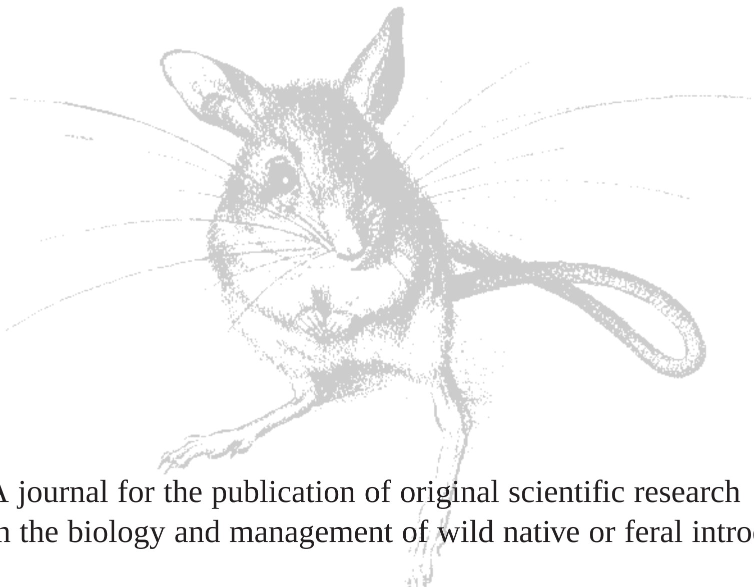
CSIRO PUBLISHING

Wildlife Research

Volume 27, 2000



A journal for the publication of original scientific research
in the biology and management of wild native or feral introduced vertebrates

www.publish.csiro.au/journals/wr

All enquiries and manuscripts should be directed to
Wildlife Research
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood — Telephone: 61 3 9662 7622
Vic. 3066 — Facsimile: 61 3 9662 7611
Australia — Email: david.morton@publish.csiro.au

CSIRO AUSTRALIA

Published by **CSIRO** PUBLISHING
for CSIRO and
the Australian Academy of Science

Academy of Science

Wildlife Research, 2000, **27**, 559–571

Effects of the *Iron Baron* oil spill on little penguins (*Eudyptula minor*). I. Estimates of mortality

S. D. Goldsworthy[A], *R. P. Gales*, *M. Giese*[B] *and N. Brothers*

Nature Conservation Branch, Department of Primary Industry, Water and Environment, GPO Box 44A, Hobart, Tas. 7001, Australia.
[A]Current address: Department of Zoology, La Trobe University, Vic. 3086, Australia.
[B]Current address: Department of Zoology, University of Melbourne, Vic. 3010, Australia.

Abstract. The bulk ore carrier *Iron Baron* ran aground on Hebe Reef at the mouth of the Tamar River in northern Tasmania, Australia, on 10 July 1995. It released an estimated 325 tonnes of bunker fuel oil. Of the wildlife species affected, the most readily detected was the little penguin (*Eudyptula minor*); 1894 were collected and treated for oiling. This study estimates the impact of the oil spill on populations of little penguins. At Ninth Island (approximately 40 km from Hebe Reef), one of the most affected little penguin colonies, pre-oil-spill population estimates were available. Extensive regular trapping and mark–recapture of birds at this site during the course of the oil spill provided longitudinal data on oiling rates from a known population size. Using these data, we estimate that 19.6% of birds from Ninth Island were oiled and survived to come ashore. This represents about 526 (1932–3108, 95% CL) adult birds, or up to 5566 (4197–6917) birds in total (adults and juveniles). For estimates of the impact on little penguin populations in the region, we provide three scenarios of the possible numbers of penguins oiled. After considering the biases of each risk assessment, we believe that between 10 000 and 20 000 penguins were killed as a result of the oil spill. The study indicates that, despite the relatively small amount of oil spilt by the *Iron Baron*, the impact on penguin populations was extensive. This study also highlights the difficulties and requirements in assessing the impact of oil spills on wildlife populations.

Introduction

On 10 July 1995, Australia's largest on-shore oil spill occurred when the bulk ore carrier *Iron Baron*, ran aground on Hebe Reef at the mouth of the Tamar River in northern Tasmania, Australia (Fig. 1). Of the estimated 325 tonnes of bunker fuel oil released from the vessel, about half came ashore on the adjacent coastline, two estuaries, and two offshore islands (Ninth and Waterhouse). On a global level, the volume of oil spilt was relatively small, but because the spill occurred close to important wildlife breeding and foraging sites, it affected a variety of resident and migratory species. These included the black-faced shag (*Leucocarbo fuscescens*), the little pied cormorant (*Phalacrocorax melanoleucos*), the southern giant petrel (*Macronectes giganteus*), the Australian pelican (*Pelecanus conspicillatus*), the black swan (*Cygnus atratus*), the silver gull (*Larus novaehollandiae*), grebes (*Tachybaptus* spp.), the Australian fur seal (*Arctocephalus pusillus doriferus*) and the water rat (*Hydromys chrysogaster*) (Holdsworth and Bryant 1995; N. Mooney, personal communication). In addition, oil probably came into contact with albatrosses, diving petrels and storm petrels. However, of all the wildlife affected, the most visible species was the little penguin (*Eudyptula minor*), with 1894 oiled birds being collected for treatment and rehabilitation.

Differential impact of oil spills on bird species has been found in other areas. In the Northern Hemisphere, oil-spills mainly affect alcids (Hope Jones *et al.* 1970; Piatt *et al.* 1990), while in the Southern Hemisphere, typically penguins are the birds most affected (Dann and Jessop 1991; Adams 1994; Gandini *et al.* 1994). Penguins are more susceptible because they spend considerably longer in the water than flying birds, are possibly less able to detect oil at sea, and even small amounts of oil on the plumage causes waterlogging, reducing insulation and buoyancy.

The extensive reports of often high numbers of seabirds killed by oil spills (Stowe 1982; Evans and Nettleship 1985; Page *et al.* 1990; Burger and Fry 1993) rarely describe how these numbers were derived. At best, estimates of overall mortality are multiples of the numbers of birds either found dead or brought in for rehabilitation (Greenwood and Keddie 1968; Hope Jones *et al.* 1970; Bibby and Lloyd 1977; Huebeck and Richardson 1980); at worst, they are guesses (Page *et al.* 1990; Burger and Fry 1993). Nonetheless, these estimates are often the only measures of impacts on local populations and species.

In the two years after the *Iron Baron* spill, a monitoring program was established to quantify the impact of oiling on little penguins. The program had three main aims: (1) to esti-

