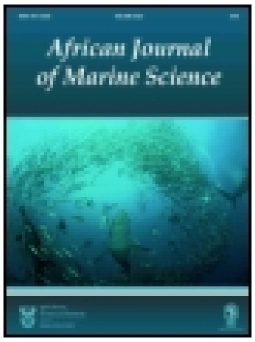

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Impact of flipper-banding on breeding success of African penguins *Spheniscus demersus* at Robben Island: comparisons among silicone rubber bands, stainless-steel bands and no bands

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From 2001 to 2006, two new designs of flipper bands made from silicone rubbers were tested on African penguins *Spheniscus demersus* at 365 nests on Robben Island, South Africa. We compared, over six years, the breeding success, from hatching to fledging, of three different groups of penguins: those with rubber bands (117 nests), with conventional stainless-steel bands (103 nests) and without bands (145 nests). There were no significant differences in breeding success between the three groups, suggesting that neither the currently used steel bands, nor either of the new rubber-band designs, were harmful during the seasons investigated. The rubber bands caused less wear of feathers and less drag on a model penguin than the steel bands. In captivity, the behaviours of African penguins fitted with rubber bands were not noticeably different to those of unbanded birds.

Keywords: African penguin, behaviour, effects of flipper-banding, drag, fledging success, silicone rubber, *Spheniscus demersus*, stainless steel

Introduction

Demographic studies of birds have relied, to a large extent, on the use of numbered metal rings since Hans Mortensen's pioneering development of the aluminium bird ring in 1899 (Jenni 2001). The most commonly used rings are made from metal alloys and are fixed around the bird's leg. However, in the case of penguins, leg rings are generally felt to be unsatisfactory as they cause injuries, are not visible on nesting birds and are difficult to read in the field (Renner and Davis 2000). Accordingly, since the 1960s, nearly all studies have used stainless-steel flipper bands (Sladen 1958, Cooper and Morant 1981).

The use of metal flipper bands has been suggested to be a potential hazard to penguins (Jackson and Wilson 2002, Petersen *et al*. 2005). For example, in the extreme case, it was claimed that one design of flipper band increased hydrodynamic drag, leading to an increase in energy used while swimming exceeding 20% in Adélie penguins *Pygoscelis adeliae* (Culik *et al*. 1993). Observations of Adélie, chinstrap *Pygoscelis antarctica* and gentoo *Pygoscelis papua* penguins on the Antarctic Peninsula indicated that flipper-banded birds had a reduced annual return rate to their colonies (Trivelpiece and Trivelpiece 1994). A detailed study on king penguins *Aptenodytes patagonicus* showed that banding resulted in birds arriving at the breeding site later than unbanded birds, and that banded birds had lower breeding success than unbanded birds (Gauthier-Clerc *et al*. 2004). A study of Adélie penguins found that flipper bands decreased apparent annual survival in the years 2000–2003, but over a longer time period (1996–2003), there was a high annual variability, including years of high survival for banded birds (Dugger *et al*. 2006). To the authors' knowledge, there are no published studies that have demonstrated a negative impact of flipper bands on any of the four species of *Spheniscus* penguins.

Two workshops have concluded that there is a real and pressing need for alternatives to the present steel flipper bands used to mark penguins (Fraser and Trivelpiece 1994, Fraser 1997). The more recent one resolved that band design could be improved by using modern materials technology (Fraser 1997).

Transponders are considered to ameliorate most of the detrimental effects of flipper banding (e.g. Renner and Davis 2000). However, research on their effects on penguins (e.g. migration within the body of the penguin) is still in progress (Clarke and Kerry 1998). Furthermore, transponders are not suitable for many types of study (Renner and Davis 2000). For the African penguin *Spheniscus demersus*, and for other species, a great deal is learnt from reports of sightings by the public and from bands returned from dead birds that are washed up on the shores. This information can only come from birds that are clearly wearing an external marker. A second disadvantage of transponders is that they have a limited range. With present technology, a bird needs to pass within c. 1 m of a detector before the transponder will be registered. Unless fences are placed so that penguins are forced to pass a particular location, data are recorded sporadically. This problem is particularly acute with the African penguin, because at many colonies there are no habitually used narrow path routes between the shore and the nest site (RJMC pers. obs.).

