

African Journal of Marine Science

ISSN: 1814-232X (Print) 1814-2338 (Online) Journal homepage: www.tandfonline.com/journals/tams20

Impact of the *Treasure* oil spill on African penguins *Spheniscus demersus* at Dassen Island: case study of a rescue operation

AC Wolfaardt, LG Underhill, R Altwegg, J Visagie & AJ Williams

To cite this article: AC Wolfaardt, LG Underhill, R Altwegg, J Visagie & AJ Williams (2008) Impact of the *Treasure* oil spill on African penguins *Spheniscus demersus* at Dassen Island: case study of a rescue operation, African Journal of Marine Science, 30:2, 405-419, DOI: 10.2989/AJMS.2008.30.2.13.563

To link to this article: https://doi.org/10.2989/AJMS.2008.30.2.13.563

Published online: 08 Jan 2010.

Submit your article to this journal

Article views: 226

View related articles

Citing articles: 5 View citing articles

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=tams20

African Journal of Marine Science 2008, 30(2): 405–419
Printed in South Africa — All rights reserved

Copyright © NISC Pty Ltd
AFRICAN JOURNAL OF MARINE SCIENCE
ISSN 1814–232X EISSN 1814–2338
doi: 10.2989/AJMS.2008.30.2.13.563

Impact of the *Treasure* oil spill on African penguins *Spheniscus demersus* at Dassen Island: case study of a rescue operation

AC Wolfaardt[1,2,3]*, LG Underhill[2], R Altwegg[2], J Visagie[1] and AJ Williams[1,2]

[1] *Western Cape Nature Conservation Board, Private Bag 5014, Stellenbosch 7599, South Africa*
[2] *Animal Demography Unit, Department of Zoology, University of Cape Town, Rondebosch 7701, South Africa*
[3] *Current address: Joint Nature Conservation Committee, PO Box 585, Stanley, Falkland Islands, FIQQ 1ZZ, UK*
* *Corresponding author, e-mail: anton.wolfaardt@jncc.gov.uk*

Manuscript received February 2008; accepted June 2008

The bulk ore carrier MV *Treasure* sank between Robben and Dassen islands off western South Africa in June 2000. Although releasing less oil than the *Apollo Sea* spill six years earlier, the number of African penguins *Spheniscus demersus* oiled (approximately 19 000) in the *Treasure* spill was almost double the number oiled in the *Apollo Sea* incident. The majority of oiled penguins was collected from Robben Island. The capture, stabilisation and transport of oiled penguins following the *Treasure* spill were substantially more successful than during the *Apollo Sea* rescue operation and resulted in an increase in the percentage of oiled penguins that were released back to the wild. In addition to the 19 000 oiled penguins that were caught, 19 500 un-oiled birds (12 345 from Dassen Island) were evacuated to Cape Recife, 800 km to the east, to prevent them from becoming contaminated. The evacuated birds returned rapidly to Dassen Island and many resumed breeding soon after their return. The restoration success (proportion of birds observed at Dassen Island that were recorded breeding) was substantially greater for evacuated birds than for de-oiled birds. Lightly oiled birds that were released without being cleaned had lower survival rates and were less successfully restored into the breeding population than de-oiled birds, especially if more than 5% of their body was covered in oil. Reproduction exerted a greater cost to de-oiled birds than to evacuated birds. A total of 1 787 orphaned chicks was hand-reared at two separate facilities on the mainland and were released at Robben and Dassen islands. The chicks did not necessarily return to the colony at which they were released. The survival rates and restoration success of chicks reared at the two facilities differed, probably as a result of one group being overfed. Despite the death of about 2 000 African penguins in the *Treasure* spill, and the substantial disturbance that resulted from the rescue operation, the penguin colonies at Robben and Dassen islands increased by 18% and 26% respectively in the year following the spill. This increase was attributed to a significant increase in the biomass of anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax* in 2001. These findings highlight the importance of preventing oil spills in the first place, and in the event of a large oil spill, the conservation value of evacuating un-oiled penguins to minimise their risk of becoming contaminated.

Keywords: African penguin, captive rearing, Dassen Island, de-oiling, oil spill, relocation, *Spheniscus demersus,* South Africa

Introduction

The African penguin *Spheniscus demersus* is currently classified as Vulnerable, both regionally and globally (Crawford 2000, Whittington *et al.* 2000, BirdLife International 2004) on the basis of a substantial decline of its population, especially during the 20th century (Crawford *et al.* 1990, 1995). The initial decline in numbers of African penguins was largely due to direct exploitation by humans, chiefly through harvesting of penguin eggs and the disturbance and habitat alteration associated with scraping of guano (Siegfried and Crawford 1978). These activities have ceased at all penguin colonies in South Africa. More recently, reduced availability of pelagic fish due to competition with commercial fisheries has been responsible for persistent declines (Crawford *et al.* 1990, Crawford and Dyer 1995, Crawford *et al.* 2001). Presently, mortality associated with oil spills is considered to be one of the principal threats to the African penguin (Whittington *et al.* 2000, Nel *et al.* 2003). The vulnerability of African penguins to oil contamination is exacerbated by the geographic distribution of their breeding colonies. More than 80% of the population breed within 100 km of major shipping harbours (Nel *et al.* 2003).

Published online 08 Jan 2010

The foundering of the bulk ore carrier *Apollo Sea* in June 1994 caused the worst oiling incident in South Africa up to that time, in terms of the numbers of seabirds (mostly African penguins) that were contaminated (Underhill *et al.* 1999). The *Apollo Sea* sank about 26 km south-west of Dassen Island (33˚25′ S, 18˚05′ E) in the Western Cape. Approximately 10 000 oiled African penguins were collected and transported to the Southern African Foundation for the Conservation of Coastal Birds (SANCCOB) rehabilitation centre; the majority (8 000 birds) of these was collected from Dassen Island (Dehrmann 1994, Erasmus 1995, Underhill *et al.* 1999), a Provincial Nature Reserve managed by the Western Cape Nature Conservation Board. Of these oiled birds, 54% died; around half within the initial 48 hours of capture (Williams 1995). Approximately 1 700 birds died during their transport from the island colonies to the rehabilitation centre, probably as a result of excessive handling and poor ventilation, and a further 1 200 birds died during their first 24 hours at the rehabilitation centre. The large number of deaths in the initial phases of the rescue operation highlighted the lack of preparedness of the conservation authorities for large-scale oil spill events. The survival and restoration success of the 4 076 penguins that were successfully de-oiled and released back into the wild with flipper bands has been well documented (Underhill *et al.* 1999, Whittington 1999, Underhill *et al.* 2000, Whittington 2002, Wolfaardt *et al.* in 2008, in press b, c).

Six years after the *Apollo Sea* sank, another bulk ore carrier, the MV *Treasure*, sank about 16 km north of Robben Island (33°48′ S 18°23′ E) (Cheney 2000, Crawford *et al.* 2000). The amount of fuel spilled following the sinking of the *Treasure* (1 400 t; Crawford *et al.* 2000) was less than was spilled following the sinking of the *Apollo Sea* (2 400 t; Underhill *et al.* 1999). However, the position of the *Treasure* wreck between Dassen and Robben islands, which supported the largest and third largest colonies of African penguins at the time (accounting for about 40% of the total population), and the atypical calm weather, which failed to break up and disperse the resulting oil slick, caused the oiling of over 19 000 African penguins, mostly from Robben and Dassen islands (Crawford *et al.* 2000). In addition, a further 19 500 un-oiled penguins were evacuated from Robben and Dassen islands to Cape Recife (34°02′ S, 18°30′ E) in the Eastern Cape, to prevent them from becoming oiled (Crawford *et al.* 2000). In terms of impacts on seabirds, the *Treasure* oil spill is the worst oiling incident to affect southern Africa to date.

Following the *Apollo Sea* spill, several recommendations were made to improve the preparedness of authorities to manage large-scale oil spills (Barrett *et al.* 1995). These included a post-release monitoring programme to assess the conservation value of de-oiling African penguins (Wolfaardt *et al.* in 2008, in press b, c). A conservation manager was stationed at Dassen Island from 1998. Prior to this a ‘headman’ was based on the island, whose main job was to control human access to the island. A Conservation Management Plan for Dassen Island was developed and finalised in early 2000 (Wolfaardt 2000). An oil spill contingency plan dealing specifically with the rescue of oiled seabirds at Dassen Island was produced in 1998 (Wolfaardt *et al.* 1998), and is revised annually. In 1999 a seabird stabilisation facility was developed at Dassen Island (Wolfaardt *et al.* 1998).

Crawford *et al.* (2000) provided an overview of the *Treasure* oil spill and its initial impacts on penguins, and predicted that the spill would negatively influence breeding activities during 2001, including a reduction in the number of birds breeding at Robben and Dassen islands and lower breeding success. Our paper provides a case study on the rescue operation that followed the *Treasure* spill at Dassen Island in June 2000, and assesses, over the following five years, the efficacy of the operation relative to the rescue of oiled birds after the *Apollo Sea* spill. We investigate the return of de-oiled and evacuated birds to Dassen Island and their restoration into the breeding population, as well as that of hand-reared chicks that were orphaned as a result of the spill. We consider the conservation value of evacuating clean penguins as a management tool in large oil-spill events. Overall, we determine the impact of the *Treasure* oil spill on the breeding population of African penguins in the years following the spill.

Material and Methods

Fieldwork protocols

The housing and storeroom complex of the Western Cape Nature Conservation Board is located on the northern side of Dassen Island, hereafter referred to as ‘the base’ (Figure 1). Immediately following news of the stricken *Treasure*, before it actually sank, the Seabird Rescue Plan for Dassen Island (Wolfaardt *et al.* 1998) was activated. From 23 June to 1 July 2000, the coastline of the island was searched for oiled penguins throughout the day, and attempts were made to catch all oiled birds. Catching teams were made up of 5–15 people. The teams comprised one or two people in wetsuits who swam around the beach groups of penguins and moved towards them from the seaward side so as to prevent them from fleeing into the water. Other members of the catching team used corral units (lightweight aluminium frames with mesh netting) to ‘herd’ the penguins into a contained group (see Figure 7a in Crawford *et al*. 2000). Once oiled birds were caught, they were placed in well-ventilated plastic crates, and carried to the nearest road access, from where they were transported by vehicle to the base.