10.1071/WR99075 1035-3712/00/060559

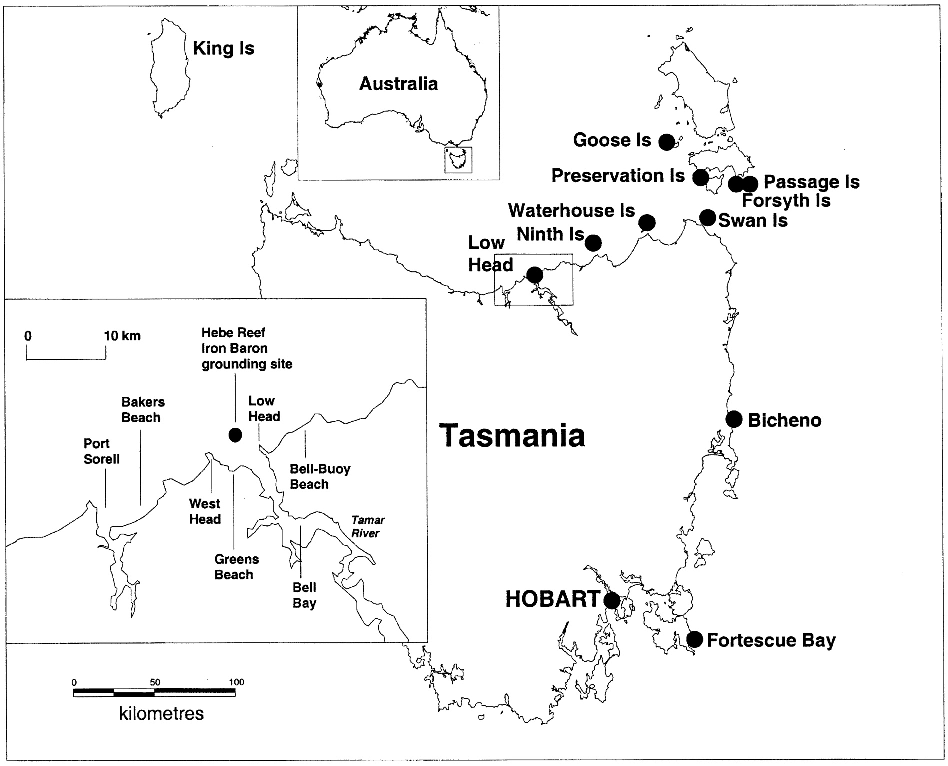


Fig. 1. Map of Tasmania, indicating where the *Iron Baron* ran aground, and the locations where oiled penguins were collected. The translocation sites (Bicheno and Fortescue Bay) where some birds were released are also indicated.

mate the effects of the oil spill on little penguin populations within the area known to be affected by the spill, (2) to determine the post-release survival of oiled and rehabilitated little penguins, and (3) to assess the long-term impact of oiling on the breeding success of oiled–rehabilitated little penguins in the seasons after their release.

This paper reports on the first of these aims. Survival and breeding success are reported in Goldsworthy *et al.* (2000) and Giese *et al.* (2000), respectively.

Methods

Study species

The little penguin, the smallest penguin species, is found only in southern Australia and New Zealand. It is active both at night and during the day (Stahel and Gales 1987), arriving at its breeding site at dusk and departing at dawn. It feeds at depths generally no greater than 15 m below the surface, predominantly on small shoaling fish and squid (Gales *et al.* 1990; Gales and Pemberton 1990; Cullen *et al.* 1992). Breeding typically occurs between September and February each year, although the timing and duration of breeding can show considerable latitudinal and inter-annual variation (Gales 1985).

The breeding biology of little penguins is summarised in Stahel and Gales (1987) and Fortescue (1995). Briefly, the female lays two eggs, but both parents share equally in incubation (36 days) and chick rearing (two months). After the chicks have fledged, the adults forage intensively at sea for about two weeks, during which time they double their mass in preparation for a moult that requires a three-week fast ashore.

Data limits

Accurately estimating the total number of seabirds affected by an oil spill is difficult because seabird populations can be highly dispersed and the size and distribution of populations prior to oil spills are often poorly known. Further, because the population demographics of seabird populations is generally poorly understood, the numbers of juvenile birds in the population, their degree of dispersion and risk of oiling is also poorly known. These problems were apparent in assessing the impact of the *Iron Baron* oil spill on little penguin populations in south-eastern Bass Strait. Although some pre-oil-spill data on population size were available for the area, some island populations affected by the spill were not surveyed until several weeks or months after the *Iron Baron* ran aground. However, the largest recovery of oiled penguins was made on Ninth Island, where the most detailed surveys to determine the number of birds oiled from that population had been made. We use these data, and data available from other affected island populations in the area, to estimate the numbers of little penguins killed in southern Bass Strait as a result of the *Iron Baron* oil spill.

Pre- and post-oil-spill population surveys at Ninth Island

The breeding population of penguins at Ninth Island prior to the *Iron Baron* oil spill was surveyed on 15 October 1986 (survey by NB). Population size was estimated from the densities of burrows found along 14 regularly spaced, 1-m-wide, north–south transects across the island. This survey was repeated four months after the *Iron Baron* oil spill, during 16–19 November 1995, using 19 north–south transects 50 m apart across the entire length of the island (Fig. 2). Similar surveys were also conducted on 20–21 November and 16–17 December 1996. All burrows within transects were examined. Burrows with adult birds, eggs, chicks or signs of use (recent digging, faecal material, etc.) were classified as active. Vegetation type and substrate (rock or soil) were also noted along the length of each transect. The number of breeding pairs on the island was calculated as the average density of active burrows per transect area (minus the area of transect that was bare rock), multiplied by the area of the island with habitat suitable for penguin breeding. The area of available habitat on Ninth Island was calculated from digitising aerial photographs of the island.

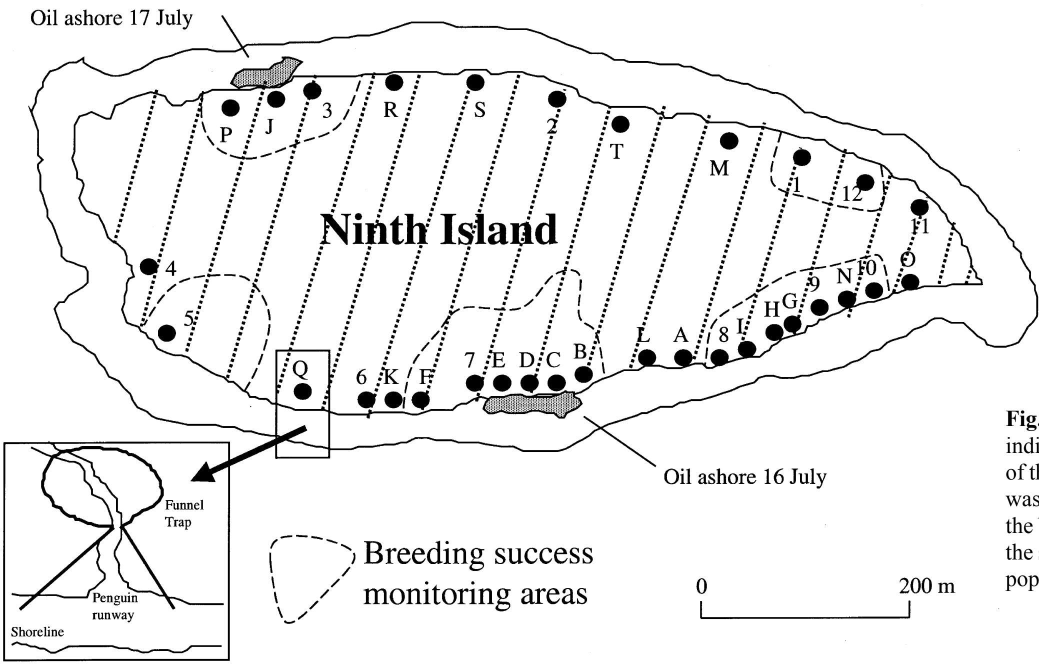


Fig. 2. Map of Ninth Island, indicating the approximate location of the 32 trapping sites, where oil washed ashore, and the position of the burrow transects used to survey the size of the little penguin population.

Monitoring oiled penguins at Ninth Island

Ninth Island was visited briefly on 14 July 1995, four days after the grounding of the *Iron Baron*. In total, 39 oiled penguins were collected within 1 h, and removed from the island for treatment at a rehabilitation centre established at the Low Head Pilot Station (see Rogers and Holdsworth 1999). The following day, a team returned to the island where they captured more oiled birds by hand. Wire funnel traps were installed on runways (paths used by penguins to reach their burrows) to capture penguins as they returned to the island from sea. In all, 32 traps were erected between 16 and 23 July, and were operated most nights until 16 August 1995 (Fig. 2). Each trap consisted of two 1-m-high lengths of wire mesh set at 20–25° either side of a penguin runway, 5–20 m inland from the shoreline (Fig. 2). These lengths of mesh converged and effectively funneled the penguins into a holding pen through a small tunnel entrance. Traps were typically set late in the afternoon and remained open until 1–2 h after dusk. All trapped penguins were then checked, after which the mesh was raised from the ground to give the birds an unimpeded path to the shore the next morning.