Of the world's 17 species of penguins, three species are Endangered, seven are Vulnerable, two are Near Threatened and five are Least Concern (Ellis *et al*. 2007, Boersma 2008). The poor conservation status of most penguin species makes it imperative to conduct conservation-oriented research. In many contexts, this can be achieved using suitable bands to identify individual birds throughout their lives. Suitable bands have not yet been satisfactorily designed and field-tested. Large proportions of the population of African penguins have been significantly affected twice in recent years by oil spills — in 1994 and 2000 — (Underhill *et al*. 1999, Crawford *et al*. 2000). For example, at the end of the *Treasure* oil spill rescue operation in 2000, more than 10% of the global population of African penguins had at one time or another been de-oiled (Crawford *et al*. 2000). The likelihood of further such events in the future highlights the need for detailed knowledge of survival rates and overall breeding productivity of African penguins. In particular, future conservation planning will rely on knowledge of the subsequent breeding success and survival rates of birds that have been de-oiled. If the survival rate and breeding productivity of this large sector of the population differs substantially from those of never-oiled birds, models of population dynamics will be biased. Furthermore, a recent eastward shift of prey, possibly driven by climate (Crawford *et al*. 2008b), caused a substantial mismatch in the distributions of the breeding localities and prey of African penguins (Crawford *et al*. 2008c). An understanding of the responses of penguins to such events is necessary to mitigate their impact (e.g. Crawford *et al*. 2008a), and requires the ability individually to identify large numbers of birds over an extended period. The same is the case with assessment of management interventions, such as the relocation of birds to prevent their becoming oiled (Barham *et al*. 2006).

Stonehouse (1999) suggested the use of plastics to design a new generation of flipper bands. This paper reports on two silicone rubber bands designed in response to this suggestion (Barham 1999). It compares the fledging success at Robben Island of African penguins that were unbanded, or fitted with rubber and stainless-steel bands, and reports the behaviour of captive penguins that were fitted with rubber bands.

Material and Methods

Band designs

A number of possible materials were considered for flipper bands. The principal criteria were that the material should be completely inert, should be softer than penguin feathers and should be sufficiently elastic so that the bands could be fitted simply by stretching them and sliding them over a penguin's flipper. We chose a silicone rubber (specifically Dow Corning 'Silastic P-1' range of silicone rubbers), because it is non-toxic, has high strength, is highly elastic, is UV resistant and should have a lifetime greater than 50 years with no appreciable deterioration of properties.

In the first design (Figure 1a), tested in 2001 and 2002, we were particularly concerned to reduce the hydrodynamic drag caused by the band. The design was tested initially on a model penguin in a water tank. The model was made so that the flippers were extended and did not move. We found that, provided the model was moved forward at a speed >0.8 m s^{-1}, the band was pushed up against the body and it was sufficiently flexible to adopt the shape of the body.

The design was fundamentally different from conventional bands. This band was intended to fit closely to the penguin's body and to sit perpendicular to the plane of the flipper with a thin, flexible sleeve to help hold it in place. The band was designed so that it should remain parallel to the body of a swimming penguin and lie along the streamlines, minimising drag. The band was shaped to form a partial aerofoil which kept it pressed against the body of the swimming penguin. However, the design was ultimately rejected because it was discovered that, on rare occasions, it turned upside down, resulting in a large increase in drag.

The second design (Figure 1b), tested during the period 2003–2006, was similar to that of conventional bands, except that it had an additional thin strip of rubber that pressed gently against the flipper so as to hold the band steady, but still allow for expansion. In the test tank, we found that this internal 'spring' effectively prevented vibration of the bands, which otherwise occurred at speeds in excess of c. 0.2 m s^{-1}. This design was less streamlined than the first design, but remained in the correct position and the soft silicone rubber substantially reduced the possibility of feather wear.

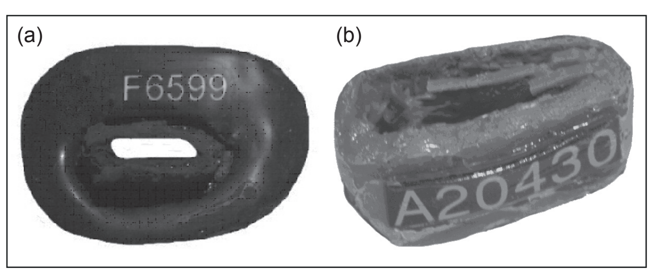

Figure 1: Examples of silicone rubber flipper bands: (a) band designed to fit close to the body of the penguin and thus reduce drag; (b) band designed to fit around the flipper in the same way as a conventional steel band

In both designs, the identification numbers were larger than those engraved on conventional steel bands, and were printed in yellow on a black background and laminated with a 0.2 mm thick film of transparent silicone rubber to ensure they would not wear. The new bands could be read more easily and at much greater distances than conventional bands. Using a typical spotting telescope (with magnifications 20–40×), an experienced observer can read conventional bands on penguins to a distance of 70 m, depending on the light conditions; both of the new designs can be read on penguins to a distance of 120 m.

