Seabirds and climate change in southern African – some considerations

ROBERT J.M. CRAWFORD[1, 3] & RES ALTWEGG[2, 3]

[1]*Marine and Coastal Management, Dept of Environmental Affairs and Tourism, P/Bag X2, Rogge Bay 8012, South Africa*
[2]*South African National Biodiversity Institute, Kirstenbosch Research Centre, P/Bag X7, Claremont 7735, South Africa*
[3]*Animal Demography Unit, Department of Zoology, University of Cape Town, Rondebosch 7701, South Africa*

Crawford, R.J.M. & Altwegg, R. 2009. Seabirds and climate change in southern Africa – some considerations. pp. 1–5. In: Harebottle, D.M., Craig, A.J.F.K., Anderson, M.D., Rakotomanana, H. & Muchai, M. (eds). *Proceedings of the 12th Pan-African Ornithological Congress, 2008.* Cape Town, Animal Demography Unit.

Keywords: African Penguin, Bank Cormorant, Cape Cormorant, Cape Gannet, climate change, indicator, fishing, food, range extension, seabird parameters, southern Africa, Swift Tern

Population, demographic, diet and distribution parameters of several seabirds in southern Africa (including African Penguin, Cape Gannet, Bank Cormorant, Cape Cormorant and Swift Tern) have been related to trends in the abundance or availability of commercially-exploited fish on which they prey. This makes seabirds potentially useful indicators of the status of prey resources and, if the latter are influenced by climate, of climate change. However, seabirds and their prey are also affected by other factors, such as oil spills and fishing, so that changes in parameters need not result from climate change. In order to use seabirds as indicators of climate change it will be necessary to distinguish between environmental and other factors that may be influencing populations and associated parameters. Information that will be useful in achieving this objective includes assessment of the influence of environmental parameters, e.g. oxygen concentration and sea temperature, and other factors, e.g. disease, on populations. Ancillary information, e.g. range changes, for seabirds that do not feed on commercially-exploited prey and consideration of the degree of congruency of changes in populations at a broad regional, or even basin, scale is also likely to have value, as climate may be expected to influence wide areas. Used in conjunction with such additional information, seabird parameters should prove useful in interpreting the impact of climate change on marine ecosystems and facilitating appropriate management.

INTRODUCTION

Seabirds breed on land, often at islands, and they obtain all or much of their food at sea. They may be good indicators of the health of the resources on which they feed (e.g. Crawford & Shelton 1978, Crawford *et al*. 1992). Those that feed near the apex of the food chain will be influenced by processes happening lower in the chain, and hence may be good integrators of the state of marine ecosystems (Underhill & Crawford 2007). Therefore, should changing climate alter the structure or functioning of marine ecosystems, it may be expected that seabirds will be influenced by these changes. However, factors other than climate change, e.g. fishing, may also influence marine ecosystems (Crawford 2007), so that changes in seabird parameters are not necessarily caused by climate change. Furthermore, in an environmentally-dynamic marine ecosystem, there will be frequent environmental change, for example the Humboldt system in the south-east Pacific Ocean where *El Niños* occur at a quasi-regular frequency having major impacts for seabirds (Crawford *et al*. 2006b). It is preferable to distinguish this shorter-term change from long-term change that results from an altered climate.

The manner in which seabirds respond to change will be linked to their biology and ecology. Some seabirds are long-lived, so that their populations comprise several (often many) age classes. This buffers them against short-term variability in their environment, such as periodic food shortages that may lead to poor breeding success and a subsequent weak cohort (Hunt *et al*. 1996). It also means that there may not be an immediate response in population size to a change in the marine environment (e.g. Crawford 2007). By contrast, parameters such as breeding success, the proportion of mature birds that breeds, the condition of birds and their diet may respond more rapidly to change (e.g. Cairns 1987, Crawford *et al*. 1992, 2006a, 2008b, 2008e). The same amounts of environmental change may not affect all seabird parameters equivalently (Cairns 1987). For example, long-lived seabirds may select not to breed, or terminate breeding attempts, in years of reduced food availability, in order to maximise their own chances of survival. Thus survival may not be affected by a modest decrease in food availability, whereas the proportion of birds that breed and breeding success may decrease. Survival may only be affected once food becomes exceptionally scarce (Cairns 1987).