In addition to trapping, the shore-line of Ninth Island was searched 3–4 times daily, between 15 July and 16 August 1995. As oiled penguins returned to the island during daylight hours as well as dusk, they were vulnerable to predation by Pacific gulls (*Larus pacificus*). Birds with more than a trace of oil on their plumage were retained and transported to Low Head for rehabilitation the following day. These were classed as oiled birds. All other birds were marked with coloured paint and released (such marking has not appeared to affect penguins in other studies: Gales and Green 1990). These were classed as non-oiled birds.

Mark–recapture estimates

For each night of trapping, all birds were counted and recorded as either being oiled (and removed for rehabilitation) or non-oiled (marked and released inland from trap). The number of birds using each runway ($\tilde{N}^j$) was estimated by the modified Peterson formula (attributed to D.G. Chapman by Seber 1982):

$$\tilde{N}_j = ((M + 1)(n + 1) / m + 1) - 1 ,$$

where M is the number of paint-marked penguins at risk of being sampled during recapture (a night's trapping j), n is the number of penguins sampled, and m is the number of paint-marked penguins recaptured. The mean ($\tilde{N}$) of several mark–recapture estimates for each trap catchment ($\tilde{N}^j$) was calculated from

$$\tilde{N} = \Sigma_{j=1}^{q} \tilde{N}_j / q,$$

where q is the number of estimates obtained. The variance of this estimate was calculated from

$$\mathrm{Var}(\tilde{N}) = 1 / q^2 \, \Sigma_{j=1}^{q} \mathrm{Var}(\tilde{N}_j)$$

and its standard deviation from

$$\sqrt{[\mathrm{Var}(\tilde{N})]}.$$

The number of birds in each trapped sub-population was calculated for each four-day period between 15 July and 16 August, and the final estimate of numbers of birds using each runway was calculated using the mean of these. The number of oiled birds caught during this period and removed for rehabilitation were added to these totals.

Estimating the total number of oiled birds from the Ninth Island population

The proportion of oiled birds in the trapped population was calculated by dividing the total number of oiled birds trapped by the total number of birds estimated to have used the trapped runways. Estimates of the numbers of Ninth Island penguins oiled were derived by multiplying the proportion of oiled birds from the trapped population by estimates of the island's population size. As non-breeding birds (juveniles) were estimated to account for 56.9% of little penguin populations elsewhere (Dann and Cullen 1990), the total Ninth Island population size was estimated by multiplying the estimate for breeding adults by 2.32.

In this study, we assumed that all adult birds from the Ninth Island population were at risk of being oiled. Hence the estimated number of oiled adults is a minimum estimate of the total number of birds oiled, because the estimate does not include juvenile birds. The maximum number of oiled birds was estimated from the total population estimate that included juveniles. Because an unknown proportion of the juveniles was likely to be in the vicinity of their natal colony at the time of the spill (Dann *et al.* 1992), the actual number of oiled birds from Ninth Island is likely to be somewhere between the minimum estimate based only on adults, and the maximum estimate based on all age classes.

Other islands surveyed

Little penguin populations in the Furneaux Group of south-eastern Bass Strait (Fig. 3) were not visited until 20–26 days after the grounding of the *Iron Baron*. At this time, funnel traps were erected on Forsyth, Passage, Goose, Preservation, Waterhouse and Swan islands (Figs 1, 3). Mark–recapture estimates were not undertaken at these sites, hence the size of the trapped population that oiled birds were taken from was not known at these sites. Instead, daily oiling-rates (the numbers of oiled birds captured as a percentage of the total caught) were calculated. Trapping on the islands varied between 6 and 18 days, depending on the numbers of oiled birds being caught. Trapping ceased when daily oiling-rates fell below 2% for three consecutive days. Population estimates for these islands prior to the oil spill were based on surveys conducted throughout the 1980s (N. Brothers, unpublished data).

Results

Movement of oil at sea

The movement of oil at sea was estimated by oil-spill trajectory models incorporating data on wind speed, wind direction and current (Lawson and Treloar 1996). These models approximated the potential dispersal of oil released by the *Iron Baron* over the two weeks following its grounding (Fig. 3). Two models using 3 and 4% of wind speed, are shown in Fig. 3. Briefly, the models indicate that oil released from the *Iron Baron* could have spread about 60 km east, 30 km north and 30 km west within 14 days of the spill. The models underestimated the speed and extent of the easterly movement of oil, as oil was not predicted to be close to Ninth Island until about 20 July 1995, four days after oil had washed ashore on the island. Furthermore, the model did not predict oil spreading further east of Ninth Island (Fig. 3), when in fact some oil had washed ashore on Waterhouse Island sometime prior to 1 August. It is possible, however, that some oil leaked from the vessel as it was being towed to its scuttling site (east of Flinders Island) between 27 and 30 July 1995 (Fig. 3).

Number of oiled birds recovered

A total of 1894 penguins were treated for oiling. Most birds were collected from Ninth Island (1076, 57%), with the remainder from Low Head (550, 29%), Port Sorell (102, 5%), Forsyth Island (98, 5%) and 12 other locations where 1–30 birds were captured (Table 1, Fig. 1). Of the penguins treated at Low Head, 95% were released and the remaining 5% (97 birds) died in captivity. Due to logistic constraints, the intensity and regularity of search effort varied considerably between sites.

Size of little penguin population at Ninth Island in 1986 and 1995

Results of burrow transects and estimates of the number of burrows, adults and population size are presented in Table 2. In 1986, the area within the 14 transects suitable for penguin nesting was 3719 m^2 (Table 2). The total area of Ninth Island available for nesting (minus bare rock) was estimated to be 189 496 m^2. With a mean burrow density of 0.031 m^{-2}, the number of active nests at the time of the 1986 survey was estimated to be 5874 (4389–7360, 95% confidence limits). The total number of breeding birds was estimated to be 11 749 birds (8777–14 720). This was adjusted by the factor of 2.32

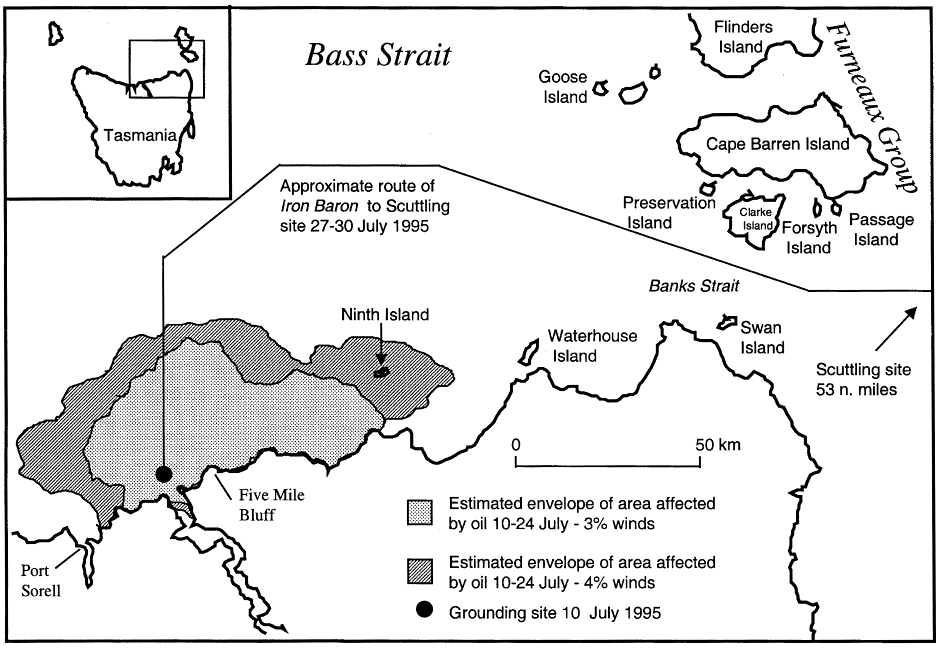


Fig. 3. The envelope of the area affected by oil spilled from the *Iron Baron* in the period 10–24 July 1995 as predicted by two oil-spill trajectory models developed by Lawson and Treloar (1996). These use 3 and 4% of wind-speed and modelled currents. The approximate route over which the *Iron Baron* was towed to its scuttling site east of Flinders Island, in relation to islands where oiled penguins were recovered, is also marked.

