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**Post-release survival and productivity of oiled  
little blue penguins (*Eudyptula minor*) rehabilitated  
after the 2011 C/V *Rena* oil spill**



A thesis presented in partial fulfilment of the requirements for the  
degree of Master of Science in Conservation Biology

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## Thesis Abstract

There is ongoing global debate about the effectiveness and conservation value of rehabilitating oiled wildlife, with post-rehabilitation monitoring of released individuals being required to evaluate the medium- and long-term effectiveness of the rehabilitation process.

This study provides the first assessment of the efficacy of the oil-rehabilitation process used in New Zealand by monitoring the post-release survival and productivity of little blue penguins (*Eudyptula minor*) that were oiled and subsequently rehabilitated following the 2011 C/V *Rena* oil spill in Tauranga, New Zealand. This study was enabled as all rehabilitated penguins were tagged with passive integrated transponders (PIT-tags/micro-chips) before release, as were similar numbers of non-oiled control penguins from within the local area around the same time. This enabled survival and productivity to be compared between rehabilitated and non-oiled penguins.

Surveys for the presence of marked penguins were made in 18 of the 23 months following the release of rehabilitated penguins at three study sites (Mount Maunganui/Mauao, Leisure Island/Moturiki, and Rabbit Island/Motuotau). Mark-recapture analyses indicated that survival rates of rehabilitated penguins were comparable to those of control penguins. However, survival was reduced for both groups in the first six months following rehabilitation/micro-chipping. Survival probabilities increased thereafter and were high and reasonably constant over time. Probabilities estimated are likely to represent minima as by the end of the study an asymptote of first-time re-sightings of control and rehabilitated penguins was yet to be reached. Survival was not influenced by selected variables including oiling degree, admission and release body mass index, packed cell volume, total protein levels, blood glucose levels, and captive duration.

This work also found that rehabilitated penguins were heavier than control penguins upon release and during the subsequent two months, however following the moult and post-moult foraging period masses reduced and thereafter were similar to those of control penguins. The behaviour of individual penguins was also recorded during surveys; rehabilitated penguins were more likely to stay (not move) when approached during surveys and were more docile than control penguins when handled.

Breeding monitoring found that productivity of rehabilitated penguins was somewhat reduced in the year after the spill. The timing and duration of egg laying, clutch sizes and pre-fledging chick masses were similar between rehabilitated pairs (pairs including at least one rehabilitated penguin) and control pairs (pairs including two control penguins), whereas hatching, fledging and egg success were lower in rehabilitated pairs; however, only hatching success was significantly reduced. Despite these reductions, hatching, fledging and egg success rates of rehabilitated pairs were within ranges reported for other little blue penguin colonies in Australia and New Zealand.

These findings suggest that the oil-rehabilitation process used during the *C/V Rena* oil spill was reasonably effective at treating and reversing most negative effects of oil-contamination on the post-release survival and productivity of rehabilitated penguins. This demonstrates the general effectiveness of the rehabilitation process used to treat oiled little blue penguins in New Zealand and justifies, with on-going improvement and adaption of treatments and techniques used, the continued practise of oiled wildlife rehabilitation in New Zealand.

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# Chapter One

## Thesis introduction



Image credit: PerthNow News 2011

## Marine oil pollution and the rehabilitation debate

Oil pollution has been a significant contributor to the contamination and degradation of marine ecosystems (Atlas and Bartha 1973; Peterson et al. 2003). The most noticeable effect of this pollution is when large numbers of oiled carcasses of marine and coastal animals (particularly seabirds) wash ashore (Piatt et al. 1990; Furness and Camphuysen 1997). Oiled wildlife may also wash ashore alive but in varying states of distress. Without human intervention (such as rescuing and attempting to rehabilitate oiled animals) many of these distressed animals die. Of those that survive, many suffer from the detrimental effects of external contamination and the toxic sub-lethal effects of oil ingestion (Fry and Lowenstine 1985; Burger and Fry 1993).

One of the main sources of marine oil pollution are acute, large-scale oil spills. These spills generally occur as a result of blowouts of oil wells drilled at sea (Jerneloiev 2010; Allan et al. 2012) or from accidents involving marine vessels (such as oil tankers and cargo ships) (Wolfaardt et al. 2009b; Sammarco et al. 2013). Large well blowouts are not that frequent however when they occur the results can be catastrophic (Jerneloiev 2010). This is particularly so if the blowouts take place in deep water as it may take months for relief wells to be drilled and/or cement plugs to be put in place to stop the spillage; consequently, large quantities of oil may be spilled into the marine environment (Jerneloiev 2010). Marine vessel accidents can also result in large-scale oil contamination. These vessels can carry thousands of tonnes of oil (super-tankers have the capacity to carry over 200,000 tonnes of oil) (Hansen and Tourk 1974; Zronik 2004) and thus like well blowouts, shipping accidents have the potential to cause catastrophic oil spills with devastating environmental impacts. Concerningly, the frequency and severity of such spills has increased significantly since the mid-twentieth century due to increased international transportation of fuel oil in response to increased fuel demand (Clark and Gorney 1987).

Five such acute oil spills that received a lot of attention are the *Torrey Canyon*, *Exxon Valdez*, *Prestige*, *Treasure*, and *Deepwater Horizon* oil spills (the first four of these spills occurred as a result of marine vessel accidents and the last spill was the result of an oil well blowout). These spills gained notoriety due to the amount of oil spilled, the number of animals killed, and/or the attempts made to rehabilitate oil-contaminated wildlife. Firstly, the 1967 *Torrey*

*Canyon* oil spill off the coast of England is known as the first of a succession of oils spills that stimulated global concern about the impacts of oil pollution (Bourne et al. 1967; Bourne 1970a, b). This concern was borne as a result of the mortality of approximately 8000 seabirds, predominantly common murrets (*Uria aalge*) and razorbills (*Alca torda*), and the extreme ineffectiveness of attempts to rehabilitate oiled birds (Clark 1978). Further attention was received after the 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska. This spill is renowned as being one of the worst oil spills in history in terms of the volume of oil spilled (36,400 tonnes) (Piatt and Lensink 1989; Piatt et al. 1990; Stewart et al. 1991) and in terms of wildlife mortality; mortality estimates ranged from 100,000 to 690,000 for seabirds (Piatt and Ford 1996) and 1500 (Lensink 1990) to 4600 (Garrott et al. 1993) for sea otters (*Enhydra lutris*). Likewise, the 2002 *Prestige* oil spill, which contaminated coastal waters off Spain, Portugal and France (Garcia et al. 2003), is known for the large volume of oil spilled (63,000 tonnes of oil) and for causing a high rate of seabird mortality; it was estimated that overall seabird mortality exceeded 200,000 (Munilla et al. 2011). In comparison to the *Exxon Valdez* and *Prestige* oil spills, the amount of oil spilled during the 2000 *Treasure* spill in South Africa was small (approximately 1400 tonnes); what the *Treasure* oil spill is renowned for is its large-scale rescue and rehabilitation of approximately 19,000 African penguins (*Spheniscus demersus*) as well as the pre-emptive capture and relocation of 19,500 unoiled penguins to Cape Recife (800 km away) to prevent them from becoming oiled (Crawford et al. 2000; Wolfaardt et al. 2008b). These rehabilitation and relocation efforts in response to the *Treasure* oil spill are to date the largest ever attempted in South Africa and had a profound impact on the African penguin population. Lastly, the *Deepwater Horizon* oil spill occurred at the Macondo oil well in the Gulf of Mexico. A blowout at the well, which was being drilled by the BP-operated *Deepwater Horizon* oil rig, (Jerneloiev 2010; Allan et al. 2012) resulted in at least 250,000-400,000 tonnes of oil spilling over a three month period. This spill received immense media attention and the President of the United States, Barack Obama, even described it as “potentially the worst environmental disaster in American history” (Jerneloiev 2010). The worst affected wildlife species was the critically endangered Kemp’s Ridley turtle (*Lepidochelys kempii*), 500 of which were found dead or debilitated. 70,000 turtle eggs were transported to the east of Florida to reduce exposure to the oil and to hopefully assist recruitment in the next cohort (Safina 2011).

As illustrated in these examples, seabirds are particularly vulnerable to oiling and in general are the group of animals most visibly affected by marine oil pollution. Other groups of animals that are also affected by oil, but to a less noticeable extent than seabirds, include marine mammals (especially furred species such as otters and seals) (Garrott et al. 1993; Garshelis 1997; Lander et al. 2002; Jerneloiev 2010; Barron 2012) and reptiles (such as turtles and marine iguanas *Amblyrhynchus cristatus*) (Wikelski et al. 2002; Barron 2012). The main reason seabirds are particularly vulnerable to oiling is because, unlike marine mammals and reptiles, seabirds spend a lot of time floating on water and foraging at sea at or near the water surface and thus are more likely to encounter marine oil slicks (Leighton 1993). Most vulnerable are the diving seabirds, notably alcids and Pelecaniformes in the northern hemisphere (Stowe and Underwood 1984; Piatt et al. 1990) and Sphenisciformes (penguins), Procellariiformes (tube-nosed birds such as petrels and shearwaters) and Pelecaniformes (mainly gannets) in the southern hemisphere. These species are often concentrated in large groups or colonies near busy shipping lanes where oil pollution is worst, and they spend most of their time either diving beneath the surface to get prey, or floating on top of the water. As a result, these birds more frequently encounter and become contaminated by oil (Gandini et al. 1994; Crawford et al. 2000; Goldsworthy et al. 2000b; Parsons and Underhill 2005; Garcia-Borboroglu et al. 2006; Altwegg et al. 2008). As a group, seabirds are most visibly affected by oil contamination as shortly after becoming oiled seabirds try to make landfall (Underhill et al. 1999). They do so in an attempt to avoid death by drowning, exhaustion or hypothermia as external contamination mats the plumage resulting in reduced buoyancy, an inability to fly (in seabirds other than penguins), impaired thermoregulation (as the insulative properties of the plumage are lost), and depletion of energy reserves (as their metabolic rate increases in an attempt to maintain body temperature) (Burger and Fry 1993; Leighton 1993). Some oiled birds make it ashore (noticeably penguins as they are good swimmers), however others are unsuccessful and die at sea (these unsuccessful birds are often pelagic species which get oiled in the open ocean far from land and thus struggle to make it ashore) (K. Morgan, pers. comm.). Consequently, after large, acute oil spills, coastlines may become covered in hundreds to thousands of oiled birds, both dead and alive, with the dead birds that wash ashore generally representing only a fraction of the birds that died as many carcasses are scavenged and never come ashore (Burger and Fry 1993).

In countries that attend to oiled wildlife as part of their oil spill response, the presence of oiled and distressed birds on coastlines generally results in large-scale operations being put into action to rescue and rehabilitate these oil-contaminated birds. Although such rescue and rehabilitation operations have frequently occurred over the past 50 years (Newman et al. 2003) and since 1990 have been mandated by law in the state of California (Golightly et al. 2002; Newman et al. 2003), there is controversy amongst wildlife and conservation biologists regarding this response (De la Cruz et al. 2013). This controversy regards the effectiveness of rehabilitation as a conservation tool.

Opponents argue that rehabilitation fulfils only an ethical, humanitarian need to alleviate the distress of oiled seabirds and has very little or no conservation value (Sharp 1996; Wolfaardt et al. 2009b). It has also been suggested that unsuccessful rehabilitation programmes may prolong the suffering of oiled seabirds (Wernham et al. 1997). These viewpoints are based on the results of some scientific studies showing low captive survival rates of birds in rehabilitation facilities (Bourne 1970a; Smith 1975; Ford et al. 1991; J. White pers. comm. In: Sharp 1996), low post-release survival (Speich 1986; Freedman 1995; Anderson et al. 1996; Sharp 1996; Camphuysen et al. 1997; Wernham et al. 1997; Estes 1998; Ben-David et al. 2002; Joys et al. 2003; De la Cruz et al. 2013), low productivity of rehabilitated birds (based on limited direct evidence of rehabilitated birds breeding post-release) (Morant et al. 1981; Newman et al. 2003), and behavioural abnormalities once released (Anderson et al. 1996; Anderson et al. 2000; Newman et al. 2000). Sub-lethal effects of oiling have also been noted (such as permanent damage to organ systems and altered functioning of processes critical for health and fitness) (Burger and Fry 1993; Anderson et al. 1996; Sharp 1996; Wernham et al. 1997; Golightly et al. 2002), indicating that rehabilitation is not always successful in reversing the negative effects of oil contamination and ingestion. Furthermore opponents argue that rescue and rehabilitation operations are extremely costly (Anderson et al. 1996; Sharp 1996; Estes 1998; Jessup 1998) and often only benefit a few individuals (Estes 1991). This was demonstrated by the *Exxon Valdez* oil spill in Alaska where approximately US\$41 million dollars was spent on the rescue, treatment and release of about 800 seabirds (Sharp 1996) and over US\$17 million dollars on 222 sea otters (Estes 1991); these rehabilitated animals represented only a small fraction of the local populations (Estes 1998) and thus are likely to have contributed little to the

recovery of these populations. This individual- rather than population-oriented focus has been criticised (Estes 1998) and some believe that the money spent on rehabilitating these few individuals would have been better spent on increasing entire populations and reducing their vulnerability to future threats (Bourne 1970a; Estes 1991; Boersma 1995; Newman 1995).

Three other points of concern regarding rehabilitation are that removal of oil-contaminated birds may damage habitat and disturb unoiled birds (Boersma 1995; Shannon and Crawford 1999; Wolfaardt et al. 2009b) potentially causing undue stress and other negative effects, birds that survive post-release but do not breed are effectively competing for scarce resources with the breeding population (Wolfaardt et al. 2008a), and rehabilitation lulls the public into a false sense of security and preparedness regarding oil spills (Estes 1991). This latter concern is because of the way in which rehabilitation is often viewed as a means of mitigating the effects of seabird oil contamination and thus can downplay the devastating effects of oil spills; this is despite the fact that in most cases significantly more birds die from oil contamination that can ever be saved by rehabilitation efforts (Goldsworthy et al. 2000b).

In contrast, proponents of rehabilitation argue that it is a worthy animal welfare and conservation tool that contributes to the post-spill recovery of populations. They claim that the cost of rehabilitation is justified (as the money spent on rehabilitating oiled birds has been set aside for this specific purpose and cannot be spent on other conservation efforts) and that cost-effectiveness is increasing with increased rehabilitation efficacy. More recent studies have substantiated these claims through findings of significantly increased captive survival (Crawford et al. 2000; Goldsworthy et al. 2000b; Golightly et al. 2002; Nel et al. 2003; Saba and Spotila 2003; Parsons and Underhill 2005; Wolfaardt et al. 2009b), post-release survival (Underhill et al. 1999; Whittington 1999; Crawford et al. 2000; Golightly et al. 2002; Whittington 2002; Saba and Spotila 2003; Barham et al. 2006; Altwegg et al. 2008) (see Table 1.1) and reproduction rates (Giese et al. 2000; Wolfaardt and Nel 2003; Wolfaardt et al. 2009b) of rehabilitated animals over time (see Table 1.2); in some cases these survival and reproduction rates are equivalent to non-oiled, non-rehabilitated control animals (Underhill et al. 1999; Whittington 1999; Golightly et al. 2002; Whittington 2002; Wolfaardt and Nel 2003; Altwegg et al. 2008) illustrating that the effects of oiling have been

reversed through rehabilitation. These increases in survival and reproduction are concomitant with significant improvements in oiled wildlife response plans and the transportation conditions of oiled wildlife taken to rehabilitation centres (Wolfaardt et al. 2008b), the increased availability and mobilisation of appropriate equipment required during an oiled wildlife response (K. Morgan, pers. comm.), the implementation of improved stabilisation, treatment (Wolfaardt et al. 2009b), washing and rehabilitation procedures and techniques, and improved captive management and husbandry of birds in rehabilitation (Ben-David et al. 2002; Kuyper and Williams 2004; Newman et al. 2004; Ziccardi 2008). The intensity, duration and search effort of post-release monitoring studies have also increased resulting in more accurate and often higher estimates of survival and productivity (Wolfaardt et al. 2009b). The duration between oiling and decontamination of oiled wildlife has also reduced due to better preparedness and quicker responses of oiled wildlife response teams (Wolfaardt et al. 2008b), particularly if the teams are integrated within the overall oil spill response management system as they can be rapidly deployed and are more efficient. Additionally, these response teams are composed of highly experienced personnel with a range of skills; in some cases expert responders are flown in from overseas (K. Morgan pers. comm.). In combination these factors have contributed to the greatly improved captive survival rates and post-release survival and reproductive rates of oil-rehabilitated that have been documented over time.

These arguments for and against rehabilitation, with respect to post-release survival and reproduction of rehabilitated seabirds, albeit seemingly substantial, are actually based upon relatively few post-release monitoring studies (De la Cruz et al. 2013). The results of these studies, some of which are presented in Tables 1.1 and 1.2, are highly variable between species and over time and are influenced by the study intensity, duration and geographic range covered. For example in Table 1.1, the low apparent post-release survival rate reported for Magellanic penguins (*Spheniscus magellanicus*) rehabilitated after various oil spills along coastal South America is due to difficulty monitoring the large geographic range these migratory birds inhabit as well as the low intensity of re-sighting surveys; consequently few rehabilitated penguins were re-sighted (Ruoppolo et al. 2012). This varying, limited depth of data and associated conclusions made from post-release monitoring studies may thus inaccurately reflect the efficacy of rehabilitation operations.

This highlights the importance of continued conductance of longer-term post-release monitoring surveys to better determine survival and reproductive rates of rehabilitated birds (of a variety of species), to enable on-going assessment of the effectiveness of rehabilitation and its conservation value (Parsons and Underhill 2005; Wolfaardt et al. 2009b). These post-release studies are crucial as they provide a far better assessment of rehabilitation efficacy than captive survival rates (the proportion of birds admitted for rehabilitation that survive to be released back to the wild) as they show whether upon release rehabilitated birds survive the transition back to the wild, and thereafter have long-term survival and reproductive rates equivalent to control birds (Wolfaardt et al. 2009b). However, regardless of what future post-release studies determine about the effectiveness of rehabilitating oiled wildlife, opponents of this action must come to terms with the fact that, despite debate, rehabilitation will continue to occur due to public demand to clean and alleviate the suffering of these oiled animals (Estes 1998). It is therefore important to address the concerns of opponents and use these post-release studies to provide positive feedback on how treatments and rehabilitation techniques and procedures can be adapted and improved over time to achieve greater rehabilitation success in the future.

**Table 1.1.** Information on various oil spills and the associated post-release survival of oil-rehabilitated (rehab group PRS) and control animals (control group PRS).

Year	Vessel/source	Location	Species rehabilitated	Rehab group PRS (%)	Control group PRS (%)
1970-79 <sup>1</sup>	Seven different oiling incidents	South Africa	African penguin	30	-
1979 <sup>2</sup>	Unknown	St Croix Island, South Africa	African penguin	87	-
1979-95 <sup>3</sup>	Various unspecified spills	The Netherlands	Various guillemot species (genera <i>Uria</i> and <i>Cepphus</i> )	22	85
1983 <sup>4</sup>	<i>Castillo de Bellver</i>	Saldanha Bay, South Africa (Malgas Island)	Cape gannet ( <i>Morus capensis</i> )	85.5	87.8
1983 <sup>4</sup>	<i>Castillo de Bellver</i>	Saldanha Bay, South Africa (Lambert's Island)	Cape gannet	88	89.6
1994 <sup>5,6</sup>	<i>Apollo Sea</i>	Dassen Island, South Africa	African penguin	73	-
1995 <sup>7</sup>	<i>Iron Baron</i>	Tasmania, Australia (Ninth Island)	Little penguin ( <i>Eudyptula minor</i> )	59	77
1995 <sup>7</sup>	<i>Iron Baron</i>	Tasmania, Australia (Low Head)	Little penguin	44	50
1995 <sup>6</sup>	Unknown	Near Dyer Island, South Africa	African penguin	40	
1995 <sup>8</sup>	Pipeline spill	California, USA	American coot ( <i>Fulica americana</i> )	49	76
1997 <sup>9</sup>	Torch/Platform Irene Pipeline	California, USA	Western gull ( <i>Larus occidentalis</i> )	100	90
1998 <sup>6,10</sup>	Pipeline spill	Cape Town Harbour, South Africa	African penguin	58	
2000 <sup>11</sup>	<i>Treasure</i>	North of Robben Island, South Africa (Robben Island)	African penguin	52	-
2000 <sup>12</sup>	<i>Treasure</i>	North of Robben Island, South Africa (Dassen Island)	African penguin	45	-
2000 <sup>13</sup>	Pipeline spill	Pennsylvania, USA	Freshwater turtle species ( <i>Chrysemys picta</i> , <i>Chelydra serpentina</i> , <i>Trachemys scripta</i> , <i>Pseudemys rubriventris</i> )	75	69
2007 <sup>14</sup>	M/V <i>Cosco Busan</i>	San Francisco Bay, California, USA	Surf scoter ( <i>Melanitta perspicillata</i> )	14.3	49.8
2000-10 <sup>15</sup>	Eight different oiling incidents	Coast of South America	Magellanic penguin	1.88	-

**Sources:** <sup>1</sup>(Morant et al. 1981). <sup>2</sup>(Randall et al. 1980). <sup>3</sup>(Camphuysen et al. 1997). <sup>4</sup>(Altwegg et al. 2008). <sup>5</sup>(Crawford et al. 2000). <sup>6</sup>(Whittington 2002). <sup>7</sup>(Goldsworthy et al. 2000b). <sup>8</sup>(Anderson et al. 2000). <sup>9</sup>(Golightly et al. 2002). <sup>10</sup>(Whittington et al. 2000). <sup>11</sup>(Barham et al. 2007). <sup>12</sup>(Wolfaardt et al. 2001). <sup>13</sup>(Saba and Spotila 2003) <sup>14</sup>(De la Cruz et al. 2013). <sup>15</sup>(Ruoppolo et al. 2012).

**Table 1.2.** Information on various breeding success parameters for oil-rehabilitated bird species and con-specific non-oiled control birds. Rehab and control PRR (post-release reproductive rate of rehabilitated and control birds) refers to the percentage of re-sighted marked birds observed breeding.

