breeding success of Cape Gannets by averaging annual values for the two colonies, as we similarly did for the contribution of anchovy and of sardine to diet of Cape Gannets. We summed the contribution of anchovy and sardine to the diet of gannets to form

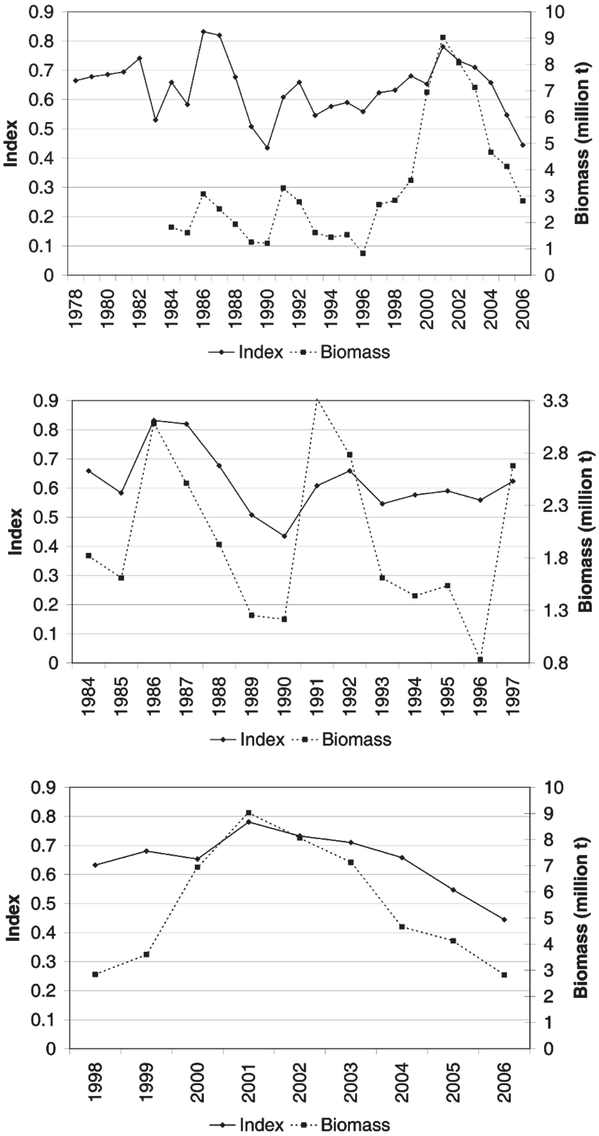

Figure 1: Trends in the index of the state of health of the epipelagic component of the southern Benguela ecosystem derived from seabirds and in the combined biomass of anchovy and sardine off South Africa (from van der Lingen *et al.* 2006) a) for 1978–2006, b) for 1984–1997 when an EK400 echo sounder was used to estimate biomass, and c) for 1998–2006 when an EK500 echo sounder was used to estimate biomass

one index for the diet of gannets. Therefore, there were nine time-series of information that were used to develop the index of health: four indices of numbers breeding; one of numbers of adult birds, one of numbers of immature birds, two of reproductive success and one of diet. It might be expected that, because the four seabirds all have considerable longevity (Hockey *et al.* 2005), the first five of these indices would show inertia in their responses to changes in fish availability, whereas the last four could be expected to respond more rapidly. African Penguins moult from immature to adult plumage about 18 months after fledging (Randall 1989).

The index of Underhill and Crawford (2005) used minimum and maximum target population sizes for seabird populations to transform estimates of abundance into a "happiness" function. Low population sizes were considered undesirable because populations were then at risk of extinction; at high populations, some species had adverse impacts on threatened seabirds. None of the four seabirds considered here had adverse impacts on other species, so no maximum target populations were assigned to them by Underhill and Crawford (2005). In this paper, we also did not assign maximum populations and used the minimum target populations adopted by Underhill and Crawford (2005).

The number of African Penguins breeding at Robben Island peaked at 8 500 pairs in 2004 (Underhill *et al.* 2006), which if multiplied by a factor of 3.2 (Crawford and Boonstra 1994) suggests the presence of about 27 000 birds in adult plumage. The African Penguin continues to decrease in abundance (Crawford *et al.* 2007b), so a large number of penguins at Robben Island is desired. Hence, the minimum target population for adult-plumaged birds at Robben Island was set at 25 000 birds.

For immature-plumaged penguins at Robben Island, the minimum target level was taken to be the number that would maintain the population of adult-plumaged birds at 25 000. Let S_a be the annual survival rate of birds after they moult from immature to adult plumage and I be the number of immature birds required to maintain the population at 25 000 adult-plumaged birds, then:

$$I = (1 - S_a)\ (25\ 000)\ (S_a^{-1}).$$

Based on information in Crawford *et al.* (1999), it was assumed $S_a = 0.85$. Hence $I \approx 4\ 500$.

With regard to the breeding success (B) of African Penguins, it was felt that the minimum desired level would be one that would maintain a stable adult population. Then, assuming an age at first breeding of four years (Crawford *et al.* 1999), that all birds subsequently breed each year, an equal sex ration of birds of breeding age, $S_a = 0.85$ and the survival rate of birds in immature plumage (S_i) = 0.50 (Shannon and Crawford 1999),

$$B = (1 - S_a)\ (2)\ (S_i^{-1}\ S_a^{-2}) = 0.83 \text{ chicks per pair per year.}$$

For Cape Gannets, the necessary breeding success to maintain a population is 0.32 chicks per pair per year, in the absence of high post-fledging losses to predation by Cape Fur Seals *Arctocephalus pusillus pusillus*, which have recently occurred (Makhado *et al.* 2006). The minimum target level was taken as 0.40 chicks per pair per year.

