

Regionally coherent trends in colonies of African penguins *Spheniscus demersus* in the Western Cape, South Africa, 1987–2005

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From 1987 to 2005, numbers of African penguins *Spheniscus demersus* breeding in South Africa's Western Cape Province increased by about 50%. Numbers decreased at the four northernmost colonies in the region: Lambert's Bay and the three colonies in Saldanha Bay, although at Jutten Island the decrease is inferred from an estimate for 1987, derived from interpolation. Numbers also decreased at Geyser Rock and Dyer Island on the South Coast. At five colonies between Saldanha Bay and Dyer Island there were large increases. At a sixth colony in that region, Seal Island, where Cape fur seals *Arctocephalus pusillus pusillus* limit breeding space, numbers remained stable. At two colonies that were initiated in the early 1980s, Robben Island and Boulders, increases were initially rapid (>20% per annum) and matched growth of the South African stock of sardine *Sardinops sagax*. Strong

growth at Dassen and Vondeling islands, between Robben Island and Saldanha Bay, was observed from about 1996–2002, when there was a large increase in the biomass of pelagic fish off South Africa. Increases at colonies between Saldanha Bay and Boulders slowed after 2002, whereas the colony at Dyer Island stabilised at that time. In 2003, a new colony was initiated east of Dyer Island at De Hoop Nature Reserve. These latter trends followed an eastward shift in the distribution of sardine. Small penguin colonies may act as foci for growth in a period when the distribution of prey is changing. Hence, it is important that they be maintained, especially those that, if lost, would increase the isolation of regional populations. Some of the small colonies are less susceptible to oil spills than colonies in the proximity of harbours, and for that reason also are important.

Keywords: African penguin, breeding colonies, food availability, management, oiling, population trends

Introduction

The African penguin *Spheniscus demersus* is endemic to southern Africa, breeding from Hollamsbird Island, Namibia, to Bird Island, Algoa Bay, South Africa (Crawford and Whittington 1997, Crawford 2000). The total population decreased by at least 90% during the 20th century; during the early 1990s the population was estimated to be about 180 000 penguins, and to be decreasing at a rate of 2% per year (Crawford *et al.* 1995b, Ellis *et al.* 1998, Whittington *et al.* 2000).

Due to the rapid decline of the African penguin population, its IUCN threat status is Vulnerable (Crawford 2000, du Toit *et al.* 2003, BirdLife International 2004). Factors implicated in the decline during the early part of the 20th century included egg exploitation, habitat alteration and disturbance associated with commercial exploitation of guano (Whittington *et al.* 2000). These activities have largely ceased. Egg

collections no longer pose a significant threat, but the loss of guano in which burrows may be constructed has probably reduced breeding success and made penguins more vulnerable to displacement from breeding sites by larger animals (e.g. Shaughnessy 1980, Crawford *et al.* 1989). In the latter half of the 20th century, reduced availability of pelagic fish as a result of competition with commercial fisheries was held responsible for much of the decline (Crawford *et al.* 2001). Other factors at present adversely influencing the population include mortality in oil spills, competition with Cape fur seals *Arctocephalus pusillus pusillus* for breeding space, predation by seals, feral cats *Felis catus* and kelp gulls *Larus dominicanus*, and entanglement in fishing gear and other marine debris (Crawford *et al.* 2000a, Whittington *et al.* 2000, David *et al.* 2003).

Trends in the global population of the African penguin up to 1994 were reviewed by Crawford *et al.* (1995b). In this paper, we focus on trends in the Western Cape, South Africa, for the period 1987–2005. Comparisons are also made with two earlier years in which all the colonies then extant in the Western Cape were surveyed: 1956 and 1979.

The review period was punctuated by two major oiling incidents. In spite of extensive efforts to clean and release oiled penguins (Nel and Whittington 2003), the number of penguins lost represented a substantial proportion of the population of the region. In the *Apollo Sea* spill of 1994, 10 000 penguins were oiled, of which 5 000 died (Underhill *et al.* 1999); in the *Treasure* spill of 2000, 19 000 penguins were oiled, of which 2 000 died (Crawford *et al.* 2000a). The impact of these losses is considered.