Table 1. Number of little penguins captured and treated during the *Iron Baron* oil spill

The locations of the capture sites are given in Fig. 1

Capture location	Number of birds			
	Total	Oiled	Died in captivity	Released
Ninth I.	1107	1076	48	1059
Low Head	683	550	18	665
Port Sorell	102	102	12	90
Forsyth I.	100	98	4	96
Greens Beach	30	30	9	21
Passage I.	11	10		11
Waterhouse I.	5	5		5
Bakers Beach	5	5	2	3
Swan I.	3	3		3
King I.	3	3	1	2
Goose I.	3	3		3
East Sandy Point	3	3	1	2
West Head	2	2	1	1
Bell-Buoy Beach	2	2	1	1
Preservation I.	1	1		1
Bell Bay	1	1		1
Total	2061	1894	97	1964

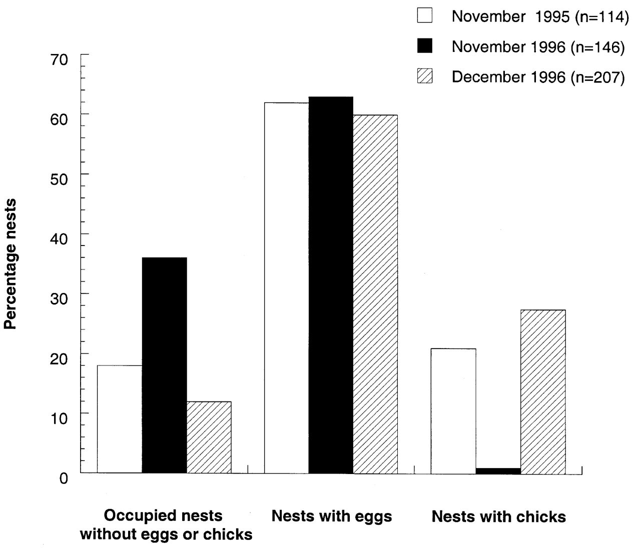


Fig. 4. Percentage of nests surveyed during three censuses at Ninth Island relative to occupancy status.

to account for juveniles to a total population estimate of 27 257 (20 364–34 151) birds. The population estimates based on burrow densities in 1995 and 1996 ranged between 16 792 and 25 438 (Table 2).

Pair-wise comparisons of mean burrow density between surveys indicated no significant differences between the October 1986, November 1995 and December 1996 surveys (all $P > 0.48$), nor between the November 1995 and November 1996 surveys ($P = 0.116$). However, the mean density of burrows differed significantly between October 1986 and November 1996 ($t = 2.391$, d.f. = 31, $P = 0.023$), and between November and December 1996 ($t = 2.531$, d.f. = 36, $P = 0.016$).

Information on the stage of the breeding season during which censuses were conducted are available for the surveys of November 1995 and November and December 1996 (Fig. 4). The proportion of burrows containing birds without eggs was significantly higher in November 1996 than in November 1995 or December 1996 ($G_{adj} = 9.656$, $P < 0.01$, and $G_{adj} = 30.276$, $P < 0.01$, respectively; Fig. 4). Also, the proportion of burrows containing chicks was significantly lower in November 1996 than in either November 1995 or December 1996 ($G_{adj} = 29.973$, $P < 0.001$, and $G_{adj} = 54.641$, $P < 0.01$, respectively; Fig. 4). However, the proportion of nests surveyed that contained birds on eggs was not different between the surveys (all pair-wise comparisons $P > 0.05$).

Given the difference in the timing of the 1986 and 1995 surveys, confident comparisons of the population size

Table 2. Burrow transect data and estimated size of the little penguin population at Ninth Island before and after the oil spill

		15 October 1986	16–19 November 1995	20–21 November 1996	16–17 December 1996
Survey data					
Number of transects		14	19	19	19
Total length of transects (m)		3719	4742	4294	4330
Total number of active burrows		102	118	158	228
Burrow density (per m^2)	Mean ± s.e.	0.031 ± 0.004	0.028 ± 0.005	0.019 ± 0.002	0.029 ± 0.003
Population estimates					
Number of burrows	Total ± s.e.	5874 ± 758	5253 ± 906	3619 ± 467	5482 ± 567
	95% CL	4389–7360	3478–7028	2705–4534	4372–6593
Number of adults[A]	Total ± s.e.	11 749 ± 1516	10 506 ± 1811	7238 ± 933	10 965 ± 1133
	95% CL	8777–14 720	6956–14 057	5409–9067	8743–13 186
Total population[B]	Total ± s.e.	27 257 ± 3517	24 374 ± 4203	16 792 ± 2165	25 438 ± 2630
	95% CL	20 364–34 151	16 137–32 612	12 549–21 036	20 284–30 592

[A]Number of breeding adults estimated by doubling number of burrows.
[B]Total population size estimated by multiplying number of adults by 2.32 to account for juveniles (see Methods).

between the two periods are not possible. Further, the 1995 and 1996 surveys indicate that conducting them at the same time of year does not guarantee comparable data, as the timing of breeding may vary annually (Gales 1985). Information on nest contents suggests that the November 1995 and December 1996 surveys were conducted at a comparable stage of the breeding season, and mean burrow densities and population estimates during these censuses varied by less than 5% (Table 2). Although the extent of change in the Ninth Island penguin population as a consequence of the *Iron Baron* oil spill cannot be determined from the population censuses alone, the 1995 and 1996 estimates of a population numbering 25 000 penguins provide a baseline against which future changes can be measured.

Number of oiled penguins caught at Ninth Island

The number of oiled penguins trapped and caught by hand at Ninth Island between 14 July and 16 August 1995 are summarised in Table 3. In total, 1076 live oiled birds were collected at Ninth Island, and 9 oiled birds were found dead. More oiled birds were caught in traps at night (57%) than by hand during day and night searches (43%). In addition to these birds, 192 of the non-oiled birds captured had trace amounts of oil on their plumage but were released on the island. Although trapping effort increased with time from 12 to 32 traps between 16 and 23 July 1995, the number of oiled birds caught peaked on 18 July, while the total number of birds caught peaked on 23 July (Table 3). The peak in oiled birds followed oil washing ashore near Trap D on 16 July (Fig. 2). The number of oiled birds caught ashore during the day steadily declined after the first day of systematic collecting on 15 July (Table 3).

Estimates of the number of penguins oiled at Ninth Island

Estimates of the total number of Ninth Island birds that were oiled rely on several assumptions. The main variable in these

Table 3. The number of non-oiled and oiled little penguins captured either by hand (day and night) or in traps at Ninth Island between 14 July and 16 August 1995

Date	Trap-caught birds			Hand-caught oiled birds			Total no. of live oiled birds
	Number	Number oiled	% oiled	Day	Night	Dead	
14 July				39			39
15 July				75	53	2	128
16 July	516	59	11.4	31			90
17 July	386	120	31.1	48	46	1	214
18 July	533	214	40.2	37	21	1	272
19 July	424	86	20.3	18	20		124
20 July	562	72	12.8	12	15		99
21 July	430	29	6.7	14	7		50
22 July	510	15	2.9	5	15		35
23 July	572	16	2.8	6	2		24
24 July	552	8	1.4	4			12
25 July	403	2	0.5				2
26 July	57						
27 July	157	1	0.6		2		3
28 July	288	3	1.0		1		4
29 July	399	4	1.0				4
30 July	386	2	0.5			1	2
31 July	74	1	1.4	1		1	2
1 August	126						
2 August	295	1	0.3				1
3 August	114						
4 August	181	2	1.1				2
5 August	230						
6 August	50					1	
8 August	71					2	
9 August	49						
10 August	60						
11 August	88						
12 August	76						
13 August	113						
14 August	139						
15 August	220						
16 August	252						
Total	8313	635		290	182	9	1107

estimates is when, and how many, birds from Ninth Island were foraging within range of the spilled oil. The following estimates detailing the number of penguins (additional to those trapped) that were oiled, vary in relation to when penguins from the island came into contact with oil at sea. The major unknown factor in all these estimates is the number of birds that died at sea and did not wash ashore.