Oiled penguins were placed in temporary pens that were made up using wire mesh corral units with shade cloth. The number of penguins placed in each pen ranged from five to approximately 50, depending on the size of the pen, the main objective being to prevent overcrowding within the pens. Juvenile birds were kept separate from adults to prevent aggressive interactions between the two groups (Ryan *et al.* 1987). Weak birds were separated from the rest of the group (Parsons and Underhill 2005). Each oiled bird was treated according to the stabilisation procedure outlined in Wolfaardt *et al.* (1998), and detailed records were kept of the treatment history for each individual. The oiled birds were kept at Dassen Island until they could be transported

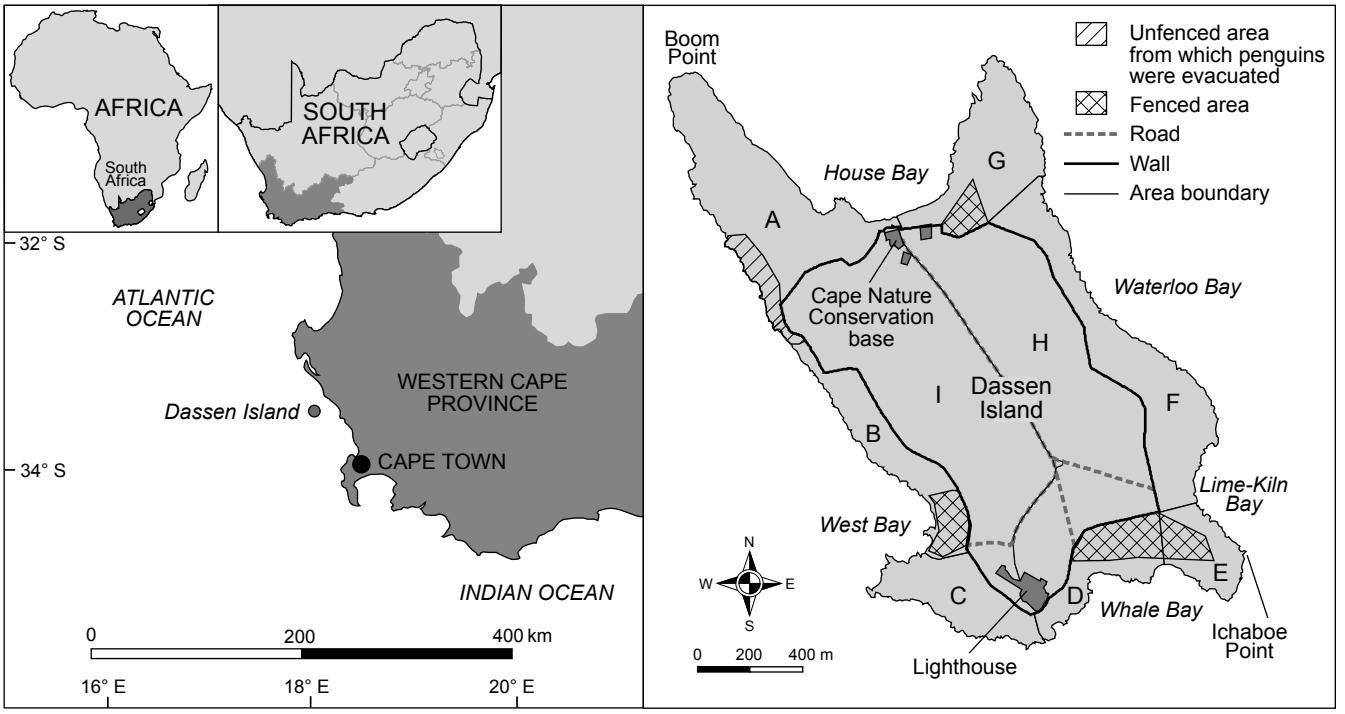


Figure 1: Map of Dassen Island, showing the monitoring and management areas (A–I), the location of infrastructure, the position of the interior wall that was used to prevent African penguins from accessing the coast, and the additional areas that were fenced for the same purpose

to Yzerfontein by boat. The birds were transported off the island in cardboard boxes that had been designed for transporting oiled penguins after the *Apollo Sea* spill (Crawford *et al.* 2000). A maximum of three penguins was placed in a box, and juvenile birds were separated from adults. At Yzerfontein, the birds were collected by vehicle and transported about 100 km to SANCCOB.

From 25 June, the oil slick started to move northwards from the location where the *Treasure* sank towards Dassen Island; a decision was therefore taken on 26 June to fence off penguin colonies at Dassen Island to prevent penguins from going to sea. This was done between 27 June and 1 July 2000, in two ways. First, the wall that surrounds the interior of the island (Figure 1) was repaired to serve as a barrier for penguins nesting within its confines, thereby preventing them from entering the sea. Clean penguins on the seaward side of the wall were moved to the inland side of the wall. Second, three large penguin colonies outside of the wall were fenced in using plastic mesh fencing and metal droppers (Figure 1). Because African penguins are diurnal foragers (Wilson and Wilson 1995), the fences were opened from about 18:00 each evening to allow un-oiled penguins returning from foraging trips to enter the enclosed areas, thereby maximising the number of penguins held in the fenced areas. The fences were closed before first light the following morning to prevent birds from leaving the enclosed areas.

On 1 July, a helicopter inspection of the sea surrounding Dassen Island revealed a large oil slick encircling the island. Evacuating of un-oiled birds from the island began the following day and continued for a total of three days. The aim was to evacuate as many penguins as possible to Cape Recife so that they could swim back to Dassen Island, allowing sufficient time for the oil to be cleared before their return. Details regarding the choice of Cape Recife as the translocation destination are provided in Crawford *et al.* (2000). The evacuation operation was limited to three days because there were over 1 000 penguins on the island that had already become oiled, and those birds needed to be caught as soon as possible. The capture and removal of oiled penguins resumed after the evacuation operation, on 5 July, and continued until 28 July.

The capture of clean penguins began at colonies that had been fenced in for longest. Penguins that were standing outside of burrows in the colony were herded by a group of catchers into a corral unit. Large groups of penguins herded into the unit were separated into smaller groups to avoid overcrowding and stress to the birds. All oiled penguins and juveniles were immediately released, so that only clean adult penguins were evacuated. After the majority of birds outside of burrows had been collected, the capture team worked systematically through the burrows of the colony, removing all clean adult birds, marking each nest by scraping a cross in the ground to show that the birds had been removed. Two or three record keepers were stationed at the capture sites to record the flipper-band numbers of penguins that were caught and boxed. The number of people working in the colonies was limited to reduce the incidence of collapsing burrows. Penguins were first packed into ventilated plastic crates (10 penguins to a crate), then taken by foot to outside the colony area, where they were packed into the penguin transportation boxes. Five penguins were placed in a box,

and the boxes were then closed and placed on a vehicle and trailer for transportation to the base.

Upon arrival at the base, the boxes were offloaded, counted (including the number of penguins) and placed in the shade until there were sufficient boxes to be transported to Yzerfontein. On the first day of the evacuation operation (2 July), the penguins were transported from Dassen Island to Yzerfontein by boats and a Sikorski helicopter. On the second and third day of the operation, only the helicopter was used because it was a more effective means of maximising the number of penguins transported to Yzerfontein.

Once the boxes of penguins arrived at Yzerfontein, a separate team unloaded the boxes from the boats or helicopter, and re-packed the penguins so that there were three birds to a box to prevent problems with overcrowding and poor ventilation. Tiered sheep trucks were used to transport the penguins from Yzerfontein to Cape Recife. On arrival there, the boxes were offloaded and the penguins were released immediately.

On the final day of the penguin evacuation (4 July), a team began collecting chicks that had become orphaned as a result of their parents having been sent off the island. These activities were initially focused in the areas where clean adults had been evacuated, and at a later stage moved into areas where large numbers of oiled penguins had been caught. The collection of abandoned chicks took place from 4 July to 14 July. All chicks were sent to the satellite rehabilitation centre that had been set up at Salt River in Cape Town. Upon arrival, the chicks were screened by veterinary personnel before being sent to one of the chick-rearing centres. Chick-rearing centres were established at SANCCOB and its satellite centre in Salt River, and at a private rehabilitation centre in Melkbosstrand (33°43′ S 18°26′ E), called Monty's. Chicks removed from Dassen and Robben islands were not kept separate. The natal island of the chicks at the different chick rearing centres was therefore not known. Chicks that were hand-reared at Monty's were later released on Dassen Island; chicks hand-reared at SANCCOB and its satellite station were released on Robben Island.

On 5 July, the fences were removed, and the exclusion wall surrounding the interior of the island was re-opened so that penguins remaining within these confines could enter the sea to feed.

Flipper-banding penguins

In order to monitor the efficacy of the translocation intervention, 969 penguins from within the fenced-off areas were fitted with flipper-bands on 1 July. Many of the penguins that became oiled as a result of the *Treasure* spill had only small or superficial patches of oil on their plumage. Such were treated as clean birds and were not de-oiled. On 8 July, 255 of these penguins were caught at Whale Bay and House Bay. For each bird, the extent of the oiling was classified into one of the following percentage categories: <5%, 5%, 10%, 15% and 20%, which represented the percentage of body covered in oil. Whether the contamination was superficial or had reached the skin of the penguin (deeply oiled) was also noted. Subsequent re-sightings of these (and other) penguins were made from August 2000 until March 2005, and for adults the re-sighting probabilities in each oiling category were analysed using a generalised linear model (GLM). The un-oiled evacuated penguins (all adults) that were flipper-banded were used as a control baseline, against which to compare the oiling categories. These birds were banded at approximately the same time and in the same areas as the experimental birds.

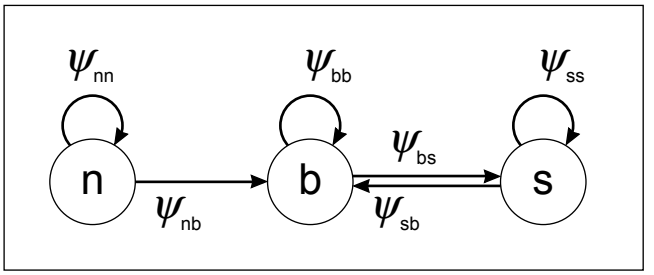


Figure 2: Diagram showing the states used in the multistate capture-mark-recapture analyses for African penguins on Dassen Island. Penguins can either be non-breeders (n), breeders (b), or secondary non-breeders (s). Recapture and survival rates were estimated separately for each state, and the probabilities of moving between states (ψ) were estimated. The way in which the states were defined results in non-breeders being unable to become secondary non-breeders directly, but breeders cannot move back to the initial non-breeder stage. These transition rates were thus fixed to zero in the analyses. See text for further details

The bird ringing and re-sighting database curated by the South African Bird Ringing Unit (SAFRING) was checked for any records of 'Dassen Island' birds that had been seen elsewhere, either dead or alive. These sightings were incorporated into the Dassen Island database so that they could be included in the analyses. Twenty of the flipper-banded penguins that were evacuated were weighed upon their return to Dassen Island with a Salter® spring balance to an accuracy of 25 g.