Vessel/ source	Study length (years)	Location	Rehab species	Rehab PRR (%)	Control PRR (%)	Breeding delay* (%)	Reduced clutch size	Rehab hatching success (%)	Control hatching success (%)	Rehab fledging success (%)	Control fledging success (%)	Rehab egg success (%)
Unspecified oil spill (1979) <sup>1</sup>	0.5	St. Croix Island, South Africa	African penguin	7	-	-	-	-	-	-	-	-
<i>Castillo de Belver</i> (1983) <sup>2</sup>	6	Saldanha Bay, South Africa	Cape Gannet	Not Reduced	-	-	-	-	-	-	-	-
<i>Apollo Sea</i> (1994) <sup>3</sup>	5.5	Dassen Island, South Africa	African penguin	40	-	-	No	67.8	71.7	63.7	67.8	-
<i>Apollo Sea</i> (1994) <sup>4</sup>	10.5	Dassen Island, South Africa	African penguin	61	-	Yes	-	-	-	-	-	-
<i>Apollo Sea</i> (1994) <sup>4</sup>	10.5	Two intensively monitored sites on Dassen Island, South Africa	African penguin	73	-	Yes	-	-	-	-	-	-
Seven unspecified oil spills (1970-79) <sup>5</sup>	-	South Africa	African penguin	0-30	-	-	-	-	-	-	-	-
Unspecified oil spills (1995) <sup>6</sup>	4	Dyer Island, South Africa	African penguin	30	-	-	-	-	-	-	-	-
Pipeline oil spill (1998) <sup>6</sup>	1	Cape Town Harbour, South Africa	African penguin	4.5	-	-	-	-	-	-	-	-
<i>Iron Baron</i> (1995) <sup>7</sup>	2	Tasmania, Australia	Little penguin	-	-	Yes	-	Not reduced	-	-	-	Reduced first season only
<i>Treasure</i> (2000) <sup>8</sup>	2	Dassen Island, South Africa	African penguin	17	60	-	-	-	-	-	-	-
<i>Treasure</i> (2000) <sup>9</sup>	5	Dassen Island, South Africa	African penguin	30	68	-	-	Not reduced	-	-	-	-

**Sources:** <sup>1</sup>(Randall et al. 1980). <sup>2</sup>(Altwegg et al. 2008). <sup>3</sup>(Wolfaardt et al. 2008c). <sup>4</sup>(Wolfaardt et al. 2008a). <sup>5</sup>(Morant et al. 1981). <sup>6</sup>(Whittington 2002). <sup>7</sup>(Giese et al. 2000). <sup>8</sup>(Wolfaardt and Nel 2003). <sup>9</sup>(Wolfaardt et al. 2008b).

**Table 1.3.** Effects of oil contamination from spills and experimental studies on the success of various breeding parameters for non-rehabilitated bird species.

Dose/spill	Study length (years)	Species	Breeding delay	Reduced clutch size	Hatching success	Fledging success	Egg success	Other findings
Braer oil spill, Shetland, Scotland (1993) <sup>1</sup>	1	Kittiwake ( <i>Rissa tridactyla</i> )	No	No	Not reduced	Not reduced	-	Anaemia, low return rates to breeding colonies, low mate and nest-site fidelity
5mL oil per 100g food <sup>2</sup>	<1	Khaki Campbell duck ( <i>Anas platyrhynchos domesticus</i> )	Yes	-	-	-	-	Reduced eggshell thickness and oviposition rate
3mL oil per 100g food <sup>3</sup>		Mallard ( <i>Anas platyrhynchos</i> )	Yes					Reduced eggshell thickness and oviposition rate
Fed a capsule with 200mg of oil <sup>4</sup>	~0.1	Japanese quail ( <i>Coturnix japonica</i> )	-	Yes	Yes	-	-	Altered yolk structure
Exxon Valdez oil spill, Alaska, 1989 <sup>5</sup>	13	Pigeon guillemots ( <i>Cepphus columba</i> )	-	Yes	-	-	-	-
Prestige oil spill, Spain (2002) <sup>6</sup>	1	European shags ( <i>Phalacrocorax aristotelis</i> )	-	-	-	-	50% reduction	-
20µL oil applied to eggs <sup>7</sup>	<0.1	Common eider ( <i>Somateria mollissima</i> )	-	No	Reduced	-	-	Significantly increased embryo mortality
Varying doses of oil in food <sup>8</sup>	3	Leach's storm petrel ( <i>Oceanodroma leucorhoa</i> )	-	-	Yes	Yes	-	Reduced chick growth rates and survival
Fed oil as 0.25 and 2.5% of the total diet <sup>9</sup>	0.5	Mallard	-	Yes	No	-	-	Reduced oviduct weight of oil-fed hens
Exxon Valdez oil spill, Alaska, 1989 <sup>10</sup>	2	Black oystercatcher ( <i>Haematopus bachmani</i> )	-	No	No	No	No	Reduced growth rates of chicks raised in areas with heavily oiled shorelines
Dosed with oil at a rate of 2.5ml/kg body weight <sup>11</sup>	2	Leach's storm petrel	-	-	-	Yes	-	Reduced chick growth and survivability
External application or oral ingestion of 0.1-2.0mL of oil <sup>12</sup>	0.33	Wedge-tailed shearwater ( <i>Puffinus pacificus</i> )	-	Yes	Yes	Yes	Yes	-

**Sources:** <sup>1</sup>(Walton et al. 1997). <sup>2</sup>(Harvey et al. 1981). <sup>3</sup>(Holmes et al. 1978). <sup>4</sup>(Grau et al. 1977). <sup>5</sup>(Golet et al. 2002). <sup>6</sup>(Velando et al. 2005). <sup>7</sup>(Albers and Szaro 1978). <sup>8</sup>(Butler et al. 1988). <sup>9</sup>(Coon and Dieter 1981). <sup>10</sup>(Andres 1999). <sup>11</sup>(Trivelpiece et al. 1984). <sup>12</sup>(Fry et al. 1986).

## **Internationally recommended rehabilitation protocols**

Cleaning and rehabilitation techniques, procedures and protocols have been developed and adapted over time by organisations involved in oiled wildlife rescue, rehabilitation and research. These developments enable oiled seabirds to be treated, cleaned and rehabilitated in the most effective manner to maximise survival.

See Chapter 1 Appendix for an overview of procedures used and recommended by various organisations and specialist personnel to clean and rehabilitate oiled seabirds. Included is information on procedures used by the Oiled Wildlife Care Network (OWCN) in California and the South African Foundation for the Conservation of Coastal Birds (SANCCOB), two organisations that are actively practicing oiled wildlife response techniques.

## **Oil spills and oiled wildlife rehabilitation in New Zealand**

The rugged nature of New Zealand's coastlines has resulted in a number of shipping accidents. In some cases these accidents have caused oil spills. Some significant marine oil spills that have occurred in New Zealand since 1990 are summarised in Table 1.4 (MNZ 2013a). Of those listed, the most significant oil spill is that associated with the grounding of the C/V *Rena* (hereafter referred to as the *Rena*) in 2011. This spill has been described as "New Zealand's worst maritime environmental disaster" (Harper et al. 2011) as a result of the large amount of oil spilled into the ocean, which caused widespread contamination of the marine and coastal environment and associated wildlife. In response to this spill a large-scale rescue and rehabilitation operation was conducted by New Zealand's Oiled Wildlife Response Team which is co-ordinated by Wildbase, Massey University under contract to Maritime New Zealand (H. McConnell, pers. comm.; Michael et al. 2012). This operation was the largest oiled wildlife response conducted in New Zealand and provided the first opportunity to assess the effectiveness of the rehabilitation process in the form of post-release survival and reproduction monitoring of rehabilitated little blue penguin

## Box 1. Little blue penguin biology

Little blue penguins, also known by their Maori name Korora in New Zealand and as fairy penguins or little penguins in Australia, are colonial seabirds native to coastal areas and offshore islands in New Zealand and southern Australia (Gales and Green 1990). The conservation status of the species is 'least concern' however, population numbers are in decline (IUCN 2012) due mainly to predation (mustelids and dogs are the main predators) and threats posed by human activities and disturbance (Taylor 2000) such as near shore set-net fishing (Taylor 1999), coastal development encroaching into penguin breeding habitat (Taylor 2000), close proximity of roads and walkways to nesting birds, and habitat degradation (Braidwood 2009).

Little blue penguins are the smallest species of penguin in the world, averaging 40 cm in height (Marchant and Higgins 1990; Robertson and Heather 2005; Scofield and Stephenson 2013) and 1100 g in weight (Robertson and Heather 2005). During the day they forage in shallow coastal waters feeding on squid and a variety of small shoaling fish (Gales and Green 1990; Gales and Pemberton 1990; Flemming et al. 2013) such as pilchards and anchovies (Chiaradia et al. 2003). When foraging they generally remain within 20 km of the coast, however the lengths and distances of their foraging trips are highly variable and often depend on food availability and time of year (Reilly 1994).

Little blue penguins are monomorphic, and reach sexual maturity at two to three years of age (Dann and Cullen 1990; Dann et al. 1995). In general breeding adults are monogamous (Marchant and Higgins 1990; Wolfaardt et al. 2008c) and site fidelic (Reilly and Cullen 1981; Bull 2000; Johannesen et al. 2002a), usually only seeking a new mate and/or nest if their mate dies and/or previous breeding attempts have been unsuccessful (Reilly and Cullen 1981; Johannesen et al. 2002a). Breeding generally occurs between September and February (the period during which the *Rena* oil spill and associated rescue and rehabilitation efforts took place), however there is considerable variation in the timing and duration of breeding with latitude and between years (Gales 1985). Eggs are laid in burrows or under other covered areas (Gales and Green 1990) including rocks, vegetation, caves, rabbit burrows, driftwood (Perriman and McKinlay 1995) and artificial structures (such as corrugated iron sheets (Braidwood 2009), wooden nest boxes and drain pipes (Perriman and McKinlay 1995)). In general, each clutch produced consists of two eggs laid on average 2.8 days apart (Stahel and Gales 1987; Davis and Renner 2003). Once the clutch is completed the eggs are incubated until the chicks hatch; this occurs after an incubation period of approximately 35 days (Williams 1995; Chiaradia and Kerry 1999). Once hatched the chicks are constantly brooded by their parents for 21 days. Both of these parental duties (incubation and brooding) are shared equally between the partners of breeding pairs, with one parent out foraging while the other incubates or guards the chicks (Gales and Green 1990; Williams 1995). Following the brood period the chicks are left alone during the day and are only visited at night to be fed (Williams 1995). After the chicks fledge, which occurs when they are seven to eight weeks old (Moon 2011), the adults return to the sea for a few weeks to feed and build up their fat reserves in preparation for the 2–3 week fasting period during their annual moult; this occurs on land with the peak period in February and March. After moulting the penguins again return to sea to fatten up and only periodically return to their colonies during winter. These visits then become more frequent as the next breeding season approaches (Gales and Green 1990).

**Table 1.4.** Summary of significant oil spills in New Zealand maritime waters since 1990. Wildlife affected (both dead and alive) represents minimum estimates of impact.

Year	Vessel	Location	Type of oil Spilled	Amount spilled (tonnes)	Wildlife affected
1998 <sup>1</sup>	<i>Don Wong 529</i>	Stewart Island	Automotive gas oil	400	0
1999 <sup>1</sup>	<i>M/V Rotoma</i>	Poor Knights Island	Oily bilge discharge	7	0
2000 <sup>1</sup>	<i>Sea Fresh</i>	Stewart Island	Diesel	60	0
2002 <sup>1</sup>	<i>Jody F Millennium</i>	Gisborne	Fuel oil	25	8 birds <sup>2</sup>
2011 <sup>1</sup>	<i>C/V Rena</i>	Tauranga	Fuel oil	~360	2448 marine and coastal birds, 24 terrestrial birds, 17 fur seals, 4 whales <sup>3</sup>

<sup>1</sup>(MNZ 2013a). <sup>2</sup>(B. Gartrell, pers. comm.). <sup>3</sup>(Wildbase, Massey University, unpublished data).

Outlined below is information about the *Rena* grounding and oil spill, the associated effects on wildlife, the oiled wildlife response, and the post-release monitoring studies conducted.

### **C/V *Rena* incident overview**

At 2:20 am on 5 October, 2011, the 21 year old, Liberian-flagged cargo vessel *Rena* en route from Napier to Tauranga, North Island, New Zealand struck the Astrolabe Reef (Otaiti), 12 nautical miles (22.2 km) off the coast of Tauranga in the Bay of Plenty (MNZ 2013a) (Figure 1.1). At the time 1368 containers were on board the *Rena* as well as 1733 tonnes of heavy fuel oil (Massey University 2013; MNZ 2013a). The vessel, which was travelling at approximately 21 knots when it struck the reef, subsequently partially grounded with the bow section of the vessel wedged on the reef whilst the stern section remained afloat. The impact of the strike resulted in damage to the hull and the flooding of two cargo holds. By evening an oil leak had been detected with oil spilling into the ocean (MNZ 2013a).



**Figure 1.1.** *Rena* grounding location. The inset map shows New Zealand and the Bay of Plenty region. The main map shows the location of Tauranga within the Bay of Plenty region and the specific location of the grounding (Image credit: Edwards 2011). 12NM (nautical miles) represents the distance from the wreck to the Tauranga coastline. 1 is Mount Maunganui (Mauao), 2 is Leisure Island (Moturiki) and 3 is Rabbit Island (Motuotau) (the three study sites).

Based on inspections of the vessel and risk assessments, Maritime New Zealand’s Marine Pollution Response Service declared the situation to be a Tier 3 Oil Spill Response. This is the highest national level of emergency oil spill response (MNZ 2013b,c). This declaration prompted the mobilisation of the National (oil spill) Response Team and their equipment to Tauranga to co-ordinate and respond to the situation. Other responders included local and regional councils, the Department of Conservation, the New Zealand Defence Force, the World Wildlife Fund, Waikato University, the New Zealand Fire Service and volunteers (MNZ 2013b). The National Oiled Wildlife Response Team was also a key response organisation; this is a large team co-ordinated by Massey University (Palmerston North, New Zealand) under contract to Maritime New Zealand and consists of 47 personnel including veterinarians, pathologists, wildlife technicians, Regional Council staff, ornithologists and expert responders (H. McConnell, pers. comm.).

On 6 October the first dead oil-contaminated birds were seen at sea (Massey University 2013) and on 7 October, within 36 hours of the grounding of the *Rena*, a temporary oil decontamination and treatment facility (the “Oiled Wildlife Facility, OWF” was established at the Tauranga Wastewater Treatment Plant in Te Maunga, Tauranga (H. McConnell, pers. comm.). This was a tent-based facility that was centred around two purpose-built containerised units for the provision of wash requirements for oiled animals. This facility was put into action that same day with the admittance of the first oiled bird that was rescued by members of the oiled wildlife field response team (MNZ 2013b). During the response, additional transient oiled wildlife facilities were also established at Motiti Island and Te Kaha to allow initiation of stabilisation of oil-affected animals prior to their transport to the OWF. On 9 October the *Awanuia* fuel tanker arrived from Auckland to start fuel recovery operations (H. McConnell, pers. comm.; MNZ 2013c). The initial stages of these operations were unfortunately hampered by bad weather, changeable conditions and equipment breakdowns (MNZ 2013a), and on 11 October a storm caused significant damage to the hull resulting in a large oil spill. The storm also resulted in the vessel developing a 20 degree list (Michael et al. 2012). In total, approximately 350 tonnes of oil leaked from the fuel tanks into the ocean between 5-11 October (H. McConnell, pers. comm.; Michael et al. 2012; MNZ 2013a). Another storm on 22 October resulted in the loss of a further 5-10 tonnes of oil. Additional oil was lost in small quantities over time (MNZ 2013a). Cumulatively, the oil that leaked caused major pollution of the marine environment and some Bay of Plenty coastlines, and resulted in oil contamination of many marine organisms, most noticeably seabirds (MNZ 2013a,b).

Additional marine pollution occurred through the loss of containers overboard with the contents of many emptying into the ocean (32 of which contained dangerous goods) and washing up on coastlines. Four such containers contained plastic polymer beads (2-3 mm in diameter); these beads washed ashore and caused widespread coastal contamination and posed a risk to seabirds via ingestion (MNZ 2013e). It is estimated that 86 containers were lost overboard on 12 October and a further 200-300 containers on 8 January, 2012 as a result of rough seas that broke the vessel in half (MNZ 2013a). A total of 19 additional containers were also lost overboard during more rough seas on 21 March and 3 April (MNZ 2013d).

In response to this significant marine and coastal pollution large-scale container recovery and clean-up operations were undertaken. Container recovery began on 16 November, 2011, the day after all accessible oil (1300 tonnes) had been removed from the vessel. Dutch company Svitzer were responsible for removal of oil and containers from the vessel, and Braemar-Howells, a UK-based company, was responsible for the salvage of containers at sea and their contents (MNZ 2013a). The clean-up operations involved cleaning oil-contaminated beaches, rocky shorelines and seabird habitat, and removing waste and debris (emptied from containers) from the sea and shorelines; over 1000 tonnes of waste was collected. These large-scale, intensive clean-up operations were largely enabled due to huge support from the local community, with up to 8000 volunteers involved at some point during the response (MNZ 2013a).

The height of the oiled wildlife response was reached on 17 November, 2011, with 420 oil-contaminated birds in care facilities. This was shortly followed by the first public release of 49 rehabilitated little blue penguins on Mount Maunganui beach between Leisure Island and Rabbit Island on 22 November (Massey University 2013; MNZ 2013b). Thereafter, rehabilitated penguins were released in batches when individual birds met release criteria. On 23 December the oiled wildlife facility at Te Maunga was demobilised with the remaining 16 birds in care relocated to Massey University (Massey University 2013); the last oiled penguin was collected and admitted for care on 17 January, 2012 (Wildbase, Massey University). The final major release of rehabilitated penguins occurred by boat on 17 February, 2012, near Motiti Island (Massey University 2013).

## **Effects on wildlife**

Despite the effort put into the clean-up operations, the oil spill had an adverse effect on local wildlife. During the first seven weeks of the wildlife response, 2083 dead animals were collected through beach and boat searches; 1379/2082 (66%) of the carcasses were oiled, however it is unknown how many became oiled post-mortem (S. Hunter, pers. comm.). These 2083 carcasses included 2030 (97.5%) marine and coastal birds, 23 (1.1%) terrestrial birds, 9 (0.4%) unidentified birds, 17 (0.8%) fur seals and 4 whales (0.2%) (Wildbase, Massey University, unpublished data). This total is a minimum estimate of mortality however, as it is

likely that some birds that washed ashore may have been buried in sand or scavenged preventing their collection; other carcasses may not have even made it ashore due to unfavourable offshore winds and ocean currents, or they may have sunk or been scavenged at sea (Page et al. 1990; Underhill et al. 1999). These factors are likely to have contributed to an underestimation of the total spill-induced mortality.

Live oiled birds found on local beaches within the affected area (from Waihi to Maketu) were also collected during the oiled wildlife response. As the majority of the oiled birds collected were little blue penguins, a decision was made to also conduct targeted night searches for oiled penguins at local colonies. All birds found with more than very minor oiling were admitted for care at the OWF; overall 420 live oil-contaminated birds were admitted, 383 (91%) of which were little blue penguins (the numbers of penguins admitted and released over time are shown in Appendix Figure 1.1). The remaining birds consisted of 6 (1.4%) shearwaters, including Buller's shearwaters *Puffinus bulleri*, fluttering shearwaters *Puffinus gavioides*, and sooty shearwaters *Puffinus griseus* (Wildbase, Massey University, unpublished data); 19 (4.5%) petrels, including grey-faced petrels *Pterodroma macroptera* and diving petrels *Pelecanoides urinatrix*; 5 (1.2%) pied shags *Phalacrocorax varius*; 3 (0.7%) Australasian gannets *Morus serrator*; 1 (0.2%) red-billed gull *Larus novaehollandiae scopulinus*; 1 (0.2%) kingfisher *Halcyon sancta*; 1 (0.2%) white-faced heron *Egretta novaehollandiae*; and 1 (0.2%) white-fronted tern *Sterna striata* (Wildbase, Massey University, unpublished data). Seabirds were thus the group of animals most visibly affected by the oil spill and in terms of the oiled birds that were found alive, little blue penguins were the species most affected by the spill.

As the *Rena* grounding and resulting oil spill occurred during the 2011–2012 little blue penguin breeding season, a decision was made to only clean and rehabilitate adults (Conayne et al. 2012). This decision was made based on the fact that adults have higher survival chances than juveniles, and that the recovery of local populations post-spill depends on the productivity of the breeding population (Wolfaardt et al. 2009b). Eggs were thus left at nests and protocol was that chicks taken to rehabilitation centres were euthanised as previous experiences indicated that hand-reared chicks often imprinted on humans and therefore were not fit for survival in the wild (Conayne et al. 2012). Consequently, due to the timing of the spill and decisions made regarding rehabilitation

priorities, the breeding season was severely disrupted and productivity was likely to have been extremely low. This indicates the importance of successfully rehabilitating and releasing these adults so that productivity can be restored in future breeding seasons.

## **Rehabilitation process for little blue penguins**

Stabilisation, treatment, decontamination and rehabilitation of oiled seabirds occurred in temporary oiled wildlife facilities set-up at the Te Maunga OWF after the *Rena* grounding. Oiled seabirds washed ashore in the Bay of Plenty (predominantly little blue penguins) were rescued and transported to this facility where they were cared for, cleaned and nursed back to health. Upon admittance to the facility, little blue penguins underwent an intake process before initiating stabilisation of physiological parameters. For each penguin the intake procedures involved: a full physical examination (with data collected on percentage of oiling (Appendix Figure 1.2), body condition, mass (Appendix Figure 1.3) and oil affected body regions); application of a temporary unique plastic wing band to allow individual identification whilst in care; superficial oil decontamination of the eyes, nares and oral cavity (if required); collection of a blood sample to assess blood glucose, packed cell volume and total plasma protein (Appendix Figure 2.1); administration of moxidectin for treatment of endoparasites; initiation of prophylactic itraconazole to minimise development of aspergillosis; and administration of oral electrolytes to start rehydration of the birds (Michael et al. 2012).

