

## Differences in breeding success between African Penguins (*Spheniscus demersus*) that were and were not oiled in the MV *Treasure* oil-spill in 2000

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**Abstract.** About 19000 African Penguins (*Spheniscus demersus*) were oiled when the bulk ore carrier MV *Treasure* sank off the west coast of South Africa in June 2000. Of these, more than 17000 Penguins were cleaned, rehabilitated and released back to the wild. The breeding success of these birds was compared with unoiled birds and birds oiled during other oil-spills, by measuring fecundity, hatching success and fledging success of both groups from 2001 to 2005 on Robben Island. Fledging success averaged 61% in unoiled birds and 43% in birds oiled during the *Treasure* event, with a large proportion of the reduction attributable to higher mortality of older chicks. Factors that may have contributed to differential fledging success include long mean intervals between capture and cleaning (22 days) and between capture and release (48 days) for birds oiled in the *Treasure* spill. One implication of these results is, if a similar large spill should occur in the future, every effort should be made to treat the oiled birds as quickly as possible to reduce the risk of their suffering a similar reduction in breeding productivity. Further, the other interventions, such as relocation of unoiled birds and captive-rearing of orphaned chicks may need to receive higher priority than hitherto.

### Introduction

African Penguins (*Spheniscus demersus*) breed at 31 localities along the coast of southern Africa, between Algoa Bay and central Namibia. The bulk of the population is located in South Africa's Western Cape, especially at Robben and Dassen islands near Cape Town (du Toit *et al.* 2003; Underhill *et al.* 2006). The overall population declined dramatically during the 20th century, from about two million in 1930 to 200 000 birds in 2000 (Shannon and Crawford 1999; Hockey *et al.* 2005). Past causes of the decrease included loss of habitat through removal of guano (which stopped in South Africa in 1991) and collection of eggs (stopped in 1967) (Crawford *et al.* 1995b). During the second half of the 20th century oil pollution became an increasingly important factor contributing to the ongoing decrease of African Penguins (Nel *et al.* 2003).

On 23 June 2000, a bulk ore carrier, MV *Treasure*, sank off Robben Island, South Africa, ~40 km north of Cape Town. The ship was carrying ~1300 t of heavy fuel oil, most of which leaked out to pollute the surrounding seas (Crawford *et al.* 2000). Although this was a comparatively small oil-spill, the washing of oil onto beaches used by Penguins at Robben and Dassen Islands resulted in 19000 African Penguins being oiled, the largest number contaminated in a single spill (Crawford *et al.* 2000). African Penguins breed on Robben and Dassen

islands throughout the year. The peak of laying occurs February to April (Crawford *et al.* 1995a), so that by late June, when the spill occurred, there were large numbers of chicks of all sizes in the colonies. The disruption to breeding meant that the overall number of chicks that were naturally reared on these islands in 2000 was small (Crawford *et al.* 2000).

Because fish often associate with floating objects, and in the laboratory have associated with floating oil, seabirds at sea may be attracted to patches of oil (Kerley *et al.* 1987). Once their feathers are oiled, penguins lose their waterproofing and become hypothermic. They normally swim ashore (Underhill *et al.* 1999). Onshore they ingest oil when they preen, causing internal injuries through petrochemical poisoning (Birrel 1994; Crawford *et al.* 2000).

As a result of the *Treasure* spill, nearly 19000 oiled African Penguins were collected, of which most, ~15000, were removed from Robben Island; 17287 (90%) were successfully cleaned at the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) and returned to the wild (Crawford *et al.* 2000; Nel and Whittington 2003). All these Penguins were flipper-banded before release with stainless steel flipper bands similar to the design described by Cooper and Morant (1981).

After the *Apollo Sea* oil-spill of 1994, the survival rates of oiled and cleaned African Penguins were indistinguishable from those of Penguins that had never been oiled (Whittington 2002). Apart from a weak transient effect in the first two years after birds were oiled, in a study which spanned six years from the oil-spill, there was also no difference in reproductive success of pairs with at least one Penguin oiled in the *Apollo Sea* spill and pairs that had never been oiled (Wolfaardt and Nel 2003). We consider whether this result was replicated after the *Treasure* oil-spill.