The influence of climate change on seabirds has been especially noticeable at high latitudes. In the Antarctic Peninsula, warming led to a southward extension in the breeding ranges of Gentoo *Pygoscelis papua* and Chinstrap *P. antarctica* Penguins (Emslie *et al*. 1998). At the South Orkney Islands, warming and a decrease in sea-ice extent brought about an increase in Gentoo Penguins but decreases in Chinstrap and Adélie *P. adeliae* Penguins (Forcada *et al*. 2006). Changes have also been observed at mid latitudes. Large decreases of Rockhopper Penguins *Eudyptes chrysocome* at several sub-Antarctic localities may have resulted from decreased primary production in the surrounding oceans (Hilton *et al*. 2006). At South Africa's Marion Island, mass of Rockhopper Penguins returning from overwintering feeding grounds to breed decreased by some 20% between 1994 and 2007, and was significantly correlated with breeding success, which also decreased (Crawford *et al.* 2008b). Off Argentina, Magellanic Penguins *Spheniscus magellanicus* recently extended their breeding and foraging ranges to the north (Boersma 2008).

The response of seabirds to climate change is of interest for at least two reasons. First, seabirds may prove to be sentinels that provide early warning of change (Boersma 2008). Second, the conservation status of seabirds may be worsened by climate change, necessitating the implementation of measures to mitigate adverse impacts (Crawford *et al.* 2008c). Here we consider the responses of southern African seabirds to an altered availability of prey and their usefulness as monitors of their oceanic environment. Seabirds may also be affected by climate operating at their breeding localities, where, for example, excessive temperatures may cause birds to abandon breeding attempts (Randall 1983), or flooding may destroy eggs and chicks (Randall & Ross 1979, Boersma 2008). However, such influences are beyond the scope of the present paper.

RESPONSES OF SOUTHERN AFRICAN SEABIRDS TO AN ALTERED FOOD ENVIRONMENT

In this section we review information on how the size and distribution of breeding populations of seabirds in southern Africa, their survival, the proportions of birds breeding, their breeding success and their diet have been related to food availability.

Size and distribution of the breeding population

After 1956 numbers of African Penguins *S. demersus* and Cape Gannets *Morus capensis* breeding in Namibia decreased respectively by 90% and 95%, and after 1978 numbers of Cape Cormorants *Phalacrocorax capensis* by 76% (Crawford 2007). The decreases were significantly related to a decrease of Namibia's sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus* resources, the main food of the three seabirds (Hockey *et al.* 2005, Crawford 2007). In the 1970s, the Namibian sardine collapsed and as it did so its range contracted to the north (Crawford *et al.* 1987), away from the southern breeding localities of penguins and gannets. The decrease of penguins, which have a shorter foraging range than gannets while breeding (Hockey *et al.* 2005), preceded that of gannets. For Cape Cormorants, artificial breeding platforms were built in central Namibia, and presumably enabled cormorants to exploit the diminishing sardine resource for a longer period than penguins and gannets (Crawford 2007).

Whereas before the mid 1970s, the combined biomass of sardine and anchovy was much greater off Namibia than off South Africa, from the mid 1980s there were considerably more of these epipelagic fish species off South Africa. Over the 50-year period 1956–2005, trends in the proportions of epipelagic fish and gannets off Namibia and South Africa showed marked similarity (Crawford *et al.* 2007a). As the South African stock of sardine, which collapsed in the 1960s, commenced a recovery in the early 1980s three new colonies of African Penguins were formed in the Western Cape: at Betty's Bay in 1982, Robben Island in 1983 and Boulders in 1985 (Crawford *et al.* 1995). Subsequent growth of the three penguin colonies was strongly associated with an increased abundance of sardine (Cury *et al.* 2000, Crawford *et al.* 2001a).