After intake and the initial stabilisation process, the penguins were moved to pre-wash stabilisation tents where they were housed for at least two days prior to oil decontamination. In these tents up to six penguins were housed together (Michael et al. 2012) in plastic fruit crates that were modified to have a netted bottom to prevent contamination of birds with faecal material and to reduce the incidence and severity of pododermatitis (Conayne et al. 2012; Michael et al. 2012). Heat lamps and ducted heating maintained the ambient temperature within these tents between 20 and 25°C to assist birds with impaired thermoregulation. The penguins were treated and force-fed a slurry of salmon, fluids and multivitamins twice daily until deemed strong enough to cope with the stress of oil decontamination (Michael et al. 2012).

Prior to oil decontamination some birds were treated with warmed canola oil as a pre-treatment to soften any tarry or weathered oil on the plumage. After approximately 20 minutes the oil was sufficiently softened and the birds were decontaminated (P. Conayne, pers. comm.). This process involved 30–45 minutes of cleaning, washing and rinsing of oil-contaminated body regions (Michael et al. 2012) using warm water (39–40°C, hardness of 3 ppm, and maintained at a pressure between 60 and 80 psi) and a detergent (preferably Dawn™ (Procter & Gamble), although Tergo, Sunlight or Palmolive were also tried but were less successful) (P. Conayne, B. Dwyer, and K. Morgan, pers. comm.).

After decontamination, penguins were moved to heated rehabilitation tents for recovery. Here they were gavage-fed an electrolyte solution and force-fed a slurry mixture twice daily; over time the slurry was replaced with whole anchovies. The penguins were put into pools for increasing periods of time each day and monitored until waterproofing was regained. Birds were considered waterproof once they were able to swim for six hours without water penetration of their plumage. Once achieved, normally a week after de-contamination (Michael et al. 2012), the penguins were moved to purpose-built outdoor aviaries with in-built pools and rubber tube matting floors (Conayne et al. 2012; Michael et al. 2012) where they were fed and treated twice daily (Michael et al. 2012). Despite the presence of pools, many birds chose not to swim. In the wild penguins spend most of their day foraging at sea therefore the prolonged periods of standing experienced in captivity resulted in many penguins developing inflamed pressure sores on their feet (pododermatitis) despite the floors being soft and padded (Michael et al. 2012). The feet of each bird were given a score between 0 and 5 based on the severity of their pododermatitis lesions (0=no sign of lesions or abnormality; 1=superficial lesions; 2=deeper and more extensive lesions, possibility of lameness; 3=necrotic plug of tissue within the lesion, often associated with swelling, pain and lameness; 4=cellulitis, marked lameness, possibility of secondary infection and involvement of deeper tissues; 5= osteomyelitis). Surgical debridement of necrotic tissue was performed on penguins with lesions graded as 3 or more. To prevent the progression and further development of pododermatitis each bird was forced to swim for a set period each day which reduced the time spent standing (Michael et al. 2012). In contrast to the incidence of pododermatitis and unlike previous reports of captive penguins (Carrasco et al. 2001; Balseiro et al. 2005; Xavier et al. 2007), the incidence of aspergillosis (a fungal

respiratory disease) was very low with only 2/18 penguins that were euthanised or died in care showing signs of aspergillosis infection post-mortem (Michael et al. 2012). This may have been due to preventative husbandry techniques such as administering prophylactic doses of itraconazole (an anti-fungal medication) and ventilating the aviaries via natural air flow to prevent the build-up of fungal spores (Michael et al. 2012).

In order to reactivate salt glands which were likely to have atrophied due to the lengthy periods of housing in freshwater, salt was introduced to the aviary pools. The salt concentration was increased by 1% intervals over a week until the concentration was equivalent to that of seawater (3%) (Michael et al. 2012).

The penguins were kept in captivity until the risk of re-oiling from further spills from the *Rena* wreck was minimal, their habitat was deemed sufficiently cleaned of oil, and release criteria as specified by the Oiled Wildlife Care Network were met (OWCN 2000; Michael et al. 2012, MNZ 2013a). For each penguin these included that: their plumage was of sufficient quality to enable survival in the wild; the bird was deemed fit and healthy based on a physical examination by a veterinarian (Michael et al. 2012); their plumage was waterproof as assessed by a 6-hour swim test (Michael et al. 2012; MNZ 2013a); their BMI (length/weight) score was at least 2.5 (release masses, which were significantly higher than admission masses ( $T=-17.7676$ ,  $p=2.2e^{-16}$ ), are shown in Appendix Figure 1.3); the bird had a packed cell volume value between 38-53%, a total protein value between 25-60 g/L and a buffy coat value <2%; the bird was bright, alert and responsive; behaviour was normal (the bird was seen preening, swimming and walking in a normal manner); a pre-release disease screening of 60 randomly selected birds showed negative results for *Salmonella* and *Yersinia* species on a cloacal culture; their salt gland had been reactivated; the bird had a pododermatitis score of 2 or less; and the temporary identification band was removed and replaced with a permanent Allflex 11 mm PIT-tag (passive integrated transponder/microchip) implanted subcutaneously between the scapulars. Penguins that met these release criteria were transported back to the place they were collected from and released on the beach or at sea (Michael et al. 2012).

Due to the extended duration to remove oil from the *Rena* and the subsequent on-going threat of oiling, many penguins were held in captivity long after they had regained their

fitness. The duration spent in captivity varied between birds; those more severely oiled, in moult, and/or with health issues remained in captivity for longer. Overall, the mean captive duration of oiled and subsequently rehabilitated penguins that survived captivity and were released back to the wild (361/383 (94.3%) of those admitted) was 51.6 days with a range of 16-129 days (Wildbase, Massey University, unpublished data) (Appendix Figure 1.4). On average, irrespective of captive duration, release masses (865.2 g) were significantly higher than admission masses (736.8 g) ( $T=-17.7676$ ,  $p=2.2e^{-16}$ ) (Appendix Figure 1.3). The captive survival rate of 94.3% was high when compared to rates reported from other oil rehabilitation operations (Table 1.5) and very similar to that reported for little blue penguins after the 1995 *Iron Baron* oil spill (95%) (Giese et al. 2000).

**Table 1.5.** Captive survival rates (CSR) of oiled animals rehabilitated after various oil spills over time.

Year	Vessel/source	Location	Species de-oiled	CSR(%)
1967 <sup>1</sup>	<i>Torrey Canyon</i>	Southwest coast of the United Kingdom	Unspecified bird species	2
1970's <sup>2</sup>	Unspecified oil spills	South Africa	Unspecified bird species	52
Up to mid-1974 <sup>3</sup>	Unspecified oil spills	South Africa	African penguin	65
1979 <sup>4</sup>	Unknown	St Croix Island, South Africa	African penguin	68
1983 <sup>5</sup>	<i>Castillo de Bellver</i>	Saldanha Bay, Malgas Island, South Africa	Cape gannet	65
1986 <sup>6</sup>	<i>Arco Anchorage</i>	Washington, USA	Unspecified bird species	18
1989 <sup>7</sup>	<i>Exxon Valdez</i>	Prince William Sound, Alaska, USA	Sea otter	67
1990's <sup>2</sup>	Unspecified oil spills	South Africa	Unspecified bird species	78
1990 <sup>6</sup>	<i>American Trader</i>	California, USA	Unspecified bird species	60
1991 <sup>6</sup>	<i>Orphan</i>	California, USA	Unspecified bird species	9
1994 <sup>8</sup>	<i>Apollo Sea</i>	Dassen Island, South Africa	African penguin	48
1995 <sup>9</sup>	Unknown	Near Dyer Island, South Africa	African penguin	40
1995 <sup>10</sup>	<i>Iron Baron</i>	Ninth Island and Low Head, Tasmania, Australia	Little penguin	95
1998 <sup>9,11</sup>	Pipeline spill	Cape Town Harbour, South Africa	African penguin	58
1996-2000 <sup>2</sup>	Unspecified oil spills	South Africa	African penguin	84
2000 <sup>12</sup>	Pipeline spill	John Heinz National Wildlife Refuge, Pennsylvania, USA	Freshwater turtle species ( <i>Chrysemys picta</i> , <i>Chelydra serpentina</i> , <i>Trachemys scripta</i> , <i>Pseudemys rubriventris</i> )	95
2000 <sup>8,13</sup>	<i>Treasure oil</i>	Robben Island and Dassen Island, South Africa	African penguin	91
2001-02 <sup>14</sup>	Unspecified oil spills	South Africa	African penguin	86
2001-02 <sup>14</sup>	Unspecified oil spills	South Africa	Hartlaub's gull ( <i>Chroicocephalus hartlaubii</i> )	75
2001-02 <sup>14</sup>	Unspecified oil spills	South Africa	Cape gannet	87
2000-10 <sup>15</sup>	Unspecified oil spills	South American coastline	Magellanic penguin	80-95
Unspecified <sup>16</sup>	Unspecified oil spills	South Africa	African penguin	95
Unspecified <sup>17</sup>	Unspecified oil spills	North America	Unspecified seabird species	9-60

**Sources:** <sup>1</sup>(Bourne 1970b). <sup>2</sup>(Nel et al. 2003). <sup>3</sup>(Frost et al. 1976). <sup>4</sup>(Randall et al. 1980). <sup>5</sup>(Altwegg et al. 2008). <sup>6</sup>(J. White pers. comm. in (Sharp 1996)). <sup>7</sup>(Piatt and Ford 1996). <sup>8</sup>(Wolfaardt et al. 2009b). <sup>9</sup>(Whittington 2002). <sup>10</sup>(Goldsworthy et al. 2000b). <sup>11</sup>(Whittington et al. 2000). <sup>12</sup>(Saba and Spotila 2003). <sup>13</sup>(Underhill et al. 1999; Crawford et al. 2000; Barham et al. 2006). <sup>14</sup>(Parsons and Underhill 2005). <sup>15</sup>(Ruoppolo et al. 2012). <sup>16</sup>(Percy et al. 1972). <sup>17</sup>(Sharp 1996).

## Study aims and components

This large-scale rescue and rehabilitation operation after the *Rena* oil spill provided the opportunity to assess the success of the rehabilitation process used in New Zealand by the National Oiled Wildlife Response Team to rehabilitate oiled seabirds. This assessment, which is based on an on-going monitoring programme conducted at three oil-affected little blue penguin colonies in Tauranga (Figure 1.1), aims to compare the post-release survival and productivity of oil-rehabilitated penguins at these colonies to that of un-oiled control penguins. Specifically, by monitoring the presence of marked penguins during fortnightly-monthly shoreline surveys, and the breeding success of pairs of known oiling status, I aim to determine:

1. Whether survival rates differ between rehabilitated and control penguins,
2. Whether reproductive success differs between rehabilitated and control penguins,
3. Which factors influenced the post-release survival and productivity of penguins, and
4. What influence captivity has on the post-release behaviour of rehabilitated penguins.

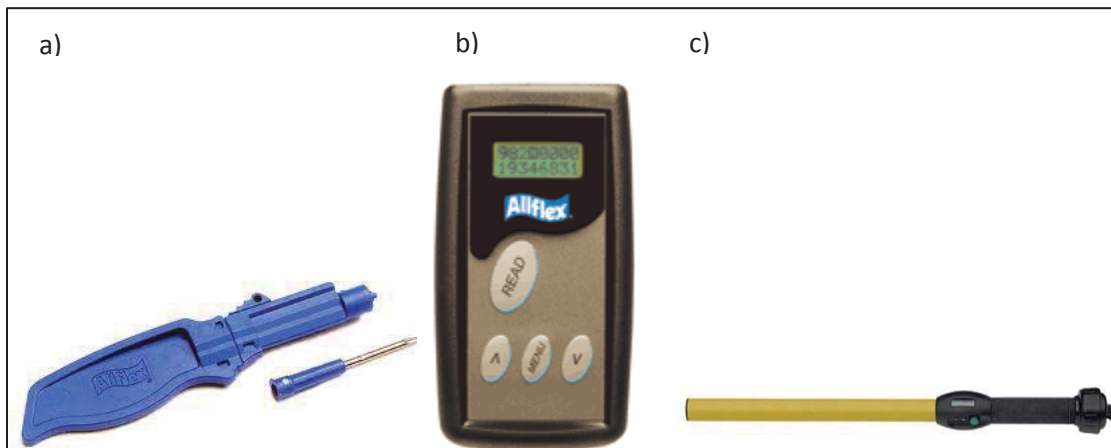
The monitoring programme was established by Massey University, Palmerston North, New Zealand under permits BP-32897-CAP and 37409-FAU issued by the Department of Conservation, and is modelled on studies conducted on little blue penguins by Giese et al. (2000) and Goldsworthy et al. (2000b) following the 1995 *Iron Baron* oil spill in Tasmania, Australia. The study was approved by the Massey University Animal Ethics Committee (MUAEC 12/22).

This is the first such study conducted in New Zealand and the knowledge gained about the fates and breeding success of the rehabilitated penguins will help clarify the effectiveness (and thus conservation value) of the techniques used to clean oiled seabirds, and will contribute to planning for future oil spills in New Zealand and Australia (where little blue penguins are also present). This knowledge will also contribute to the wider assessment of the impact of the *Rena* oil spill on wildlife and the marine environment, as well as global assessments of the conservation value of rehabilitation efforts.

## Identification of rehabilitated and control penguins

All penguins in this study were implanted between the scapulars with an Allflex 11 mm PIT-tag (passive integrated transponder/microchip; Allflex 2013) to enable individual identification during surveys. All rehabilitated penguins (n=347) were tagged before release. Around the same period (from 21 November 2011 to 19 January 2012) 361 control penguins were marked on the shorelines of Mount Maunganui, Leisure Island and Rabbit Island. Implantation was conducted by veterinarians or appropriately trained personnel using standard operating procedures (DOC 2012). Each of these tags has a unique, individually identifiable 15 digit number that can be read by scanning over the tag with an Allflex Compact Pocket Microchip Reader or Yellow Stick Microchip Reader (the Yellow Stick Reader can read microchip numbers from a distance of approximately 20 cm from the microchip whereas the pocket reader must be scanned against the plumage of the penguin directly above the position of the microchip) (Allflex 2013) (Figure 1.2).

Some of the penguins that were micro-chipped were already marked with metal flipper bands as part of a pre-*Rena* study run by the Bay of Plenty Polytechnic. These bands were removed and replaced with a microchip as studies have found that flipper bands can increase energy expenditure whilst swimming and may reduce survival (Culik et al. 1993; Stonehouse 1999; Jackson and Wilson 2002). Collectively, this population of marked penguins enabled our post-release monitoring study to be conducted which evaluated and compared the survival and productivity of rehabilitated and control penguins.



**Figure 1.2.** Equipment used to microchip and scan the little blue penguins. a) is an Allflex Microchip Applicator, b) is an Allflex Compact Pocket Microchip Reader, and c) is an Allflex Yellow Stick Microchip Reader (Image credit: Allflex 2013).

### Study sites

Survival monitoring surveys were conducted at Mount Maunganui, Leisure Island and Rabbit Island. Reproduction monitoring was conducted at Mount Maunganui and Leisure Island only. These three sites are located in Tauranga, in the Bay of Plenty region of New Zealand (Figures 1.1 and 1.3). Breeding of little blue penguins in the Tauranga area is concentrated at these sites and it is estimated that approximately 300 pairs breed on Mount Maunganui, 100 pairs on Leisure Island and 200 pairs on Rabbit Island (Dave Richards, pers. comm.).



**Figure 1.3.** Study sites for post-release monitoring of rehabilitated penguins. 1 is Mount Maunganui, 2 is Leisure Island and 3 is Rabbit Island (Image credit: Getty Images 2013).

## Site descriptions

### ▪ Mount Maunganui

Mount Maunganui (Maori name Mauao) is a 232 m high remnant of a rhyolitic lava dome (Jones et al. 2011) located in the entrance to the Tauranga Harbour in the Bay of Plenty (37° 37.75' S, 176° 10.21' E). It is an historic scenic reserve (Winter 2000) encompassing approximately 76 ha and has unrestricted public access (Jones et al. 2011). There are many popular walking tracks on Mount Maunganui and much of the lower hillside is covered in exotic grasses and is grazed by sheep. The rest of the hillside is covered in scrub vegetation dominated by native species including pohutukawa (*Metrosideros excelsa*), kawakawa (*Macropiper excelsum*), hangehange (*Geniostoma rupestre*), and mahoe (*Melicytus ramiflorus*). In the past there have been fires on Mount Maunganui, and the site is prone to erosion and slips. The rocky shorelines and lower altitude vegetation provide suitable nesting habitat for little blue penguins (Winter 2000; Jones et al. 2011).

### ▪ Leisure Island

Leisure Island (Maori name Moturiki) is a small recreational reserve (Winter 2000) located approximately 700 m east of Mount Maunganui and 500 m west of Rabbit Island (37° 38' S, 176° 11' E) (Bell and Goring 1998). The reserve, which extends seawards, is a steep-sided rocky outcrop (reaching 23.5 m at its highest point) connected to the main Mount Maunganui beach by a man-made land bridge and is an accessible and popular area to go walking and fishing. Parts of the island have undergone extensive modification as a result of previous land use (quarrying and recreational uses ("Marineland", a marine park and "Leisure Island", a water park)), however much of the island has been re-vegetated with both native and exotic vegetation (TCC 1998). The rocky shorelines of the island provide many suitable nesting sites for little blue penguins (Winter 2000).

### ▪ Rabbit Island

Rabbit Island (Maori name Motuotau) is a small (2.5 ha) scenic reserve located approximately 2 km offshore from Mount Maunganui (37° 38' S, 176° 12' E) (Miskelly et al.

2009). The island is a steep-sided, 45 m high rhyolitic dome and is covered in dense native vegetation (Jones et al. 2011). Unlike Mount Maunganui and Leisure Island, Rabbit Island is free of introduced mammalian predators and is inhabited by a high density of burrow nesting seabirds (Miskelly et al. 2009). Although public access is unrestricted, the island is rarely visited due to poor accessibility (only by some form of marine transport) and thus is relatively undisturbed by human activities (Jones et al. 2011). Little blue penguins nest on the rocky shorelines of the island and amongst the hillside vegetation.

## **Thesis outline**

There are two research chapters to my thesis. Chapter 2 (“Impacts of oiling and rehabilitation on breeding success of little blue penguins following the C/V *Rena* oil spill in New Zealand”) tests whether any readily-measured breeding parameters differed in the first breeding season post-spill between penguins that had been oiled and rehabilitated and control birds that had not gone through the rehabilitation process. Chapter 3 (“Rehabilitation works: comparable survival rates in oiled and non-oiled little blue penguins after the C/V *Rena* oil spill in New Zealand”) tests whether post-release survival rates of oiled birds were equivalent to rates of control birds. Chapter 4 provides a general synthesis and discussion of these findings in relation to global studies of the impacts of oiling and rehabilitation on wildlife. It should be noted that the research approaches taken were deliberately low impact and non-invasive. Given the direct impact of the oil spill on the local penguin populations, it was agreed during planning not to undertake detailed physiological or breeding studies that would require invasive sampling or extensive handling of the birds.

## **Chapter One Appendix**

### **Internationally recommended rehabilitation protocols**

#### **Steps in oiled seabird rescue and rehabilitation**

- **Collection and stabilisation**

A rapid response is required to collect oiled seabirds (by foot or by boat) and bring them to a staging site on the beach. If the rehabilitation facility is far away and/or the birds are in poor condition, stabilisation may commence in the field at the staging site (OWCN 2000). Stabilisation procedures may include: clearing oil from the mouth/nares; removing any excess oil; providing oral hydration; irrigating the eyes; and warming the birds (OWCN 2000; Berg 2003). Conversely if the rehabilitation facility is close to the site of oiling and the birds are in good condition, field stabilisation may be foregone in favour of direct transportation to the rehabilitation facility.

- **Transportation**

Following collection and field stabilisation, oiled seabirds should be transported to rehabilitation facilities as quickly as possible (Berg 2003) to reduce the period between oiling and rehabilitation. Transportation is by vehicle or aircraft in boxes or carriers, the bottoms of which should be lined with towels, sheets, or soft-absorbent pads to reduce travel-induced injury (OWCN 2000; Berg 2003; Norman 2006; GDC 2011; PRBO and OWCN 2014). Generally one bird should be housed per box, except in the case of gregarious, non-aggressive birds, where it is acceptable for an appropriate sized box to hold two-three birds. It is important that these boxes are well ventilated and that there is sufficient room between boxes to allow adequate air flow (OWCN 2000; Berg 2003; Massey 2006; Norman 2006; PRBO and OWCN 2014). It is also important that an appropriate ambient temperature is maintained during transport to rehabilitation centres to prevent the oiled birds from becoming hypothermic. The birds should also be periodically monitored to check on their condition (OWCN 2000; Berg 2003; Massey 2006).

- **Intake procedures and stabilisation**

Upon admittance to a rehabilitation centre each bird should be photographed and have an oil sample taken by plucking a few feathers (Massey 2006; PRBO and OWCN 2014). The birds then need to be marked with a temporary band to allow individual identification whilst in care and details should be recorded for each bird including their identity (species), sex, age and capture location, date and time. Physical examinations need to be conducted on all birds and information should be recorded on their mass, body condition, which body regions are oiled, their degree of oiling, and the depth of oil penetration through the plumage (Tseng 1999; OWCN 2000; Berg 2003; Massey 2006; Norman 2006; PRBO and OWCN 2014). Following this exam blood samples need to be taken to test packed cell volume (PCV), total solids (TS), and blood glucose (BG) levels (Frink and Miller 1995; Tseng 1999; OWCN 2000; Berg 2003; Massey 2006; Norman 2006). The results of the physical exam and these blood tests will help triage the birds; for example for birds found to be anaemic (PCV <15%), hypoproteinemic (TP <1.0 g/dl) or in poor physical condition it may be better to euthanise rather than rehabilitate them as such birds often have low captive survival rates (Tseng 1999; OWCN 2000). Other intake procedures that should be conducted involve: superficial oil de-contamination of the eyes, nares, oral cavity and cloaca; stabilising the birds by warming (if necessary); and orally administering isotonic fluids (to rehydrate them) (Tseng 1999; OWCN 2000; Parsons and Underhill 2005; Massey 2006). Susceptible species of birds should also be dosed with itraconazole (an anti-fungal medication) for aspergillosis prophylaxis (aspergillosis is the most common infectious disease seen in captive birds). Iron and vitamin injections may also be administered if deemed necessary based on blood test results (OWCN 2000; Norman 2006). Following these procedures, oiled birds need to be housed in well ventilated, net-bottomed pens (to avoid pressure sores) where temperature control maintains an even warm ambient temperature so that the birds do not become hypothermic (in temperate climates) or hyperthermic (in very hot regions). Whilst in these pens the birds should be tube-fed fish slurry (OWCN 2000). These stabilisation procedures are very important as they help improve the condition and physiological state of the birds so that they are better prepared to cope with the stress of oil de-contamination.