Counts of active nest sites of African penguins have been conducted annually at Dassen Island and most other South African colonies since the late 1980s. Details of the methods used are provided in Wolfaardt *et al.* (2001, in press a).

Capture-mark-recapture models

Multistate capture-mark-recapture (CMR) models were used, which separate survival from recapture rates, to estimate the survival of three groups of birds that were re-sighted at Dassen Island: (1) de-oiled adult birds from the *Treasure* spill; (2) un-oiled adults that were evacuated; and (3) hand-reared chicks that were orphaned as a result of the spill. We only included the hand-reared chicks that were released on Robben Island (i.e. hand-reared at SANCCOB), because there were insufficient data to estimate survival for the hand-reared chicks released on Dassen Island (i.e. those hand-reared at Monty's). We defined three states that penguins could assume: (1) non-breeders (n); (2) breeders (b); and (3) secondary non-breeders (s) (Figure 2). A bird was defined as a breeder if it was recorded with eggs or chicks; non-breeders were birds observed at Dassen Island, but not with eggs or chicks. A secondary non-breeder was a bird that was observed in

Table 1: Summary of model selection of multistate capture-mark-recapture analysis for three groups (*g*) of African penguins at Dassen Island, 2000–2004: de-oiled adults (de-oiled), evacuated birds (evacuees) and orphaned chicks (orph). We modelled survival in each breeding state (S_n, S_b, S_s for non-breeder, breeder and secondary non-breeder respectively) as well as recapture rates in these states (P_n, P_b, P_s). Also modelled were transitions between states (ψ_{nb}, ψ_{bs}, ψ_{sb}, see Figure 2), and we included a transients effect (trans) to account for 'visiting' birds. See text for further details. All components were modelled as variable over time (*t*) or constant (.). The models were assessed using Akaike's Information Criterion (AICc), where a lower value indicates a better model. ΔAICc shows the difference in AICc between the particular model and the best one. The relative performance of each model compared with the other ones in the set is measured by the Akaike weight. *K* is the number of parameters. The deviance is the difference in –2 log-likelihood between the current model and the saturated model, the latter being the model with the number of parameters equal to the sample size

	Model	AICc	Δ AICc	Akaike weight	*K*	Deviance
1	$\{S_n(g*t_\text{trans:de-oiled,orph})S_b(g*t_\text{orph:const})S_s(g)P_n(.)P_b(.)P_s(t)\psi_{nb}(t*g)\psi_{bs}(g)\psi_{sb}(g)\}$	10 525.10	0.00	0.892	52	503.40
2	$\{S_n(g*t_\text{trans:all})S_b(g*t_\text{orph:const})S_s(g)P_n(.)P_b(.)P_s(t)\psi_{nb}(t*g)\psi_{bs}(g)\psi_{sb}(g)\}$	10 530.18	5.08	0.070	55	502.36
3	$\{S_n(g*t_\text{trans:all})S_b(g*t_\text{orph:const})S_s(g)P_n(t)P_b(.)P_s(t)\psi_{nb}(t*g)\psi_{bs}(g)\psi_{sb}(g)\}$	10 531.43	6.33	0.038	57	499.53
4	$\{S_n(g*t_\text{trans:all})S_b(g*t_\text{orph:const})S_s(g)P_n(t)P_b(.)P_s(t)\psi_{nb}(t*g)\psi_{bs}(.)\psi_{sb}(.)\}$	10 545.05	19.95	0.000	55	517.23
5	{breeder-survival:de-oiled=evacuees, otherwise like Model 1}	10 545.08	19.97	0.000	48	531.51
6	{ψ_{nb}:de-oiled=evacuees, otherwise like Model 1}	10 581.79	56.68	0.000	48	568.22

a particular year as a non-breeder, but had previously been recorded breeding (subsequent to the *Treasure* oil spill). The models were also used to estimate the probability of an individual making the transition from the non-breeder state to the breeder state, and for a breeder to become a secondary non-breeder, for the three groups of birds.

The re-sighting data contained transients. These were birds that were sighted once, but never again, and likely comprise 'visiting' rather than resident birds. A mixture of transient and resident birds causes survival to be underestimated (Pradel *et al.* 1997). We therefore accounted for the effect of transients by allowing survival to be lower during the intervals following the initial sighting of these birds. We only report survival rate for resident birds. Transients among breeders were not accounted for, because once birds initiate breeding activities at a colony, they almost always remain resident there (Randall *et al.* 1987, Crawford 1998, Whittington *et al.* 2005a). Details of the re-sighting method are provided in Wolfaardt *et al.* (2008).

The analysis was restricted to all birds that were re-sighted at Dassen Island after the *Treasure* oil spill. The starting point was therefore the initial sighting of an individual at Dassen Island, rather than the banding and release of the individual from the rehabilitation centre(s), or Cape Recife in the case of the evacuated birds. Recapture periods were not calendar years, but were set to start in March and end in February of the following year, except for 2000, which started in July 2000 (the first month after the *Treasure* spill) and ended in February 2001. The March–February recapture period was selected to coincide with the end of the peak moult period (February) (Wolfaardt *et al.* 2008). Re-sighting data were collected from July 2000 to March 2005.

The most general model contained transient and time effects on all three groups for survival, except that breeder survival was constant for the orphaned chicks, which were few in number (Model 3, Table 1). In that model, recapture rates were variable over time, except for breeders, where it was constant. The probability of transition from non-breeder to breeder state (Ψ_{nb}) varied among groups and years, and the probability of transition from breeder to secondary non-breeder state (Ψ_{bs}) and secondary non-breeder to breeder state (Ψ_{sb}) varied among groups. We assessed the goodness-of-fit for this model using a procedure based on Monte Carlo simulation, termed the median-$\hat{c}$ approach, in program MARK 4.3 (White and Burnham 1999). The test showed that there was slight overdispersion (estimated $\hat{c}$ = 1.23, SE = 0.03). This estimate was used as a variance inflation factor and adjusted the standard errors and confidence intervals accordingly.

All other models were simplified versions of this general model. Model 4 had constant Ψ_{bs} and Ψ_{sb} (Table 1). Model 2 kept the recapture rate of non-breeders constant over time. Model 1 further ignored the possibility of transients among the evacuated group. Models 5 and 6 were similar to Model 1, except they treated de-oiled birds and evacuees equal in terms of survival (Model 5) and Ψ_{nb} (Model 6). Model selection was based on Akaike's Information Criterion (AICc), adjusted by sample size (Burnham and Anderson 2002).

Results

Numbers of birds caught and rescued

The first oiled penguins were observed ashore at Dassen Island on 24 June, one day after the *Treasure* sank. From 25 June to 28 July, a total of 3 530 oiled penguins was collected at Dassen Island. Of the birds caught, 14 died on the island; 11 birds in adult plumage and three juveniles. The majority (78%) of the oiled birds sent to SANCCOB were in adult plumage; the remainder comprised juvenile birds (21%) and four feathered chicks (Table 2). Some 60% of the total number of oiled penguins sent off the island had been caught by 2 July, when the evacuation of clean penguins began. By 8 July, when the shoreline of the island was largely clear of oil (Crawford *et al.* 2000), 95% of the oiled penguins had been sent off the island (Table 2). Of the oiled birds collected at Dassen Island, 52 were flipper-banded prior to the spill, 19 of which had been oiled and treated by SANCCOB previously. In total, 14 825 oiled African penguins were collected at Robben Island (Crawford *et al.* 2000).

From 2 to 4 July, a total of 12 345 un-oiled adult African penguins were caught at Dassen Island (Table 2). Of the

Table 2: Numbers of African penguins transported off Dassen Island after the *Treasure* oil spill, on different days during June–July 2000. Oiled birds and orphaned chicks were sent to SANCCOB and satellite rehabilitation centres. Clean adults were evacuated to Cape Recife

Date	Oiled adults	Oiled juveniles	Oiled chicks	Clean adults	Orphaned chicks	Mode of transport
25/06/2000	29	15				Boats
26/06/2000	83	29				Boats
27/06/2000	198	103				Boats
28/06/2000	92	51				Boats
29/06/2000	571	59				Boats
30/06/2000	77	26				Boats
01/07/2000	563	211				Boats
02/07/2000				3 580		Boats and helicopter
03/07/2000				4 735		Helicopter
04/07/2000				4 030	171	Helicopter
05/07/2000	750	152			170	Boats
06/07/2000	212	62			108	Boats
08/07/2000	43	17			108	Boats
10/07/2000	66	29			68	Boats
11/07/2000	39	11	4			Boats
14/07/2000	14	2			82	Boats
17/07/2000	1					Boats
21/07/2000	2	1				Boats
23/07/2000	1					Boats
28/07/2000	3					Boats
Totals	2 744	768	4	12 345	707	

un-oiled birds evacuated from Dassen Island, 1 019 were flipper-banded. An additional 7 161 un-oiled penguins were evacuated from Robben Island to Cape Recife, of which 2 232 were flipper-banded (Crawford *et al.* 2000, Barham *et al.* 2006). All birds evacuated from Dassen Island were transported in three-tiered open trucks, whereas birds evacuated from Robben Island were transported in closed trucks. The Robben Island birds were held for 24–48 hours at the Marine and Coastal Management research aquarium in Sea Point (33°54′ S, 18°23′ E) before they were transported to Cape Recife (Crawford *et al.* 2000). The 255 lightly oiled birds that were flipper-banded and released again at Dassen Island on 8 July without being de-oiled comprised 181 birds in adult plumage and 74 juveniles. The majority (79%) of these birds had 5% or less of the underside of their bodies covered by oil.

From 4 to 14 July, 707 orphaned chicks were collected at Dassen Island and sent to the Salt River satellite rehabilitation centre (Table 2). Approximately 2 600 orphaned chicks were collected from Robben Island for captive rearing (Crawford *et al.* 2000).

Numbers of birds released

A total of 17 287 de-oiled birds, 91% of the oiled birds that were caught after the *Treasure* spill, were successfully returned to the wild (Crawford *et al.* 2000). Most were released between 19 July and 30 August 2000 at Milnerton beach (33°51′ S, 18°29′ E) and were wearing steel flipper bands. It was not known at which island each bird had been collected, and therefore how many of the oiled birds collected at Dassen Island were among the de-oiled birds that were successfully released.

Of the 19 506 evacuated birds trucked to Cape Recife, 241 died during transit, or at the release site (Crawford *et al.* 2000). Of these, 17 had flipper bands; 16 had been evacuated from Robben Island and one from Dassen Island. These mortalities represent 2.2% and 1.4% of the total numbers of flipper-banded birds evacuated from Robben Island and Dassen Island respectively. Applying these percentages to the total number of birds released from each island over-represents the total number of mortalities by about 37%, suggesting that a greater proportion of flipper-banded birds died during the evacuation process than unbanded birds.