From the mid 1990s, there was a large eastward displacement of sardine and anchovy off South Africa (Fairweather *et al.* 2006, Roy *et al.* 2007). This brought about a mismatch in the distributions of breeding localities and prey of African Penguins and Cape Gannets in the Western Cape and substantial decreases in numbers of these seabirds in that province (Crawford *et al.* 2008c). However, numbers of gannets in the Eastern Cape increased as sardine became more available to them. The numbers of gannets breeding in the Western and Eastern Cape were significantly negatively and positively related to an index of the eastward displacement of sardine, respectively (Crawford *et al.* 2008c). From 1987–2006, numbers of African Penguins breeding in the Western Cape were significantly related to an index of the biomass of sardine available to birds in the Western Cape, as well as to the combined biomass of young-of-the-year anchovy and sardine (Crawford *et al.* 2008e).

From 1985–1992 numbers of Cape Cormorants breeding in the Western Cape were significantly related to the biomass of anchovy (Crawford & Dyer 1995). From 1987–2000, numbers of Swift (Crested) Terns *Sterna bergii* breeding in South Africa's Western Cape were significantly related to the combined biomass of anchovy and sardine, two of their main prey items (Crawford 2003). The sizes of breeding aggregations of Swift Terns also were significantly related to the combined biomass of anchovy and sardine (Crawford 2003). Proportions of Cape Cormorants and Swift Terns in the Western Cape that bred in the south of this province were positively related to an index of the eastward displacement of sardine (Crawford *et al.* 2008c). In the mid 1990s, Cape Cormorants extended their breeding range northward into southern Angola, probably as a result of food shortage in northern Namibia (Crawford *et al.* 2007b). Cape Fur Seals *Arctocephalus pusillus pusillus* also extended their breeding range northwards to northern Namibia and southern Angola (Kirkman *et al.* 2007).

At about the same time that sardine and anchovy were displaced to the east off South Africa, there was a southward shift in the catches of West Coast rock lobster *Jasus lalandii* off South Africa (Cockcroft *et al.* 2008). This coincided with decreases of Bank Cormorants *P. neglectus* breeding in the north of the Western Cape and increases at some more southern colonies (Crawford *et al.* 2008a). For several areas in the Western Cape, the numbers of Bank Cormorants breeding were significantly related to the commercial landings of rock lobsters (Crawford *et al.* 2008a). In the Western Cape, rock lobster is an important food of Bank Cormorants (Hockey *et al.* 2005).

Survival

At Robben and Dassen Islands, western South Africa, between 1987 and 1994 survival of African Penguins in their first year was related to the biomass of anchovy (Whittington 2002). At Dassen Island, the annual survival rate of adult penguins decreased from 0.80–0.84 during 1995–2002 to 0.45 in 2004 (Wolfaardt *et al.* 2008). At Robben Island, it decreased from 0.82 in the 1990s (Crawford *et al.* 1999, Whittington 2002) to a maximum of 0.72 from 2003/04–2006/07 (Crawford *et al.* 2008e). At Lambert's Bay and Malgas Island, western South Africa, survival of adult Cape Gannets was greater than 0.80 from 1991–2003, except at Malgas Island in 1997 (0.76), but it decreased to 0.75 at Lambert's Bay and 0.44 at Malgas Island in 2005 (Altwegg *et al.* 2008). The recent estimates of survival of adult penguins and gannets have uncertainty that should decrease as time series are extended, but occurred during the period of eastward displacement of sardine and anchovy (Fairweather *et al.* 2006, Roy *et al.* 2007).