Hydrodynamic drag

A simple model system was used to estimate the drag that bands of different types might cause. The bands investigated were the initial and later versions of the rubber band and the conventional steel band. Drag was also investigated for steel bands when the gap between the flipper and the band was filled with foam. An idealised model of an African penguin was made by turning a piece of wood to have a rotationally symmetric shape similar to that of a penguin and weighted to have neutral buoyancy in water. Model flippers (with the shape and size taken from measurements of real African penguins) were fixed to the model perpendicularly to the surface. This model penguin was mounted on a gantry so that the flippers were in a horizontal plane and dragged through a large (c. 30 m long × 4.2 m wide × 1.8 m deep) water-filled tank. The model was pulled along the gantry using an electric motor and the force on the penguin was measured using strain gauges in the mounting arm. Once the penguin had been accelerated and was moving at a constant speed, the average force required to keep it moving was measured over at least three separate runs of at least 5 m length, each over a range of speeds from 0.1 m s^{-1} to 5 m s^{-1}).

Measurements of the drag force on the penguin indicated that the flow was approximately laminar at low speeds (at 0.1 m s^{-1}, with the Reynolds number just over 5 000) and started to become turbulent at higher speeds (at 2 m s^{-1}, with the Reynolds number well over 10^5). The drag coefficient (C_d) of the model tended to 0.041 at speeds above 1 m s^{-1}.

The 'drag' caused by a band was recorded as the fractional increase in force needed to keep the model penguin moving at the chosen speed when it was fitted with the band. These quasi-static measurements were not accurate representations of what happens when a real penguin is swimming. For example, the flippers did not move relative to the body. However, the measurements are of value in that they enabled us to reject band designs that showed an increase in 'drag' greater than that of a steel band.

Zoo tests

Before the bands were used in the field on wild birds, they were tested on African penguins in Bristol Zoo Gardens (Bertram 2003). Birds wearing the bands were observed before and after the bands were fitted to determine whether there were any changes in their behaviour. Behaviour was assessed by time spent preening or swimming, and whether or not they pulled at or otherwise appeared to notice the bands. Penguins were monitored for 15-minute intervals each hour from dawn to dusk (approximately three hours per day), for one week before and two weeks after fitting with the bands.

Breeding productivity

From 2001 and 2006, we monitored the breeding success of African penguins at a number of nests on Robben Island, off the west coast of South Africa (33°46′ S 18°22′ E). Each year, nests with eggs were selected near the start of the peak breeding season (mainly in March and April, the austral autumn). To minimise additional disturbance, nests were selected in areas that were already receiving some disturbance from occasional movement of people through the colony. The results reported here form one aspect of a larger study, which compared the breeding success of birds that were oiled in the *Treasure* spill in 2000 with those that were not. Penguins oiled in the *Treasure* spill had poorer breeding productivity than un-oiled birds (Barham *et al*. 2007) and were therefore excluded from this paper. Because virtually all de-oiled penguins released after the *Treasure* spill were banded, it can thus be assumed that an unbanded penguin had not been de-oiled.

During periods of hot weather, African penguins are prone to abandon their nests (Randall 1983, Crawford *et al*. 1995). This happened to a large proportion of nests early in the breeding season in 2001. In 2002, a major winter storm led to flooding of a significant proportion of the nests under study. In both cases, the nest losses were due to climatic conditions, so these nests were excluded from the study. Including nests where abandonment can be directly attributed to a natural cause would make any effects due purely to bands more difficult to detect statistically. Some nests were abandoned shortly after identification. The disturbance caused by the visits of the researchers may have been a contributory factor, so such nests were omitted from the study.

The nests were monitored at regular intervals, normally once every four days, but sometimes at longer intervals of up to two weeks. Monitoring of nests started early in the breeding cycle. We report here on results of individual chicks from hatching to death or fledging. This is the period during which foraging demands on parents are greatest, and during which the impacts of flipper banding on breeding success should be most evident. We checked the nest contents, noting hatching date and the approximate size of chicks. Ultimately, many surviving chicks joined crèches and so could not be identified individually. We did not flipper-band chicks. Chicks were assumed to have fledged if they had grown to at least three-quarters of adult size.