From 29 July to 6 November 2000, a total of 732 chicks hand-reared at Monty's rehabilitation centre was released on Dassen Island. An additional 1 055 hand-reared chicks from SANCCOB were released on Robben Island (Barham *et al.* 2008). Hand-reared chicks were released with flipper bands.

Re-sightings of de-oiled birds

From July 2000 to March 2005, 6 721 re-sightings of 2 818 de-oiled adult birds were made at Dassen Island. It is not known what proportion of these were among the 3 530 originally collected, as oiled birds, from Dassen Island. In all, 28% of the de-oiled adults re-sighted at Dassen Island were also observed at Robben Island during the study period. Of the de-oiled adults re-sighted at Dassen Island, 55% had been seen by the end of August 2001, approximately one year after their release; 80% and 92% had been re-sighted by the end of August 2002 and August 2003 respectively (Table 3).

Of the de-oiled adult birds that were re-sighted at Dassen Island, 841 (30%) had been recorded breeding by March 2005 (Table 3). Of these, 247 (29%) had bred by the end of August 2001, i.e. within one year of their release. The proportion of re-sighted de-oiled birds that were recorded breeding each year increased from 3.8% in 2000 to between 34% and 38% from 2002 to 2005 (Table 4). The mean number of

Table 3: Cumulative numbers of African penguins re-sighted and recorded breeding at Dassen Island over different time periods following release

Time elapsed	De-oiled adults			Evacuated adults		
	Number observed	Number breeding	Proportion breeding (%)*	Number observed	Number breeding	Proportion breeding (%)*
July 2000–August 2001	1 557	247	15.9	644	404	62.7
July 2000–August 2002	2 248	590	26.3	734	500	68.1
July 2000–August 2003	2 596	732	28.2	750	518	69.1
July 2000–August 2004	2 766	832	30.1	763	521	68.3
July 2000–March 2005	2 818	841	29.8	766	521	68.0

***** Cumulative proportion of birds observed at Dassen Island that were recorded breeding there over the different time intervals

Table 4: Numbers of African penguins affected by the *Treasure* oil spill observed and recorded breeding at Dassen Island each year, July 2000–March 2005

Year	De-oiled adults			Lightly oiled adults			Evacuated adults		
	Number observed	Number breeding	Proportion breeding (%)	Number observed	Number breeding	Proportion breeding (%)	Number observed	Number breeding	Proportion breeding (%)
2000[a]	796	30	3.8	52	0	0.0	499	232	46.5
2001	1 162	247	21.3	39	4	10.3	518	348	67.2
2002	1 145	428	37.4	32	12	37.5	424	298	70.3
2003	636	241	37.9	27	8	29.6	234	149	63.7
2004	486	167	34.4	18	6	33.3	127	65	51.2
2005[b]	94	35	37.2	6	2	33.3	25	15	60.0

[a] July 2000–December 2000
[b] January 2005–16 March 2005

years in which de-oiled birds were recorded breeding during the study period was 1.37 (SD = 0.77 years, n = 841 birds).

A total of 274 de-oiled penguins released in juvenile plumage was observed at Dassen Island between July 2000 and March 2005, 60 of which were also re-sighted at Robben Island. Of the de-oiled juvenile birds re-sighted at Dassen Island, 42 (15.3%) were recorded breeding.

Re-sightings of lightly oiled birds

Of the 181 lightly oiled adult birds that were banded and released without being de-oiled on 8 July 2000 at Dassen Island, 104 (59%) were observed at Dassen Island between September 2000 and March 2005. None of these birds, where oil had penetrated to the skin, were re-sighted. For birds superficially oiled, 67% of those that were <5% contaminated were re-sighted (Figure 3). The proportion of lightly oiled birds re-sighted decreased as the extent of contamination increased, from 55% (for birds that were 5% contaminated) to 0% (for birds that were 20% contaminated) (Figure 3). This outcome was evaluated for adults using a GLM. Using the un-oiled evacuated birds as controls, the degree of oiling was entered into the model as a categorical variable. The modelled re-sighting probability for penguins with <5% oiling was not significantly different from that of un-oiled birds (p = 0.114). However, higher levels of oiling were associated with significantly lower re-sighting probabilities (5% oiling, p = 0.001; 10%, p = 0.005; 15% or more, p = 0.057, but the sample size for this category was only four). The proportion of re-sighted birds that were recorded breeding decreased with the degree of oiling, from 28% for birds <5% contaminated, to 25% for birds with 5% contamination, and 6% for birds that were 10% oiled. No birds that were >10% oiled were recorded breeding (Figure 3). The results of the GLM indicated that, even for penguins that were <5% oiled, the probability of resuming breeding

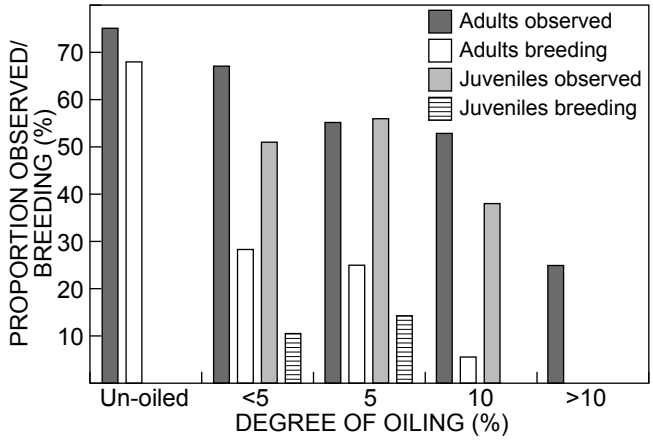


Figure 3: Proportions of flipper-banded adults and juvenile African penguins from the *Treasure* oil spill with different degrees of oiling that were observed, and the proportion of those observed that were recorded breeding, at Dassen Island between August 2000 and March 2005. These oiled penguins were not sent to SANCCOB, but released at Dassen Island without being de-oiled. The un-oiled group comprises flipper-banded penguins (adults only) that were evacuated from Dassen Island during the spill, and serves as a control (see text for details)

after capture was significantly lower than for un-oiled birds ($p < 0.001$). The remaining categories also showed significantly reduced probabilities (all $p < 0.001$). No lightly oiled adults were recorded breeding in 2000 (Table 4). In 2001, 10% of the lightly oiled adults re-sighted were recorded breeding; from 2002 to 2005, this proportion fluctuated between 30% (in 2003) and 38% (in 2002) (Table 4).

In all, 50% of the lightly oiled juveniles were re-sighted during the study period. Larger proportions of birds with oil contamination of 5% or less were re-sighted than those with greater levels of oil contamination; no juveniles with >10% contamination were re-sighted (Figure 3). Four juveniles that had been lightly oiled, all <10% contaminated, were recorded breeding by the end of March 2005.

Re-sightings of evacuated birds

In total, 766 (68%) of the flipper-banded birds evacuated from Dassen Island were re-sighted there between July 2000 (after their release) and March 2005 (Table 3). Evacuated birds were re-sighted at Dassen Island from 14 July 2000. The median interval between release and first sighting was 101 days (range: 11–1 627). By the end of July 2000 (i.e. within a month of the evacuation), 194 evacuees had been re-sighted. This figure represents 19% of the total number of evacuees that were released with flipper-bands, and 25% of the flipper-banded evacuees that were re-sighted during the study period. By the end of August 2001, 84% of the re-sighted birds had been recorded (Table 3). The mean mass of evacuees first re-sighted between 14 July 2000 and 19 July 2000 was 3.36 kg (SD = 0.42 kg, $n = 20$). This mean is higher than the mean masses of both male and female African penguins, given by Hockey *et al*. (2005) as 3.31 and 2.96 respectively. Twelve (1.2%) of the 1 019 flipper-banded birds that were evacuated from Dassen Island were observed at Robben Island during the study period; all were also re-sighted at Dassen Island.

In total, 521 (68%) of the re-sighted evacuees were recorded breeding during the study period (Table 3). Of these, 13 were recorded breeding within a month of their evacuation from Dassen Island. During the first year following the evacuation, 404 evacuees had been recorded breeding (Table 3), representing 63% of the total number of evacuees re-sighted at Dassen Island and 78% of the total number of evacuees that were recorded breeding. The rate of cumulative re-sightings over time indicates a more rapid return of evacuees to Dassen Island compared with de-oiled birds, and a substantially faster rate of restoration into the breeding population (Table 3). For example, by August 2002 (two years after the event), 2 248 de-oiled penguins had been re-sighted and of these 590 (26%) had been recorded breeding; for evacuated penguins these values were 734 and 500 (68%) respectively; this difference is significant ($\chi^2 = 418.4$, df = 1, $p < 0.001$). The proportion of re-sighted evacuees breeding each year was lowest in 2000 (47%) and highest in 2002 (70.2%), and was on average double the proportion of de-oiled and lightly oiled birds recorded breeding each year (Table 4). The mean number of years in which evacuees were recorded breeding was 2.12 (SD = 1.24 years, $n = 521$), significantly greater than the frequency of breeding for de-oiled birds ($t = 13.97$, df = 1 360, $p < 0.001$).

Of the 2 232 flipper-banded penguins evacuated from Robben Island, 677 (30%) were re-sighted at Dassen Island. Of these, 62 were also observed at Robben Island and were probably transient visitors to Dassen Island when they were observed there. The remaining 615 birds were never re-sighted at Robben Island after their evacuation. A total of 408 of the Robben Island evacuees was observed breeding at Dassen Island, equivalent to 60% of the total number of Robben Island evacuees observed at Dassen Island, and 66% of the birds that were observed only at Dassen Island. In the first year following the evacuation, 228 of the Robben Island evacuees were recorded breeding at Dassen Island, 56% of the total that were recorded breeding during the study period.

Re-sightings of hand-reared chicks

Between January 2001 and March 2005, 361 (20.2%) of the 1 787 hand-reared chicks released with flipper bands were re-sighted at Dassen Island (Table 5). A significantly greater proportion of the birds released on Robben Island (27%), compared with those released on Dassen Island (11%), were re-sighted at Dassen Island ($\chi^2 = 43.3$, df = 1, $p < 0.001$; Table 5). In total, 82 of the hand-reared chicks released on Dassen Island were observed between 2001 and 2006 at Robben Island (Barham *et al.* 2008), 10 of which were also observed at Dassen Island. The majority (71%) of the 287 hand-reared chicks re-sighted at Robben Island had been released on Robben Island (Barham *et al.* 2008). Fifty of the 205 orphans that were released on Robben Island and later re-sighted there were also observed at Dassen Island. Of the hand-reared chicks that were released at Dassen and Robben islands, 9.9% of the birds released and later re-sighted at Dassen Island and 9.3% of those released at Robben Island and subsequently re-sighted at Dassen Island were recorded breeding at Dassen Island (Table 5).