Breeding proportion

At Robben Island from 1988–1995, the proportion of adult

African Penguins that bred was related to the biomass of both anchovy and sardine (Crawford *et al.* 1999). At the same locality, an index of the proportion of mature birds breeding increased by 40% between 1989–1995 and 1996–2006, coinciding with an increase in the biomass of sardine and anchovy after 1996 (Crawford *et al.* 1999). The proportion of Cape Cormorants breeding in the Western Cape decreased markedly in 1989 and 1990, when anchovy was scarce (Crawford & Dyer 1995). Most Cape Cormorants breed for the first time when two years old, but poor feeding conditions may cause postponement of first breeding until three years (Crawford *et al*. 2001b). In years when food was scarce numbers of Swift Terns breeding in the Western Cape decreased by up to 67% (Crawford 2000). Although Swift Terns mature when three years old, first breeding may be postponed until an age of six years in periods of food scarcity (Crawford *et al*. 2002).

Breeding success

From 1989–2004, for African Penguins at Robben Island breeding success was significantly positively related to the biomass of both anchovy and sardine (Crawford *et al*. 2006a). In 1970, at all three Namibia colonies of Cape Gannets there was high mortality of chicks from starvation following the collapse of the sardine (Crawford *et al*. 1983). In the Western Cape in the 2005/06 breeding season, at Lambert's Bay the entire Cape Gannet colony abandoned breeding (Crawford *et al*. 2007a) and at Malgas Island very low breeding success was recorded (Grémillet *et al*. 2008), following eastward displacement of sardine and anchovy (Fairweather *et al*. 2006, Roy *et al*. 2007). In years of food scarcity up to 70% of breeding Cape Cormorants may desert nests (Crawford *et al*. 1992).

Diet

Off Namibia, in the 1950s three seabirds fed mainly (76–99% by mass) on sardine: African Penguin, Cape Gannet and Cape Cormorant (Matthews 1961, Matthews & Berruti 1983). In the late 1970s and early 1980s, following its collapse, sardine contributed minimally to the diet of these seabirds (Crawford *et al*. 1985). In South Africa's Western Cape, from 1984–1993 the contribution of anchovy to the diet of Cape Gannets was significantly related to the biomass of anchovy (Crawford & Dyer 1995). Sardine began to increase in the diet after 1983, as South Africa's sardine stock commenced its recovery (Berruti & Colclough 1987), and by 1987 contributed more than 40% of the food. It remained an important prey for gannets in the Western Cape until 2003. Then, as sardine moved east, its contribution to the diet of gannets in the Western Cape decreased rapidly, whereas it increased in the diet of gannets in the Eastern Cape. The contribution of sardine to the diet of gannets in the Western and Eastern Cape was significantly negatively and positively related to an index of the eastward displacement of sardine, respectively (Crawford *et al*. 2008c).

DISCUSSION

From the foregoing it is apparent that there are many examples for southern Africa seabirds where population, demographic, diet or distribution parameters have been related to, or conform with, trends in the abundance or availability of fish species on which they feed. Most of the examples relate to the four seabirds that feed mainly on anchovy and sardine. For South Africa's Western Cape, nine time-series of information for these four seabirds were combined to develop an index of health of the epipelagic component of the southern Benguela ecosystem. The index was significantly related to the combined biomass of anchovy and sardine (Underhill & Crawford 2007), confirming the usefulness of seabirds as indicators of the status of resources on which they feed.

Therefore, if the resources on which southern Africa's seabirds feed are influenced by climate change, then seabirds are likely to reflect this impact. However, because intensive fisheries operate on several of the seabird prey species, including anchovy, sardine and rock lobster (Crawford *et al*. 1987), it is uncertain that changes in the prey resources will have been caused by climate change. Seabirds themselves are also affected by factors such as oil spills (e.g. Crawford *et al*. 2000) and disease (e.g. Waller & Underhill 2007). Further information is required to differentiate between anthropogenic impacts and environmental change on seabirds. In the southern African context, four additional sources of information may prove useful.