The breeding attempts reported here refer to three groups of nests: (1) steel-banded group — both adults were already banded with steel flipper bands and neither had been oiled in the *Treasure* spill; (2) unbanded group — neither adults was banded; (3) rubber-banded group — neither bird was originally banded and both were fitted with rubber bands, either of the first (used in 2001 and 2002) or second (2003–2006) design. Nests with both adults unbanded were assigned randomly to Group 2 or Group 3. To reduce the risk of desertion, most birds in Group 3 were banded one or two weeks after their eggs had hatched. The data for Groups 1 and 2 from the first five of the six years reported here were two of the three groups used to compare the success of oiled *Treasure* birds with those that were not oiled in the spill (Barham *et al*. 2007).

Return of banded birds

Unlike Adélie, chinstrap, gentoo and king penguins, African penguins do not migrate away from their colony. Although they are absent between breeding attempts and before and after moult, they are frequently present within their colony for extended periods. Thus, it was not feasible to determine whether or not banded birds started to breed later than unbanded ones, which were not individually identifiable. We attempted to measure whether or not the type of band affected the time when African penguins returned to their nests to breed, and also to estimate overall return rates, by searching out those birds that had been in the previous year's study at the start of the next year's study. These observations were made between the 2004 and 2005 breeding seasons and between the 2005 and 2006 breeding seasons. In previous years, we had removed the rubber bands at the end of the breeding season to carry out laboratory tests on them.

At the start of the 2005 and 2006 seasons we revisited the nest sites of most of the birds in the steel-banded and rubber-banded groups from the previous year, excluding those nests from the rubber-banded group in which the bands were removed for laboratory testing of the longevity of the bands. Some nest sites had been destroyed and others could not be found. The nests sites were visited on at least three occasions during late March and early April to determine whether or not birds had returned. Additionally, all nests within 10 m of the original nest were examined, in case the birds had not returned to their previous year's nest but to a different site close by. African penguins at Robben Island are not as faithful to nest sites as at some other colonies (Crawford *et al*. 1995).

Results

Hydrodynamic drag

All band designs showed an increase in the force needed to move the model penguin through the tank. For all but the initial, 'hydrodynamic', rubber-band design, the increase in force relative to an unbanded penguin increased with the speed at which the model penguin was dragged through the water (Figure 2).

The greatest drag occurred when the model was fitted with a conventional steel band, which increased the force by 8–14%. It was noticed that the steel band vibrated on the flipper, particularly as the speed increased above 1 m s^{-1}. When the gap between the flipper and the band was filled with foam rubber to prevent this vibration, the drag was reduced considerably (Figure 2).

The drag from the initial 'hydrodynamic' rubber-band design was similar to that of the steel band at low speeds (up to 0.3 m s^{-1}), but then decreased as the band flattened against the body of the model penguin, so that no increase

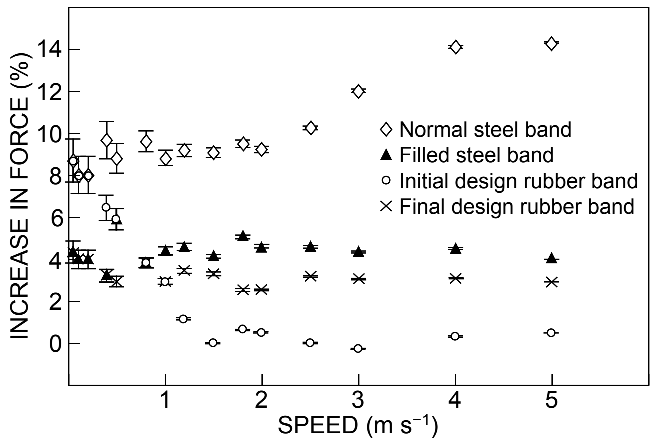

Figure 2: Percentage increase in the force (*N*) required to drag a model African penguin, wearing a flipper band, through water, compared to the same model with no band attached, as a function of the speed at which the model is moved. Error bars denote ±SE

in drag could be measured at speeds above 2 m s^{-1} (Figure 2). The drag from second design of rubber band was lower than that of the initial design for speeds up to 1 m s^{-1}, but then increased to just below that of the steel band filled with foam rubber (Figure 2).