CMR results

Model selection favoured a model with constant recapture rates for non-breeders and breeders, time and group effects

Table 5: Numbers of hand-reared African penguin chicks that were released from Dassen and Robben islands after the *Treasure* oil spill that were re-sighted and recorded breeding at Dassen Island between 2001 and March 2005

Release island	Number released	Number re-sighted	Number breeding
Dassen	732	81	8
Robben	1 055	280	26
Total	1 787	361	34

on survival, together with transient effects for de-oiled adults and orphaned chicks (Model 1, Table 1). Model 1 was therefore used to estimate the survival and breeding parameters. This model also indicated variation in the transition from non-breeder to breeder (Ψ_{nb}) between groups and years, and variation between groups in the transition from breeder to secondary non-breeder (Ψ_{bs}), and from secondary non-breeder to breeder (Ψ_{sb}) (Table 1). The improved fit of Model 1 to the data compared with Models 5 and 6, in which de-oiled birds and evacuees were treated equal in terms of survival and Ψ_{nb}, indicates that survival and the probability of transition from non-breeder to breeder differed between these two groups (Table 1, ΔAICc = 19.97 and 56.68 for survival and probability of breeding respectively).

The mean survival of de-oiled breeders remained lower than evacuated breeders throughout the study, ranging from 7% lower for the period 2000/2001 to 17% lower for the periods 2001/2002 and 2002/2003 (Figure 4). The survival estimates for the first interval (2000/2001) are for an eight-month period, and so would be expected to be slightly higher than the annual survival estimates in the other periods (Figure 4).The mean survival of de-oiled and evacuated non-breeders varied similarly throughout the study. For both groups, the mean survival rates declined in the period 2002/2003, before increasing again in 2003/2004 (Figure 5). For evacuated birds, the reduction in the survival rate in 2002/2003 and the large confidence intervals in 2003/2004 (Figure 5) probably reflects the reduced size of the non-breeding population (the models predict that by the end of the 2002 interval, 69% of the surviving evacuees had resumed breeding).

In the first year following the *Treasure* spill (the period 2000/2001), the model predicted that 44% of the evacuated birds resumed breeding, compared with 12% of the de-oiled birds (Figure 6). These figures are lower than those obtained from the re-sighting data alone, because the CMR models quantify the probability of a bird making the transition from non-breeder to breeder state, and only include breeding records that are preceded by a 'non-breeding' sighting. The proportions of evacuated and de-oiled birds that resumed breeding in 2001/2002 and each subsequent period were similar (Figure 6). Consequently, the overall proportion of re-sighted evacuees that resumed breeding was substantially greater than for de-oiled birds.

The improved fit of Model 3 over Model 4 (ΔAICc = 13.62, Table 1), in which the modelled transition from breeder to secondary non-breeder (Ψ_{bs}) was kept constant, shows that this transition differed between groups. De-oiled adults stopped breeding at a higher rate (mean = 0.44, SE = 0.03) than evacuated birds (mean = 0.30, SE = 0.02) over the course of the study.

The estimated annual survival rates for hand-reared orphans released at Robben Island and re-sighted at

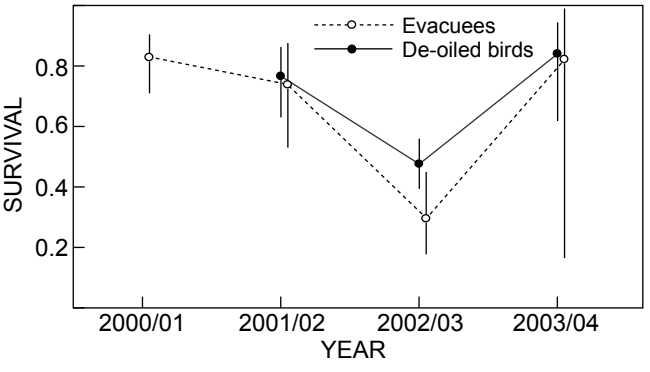


Figure 5: Annual survival rates of de-oiled and un-oiled evacuated African penguin non-breeders following the *Treasure* oil spill from 2000/2001 to 2003/2004. The intervals for each year are as described in Figure 4. Survival could not be estimated for de-oiled non-breeders in the first year following the spill (2000/2001) because of the effect of transients on survival (see text). The vertical lines show 95% confidence intervals. The estimates are from Model 1, Table 1. The symbols are slightly offset to facilitate comparison

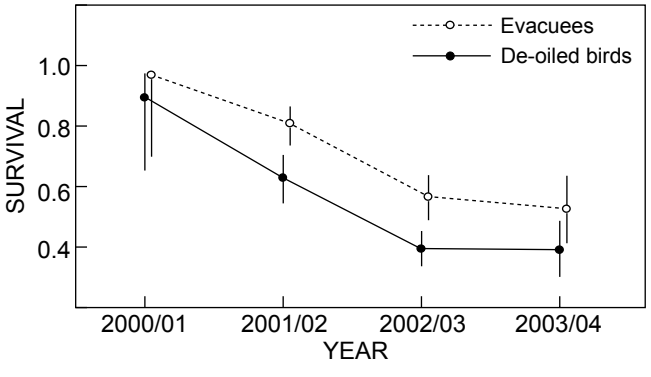


Figure 4: Annual survival rates of de-oiled and un-oiled evacuated African penguin breeders following the *Treasure* oil spill from 2000/2001 to 2003/2004. The year 2000/2001 corresponds to the period July 2000–February 2001; 2001/2002 comprises the period March 2001–February 2002, as is the case for 2002 and 2003. the vertical lines show 95% confidence intervals. The estimates are form Model 1, Table 1. The symbols are slightly offset to facilitate comparison

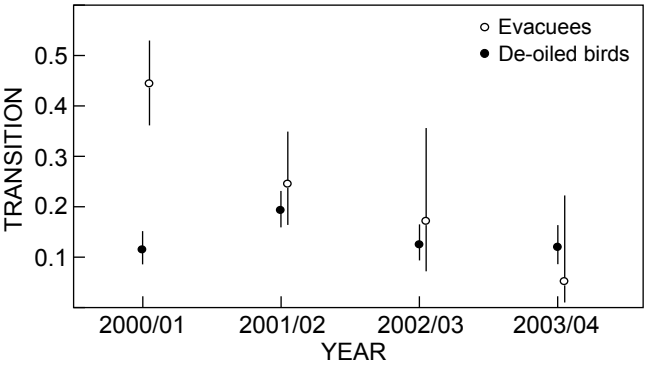


Figure 6: Estimates of the probability of transition from non-breeder to breeder state (ψ_{nb}) for de-oiled and un-oiled evacuated African penguins following the *Treasure* oil spill from 2000/2001 to 2003/2004. The time periods for each year are as described in Figure 4. For each year, the probability of becoming a breeder applies to those birds that have not yet been recorded breeding. The vertical lines show 95% confidence intervals. The estimates are from Model 1, Table 1

Dassen Island was 0.60 for the period 2001/2002; it decreased to 0.41 in 2002/2003 and increased again to 0.79 in the period 2003/2004. During the first year following the spill (2000/2001), residents could not be separated from transients, and so we were unable accurately to estimate survival for this period. No orphaned chicks were recorded breeding in the first two years after the spill. The model suggests that 8.5% of the surviving orphans initiated breeding from 2002/2003 (95% confidence interval: 3.4–19%), and an additional 20.4% from 2003/2004 (95% confidence interval: 10.4–36.4%).

Discussion

Rescue and de-oiling success

The impact of an oil spill on African penguins is influenced more by the location of the spill and the prevailing weather conditions than the quantity of oil that is spilled (Morant *et al.* 1981, Whittington 2002, 2003). The *Apollo Sea* released approximately 2 400 t of oil after it sank, and contaminated about 10 000 African penguins (Erasmus 1995, Underhill *et al.* 1999). Although the oil released from the *Treasure* wreck six years later was 58% (1 400 t) of the amount spilled by the *Apollo Sea*, it resulted in the contamination of 90% more penguins (19 000), and prompted the evacuation and relocation of an additional 19 500 penguins (Crawford *et al.* 2000).

Despite this fourfold increase in the number of birds that were handled during the *Treasure* oil spill, the mortality rate of penguins in the initial stages of the rescue operation was substantially lower than was the case during the *Apollo Sea* spill. Of the 15 875 penguins that were captured on Dassen Island following the *Treasure* spill, only 14 (0.09%) died before they could be transported off the island. By 18 August 2000, a total of about 2 000 adult and juvenile penguins had died, 11% of the approximately 19 000 that were oiled (Crawford *et al.* 2000). The greater success in the early stages of the *Treasure* spill translated into a higher release rate. Approximately 90% of the oiled penguins collected after the *Treasure* oil spill were successfully released after de-oiling (Crawford *et al.* 2000), compared with 46% following the *Apollo Sea*, equivalent to 75% of the birds that survived their first 24 hours in captivity (Williams 1995, Nel *et al.* 2003). The improved success in the capture phase of the rescue operation and in the final release of de-oiled birds was due largely to the implementation of measures to remedy the shortcomings raised by Williams (1995), including the design and use of a well-ventilated penguin transport box (Crawford *et al.* 2000), vastly improved communication between staff on the islands, and between the islands and the mainland, and improved capacity and preparedness to respond to oil spill events.

De-oiling versus evacuation

Prior to the *Treasure* spill, the main focus of South African seabird rescue operations following oil spills was to catch and treat oiled birds as soon as possible, before releasing them back into the wild; measures to prevent birds becoming oiled were not part of any oil spill contingency plans (Wolfaardt 2004). Given the severity of the *Treasure* spill and the potential for unmanageable numbers of penguins to become contaminated, it soon became apparent that additional measures had to be taken to minimise the number of penguins becoming oiled. The idea of fencing breeding colonies to prevent un-oiled penguins from entering the sea, where they could potentially become contaminated, was implemented at Dyer Island following the sinking of the *Wafra* in 1971 (Morant *et al.* 1981). However, this was not possible during the *Treasure* spill, because of the large number of penguins involved. Consequently, a decision was taken to evacuate clean birds from Dassen and Robben islands and release them at Cape Recife, which was considered sufficiently distant (c. 800 km to the east) to allow enough time for the oil to be cleaned (Crawford *et al.* 2000). In 1995, de-oiled and un-oiled little penguins *Eudyptula minor* were successfully evacuated to sites away from the area that was contaminated after the grounding of the *Iron Baron* in northern Tasmania (Hull *et al.* 1998, Goldsworthy *et al.* 2000).