## Methods

### Study location

Robben Island (33°49'S, 18°22'E) is a World Heritage Site and an Important Bird Area (Barnes 1998; Crawford and Dyer 2000). At the time of the MV *Treasure* oil-spill in 2000, Robben Island had the third largest colony of African Penguins (6000 breeding pairs). Dassen Island, some 30 km to the north, held the largest colony (17000 breeding pairs). The numbers of African Penguins in adult plumage at these islands were estimated at 18000 and 55000 birds respectively (Crawford *et al.* 2000). Together these islands accounted for ~40% of the global population (Crawford *et al.* 2000; du Toit *et al.* 2003; Underhill *et al.* 2006).

### Nest monitoring

The breeding success of African Penguins was monitored at Robben Island over the five breeding seasons (2001–05) after the *Treasure* oil-spill. In each year, samples of 50–140 nests were selected in March and April, near the start of the breeding season (Crawford *et al.* 1995a). For this study, which was part of a larger project to determine the effects of different types of flipper bands on breeding by Penguins, we only included nests that were monitored at least 10 days before any eggs hatched. To minimize disturbance, nests were chosen in areas where there was already occasional movement of people through the colony.

The nests were monitored at regular intervals, normally once every 4 days, but sometimes at longer intervals of up to 2 weeks. On each visit to a nest, its content was checked and the approximate size of chicks was noted. The hatching date of chicks was gauged. We did not weigh chicks, but classified them into five stages of development: P0 – newly hatched chicks; P1 – small downy chicks; P2 – medium to large downy chicks; P3 – large downy chicks; and P4 – chicks with more than half their body covered with final fledgling plumage, i.e. when ~45 days or older (Seddon and van Heezik 1993). Many chicks eventually joined crèches, when they could not be identified individually as they were not banded. A chick was considered to have fledged if it reached the P4 stage. Therefore, breeding success may be overestimated.

African Penguins abandon their nests in conditions of excessive heat, when they leave to sea to cool (Randall 1989). This happened to a large proportion of nests in the 2001 breeding season. In 2002, a winter storm led to flooding of a large proportion of monitored nests. In both cases, nest-losses were a result of climatic conditions and we excluded these nests from the study.

### Breeding success

For each year, breeding success was calculated for three groups of breeding pairs. (1) Those pairs where at least one of the two adults had been oiled in the *Treasure* oil-spill, cleaned and released with a flipper band (Treasure Group). (2) Pairs where neither bird was banded and, therefore, neither adult had been oiled, since all birds involved in previous oiling events have been released with flipper bands (Unbanded Group). (3) Pairs where at least one of the adults had a steel flipper band, which meant we had historical data on the bird (see below), but neither bird had been oiled in the *Treasure* spill (Banded Group). We were therefore able to make comparisons between the breeding success of the birds oiled in the *Treasure* spill and two groups of birds that were not oiled in the spill. We had no control over the mate selection of the Penguins, so there are pairs in the Treasure Group in which: (1) the second adult was also oiled in the *Treasure* spill and flipper banded; (2) pairs where the second adult was flipper banded but not oiled in the *Treasure* spill; and (3) pairs where the second adult was not flipper banded.

The Banded Group included pairs in which at least one bird: had been involved in the *Apollo Sea* spill of 1994 (Underhill *et al.* 1999) or the Cape Town Harbour spill of 1998 (Whittington 1999); was one of the ongoing stream of oiled and injured Penguins that passed through SANCCOB either before or after, but not during the *Treasure* oil-spill, described in detail for 2001 and 2002 by Parsons and Underhill (2005); was a un-oiled bird relocated to Port Elizabeth during the *Treasure* spill; was one of the small number of Penguins banded by researchers for specific projects; or was a so-called 'orphan' chick, which are chicks abandoned by their parents at the end of the breeding season and taken to SANCCOB for captive rearing (Parsons and Underhill 2005), chicks whose parents had been oiled or were removed to prevent them from being oiled, during the *Treasure* oil-spill (Crawford *et al.* 2000). Within the Banded Group we could identify three subgroups: (1) pairs in which both birds had been banded for research purposes (11 nests); (2) pairs in which both birds had been banded after previous rehabilitation at SANCCOB (13 nests) and (3) pairs in which both birds had been relocated to Port Elizabeth during the *Treasure* oil-spill (10 nests). The remaining nests in the banded group were occupied by mixed pairs.