Zoo tests

There were no behavioural changes before and after penguins were fitted with rubber bands. In all, 21 penguins were observed for a total of approximately nine hours each, three hours prior to the fitting of bands and six hours afterwards. Nine birds were fitted with bands of the initial design and 12 with bands of the second design. Before banding with the initial band design, the average proportion of time spent swimming was 17.1% and after banding it was 17.3%. The average proportion of time spent preening was 8.2% before banding and 8.1% after banding. Of the nine birds banded with the initial band design, two were observed to pull at the bands; one did so for one day and the other for one week. Before banding with the second band design, the average proportion of time spent swimming was 15.2% and after banding it was 16.1%; the average proportion of time spent preening was 8.9% before banding and 8.5% after banding. Of the 12 birds banded with the second band design, three were observed to pull at the bands; two did so only during the first day after banding, whereas the other continued to peck at its band for up to two weeks.

In the longer term, penguins fitted with the second design of rubber bands exhibited little or no feather wear. However, those fitted with conventional steel flipper bands showed worn body feathers adjacent to the band and occasionally showed damage to the leading edge of the flippers.

Breeding productivity

In all, 365 nests with hatchlings were studied: 103 nests in the steel-banded group, 145 in the unbanded group and 117 in the rubber-banded group. At 34 nests, the initial band

Table 1: Numbers (*n*) and frequency (%) of nests with different patterns of fledging success for the three groups of African penguins monitored on Robben Island, 2001–2006

Group	1 hatchling, 0 fledgling		1 hatchling, 1 fledgling		2 hatchlings, 0 fledgling		2 hatchlings, 1 fledgling		2 hatchlings, 2 fledglings		Total nests
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	
2001											
Steel-banded	0	0	4	33	3	25	1	8	4	33	12
Unbanded	0	0	0	0	0	0	1	25	3	75	4
Rubber-banded 1	7	28	10	40	1	4	1	4	6	24	25
2002											
Steel-banded	1	9	2	18	2	18	1	9	5	46	11
Unbanded	0	0	4	36	2	18	1	9	4	36	11
Rubber-banded 1	2	22	2	22	1	11	1	11	3	33	9
2003											
Steel-banded	2	9	8	36	6	27	1	5	5	23	22
Unbanded	11	38	6	21	7	24	1	3	4	14	29
Rubber-banded 2	6	26	4	17	3	13	5	22	5	22	23
2004											
Steel-banded	9	36	6	24	3	12	0	0	7	28	25
Unbanded	4	18	5	23	4	18	2	9	7	32	22
Rubber-banded 2	3	15	9	45	1	5	1	5	6	30	20
2005											
Steel-banded	0	0	0	9	0	0	2	67	1	33	3
Unbanded	5	12	11	28	3	8	5	12	16	40	40
Rubber-banded 2	1	7	3	21	2	14	2	13	6	43	14
2006											
Steel-banded	3	10	8	27	2	7	4	13	13	43	30
Unbanded	4	10	9	23	5	13	6	15	15	38	39
Rubber-banded 2	4	15	6	23	3	12	2	6	11	42	26
Overall											
Steel-banded	15	15	28	27	16	16	9	9	35	34	103
Unbanded	24	17	35	24	21	14	16	11	49	34	145
Rubber-banded	23	20	34	29	11	9	12	10	37	32	117
Total	62	17	97	27	48	13	37	10	121	33	365

design was used and the second design was used at 83 nests (Table 1). The number of nests monitored each year varied between 31 and 95. The total number of hatchlings that were followed to success or death was 571: 163 from the steel-banded group, 231 from the unbanded group, and 177 from the rubber-banded group (47 and 130 at nests with the first and second designs respectively).

In the nests selected for the study, the proportions of broods with a single hatchling were similar in the three groups: 42% (43 of 103) in the steel-banded group, 41% (59 of 145) in the unbanded group and 49% (57 of 117) in the rubber-banded group. These differences were not statistically significant (χ^2 = 1.89, df = 2, p = 0.389). Overall, the proportion of hatchlings that fledged in broods that consisted of a single hatchling was 61% (97 fledglings from 159 nests, with one hatchling) and in broods with two hatchlings was 68% (279 fledglings from 206 nests, with two hatchlings). The difference was not significant (χ^2 = 2.30, df = 1, p = 0.132), but the trend is opposite to that predicted if brood reduction had occurred. We therefore did not consider single-chick and two-chick broods separately.