First, environmental parameters may be associated with changes in prey species. For example, an eastward shift in the distribution of spawning anchovy coincided with decreased sea surface temperatures over the Agulhas Bank (Roy *et al*. 2007). The reduced biomass of rock lobsters in the north of the Western Cape was associated with reduced somatic growth and increased walkouts of lobsters, both suggestive of environmental forcing, and there was a marked increase in the volume of low-oxygen water in this region after 1993 (Cockcroft *et al*. 2008). In the 1990s, low oxygen concentrations caused high mortality of fish off northern Namibia (Crawford *et al*. 2007b).

Second, it is important to understand all factors influencing the population dynamics of seabirds including, for example, mortality attributable to oiling and disease, so that these factors may be accounted for in gauging trends in seabird parameters. It is also important to understand factors that are influencing ecological processes, such as a mismatch in the distributions of predators and prey or the availability of alternative prey, as these may alter the contributions of prey species to the diet of predators.

Third, ancillary information on seabirds that do not feed on commercially-exploited prey species should be collected. There have been recent eastward extensions in the ranges of several such seabirds, including Crowned Cormorant *P. coronatus*, Kelp Gull *Larus dominicanus* and Hartlaub's Gull *L. hartlaubii*, which occurred at more or less the same time as the shifts in the distributions of anchovy, sardine and rock lobster off South Africa, again suggesting the influence of environmental forcing (Crawford *et al*. 2008d).

Fourth, if climate is driving change in marine populations, it is likely to operate over wide areas. Therefore, it will be useful to compare processes at regional, even basin, scales. Recent changes in seabird populations at the Prince Edward Islands in the south-west Indian Ocean (e.g. Crawford *et al*. 2008b) and in Argentina (Boersma 2008) are approximately congruent with changes in southern Africa. Southward range extensions of seabirds in the south-east Indian Ocean (Dunlop & Wooler 1986) approximately coincided with an earlier shift of Cape Gannets from Namibia to South Africa.

If climate is altering the structure and functioning of marine ecosystems, historical information on processes (e.g. predation) and rates (e.g. growth and mortality) in marine populations may no longer apply (e.g. Crawford *et al*. 2007c, Cockcroft *et al*. 2008). Hence management of resources based on assumptions regarding rates and processes will need to be adapted. Used in conjunction with other data sources, seabird parameters should prove useful in interpreting the impact of climate change on marine ecosystems and facilitating appropriate management.

ACKNOWLEDGEMENTS

We thank our research institutes (listed under addresses) and the National Research Foundation, through its Seachange Programme, for supporting this research. We are grateful to all who assisted with surveys of seabirds, as well as to many colleagues, with whom discussions led to the formulation of our thoughts. CapeNature, Department of Environmental Affairs and Tourism (South Africa), Ministry of Fisheries and Marine Resources (Namibia), Robben Island Museum, South African National Parks and South African Navy provided logistical support for surveys.

REFERENCES

Altwegg, R., Crawford, R.J.M., Underhill, L.G. & Williams, A.J. 2008. Long-term survival of de-oiled Cape Gannets after the *Castillo de Bellver* oil spill of 1983. *Biological Conservation* 141: 1924–1929.

Berruti, A. & Colclough, J. 1987. Comparison of the abundance of pilchard in Cape Gannet diet and commercial catches off the Western Cape, South Africa. *South African Journal of Marine Science* 5: 863–869.

Boersma, P.D. 2008. Penguins as marine sentinels. *Bioscience* 58: 597–607.

Cairns, D.K. 1987. Seabirds as indicators of marine food supplies. *Biological Oceanography* 5: 261–271.

Cockcroft, A.C., van Zyl, D. & Hutchings, L. 2008. Large-scale changes in the spatial distribution of South African West Coast rock lobsters: an overview. *African Journal of Marine Science* 30: 149–159.