Mark–recapture calculations estimated that a population of 5256 (s.d. = 22) penguins used the runways where traps were erected at Ninth Island (Table 4). The 635 oiled penguins trapped between 16 July and 16 August 1995 accounted for 12.1 ± 0.05% of this trapped population (Table 4). This estimated proportion is, however, likely to be biased for two reasons. Firstly, the number of oiled birds we trapped was strongly negatively affected by the date on which the trap was first set ($t = 4.94$, d.f. = 5, $P = 0.008$, $r^2 = 0.82$, excluding days when only single traps were constructed). This could have been because the first traps set were situated on the most-used runways, and each day we progressively removed oiled birds leaving fewer remaining oiled birds in the population available for sampling. Secondly, the most-used trap on the island (Trap D) was near to where a large quantity of oil came ashore, contaminating the adjacent runway (Fig. 2); this may have inflated estimates of oiling rates across the island.

Table 4. The estimated size of each trap population on Ninth Island based on mark–recapture and trapping data between 16 July and 16 August 1995

The number of oiled birds taken from each trap is also indicated

Trap	Date trap constructed	Total oiled birds captured	Estimated trap population Mean	s.d.
Trap 1	16 July	3	140	11
Trap 2	16 July	4	117	14
Trap 3	16 July	19	185	30
Trap 4	16 July	45	413	27
Trap 5	16 July	5	51	14
Trap 6	16 July	35	284	19
Trap 7	16 July	24	150	15
Trap 8	16 July	11	70	11
Trap 9	16 July	20	196	8
Trap 10	16 July	10	121	12
Trap 11	16 July	4	310	48
Trap 12	16 July	26	233	10
Trap A	17 July	11	80	11
Trap B	17 July	22	86	8
Trap C	17 July	7	15	3
Trap D	17 July	277	401	35
Trap E	17 July	25	49[A]	
Trap F	17 July	11	181	28
Trap G	18 July		7[A]	
Trap H	18 July	5	94	18
Trap I	18 July	12	81	7
Trap J	18 July	21	276	38
Trap K	18 July	22	311	35
Trap L	19 July	6	16	8
Trap M	20 July	1	156	3
Trap N	20 July	2	95	7
Trap O	21 July	1	41	6
Trap P	21 July	2	88	19
Trap Q	22 July	2	352	41
Trap R	23 July	1	254	39
Trap S	23 July	1	306	5
Trap T	23 July	1	94	11
Total		635	5256	22
Traps 1–4, 6–10, 12		197	1910	16

[A]Number based on total birds marked and oiled.

To reduce these potential biases, we used data from a subset of 10 traps (Traps 1–4, 6–10 and 12) (Tables 4, 5) that provided the best temporal data to investigate how oiling rates changed with time and excluded Trap D (data from Traps 5 and 11 were excluded because birds caught in these traps had escaped on several occasions). These traps were established on the first day of trapping (16 July 1995) at Ninth Island and were operated continuously until 25 July. The population of birds using the 10 runways was estimated to be 1910 (s.d. = 16) (Tables 4, 5). Of these, 197 (10.3%) were oiled (Tables 4, 5). However, as systematic trapping of penguins at Ninth Island did not start until six days after the grounding of the *Iron Baron*, this estimate does not account for birds oiled before 16 July 1995. Oil-spill trajectory models and a contemporaneous radio-tracking study of the foraging locations of Ninth Island penguins indicates that most of the population was likely to be foraging south-west of the island near the epicentre of the oil spill (Hull *et al.* 1998). As such, it is likely that some birds from Ninth Island encountered oil at sea within one day of the grounding of the vessel. Plots of the log-transformed number of oiled birds trapped each day in the subset of 10 traps produced a highly significant linear regression ($t = 5.37$, d.f. = 9, $P = 0.001$, $r^2 = 0.69$) (Fig. 5), indicating that the oiling rates of birds were greatest in the days following the spill and then declined steadily (see also Table 3). The exponential equation derived from this regression was used to estimate the number of oiled birds that came ashore on the 10 runways on each night before 16 July 1995 (Fig. 5, Table 5).

If trapping at Ninth Island had begun one day earlier (15 July), we estimate that 286 oiled birds would have been captured (14.3% of the trapped population) (Table 5). However, if trapping had begun five days earlier (11 July) an estimated 1324 (43.6% of trapped population) oiled birds would have been trapped (Table 5). We know that oiled penguins were ashore on Ninth Island on 14 July, for 39 oiled penguins were collected during a brief visit to the island that day (Table 3). If traps had been erected on 14 July and no birds were oiled prior to this date, we estimate that 418 (19.6%) of the estimated 2131 penguins using the runways would have been oiled (Fig. 5, Table 5). Using this conservative estimate, in conjunction with pre-spill estimates of the island population, we estimate that between 2303 (1709–2885, 95% CL) adult penguins and 5343 (3964–6694) penguins in total (adults and juveniles) from the Ninth Island population were oiled from 14 July 1995. To these figures can be added 223 birds from Trap D estimated to have been oiled due to on-shore oil (i.e. 277 – (277 × 0.196)), giving an estimated range of between 2526 (1932–3108) adult penguins and 5566 (4197–6917) penguins in total oiled between 14 and 25 July 1995 (Table 5). Other scenarios of when the numbers of birds from Ninth Island oiled relative to when they first encountered oil are given in Table 5. These indicate that if birds encountered oil within a day of the grounding of the *Iron Baron*, then up to 12 000 (9042–15 114) penguins from Ninth Island could have been oiled (Table 5).

Potential impact of Iron Baron oil spill on penguin populations in southern Bass Strait

Of the islands surveyed in south-eastern Bass Strait, oiled penguins were collected from Forsyth (98), Passage (10), Waterhouse (5), Goose (3), and Swan islands (3) (Table 1). All were surveyed 2–3 weeks after the grounding of the *Iron Baron* and up to a week after the vessel had been towed through Banks Strait on its way to the scuttling site (Table 6, Fig. 3). In addition, for islands in the Furneaux Group it could not be determined whether birds had been oiled as a consequence of the original spill, by oil leaked from the towed ship, or both. Many other islands within the Furneaux Group that have breeding colonies of little penguins have not been surveyed since the *Iron Baron* oil spill. Therefore, while the numbers of Ninth Island penguins that were oiled could be estimated, this could only be achieved with reduced precision (no confidence intervals) for the other affected populations.

In an attempt to overcome some of these limitations, we provide three scenarios of the numbers of little penguins that may have been affected in south-eastern Bass Strait.

Scenario 1: All oiled birds were captured

Scenario 1 assumes that all penguins oiled as a consequence of the *Iron Baron* spill were recovered and treated. This would suggest that 1894 penguins were oiled, 97 of which died in captivity (Table 1).