Material and Methods

All available counts, during the main breeding season, of breeding pairs of African penguins at the 13 colonies in the Western Cape that were occupied between 1987 and 2005 were extracted from the database of Marine and Coastal Management. Counts were conducted as described by Crawford *et al.* (1995b). For each year, the highest count obtained was assumed to represent the breeding population. This makes the assumption that all breeding pairs were present at the time of that count. This is most likely to be the case when counts are repeated frequently through the breeding season, which was the case for readily accessible colonies but not for more remote localities. Furthermore, the larger colonies tended to be counted less

frequently than the smaller colonies and it took much longer to count them.

Of the 230 possible counts, 46 were not made. These missing values were filled in by linear interpolation between actual counts made at the colony. The longest run of missing values was four years. The total number of additional breeding pairs imputed in this way was 64 611 pairs, 14% of the estimated total number of breeding pairs (455–568) over the 19-year period (Table 1). In all, 40 245 (62%) of the imputed birds related to the years 1987–1989 at Dyer Island (Table 1). The Dyer Island colony was surveyed in 1986, when 18 481 breeding pairs were counted and next in 1990 when there were 8 349 pairs (Crawford *et al.* 1995b). At Jutten Island, there were no counts of the number of breeding pairs during the main breeding season from 1980 to 1990, so the size of the population there in 1987 is uncertain.

At each colony, a moving percentage rate of increase (or decrease) over the period 1987–2005 was obtained by fitting a weighted linear regression to growth curves of the form $y_n = a(1 + r)^n$, where n is the year, and a and r are constants, and r is defined as the annual growth rate. The growth curve was linearised, so that $\log(y_n) = \log(a) + n \log(1 + r)$. A weighted regression was fitted for each year in turn, with weights chosen in such a way that they decreased rapidly for years farther away from the target year, so that the growth rate for that year depended mostly on the population sizes over a period of seven years centred on the target year (details in the Appendix). The estimated annual growth rate r was multiplied by 100 and expressed as a percentage; positive values indicated an increase and negative

Table 1: Counts of numbers of breeding pairs of African penguins at colonies in the Western Cape, South Africa, 1956, 1979 and 1987–2005. Values for 1956 are estimates of the population divided by two (Rand 1963). Values for later years are maximum counts of numbers of breeding pairs (updated from Crawford *et al.* 1995b, 2001, Wolfaardt *et al.* 2001). Interpolated values (see text) are shown in italics

Year	Number of breeding pairs												Total
	Lambert's Bay	Malgas	Marcus	Jutten	Vondeling	Dassen	Robben Boulders	Seal	Stony Point	Dyer	Geyser		
1956	250	2 500	4 750	7 500	300	72 500	0	0	250	0	4 000	1	92 051
1979	50	1 022	1 243	2 878	495	12 646	0	0	82	0	22 655	318	41 389
1987	21	142	214	1 497	196	4 588	476	7	83	41	15 948	291	23 504
1988	23	122	212	1 324	153	6 508	849	34	83	55	13 415	300	23 077
1989	27	101	211	1 151	109	8 428	829	38	83	69	10 882	310	22 236
1990	30	118	209	979	169	8 720	1 278	54	83	89	8 349	319	20 395
1991	25	80	207	806	229	9 012	1 879	131	82	77	6 115	328	18 971
1992	18	99	206	991	133	7 563	2 027	158	95	57	7 579	250	19 015
1993	22	70	205	526	141	7 199	2 176	241	85	40	2 374	172	13 109
1994	16	80	204	1 349	169	9 389	2 799	359	75	44	4 649	111	19 245
1995	26	74	160	891	205	9 792	2 279	366	65	51	4 260	50	18 219
1996	20	71	99	779	258	9 502	3 097	416	90	58	3 279	47	17 716
1997	23	43	73	947	361	8 651	3 336	726	85	65	2 745	5	17 060
1998	27	61	122	962	157	10 918	3 467	555	79	72	1 963	3	18 386
1999	11	67	116	759	333	15 155	4 399	906	80	88	2 363	1	24 278
2000	10	48	96	898	528	15 598	5 705	949	81	104	2 220	1	26 238
2001	9	55	114	1 338	649	21 409	6 723	1 054	82	111	2 088	1	33 633
2002	9	58	57	1 042	544	22 883	7 252	1 083	82	117	2 145	2	35 274
2003	18	43	65	719	622	20 319	6 433	1 033	83	123	1 929	2	31 389 ^a
2004	22	28	78	848	612	24 901	8 524	1 196	84	98	2 216	2	38 610 ^a
2005	10	26	53	801	564	22 687	7 152	1 227	76	186	2 053	1	34 840 ^a