Crawford, R.J.M. 2003. Influence of food on numbers breeding, colony size and fidelity to localities of Swift Terns in South Africa's Western Cape, 1987–2000. *Waterbirds* 26: 44–53.

Crawford, R.J.M. 2007. Food, fishing and seabirds in the Benguela upwelling system. *Journal of Ornithology* 148 (Suppl 2): S253–S260.

Crawford, R.J.M. & Dyer, B.M. 1995. Responses by four seabirds to a fluctuating availability of Cape Anchovy *Engraulis capensis* off South Africa. *Ibis* 137: 329–339.

Crawford, R.J.M. & Shelton, P.A. 1978. Pelagic fish and seabird interrelationships off the coasts of South West and South Africa. *Biological Conservation* 14: 85–109.

Crawford, R.J.M., Shelton, P.A. & Berruti, A. 1983. Cape Cormorants as potential indicators of pelagic fish stocks off southern Africa. *South African Journal of Science* 79: 466–468.

Crawford, R.J.M., Cruickshank, R.A., Shelton, P.A. & Kruger, I. 1985. Partitioning of a goby resource amongst four avian predators and evidence for altered trophic flow in the pelagic community of an intense, perennial upwelling system. *South African Journal of Marine Science* 3: 215–228.

Crawford, R.J.M., Shannon, L.V. & Pollock, D.E. 1987. The Benguela ecosystem. Part IV. The major fish and invertebrate resources. *Oceanography and Marine Biology Annual Review* 25: 353–505.

Crawford, R.J.M., Underhill, L.G., Raubenheimer, C.M., Dyer, B.M. & Martin, J. 1992. Top predators in the Benguela ecosystem – implications of their trophic position. *South African Journal of Marine Science* 12: 675–687.

Crawford, R.J.M., Williams, A.J., Hofmeyr, J.H., Klages, N.T.W., Randall, R.M., Cooper, J., Dyer, B.M. & Chesselet, Y. 1995. Trends of African Penguin *Spheniscus demersus* populations in the 20th century. *South African Journal of Marine Science* 16: 101–118.

Crawford, R.J.M., Shannon, L.J. & Whittington, P.A. 1999. Population dynamics of the African Penguin *Spheniscus demersus* at Robben Island, South Africa. *Marine Ornithology* 27: 139–147.

Crawford, R.J.M., Davis, S.A., Harding, R., Jackson, L.F., Leshoro, T.M., Meÿer, M.A., Randall, R.M., Underhill, L.G., Upfold, L., van Dalsen, A.P., van der Merwe, E., Whittington, P.A., Williams, A.J. & Wolfaardt, A.C. 2000. Initial impact of the *Treasure* oil spill on seabirds off western South Africa. *South African Journal of Marine Science* 22: 157–176.

Crawford, R.J.M., David, J.H.M., Shannon, L.J., Kemper, J., Klages, N.T.W., Roux, J-P., Underhill, L.G., Ward, V.L., Williams, A.J. & Wolfaardt, A.C. 2001a. African Penguins as predators and prey – coping (or not) with change. *South African Journal of Marine Science* 23: 435–447.

Crawford, R.J.M., Dyer, B.M., Upfold, L. & Ward, V.L. 2001b. Age at first breeding of Bank, *Phalacrocorax neglectus*, and Cape Cormorants, *P. capensis*. *Ostrich* 72: 145–148.

Crawford, R.J.M., Cooper, J., Dyer, B.M., Upfold, L., Venter, A.D., Whittington, P.A., Williams, A.J. & Wolfaardt, A.C. 2002. Longevity, inter-colony movements and breeding of Crested Terns in South Africa. *Emu* 102: 1–9.

Crawford, R.J.M., Barham, P.J., Underhill, L.G., Shannon, L.J., Coetzee, J.C., Dyer, B.M., Leshoro, T.M. & Upfold, L. 2006a. The influence of food availability on breeding success of African Penguins Spheniscus demersus at Robben Island, South Africa. Biological Conservation 132: 119–125.