We used several measures to quantify the breeding success of each group of Penguins. We attached less importance to measures that covered the period up until hatching (apparent clutch-size, the proportion of eggs that hatched, and the proportions of broods of two chicks at the point of hatching) than to measures that related to the period between hatching and fledging (the proportions of hatched chicks that fledged, and the fledging period). This was because we anticipated that, if *Treasure* birds were hampered in any way, it would be during the pre-fledging period when food demand is at its peak. Because we restricted our comparisons to the period between hatching and fledging, it was not necessary to use the Mayfield method to measure success (Mayfield 1975).

In years of poor food supply, brood reduction has been reported in African Penguins, so that only one chick in a brood of two is able to survive (Seddon and van Heezik 1991). We therefore considered whether the fledging success of a brood

with two hatchlings differed from that of broods with a single hatchling in each of the three groups.

#### Fledging period

The fledging period was taken as the difference between the date on which a chick was first seen in the nest and the last date on which it was seen at the nest as a P4 chick. This method will always underestimate the actual fledging period. The maximum possible time between actual hatching and first observation of a chick in our data is 15 days, although in most cases it is less than 5 days. The time between a P4 chick last being seen and when it actually first goes to sea is more difficult to estimate. At some nests the interval between visits around the time the eggs hatched and around the time the P4 chicks disappeared were so long that the overall uncertainty in calculating the fledging period as described above was > 20 days; such results were discounted as being too unreliable.

#### Results

Over the five-year period, 420 nests were monitored. Monitoring of nests began at least 10 days before hatching and continued until the nests were abandoned or the chicks had fledged. The Treasure Group consisted of 225 nests, at 109 (48%) of which both adults were banded and 58 (26%) of which both parents had been oiled in the *Treasure* spill; eggs hatched at 211 of these nests. The Unbanded Group consisted of 118

nests where neither adult was banded; eggs hatched at 108 of these nests. The Banded Group contained 77 nests. It included 22 birds that had been relocated to Port Elizabeth during the *Treasure* oil-spill, 78 birds that had been rehabilitated at SANCCOB in other incidents, 51 that had been banded but never oiled and three that were hand-raised orphaned chicks taken from Robben or Dassen islands during the *Treasure* oil-spill. Eggs were hatched at 73 nests, at 23 (30%) of which both adults were banded.

Most pairs in all groups had clutches of two but because we did not begin monitoring before laying, we cannot be certain of the exact initial clutch-sizes. Apparent clutch-sizes, at time of entry of nests into the study, were similar for the three groups: 1.89 eggs per nest for Treasure Group (426 eggs in 225 nests), 1.86 for Unbanded Group (220, 118) and 1.88 for the Banded Group (145, 77).

Across the five years of the study, hatching success per nest was similar for each of the three groups: the Treasure Group produced 1.43 hatchlings per nest (321 hatchlings in 225 nests), the Unbanded Group 1.44 (170, 118) and the Banded Group 1.48 (114, 77). The total number of hatchlings followed to success or death was therefore 605 (Table 1). Likewise, the proportions of broods with a single hatchling were similar in the three groups: 48% (101 with a single hatchling and 110 with two), 43% (46 and 62) and 44% (32 and 41) in the Treasure, Unbanded and Banded Groups respectively (Table 1). These differences are not

**Table 1. Numbers of nests with different patterns of fledging success for the three groups of African Penguins monitored at Robben Island, 2001–05**  
The percentages are expressed in terms of the total number of nests in which eggs hatched, rather than the total number of nests monitored