Scenario 2: Using oiling rates where available, minimum estimates elsewhere

In this scenario we used the population-based oiling-rate data for Ninth Island, and the maximum daily estimates of oiling rate for the six other Bass Strait islands (Table 6). Using these data, and pre-oil spill population estimates (Table 7), in the order of 3800 adults and 8800 penguins in total from these islands could have been oiled (Table 6). These estimates pertain only to the numbers of birds oiled during the period of survey, three weeks after the grounding of the *Iron Baron.* No data were collected before this time, when the impact from the oil spill would probably have been greater. Adding these figures to the estimated numbers of oiled birds from Ninth Island, and minimum estimates of the numbers of oiled birds at non-trapped locations (based on the total number of oiled birds caught), gives a total estimate of between 6322 adults, or 15 071 in total oiled in south-eastern Bass Strait (Table 8).

Scenario 3: Assuming numbers calculated to have been oiled at Ninth Island reflect impact at other sites

The minimum percentage of the Ninth Island population predicted to have been oiled between 14 and 25 July 1995 was 19.6%. Using this value as a measure of the impact on other populations gives an estimate of 14 160 adults or 34 216 in total oiled in south-eastern Bass Strait, a region with a little penguin population in the order of 170 000 birds (Tables 7, 8).

Discussion

Number of oiled penguins from the Ninth Island population

The trapping and mark–recapture estimates indicate that, conservatively, in the order of 2500 adult and 3000 juvenile penguins from the Ninth Island were oiled (and survived to come ashore) as a consequence of the *Iron Baron* oil spill. With the available data, the number of oiled adults could be predicted with some confidence because adult birds generally have localised foraging ranges (Dann *et al.* 1992; Weavers 1992). However, as juveniles are likely to be less concentrated in the vicinity of their natal island (Dann *et al.* 1992), estimating the numbers of immature birds at risk of being oiled is more difficult. Hence, the estimate of the numbers of juveniles oiled that assumes that they were at equal risk as adults may appear to overestimate the total numbers of birds oiled.

However, other sources of uncertainty in determining the impact on the little penguins, based upon apparent oiling incidence of trapped birds, would tend to increase estimates. These include the unknown numbers of oiled birds that died at sea, of birds oiled during the first four days after the grounding of the *Iron Baron*, and, as observed in other species, of birds killed by ingesting oil without external signs of oiling (Vauk *et al.* 1989). Further, although the percentage of oiled birds from the Ninth Island population was estimated with some level of precision, the number of birds in the population at the time of the spill was inferred from a survey conducted nine years before the oil spill**.** Our treatment of the Ninth Island data, then, is a conservative risk and mortality estimate for the population. Given that 1076 oiled birds were transported from Ninth Island for treatment and rehabilitation, at least another1450 (adults only) or 4490 (including juveniles) are predicted to have died. During the oil spill, Ninth Island received most of the available effort for detection and collection of oiled penguins. For this site, at best 43% of oiled birds that survived to come ashore were collected for treatment; at worst, only 19% of oiled birds were recovered.

Estimated total impact of the spill on little penguins

To assess the mortality in populations from islands other than Ninth Island, but for which such a complete data set could not

Table 5. The estimated number of oiled little penguins within the catchment of 10 traps at Ninth Island between 11 and 15 July 1995

Data from these 10 traps collected between 16 and 25 July 1995 are also presented, as are estimates of the percentage of the population oiled relative to when Ninth Island penguins encountered oil. The estimates are given for the catchment of the 10 traps, and for the number of adults and adults plus juvenile birds oiled in the Ninth Island population.

Date from which penguins were affected by oil	Estimated number of oiled penguins that would have been caught on each night prior to 16 July[A]	Accumulative total of estimated number of oiled penguins caught prior to 16 July	Estimated number of birds using 10 runways (trapped population)[C]	Estimated % of birds in trapped population oiled in relation to days exposed to oiling	Estimated number of adult birds oiled (± 95% CL) in the Ninth Island population in relation to days exposed to oiling[D]	Estimated number of adult and juvenile birds (± 95% CL) potentially oiled in theNinth Island population in relation to days exposed to oiling[D]
11 July	424	1324	3037	43.6	5345 (4024–6641)	12 107 (9042–15 114)
12 July	287	900	2613	34.4	4264 (3222–5064)	9 600 (7181–11 972)
13 July	195	613	2326	26.4	3324 (2524–4109)	7419 (5563–9239)
14 July	132	418	2131	19.6	2526 (1932–3108)	5566 (4197–6917)
15 July	89	286	1999	14.3	1903 (1466–2328)	4121 (3115–5107)
16–25 July[B]	197	197	1910	10.3	1433 (1121–1739)	3031 (2306–3741)

[A]Based on the exponential equation predicting the number of oiled birds that would be caught on a given night in Traps 1–4, 6–9 and 11, $y = 30600e^{-0.389x}$, where x is days of July. See Fig. 5.

[B]Based on trapping data for period 16–25 July.

[C]Population estimate from mark–recapture of the 10 traps during 16–25 July was 1910 (s.d. = 15.7). Estimates of population size for 11–15 July 1995 are based on the estimate of 910 (for period 16–25 July) plus additional oiled birds.

[D]Based on population estimates for Ninth Island penguins of 11 749 (8777–14 720 CL) adults and 27 257 (20 364–34 151 CL) adults and juveniles, plus an additional 223 oiled birds from Trap D that were predicted to have been oiled as a result of on-shore oil in front of this trap.

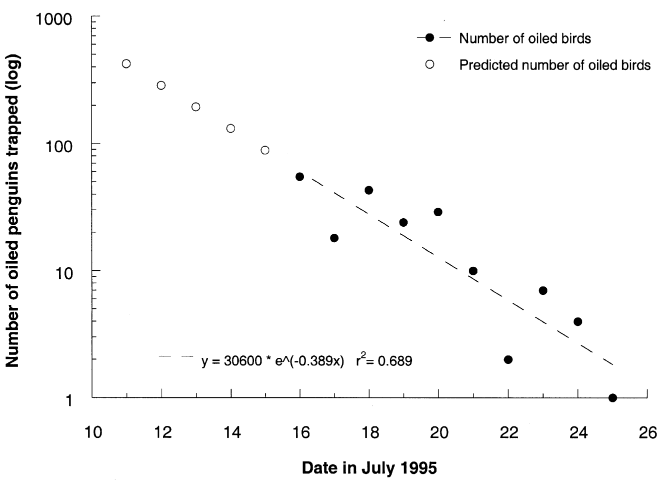


Fig. 5. The number of heavily oiled penguins captured on Ninth Island in 10 traps operated during 16–25 July 1995. The number of penguins predicted to have been captured on each day if the traps had been operated between 11 and 15 July are also shown.

be collected, three simple risk scenarios were developed. These scenarios, which differ in their reliability, are preliminary attempts at realistic, although probably conservative, risk assessments. They also illustrate a framework for determining the impacts of future oil spills on wildlife populations.

Scenario 1 provides a figure of the absolute minimum known impact (1894 birds) derived solely from the number of oiled birds captured for rehabilitation. This figure most certainly underestimates the total number of penguins oiled because only two locations near the epicentre of the spill were surveyed regularly and systematically (Ninth Island and Low Head on the Tasmanian mainland). More remote islands, where oiled penguins were subsequently found to have come ashore, were not visited until several weeks after the grounding of the *Iron Baron*, and some were not visited at all. Also, because of limited resources and the typically large, dispersed penguin colonies on these offshore islands, it was not possible to survey a representative proportion of these populations. Even at Ninth Island, where we used a large number of traps to sample birds for more than a month, we sampled less than 20% of the population.

Scenario 2 uses the best available estimates for the numbers of birds oiled that survived to come ashore. However, the range of 6300–15 070 birds oiled in south-eastern Bass Strait is also conservative, and likely to underestimate the full extent of impact, especially with respect to the estimates of numbers of oiled penguins from the large colonies on Forsyth and Passage islands. This is because estimates of the extent of oiling of birds in these populations were based on the oiling rates observed from trapping several weeks after the grounding of the *Iron Baron*. Oiling rates almost certainly would have been much higher in the days after the spill, before our surveys began. The minimum estimates for the islands where there was no systematic trapping were based simply on the numbers of birds caught.