Crawford, R.J.M., Goya, E., Roux, J-P. & Zavalaga, C.B. 2006b. Comparison of assemblages and some life-history traits of seabirds in the Humboldt and Benguela systems. African Journal of Marine Science 28: 553–560.

Crawford, R.J.M., Dundee, B.L., Dyer, B.M., Klages, N.T.W., Meÿer, M.A. & Upfold, L. 2007a. Trends in numbers of Cape Gannets (*Morus capensis*), 1956/57–2005/06, with a consideration of the influence of food and other factors. *ICES Journal of Marine Science* 64: 169–177.

Crawford, R.J.M., Dyer, B.M., Kemper, J., Simmons, R.E. & Upfold, L. 2007b. Trends in numbers of Cape Cormorants (*Phalacrocorax capensis*) over a 50-year period, 1956–57 to 2006–07. *Emu* 107: 1–9.

Crawford, R.J.M., Underhill, L.G., Upfold, L. & Dyer, B.M. 2007c. An altered carrying capacity of the Benguela upwelling ecosystem for African Penguins (*Spheniscus demersus*). *ICES Journal of Marine Science* 64: 570–576.

Crawford, R.J.M., Cockcroft, A.C., Dyer, B.M. & Upfold, L. 2008a. Divergent trends in Bank Cormorants *Phalacrocorax neglectus* breeding in South Africa's Western Cape consistent with a distributional shift of rock lobsters *Jasus lalandii*. *African Journal of Marine Science* 30: 161–166.

Crawford, R.J.M., Makhado, A.B., Upfold, L. & Dyer, B.M. 2008b. Mass on arrival of Rockhopper Penguins at Marion Island correlated with breeding success. *African Journal of Marine Science* 30: 185–188.

Crawford, R.J.M., Sabarros, P.S., Fairweather, T., Underhill, L.G. & Wolfaardt, A.C. 2008c. Implications for seabirds of a long-term change in the distribution of sardine: a South African experience. *African Journal of Marine Science* 30: 177–184.

Crawford, R.J.M., Tree, A.J., Whittington, P.A., Visagie, J., Upfold, L., Roxburg, K.J., Martin, A.P. & Dyer, B.M. 2008d. Recent distributional changes of seabirds in South Africa: is climate having an impact? *African Journal of Marine Science* 30: 189–193.

Crawford, R.J.M., Underhill, L.G., Coetzee, J.C., Fairweather, T., Shannon, L.J. & Wolfaardt, A.C. 2008e. Influences of the abundance and distribution of prey on African Penguins *Spheniscus demersus* off western South Africa. *African Journal of Marine Science* 30: 167–175.

Cury, P., Bakun, A., Crawford, R.J.M., Jarre, A., Quiñones, R.A., Shannon, L.J. & Verheye, H.M. 2000. Small pelagics in upwelling systems: patterns of interaction and structural changes in "wasp-waist" ecosystems. Academic Press *ICES Journal of Marine Science* Symposium Edition 57(3): 603–618.

Dunlop, J.N. & Wooler, R.D. 1986. Range extensions and the breeding seasons of seabirds in south-western Australia. *Records Western Australian Museum* 12: 389–394.

Emslie, S.D., Fraser, W., Smith, R.C. & Walker, W. 1998. Abandoned penguin colonies and environmental change in the Palmer Station area, Anvers Island, Antarctic Peninsula. *Antarctic Science* 10: 257–268.

Fairweather, T.P., van der Lingen, C.D., Booth, A.J., Drapeau, L. & van der Westhuizen, J.J. 2006. Indicators of sustainable fishing for South African sardine (*Sardinops sagax*) and anchovy (*Engraulis encrasicolus*). *African Journal of Marine Science* 28: 661–680.