Year Group	1 hatchling, 0 fledgling		1 hatchling, 1 fledgling		2 hatchlings, 0 fledglings		2 hatchlings, 1 fledgling		2 hatchlings, 2 fledglings		0 eggs hatched	Total nests <sup>A</sup>
2001												
Treasure	14	34.1%	8	19.5%	6	14.6%	3	7.3%	10	24.4%	3	44
Unbanded	0	0.0%	0	0.0	0	0.0%	1	25.0%	3	75.0%	2	6
Banded	0	0.0%	4	33.3%	3	25.0%	1	8.3%	4	33.3%	1	13
2002												
Treasure	8	29.6%	8	29.6%	4	14.8%	1	3.7%	6	22.2%	2	29
Unbanded	0	0.0%	4	36.4%	2	18.2%	1	9.1%	4	36.4%	1	12
Banded	1	9.1%	2	18.2%	2	18.2%	1	9.1%	5	45.5%	0	11
2003												
Treasure	17	44.7%	4	10.5%	9	23.7%	2	5.3%	6	15.8%	3	41
Unbanded	11	37.9%	6	20.7%	7	24.1%	1	3.4%	4	13.8%	2	31
Banded	2	9.1%	8	36.4%	6	27.3%	1	4.5%	5	22.7%	2	24
2004												
Treasure	31	36.5%	11	12.9%	20	23.5%	8	9.4%	15	17.6%	3	88
Unbanded	4	18.2%	5	22.7%	4	18.2%	2	9.1%	7	31.8%	3	25
Banded	9	36.0%	6	24.0%	3	12.0%	0	0.0%	7	28.0%	0	25
2005												
Treasure	0	0.0%	0	0.0%	10	50.0%	2	10.0%	8	40.0%	3	23
Unbanded	5	12.5%	11	27.5%	3	7.5%	5	12.5%	16	40.0%	4	44
Banded	0	0.0%	0	0.0%	0	0.0%	2	66.7%	1	33.3%	1	4
Overall												
Treasure	70	33.2%	31	14.7%	49	23.2%	16	7.6%	45	21.3%	14	225
Unbanded	20	18.9%	26	24.5%	16	15.1%	10	9.4%	34	32.1%	12	118
Banded	12	16.4%	20	27.4%	14	19.2%	5	6.8%	22	30.1%	4	77
Total	102	26.2%	77	19.7%	79	20.3%	31	7.9%	101	25.9%	30	420

<sup>A</sup>Total number of nests that were monitored, including both nests where eggs hatched and nests where they did not; however, the percentages given in the table are all based on the number of nests where eggs actually hatched (which can be obtained by subtracting the number of nests where eggs did not hatch – penultimate column from the total nests last column).

**Table 2. Fledging success for the three groups of African Penguins on Robben Island, 2001–05**

Fledging success is expressed as the proportion of eggs that hatched and produced fledglings

	Treasure Group			Unbanded Group			Banded Group			Overall success
	No. hatched	No. fledged	Success	No. hatched	No. fledged	Success	No. hatched	No. fledged	Success	
2001	60	31	52%	8	7	88%	20	13	65%	58%
2002	38	21	55%	18	13	72%	19	13	68%	62%
2003	55	18	33%	41	15	37%	34	19	56%	40%
2004	128	49	38%	35	21	60%	35	20	57%	45%
2005	40	18	45%	68	48	71%	6	4	67%	61%
Total	321	137	43%	170	104	61%	114	69	61%	51%

statistically significant ( $\chi^2_2 = 0.92$ ,  $P = 0.63$ ). Within the Unbanded and Banded Groups, 62% and 61% of hatchlings fledged respectively. There was no difference in fledging rate between broods of one or two chicks (Table 1). For the Treasure Group, 31% of chicks in single-chick broods fledged, and 48% in two-chick broods. This difference goes in the opposite direction to that predicted if brood reduction were occurring in two-chick broods. Further evidence of the lack of brood reduction was the smaller-than-expected number of single chicks fledging from broods of two (Table 1). We therefore did not consider single-hatchling and two-hatchling broods separately.

Fledging success (measured as the proportion of hatchlings that fledged) was 43% for the Treasure Group, and 61% for both the Unbanded and Banded Groups (Table 1). These differences are significantly different. A generalised linear model with binomial distribution and logistic link function performed on the data of Table 1 suggested that there was no difference between the Unbanded and Banded Groups (change of deviance = 0.03, d.f. = 1,  $P = 0.86$ ). These two groups were therefore combined to form a Non-Treasure Group.