The greater rates of return and restoration shown by evacuated birds relative to de-oiled birds in this study demonstrate the conservation value of evacuating penguins in large oil spill events. Differences in these variables also highlight the negative impact of oil contamination on African penguins, particularly on their ability to breed.

The evacuated birds returned rapidly to their colonies, and many resumed breeding soon after their return. The first evacuated birds were recorded back at Dassen Island on 14 July, 11 days after their release from Cape Recife. The last oil was removed from the *Treasure* on 18 July, but the areas around Dassen and Robben islands were mostly cleared of oil by 14 July (Crawford *et al.* 2000). The choice of Cape Recife was therefore appropriate in this case because it was sufficiently distant to allow enough time for the oil to be cleared before the birds returned, but close enough for most birds to return within two to four weeks, thereby minimising the disruption to breeding and moult activities.

The overall proportion of evacuated birds that were recorded breeding during the study period was more than double the proportion of de-oiled birds that were recorded breeding. This difference is likely to result from a number of factors. First, the evacuated birds were, on average, away from the island for a shorter period (2–3 weeks) than the birds that were de-oiled (an average of six weeks between capture and release after treatment at SANCCOB). This resulted in evacuated birds returning to Dassen Island more rapidly than de-oiled birds. De-oiled birds may, for example, experience a degree of disorientation following their release from the rehabilitation centre, causing them to move short distances away from their breeding colony before returning there (Whittington *et al.* 2005b). One year after the spill, 84% of the total number of evacuated birds that were re-sighted had been observed, compared with 55% of the de-oiled birds. Consequently, the breeding and moult activities of the evacuated birds would have been less disrupted than was the case for de-oiled birds. Second, the evacuated birds were un-oiled and so did not suffer any of the harmful biological impacts of oiling (Bourne 1976, Burger 1992, Burger and Fry 1993, Nisbet 1994, Burger 1997, Burger and

Gochfeld 2002). Oil contamination and the de-oiling process following the *Apollo Sea* spill in 1994 resulted in delayed and reduced breeding for some penguins, whereas others were never recorded breeding again (Wolfaardt *et al.* 2008).

Another factor that may have influenced the difference in the proportions of evacuated and de-oiled birds recorded breeding is the incidence of transients (i.e. non-residents) in the two groups. The evacuated birds were collected from within fenced breeding colonies, whereas almost all of the oiled birds were caught along the coastline. When oiled, African penguins generally make landfall at the nearest site (Underhill *et al.* 1999), and so oiled birds collected at Dassen Island (and Robben Island) may have been residents at other locations. That a much lower proportion (1.6%) of the re-sighted Dassen Island evacuees was observed at other colonies than de-oiled birds (28%) suggests the presence of transients within the de-oiled group and/or disorientation of de-oiled birds. The large difference in the proportions of evacuated and de-oiled birds re-sighted in the first two years following the spill may also have been due to delayed breeding of de-oiled birds. Further evidence for real differences in these proportions was provided by the CMR models, which, after accounting for transients, indicated significant differences in the probability of breeding between evacuated and de-oiled birds.

The CMR models also suggested that breeding activities exerted a greater cost to de-oiled birds than evacuated birds. The estimated survival rates for de-oiled and evacuated non-breeders were similar. However, the de-oiled birds survived less well once they started breeding. As was reported for de-oiled survivors of the *Apollo* spill, the adverse effects of oil contamination may become more apparent as a result of breeding activities (Wolfaardt *et al.* 2008), especially the energetically demanding requirements of chick rearing (Ricklefs 1974, 1983). Reproduction was shown to impose a greater cost, as measured by changes in body mass after breeding, to de-oiled little penguins than to un-oiled birds in the two seasons following the *Iron Baron* spill (Giese *et al.* 2000, Goldsworthy *et al.* 2000). De-oiled African penguins from the *Treasure* spill had a higher probability of stopping breeding (i.e. becoming a secondary non-breeder) than evacuees. Breeding success of de-oiled *Treasure* birds was not measured in this study. However, between 2001 and 2005 at Robben Island, the mean fledging success of de-oiled *Treasure* birds was 18% lower than that of un-oiled birds (Barham *et al.* 2007). The reduced fledging success of de-oiled birds relative to un-oiled birds was driven largely by increased mortality of chicks of medium to large size (Barham *et al.* 2007), suggesting that de-oiled birds experienced greater stress during chick rearing than un-oiled birds.

Of the un-oiled penguins evacuated from Robben Island, 40% had been re-sighted by the end of December 2004, some four and a half years after the spill (Barham *et al.* 2006). This proportion is substantially less than the proportion (75%) of those evacuated from Dassen Island that had been re-sighted there by March 2005. It is also less than the proportion (67% of those in adult plumage when oiled) of de-oiled birds estimated to have been from Robben Island that were re-sighted there over the same time period (Barham *et al.* 2006). Given the demonstrated impacts of oil contamination on African penguins (Barham *et al.* 2007), it is surprising that, in contrast to the results at Dassen Island, a greater proportion of the de-oiled birds from Robben Island were re-sighted than evacuated birds. The penguins evacuated from Robben Island experienced a substantially higher mortality rate between their capture on the island and their release at Cape Recife than the penguins evacuated from Dassen Island. This was almost certainly due to the different types of vehicles used to transport the birds from the Western Cape to Cape Recife. The Dassen Island birds were transported in open-tiered trucks whereas the Robben Island birds were placed in closed trucks with less ventilation. Post-mortem examination of the birds that were found dead at Cape Recife revealed that the deaths were probably caused by carbon monoxide poisoning (Crawford *et al.* 2000). Another difference between the birds that were evacuated from Robben and Dassen islands was the way in which they were held before being transported to Cape Recife. The Dassen Island birds were fenced in at the island, whereas the Robben Island birds were transported off the island and kept in a holding facility on the mainland, where they were allowed to swim and drink, before being re-packed into penguin boxes and trucked to Cape Recife (Crawford *et al.* 2000).

However, these factors cannot account for the discrepancy between the proportions of evacuated birds re-sighted at the two islands. The fact that 30% of the Robben Island evacuees were observed at Dassen Island, whereas only 1% of the Dassen Island evacuees were observed at Robben Island, suggests that a large proportion of the un-oiled birds evacuated from Robben Island may have been transient visitors to the island when they were caught. The un-oiled penguins evacuated from Robben Island were caught along the shore (Barham *et al.* 2006), whereas those from Dassen Island were from within the breeding colonies and so are more likely to have been resident breeders. The presence of non-resident penguins at Robben Island following the *Treasure* spill is highlighted by the fact that the number of penguins removed from the island exceeded the estimated population of the colony in 2000 by more than 4 000 individuals (Crawford *et al.* 2000). It is noteworthy that, excluding birds that were observed at both islands, the proportion of Robben Island evacuees re-sighted on Dassen Island that was recorded breeding there was similar to the proportion of Dassen Island evacuees recorded breeding. If the transient visitors that were collected at Robben Island returned to their resident colony following release, as would be expected, the proportion of released birds re-sighted at Robben Island would underestimate survival. If birds evacuated from Robben Island and re-sighted at Dassen Island are considered, the proportion of Robben Island evacuees that was re-sighted increases to 65%. This is similar to the 69% of de-oiled penguins observed at Robben Island over the same period (Barham *et al.* 2006), but less than the 75% of Dassen Island evacuees that were re-sighted. Because re-sighting effort after the *Treasure* spill was largely limited to Dassen and Robben islands, it is not possible to determine the degree of movement or return of birds to other colonies.

It is also noteworthy that the nesting habitats at Dassen and Robben islands differ, which in turn influences the probability of re-sighting banded individuals at the two colonies. For example, parts of Robben Island are infested with dense stands of *Acacia cyclops* shrubs and trees, under which penguins breed. These birds are generally more difficult to detect than birds nesting in more open colonies, which are more characteristic of Dassen Island. This highlights the importance of accounting for recapture probabilities in estimating survival and related parameters (Lebreton *et al.* 1992).

Lightly oiled penguins

It appears that the extent of oiling influences both survival (inferred from the re-sighting probabilities) and restoration success (proportion of re-sighted birds recorded breeding), and that even low levels of contamination are harmful to African penguins. A larger proportion of penguins with 5% or less of their body covered in oil was re-sighted and recorded breeding than penguins with more extensive oiling. Similarly, the proportion of juvenile penguins re-sighted and recorded breeding was largest for penguins that had 5% or less of their body covered in oil; no juvenile penguins with >5% contamination were recorded breeding. The small sample sizes necessitate some caution in interpretation. However, the degree of oiling, and its effect on body mass, was found to be the most important factor determining post-release survival of de-oiled little penguins following the *Iron Baron* spill in Tasmania (Goldsworthy *et al.* 2000). In the *Iron Baron* study, the likelihood of post-release survival declined by about 11% per year for every 25% increase in the extent of oiling (Goldsworthy *et al.* 2000). Body mass at capture and the period between capture and de-oiling significantly influence the survival rates of oiled African penguins through the de-oiling process; birds that are caught at weights <2 kg suffer greater mortality than heavier birds (Kerley and Erasmus 1987).

Interestingly, Parsons and Underhill (2005) found no correlation between the extent of oiling of African penguins on admission to SANCCOB in 2001 and 2002 and their probability of surviving the de-oiling process. It is possible that a greater extent of oiling of African penguins manifests itself in reduced survival and restoration after the birds have been released from SANCCOB.

Success of hand-rearing orphaned chicks

Up until March 2005, 20% of the hand-reared chicks that were released with flipper bands had been re-sighted at Dassen Island. This is slightly larger than the proportion (16%) observed at Robben Island until the end of December 2006 (Barham *et al.* 2008). In total, 588 individuals (33% of those released) had been re-sighted by the end of December 2006 at the two colonies, 60 (10%) of which were observed at both islands. The total proportion of *Treasure* orphans re-sighted at Robben and Dassen islands was substantially greater than the proportion (10.8%) of hand-reared chicks that were re-sighted following the *Apollo Sea* spill over a five-year period (Whittington 2002). In the latter study, the survival rate of hand-reared chicks was similar to that of naturally fledged chicks from Dassen Island (Whittington 2002).