^a There was one breeding pair at a new site at De Hoop Nature Reserve in 2003, approximately seven pairs in 2004 and 15 pairs in 2005

values a decrease. Particular interest was taken in the years in which the growth rate turned from being negative to positive (and *vice versa*), and at the points of inflection of growth rates (where the rates of increase and decrease of growth rates had their turning points).

Results

The number of pairs of African penguins breeding in the Western Cape increased by 48%, from 23 500 in 1987 to

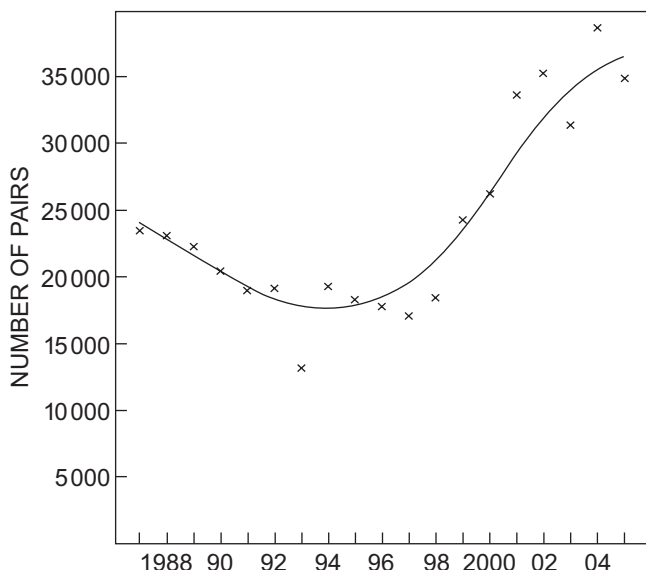


Figure 1: Estimates of, and the modelled rate of increase or decrease of, the total numbers of pairs of African penguins breeding in the Western Cape, 1987–2005

34 850 in 2005. The minimum count was 13 100 pairs in 1993 and the maximum was 38 700 in 2004 (Table 1). Numbers initially decreased and then increased (Figure 1).¹ The weighted linear regression suggests that the turning point occurred about 1994. The rate of growth attained a maximum from 1998 to 2001 and then slowed (Table 2).

Between 1987 and 2005, numbers of African penguins decreased at the three northernmost colonies (Lambert’s Bay, Malgas and Marcus islands) and, if interpolated values are considered, also at Jutten Island. They also decreased at the two easternmost colonies (Dyer Island and Geyser Rock). They increased at five central colonies (Vondeling, Dassen and Robben islands, Boulders and Stony Point). At Seal Island, where breeding space is restricted (Crawford *et al.* 1994), numbers remained stable (Table 1). A new breeding site was discovered at De Hoop Nature Reserve in 2003 when one pair of penguins bred there. This grew to 15 pairs in 2005.

The decreases in the north and east and increases at central colonies indicate regional coherence in trends. However, similar trends were not always entirely synchronous. For example, the decrease at Dyer Island was initiated ahead of the decrease of the smaller colony at adjacent Geyser Rock. In Saldanha Bay, the colony at Malgas Island decreased throughout the study period but that at Marcus Island only after 1994. At Jutten Island, if the interpolated estimates for 1987–1990 are disregarded, the colony remained stable through most of the study period.

The rates of decrease at both Malgas Island and Marcus Island slowed between 1997 and 2000 (Table 2). The colony at Vondeling Island began to increase from about 1989, the increase being maintained until 2004 (Figure 2).

¹ The small decline observed in the total number of breeding pairs between 2004 and 2005 (Table 1, Figure 1) was followed by a much larger decline in 2006 to c. 21 000.