Scenario 3 assumes that the level of oiling observed at Ninth Island was similar to that experienced at all other sites known to have been oiled. It uses an estimate of the pre-spill numbers of little penguins in south-eastern Bass Strait of 170 570 birds. The estimate of 14 160–34 216 oiled penguins possibly overestimates the impact for some island populations, especially those in the Furneaux Group. The impact would probably decrease with increasing distance from the epicentre of the spill, such that the percentage of oiled birds would be highest at sites nearest the spill, and lowest at those more distant. However, it is possible that many birds from regions outside the area of the oil spill were also affected. For example, during an oil spill off Apollo Bay (Victoria) in 1986, oiled penguins were recovered at colonies up to 200 km away (P. Dann, personal communication). This observation suggests that oiled little penguins endeavour to return to their colony, even if it is distant from where they were oiled. Hence, birds from distant colonies not considered in these analyses may also have been affected if they were foraging in the region of the oil spill. This may be especially the case for juvenile birds from populations some distance from the oil spill. Band recoveries of beach-washed birds subsequent to the oil spill are distributed over a broad area of Bass Strait (Cape Otway, Port Campbell, Wilson's Promontory, King Island, Cape Grim), indicating an extensive use of most of Bass Strait waters by little penguins (Goldsworthy *et al.*, unpublished). Some birds from populations outside south-eastern Bass Strait would almost certainly have been foraging within the area of the oil spill at the time and may also have been oiled.

Having considered the basis of each of the three scenarios, and, importantly, the lack of estimates of the numbers of birds dying at sea, we judge that the likely range of the number of birds killed is between the estimates of Scenarios 2 and 3. We predict, therefore, that the total number of penguins oiled as a result of the *Iron Baron* spill was in the order of 10 000–20 000 individuals.

The extent of impact of oil spills on wildlife is sometimes gauged by the number of oiled birds found on beaches. Previous estimates of the percentage of affected birds that wash ashore after a spill range from 0 to 59% (Bibby and Lloyd 1977; Hope-Jones *et al.* 1978). Corpse drift experiments conducted after the *Exxon Valdez* spill recovered only 3% of carcasses released 10 km offshore (Piatt *et al.* 1990). Even fewer penguins may be expected to be recovered as, compared with flying birds, penguins have higher densities and are more likely to sink at sea soon after death (Burger and Fry 1993).

In the days and weeks after the *Iron Baron* oil spill there were very few sightings of beach-washed carcasses. Some beaches between Low Head and Port Sorell and east of Low Head were surveyed, but large tracts, including the extensive coastlines of islands in the Furneaux Group were not

Table 6. The time delay (in days) between the grounding and towing of the *Iron Baron*, and when islands in south-eastern Bass Strait were surveyed for oiled penguins

The maximum oiling rates determined from trapping, the estimated size of the penguin populations (Brothers, unpublished data; Table 8) and the estimated number of birds oiled calculated from the oiling rates are presented. Maximum oiling rate refers to the number of oiled birds caught as a percentage of all birds trapped on a given night

Site	Days from *Iron Baron* grounding to first survey	Days from towing to first survey	Days trapping on each island	Number of penguins trapped	Maximum oiling rate recorded (%)	Breeding population estimate 1985 (adults)	Total population estimate 1985	Estimated number of oiled adults	Estimated number of adults and juveniles oiled
Forsyth I.	21	4	18	4530	7.7	40 000	92 800	3080	7146
Passage I.	25	7	12	1064	11.1	4500	10 441	500	1159
Preservation I.	26	8	13	310	2.7	550	1276	15	34
Swan I.	20	3	8	194	4.8	400	928	19	45
Goose I.	26	8	13	978	10.0	1500	3480	150	348
Waterhouse I.	20	3	6	820	3.2	1000	2320	32	74
Total								3796	8806

Table 7. Estimates of the populations size of little penguins at islands and sites in south-eastern Bass Strait where oil from the *Iron Baron* is likely to have had impact

Population estimates are based on surveys conducted in the mid-1980s by N. Brothers (unpublished data)

Population	Breeding adults	Estimated total population size
Forsyth I.	40 000	92 800
Passage I.	9000	20 880
Boxen I.	4000	9280
Goose I.	1500	3480
Waterhouse I.	1000	2320
Little Waterhouse I.	35	81
Swan I.	400	928
Little Swan I.	600	1392
Foster Islet I.	700	1624
Preservation I.	550	1276
Night Islet	170	394
Low Head	1000	2320
The Carbuncle	210	487
Penguin I.	316	733
Port Sorell	1500	3480
Ninth I.	14 264	33 092
Total	75 245	174 570

(e.g. Clarke, Cape Barren and Flinders: Fig. 3). Oiled carcasses drift under the influence of wind, currents and tides, typically at 2–3% of wind velocity; similar to the movement of oil at sea (Hope Jones *et al.* 1970; Bibby and Lloyd 1977; Ford *et al.* 1991). The strongest influence on the movement of carcasses in open water is the direction and speed of wind. Wave action near shore may actually prevent carcasses from beaching, and most carcasses appear on beaches after strong onshore winds (Camphuysen 1989). The Lawson Treloar (1996) oil-dispersal models show a strong movement of the oil to the east under the influence of westerly winds and residual current (Fig. 3). This, and the fact that no oil was reported ashore on the Tasmanian mainland east of Five Mile Bluff (Fig. 3), may explain the low number of recorded beach carcases.

The spillage of 325 tonnes of bunker fuel from the *Iron Baron* had an extensive impact on wildlife, especially little penguins. In other areas, similarly 'small' spills have resulted in the deaths of many thousands of seabirds (Barrett 1979). For example, the *Apex Houston* spill along the central Californian coast involved only 87 tonnes of crude oil but killed an estimated 10 577 seabirds (Page *et al.* 1990), and the *Nestucca* barge, which spilt 770 tonnes of bunker fuel killed an estimated 56 000 seabirds (Ford *et al.* 1991). At the other end of the scale, in terms of volume of oil, the loss of 36 400 tonnes of crude oil from the *Exxon Valdez* killed an estimated 350 000–390 000 birds (Burger and Fry 1993 and references therein).

Any effort to assess the extent of mortality after an oil spill is problematic for an array of reasons. Not the least of these is the fact that the process for recovering oiled wildlife is conducted with the aim of maximising the recovery of live oiled wildlife, rather than representing a random and unbiased protocol. Nonetheless, our attempts to assess the impacts of the *Iron Baron* oil spill on populations of little penguins have highlighted some of these difficulties. Ideally, during the course of an oil spill there needs to be careful monitoring of oiling rates of wildlife over time at all significant colonies considered to be at risk. To identify the populations at risk, the area exposed to oiling needs to be known, as well as the foraging range of the birds and the proportion of populations within the range of the oil spill. With these data, to realistically predict the impact on the populations, valid population size data are required for each of the different locations. Only proactive initiatives to equip ourselves with such information, and to anticipate more robust and effective monitoring and rescue regimes, will stand us better prepared for the next incident.