- **Wash procedure**

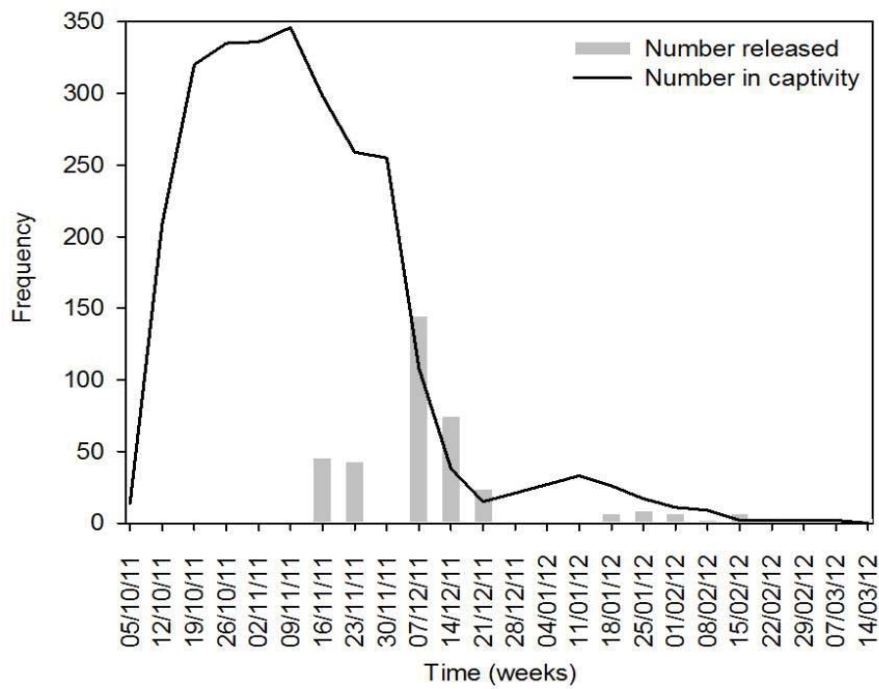
Four criteria must be met before oil de-contamination occurs. These are that: the birds must have been in rehabilitation for at least 48 hours; their PCV values must be greater than or equal to 30%; a TS reading taken at least 24 hours prior must be greater than or equal to 2.5 g/dl; and they must be bright, alert and responsive (Tseng 1999; OWCN 2000; Massey 2006; Norman 2006). Once these criteria are met washing can commence. The first stage of washing may involve a pre-treatment of the plumage with one of several pre-treatment solutions (such as canola oil or methylolate) if the oil is weathered and tarry (OWCN 2000; Massey 2006). Thirty minutes after this treatment the oil should be sufficiently softened to enable the birds to be washed using a dish washing detergent (Dawn™, Procter & Gamble, dish washing soap is recommended) and warm water (Frink and Miller 1995; Tseng 1999; OWCN 2000). The water needs to be heated to 40 degrees Celsius (Norman 2006) and should be of two to three grains of hardness to maximise cleaning efficiency. The bird's plumage needs to be thoroughly and efficiently washed to remove all traces of oil whilst maintaining feather integrity (GDC 2011). As the water becomes oily, birds should be transferred to new tubs of water until the birds are no longer oiled (Frink and Miller 1995; Tseng 1999; OWCN 2000; Parsons and Underhill 2005; Massey 2006). This procedure will take 10-30 minutes based on the type of oil, degree of oiling and species of bird. Following washing birds need to be rinsed with warm water (40 degrees Celsius) (Norman 2006) of two to three grains hardness using a pressurised spray nozzle (water pressure should be between 40 to 60 psi) (Tseng 1999; Massey 2006) until beads of water form and drop off the plumage. This process generally takes 20-30 minutes (Tseng 1999; OWCN 2000). The birds should then be dried in drying rooms where the temperature is maintained at 32-35 degrees Celsius using pet driers or heat lamps. When dry (after approximately 30 minutes), birds need to be tested for waterproofing by being placed into a freshwater pool (OWCN 2000; Berg 2003; Massey 2006). If the plumage is waterproof, as indicated by water not penetrating through to the skin, birds should be placed in outdoor pens. If waterproofing is not adequately restored, birds should undergo further cycles of washing and rinsing until they are sufficiently waterproof (Tseng 1999; OWCN 2000). Full waterproofing will take some time (days to weeks) as this relies on the birds preening their plumage and re-aligning the intricate feather structure.

- **Post-wash rehabilitation, release criteria, and post-release monitoring**

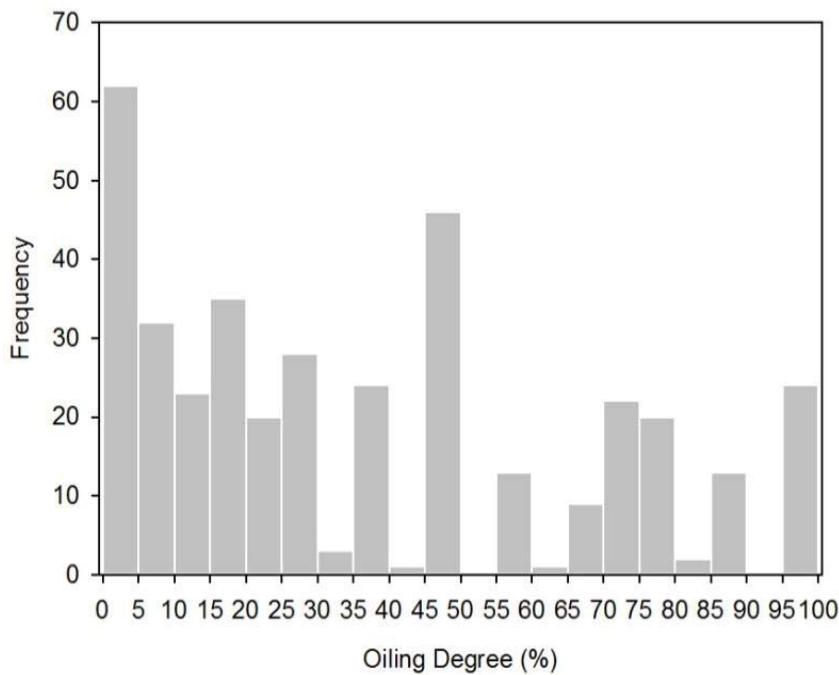
Following cleaning and drying, birds should be put in outdoor pens where they are fed fish with added multivitamins, have access to swimming pools, are assessed daily by veterinarians, have weekly blood samples taken and are also weighed weekly (Parsons and Underhill 2005). They need to remain in these pens until they have sufficiently recovered to meet release criteria. These include that the birds: behave normally; are of normal body weight (within 10% of the average for their species); have fully waterproof plumage; have been acclimated to salt water; have normal blood values; pass their physical examination (Frink and Miller 1995; Tseng 1999; OWCN 2000; Massey 2006; Norman 2006;) and are free of apparent disease. Additionally, their habitat must be cleaned of oil so there is little risk of re-contamination once released (Frink and Miller 1995; Tseng 1999; Berg 2003). Prior to release the temporary identification bands should be removed from each bird and replaced with a permanent metal leg band or a subcutaneous microchip. Permanent identification aids post-release monitoring of these birds as data provides information on mortality rates of released birds. Additionally, these identification methods enable long term observational studies to be conducted (OWCN 2000; Berg 2003; Massey 2006; HELCOM 2009); where post-release survival and reproductive rates of rehabilitated birds can be estimated based on re-sightings of these banded birds.

By adhering to these best practise guidelines rehabilitation success should be maximised, and if post-release survival and reproductive rates of rehabilitated birds are equivalent or near equivalent to non-oiled, non-rehabilitated birds, then the rehabilitation operation can be deemed effective.

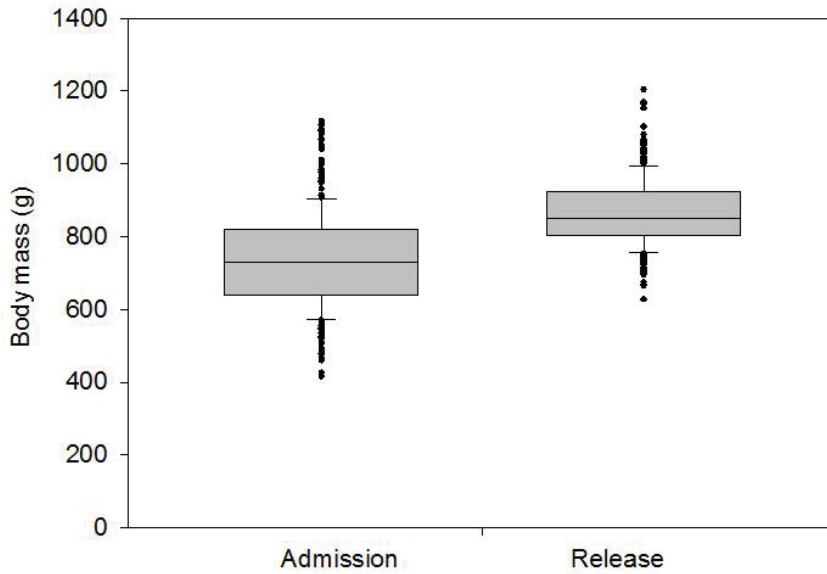
## Captive variables



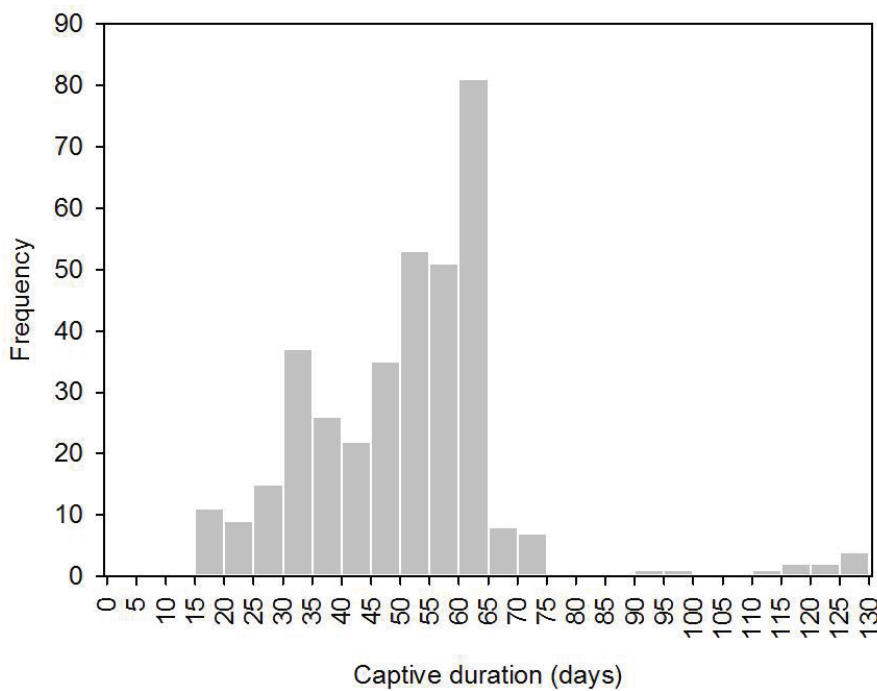
**Appendix Figure 1.1.** The number and dates of live, oiled little blue penguins recovered, rehabilitated and subsequently released from the Bay of Plenty during the C/V *Rena* oil spill response, October 2011-March 2012.



**Appendix Figure 1.2.** Frequency graph showing the degree of oiling of little blue penguins admitted for care during the *Rena* oil spill.



**Appendix Figure 1.3.** Body masses of oiled little blue penguins upon admission for captive rehabilitation during the *Rena* oil spill, and just prior to release back into the wild. Boxes represent 25<sup>th</sup>, 50<sup>th</sup> and 75<sup>th</sup> percentiles, whiskers 5 and 95% and outliers are shown as dots.



**Appendix Figure 1.4.** Durations in captivity for little blue penguins rehabilitated during the *Rena* oil spill.

# Chapter Two

Impacts of oiling and rehabilitation on breeding success of little blue penguins following the C/V *Rena* oil spill in New Zealand



## Abstract

During the 2011 C/V *Rena* oil spill in Tauranga, New Zealand 383 little blue penguins (*Eudyptula minor*) were oiled, rescued and rehabilitated. Three hundred and sixty one (94.3%) survived the rehabilitation process and were released to the wild. Before release all penguins were tagged with individually identifiable passive integrated transponders (PIT-tags/microchips); at a similar time a group of non-oiled, control penguins from within the oil-affected area were also tagged. The breeding success of these penguins was monitored during the first breeding season post-release (2012-13) to assess whether productivity differed between rehabilitated and control penguins.

Rehabilitated penguins were confirmed breeding post-release; in fact a higher proportion of rehabilitated penguins that were confirmed alive at Mount Maunganui and Leisure Island were observed breeding than control penguins. Clutch size and the duration and timing of egg laying were similar for rehabilitated pairs (pairs including at least one rehabilitated penguin) and control pairs (pairs including two control penguins). Hatching, fledging and egg success were lower for rehabilitated pairs, however only hatching success was significantly reduced. The number of chicks fledged per pair was also marginally significantly reduced in rehabilitated pairs. Despite these reductions, hatching, fledging and egg success rates of rehabilitated pairs were within ranges, sometimes towards the higher end, reported for other little blue penguin colonies in Australia and New Zealand. Sample sizes were too small to confidently conclude what effect the presence of two rehabilitated penguins within a breeding pair had on breeding success, and whether different predictor variables had any effect on overall hatching and fledging success (whether pairs hatched at least one egg or chick respectively).

Overall, these results suggest that, despite the slightly reduced productivity of rehabilitated pairs relative to control pairs, rehabilitated penguins were breeding as well and sometimes better than penguins at other colonies unaffected by oil. Consequently, it can be concluded that the process used to rehabilitate oiled penguins was reasonably successful at treating most negative effects of oil contamination on breeding parameters influencing productivity. However, the persistence of some negative effects of oiling suggests that improvements

could be made to the rehabilitation process to maximise the effectiveness of future efforts to rehabilitate oiled wildlife in New Zealand.

## Introduction

Rehabilitation of oiled seabirds may successfully reverse the physical impacts of oil contamination, however physiological and behavioural effects may still persist (Giese et al. 2000). Rather than being immediately evident, these effects may be subtle, manifesting only in the longer term during stressful and energetically demanding periods of the annual cycle (Giese et al. 2000; Wolfaardt et al. 2009b); one such period is the breeding season (Giese et al. 2000; Whittington 2002; Wolfaardt et al. 2009b). Up to this time of year oil-rehabilitated birds may appear healthy as discerned from post-release masses and survival rates comparable to control birds (Giese 1996). However, the true test of health and fitness is whether rehabilitated birds have the ability to successfully reproduce during the first post-spill (and post-rehabilitation) breeding season as well as during subsequent breeding seasons (Wolfaardt et al. 2008a). If breeding success is significantly lower than that of control birds this may indicate that the rehabilitation process has been unsuccessful at reversing all adverse impacts of oiling on anatomical structures, physiological processes and behaviours necessary for successful reproduction (Wolfaardt 2007).

It is thus important to assess post-release breeding success by conducting post-release productivity studies. In addition to post-release survival studies, these studies provide another measure from which rehabilitation success can be assessed (Giese et al. 2000; Wolfaardt et al. 2008a; Wolfaardt et al. 2009b). Productivity studies are vital as although it is important that rehabilitated birds survive upon release back into the wild, rehabilitation success is only truly achieved if these birds are restored back into the breeding population and have long term reproductive rates equivalent to control birds (Wolfaardt 2007; Wolfaardt et al. 2009b). If this is not achieved then these birds may in fact have a negative effect on the breeding population through competition for resources (such as food and breeding sites), especially when resources are scarce (Wolfaardt 2007; Wolfaardt et al. 2008a). Successful restoration of rehabilitated birds is particularly important for threatened or endangered populations, populations of bird species that mature late, lay small clutch sizes and are long-lived, and populations where oil-induced mortality is high as their perpetuation and/or recovery depends on successful reproduction (Ainley et al. 1981; Giese

et al. 2000; Wolfaardt et al. 2008c). Post-release productivity studies are thus valuable tools for assessing the conservation value of oil rehabilitation.

Despite their conservation value relatively few post-release productivity studies have been conducted on oil-rehabilitated seabirds. This is because few seabird species are coastal with high site fidelity (characteristics that assist in conducting post-release studies); many species are instead pelagic, migratory and spend little time on land (Fry et al. 1986) which reduces the ease and feasibility of undertaking post-release monitoring studies. As a result of these difficulties, most studies looking at the effects of oil on the productivity of seabirds have been conducted in artificial laboratory environments using captive birds experimentally dosed with varying quantities of oil (Grau et al. 1977; Leighton et al. 1983). A small number of studies have also orally administered oil to birds and have managed to monitor their post-release reproductive success (Trivelpiece et al. 1984; Fry et al. 1986; Butler et al. 1988; Eppley and Rubega 1990). It has been questioned however whether the results of these experimental studies are also applicable to wild birds and to seabirds rehabilitated following oiling in marine oil spills (Holmes et al. 1979; Fry et al. 1986); a reasonable degree of applicability is likely, however this reinforces the importance of undertaking post-release breeding studies on different seabird species to determine how similar the effects are.

Of the few post-release breeding studies conducted, results have been variable. One study found no evidence of breeding restoration in rehabilitated seabirds (Anderson et al. 1996), however most studies have shown varying degrees of restoration and breeding success (Randall et al. 1980; Morant et al. 1981; Walton et al. 1997; Underhill et al. 1999; Giese et al. 2000; Barham et al. 2007; Wolfaardt et al. 2008a; Wolfaardt et al. 2008b). In one study breeding success was high and similar to that of control birds (Wolfaardt and Nel 2003), however in other studies success has been comparably reduced (Giese et al. 2000; Barham et al. 2007) or low (Morant et al. 1981). A few studies have also reported delays in reproductive attempts (Wolfaardt et al. 2008a; Wolfaardt et al. 2008b) and that in comparison to control birds a greater proportion of rehabilitated birds become secondary non-breeders (breed intermittently) (Wolfaardt et al. 2008a; Wolfaardt et al. 2009b).

The reasons for the reduced productivity of some oiled birds (any bird species, not just seabirds) are also variable. Some reasons include: reductions in egg production (Grau et al.

1977; Harvey et al. 1981; Fowler et al. 1995), fertility (Harvey et al. 1981), and hatching rates (Grau et al. 1977; Albers and Szaro 1978); eggshell thinning, making eggs more prone to cracking and accidental parental destruction (Grau et al. 1977; Ainley et al. 1981; Harvey et al. 1981); embryotoxicity (Hoffman 1979); teratogenic malformations (Hoffman 1978); embryo mortality (Ainley et al. 1981); suppressed production and secretion of reproductive hormones (Leighton 1993; Fowler et al. 1995); impaired ovarian function (Harvey et al. 1981); abnormal behaviours (Anderson et al. 1996) such as increased rates of temporary nest desertion (Butler et al. 1988), failure to incubate (Leighton 1993) and reduced rates of nest establishment (Fowler et al. 1995); inability to meet the energetic demands of the chicks (Giese et al. 2000); and disruption of pair bonds (Leighton 1993; Crawford et al. 2000; Giese et al. 2000; Whittington 2002). Acting singly or in combination, these effects can impair reproductive performance. The severity of these effects tends to be dose- and species-specific and depends on the type of oil ingested (Holmes et al. 1978) and the timing of ingestion relative to the next breeding season. This variability highlights the importance of conducting post-release monitoring studies on a variety of oil-rehabilitated species so that the effects of oiling can be better understood and hopefully reduced by improving techniques used in oiled wildlife rehabilitation.

This study thus aims to add to existing knowledge on the effects of oiling on rehabilitated seabirds by determining the effects of contamination on the post-release productivity of little blue penguins (*Eudyptula minor*) rehabilitated after the 2011 C/V *Rena* oil spill in Tauranga, New Zealand. This is to be achieved by comparing the reproductive success of breeding pairs including at least one rehabilitated adult to that of pairs including two control adults (local penguins not oiled or rehabilitated) in the first post-spill (and post-rehabilitation) breeding season. This data will also be used as part of the assessments of the overall impact of the *Rena* oil spill on little blue penguins, and the effectiveness of the oil rehabilitation process conducted by New Zealand's National Oiled Wildlife Response Team.

# Methods

## Locating nests

Nest searches were conducted from mid-August 2012 to the end of the 2012-2013 breeding season, the first breeding season following oil contamination and subsequent rehabilitation and release. Searches were conducted by both day and night along the rocky shorelines and vegetated areas of Mount Maunganui (Mauao) and Leisure Island (Moturiki Island). Rabbit Island (Motuotau Island) was not monitored due to difficulties associated with regularly accessing the site and concern regarding disturbance of other nesting seabirds. Little prior knowledge existed regarding the location of burrows at the two study sites, therefore burrows were found by following guano trails (indicators of the presence of nesting penguins) and searching all nearby rock crevices and potential nesting sites. The strong, distinct smell of penguin guano also aided burrow detection as did vocalisations of penguins within burrows. Drain pipes, old wooden nesting boxes and other artificial structures that had potential as opportunistic nesting sites were searched also.

## Burrow monitoring

The GPS position of all burrows found were recorded and later plotted on a map. The fate of each accessible burrow (those whose contents could be observed) was monitored over the course of the breeding season through checks conducted approximately every 1-2 weeks up until chicks were close to fledging, characterised as when they had lost approximately 75% of their down feathers. Thereafter, burrow checks became more frequent (approximately every 3-4 days) so that chick fledging dates could be determined with reasonable accuracy (within one week).

Burrows were checked visually by either inserting a burrowscope (a small camera on the end of a flexible, extendable (1-4 m) arm which transmits an image of the burrow contents to a monitor screen held by the observer outside the burrow), taking a photo, or looking into the burrow. The method of inspection used depended on the nature and accessibility of the burrow. These checks provided information for each nest on their contents, the approximate timing of egg laying, clutch size, the number of chicks hatched, the number of

chick surviving through to fledging, and approximate fledging dates. The data collated for each nest were also used collectively to determine overall ranges and values for each of these breeding success parameters at the study sites and to provide information on the timing and duration of the breeding season.