Table 2: Modelled rates of increase and decrease (negative) at the individual colonies of African penguins in the Western Cape, 1987–2005 (see text for methods)

Year	Rate of change												
	Lambert’s Bay	Malgas	Marcus	Jutten	Vondeling	Dassen	Robben	Boulders	Seal	Stony Point	Dyer	Geyser	Total
1987	5.6	-9.8	-0.8	-12.4	-4.6	18.0	34.1	89.4	0.3	16.9	-19.5	0.1	-4.9
1988	2.6	-9.2	-0.9	-11.8	-1.4	13.4	32.2	78.3	0.5	11.3	-19.8	-2.3	-5.4
1989	-0.5	-8.6	-1.1	-10.7	0.8	9.1	29.8	69.5	0.6	4.9	-19.9	-6.0	-5.7
1990	-3.2	-8.2	-1.7	-8.9	1.8	5.4	26.7	62.0	0.3	-1.1	-19.7	-11.4	-5.7
1991	-4.7	-7.7	-3.08	-6.3	2.3	3.1	22.6	54.7	-0.3	-5.5	-18.8	-18.4	-5.1
1992	-4.4	-7.3	-5.4	-3.2	3.7	2.5	18.2	46.8	-1.2	-6.7	-17.0	-26.6	-3.8
1993	-2.8	-7.1	-8.7	-0.6	6.4	3.1	14.4	38.8	-1.7	-4.5	-14.5	-35.3	-1.8
1994	-1.2	-7.1	-11.7	0.6	9.5	4.3	12.0	31.8	-1.3	0.4	-12.4	-43.5	0.3
1995	-1.4	-7.1	-12.9	0.7	11.6	5.7	11.4	26.6	-0.4	5.8	-11.5	-50.3	2.2
1996	-4.4	-6.5	-11.3	0.4	12.5	7.8	12.2	23.0	0.4	10.1	-11.4	-54.1	4.3
1997	-8.9	-5.2	-8.1	0.7	13.7	10.8	13.8	20.4	0.6	12.5	-10.6	-53.7	7.1
1998	-12.5	-4.0	-5.6	1.4	16.1	13.8	15.4	17.9	0.4	13.3	-8.8	-47.8	10.0
1999	-12.7	-3.9	-5.5	2.0	18.4	15.4	15.9	15.1	0.2	12.6	-6.3	-36.2	11.8
2000	-8.9	-5.3	-7.3	1.3	18.1	15.0	14.9	12.1	0.2	11.0	-4.1	-20.6	11.9
2001	-2.3	-7.9	-9.2	-0.6	14.8	12.8	12.6	9.3	0.2	9.2	-2.7	-5.2	10.4
2002	4.1	-11.2	-10.0	-3.1	10.2	10.1	9.9	7.2	0.04	7.9	-1.8	5.5	8.3
2003	7.4	-14.4	-9.8	-5.0	6.1	7.6	7.6	5.9	-0.4	7.8	-1.1	10.3	6.3
2004	6.6	-17.1	-9.2	-5.9	2.9	5.6	5.7	5.4	-0.9	9.2	-0.6	10.8	4.7
2005	2.2	-18.9	-8.9	-5.8	0.8	4.2	4.2	5.4	-1.7	12.0	-0.2	9.0	3.5