Within the Banded Group, the 11 pairs of birds that had been banded for research purposes had a fledging success of 0.64 fledglings per hatchling, from a total of 14 hatchlings (0.82 fledglings per nest). The 13 pairs of birds that had been banded after rehabilitation at SANCCOB raised 0.71 fledglings per hatchling, from a total of 17 hatchlings (0.92 fledglings per nest). The ten pairs that had been relocated to Port Elizabeth during the *Treasure* spill raised 0.69 fledglings per hatchling, from a total of 13 hatchlings (0.90 fledglings per nest). The results from each of these subgroupings were similar.

Over the five-year period of the study, 43% of hatchlings raised by birds in the Treasure Group fledged, and 61% of hatchlings raised by both Non-Treasure Groups fledged (Table 2). Inclusion of a year effect suggested that there were between-year differences in fledging success (change of deviance = 19.9, d.f. = 4,  $P < 0.001$ ). While there were differences between the groups, especially when the sample size was small, overall the fledging success was highest in 2002 and lowest in 2003 (Table 2). A model that included factors for the two groups (Treasure and Non-Treasure) explained 44% of the deviance; additional inclusion of the year effects explained 88% (Table 3). In the logistic scale, the magnitude of the *Treasure* effect was 0.785 (s.e. = 0.175,  $t_0 = 4.48$ ,  $P < 0.001$ ) (Table 3). On the probability scale, for 2005 (the year of median breeding success), this translates into estimated breeding successes of 68% for Non-Treasure birds and 49% for Treasure birds, a difference of 19%.

At successful nests, the median fledging period in the Treasure Group was 65 days (range 48–87, quartiles 60 and 71,  $n = 82$ ); in the Unbanded and Banded Groups the fledging period was 59 days (range 49–76, quartiles 55 and 64,  $n = 69$ ) and 57 days (range 47–76, quartiles 54 and 63,  $n = 47$ ) respectively. The fledging periods of the chicks in the Unbanded and Banded Groups did not differ (Mann–Whitney  $U = 1437$ ,  $P = 0.30$ ). However, the fledging period for the Treasure Group was significantly longer than for chicks in the two Non-Treasure Groups (Kruskal–Wallis  $H = 28.8$ ,  $P < 0.001$ ).

The stages at which chicks died differed among the three groups (Table 4). The percentages of hatchlings that died at stages P0 and P1 were similar in the three groups: 28%, 31% and 34% in the Treasure, Unbanded and Banded Groups respectively. This indicates that the mortality rate of young chicks in the Treasure Group was similar to that of young chicks in the Non-Treasure Groups. However, the percentage of hatchlings in the Treasure Group that died at stages P2 and P3 was 30%, whereas these percentages were 8.2% and 5.3% for chicks in the Unbanded and Banded Groups respectively. Thus, for the Treasure Group, 52% of chicks that died were at stages P2 or P3, whereas these percentages were 21% and 13% in the Unbanded and Banded Groups respectively. The patterns of mortality between stages P0 and P2 were not significantly different between the Unbanded and Banded Groups ( $\chi^2_2 = 1.12$ ,  $P = 0.56$ ), but differed significantly from that of the Treasure Group ( $\chi^2_4 = 35.2$ ,  $P < 0.001$ ).

## Discussion

This study was feasible because the decision was taken to mark every Penguin that was oiled and rehabilitated in the *Treasure* spill of 2000. If this had not been done, we would have been

**Table 3. Results of the generalized linear model relating *Treasure* effect and year effect to fledging success of African Penguin chicks at Robben Island**Logit (fledging probability) =  $C + \textit{Treasure}$  effect + Year effect

Parameter	Parameter estimate	Standard error	$t_0$	$P$
$C$	0.869	0.253	3.44	< 0.001
<i>Treasure</i>	-0.785	0.175	-4.48	< 0.001
Year 2002	0.066	0.328	0.20	0.841
Year 2003	-0.959	0.291	-3.29	< 0.001
Year 2004	-0.548	0.263	-2.08	0.037
Year 2005	-0.116	0.300	-0.39	0.699

unable to assign control birds to the Unbanded Group because we would not have been able to make the inference that an unbanded bird was a bird that had not been oiled and rehabilitated in the *Treasure* spill. There was no significant difference in breeding performance between the Unbanded and Banded Groups.