### **Identifying pairs**

Efforts were made to determine the “identity” of both partners of each breeding pair being monitored. Identity refers to whether pairs consisted of two rehabilitated penguins, two control/unmarked penguins, or a combination of both, and was determined by scanning penguins with a microchip reader. If a microchip was present the penguin could be identified as a control or rehabilitated penguin according to the microchip number; penguins without microchips were also classed as control birds (as all rehabilitated penguins were micro-chipped). Pairs were identified so that it could be estimated what proportion of control and rehabilitated penguins re-sighted during survival monitoring surveys were observed breeding as well as to enable comparisons to be made between the reproductive successes of pairs with different oiling statuses. These were either pairs with two control penguins, pairs with two rehabilitated penguins, or pairs with at least one rehabilitated penguin. The latter category included pairs in which only one penguin could be scanned and it was a rehabilitated bird; pairs in which only a control bird was confirmed but the status of the second bird was not known were not included in analyses of oiling status.

### **Pre-fledging chicks**

Pre-fledging chicks (those that had lost >90% of their mesoptyle down feathers) were temporarily removed from burrows by hand or with a homemade noose and weighed. Chick weights were determined to the nearest 10 g by placing them in a pre-weighed bag, weighing them using a Pesola™ spring scale and correcting for bag weight. Each chick also had a microchip inserted. As with marked adult penguins, Allflex™ 11 mm microchips were used and they were inserted subcutaneously between the scapulars using standard operating procedures (DOC 2012). Gloves were worn whilst handling the chicks.

## **Chick mortality**

Any chicks found dead within monitored burrows that could be accessed and were not too decomposed were collected. They were then sent to Massey University for post-mortem examination in the hope that the cause of death could be determined.

## **Minimising disturbance**

All efforts were made to minimise potential disturbance to the nests during monitoring. This included excluding nesting adults from routine weighing during survival monitoring surveys, conducting nest checks as quickly and efficiently as possible (particularly when the frequency of nest checks increased in anticipation of chicks fledging the nest), and using an Allflex™ Yellow Stick Reader to scan the nesting adults. The use of the stick reader is a passive method of identification as this scanner does not require the penguins to be caught, held or removed from the nest.

## **Statistical analyses**

### **Software used**

Statistical analyses were conducted using the R statistical programming package (R Core Team 2013). Statistical tests conducted were reported to 95% significance ( $p=0.05$ ).

### **Timing and duration of breeding**

In most burrows it was not possible to record egg lay-dates directly as on burrow discovery eggs had already been laid or chicks had hatched. Lay-dates were therefore indirectly estimated by subtracting 90 days from the average fledging date for each nest. This 90-day period is based on an incubation period of approximately 36 days and a nestling period of approximately 54 days (Robertson and Heather 2005; Heber et al. 2008). Lay-dates could only be estimated by this method for successful burrows, classified as those that fledged one or two chicks.

The lay-date period was divided into weekly intervals and the frequency distribution of control pairs and pairs including at least one rehabilitated adult beginning egg laying within this period was determined. Additionally, a running total of the proportion of control pairs and rehabilitated pairs beginning egg laying was calculated to determine the degree of overlap in the timing of breeding.

The lay-date data were tested for normality using the Shapiro-Wilk normality test. Mann-Whitney U-tests were then performed on the data to determine whether lay-dates differed significantly between pairs from Mount Maunganui and Leisure Island and between pairs consisting of two control penguins and pairs including at least one rehabilitated penguin.

### Reproductive success

Reproductive success was assessed by comparing the clutch size, hatching success, fledging success and egg success of nests containing two control adults against nests containing at least one rehabilitated adult and nests containing two rehabilitated adults. Measures were evaluated on a per-egg basis and on a per-nest basis as follows (Table 2.1).

**Table 2.1.** Measures of breeding success analysed.

Measure	Per egg or chick	Per pair (binary response)
Hatching success	Proportion of chicks hatched from the number of eggs laid	One or more eggs hatched
Fledging success	Proportion of pre-fledging chicks from the number of chicks hatched	One or more chicks fledged
Egg success	Proportion of pre-fledging chicks from the total number of eggs laid	N/a – equivalent to fledging success

Classified this way, hatching, fledging and egg success are calculable as proportions on a per egg or per chick basis. At the pair level, success or failure to hatch or fledge at least one egg or chick is a binary response; egg success and fledging success are then identical so only hatching and fledging success are analysed at the pair level.

To determine whether breeding success parameters differed significantly between sites (Mount Maunganui and Leisure Island), between control pairs and pairs with at least one rehabilitated bird, and between control pairs and pairs with two rehabilitated pairs, randomisation tests were performed. These make no assumptions about underlying population distributions and can be a powerful way to test for differences between groups with small sample sizes or with limited variation options in the data (e.g. proportional data from 2-eggs nests can only ever be 0, 0.5 or 1; binary response data can only be 0 or 1). Randomisation tests simply ask how many times a randomly-drawn sample of the same size as the test data would give a larger difference between the groups than was shown by those test data. Tests were run 10,000 times and the proportion of tests generating a larger difference calculated; this is in effect the P-value (e.g.  $p=0.05$  means that 5% of the randomisations gave a larger difference between the samples than in the test data).

### **Pre-fledging chick masses**

Shapiro-Wilk normality tests and Welch's two sample t-tests were performed on the pre-fledging chick mass data to determine whether masses significantly differed between sites (Mount Maunganui and Leisure Island), and between nests with two control adults and nests with at least one rehabilitated adult.

### **Fledging dates and requirements**

Chick fledging dates were recorded as the median date of the period between the last sighting of the pre-fledging chick and discovery that the chick had fledged. Chicks that were micro-chipped were considered to have successfully fledged if they weighed at least 500 g at the time of micro-chipping and were not found dead prior to fledging (Nisbet and Dann 2009). Chicks that were not micro-chipped (due to difficulty accessing them) were considered to have successfully fledged if they were not found dead prior to fledging and if they had lost >90% of their mesoptyle down feathers when last re-sighted.

## **Factors influencing reproductive success**

Binary logistic regression was conducted to assess the significance of different variables in predicting overall hatching and fledging success of breeding pairs including at least one rehabilitated adult. The drop function was used to test for model improvement when dropping off predictor variables. The independent explanatory variables tested against these two response variables were degree of oiling (Appendix Figure 1.2), mass on admission to the Oiled Wildlife Facility (Appendix Figure 1.3), admission packed cell volume (PCV), admission blood glucose (BG), admission total protein (TP) (Appendix Figure 2.1), release mass (Appendix Figure 1.3), and captive duration (Appendix Figure 1.4) of the rehabilitated adult within the pair.

## Results

### **Burrows monitored and identity of breeding pairs**

One hundred and twenty-three occupied burrows were located at Mount Maunganui (n=74) and Leisure Island (n=49) during the 2012-13 breeding season (Figure 2.1). Eighty-three of these burrows were accessible (burrow contents could be observed) and were monitored throughout the breeding season (51 on Mount Maunganui and 32 on Leisure Island). The “identity” of both partners of a breeding pair was determined in 56/83 (67.5%) of the burrows. Five other burrows where the identity of only one breeding partner was determined included a rehabilitated penguin (Table 2.2). In total, 33 breeding pairs monitored included at least one rehabilitated adult (hereafter referred to as “rehabilitated pairs”) and 28 pairs consisted of two control adults (“control pairs”).

a)



b)



**Figure 2.1.** Locations of known little blue penguin burrows during the 2012-2013 breeding season at a) Mount Maunganui and b) Leisure Island. Those marked in green are accessible burrows that were monitored; those in black and red are known but inaccessible burrows that could not be monitored. Image credit: Google Maps 2014.

**Table 2.2.** Little blue penguin pairs at Mount Maunganui and Leisure Island during the 2012-13 breeding season whose identity was known, or at least one penguin in the pair was known to be a rehabilitated bird.

Pair identities	Number of breeding pairs		Total
	Mount Maunganui	Leisure Island	
Rehabilitated/rehabilitated	3	4	7
Control/control	11	17	28
Rehabilitated/control	13	8	21
Rehabilitated/unknown	5	0	5
<b>Total</b>	32	29	61

### Proportions of control and rehabilitated penguins seen breeding

The proportions of rehabilitated and control penguins from Mount Maunganui and Leisure Island observed breeding during the 2012-13 breeding season were similar (40/157 (25.5%) rehabilitated versus 54/242 (22.2%) control ( $\chi^2=0.4045$ , d.f.=1,  $p=0.5248$ )). When considering only penguins re-sighted during survival monitoring surveys (Chapter 3) at Mount Maunganui and Leisure Island then proportionately more rehabilitated penguins assumed to be from these sites were observed breeding (32/84 (38.1%)) than control penguins micro-chipped at these sites (48/174 (27.6%)), however this difference was not statistically significant ( $\chi^2=2.0178$ , d.f.=1,  $p=0.1555$ ).

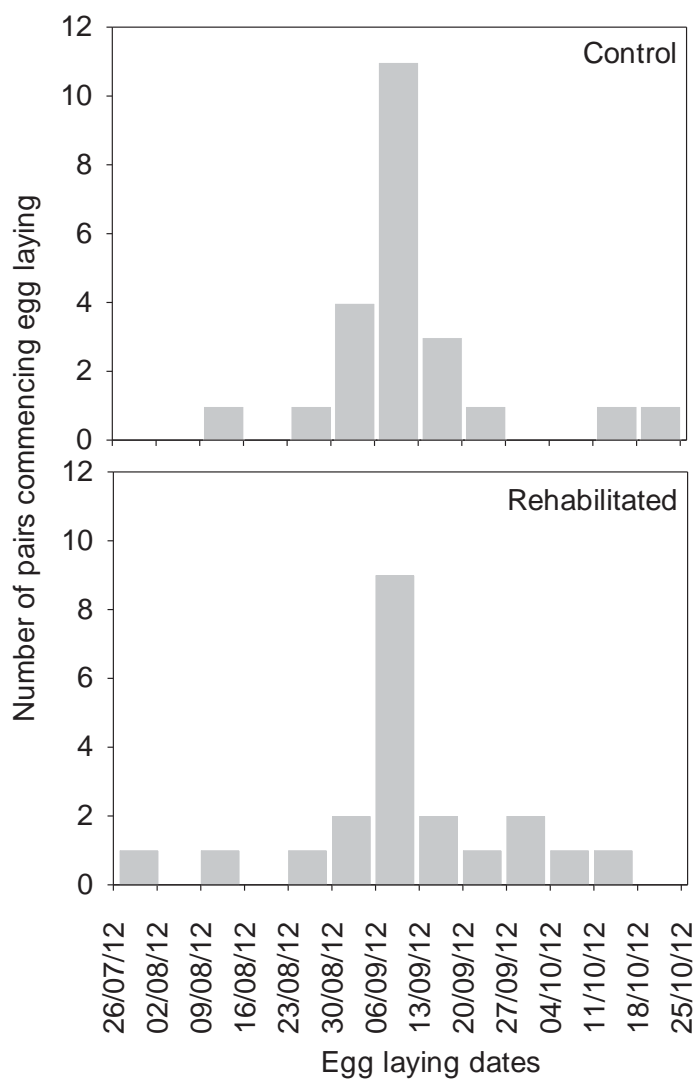
### Timing and duration of breeding

The timing of breeding did not differ between pairs from Mount Maunganui and Leisure Island (Mann-Whitney  $U=445$ ,  $p=0.8154$ ); data from these breeding pairs were therefore pooled together for subsequent analyses.

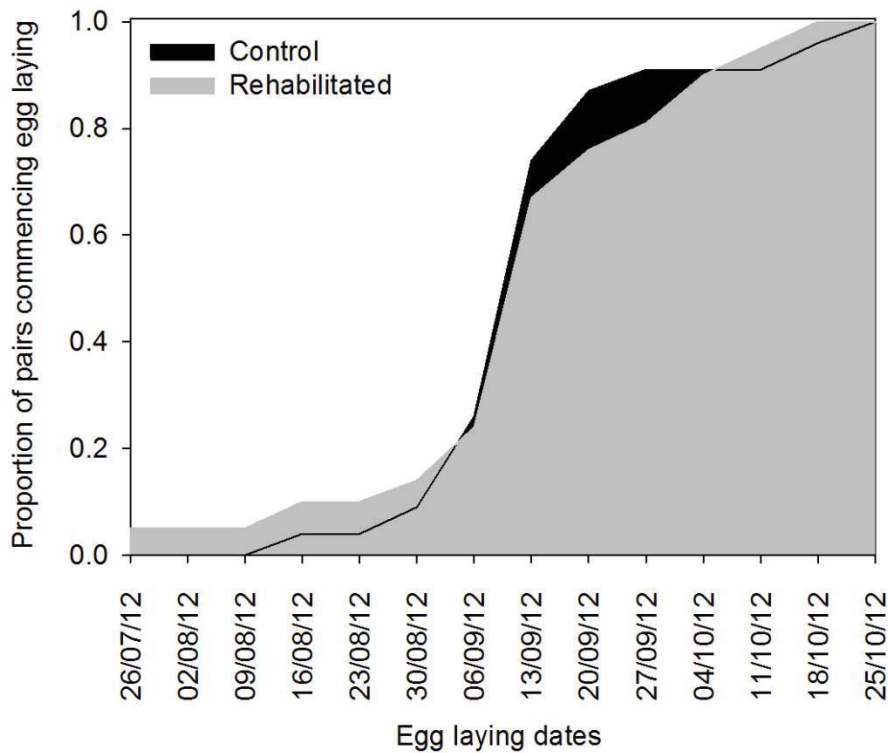
Egg laying dates for successful control pairs (pairs that fledged one or two chicks) ranged from 9 August to 22 October 2012, mean 9 September 2012 ( $n=23$  pairs). Lay-dates for successful rehabilitated pairs ranged from 26 July to 12 October 2012, mean 9 September 2012 ( $n=21$  pairs). The peak lay period for both control and rehabilitated pairs was from 5–12 September, 2012; 11/23 (47.8%) and 9/21 (42.9%) of the pairs laid at this time respectively (Figure 2.2).

The earlier onset of egg laying in rehabilitated pairs is only attributed to one pair; likewise the later completion of egg laying by control pairs is also attributed to a single pair. The distribution of lay-dates were otherwise very similar between pairs of differing oiling status (Figure 2.3; Mann-Whitney  $U=225.5$ ,  $p=0.715$ ).

Lay-dates could not be determined for unsuccessful pairs (pairs which fledged no chicks) as lay-dates for each nest were estimated by subtracting 90 days from chick fledging dates; consequently it is unknown whether lay-dates of unsuccessful pairs differed (either earlier or later) from successful pairs.



**Figure 2.2.** Frequency distribution of egg laying dates of control and rehabilitated little blue penguin pairs during the 2012-13 breeding season at Mount Maunganui and Leisure Island. Control pairs include two control adults and rehabilitated pairs include at least one rehabilitated adult.



**Figure 2.3.** Running total of the proportion of control and rehabilitated little blue penguin pairs commencing egg laying over time at Mount Maunganui and Leisure Island (pooled data).

### Clutch size

At least 65/83 (81.9%) of the monitored breeding pairs laid two eggs. It is uncertain whether burrows that had a single chick when discovered had resulted from just one egg being laid or two eggs being laid but one egg or chick being lost before discovery. Consequently, the following breeding success results are presented assuming (1) that all pairs laid two eggs, and (2) that pairs with one chick had laid only one egg (Table 2.3).

### Reproductive success

None of the reproductive parameters differed between the two study sites (Mount Maunganui and Leisure Island) as determined from non-significant results from randomisation tests conducted; consequently the data from all breeding pairs (irrespective of site) were pooled for the following analyses.

While breeding parameters tended to be lower for rehabilitated pairs than control pairs, only the number of eggs hatched per pair and per egg laid differed significantly (1.45 versus 1.75 chicks per pair,  $p=0.0158$ ; 0.73 versus 0.88 chicks per egg assuming 2-egg nests,  $p=0.0162$ ; Table 2.3). The number of chicks fledged per pair approached significance between the two groups ( $p=0.0722$ ; Table 2.3).

Pairs confirmed as consisting of two rehabilitated penguins had significantly lower egg production ( $p=0.0409$ ) and overall fledge success per pair ( $p=0.0315$ ) compared to pairs with two control penguins; no significant differences were found between these two groups for hatch success ( $p=0.1177$ ), fledge success ( $p=0.1038$ ) and overall hatch success per pair ( $p=0.2018$ ). These results however should be interpreted with caution as the sample size for pairs with two rehabilitated penguins was very small ( $n=7$ ).

**Table 2.3.** Breeding success of rehabilitated and control little blue penguin pairs at Mount Maunganui and Leisure Island during the 2012-13 breeding season. Significant results are indicated by an asterisk (\*).

<i>Per egg basis Rehab/control</i>	N pairs	N eggs	N hatched	N fledged	Hatched per egg	Fledged per egg	Fledged per hatch	
<b>Assuming 1- or 2-egg nests</b>								
1 or 2 rehab	33	59	48	36	0.81	0.61	0.75	
2 control	28	53	49	38	0.93	0.72	0.78	
Significance	N/A	N/A	N/A	N/A	0.1025	0.1499	0.229	
<b>Assuming 2-egg nests</b>								
1 or 2 rehab	33	66	48	36	0.73	0.55	0.75	
2 control	28	56	49	38	0.88	0.68	0.78	
Significance	N/A	N/A	N/A	N/A	0.0162*	0.1272	0.229	
<i>Per pair basis Rehab/control</i>	N nests	N eggs per pair	N nests hatching	N nests fledging	Hatched per pair	Fledged per pair	Hatch success per pair	Fledge success per pair
<b>Assuming 1- or 2-egg nests</b>								
1 or 2 rehab	33	1.79	31	24	1.45	1.09	0.94	0.73
2 control	28	1.89	27	23	1.75	1.36	0.96	0.82
Significance	N/A	0.2246	N/A	N/A	0.0158*	0.0722	0.559	0.2934

## **Pre-fledging chick masses**

Thirty-two pre-fledging chicks were weighed and micro-chipped, 17 from Leisure Island and 15 from Mount Maunganui. As the masses of the chicks from these sites did not differ (Mann-Whitney  $U=161.5$ ,  $d.f.=2$ ,  $p=0.2052$ ), their data were pooled for subsequent analyses.

Average chick masses did not differ between control and rehabilitated pairs (759 g and 769 g respectively; Mann-Whitney  $U=83$ ,  $d.f.=2$ ,  $p=0.7459$ ).

## **Chick mortality and causes of death**

23/97 (23.7%) of the chicks hatched in our monitored burrows died before fledging. Eleven were raised by control pairs and 12 by rehabilitated pairs. The causes of mortality are largely unknown as upon discovery the carcasses were generally too decomposed to collect and examine post-mortem. Many carcasses were also inaccessible and could not be reached for collection. In total four pre-fledging carcasses were collected and taken to Massey University, three of which were raised by rehabilitated pairs and one by a control pair. Post-mortems indicated that all four chicks died from emaciation due to starvation (as evidenced by a lack of body fat, pectoral muscle, and food in the stomach, as well as the presence of melena in the intestines).

## **Factors that influenced breeding success**

Binary logistic regression analyses determined that no predictor variables (oiling degree, admission PCV (packed cell volume), admission TP (total protein), admission BG (blood glucose), admission mass, release mass and captive duration) had a significant influence on overall hatching and fledging success of breeding pairs including at least one rehabilitated penguin; this was evidenced by no improvement in the generalised linear model when different variables were added singly or in combination.

## **Discussion**

### **Results summary**

In the first post-spill breeding season (2012-13), the number of eggs hatched per pair was significantly lower in pairs including at least one rehabilitated little blue penguin than pairs including two control penguins (hereafter referred to as rehabilitated pairs and control pairs respectively). The number of chicks fledged per pair was also marginally significantly reduced in rehabilitated pairs. Other breeding parameters studied, including breeding activity, timing and duration of egg laying, clutch size, egg success, and pre-fledging chick masses, were comparable between these two groups. Sample sizes were too small to confidently conclude whether reproductive success was reduced in pairs including two rehabilitated penguins and whether overall hatching and fledging success were influenced by variables such as oiling degree and captive duration.

As outlined below, these results are both similar to and in contrast with results from field and experimental studies on the productivity of oil-rehabilitated, oil-exposed, or oil-dosed birds.

### **Context with other studies**

- **Breeding activities**

At Mount Maunganui and Leisure Island, 38% of the rehabilitated penguins and 28% of the control penguins re-sighted during survival monitoring surveys were recorded breeding. These are minimum estimates as it is unlikely that all breeding burrows were located. Rehabilitated penguins paired with control penguins indicating that rehabilitation did not affect how oiled and non-oiled birds reacted to each other. These findings confirm that rehabilitated penguins were capable of resuming “normal” breeding activities in the first breeding season post-release. Such confirmation has been reported for other oil-rehabilitated seabirds, particularly penguins, with varying degrees of restoration success documented (Randall et al. 1980; Underhill et al. 1999; Giese et al. 2000; Wolfaardt et al. 2008a). The restoration estimate for rehabilitated penguins in this study is higher than that

reported in South Africa for African penguins after (1) seven different oiling incidents between 1970 and 1979 (range of 0-30%, with an average of 20%) (Morant et al. 1981), (2) an oil spill near St. Croix Island (7%; Randall et al. 1980), (3) oil spills near Dyer Island in 1995 (30%; Whittington 2002), (4) a pipeline oil spill near Cape Town harbour in 1998 (4.5%; Whittington 2002), and (5) the *Treasure* oil spill in 2000 (30%; Wolfaardt et al. 2008b). The post-*Rena* estimate is, however, substantially lower than that reported for rehabilitated penguins re-sighted at two intensively monitored sites on Dassen Island (74%) and Dassen Island as a whole (63%) during a 10 year study conducted after the 1994 *Apollo Sea* oil spill (Wolfaardt et al. 2008a). The difference in restoration success between this study and the *Apollo Sea* study may be attributed to study duration (one year versus ten years respectively); it is thus likely that if this study continues, apparent restoration success will increase over time.