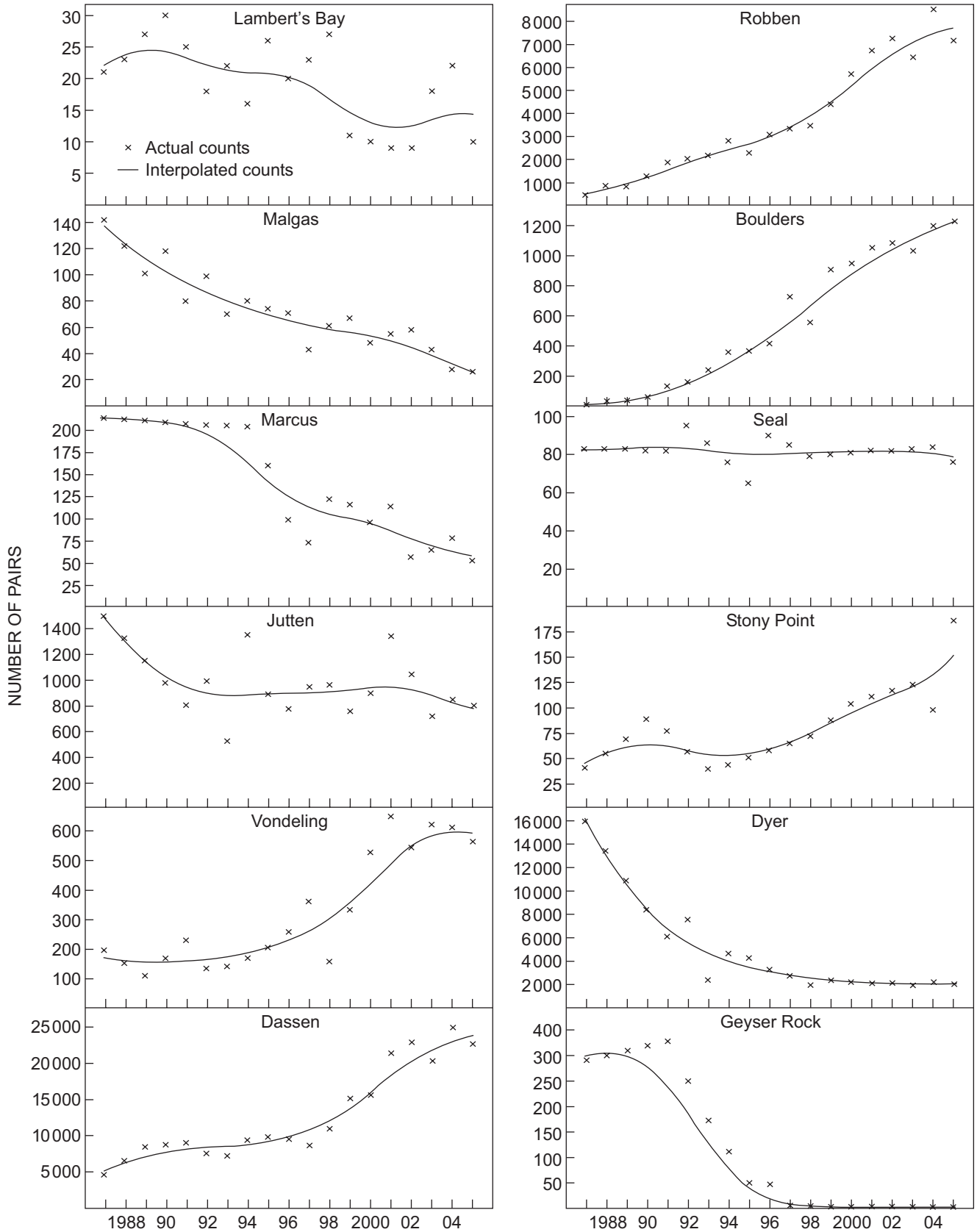


Figure 2: Estimates of, and the modelled rate of increase or decrease of, the numbers of pairs of African penguins breeding at 12 colonies in the Western Cape, 1987–2005. Note different values on the y-axis

Initially, the rate of increase was low (1–4% from 1989 to 1992). The rate increased to >10% from 1995 to 2002, and then slowed. There was substantial growth of the colony at Dassen Island between 1987 and 1989 (Figure 2). Thereafter, the pattern was similar to that for Vondeling Island: growth was slow (2–5%) from 1990 to 1994, >10% from 1997 to 2002, and less subsequently. There was rapid growth of the colonies at Robben Island until 2004 and at Boulders until 2005. Estimated rates of growth exceeded 10% per annum up until 2000, and for Robben Island also in 2001. Growth at these two colonies then slowed. At Stony Point, there was an initial increase in the colony, followed by a decrease from 1990 to 1993 and then a rapid increase. The rate of increase was >10% from 1987 to 1988, from 1996 to 2000 and in 2005. At Geysers Rock and Dyer Island, the colonies decreased through most of the study period. At Dyer Island, the rate of decrease was >10% per annum until 1997, and then negligible.

There was a better fit of the growth curves at some localities (e.g. Malgas Island) than at others (e.g. Jutten Island; Figure 2). This is attributable to some localities being easier to count than others, and some localities being counted more frequently than others during the breeding season.