That a greater proportion of the chicks released at Robben Island were observed at both Robben and Dassen islands is interesting. The natal colony of the chicks was not known. All of the chicks that were reared at Monty's rehabilitation centre were released at Dassen Island, and chicks that were raised at SANCCOB and its satellite centres were released at Robben Island. The larger proportion of Robben Island birds re-sighted at both islands suggests that these birds may have experienced a lower mortality rate than those released on Dassen Island. The chicks reared at Monty's (and released on Dassen Island) were routinely released at a heavier mass than even the largest naturally reared chicks (ACW pers. obs). Although the intention of the volunteers at Monty's was to fatten the birds so that they were better equipped to survive once they were released, it is possible that these birds were 'overweight'. Juvenile African penguins are less efficient swimmers than adults (Wilson 1985), and so are less able to evade predators such as Cape fur seals *Arctocephalus pusillus pusillus* and sharks (Cooper 1974, Randall *et al.* 1988). Overweight chicks are less agile than those that fledge at an optimum weight, and therefore less likely to escape an attack from a predator.

On the basis of the large degree of mixing of the two groups of hand-reared chicks subsequent to their release, it is clear that chicks do not necessarily recruit to the colony at which they were released. African penguins are known to be strongly faithful to their natal islands, and generally return there to breed (Randall *et al.* 1987, Whittington *et al.* 2005a). However, birds have been reported emigrating as first-time breeders from their natal colony to localities where conditions (generally food availability) are more favourable at the time, and remain faithful to that colony thereafter (Crawford 1998, Whittington *et al.* 2005a). A recent proposal to bolster extant but declining colonies of African penguins through introductions to these colonies of chicks reared in captivity (RJM Crawford, Marine and Coastal Management, *in litt.*) requires an understanding of the cues used by penguins to return to their natal island. The results presented here suggest that the release site alone may not be sufficient to determine the locality at which the birds will settle. A greater degree of success may be obtained if chicks were brought to the colonies earlier and kept there for longer before being released. Alternatively, we may have to rely on the penguins themselves to determine the best location at which to breed.

The annual survival rates for hand-reared orphans released at Robben Island but re-sighted at Dassen Island varied during the course of the study (2001–2004). Annual survival was lowest (0.41) for the period 2002–2003, increasing the following year to the highest recorded estimate of 0.79. The estimated survival of *Treasure* hand-reared orphans at Robben Island was just <0.50 in 2000 and 2001, and increased to about 0.80 from 2002 to 2004 (Barham *et al.* 2008). Except for 2002, the survival estimates were similar. The CMR models used to estimate survival in both the Dassen Island and Robben Island analyses did not distinguish between mortality and

permanent emigration. It is possible that the relatively low survival estimated for Dassen Island in 2002 resulted from emigration. The orphans then would all have been subadults, i.e. not of breeding age.

About 9.6% of the hand-reared *Treasure* chicks re-sighted at Dassen Island during the study period were recorded breeding, slightly less than the proportion (c. 15%) that attempted breeding following the *Apollo Sea* (Whittington 2002). In total, 97 (33.8%) of the hand-reared *Treasure* chicks that were re-sighted at Robben Island were recorded breeding by the end of December 2006 (Barham *et al.* 2008). The lower proportion of birds breeding at Dassen Island is likely to be due to the lower re-sighting effort at Dassen Island (relative to Robben Island) from 2003 onwards, when these birds started breeding for the first time.

Census results following the Treasure *spill*

Against the background outlined in the Introduction, and the concern about the impact of the *Treasure* oil spill on the breeding population, the results of the 2001 census were surprising. The increase in the number of penguins breeding in 2001 can be attributed to several factors. The combined spawner biomass of anchovy *Engraulis encrasicolus* and sardine *Sardinops sagax,* the two most important prey items for African penguins (Berruti *et al.* 1989, Crawford and Dyer 1995, Crawford *et al.* 2006), in South African waters in 2001 was double any previous estimate obtained by a direct survey (Crawford *et al.* 2006). The abundance of food for penguins in 2001 is likely to have resulted in a large percentage of birds of breeding age attempting to breed. Indeed, the proportion of re-sighted *Apollo Sea* birds recorded breeding each year between 1994 and 2005 peaked from 2001 to 2003 (Wolfaardt *et al.* 2008). Increased recruitment in the few years before the *Treasure* spill likely also contributed to the growth in penguin numbers. African penguins recruit to the breeding population at 3–4 years of age, and the four years prior to the 2001 census were markedly better food years than earlier years (Barange *et al.* 1999). The anticipated adverse impact of the *Treasure* spill was therefore fortuitously offset by favourable feeding conditions.

Given the death of about 2 000 adult penguins in the *Treasure* oil spill in 2000 (Crawford *et al.* 2000), and the relatively small proportion of de-oiled birds that attempted breeding in 2001, it is clear that the increased breeding populations observed in 2001 would have been even greater had the oil spill not occurred. Feeding conditions remained favourable for penguins in the Western Cape up until 2004 (Crawford *et al.* 2006). Consequently, numbers of African penguins breeding in the Western Cape, and especially at Dassen and Robben islands, continued to increase after 2001, reaching a peak in 2004 (Underhill *et al.* 2006, Wolfaardt *et al.* in press a). It seems that 2002 must have been a particularly good year because it was the period in which the greatest proportion of re-sighted *Apollo Sea* birds (Wolfaardt *et al.* 2008), and all *Treasure* affected birds, were recorded breeding. It was also the year in which the best breeding success was recorded for African penguins at Robben Island in a study which spanned the period 2001–2005 (Barham *et al.* 2007).

Subsequently, an eastward shift in the distribution of sardine (van der Lingen *et al.* 2005, Fairweather *et al.* 2006), and a decline in the biomass of anchovy (Crawford *et al.* 2008a) led to a substantially reduced availability of prey for penguins west of Cape Point, and a 45% reduction in the breeding population of African penguins in the Western Cape between 2004 and 2006 (Crawford *et al.* 2008a, Wolfaardt *et al.* in press a).

The results reported here highlight the importance of two factors for the future of African penguins: oiling, and the availability of pelagic fish as a food resource. Better management of the oil pollution problem, and specifically reducing the frequency of oiling incidents and the number of penguins that become oiled, will have a positive effect on the conservation status of African penguins. However, South Africa is a global oiling hotspot, because of its position on a major international sea route, and so it is reasonable to expect that major oil spills will occur in the future. It is therefore crucial that seabird rescue operations and the de-oiling process continue to be improved, so that the impacts of future spills on the already threatened African penguin (and other seabirds) can be minimised. Wise management of fish stocks aimed at increasing this resource will have a positive impact on the conservation status of African penguins. The corollary is that reduced pelagic fish resources, or even a shift in the distribution of prey, may have severe consequences for central-place foragers such as the African penguin (Crawford *et al*. 2008b).

Acknowledgements — We thank the many field workers and volunteers who participated in the capture, rehabilitation, relocation and rearing of the contaminated and affected penguins, as well those involved in post-release monitoring activities. P Barham allowed us to make use of the penguin re-sighting data from Robben Island. ACW acknowledges logistical and financial support from the Western Cape Nature Conservation Board, and financial support from the National Research Foundation, the International Fund for Animal Welfare, WWF-SA and the International Tanker Owners Pollution Federation. LGU was supported by the Seachange Programme of the National Research Foundation, the Earthwatch Institute and the University of Cape Town Research Committee. RA acknowledges support from the Swiss Science Foundation (SNF, fellowship no. PA00A – 113066/1). N Parsons, R Crawford and an anonymous referee provided helpful comments to improve the paper.

References

Barange M, Hampton I, Roel BA (1999) Trends in the abundance and distribution of anchovy and sardine on the South African continental shelf in the 1990s, deduced from acoustic surveys. *South African Journal of Marine Science* **21**: 367–391

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

Barham PJ, Crawford RJM, Underhill LG, Wolfaardt AC, Barham BJ, Dyer BM, Leshoro TM, Mëyer MA, Navarro R, 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, Altwegg R, Leshoro TM, Bolton D, Dyer BM, Upfold L (2008) The efficacy of hand-rearing

penguin chicks: evidence from African penguins (*Spheniscus demersus*) orphaned in the *Treasure* oil spill in 2000. *Bird Conservation International* **18**: 144–152

Barrett J, Erasmus Z, Williams AJ (eds) (1995) *Proceedings: Coastal Oil Spills: Effect on Penguin Communities and Rehabilitation Procedures.* Cape Nature Conservation, Cape Town

Berruti A, Adams NJ, Jackson S (1989) The Benguela ecosystem Part VI: seabirds. *Oceanography and Marine Biology: an Annual Review* **27**: 273–335

BirdLife International (2004) *Threatened Birds of the World 2004.* CD Rom version. BirdLife International, Cambridge, UK

Bourne WRP (1976) Seabirds and pollution. In: Johnston R (ed) *Marine Pollution*. Academic Press, London, pp 403–502

Burger AE (1992) The effects of oil pollution on seabirds off the west coast of Vancouver Island. In: Vermeer K, Butler RW, Morgan KH (eds) *The Ecology, Status and Conservation of Marine and Shoreline Birds on the West Coast of Vancouver Island*. Canadian Wildlife Service, Ottawa, pp 120–128

Burger AE, Fry DM (1993) Effects of oil pollution on seabirds in the northeast Pacific. In: Vermeer K, Briggs KT, Morgan KH, Siegel-Causy D (eds) *The Status, Ecology and Conservation of Marine Birds in the North Pacific.* Canadian Wildlife Service Special Publication, Ottawa, pp 254–262

Burger J (ed) (1997) *Oil Spills.* Rutgers University Press, New Brunswick, New Jersey

Burger J, Gochfeld M (2002) Effects of chemicals and pollution on seabirds. In: Schreiber EA, Burger J (eds) *Biology of Marine Birds*. CRC Press, Boca Raton, Florida, pp 485–525

Burnham KP, Anderson DR (eds) (2002) *Model Selection and Multimodel Inference: a Practical Information-Theoretic Approach* (2nd edn). Springer-Verlag, New York

Cheney C (2000) The *Treasure* oil spill: the results, the event, the background. *Penguin Conservation* **13**: 34–40

Cooper J (1974) The predators of the jackass penguin. *Bulletin of the British Ornithological Club* **94**: 21–24

Crawford RJM (1998) Responses of African penguins to regime changes of sardine and anchovy in the Benguela system. In: Pillar SC, Moloney CL, Payne AIL, Shillington FA (eds) *Benguela Dynamics: Impact of Variability on Shelf-Sea Environments and their Living Resources. South African Journal of Marine Science* **19**: 355–364

Crawford RJM (2000) African penguin. In: Barnes KN (ed) *The Eskom Red Data Book of Birds of South Africa, Lesotho and Swaziland*. BirdLife South Africa, Johannesburg, pp 56–57

Crawford RJM, Barham PJ, Underhill LG, Shannon LJ, Coetzee JC, Dyer BM, Leshoro TM, Upfold L (2006) The influence of food availability on breeding success of African penguins *Spheniscus demersus* at Robben Island, South Africa. *Biological Conservation* **132**: 119–125