The lower reproductive success of African Penguins oiled in the *Treasure* spill than of control birds is of considerable interest because of its possible implications for prioritisation of management interventions in the event of future spills. It cannot now be assumed that rehabilitated adult birds will have the same reproductive output as other birds. Hence the relocation of clean birds to prevent their becoming oiled and the captive-rearing of orphaned chicks (Crawford *et al.* 2000) may receive higher priority than hitherto.

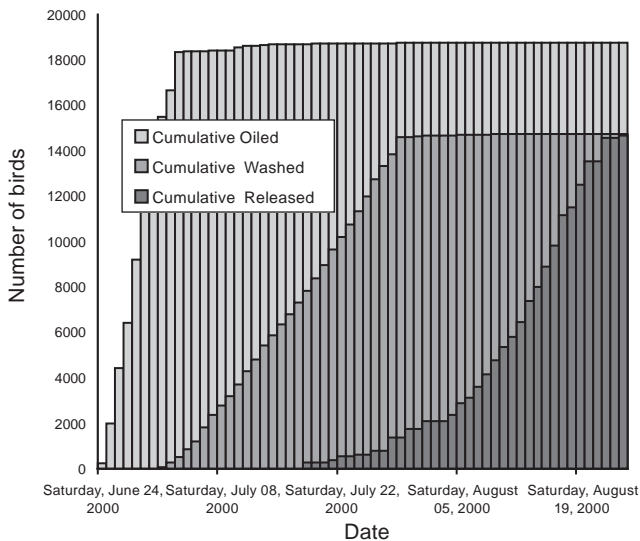
However, other rehabilitated, oiled Penguins in the Banded Group did not have a poorer fledging success than birds that had not been oiled. Similarly, in a study at Dassen Island there was no long-term difference in reproductive success of birds that had been oiled in the *Apollo Sea* spill and birds that had not been oiled (Wolfaardt and Nel 2003). This highlights the fact that results from one oil-spill cannot be generalized to all spills and poses the question why birds oiled in the *Treasure* spill performed less well than other oiled birds. At least three reasons can be given for the poor performance of the Penguins in the *Treasure* Group: (1) prolonged captivity; (2) length of time from oiling to washing; and (3) toxicity of the heavy oil in the *Treasure* spill. The length of time spent in captivity may influence the stability of pair-bonds. African Penguins show high

fidelity to their mates (Randall 1983; Crawford *et al.* 1995a), but a long absence from a mate during the breeding period may lead to the assumption of mate-loss and the setting up of new pair-bonds. In other long-lived seabirds, increased experience with a particular mate results in improved breeding success (Wooller *et al.* 1989; Bradley *et al.* 1995).

The greater delay between oiling and cleaning following the *Treasure* spill will have increased the duration of exposure to intoxication and resultant tissue injury or behavioural impairment from petroleum hydrocarbons. An alternative explanation is that the oil in the *Treasure* spill differed in toxicity from that in the *Apollo Sea* (and other) spills. The mean duration of treatment of an oiled penguin at SANCCOB in 2001 and 2002, a period with no major oiling incidents, was 24 days from admission to release (Parsons and Underhill 2005). During such periods, birds are washed as soon as they are stable, 3–5 days after admission (N. J. Parsons, *in litt.*) The *Apollo Sea* spill of 1994 took place on 20 June, and half of the birds had been released by 1 August (Underhill *et al.* 1999). Given that most oiled birds were admitted to SANCCOB within a few days of the event, the treatment period averaged ~38 days. During the *Treasure* oil-spill of 2000, because of the large number of birds involved, the treatment period was considerably longer (Fig. 1). Virtually all oiled birds had been collected within a week of the spill, which took place on 23 June. Many of these birds were oiled soon after the spill, but were not collected for several days, again because of the large numbers involved. The average waiting time before washing was 22 days. The average time between oiling, assuming 25 June as the mean oiling date, and

**Table 4.** Size classification (see text) of African Penguin chicks at the time of their death at Robben Island for the three groups of Penguins (numbers of chicks). The proportion of chicks that fledged is also shown