Discussion

Influence of food

Long-term changes in the distribution and abundance of prey are thought to influence the suitability of localities for breeding by African penguins (Crawford 1998). The most striking development between 1979, when there was a complete census of colonies, and the start of the review period in 1987, was the establishment between 1982 and 1985 of three colonies that did not exist earlier in the 20th century: Robben Island, which has grown to become the second largest colony in the Western Cape (Crawford *et al.* 2001), and the two mainland colonies at Stony Point and Boulders (Crawford *et al.* 1995a). The initiation and subsequent growth of these colonies closely matched the recovery of South Africa's sardine *Sardinops sagax* stock (Crawford 1998). From 1989 to 2005, the breeding success of African penguins at Robben Island was significantly related to the abundance of sardine and anchovy *Engraulis encrasicolus* (Crawford *et al.* 2006).

The three colonies initiated in the early 1980s increased ahead of others in the Western Cape. Later, the increases spread north to include the colonies at Dassen and Vondeling islands (Crawford *et al.* 2001, Table 1). There was especially rapid growth of the colonies at Dassen and Vondeling islands from 1997–2001, when there was a large increase in the biomass of sardine and anchovy in South Africa (Barange *et al.* 2004). At that time also, the rate of decrease of the colony at Malgas Island slowed and there was a short-lived increase in numbers of penguins breeding at Marcus Island (Figure 2). After 2001, the rates of increase at Vondeling, Dassen and Robben islands and at Boulders and Stony Point slowed. At the same time, rates of decrease of the colonies at Malgas and Marcus islands increased and there was indication that the colony at Jutten

Island started to decrease. Conversely, the rate of decrease of the colony at Dyer Island slowed. Since about 1998, this colony was more or less stable (Figure 2). The decreases and slowed rates of increase at western colonies, and the stability of the colony at Dyer Island and initiation of the colony in the De Hoop Nature Reserve at the end of the study period, accord with an eastward shift in the distribution of spawning sardine from 2001 onwards and in the distribution of catches of anchovy and sardine after 1997 (van der Lingen *et al.* 2005).

Dyer Island was the only colony having more than 2 000 pairs at the start of the review period, at which the breeding population subsequently declined. In 1956, the size of the colony at Dyer Island was estimated at 4 000 pairs (Rand 1963). During the next population survey, in 1979, 22 655 pairs were counted, and numbers remained at a similar level until 1986, when there were 18 481 pairs (Crawford *et al.* 1995b). The increase between 1956 and 1979 was attributed to emigration of first-time breeders from colonies farther west to Dyer Island, following collapses of the sardine stocks off South Africa and Namibia (Crawford 1998, Crawford *et al.* 2001). The subsequent decrease was attributed to a fluctuating decrease in the South African stock of anchovy from 1986–1997, and the emigration in this period of first-time breeders to colonies to the west, as the South African sardine stock recovered (Crawford 1998, Crawford *et al.* 2001). From 1987–1997, the estimated annual rates of decrease of penguins at Dyer Island were from 10–20% (Table 2). It is likely that many of the penguins that fledged at the island did not return to breed there. The rates of increase in the populations at Boulders and Robben Island were far larger than could be achieved by the breeding productivity of the resident penguins alone (Crawford *et al.* 1999, 2000b). Supplementation of these populations and that at Stony Point by emigration of young birds from Dyer Island has been demonstrated (Crawford *et al.* 1995a, 1999, 2001, Whittington *et al.* 1996). Young penguins from Dyer Island also emigrated to breed at Seal, Dassen and Vondeling islands (Whittington *et al.* 2005a). Of 3 212 fledglings that were flipper-banded on Dyer Island between 1978 and 1995, 29 had been recorded breeding at other islands by 1999, a larger proportion than from any other colony with more than 250 fledglings banded (Whittington *et al.* 2005a).