Overall fledging success across the six years of the study was 66% in the steel-banded group, 64% in the unbanded group and 68% in the rubber-banded group (and 68% for both designs) (Tables 1, 2). A generalised linear model with binomial distribution and logistic link function performed on the data in Table 2 suggested that, although there were between-year differences (change in deviance from a model with only a constant term = 4.35, df = 5, p < 0.001), there was no difference in fledging success between the three groups (change of deviance = 1.05, df = 2, p = 0.59). Fledging success was lowest in 2003, whereas the remaining years showed similar breeding productivity (Table 3).

At successful nests, the median fledging period in the rubber-banded group was 61 days (range 49–78, quartiles 55 and 65, n = 61); in the unbanded and steel-banded groups the fledging periods were 59 (range 49–76, quartiles 55 and 64, n = 69) and 57 (range 47–76, quartiles 54 and 63, n = 47) days respectively. The fledging periods of the chicks in the three groups did not differ (Kruskal-Wallis H = 2.30, p = 0.32).

Return of banded birds

In 2004, 16 penguins from 12 nests in the rubber-banded group did not have their bands removed and in 2005, 34 rubber-banded penguins from 18 nests remained banded. In 2004, there were 28 steel-banded birds from 14 nests and in 2006 there were six from three nests. In addition, there were 23 nests in 2005 in which one bird had a steel band (but had not been oiled in the *Treasure* spill) and the other was unbanded.

Table 2: Comparison of fledging success between the three groups of African penguins on Robben Island, 2001–2006. Fledging success is expressed as the percentage of eggs which hatched that produced fledglings

Year	Steel-banded group			Unbanded group			Rubber-banded group			Overall
	Hatched	Fledged	%	Hatched	Fledged	%	Hatched	Fledged	%	%
2001	20	13	65	8	7	88	33	23	70	70
2002	19	13	68	18	13	72	14	9	64	69
2003	34	19	56	41	15	37	36	19	53	48
2004	35	20	57	35	21	60	28	22	79	64
2005	6	4	67	64	48	75	24	17	71	73
2006	49	38	78	65	45	69	42	30	71	72
Total	163	107	66	231	149	64	177	93	68	66

Table 3: Results of the generalised linear model relating band group effect and year effect to fledging success of African penguin chicks at Robben Island: logit(fledging probability) = C + Band group effect + Year effect. Effects are relative to year 2001 and unbanded

Parameter	Parameter estimate	Standard error	t_{10}	p
C	0.702	0.326	2.15	0.031
Year 2002	–0.035	0.416	–0.09	0.932
Year 2003	–0.911	0.343	–2.66	0.008
Year 2004	–0.233	0.355	–0.65	0.516
Year 2005	0.249	0.381	0.65	0.513
Year 2006	0.159	0.339	0.47	0.640
Rubber-banded	0.221	0.223	0.99	0.321
Steel-banded	0.153	0.228	0.67	0.501

Table 4: Numbers of African penguins on Robben Island in the different groups that returned to the nest at which they bred in the previous year by early April the following year

Group	Number of birds nesting in 2004 for which we searched in 2005	Number seen at nest in 2005	Number of birds nesting in 2005 for which we searched in 2006	Number seen at nest in 2006	Total number for which we searched	Number of birds nesting in the previous year seen back at nest by mid-April
Rubber-banded	16	4	34	8	50	12
Steel-banded (not oiled in *Treasure* spill)	28	6	6	2	34	8

Of the 50 rubber-banded penguins, eight returned to their nest sites and four to nearby nests by mid-April, early in the following breeding season; a return rate of 24% (Table 4). Three additional rubber-banded birds were found later in the breeding season at, or close to, their nest sites of the previous year. In 2006, three birds that had been rubber-banded in 2004 (but were not observed in 2005) were found at or near their 2004 nests early in the season.

Similarly, of the 34 steel-banded birds for which we searched, six were at their nest sites of the previous year and two nearby by mid-April; a return rate of 23.5% (Table 4). At the 23 study nests from 2005 with one banded bird, we found five nests in 2006 in which the original banded bird was partnered by an unbanded bird, suggesting a return rate of 22% for unbanded birds. Hence, the return rates of birds banded with rubber and metal bands was similar.