The maximum combined contribution of anchovy and sardine to the diet of Cape Gannets in the Western Cape has been observed for these species combined is 78% (Schwartzlose *et al.* 1999). We adopted 80% as the target level.

For each of the nine time series, we divided the time series value by the target value, truncating values larger than one to one, to obtain the "happiness" function. This implies that once a time series exceeds its target value, it does not increase farther. For each year, we computed the ecosystem health (Bibby 1999) index as the average of the "happiness" function for the nine time series.

We compared the ecosystem health index with the sum of the estimates of the spawner biomass of anchovy and sardine in the same year. The estimates of spawner biomass were obtained in November using acoustic surveys and commenced in 1984 (Hampton 1987). The estimates of the biomass of anchovy and sardine updated from Van der Lingen *et al.* (2006). Up until 1997, the biomass estimates were obtained using an EK400 echo sounder; from 1998 an EK500 echo sounder was used (Cunningham *et al.* 2007). The introduction of the EK500 echo sounder revealed a saturation problem with the EK400 echo sounder, so that the estimates of biomass are not strictly comparable. Therefore, using linear regression, we compared the seabird index of health of the epipelagic system with estimates of pelagic fish biomass for the periods 1984–1997 and 1998–2006, as well as for 1984–2006.

Results

The index of the epipelagic portion of the southern Benguela ecosystem that is derived from the time series of the four seabirds that subsist mainly on anchovy and sardine is shown in Figure 1. The index was relatively stable from 1978–1982, then decreased in 1983 and increased to its largest values of more than 80% in 1986 and 1987. It decreased to 43% in 1990 and fluctuated between 55% and 78% until 2005. It fell to 44% in 2006.

Acoustic estimates of pelagic fish abundance fluctuated around a level of 1.9 million t up until 1996. From 1997, after the change in echo sounder equipment, the fluctuation was around an average of 5.2 million t between 1997 and 2006; the maximum was 9.0 million t in 2001 before decreasing to 2.8 million t in 2006 (Figure 1).

For the entire period 1984–2006, the correlation between the health index and biomass of epipelagic fish for the two time series was $r = 0.51$ ($n = 23$, $P = 0.006$). For the period 1984–1997, the correlation between the two time series was 0.67 ($n = 14$, $P = 0.005$). Similarly, for the period 1998–2006, the correlation between the two time series was 0.76 ($n = 9$, $P = 0.008$).

The two time series, health index and biomass of epipelagic fish, were prewhitened by fitting autoregressive models of order 1 and cross-correlating the resulting residuals, which displayed no significant autocorrelation. The cross-correlation at lag 0 was 0.57 ($n = 22$, $P = 0.003$). This confirms the correlation between the two time series. The two time periods for which different echo sounders were used were each too short to implement Box-Jenkins modelling to assess the cross-correlation between the time series.

Discussion

The good correlations between fish biomass and the index of health of the epipelagic portion of the southern Benguela system derived from seabirds, for the time period as a whole, both with and without Box-Jenkins modelling, and for the two periods (1984–1997 and 1998–2006) in which different echo sounders were used to estimate fish abundance, suggest that seabirds track changes in fish stocks relatively well. This was in spite of an apparent divergence in the time series in the late 1990s (Figure 1), when the echo sounder was changed and there was an altered availability of prey to seabirds. There was an eastward shift in the distribution of the centre of gravity of commercial catches of sardine off South Africa of 400 km between 1997 and 2005 (Fairweather *et al.* 2006), which placed a substantial portion of the fish biomass beyond the foraging range of seabirds at breeding localities in the Western Cape. African Penguins have a foraging range of up to about 40 km from breeding localities when breeding (Heath and Randall 1989; Petersen *et al.* 2006). Cape Gannets are able to forage up to 240 km from colonies (Grémillet *et al.* 2004).

In the 1990s and 2000s, other factors also exerted a strong influence on seabird populations in the Western Cape, including high mortality of Cape Cormorants to avian cholera *Pasteurella multocida* (Crawford *et al.* 1992, Williams and Ward 2002, Waller and Underhill 2007) and of African Penguins and Cape Gannets to Cape Fur Seals (Marks *et al.* 1997, Crawford *et al.* 2001, Makhado *et al.* 2006). These may not be unrelated to fish biomass. Avian cholera may be endemic to seabird populations but become evident in periods of stress, such as is caused by food scarcity (Williams and Ward 2002). Predation by seals may increase in periods of prey scarcity (Makhado *et al.* 2006).

The good correlations between the seabird health index and estimates of fish biomass, in spite of such factors, suggest that pursuing the use of seabirds as indicators of the state of the epipelagic ecosystem will be worthwhile. Any divergence between trends in the seabird and biomass indices, as appeared to happen during the late 1990s, may provide indication of a change in the structure or functioning of the ecosystem, such as an altered distribution of forage fishes, or even in the survey techniques. Further development of the seabird index may include consideration of weighting the indices on which it is based, for example to emphasise rapidly changing indices and give less weight to those expected to have greater inertia.

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