Influence of oiling

The *Apollo Sea* oil spill in June 1994 resulted in the loss of approximately 5 000 African penguins, mostly breeding adults (Underhill *et al.* 1999). An additional 2 000 were killed in the *Treasure* oil spill in 2000 (Crawford *et al.* 2000a). These birds were mostly from Robben and Dassen islands. In both these spills, large numbers of orphaned chicks died at the two islands. At Robben Island in 2000, an estimated 4 000 chicks died and a further 3 000 were collected for captive rearing (Crawford *et al.* 2000a). In the longer term, the cumulative loss of the remaining lifetime reproductive output of penguins killed as a result of oil spills also adversely impacts the population. Assuming that 2 000 adult penguins (1 000 pairs) produce

on average 520 chicks per year (based on the midpoint of the range 0.37–0.67 chicks pair⁻¹ year⁻¹ — Hockey *et al.* 2005), the loss of productivity from these birds in the first year following a spill is 520 fledged chicks, if all adults breed. If the average adult survival rate is 81% (Whittington 2002), the loss in the second year would be $0.81 \times 520 = 421$ and in the third year $0.81^2 \times 520 = 341$, etc. These figures form a geometric progression, which sums to a total of 2 700 fledglings.

There has been ongoing oiling of penguins at Dyer Island. An oil spill following the sinking of *Esso Wheeling* in November 1948 was estimated to have killed one-third of the Dyer Island population (Kruger 1949). This was prior to the establishment of the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) in 1968. At that time, there was no known treatment for oiled penguins. Substantial numbers of penguins continue to be oiled at the island (CapeNature, unpublished data). For example, during July and September 1995, 1 332 penguins were admitted to SANCCOB after being oiled in the area (Underhill *et al.* 1999). In 2001 and 2002, years without major oil spills, the percentages of oiled penguins admitted to SANCCOB from Dyer Island were 24% (91 out of 383 oiled penguins) and 35% (212 out of 608) respectively (Parsons and Underhill 2005). Oiled birds arrive at Dyer Island in poor condition, dehydrated and emaciated (Parsons and Underhill 2005). Adams (1994) suggested that currents around Dyer Island result in onshore advection, such that oil spilled offshore is moved shoreward and entrained in the region by an anticyclonic eddy, within the foraging range of penguins from the island. An alternative explanation for the disproportionate numbers of penguins oiled at Dyer Island is that oil is bubbling up on an ongoing basis from an unknown wreck in the neighbourhood of the island. Penguins from other breeding colonies also forage in the seas around Dyer Island and a number, particularly from Dassen Island, have been found oiled there (Whittington *et al.* 2005b). Penguins, once oiled, tend to make a landfall at the nearest colony (Underhill *et al.* 1999).

Influence of other factors

The northernmost colony at Lambert's Bay was probably stable at a low level until 1998. Towards the end of 1998, penguins were displaced from buildings that were renovated. This led to a decrease in numbers breeding from 1999 to 2002. A bird hide was constructed in 1998, but in subsequent years strong seas damaged the hide. In 2000, dolosse were placed adjacent to the hide to give it added protection. This provided additional breeding habitat for penguins, which nested under the dolosse in 2003, leading to an increase in numbers then breeding at the island. However, the increase was of short duration, with numbers decreasing again in 2005. Seal predation on penguins at Lambert's Bay is thought to be unsustainable (Crawford *et al.* 2001). In recent years, seals have hauled out on Bird Island, Lambert's Bay, in increasing numbers, and in 2005 they caused a major disturbance to the Cape gannet *Morus capensis* colony at the island. Construction of a breakwater between the

island and the mainland, to improve the harbour, has permitted access by terrestrial predators.

At Dyer Island, Cape fur seals killed 9% of the penguins during the mid-1990s (Marks *et al.* 1997). This predation has continued (LJ Waller, CapeNature, *in litt.*, AB Makhado, Marine and Coastal Management, *in litt.*). Stony Point was the only small colony (<100 pairs in 1987) at which the breeding population increased. However, its rate of growth was slower than that at the other two colonies initiated in the early 1980s. Penguins at Stony Point have been subjected to ongoing predation by terrestrial carnivores and have relatively low productivity (Whittington *et al.* 1996). Both these factors have limited growth of the colony. Losses to predation caused the decrease in this colony from 1990 to 1993 (Whittington *et al.* 1996).

The mainland colony at Boulders, which falls within a suburban and recreational area, is space limited as a result of policy decisions (Crawford *et al.* 2000b).