Discussion

None of our observations indicated that penguins fitted with the new design of rubber bands behaved differently from birds fitted with conventional steel bands, or indeed to birds without bands. Birds in the steel-banded group were not banded for this study, but had been banded previously. Thus, these birds may have 'adapted' to wearing bands and we cannot assess whether there is any immediate, initial impact of the fitting of steel bands.

Penguins in the rubber-banded group were handled in order to fit the flipper bands, which took place when they had small chicks. Birds in the unbanded group were not handled. Because no significant differences in breeding productivity were found between these two groups, it is concluded that stress related to the flipper-banding event was inconsequential at the colony scale.

The type of nest may affect breeding success (Seddon and van Heezik 1991). All the groups contained nests of several different types, e.g. burrows, open scrapes, scrapes under bushes providing good shade, and nests in man-made structures. The sample sizes for the various nest types were too small to attribute any significance to variations in breeding success for each group at different nest types. However, because the mix of nest types was similar for all the groups, it is considered that any effect of nest type on breeding success would not affect the overall conclusions.

Because chicks were not flipper-banded, we assumed they fledged if they moved into a crèche and had grown to at least three quarters of adult size. This is a potential source of bias. However, food requirements of chicks peak at about 40 days (Cooper 1977), when most chicks were still being monitored. Therefore, it is unlikely that crèched chicks from banded parents have a lower fledging rate than those of unbanded parents.

In summary, in captivity, birds fitted with rubber bands did not behave differently to those that were not banded. In the wild, the banding of breeding African penguins with steel and rubber bands did not influence their fledging success over six years. Further, the return rate to the colony of banded and unbanded birds appeared to be similar. Therefore, banding, whether with rubber or stainless-steel bands, was not detrimental to breeding by African penguins at Robben Island. Rubber bands have some advantages over steel bands. There is less feather wear, they are easier to read and they have less drag. Additionally, the rubber bands cannot open, so that birds wearing them cannot become snagged, e.g. by fishing line. If the rubber breaks, the band will fall off. The rubber bands we tested also have flexibility to expand, so they are unlikely to restrict blood flow, as stainless-steel bands that are fitted too tight may, e.g. when the flipper expands during moult. However, properly constructed and fitted steel bands have great longevity (Whittington *et al*. 2000). This has not yet been demonstrated in the field for the rubber bands but the design for rubber bands that will permit such testing is now satisfactory.

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References

Barham PJ (1999) Design of plastic flipper bands for penguins. *Penguin Conservation* **12**: 4–10

Barham PJ, Crawford RJM, Underhill LG, Wolfaardt AC, Barham BJ, Dyer BM, Leshoro TM, Meÿer MA, Navarro RA, Oschadleus D, Upfold L, Whittington PA, Williams AJ (2006) Return to Robben Island of African penguins that were rehabilitated, relocated or reared in captivity following the *Treasure* oil spill of 2000. *Ostrich* **77**: 202–209

Barham PJ, Underhill LG, Crawford RJM, Leshoro TM (2007) Differences in breeding success between African penguins (*Spheniscus demersus*) that were and were not oiled in the MV *Treasure* oil-spill in 2000. *Emu* **107**: 7–13

Bertram B (2003) Bristol Zoo Gardens: seal and penguin coast. ZooLex Zoo Design Organization, Vienna. http://www.zoolex.org/zoolexcgi/view.py?id=569

Boersma DP (2008) Penguins as marine sentinels. *BioScience* **58**: 597–607

Clarke J, Kerry K (1998) Implanted transponders in penguins: implantation, reliability, and long-term effects. *Journal of Field Ornithology* **69**: 149–159

Cooper J (1977) Energetic requirements for growth of the jackass penguin. *Zoologica Africana* **12**: 201–213

Cooper J, Morant PD (1981) The design of stainless-steel flipper bands for penguins. *Ostrich* **52**: 119–123

Crawford RJM, Boonstra HGvD, Dyer BM, Upfold L (1995) Recolonization of Robben Island by African penguins, 1983–1992. In: Dann P, Norman I, Reilly P (eds) *The Penguins: Ecology and Management*. Surrey Beatty, Chipping Norton, Australia, pp 333–363

Crawford RJM, Davis SA, Harding R, Jackson LF, Leshoro TM, Meÿer MA, Randall RM, Underhill LG, Upfold L, van Dalsen AP, van der Merwe E, Whittington PA, Williams AJ, Wolfaardt AC (2000) Initial impact of the *Treasure* oil spill on seabirds off western South Africa. *South African Journal of Marine Science* **22**: 157–176