Forcada, J., Tratham, P.N., Reid, K., Murphy, E.J. & Croxall, J.P. 2006. Contrasting population changes in sympatric penguin species in association with climate warming. *Global Change Biology* 12: 411–423.

Grémillet, D., Pichegru, L., Kuntz, G., Woakes, A.G., Wilkinson, S., Crawford, R.J.M. & Ryan, P.G. 2008. A junk-food hypothesis for gannets feeding on fishery waste. *Proceedings of the Royal Society, London Biological Series* 18: 1–8.

Hilton, G.M., Thompson, D.R., Sagar, P.M., Cuthbert, R.J., Cherel, Y. & Bury, S.J. 2006. A stable isotopic investigation into the causes of decline in a sub-Antarctic predator, the Rockhopper Penguin *Eudyptes chrysocome*. *Global Change Biology* 12: 611–625.

Hockey, P.A.R., Dean, W.R.J. & Ryan, P.G. (eds). 2005. *Roberts Birds of Southern Africa, 7th edn*. John Voelcker Bird Book Fund, Cape Town.

Hunt, G.L., Barrett, R.T., Joiris, C. & Montevecchi, W.A. 1996. Seabird/fish interactions: an introduction. In: Hunt, G.L. & Furness, R.W. (eds) *Seabird/fish interactions, with particular reference to seabirds in the North Sea*. *ICES Cooperative Research Report* 216: 2–5.

Kirkman, S.P., Oosthuizen, W.H., Meÿer, M.A., Kotze, P.G.H., Roux, J-P. & Underhill, L.G. 2007. Making sense of censuses and dealing with missing data: trends in pup counts of Cape Fur Seal *Arctocephalus pusillus pusillus* for the period 1972–2004. *African Journal of Marine Science* 29: 161–176.

Matthews, J.P. 1961. The pilchard of South West Africa (*Sardinops ocellata*) and the marsbanker (*Trachurus trachurus*) – bird predators, 1957–1958. *Investigational Report South West African Marine Research Laboratory* 3: 1–35.

Matthews, J.P. & Berruti, A. 1983. Diet of Cape Gannet and Cape Cormorant off Walvis Bay, 1958–1959. *South African Journal of Marine Science* 1: 61–63.

Randall, R.M. 1983. Biology of the Jackass Penguin *Spheniscus demersus* (L.) at St. Croix Island, South Africa. Unpublished Ph.D. thesis, University of Port Elizabeth.

Randall, R.M. & Ross, G.J.B. 1979 Increasing population of Cape Gannets on Bird Island, Algoa Bay, and observations on breeding success. *Ostrich* 50:168–175.

Roy, C., van der Lingen, C.D., Coetzee, J.C. & Lutjeharms, J.R.E. 2007. Abrupt environmental shift associated with changes in the distribution of Cape anchovy *Engraulis encrasicolus* spawners in the southern Benguela. *African Journal of Marine Science* 29: 309–319.

Underhill, L.G. & Crawford, R.J.M. 2007. Indexing the availability of anchovy and sardine to seabird predators in the southern Benguela ecosystem. In: Kirkman S.P. (ed.) *Final Report of the BCLME (Benguela Current Large Marine Ecosystem) Project on Top Predators as Biological Indicators of Ecosystem Change in the BCLME*. Avian Demography Unit, Cape Town, pp. 297–300.

Waller, L.J. & Underhill, L.G. 2007. Management of avian cholera *Pasteurella multocida* outbreaks on Dyer Island, South Africa, 2002–2005. *African Journal of Marine Science* 29: 105–111.

Whittington, P.A. 2002. Survival and movements of African Penguins, especially after oiling. Unpublished Ph.D. thesis, University of Cape Town.

Wolfaardt, A.C., Underhill, L.G., Altwegg, R. & Visagie, J. 2008. Restoration of oiled African Penguins after the *Apollo Sea* spill. *African Journal of Marine Science* 30.