Table 8. Three scenarios of the numbers of little penguins oiled as a result of the *Iron Baron* oil spill

Scenario	Estimated number of adults oiled	Estimated number of adults and juveniles oiled	Assumptions
Scenario 1		1894	All oiled birds were captured
Scenario 2	2526	5566	Ninth Island – based on population oiling rate of 19.6% from 14 July onwards
	3796	8807	Forsyth, Passage, Preservation, Swan, Goose and Waterhouse Islands – based on maximum observed oiling rates
		698	Other non-trapped sites – minimum estimate based on captures
	6322	15 071	Total estimate
Scenario 3	14 160	34 216	Based on minimum total oiling rate for Ninth Island (19.6%), extrapolated to other populations

Acknowledgments

We gratefully acknowledge all those who helped in the wildlife rescue and rehabilitation during the *Iron Baron* oil spill. We thank Nick Mooney for his assistance in monitoring work at Low Head, and the many volunteers who helped with fieldwork there and at Ninth Island. We thank Dave Gatenby and Colin Spry for their regular assistance with boat charter. We thank Maria Moore for digitising maps. We thank Peter Dann, Vivienne Mawson, David Pemberton and several anonymous referees from the *Iron Baron* oil spill Long-Term Impact Assessment Group (LTIAG) for commenting on the manuscript. This work was funded by the Broken Hill Pty Ltd (BHP) through the management of the *Iron Baron* oil spill LTIAG, and in part by the Tasmanian Parks and Wildlife Service.

References

Adams, N. J. (1994). Patterns and impacts of oiling on African penguins *Spheniscus demersus*: 1981–1991. *Biological Conservation* **68**, 35–41.

Barrett, R. T. (1979). Small oil spill kills 10–20 000 seabirds in North Norway. *Marine Pollution Bulletin* **10**, 253–255.

Bibby, C. J., and Lloyd, C. S. (1977). Experiments to determine the fate of dead birds at sea. *Biological Conservation* **12**, 295–309.

Burger, A. E., and Fry, D. M. (1993). Effects of oil pollution on seabirds in the north Pacific. In 'The Status, Ecology and Conservation of Marine Birds of the North Pacific'. (Eds K. Vermeer, K. Briggs, K. Morgan and D. Siegel-Causy.) pp. 254–263. (Canadian Wildlife Service: Ottawa.)

Cullen, J. M., Montague, T. L., and Hull, C. (1992). Food of little penguins *Eudyptula minor* in Victoria: comparison of three localities between 1985 and 1988. *Emu* **91**, 318–341.

Dann, P., and Cullen, J. M. (1990). Survival, patterns of reproduction and lifetime reproductive output in little blue penguins on Phillip Island, Victoria, Australia. In 'Penguin Biology'. (Eds L. Davis and J. Darby.) pp. 63–84. (Academic Press.)

Dann, P., and Jessop, R. (1991). The effect of oil on birds – an evaluation of the birds at risk along the Great Barrier Reef and a brief general review of the effects of oil on individuals and populations. In 'Proceedings of a Workshop on Oiled Seabird Cleaning and Rehabilitation'. (Eds J. Lash and S. Raaymakers.) pp. 37–44. (Great Barrier Reef Marine Park Authority.)

Dann, P., Cullen, J. M., Thoday, R., and Jessop, R. (1992). Movements and patterns of mortality at sea of little penguins *Eudyptula minor* in Victoria. *Emu* **91**, 278–286.

Evans, P. G. H., and Nettleship, D. N. (1985). Conservation of the Atlantic Alcidae. In 'The Atlantic Alcidae'. (Eds D. Nettleship and T. Birkhead.) pp. 427–488. (Academic Press, New York.)

Ford, R. G., Casey, J. L., Hewitt, D. B., Varoujean, D. H., Warrick, D. R., and Williams, W. A. (1991). Seabird mortality resulting from the *Nestucca* oil spill incident, winter 1988–89. Report for Washington Department of Wildlife. Ecological Consulting Inc., Portland, Oregon.

Fortescue, M. E. (1995). Biology of the little penguin *Eudyptula minor* on Bowen Island and at other Australian colonies. In 'The Penguins: Ecology and Management'. (Eds P. Dann, I. Norman and P. Reilly.) pp. 364–392. (Surrey Beatty and Sons: Sydney.)

Gales, R. P. (1985). Breeding seasons and double brooding of the little penguin *Eudyptula minor* in New Zealand. *Emu* **85**, 127–130.

Gales, R. P., and Green, G. (1990). The annual energetic cycle of little penguins. *Ecology* **71**, 2297–2312.

Gales, R. P., and Pemberton, D. (1990). Seasonal and local variation in the diet of the little penguin, *Eudyptula minor*, in Tasmania. *Australian Wildlife Research* **17**, 231–259.

Gales, R. P., Ritz, D., and Williams, C. (1990). Foraging behaviour of the little penguin *Eudyptula minor*, initial results and assessment of recorder effect. *Journal of Zoology (London)* **220**, 61–85.

Gandini, P., Boersma, D., Frere, E., Gandini, M., Holik, T., and Lichtschein, V. (1994). Magellanic penguins (*Spheniscus magellanicus*) affected by chronic petroleum pollution along coast of Chubut, Argentina. *The Auk* **111**, 20–27.

Giese, M., Goldsworthy, S. D., Gales, R. P., Brothers, N., and 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, S. D., Giese, M., Gales, R. P., Brothers, N., and 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.

Greenwood, J. J. D., and Keddie, J. P. F. (1968). Birds killed by oil in the Tay Estuary, March and April, 1968. *Scottish Birds* **5**, 189–196.

Holdsworth, M. C., and Bryant, S. L. (1995). Rescue and rehabilitation of wildlife from the *Iron Baron* oil spill in northern Tasmania. *The Tasmanian Naturalist* **117**, 39–43.

Hope Jones, P., Howells, G., Reese, G., and Wilson, J. (1970). Effects of *Hamilton Trader* oil on birds in the Irish Sea in May 1969. *British Birds* **63**, 97–110.

Huebeck, M., and Richardson, M. G. (1980). Bird mortality following the *Esso Bernica* oil spill, Shetland, December 1978. *Scottish Birds* **11**, 97–108.

Hull, C. L, Hindell, M. A., Meggs, R. A., Moyle, D. I., Gales, R. P., and Brothers, N. P. (1998). The efficacy of translocating little penguins during an oil spill. *Biological Conservation* **86**, 393–400.

Lawson and Treloar Pty Ltd (1996). Oil-spill trajectory modelling *Iron Baron* oil spill. Report #J5078/R1699.

Page, G. W, Carter, H. R., and Ford, R. G. (1990). Numbers of seabirds killed or debilitated in the 1986 *Apex Houston* oil spill in central California. *Studies in Avian Biology* **14**, 164–174.

Piatt, J. F., Lensink, C. J., Butler, W., Kendziorek, M., and Nysewander, D. R. (1990). Immediate impact of the '*Exxon Valdez*' oil spill on marine birds. *The Auk* **107**, 387–397.

Reilly, P. N., and Cullen, J. M. (1982). The little penguin *Eudyptula minor* in Victoria. III. Dispersal of chicks and survival after banding. *Emu* **82**, 137–42.

Rogers, T., and Holdsworth, M. (1999). Rehabilitation of oiled seabirds following the grounding of the *Iron Baron*. In '*Iron Baron* Oil Spill July 1995: Long Term Environmental Impact and Recovery'. pp. 147–173. (Department of Primary Industries, Water and Environment, Tasmania: Hobart.)

Seber, G. A. F. (1982). 'The Estimation of Animal Abundance and Related Parameters.' (MacMillan: New York.)

Stahel, C., and Gales, R. (1987). 'Little Penguin: Fairy Penguins in Australia.' (New South Wales University Press: Sydney.)

Stowe, T. J. (1982). Beached bird surveys and surveillance of cliff-breeding seabirds. Report to Nature Conservancy Council. Royal Society for the Protection of Birds, Sandy Beds, UK.

Vauk, G., Hartwig, E., Reineking, B., Vauk-Hentzelt, E. (1989). Losses of seabirds by oil pollution at the German North Sea coast. *Scientia Marina* **53**, 749–754.

Weavers, B. W. (1992). Seasonal foraging ranges and travels at sea of little penguins *Eudyptula minor*, determined by radiotracking. *Emu* **91**, 302–317.

Manuscript received 16 August 1999; accepted 27 March 2000