Crawford RJM, Sabarros PS, Fairweather T, Underhill LG, Wolfaardt AC (2008a) Implications for seabirds of a long-term change in the distribution of sardine. *African Journal of Marine Science* **30**(1): 177–184

Crawford RJM, Tree AJ, Whittington PA, Visagie J, Upfold L, Roxburg KJ, Martin AP, Dyer BM (2008b) Recent distributional changes of seabirds in South Africa: is climate having an impact? *African Journal of Marine Science* **30**(1): 189–193

Crawford RJM, Underhill LG, Coetzee JC, Fairweather T, Shannon LJ, Wolfaardt AC (2008c) Influences of the abundance and distribution of prey on African penguins *Spheniscus demersus* off western South Africa. *African Journal of Marine Science* **30**(1): 167–175

Culik BM, Wilson RP, Bannasch R (1993) Flipper-bands on penguins – what is the cost of a life-long commitment? *Marine Ecology Progress Series* **98**: 209–214

Dugger KM, Ballard G, Ainley DG, Barton KJ (2006) Effects of flipper bands on foraging behavior and survival of Adélie penguins (*Pygoscelis adeliae*). *Auk* **123**: 858–869

Ellis S, Woehler EJ, Skewgar E, Boersma PD (2007) *Penguin Conservation Assessment: Summary Document*. IUCN/SSS Conservation Breeding Specialist Group, Apple Valley, Minnesota

Fraser WR (1997) Penguin marking techniques: a summary of SCAR-BBS workshop. *Penguin Conservation* **10**: 9–12

Fraser WR, Trivelpiece WZ (eds) (1994) *Report: Workshop on Seabird-Researcher Interactions, July 15–17, Monticello, Minnesota, USA*. Office of Polar Programs, Washington, DC

Gauthier-Clerc M, Gendner CA, Fraser WR, Woehler EJ, Descamps S, Gilly C, Le Bohec C, Le Maho Y (2004) Long-term effects of flipper bands on penguins. *Proceedings of the Royal Society* Series B **271**: S423–S426

Jackson S, Wilson RP (2002) The potential costs of flipper-bands to penguins. *Functional Ecology* **16**: 141–148

Jenni L (ed) (2001) *Bird Ringing 100 Years. Proceedings of the International Conference on Helgoland, 29 September–3 October 1999*. *Ardea* **89** *Special Issue*

Petersen SL, Branch GM, Ainley DG, Boersma PD, Cooper J, Woehler EJ (2005) Is flipper banding of penguins a problem? *Marine Ornithology* **33**: 75–79

Randall RM (1983) Biology of the jackass penguin *Spheniscus demersus* (L.) at St Croix Island, South Africa. PhD thesis, University of Port Elizabeth, South Africa

Renner M, Davis LS (2000) Marking penguins with implanted transponders. *Notornis* **47**: 163–165

Seddon PJ, van Heezik YM (1991) Effects of hatching order, sibling asymmetries, and nest site on survival analysis of jackass penguin chicks. *Auk* **108**: 548–555

Sladen WJL (1958) *The Pygoscelid Penguins. I Methods of Study. II The Adelie Penguin*. Falkland Islands Dependencies Survey, Scientific Report **17**, HM Stationery Office, London

Stonehouse B (1999) Penguin banding: time for reappraisal? *Marine Ornithology* **27**: 115–118

Trivelpiece SG, Trivelpiece WZ (1994) Banding and implant studies of *Pygoscelis* penguins. In: Fraser WR, Trivelpiece WZ (eds) *Report: Workshop on Seabird-Researcher Interactions, July 15–17, Monticello, Minnesota, USA*. Office of Polar Programs, Washington, DC, p 19

Underhill LG, Bartlett PA, Baumann L, Crawford RJM, Dyer BM, Gildenhuys A, Nel DC, Oatley TB, Thornton M, Upfold L, Williams AJ, Whittington PA, Wolfaardt AC (1999) Mortality and survival of African penguins *Spheniscus demersus* involved in the *Apollo Sea* oil spill: an evaluation of rehabilitation efforts. *Ibis* **141**: 29–37

Whittington PA, Dyer BM, Klages NTW (2000) Maximum longevities of African penguins *Spheniscus demersus* based on banding records. *Marine Ornithology* **28**: 81–82