Crawford RJM, David JHM, Shannon LJ, Kemper J, Klages NTW, Roux J-P, Underhill LG, Ward VL, Williams AJ, Wolfaardt AC (2001) African penguins as predators and prey – coping (or not) with change. In: Payne AIL, Pillar SC, Crawford RJM (eds) *A Decade of Namibian Fisheries Science*. *South African Journal of Marine Science* **23**: 435–447

Crawford RJM, Davis SA, Harding RT, 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, Dyer BM (1995) Responses by four seabirds to a fluctuating availability of Cape anchovy *Engraulis capensis* off South Africa. *Ibis* **137**: 329–339

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

Crawford RJM, Underhill LG, Coetzee JC, Fairweather T, Shannon LJ, Wolfaardt AC (2008b) 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

Crawford RJM, Williams AJ, Hofmeyr JH, Klages NTW, Randall RM, Cooper J, Dyer BM, Chesselet Y (1995) Trends of African penguin *Spheniscus demersus* populations in the 20th century. *South African Journal of Marine Science* **16**: 101–118

Crawford RJM, Williams AJ, Randall RM, Randall BM, Berruti A, Ross GJB (1990) Recent population trends of jackass penguins *Spheniscus demersus* off southern Africa. *Biological Conservation* **52**: 229–243

Dehrmann A (1994) Penguins affected by oil spill in South African waters. *Penguin Conservation* **7**(2): 8–12

Erasmus Z (1995) A brief overview of the *Apollo Sea* incident. In: Barrett J, Erasmus Z, Williams AJ (eds) *Proceedings. Coastal Oil Spills: Effect on Penguin Communities and Rehabilitation Procedures*. Cape Nature Conservation, Cape Town, pp 5–7

Fairweather TP, van der Lingen CD, Booth AJ, Drapeau L, van der Westhuizen JJ (2006) Indicators of sustainable fishing for South African sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus*. *African Journal of Marine Science* **28**(3&4): 661–680

Giese M, Goldsworthy SD, Gales RP, Brothers N, Hamill J (2000) Effects of the *Iron Baron* oil spill on little penguins (*Eudyptula minor*). III. Breeding success of rehabilitated oiled birds. *Wildlife Research* **27**: 583–591

Goldsworthy SD, Giese M, Gales RP, Brothers N, Hamill J (2000) Effects of the *Iron Baron* oil spill on little penguins (*Eudyptula minor*). II. Post-release survival of rehabilitated oiled birds. *Wildlife Research* **27**: 573–582

Hockey PAR, Dean WRJ, Ryan PG. (eds) (2005) *Roberts Birds of Southern Africa* (7th edn). John Voelcker Bird Book Fund, Cape Town

Hull CL, Hindell MA, Meggs RA, Moyle DI, Gales RP, Brothers NP (1998) The efficacy of translocating little penguins during an oil spill. *Biological Conservation* **86**: 393–400

Kerley GIH, Erasmus T (1987) The management of oiled penguins. In: *1987 Oil spill Conference (Prevention, Behavior, Control, Cleanup)*. American Petroleum Institute, Washington DC, pp 465–468

Lebreton JD, Burnham KP, Clobert J, Anderson DR (1992) Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. *Ecological Monographs* **62**: 67–118

Morant PD, Cooper J, Randall RM (1981) The rehabilitation of oiled jackass penguins *Spheniscus demersus*, 1970–1980. In: Cooper J (ed) *Proceedings of the Symposium on Birds of the Sea and Shore.* African Seabird Group, Cape Town, pp 267–301

Nel DC, Crawford RJM, Parsons NJ (2003) The conservation status and impact of oiling on the African penguin. In: Nel DC, Whittington PA (eds) *Rehabilitation of Oiled African Penguins: a Conservation Success Story*. BirdLife South Africa and the Avian Demography Unit, Cape Town, South Africa, pp 1–7

Nisbet ICT (1994) Effects of pollution on marine birds. In: Nettleship DN, Burger J, Gochfeld M (eds) *Seabirds on Islands. Threats, Case Studies and Action Plans*. BirdLife International, Cambridge, UK, pp 8–25

Parsons NJ, Underhill LG (2005) Oiled and injured African penguins *Spheniscus demersus* and other seabirds admitted for rehabilitation in the Western Cape, South Africa, 2001 and 2002. *African Journal of Marine Science* **27**(1): 289–296

Pradel R, Hines JE, Lebreton J-D, Nichols JD (1997) Capture-recapture survival models taking account of transients. *Biometrics* **53**: 60–72

Randall BM, Randall RM, Compagno LJV (1988) Injuries to jackass penguins (*Spheniscus demersus*): evidence for shark involvement. *Journal of Zoology (London)* **214**: 589–599

Randall RM, Randall BM, Cooper J, La Cock GD, Ross GJB (1987) Jackass penguin *Spheniscus demersus* movements, inter-island visits and settlement. *Journal of Field Ornithology* **58**: 445–455

Ricklefs RE (1974) Energetics of reproduction in birds. In: Paynter JR (ed) *Avian Energetics*. Publications of the Nuttall Ornithological Club, No. 15, Cambridge, Massachusetts, pp 152–292

Ricklefs RE (1983) Some considerations on the reproductive energetics of pelagic seabirds. *Studies in Avian Biology* **8**: 84–94

Ryan PG, Wilson RP, Cooper J (1987) Intraspecific mimicry and status signals in juvenile African penguins. *Behavioural Ecology and Sociobiology* **20**: 69–76

Siegfried WR, Crawford RJM (1978) Jackass penguins, eggs and guano: diminishing resources at Dassen Island. *South African Journal of Science* **74**: 389–390

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

Underhill LG, Crawford RJM, Wolfaardt AC, Whittington PA, Dyer BM, Leshoro TM, Ruthenberg M, Upfold L, Visagie J (2006) Regionally coherent trends in colonies of African penguins *Spheniscus demersus* in the Western Cape, South Africa, 1987–2005. *African Journal of Marine Science* **28**(3&4): 697–704

Underhill LG, Whittington PA, Crawford RJM, Wolfaardt AC (2000) Five years of monitoring African penguins *Spheniscus demersus* after the *Apollo Sea* oil spill: a success story made possible by ringing. *Vogelwarte* **40**: 215–218

van der Lingen CD, Coetzee JC, Demarcq H, Drapeau L, Fairweather TP, Hutchings L (2005) An eastward shift in the distribution of southern benguela sardine. *GLOBEC International Newsletter* **11**: 17–22

White GC, Burnham KP (1999) Program MARK: Survival estimation from populations of marked animals. *Bird Study* **46**: S120–S139

Whittington PA (1999) The contribution made by cleaning oiled African penguins *Spheniscus demersus* to population dynamics and conservation of the species. *Marine Ornithology* **27**: 177–180

Whittington PA (2002) Survival and movements of African penguins, especially after oiling. PhD thesis, University of Cape Town, Cape Town

Whittington PA (2003) Post-release survival of rehabilitated African penguins. In: Nel DC, Whittington PA (eds) *Rehabilitation of Oiled African Penguins: a Conservation Success Story*. BirdLife South Africa and the Avian Demography Unit, Cape Town, pp 8–17

Whittington PA, Crawford RJM, Huyser O, Oschadleus D, Randall R, Ryan P, Shannon L, Wolfaardt A, Cooper J, Lacy R, Ellis S (eds) (2000) *African Penguin Population and Habitat Viability Assessment. Final Report.* IUCN/SSC Conservation Breeding Specialist Group, Apple Valley, MN

Whittington PA, Randall RM, Crawford RJM, Wolfaardt AC, Klages NTW, Randall BM, Bartlett PA, Chesselet Y, Jones R (2005a) Patterns of immigration to and emigration from breeding colonies by African penguins. *African Journal of Marine Science* **27**(1): 205–213

Whittington PA, Randall RM, Randall BM, Wolfaardt AC, Crawford RJM, Klages NTW, Bartlett PA, Chesselet Y, Jones R (2005b) Patterns of movements of the African penguin in South Africa and Namibia. *African Journal of Marine Science* **27**(1): 215–229

Williams AJ (1995) Factors to consider in the capture and transport of penguins. In: Barrett J, Erasmus Z, Williams AJ (eds) *Proceedings. Coastal Oil Spills: Effect on Penguin Communities and Rehabilitation Procedures*. Cape Nature Conservation, Cape Town, pp 15–18

Wilson RP (1985) The jackass penguin (*Spheniscus demersus*) as a pelagic predator. *Marine Ecology Progress Series* **25**: 219–227

Wilson RP, Wilson M-PT (1995) The foraging behaviour of the African penguin *Spheniscus demersus*. In: Dann P, Norman I, Reilly P (eds) *The Penguins: Ecology and Management*. Surrey Beatty and Sons, Chipping Norton, Australia, pp 244–265

Wolfaardt AC (2000) *Dassen Island Nature Reserve Management Plan.* Cape Nature Conservation, Cape Town

Wolfaardt AC (2004) The capture and removal of clean penguins from Dassen Island. In: Kuyper S, Williams AJ (eds) *Proceedings of the Penguin Workshop Following the Sinking of the Treasure in June 2000*. Avian Demography Unit, University of Cape Town, pp 8–13

Wolfaardt AC, Erasmus Z, Rossouw D (1998) *Seabird Rescue Plan in the Event of an Oil Spill at Dassen Island.* Cape Nature Conservation, Cape Town

Wolfaardt AC, Underhill LG, Altwegg R, Visagie J (2008) Restoration of oiled African penguins S*pheniscus demersus* a decade after the *Apollo Sea* spill. *African Journal of Marine Science* **30**(2): 421–436

Wolfaardt AC, Underhill LG, Crawford RJM (in press a) Comparison of moult patterns of African penguins *Spheniscus demersus* at Robben and Dassen Islands. *African Journal of Marine Science*

Wolfaardt AC, Underhill LG, Klages NTW, Crawford RJM (2001) Results of the 2001 census of African penguins *Spheniscus demersus*: first measures of the impact of the *Treasure* oil spill on the breeding population. *Transactions of the Royal Society of South Africa* **56**: 45–49

Wolfaardt AC, Underhill LG, Nel DC, Williams AJ, Visagie J (in press b) Breeding success of African penguins *Spheniscus demersus* at Dassen Island, especially after oiling following the *Apollo Sea* spill. *African Journal of Marine Science*

Wolfaardt AC, Underhill LG, Visagie J (in press c) Breeding and moult phenology of African penguins *Spheniscus demersus* at Dassen Island, and the impact of the *Apollo Sea* and *Treasure* oil spills. *African Journal of Marine Science*