Importance and management of smaller colonies

It is of conservation importance to note the extent to which a large proportion of the African penguin population of the Western Cape is usually concentrated at only a few colonies. For example, in 1956, 79% of the breeding population in the Western Cape was at Dassen Island. In 1979, 85% was at two colonies: Dyer Island (55%) and Dassen Island (30%). Averaged over 2004 and 2005, the Dassen Island colony held 65%, and the Robben Island colony, which did not exist in 1956, held 21% of the population, so that 86% of the breeding population in the Western Cape was at these two colonies. Given the vulnerability to oiling incidents of these two islands, which lie along shipping routes into Table Bay and Saldanha Bay, an obvious objective for management of the species is to encourage growth of the new colony in the De Hoop Nature Reserve and at the six smaller colonies that do not lie close to major ports: Lambert's Bay (although adjacent to a small harbour serving the diamond mining and fishing industries), Boulders (although adjacent to the Simon's Town naval base), Seal Island, Stony Point, Geyser Rock and Dyer Island.

Further, on account of long-term emigration of first-time breeders away from colonies where conditions are unfavourable at the time (Crawford *et al.* 2001), it is essential to ensure the continued existence of the smaller colonies so that they can act as foci of growth should conditions in their vicinity again become favourable for breeding. The colony at Lambert's Bay may be particularly important because it is well separated from other colonies to the north (Namibia) and south (Saldanha Bay), yet occurs in a nursery area for sardine and anchovy (Crawford 1998). It will be necessary to control predation by terrestrial predators and seals at that locality. However, even then the penguin population there is so small (10 breeding pairs in 2005 — Table 1) that it will be several years before breeding productivity at the island can make a meaningful difference to the overall population in the Western Cape. Furthermore, the small size of the population increases its vulnerability to stochastic events, such as oil spills, highlighting the tenuous future of that colony. Immigration of birds hatched at other colonies might occur,

as has happened elsewhere (Whittington 2002), but cannot be depended upon.

One experimental option to boost the colony is to use Lambert's Bay as the preferred release point for 'orphan' penguin chicks raised at SANCCOB. Orphan chicks occur in large numbers after oil spills, when one or both parents become oiled, and the chick is left in the nest (Crawford *et al.* 2000a). Some orphan chicks occur in mid-summer every year, when adults with late broods desert their chicks after initiating their moult. For example, deserted chicks at Robben Island are collected annually in December, and taken to SANCCOB to be reared in captivity. It has been established that the return rate to breed of these orphan chicks does not differ from that of naturally-reared chicks (Whittington 2002). It is not known whether orphaned chicks will return to their natal colony or their release point to breed. A possible experiment to investigate this would be to keep fledgling penguins at Lambert's Bay for varying periods and compare proportions from different treatments that return to that locality. Release of orphaned chicks at Lambert's Bay cannot be undertaken prior to implementing effective control there of predation by seals and terrestrial predators.

The new breeding site at the De Hoop Nature Reserve is strategically positioned to the east of existing colonies in the Western Cape. It helps to bridge the 600km gap between Dyer Island and the colonies in Algoa Bay, Eastern Cape Province. It is distant from any centres of seal abundance. We recommend that resources be allocated to nurturing this new breeding site, especially given the recent eastward shift in the distribution of sardine.

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Appendix: The algorithm used to estimate the rate of change of penguin colonies

Let x_1, x_2, \dots, x_{19} be the counts at a single colony over the 19-year study period. Let $y_j = \log x_j$, $j = 1, 2, \dots, 19$. The following algorithm was used to estimate the (local) rate of increase for the target year k . Let the weight attached to year j be $w_j = \exp(-((k-j)/\sigma)^2)$ where σ , the smoothing parameter, was taken to be 2. Calculate the weighted linear regression of y_j on j using w_j as weights. From the estimated regression coefficients, calculate the predicted rate of increase for year k . Repeat this for each year from Year 1 to Year 19. The choice of $\sigma = 2$ ensures that the weights attached to years decrease rapidly on either side of the target year, which has weight 1. The years on each side of the target year both have weight 0.78, the years at two years from the target year have weights 0.37, and at three years distant, the weights are 0.11. At four years distant, the weights are a negligible 0.018, and become inconsequential small thereafter. The weighted regression is therefore based almost entirely on the data from the target year and three years on either side of this, with the third years having only 11% of the weight of the target year in the analysis.