Year and group	Size classification at death				Total losses	Fledged	Total chicks hatched	Proportion fledged
	P0	P1	P2	P3				
2001								
Treasure Group	2	8	18	1	29	31	60	0.52
Unbanded Group	0	1	0	0	1	7	8	0.88
Banded Group	2	5	0	0	7	13	20	0.65
2002								
Treasure Group	2	6	9	0	17	21	38	0.55
Unbanded Group	2	3	0	0	5	13	18	0.72
Banded Group	0	5	1	0	6	13	19	0.68
2003								
Treasure Group	2	18	15	2	37	18	55	0.33
Unbanded Group	4	18	4	0	26	15	41	0.37
Banded Group	2	9	4	0	15	19	34	0.56
2004								
Treasure Group	6	32	40	1	79	49	128	0.38
Unbanded Group	3	8	3	0	14	21	35	0.60
Banded Group	5	9	1	0	15	20	35	0.57
2005								
Treasure Group	2	11	9	0	22	18	40	0.45
Unbanded Group	3	10	7	0	20	48	68	0.71
Banded Group	0	2	0	0	2	4	6	0.67
Overall								
Treasure Group	14	75	91	4	184	137	321	0.43
Unbanded Group	12	40	14	0	66	104	170	0.61
Banded Group	9	30	6	0	45	69	114	0.61
Total	35	145	111	4	295	310	605	0.51



**Fig. 1.** Cumulative numbers of oiled African Penguins that were collected, washed and released from 24 June to 25 August 2000, after the sinking of the MV *Treasure*.

release was 48 days, twice as long as SANCCOB takes when dealing with birds on an immediate basis, and ~20% longer than during the *Apollo Sea* spill. Thus, the period for which birds were held before washing, and overall, were considerably longer in the *Treasure* rescue than at other times.

The main factor explaining the difference between fledging success of chicks in the *Treasure* Group and the Non-*Treasure* Group was the increased proportion of mortality of large chicks, especially those classed as stage P2, in the *Treasure* Group (Table 4). As chicks grow, their nutritional requirements increase. It appears that birds oiled in the *Treasure* spill were less able to meet this increasing demand than other birds, either because their overall health was not as good or they had less experience breeding with their mates. Some 800 oiled Penguins rescued for cleaning and rehabilitation in the *Treasure* spill were in such poor condition that they were eventually euthanased (Crawford *et al.* 2000). Many survivors would also have had their condition seriously affected by oiling. The data available do not permit any specific conclusions to be drawn about physiological factors that may have influenced the state of health of the birds oiled in the *Treasure* spill. However, since these birds had similar clutch-sizes and similar hatching success to other groups, one may conclude that there was not a fertility problem. Further work on the physiology of birds that were and were not oiled in the *Treasure* spill is clearly needed.

Reduced breeding success in oiled African Penguins was observed in the first year following the *Apollo Sea* incident in 1994 (Wolfaardt 2007) and in Little Penguins (*Eudyptula minor*) following the *Iron Baron* spill in Australia in 1995 (Giese *et al.* 2000). Birds involved in the *Apollo Sea* incident appear not to have been affected further and had similar breeding success to non-oiled birds in later years. However, in the *Iron Baron* incident, while overall fledging success recovered after one year, the chicks fledged by oiled birds were of significantly lower weight at fledging than those of the control group,

which may be indicative of some longer term problems persisting. We note that comparisons between different spills are difficult to make as many unknown factors, such as the detailed toxicological effects of the different oils, cannot be ascertained at a later stage well after the spill occurred.

The findings of this paper lend further support to the importance of preventing penguins from becoming oiled in the first instance. In the 1970s, argument to prevent discharge of oil at sea focused on the mortality of oiled penguins (e.g. Westphal and Rowan 1971). Before the establishment of SANCCOB in 1968 (Morant *et al.* 1981), essentially all oiled penguins died. The overall mortality rate of penguins taken for rehabilitation to SANCCOB was 22% in the 1990s (Nel *et al.* 2003). Early follow-up of oiled and cleaned penguins showed that many of them bred (Underhill *et al.* 1999), and it was assumed that all of them bred. However, A. C. Wolfaardt (personal communication) noted that a substantial proportion of oiled and cleaned penguins from the *Apollo Sea* spill of 1994 survived for years in the wild, but never become part of the breeding population. This study shows that, at least in some spills, the breeding productivity of oiled and cleaned birds is impaired in comparison with control birds.

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