- **Timing and duration of egg laying**

In accordance with this study, kittiwakes (*Rissa tridactyla*) within an oil-affected area commenced egg laying during the first post-spill breeding season at a similar time as previous years (Walton et al. 1997). This contrasts with many studies which have found a significant difference in the timing and duration of lay by oiled and/or rehabilitated birds relative to control birds. For example, in the first breeding season after the *Iron Baron* oil spill, breeding pairs of little blue penguins including at least one rehabilitated bird commenced egg laying one month later than control pairs; furthermore, the duration of lay was approximately 4–5 weeks shorter than that of control pairs (Giese et al. 2000). Khaki Campbell ducks (*Anas platyrhynchos domesticus*) and mallard ducks (*Anas platyrhynchos*) experimentally dosed with oil also showed a delay in the onset of lay, with eggs laid four weeks and one week later than control birds respectively (Holmes et al. 1978). As the lay period was not delayed or shortened in this study it seems that there was sufficient time between release and the onset of breeding for rehabilitated penguins to re-establish or create new pair bonds (for penguins whose partner died during the oil spill) and prepare nests. This is likely to have assisted in the post-spill recovery of oil-affected populations.

- **Clutch size**

Similar-sized clutches between rehabilitated and control pairs have also been reported for African penguins after the *Apollo Sea* oil spill (Wolfaardt et al. 2008c). Contrasting results however have been documented for oil-dosed American kestrels (*Falco sparverius*) and Japanese quails (*Coturnix japonica*), and for pigeon guillemots (*Cephus columba*) within areas contaminated by the *Exxon Valdez* oil spill (Grau et al. 1977; Fernie et al. 2001; Golet et al. 2002) with clutch sizes significantly reduced in oil-exposed birds. As clutch size was not reduced in this study, it thus appears that rehabilitation was successful at counteracting any negative effects oiling may have had on egg production, however, given that penguins (as well as pigeon guillemots) lay only one or two eggs there is limited scope to detect clutch size reductions.

- **Hatching success**

Studies looking at the effects of oil contamination on egg hatchability have produced contrasting results. A reduction was not observed in penguins rehabilitated after the *Iron Baron*, *Apollo Sea* and *Treasure* oil spills; this was the case for all post-spill breeding seasons monitored (two, six and five seasons respectively) (Giese et al. 2000; Barham et al. 2007; Wolfaardt et al. 2008c). However, in the case of the *Iron Baron* oil spill, the first post-spill breeding season commenced shortly after release from captivity, therefore it is possible that any deleterious effects of oiling on incubation ability may have been masked by the “fattening” of penguins whilst in captivity; rehabilitated penguins thus commenced the breeding season in good condition which may have enabled them to complete incubation with the same apparent success as control pairs (Giese et al. 2000).

Reduced hatching success as observed in the present study has however been reported for laboratory-based studies on oil-dosed or externally contaminated storm petrels (*Oceanodroma leucorhoa*), wedge-tailed shearwaters (*Puffinus pacificus*), American kestrels and Cassin’s auklets (*Ptychoramphus aleuticus*) (Ainley et al. 1981; Fry et al. 1986; Fernie et al. 2001). The reduction in this study suggests that for some penguins rehabilitation did not successfully reverse all negative effects of oiling on egg hatchability.

- **Fledging success**

Like the present study, significantly reduced fledging success was not found for black oystercatchers (*Haematopus bachmani*) exposed to persistent shoreline oiling after the *Exxon Valdez* oil spill (Andres 1999). Most other studies however have had contrasting results with success significantly reduced for rehabilitated birds. For example pairs including at least one African penguin rehabilitated after the *Apollo Sea* and *Treasure* oil spills fledged 11% and 18% fewer chicks respectively than nests with two control adults. This effect was evident in 18 studies during a 6-year period after the *Apollo Sea* spill and for the entire study period (2001-2004) following the *Treasure* spill (Barham et al. 2007; Wolfaardt et al. 2008a).

Reduced chick growth and survivability (Trivelpiece et al. 1984), as well as a dose-dependent reduction in fledging success in the first breeding season after oiling (Butler et al. 1988), have been reported for oil-dosed or externally contaminated Leach's storm petrels. Low fledging success has also been reported for pigeon guillemots oiled after the *Exxon Valdez* oil spill in study sites post-spill compared to pre-spill (Golet et al. 2002) and for American kestrels fed oil with only 40% of the chicks hatched surviving to independence (Ferne et al. 2001).

- **Egg success**

In contrast to the present study, studies on penguins rehabilitated after the *Iron Baron*, *Apollo Sea* and *Treasure* oil spills have found significantly lower egg success in rehabilitated pairs relative to control pairs (Giese et al. 2000; Barham et al. 2007; Wolfaardt 2007). Reduced egg success has also been reported for European shags in an area contaminated by the *Prestige* oil spill. A year after the spill success was 50% lower than at an unoiled site (Velando et al. 2005) and after 10 years, success of oiled shags was still 45% lower than that of unoiled birds (Barros et al. 2014). Similarly, wedge-tailed shearwaters and Leach's storm petrels orally-dosed or externally contaminated with oil also showed significantly reduced egg success. This effect was evident for two and one post-spill breeding seasons respectively (Fry et al. 1986; Butler et al. 1988).

## Mechanisms contributing to reduced reproductive success

As illustrated above oil contamination can negatively affect different parameters that influence reproductive success. In some cases rehabilitation is unable to prevent these negative effects of oiling from manifesting and reducing productivity. This can occur via a number of potential mechanisms (Table 2.4).

**Table 2.4.** Proposed mechanisms of oil impacts on reproductive parameters. Behavioural mechanisms are in grey and physiological mechanisms are in white.

Mechanisms	Reproductive parameters						
	Restoration success	Timing and duration of lay	Clutch Size	Hatch success	Fledge success	Egg success	Chick Growth
Reduced nest attentiveness <sup>1,2,3,4,5</sup>				✓	✓	✓	✓
Pair bond disruption/ death of a partner <sup>6</sup>	✓	✓					
Systemic toxicity of oiled birds <sup>7,8,9,10,11,12,13</sup>	✓		✓	✓	✓	✓	✓
Embryo toxicity <sup>12,13,14,15</sup>				✓	✓	✓	✓
Impaired foraging ability <sup>4,6,16</sup>					✓	✓	✓
Prey toxicity <sup>4</sup>				✓	✓	✓	✓

**Sources:** <sup>1</sup>(Butler et al. 1988). <sup>2</sup>(Barham et al. 2007). <sup>3</sup>(Wolfaardt et al. 2008a). <sup>4</sup>(Wolfaardt et al. 2008c). <sup>5</sup>(Fry et al. 1986). <sup>6</sup>(Giese et al. 2000). <sup>7</sup>(Harvey et al. 1981). <sup>8</sup>(Holmes 1981). <sup>9</sup>(Cavanaugh and Holmes 1982). <sup>10</sup>(Leighton 1993). <sup>11</sup>(Fowler et al. 1995). <sup>12</sup>(Peakall et al. 1980). <sup>13</sup>(Gorsline and Holmes 1982). <sup>14</sup>(Miller et al. 1978). <sup>15</sup>(Grau et al. 1977). <sup>16</sup>(Trivelpiece et al. 1984).

## Mechanism explanations

### ▪ Physiological mechanisms

Systemic toxicity can negatively affect reproductive performance (Giese et al. 2000) by causing problems such as endocrine disruption, delayed ovary maturation, reduced fertility,

reduced egg production, abnormal yolk formation, eggshell thinning, reduced hatching and fledging success, reduced chick growth, and reduced nest attentiveness (Grau et al. 1977; Miller et al. 1978; Peakall et al. 1980; Harvey et al. 1982; Trivelpiece et al. 1984; Fry and Lowenstine 1985; Boersma et al. 1988; Burger and Fry 1993; Leighton et al. 1993). These impairments may be transient and only affect breeding success in the short term, however it is possible that some effects will persist and compromise productivity in the long-term (Giese et al. 2000).

Other adverse physiological effects may occur as a result of oil transferring from oiled adults to eggs during incubation (King and Lefever 1979). This can result in hydrocarbons incorporating into eggshells and causing systemic toxicity of developing embryos (Albers 1977; Hoffman 1978; Szaro et al. 1978; Leighton 1993). Possible effects of this toxicity may include reduced hatching success, teratogenic malformations, impaired embryonic growth and development, and embryonic mortality (this in turn reduces fledging and egg success) (Albers 1977; Hoffman et al. 1978). Embryo toxicity may also occur if residual hydrocarbons circulating in rehabilitated adults become incorporated into eggs during egg formation and development (Gorsline and Holmes 1982). Hatching, fledging and egg success as well as chick quality may be further reduced if food is of poor quality (due to oil-induced toxicity of prey species having negative physiological effects on prey quality), or if oiling has had an adverse effect on the ability of rehabilitated adults to forage effectively and sufficiently provision their chicks (Woldaardt et al. 2008c).

- **Behavioural mechanisms**

Behavioural aberrations can also reduce the reproductive success of oil-rehabilitated birds. For example, some birds may have reduced nest attentiveness which can result in temporary or permanent nest abandonment. This behavioural change may occur due to physiological impairment or possibly limited food availability (potentially due to oil-induced mortality of prey species) increasing the durations of foraging trips. Short- and long-term nest abandonment can reduce reproductive success by causing ineffective incubation (resulting in egg failure) and brooding of chicks (causing reduced fledging and egg success due to hypothermia-induced mortality of chicks that are unable to self-thermoregulate).

Chick growth may also be impaired and some may die from starvation due to insufficient food provisioning (Barham et al. 2007; Wolfaardt et al. 2008a; Wolfaardt et al. 2008c).

Another behavioural mechanism that can reduce reproductive success is pair bond disruption. This can occur as a result of oiled penguins being in captivity while being cleaned and rehabilitated. If there is little time between release and breeding for pairs to re-establish synchrony, or for birds whose partner had died to find a new partner, establish a new pair bond and prepare a nesting site (Giese et al. 2000), the timing of breeding may be delayed and the duration protracted, or alternatively breeding may not even occur in the first post-spill season; this can reduce restoration success and delay the recovery of oil-affected populations.

### **Applicability to this study**

In the present study the only breeding parameter that was significantly reduced in rehabilitated pairs was hatching success. The mechanism/s for this reduced egg hatchability are unknown as eggs that failed to hatch were not collected because of difficulty collecting the eggs due to the inaccessible nature of some burrows or the eggs being preyed upon prior to collection. However, based on Table 2.4, some factors that may have potentially contributed to this reduction include temporary nest abandonment by rehabilitated adults, embryo toxicity as a result of residual oil ingested by rehabilitated females incorporating into eggs during egg formation, and prey toxicity due to the presence of oil within the marine environment. Direct oil toxicity on eggs and subsequent embryo toxicity is unlikely to have been a mechanism as oil-contaminated penguins were cleaned. Breeding areas were also cleaned however small amounts of oil remained in areas that were difficult to clean, such as between and under rocks, therefore this may have resulted in some contamination. The marginally significantly reduced fledging success in this study may have also resulted from mechanisms listed in Table 2.4 such as reduced nest attentiveness, systemic toxicity, impaired foraging ability, and prey toxicity. Some mechanisms may have also influenced other breeding parameters, however not to the extent of causing a significant negative effect. Overall, it appears that rehabilitation was generally successful at treating or at least lessening the effects of oil contamination on parameters that influence

reproductive success; this enabled rehabilitated penguins to breed with similar success as control penguins in the first post-spill breeding season.

### **Other factors influencing reproductive success**

Reproductive success may also be influenced by oil- and captive-related factors. Such factors may include the toxicity of the oil (Ainley et al. 1981; Trivelpiece et al. 1984; Leighton 1993), amount of oil ingested (Butler et al. 1988; Wolfaardt et al. 2008a), degree of oiling (Goldsworthy et al. 2000b), admission mass and condition of oiled animals, duration between oiling and decontamination (Altwegg et al. 2008), species affected (Wolfaardt et al. 2008a), stress of oiling and captivity (Briggs et al. 1997), skill and efficiency of the rehabilitation team (Wernham et al. 1997), and the duration and intensity of the post-release productivity study (Wolfaardt 2007).

During the *Rena* oil spill, the oiled wildlife response was prompt and oiled little blue penguins (which like other penguin species are robust and resilient: Wolfaardt et al. 2009b) were collected and taken to the rehabilitation centre as quickly as possible where an effective and efficient oil decontamination process was carried out by skilled personnel. These factors reduced the amount of time oiled penguins were contaminated by and exposed to the toxic effects of the oil and thus may have increased the efficacy of the rehabilitation process and thereby increased post-release reproductive success.

### **Comparisons of breeding parameters with other little blue penguin colonies**

As there is no pre-spill breeding history of penguins at Mount Maunganui and Leisure Island it is unknown whether the timing and duration of egg laying, and hatching, fledging, and egg success rates reported for rehabilitated (and control) pairs are similar to previous breeding seasons. These rates and the timing of lay however are within ranges (often towards the higher end for hatch, fledge and egg success) reported for little blue penguins at other colonies in Australia and New Zealand (Tables 2.5 and 2.6). This suggests that although rehabilitated penguins had somewhat reduced reproductive success relative to control penguins, they still had a successful breeding season with many penguins capable of reproducing as well (or even better) than penguins at other non-oiled colonies, and thus

contributing to the post-spill recovery of the oil-affected populations. A factor that may have contributed to this success is the elimination of parasite loads during rehabilitation from 'de-worming' (L. Chilvers, pers. comm.). The duration of lay, 12 weeks for both control and rehabilitated pairs, however was generally less than that reported at other colonies. This may be due to a negative indirect effect of oil on food availability or else it may simply reflect the considerable variation in the timing and duration of breeding between colonies (Gales 1985).

**Table 2.5.** Comparisons of the timing and duration of breeding by little blue penguins at Mount Maunganui and Leisure Island (successful pairs only) and other colonies of unoiled penguins in New Zealand and Australia. Mount Maunganui/Leisure Island pairs are separated into control pairs (those consisting of two control penguins) and rehabilitated pairs (those containing at least one rehabilitated penguin).

NEW ZEALAND	Year	Approximate lay-date of first eggs	Lay-date range	Mean lay-date	Ave. duration of lay (weeks)
<b>North Island</b>					
Mount Maunganui/Leisure Is., Tauranga (control pairs) <sup>1</sup>	2012-13	9 Aug	8 Aug-22 Oct	9 Sep	12
Mount Maunganui/Leisure Is., Tauranga (rehab pairs) <sup>1</sup>	2012-13	26 Jul	26 Jul-12 Oct	9 Sep	12
Tiritiri Matangi, Auckland <sup>2</sup>	2005-07	9-10 Sep	9 Sep-15 Dec	-	15
Tiritiri Matangi, Auckland <sup>3</sup>	2009-10	6 Sep	6 Sep-30 Nov	-	13
Wellington harbour <sup>4</sup>	1956-57	1-20 Aug	-	-	
<b>South Island</b>					
Oamaru, Otago <sup>5</sup>	2013-14	28 Aug-3 Sep	28 Aug-1 Jan	-	18
Dunedin, Otago <sup>6</sup>	1982-84	1 Jul-16 Aug	-	-	
<b>AUSTRALIA</b>					
<b>New South Wales</b>					
Lion Island <sup>7</sup>	1990-98	20 Jun-24 Jul	20 Jun-18 Dec	16 Aug-14 Oct	31
Bowen Island <sup>8</sup>	1987-90	-	-	4-24 Sep	
<b>Victoria</b>					
Phillip Island <sup>9</sup>	1968-78	29 Jun-29 Sep	-	-	
Phillip Island <sup>10</sup>	1986-04	-	-	17 Sep-16 Nov	10
<b>Tasmania</b>					
Bruny Island, Tasmania <sup>11</sup>	1960-63	16 Sep-8 Oct	16 Sep-23 Dec	-	
Ninth Island, Tasmania <sup>12</sup>	1996-97	5-21 Oct	-	-	

**Sources:** <sup>1</sup>(This study). <sup>2</sup>(Geurts 2006; van Rensburg 2010). <sup>3</sup>(Boyer 2010) <sup>4</sup>(Kinsky 1960). <sup>5</sup>(P. Agnew, pers. comm.). <sup>6</sup>(Gales 1985). <sup>7</sup>(Knight and Rogers 2004). <sup>8</sup>(Fortescue 1991). <sup>9</sup>(Reilly and Cullen 1981). <sup>10</sup>(Nisbet and Dann 2009). <sup>11</sup>(Hodgson 1975). <sup>12</sup>(Giese et al. 2000).

**Table 2.6.** Comparisons of little blue penguin breeding success measures at Mount Maunganui and Leisure Island (upper) and other sites in Australia and New Zealand (lower).

REHAB/CONTROL (This study)	Year(s)	Hatching success	Fledging success	Egg success
<b>Assuming 1- or 2 egg nests</b>				
1 or 2 rehab	2012-13	0.81	0.61	0.75
2 control	2012-13	0.93	0.72	0.78
<b>Assuming 2-egg nests</b>				
1 or 2 rehab	2012-13	0.73	0.55	0.75
2 control	2012-13	0.88	0.68	0.78
<b>NEW ZEALAND</b>				
<b>North Island</b>				
Tiritiri Matangi Island, Auckland <sup>1</sup>	2005-07	0.27-0.53	0.27-0.38	0.10-0.33
Tiritiri Matangi Island, Auckland <sup>2</sup>	2009-10	0.51	0.06	0.04
Tiritiri Matangi Island, Auckland <sup>3</sup>	2010-13	0.57-0.94	0.51-0.94	0.30-0.88
Matiu-Somes Island, Wellington <sup>4</sup>	1995-97	0.51-0.63	0.81-0.85	0.41-0.54
<b>South Island</b>				
Motuara Island, Marlborough <sup>5</sup>	1995-96	-	0.33	0.13
Oamaru, Otago <sup>6</sup>	1998-99	0.61	-	-
Oamaru, Otago <sup>7</sup>	2008	0.74	0.91	0.67
Taiaroa Head, Otago <sup>8</sup>	1992-98	0.40-0.81	0.41-0.78	0.58-0.96
Buller, West Coast <sup>9</sup>	2006-07	0.79	0.84	0.62
Buller, West Coast <sup>10</sup>	2008-09	0.77	0.89	0.63
South Westland, West Coast <sup>10</sup>	2008-09	0.81	0.99	0.79
<b>AUSTRALIA</b>				
<b>New South Wales</b>				
North Harbour <sup>11</sup>	2002-05	0.72	-	0.70
Bowen Island <sup>12</sup>	1987-95	0.71-1	0.42-1	-
Lion Island <sup>13</sup>	1990-94	0.72-0.85	0.66-0.85	0.50-0.73
Sydney <sup>14</sup>	1990-92	0.76-0.87	0.67-0.89	-
<b>Victoria</b>				
Phillip Island <sup>15</sup>	1968-80	0.47-0.78	0.06-0.69	-
Phillip Island <sup>16</sup>	1968-99	0.47-0.87	-	-
Phillip Island <sup>17</sup>	1986-04	0.39-0.79	-	-
<b>Western Australia</b>				
Penguin Island <sup>18</sup>		0.80	-	0.41
<b>Tasmania</b>				
Bruny Island <sup>19</sup>	1959-62	0.61-0.72	0.21-0.29	0.13-0.18
Ninth Island <sup>20</sup>	1995-97	0.74	0.52	0.46
Low Head <sup>20</sup>	1995-97	0.78	0.44	0.39

**Sources:** <sup>1</sup>(Geurts 2006; van Rensburg 2010). <sup>2</sup>(Boyer 2010). <sup>3</sup>(D. Brunton, pers. comm.). <sup>4</sup>(Bull 2000). <sup>5</sup>(Renner and Davis 2001). <sup>6</sup>(Numata et al. 2000). <sup>7</sup>(P. Agnew, pers. comm.). <sup>8</sup>(Perriman and Steen 2000). <sup>9</sup>(Heber et al. 2008). <sup>10</sup>(Braidwood 2009). <sup>11</sup>(Priddel et al. 2008). <sup>12</sup>(Fortescue 1991). <sup>13</sup>(Rogers et al. 1995). <sup>14</sup>(Cunningham et al. 1993). <sup>15</sup>(Reilly and Cullen 1981). <sup>16</sup>(Kemp and Dann 2001). <sup>17</sup>(Nisbet and Dann 2009). <sup>18</sup>(Klomp and Wooller 1991). <sup>19</sup>(Hodgson 1975). <sup>20</sup>(Giese et al. 2000).

## **Reproductive success of pairs with two rehabilitated adults**

Egg production and overall fledge success per pair were significantly reduced in pairs including two rehabilitated penguins relative to control pairs. No significant differences were found between these groups for hatching success, fledging success, egg success and overall hatch success per pair. Samples of pairs including two rehabilitated penguins were small however therefore these results may not be representative of all such pairs and thus must be interpreted with caution. Following the *Apollo Sea* oil spill, fledging success, and thus overall reproductive success, was significantly reduced in pairs with two rehabilitated African penguins (relative to control pairs) due to increased mortality of chicks more than 40 days old; this reduction was evident for the six years of the study (Wolfaardt et al. 2008c). Few other studies have investigated whether the presence of two oiled and/or rehabilitated birds within a breeding pair has a different effect on reproductive parameters relative to pairs with only one rehabilitated adult.

## **Factors that influence breeding success**

When expressed as binary response variables, neither hatching nor fledging success of rehabilitated pairs were influenced by any independent explanatory variables tested. The variables tested were oiling degree, admission mass, admission packed cell volume (PCV), admission total protein (TP), admission blood glucose (BG), release mass, and captive duration of the oiled penguin/s within the rehabilitated pair.

With respect to oiling degree and the mass variables tested, this finding is in contrast to other similar studies that have been conducted. For example after the *Treasure* oil spill restoration success of rehabilitated penguins was influenced by oiling degree with success highest in penguins <5% oiled. Specifically, restoration rates decreased from 28% for penguins <5% oiled, to 25% for birds 5% oiled, and 6% for penguins 10% oiled; no penguins with higher degrees of oiling were recorded breeding (Wolfaardt et al. 2008b) indicating that birds more than 10% oiled were at a threshold of oiling beyond which negative effects of contamination on restoration success could not be successfully reversed by rehabilitation. Other studies on Adelle penguins (*Pygoscelis adeliae*) and little blue penguins also

determined that mass influenced reproductive success, with heavier birds having higher success than lighter birds (Vleck and Vleck 2002; Robinson et al. 2005).

Very few studies have investigated what effect blood parameters and captive duration have on reproductive success. One study however found that reduced packed cell volume, as a result of oil exposure, resulted in lower restoration success of kittiwakes breeding within an area contaminated by the *Braer* oil spill in Shetland, Scotland (Walton et al. 1997). With respect to captive duration, it may be expected that longer durations result in reduced reproductive success due to the disruption of synchrony between breeding pairs; this may be exacerbated if the re-establishment of synchrony is delayed, as late breeders generally have lower productivity (Perrins 1970).

The finding that no predictor variables tested influenced hatching and fledging success of rehabilitated pairs may be because there was not much variation in the outcome variables (hatching and fledging success) when conducting the binary logistic regression tests; most rehabilitated pairs monitored hatched and fledged at least one chick thus received a “1” when these parameters were expressed as binary outcome variables. Consequently, it is difficult to determine whether one or more predictor variables had a significant effect on the outcome variables. Furthermore, the reasonably small sample size of rehabilitated pairs included in the analyses may not have accurately represented all such pairs (Long 1997); these results should thus be interpreted with caution.

### **Pre-fledging chick masses**

Pre-fledging chick masses provide another measure from which reproductive success can be assessed (Reilly and Cullen 1981; Rogers et al. 1995). Egg success, the main measure of breeding success, reports the number of chicks successfully raised to independence (relative to the number of eggs laid), however this measure provides no indication of chick survival post-fledging. As there is a positive correlation between pre-fledging chick mass and survival in the first year post-fledging (Perrins et al. 1973; Reilly and Cullen 1981; Hamer et al. 1991; Rogers et al. 1995; Davis et al. 2005) it is thus important to also incorporate this measure of chick quality into the assessment of overall breeding success.

Body mass at fledging is assumed to reflect food availability and the ability of adults to provision their chicks (Barrett et al. 1987; Monaghan et al. 1989; Davis et al. 2005). As pre-fledging chick masses were low at Mount Maunganui and Leisure Island (approximately 70-400 g less than masses reported at other little blue penguin colonies in Australia and New Zealand; Table 2.7) irrespective of whether chicks were raised by control or rehabilitated pairs, it seems that low food availability may be responsible for these low chick masses rather than any persistent negative effects of oil toxicity on the chick raising ability of rehabilitated birds. Low food availability may be due to the negative effects of disturbance and changes in the environment caused by the oil spill and subsequent clean-up. As a result of these low pre-fledging chicks masses, post-fledging survival rates may have been low. However, it is possible that penguins in Tauranga simply weigh less than penguins elsewhere due to the warmer climate in the northern half of the North Island relative to the South Island (NIWA 2001) or due to geographic factors, as it has been found that masses of little blue penguins generally decrease with decreasing latitude (Gales 1987). This speculation is supported by the finding that masses of adult penguins caught during survival monitoring surveys were generally lower than masses reported at other colonies in New Zealand (Table 3.11; Kinsky 1960; Hodgson 1975; Montague 1982a; Montague 1982b; Baudinette et al. 1986; Gales 1987; Klomp 1987; Gales and Pemberton 1990). If adult penguins are lighter (and in apparent good health based on external appearances), it is reasonable to expect that pre-fledging chicks would also be lighter; post-fledging survival rates may therefore have been higher than expected based on mass.

Most other studies have reported contrasting results, with chicks raised by rehabilitated pairs having significantly lower masses than chicks raised by unoiled pairs. This was reported for little blue penguins rehabilitated after the *Iron Baron* oil spill, as well as black oystercatcher chicks raised on shorelines oiled after the *Exxon Valdez* oil spill (Andres 1999), black guillemots in a combined field and laboratory study (Peakall et al. 1980), and herring gull, storm petrel and Leach's storm petrel chicks orally dosed with oil (Miller et al. 1978; Trivelpiece et al. 1984; Boersma et al. 1988).

When interpreting these results, three factors must be kept in mind. First, the sample size of pre-fledging chick masses in the present study was reasonably small, therefore these masses may not be representative of all chicks monitored. Second, although masses of pre-fledging

chicks raised by rehabilitated pairs were not reduced, control penguins within control/rehabilitated pairs may have masked and compensated for any reduced chick raising abilities by the rehabilitated penguin and thus made it appear as though the presence of a rehabilitated adult did not reduce chick masses; the likelihood of this masking effect occurring however is quite low as in general reduced reproductive and foraging abilities by one partner has a negative influence on the pair as a whole (Giese et al. 2000). Finally, the accuracy of the speculation that pre-fledging chicks weigh less in Tauranga is unknown as there are no pre-spill data on pre-fledging chick masses. It is thus possible that the observed “low” masses may have only been observed during the breeding season studied, with chicks in previous seasons fledging at higher masses. To determine average pre-fledging chick masses, a longer-term study would need to be conducted.

**Table 2.7.** Mean masses of pre-fledging little blue penguin chicks at Mount Maunganui and Leisure Island during the 2012-13 breeding season according to the oiling status of the breeding pairs (upper). For comparison, fledging masses from other sites are also given (lower).

Region	Pairs	Mean mass (g)	N
Mt Maunganui/Leisure Is	2 controls	759 ±37.1	17
Mt Maunganui/Leisure Is	1 or 2 rehab	769 ±32.0	9
Region	Years	Mean mass (g)	N
North Harbour, NSW <sup>1</sup>	-	1062	-
Oamaru <sup>2</sup>	2007–08	1058	-
Oamaru <sup>3</sup>	2009	989	-
Buller <sup>4,5</sup>	2008–09	950 ±170	2
South Westland <sup>5</sup>	2008–09	1138 ±23.7	10
Phillip Island, Victoria <sup>6</sup>	1968-78	832-1018	208
Tiritiri Matangi <sup>7</sup>	2005-06	867	17
Tiritiri Matangi <sup>8</sup>	2006-07	877	30

**Sources:** <sup>1</sup>(Priddel et al. 2008). <sup>2</sup>(Agnew 2007, unpublished data). <sup>3</sup>(P. Agnew, pers. comm.).

<sup>4</sup>(Heber et al. 2008). <sup>5</sup>(Braidwood 2009). <sup>6</sup>(Reilly and Cullen 1981). <sup>7</sup>(Geurts 2006). <sup>8</sup>(van Rensburg 2010).

## **Limitations and recommendations**

The present study was hindered by a number of limitations. For example, little was known about the location of breeding burrows at the study sites in previous breeding seasons. Burrows were therefore discovered at varying times during the breeding season so some reproductive parameters, including the timing of egg laying and the number of eggs laid/chicks hatched, were not known for all nests. Another limitation was that there was no pre-spill history of reproductive success at the colonies monitored to which results could be compared to. While these measures were within normal ranges reported for other little blue penguin colonies in Australia and New Zealand, as there is considerable variation between colonies, it would have been better to have directly comparable data from previous years at the colonies studied to assess whether reproductive rates were within the normal range. Based on these limitations, we recommend that populations of species, particularly seabirds, that inhabit areas near busy ports and shipping lanes in New Zealand (and are thus vulnerable to future oil spills) should be identified and monitored (if yet to occur) to collect base line data so if future such studies occur, pre-spill data will be present. This will assist in the assessment of the post-spill restoration and recovery of future oil-affected populations.

Another limitation is that the sex of the rehabilitated (and control) penguins was unknown. Consequently there is uncertainty as to whether breeding success varied between males and females as was found by Giese et al. (2000) with reproductive success significantly reduced in pairs including a rehabilitated female but not in pairs including only a rehabilitated male. A recommendation for future studies therefore is to use DNA techniques to sex oil-rehabilitated birds so gender-specific effects of oiling can be determined.

A final limitation is that due to time and financial constraints, the reproductive success of additional penguin colonies within the oil-affected area could not be monitored. It is therefore recommended that if further funding is provided to extend this study that the first priority should be conduct reproduction monitoring at Motiti Island, the site from which approximately 20% of the oiled penguins were rescued from and returned to following rehabilitation; thereafter, if feasible, additional sites could also be monitored to enable a more accurate analysis of post-release productivity.

## Conclusion

In summary, this study provides evidence that rehabilitated penguins were capable of breeding post-release, and doing so successfully, as all parameters measured, except hatching success, were statistically similar between control and rehabilitated pairs. Hatch, fledge and egg success rates for rehabilitated (and control) pairs were within ranges reported (and towards the higher end) for other little blue penguin colonies in New Zealand and Australia, suggesting that despite oiling and rehabilitation, rehabilitated penguins still had a successful and productive breeding season.

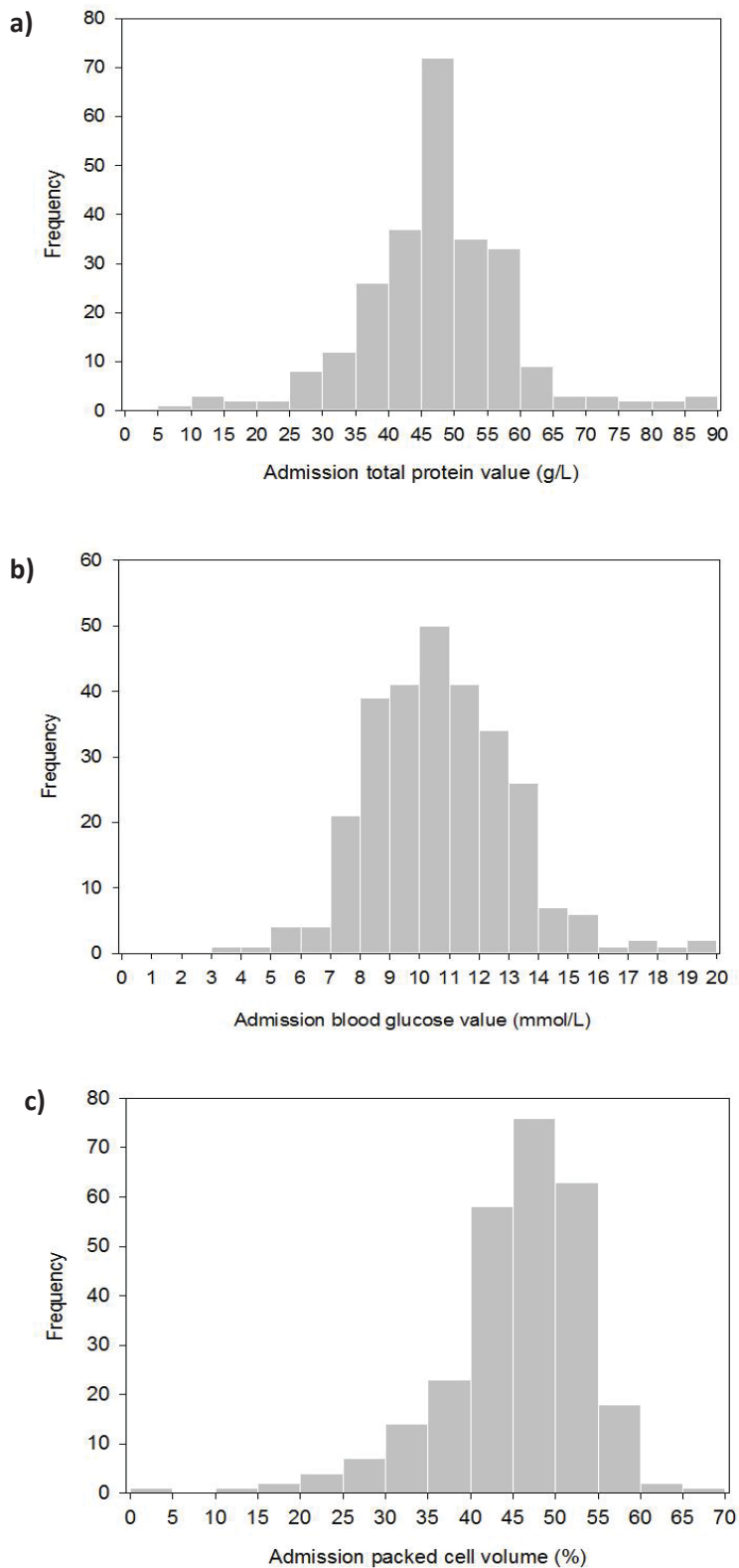
Pre-fledging chick masses were similar for chicks raised by control and rehabilitated pairs, but generally low when compared to masses reported for other colonies indicating that post-fledging survival rates may have been low. This reduction is unlikely due to an oiling effect but may have been a consequence of reduced food availability during the breeding season. Alternatively, little blue penguins in the Bay of Plenty (both adults and chicks) may simply weigh less than penguins at other colonies as a result of geographic and climatic factors, therefore “low” pre-fledging chick masses may not have translated into low post-fledging survival.

Lastly, sample sizes were too small to confidently conclude what effect the presence of two rehabilitated penguins within a breeding pair had on reproductive success, and whether different predictor variables had any effect on hatching and fledging success.

These findings are both similar to and in contrast with those of other post-spill monitoring studies and thereby demonstrate the variability in post-release reproductive success between species and spills. This variability also reflects the general paucity of post-release monitoring studies and thus highlights the importance of continuing to conduct such studies so that more consistent findings and patterns can be determined. It is also important that medium- to long-term monitoring studies are conducted so that a more accurate representation of post-release reproductive success can be ascertained. By conducting more studies and increasing study durations, the effectiveness of rehabilitation will be better assessed and this feedback will assist in further improving rehabilitation techniques.

Overall, it appears that the oil-rehabilitation process was reasonably successful at counteracting most negative effects of oil contamination on various parameters that contribute to the reproductive success of rehabilitated penguins. One aspect of the rehabilitation process however that needs to be improved and researched further is how to more effectively treat the negative effects of oil contamination on hatching success.

## Chapter Two Appendix



**Appendix Figure 2.1.** Total protein (a), blood glucose (b), and packed cell volume (c) values of oiled little blue penguins upon admission to the Oiled Wildlife Facility during the *Rena* oil spill response.

# Chapter Three

Rehabilitation works: comparable survival rates in oiled and non-oiled little blue penguins after the C/V *Rena* oil spill in New Zealand



## Abstract

The post-release survival of little blue penguins (*Eudyptula minor*) rehabilitated after the 2011 C/V *Rena* oil spill was monitored to assess the effectiveness of the oil-rehabilitation process. Survival monitoring surveys were conducted at three study sites (Mount Maunganui/Mauao, Leisure Island/Moturiki and Rabbit Island/Motuotau) during 18 months over a 23-month period to assess whether survival differed between rehabilitated and non-oiled control penguins.

Data from these re-sighting surveys were analysed using program MARK 2.8 by constructing 23 candidate models, which included parameters likely to explain the variation in the re-sighting data, and determining which models had the best fit to the data. Under the best *a priori* model, monthly survival probabilities were similar between rehabilitated and control penguins and between sites but were reduced in the first four months studied. Post-hoc analyses indicated that survival was also reduced for two subsequent months, thus survival was reduced for six months (monthly survival probability was 0.92). Thereafter monthly survival rates increased and remained reasonably constant over time (0.97-1.0). It is unknown why survival was initially reduced although a number of potentially contributing factors can be postulated, including 'true' mortality effects and some possibly confounding factors. It is thus likely that the survival rates reported represent minima.

Other key findings include: that post-release survival was not influenced by oiling degree, admission and release BMI (body mass index), admission PCV (packed cell volume), TP (total protein), and BG (blood glucose), or captive duration; that upon release rehabilitated penguins were heavier than control penguins, however after four months their masses were similar to those of control penguins, and thereafter remained so; and that behaviourally, rehabilitated penguins were more likely to stay when approached by people than control penguins and were generally more docile when handled, although there were no systematic changes in behaviours observed as handling frequency increased.

Overall, we conclude that the rehabilitation process was reasonably successful at reversing most negative effects of oiling on the post-release survival of rehabilitated penguins. This confirms that undertaking oil-rehabilitation had positive benefits on the affected populations.

## Introduction

Survival of oil-rehabilitated animals is used as a measure of assessing rehabilitation success. To determine survival rates, two main methods are used; one is based on survival during captivity and the other on post-release survival (Goldsworthy et al. 2000b; Wolfaardt et al. 2009b). Captive survival, defined as the proportion of oiled animals admitted to care that survive to be released back to the wild, is the original method that was used to assess success; for this method, the higher the captive survival rate, the higher the rehabilitation success is deemed to be (Holcomb 1991; Monahan and Maki 1991; Newman et al. 2003). The usefulness of this method however has been questioned as it does not take into account post-release survival of rehabilitated animals (a critical factor reflecting the effectiveness of rehabilitation) (Goldsworthy et al. 2000b; Wolfaardt et al. 2009b) and therefore captive survival rates may present an inaccurate portrayal of rehabilitation success. Consequently, more recent assessments of rehabilitation efficacy have looked at survival rates of rehabilitated animals once released from care facilities (i.e. post-release survival) (Anderson et al. 2000; Crawford et al. 2000; Goldsworthy et al. 2000b; Wolfaardt et al. 2001; Ben-David et al. 2002; Golightly et al. 2002; Whittington 2002; Saba and Spotila 2003; Altwegg et al. 2008; Wolfaardt et al. 2009b; Ruoppolo et al. 2012; De la Cruz et al. 2013). Such studies are enabled by marking rehabilitated animals (predominantly birds as these are the most commonly rehabilitated animal group) prior to release from captivity with individually identifiable markers (Goldsworthy et al. 2000b) such as bands, rings, radio and satellite transmitters, or PIT-tags/microchips. Subsequent observations of marked animals enables rehabilitated individuals to be identified, and the proportion of rehabilitated individuals re-sighted or detected can be used to determine minimum estimates of short-, mid- and long-term post-release survival (Wolfaardt et al. 2009b). Post-release survival of rehabilitated animals may thus be deemed a more accurate measure of rehabilitation success than captive survival as it takes into account whether rehabilitated animals are able to survive the transition from captive care (where animals are provided with food and shelter and are protected from predators and environmental extremes) back into the wild (where they must fend for themselves), and thereafter have post-release survival rates equivalent to non-oiled, non-rehabilitated control conspecifics. With this method, the closer the post-release survival rates of rehabilitated animals are to control

animals or natural survival rates, the more successful rehabilitation is deemed to be (Goldsworthy et al. 2000b; Altwegg et al. 2008; De la Cruz et al. 2013).

Post-release survival monitoring studies are thus an important conservation tool when evaluating the success of rehabilitation efforts (Goldsworthy et al. 2000b; Altwegg et al. 2008; Wolfaardt et al. 2009b). It is imperative that rehabilitated animals are capable of surviving in the wild in the long-term and can successfully reproduce so that they contribute to the recovery and persistence of oil-affected populations (Wolfaardt et al. 2008a; Wolfaardt et al. 2008b); this is particularly important for endangered or declining populations or species. If post-release survival rates are significantly lower than those for control animals (which are ideally from populations of non-oiled animals in a nearby site) or normal annual survival rates for the species concerned, and the reason(s) for this can be discerned, then this information can be used to specifically alter and adapt rehabilitation techniques and procedures to hopefully improve survival rates in future rehabilitation operations (Wolfaardt et al. 2009b).

Despite the importance of undertaking post-release survival monitoring surveys, relatively few such studies have been conducted (Sharp 1996; Ben-David et al. 2002; Wolfaardt et al. 2009b; Ruoppolo et al. 2012). One of the main reasons for this is that conducting such surveys requires a lot of time, money and resources (on top of that already invested during the oiled wildlife response) (Estes 1991; Sharp 1996), particularly if comprehensive, long term studies are undertaken. Another reason is that post-release monitoring does not fall under the definition of oil spill “response” activities, and thus in many countries, including New Zealand, post-release monitoring is not considered cost-recoverable through usual oil spill response funding mechanisms (K. Morgan, pers. comm.). Furthermore, these studies need to be set up quickly, which requires pre-spill organisation and planning; often such planning is not done, therefore the window of opportunity to undertake post-release surveys is missed (K. Morgan, pers. comm.). It is also not feasible (due to expense and difficulty) to undertake monitoring studies if the target species are migratory, inhabit large geographic ranges, and/or are pelagic and rarely make landfall (Ruoppolo et al. 2012). Many seabird species have these characteristics and thus few post-release survival (or productivity) studies have been conducted on them (Newman et al. 2004).

Of the few post-release survival studies conducted on oil-rehabilitated wildlife, results have been variable. Some studies have found survival rates of rehabilitated and released animals to be extremely low (Speich 1986; Freedman 1995; Anderson et al. 1996; Sharp 1996; Wernham et al. 1997; Ben-David et al. 2002; Ruoppolo et al. 2012; De la Cruz et al. 2013). Other studies have found comparatively high post-release survival rates of rehabilitated animals (Morant et al. 1981; Estes 1991; Wolfaardt et al. 2001), although in some cases these rates were significantly lower than those reported for control animals (Anderson et al. 2000; Goldsworthy et al. 2000b). High post-release survival rates of rehabilitated animals have also been documented (Randall et al. 1980; Barham et al. 2006) and in some cases these rates have been similar or near equivalent to that of control animals or if control groups were not established to that of natural survival rates of the population or species (Underhill et al. 1999; Whittington 1999; Golightly et al. 2002; Whittington 2002; Altwegg et al. 2008). In one study on four different freshwater turtle species in the United States of America, rehabilitated turtles were found to have higher post-release survival rates than the control group (Saba and Spotila 2003).

Many factors may contribute to the variability in post-release survival rates of oil-rehabilitated animals. These include: species differences (Grantham 2004) in the ability to withstand the stresses associated with rehabilitation and captivity, and once released the ability to adapt to life in the wild (Wolfaardt et al. 2009b); the condition and degree of oiling of animals admitted to care (Goldsworthy et al. 2000b; Saba and Spotila 2003); the duration and intensity of the search effort looking for rehabilitated individuals (Whittington 2002; Wolfaardt et al. 2009b); the geographic area searched during survival monitoring surveys (Wolfaardt et al. 2009b); the accessibility of breeding colonies for monitoring (Grantham 2004; Wolfaardt et al. 2009b); whether or not rehabilitated individuals are released near their breeding colonies (Wolfaardt et al. 2009a); the age of the individuals (Wernham et al. 1997; Wolfaardt et al. 2009b); the mass and condition of rehabilitated animals prior to release back to the wild (Goldsworthy et al. 2000b); the amount of time between oiling and cleaning and between cleaning and release; the experience and expertise of staff at rehabilitation facilities (Heubeck et al. 2003); the proximity of well-established rehabilitation centres with adequate treatment and cleaning facilities (and equipment) to the oil-contaminated area (Heubeck et al. 2003); the chemical composition and toxicity of the oil

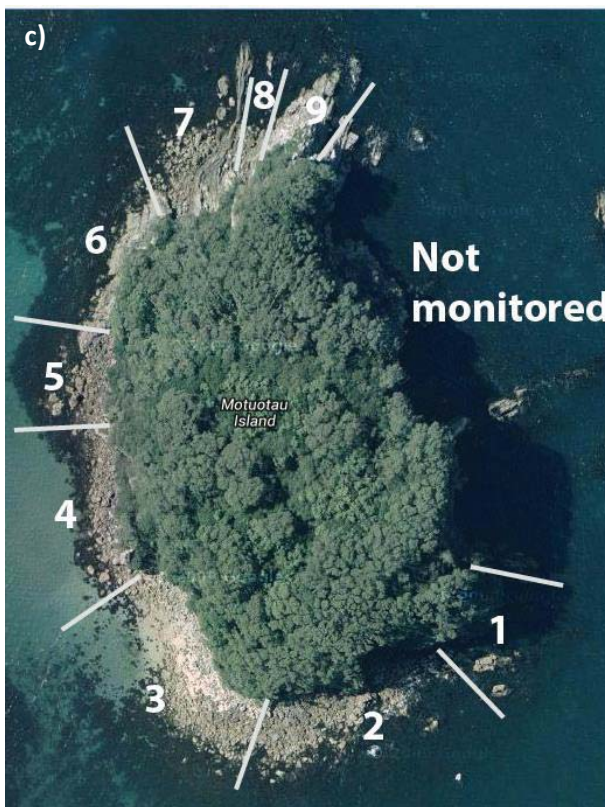
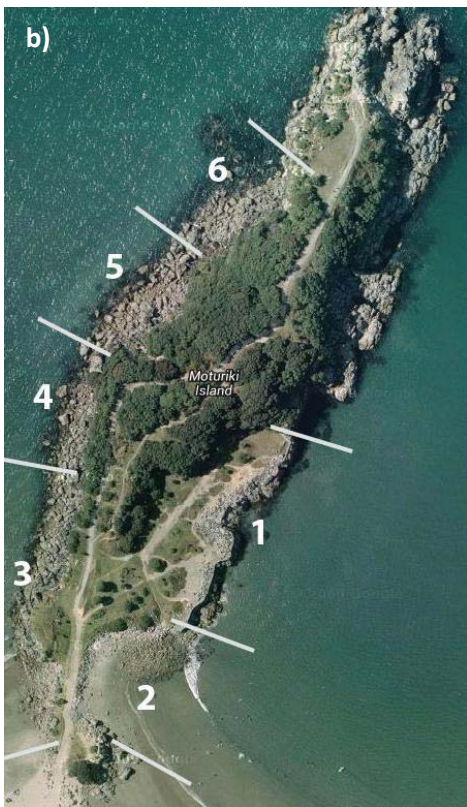
(Barham et al. 2007); and the timing of oiling and release from rehabilitation in relation to the annual cycle of the affected animal (Goldsworthy et al. 2000b).

The present study aims to evaluate the success of the rehabilitation process for oiled little blue penguins (*Eudyptula minor*) following the C/V *Rena* oil spill in Tauranga, New Zealand, 2011. Specifically, this study aims to determine whether post-release survival rates are similar to those of a control group of penguins in a two-year period after the oil spill. The study also aims to determine whether mass and behaviours observed throughout the study period had any influence on post-release survival, as well as other factors related to oiling and time spent in captivity. Results will be used as part of the assessment of the effectiveness of the oiled wildlife rescue and rehabilitation operation with respect to releasing de-oiled penguins that were healthy and capable of long-term post-release survival. These results will provide feedback on whether current oiled wildlife rescue and rehabilitation procedures used in New Zealand are effective or whether improvements or changes need to be made in order to maximise efficiency and increase post-release survival of oil-rehabilitated animals in the future.

## **Methods:**

### **Sites monitored and monitoring duration**

Post-release survival monitoring was conducted at three little blue penguin colonies within the oil-affected area in Tauranga. These sites, Mount Maunganui, Leisure Island and Rabbit Island (Figures 1.1 and 1.2), were chosen as these were areas where most oiled penguins were rescued from during the oiled wildlife response and returned back to after rehabilitation (n=217). These sites were also easily accessed and safely monitored. From May 2012 through to the end of December 2013, regular survival monitoring surveys were conducted at dusk for two hour periods along the rocky shorelines of these three sites (dusk was chosen as this is the time when most penguins make landfall (Klomp and Wooller 2001)). Less formal, irregular surveys were also conducted from November 2011 to January 2012 when the control penguins (n=361) were being micro-chipped. For monitoring purposes each site was divided into numbered sections so that the spatial distribution of penguins encountered could be recorded; the distance between these sections were similar within sites but varied between sites (ranging from approximately 75 m to 200 m) (Figure 3.1).



**Figure 3.1.** Numbered sections dividing up the three sites where post-release survival monitoring surveys were conducted. a) is Mount Maunganui (Mauao), b) is Leisure Island (Moturiki), and c) is Rabbit Island (Motuotau). Image credit: Google Maps 2014.

## **Monitoring frequency**

The formal surveys, which were conducted with the help of dedicated, enthusiastic local volunteers, were undertaken fortnightly-monthly on Mount Maunganui and Leisure Island, and approximately monthly on Rabbit Island. Surveys were less frequent on Rabbit Island due to difficulties involved in accessing this site (access was via kayaks and weather conditions did not always allow safe passage) and to minimise disturbance of other nesting seabirds at this site. Surveys were not conducted during the moult period (February-April in 2012 and February-March in 2013) to reduce disturbance to birds during this stressful time of year.

## **Monitoring process**

For each survey volunteers divided into small teams (approximately three to five people) with each team responsible for repeatedly patrolling the rocky shorelines of particular sections within the site being monitored.

All penguins encountered (except nesting adults) were caught, weighed and scanned for the presence of a microchip. To catch a penguin, one team member approached it from behind (so that it could not run back into the water) and caught it by picking it up around the abdomen, pinning the flippers against their side. Penguins spotted within 1–2 m of the water's edge were not caught until they had come further ashore; this increased the distance fleeing penguins had to cover to get to the sea to escape and thereby increased catch rates. To prevent the penguins' plumage from becoming contaminated by oils transferred from the hands of the catcher, each team member wore a pair of gloves whilst handling the birds.

Once a penguin was caught it was put into a black weigh bag and two people in the group would process the bird (one collected data and the other recorded it) whilst the other group members continued monitoring. Processing involved using a Pesola™ scale to weigh the bagged bird to the nearest 10 g (correcting for bag weight) and then scanning it with a microchip reader along the hindneck between the scapulars to see if it had a microchip. Penguins could then be identified as rehabilitated, control, or untagged.

Behaviour on approach (reaction of the penguin to a person approaching) and in hand (behaviour of the penguin when captured and held) were also recorded based on pre-determined behaviour categories. On approach, individuals were classified as stayed, moved less than 2 m, or ran. In the hand, individuals were classified as docile (did not struggle or resist whilst being handled), resistant (struggled somewhat to free themselves), or aggressive (actively struggled and resisted capture by flapping their flippers and attempting to bite the handler).

Prior to release the penguins were marked with a small dab of Twink™ (correction fluid) on their hindneck between the scapulars so that processed birds could be easily detected and would not be handled repeatedly during a survey. This marking was expected to wash off in the water and only last a couple of days; no penguins re-sighted in successive surveys at a site were still marked (this method of marking has been used in studies conducted on insects (Wineriter and Walker 1984; Backus and Cade 1986; St Pierre et al. 2005) and frogs; in the latter study it was reported that the correction fluid only lasted between two and four days depending on environmental conditions (Webster 2004).

## **Recovery and post-mortem examination of dead penguins**

Any public calls to the local Department of Conservation office regarding sightings of dead penguins were passed on to the penguin monitoring volunteer co-ordinator. The carcass was then collected and scanned to determine if it had a microchip. Carcasses with microchips were sent to Massey University, Palmerston North for routine post-mortem analysis. Any dead chicks from the monitored burrows on Mount Maunganui and Leisure Island were also collected (if the carcasses were accessible and not too decomposed) and sent for post-mortem examination.

## **Statistical analyses**

### **Software used**

Statistical analyses were conducted using the R statistical programming package (R Core Team 2013). Statistical tests conducted were reported to 95% significance ( $p=0.05$ ).

## Recapture matrix

A binary matrix was constructed that depicted the re-sighting history for each control and rehabilitated penguin during the 64 survival monitoring surveys conducted between May 2012 and December 2013; 1 was entered for penguins re-sighted during a survey, 0 was entered for penguins not re-sighted. The data were summarised into monthly periods and pooled for penguins from the mainland sites monitored, Mount Maunganui and Leisure Island; this enabled survival probabilities to be analysed over time between rehabilitated and control penguins and between the mainland and at Rabbit Island, an offshore island site, using mark-recapture methods.

## Mark-recapture survival analyses

The re-sighting data were analysed so that “apparent” survival probabilities could be estimated for control and rehabilitated penguins. The probabilities are “apparent” rather than “true” as mortality and permanent emigration from the study area are indistinguishable (Gilroy et al. 2012). The analysis was conducted using the program MARK 2.8 (White and Burnham 1999). This is a software package that can be freely downloaded from <http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm>. The “live recaptures option” was selected and four attribute groups were created to distinguish between control and rehabilitated penguins from the mainland (Mount Maunganui and Leisure Island) and offshore sites (Rabbit Island). The first time interval was set at four months (February-May 2012), as this included the period between release and the first month of monitoring. The tenth time interval was set at three months (February-April 2013), as this included the second year moult period where surveys were not conducted as well as the first subsequent month of surveying. All other time intervals were one month. Each penguin was recorded as entering the population in February 2012, as by this time all control penguins had been micro-chipped and nearly all the rehabilitated penguins from the three study sites had been released from captivity. In total there were 19 encounter occasions (initial release plus 18 survey months).

A global model,  $\{\phi_{oil*1st+FM*year+site+breed}, P_t\}$  (Table 3.1; Appendix Table 3.1) was created that incorporated all parameters likely to explain the variation in the re-sighting data in a

biologically plausible manner. The survival component of this model ( $\phi_{oil*1st+FM*year+site+breed}$ ) looks at differences in survival between rehabilitated and control penguins; between the first interval (February-May 2012) and the rest of the study (the first interval is the period between the micro-chipping and captive release of rehabilitated penguins/micro-chipping of control penguins, and the first month of post-release survival monitoring); between the moult/post-moult period (February-May) and other times of the year; between years (the first “year” was between February 2012 and January 2013 (January was chosen instead of December as this was the end of the breeding season) and the second “year” was between February and December 2013); between sites (offshore versus mainland); and between the breeding season (August to January in the first year and August to December in the second year) and the non-breeding season. The interaction  $oil*1st$  was included as survival of rehabilitated penguins may have been different in the first interval since this was the period directly following their release from captivity; there was no reason to believe that survival would be different for control penguins during this period and thus this interaction was not included. The interaction  $FM*year$  was included as survival during the moult/post-moult period may have differed between the two years of the study since the first moult period was also the time during which rehabilitated penguins were released from captivity and the control penguins were micro-chipped.

The re-sighting component of this model ( $P_i$ ) estimates separate re-sighting probabilities for each time interval. Under this model re-sighting probabilities were unpredictable over time. This was the only re-sighting model tested as there was no reason to believe that re-sighting probabilities would differ between rehabilitated and control penguins, between sites or throughout the annual cycle. As Rabbit Island was not surveyed every month (due to difficulties accessing the site), re-sighting probabilities for the months not surveyed (June 2012, December 2012, April 2013, June 2013, July 2013 and September 2013) were fixed to 0 in this model and all subsequent models tested. Differences in re-sighting rates between surveys were expected as the frequency with which penguins come ashore varies over time in accordance with the annual cycle; for example higher rates are expected during the moult period and breeding season than during the non-breeding season.

The goodness-of-fit (GOF) and degree of overdispersion of this global model was tested using the median  $c\text{-hat}$  method in MARK (White and Burnham 1999). The measure of

overdispersion is known as the variance inflation factor,  $c\text{-hat}$  (Cooch and White 2006); estimates of one indicate that the model has a perfect fit to the data, whereas  $c\text{-hat}$  estimates greater than three indicate that there are structural deficiencies in the global model (Gonzalez-Tokman et al. 2012). AIC (Akaike's Information Criteria) is used to compare candidate models if the global model is not overdispersed, whereas QAIC (Quasi Akaike's Information Criteria corrected for bias and overdispersion) is used if the global model is overdispersed.

Twenty two candidate models (Table 3.1) were created by simplifying the global model. Comparison of these models using QAIC<sub>c</sub> allowed the most parsimonious models describing penguin survival throughout the study duration to be determined. The best model was that with the lowest QAIC<sub>c</sub>, indicating the best compromise between the fit of the model (lowest observed deviance) and simplicity (lowest number of parameters).

**Table 3.1.** Candidate survival models describing the post-release survival of little blue penguins rehabilitated after the *Rena* oil spill and the survival of control penguins following micro-chipping. Interactive factors are denoted by a “\*” within models; additive factors are denoted by a “+”.

<b>Survival models</b>	<b>Model description</b>
oil*1st+FM*year+site+breed	Survival based on all factors considered in other models
.	Survival constant
site	Survival different between sites
oil	Survival different between rehabilitated and control penguins
site+oil	Survival different between sites and between rehabilitated and control penguins; factors acting in parallel
breed	Survival different between the breeding vs non-breeding seasons
site+breed	Survival different between sites and between the breeding vs non-breeding seasons; factors acting in parallel
oil+breed	Survival different between rehabilitated and control penguins and between the breeding vs non-breeding seasons; factors acting in parallel
site+oil+breed	Survival different between sites, between rehabilitated and control penguins and between the breeding vs non-breeding seasons; factors acting in parallel
year	Survival different between years
site+year	Survival different between sites and between years; factors acting in parallel
oil+year	Survival different between rehabilitated and control penguins and between years; factors acting in parallel
site+oil+year	Survival different between sites, between rehabilitated and control penguins and between years; factors acting in parallel
FM	Survival different between Feb-May (moult/post-moult foraging period) and the non-moult period
site+FM	Survival different between sites and between Feb-May (moult/post-moult foraging period) and the non-moult period; factors acting in parallel
oil+FM	Survival different between rehabilitated and control penguins and between Feb-May (moult/post-moult foraging period) and the non-moult period; factors acting in parallel
site+oil+FM	Survival different between sites, between rehabilitated and control penguins and between Feb-May (moult/post-moult foraging period) and the non-moult period; factors acting in parallel
1st	Survival different between the first interval and the rest of the study
1st+site	Survival different between the first interval and the rest of the study, and between sites; factors acting in parallel
1st+oil	Survival different between the first interval and the rest of the study, and between rehabilitated and control penguins; factors acting in parallel
1st+oil+site	Survival different between the first interval and the rest of the study, between rehabilitated and control penguins, and between sites; factors acting in parallel
1st(rehab only)	Survival different in the first interval for rehabilitated penguins only
1st(rehab only)+site	Survival different in the first interval for rehabilitated penguins only, and between sites; factors acting in parallel

## **Re-sighting rates and inter-colony movements**

The re-sighting matrix was also used to determine how many rehabilitated and control penguins were re-sighted for the first-time since release (rehabilitated birds) and micro-chipping (control birds) in each survey as well as the number of inter-colony movements (between the three study colonies) made by penguins re-sighted more than once during the survival surveys. A penguin always re-sighted at the same colony was said to have made no inter-colony movements, a penguin seen at one colony, then at another colony was said to have made one inter-colony movement, and a penguin seen at one colony, then at another colony, then back again at the first colony was said to have made two inter-colony movements.

## **Post-release masses**

The masses of all penguins encountered during survival monitoring surveys were combined for each of the three sites monitored and average monthly masses were calculated for control and rehabilitated penguins (control penguins included both marked and unmarked birds). For months where more than ten control and rehabilitated penguins were encountered and weighed, Shapiro-Wilk normality tests were conducted followed by Mann-Whitney U-tests to determine whether monthly masses significantly differed between control and rehabilitated birds throughout the study duration.

## **Post-release behaviour**

Behaviour data recorded during the post-release survival monitoring surveys were summarised to determine whether the proportions of behaviours expressed by control and rehabilitated penguins on approach (stayed, moved <2 m, ran) and in hand (docile, resists, aggressive) differed with repetitive handling to the behaviour of individuals when first encountered during these surveys (that is, did penguins handled twice, three times, four times and so on, express behaviours in the same proportion as when first caught). These proportions were also used to determine whether behaviour differed between control and rehabilitated penguins in successive handlings. Significance was tested by conducting Chi-square tests. If a significant difference was found then the observed values for the

behaviours expressed (for the particular number of handlings) were subtracted from the expected values to determine which behaviour(s) had altered over time.

### **Post-release survival with respect to oiling degree and captive duration**

Data on oiling degree (Appendix Figure 1.2) admission BMI (body mass index) (Appendix Figure 1.3), admission PCV (packed cell volume), admission TP (total protein), admission BG (blood glucose) (Appendix Figure 2.1), presence of pododermatitis (irrespective of grade), release BMI and captive duration of rehabilitated penguins (Appendix Figures 1.3 and 1.4) were analysed to determine whether these variables had any influence on apparent post-release survival. This was done by firstly conducting Shapiro-Wilk normality tests on the data for each variable for penguins yet to be re-sighted during post-release survival monitoring surveys and for penguins re-sighted at least once since release. Based on these results, Mann-Whitney U-tests or Student T-tests were performed on these data to determine whether these variables significantly differed between penguins re-sighted and those not re-sighted and thus assumed to be dead.

## Results

### Post-release survival

No rehabilitated penguins and only one control penguin were found dead during the study. The control penguin appeared to have died from a flipper laceration that likely rendered it unable to swim or forage properly.

### Apparent post-release survival using mark-recapture methods

In total there were encounter histories for 583 individuals, 217 for rehabilitated penguins and 361 for control penguins. The goodness-of-fit test of the global model indicated that the model  $\{\phi_{oil*1st+FM*year+site+breed}, P_{time}\}$  was somewhat overdispersed but still a reasonable fit to the data ( $\hat{c}=1.25$ ). Of the candidate survival models subsequently tested, the best model (lowest QAICc) was  $\{\phi_{1st}\}$  (Table 3.2). Under this model, survival probability was estimated separately for the first interval but was otherwise constant over time, and unaffected by site (mainland vs. offshore) or oiling status (rehabilitated vs. control); the estimated monthly survival probability was 0.90 ( $se=0.012$ , 95% CI=0.88-0.92) in the first interval and 0.97 ( $se=0.006$ , 95% CI=0.96-0.98) during the rest of the study.

Qdeviances for the next best models,  $\{\phi_{1st+oil}\}$ ,  $\{\phi_{year}\}$ , and  $\{\phi_{1st+site}\}$  were reasonably close to that for the best model,  $\{\phi_{1st}\}$ , and the QAICc values for these three models increased by two units (which occurs when one irrelevant parameter is added). With respect to the models  $\{\phi_{1st+oil}\}$  and  $\{\phi_{1st+site}\}$ , these results indicate that the addition of the parameters oiling and site had little effect in further explaining the data; the first interval factor was having the main effect. Although the QAICc value for the model  $\{\phi_{year}\}$  also increased by two units, this model can be considered as the only possible competitor model to  $\{\phi_{1st}\}$  as standing alone without the first interval parameter, this model had 37% model likelihood (Table 3.2). This year effect was analysed further *post hoc* by examining survival estimates from the global model (Figure 3.2). From this it was determined that survival of control and rehabilitated penguins was not only low in the first interval monitored (February-May 2012), as indicated by the best *a priori* models, but also for the subsequent two months before the breeding season (six months in total). Therefore, a *post hoc* model was created  $\{\phi_{breed+year}\}$ ,

where survival is different between the breeding and non-breeding season and between years, with these factors acting in parallel. Based on this model, the monthly survival probability in the first six months (the non-breeding season) was 0.92 (se=0.010, 95% CI=0.89-0.93) compared to 0.98 (se=0.020, 95% CI=0.87-1.0) in the first breeding season. In the second year, monthly survival in the first six months was 0.97 (se=0.021, 95% CI=0.87-1.0) (which is much higher than in the first year) and survival during the breeding season was 0.99 (se=0.004, 95% CI=0.98-1.0).

Under the models  $\{\phi_{oil}\}$  and  $\{\phi_{site}\}$ , monthly survival probabilities were extremely close between control and rehabilitated penguins and between the mainland and offshore sites; this indicates that survival did not differ with oiling status and between sites (Figure 3.2; Table 3.3). Under the best post hoc model,  $\{\phi_{breed+year}\}$ , the annual survival probability of control and rehabilitated penguins was lower in the first year than the second year studied (Table 3.4).

**Table 3.2.** Results of the mark-recapture analysis conducted to estimate post-release survival rates of oil-rehabilitated little blue penguins.

Model <sup>a</sup>	QAICc <sup>b</sup>	Delta QAICc <sup>c</sup>	QAICc Weights <sup>d</sup>	Model Likelihood <sup>e</sup>	No. Par. <sup>f</sup>	QDeviance <sup>g</sup>
1 <sup>st</sup>	4116.059	0.0000	0.35436	1.0000	20	1073.5272
1st+oil	4118.039	1.9804	0.13165	0.3715	21	1073.4465
Year	4118.054	1.9947	0.13071	0.3689	20	1075.5220
1st+site	4118.119	2.0595	0.12654	0.3571	21	1073.5256
site+year	4120.001	3.9419	0.04937	0.1393	21	1075.4081
oil+year	4120.014	3.9549	0.04905	0.1384	21	1075.4210
1st+oil+site	4120.100	4.0412	0.04698	0.1326	22	1073.4432
Breed	4121.236	5.1766	0.02663	0.0751	20	1078.7038
FM	4121.704	5.6451	0.02107	0.0595	20	1079.1723
site+oil+year	4121.946	5.8865	0.01867	0.0527	22	1075.2886
oil+breed	4123.229	7.1697	0.00983	0.0277	21	1078.6358
site+breed	4123.294	7.2345	0.00952	0.0269	21	1078.7006
oil+FM	4123.725	7.6661	0.00767	0.0216	21	1079.1322
site+FM	4123.748	7.6893	0.00758	0.0214	21	1079.1555
oil*1st+FM*year + site+breed	4125.082	9.0234	0.00389	0.0110	26	1070.1392
site+oil+breed	4125.291	9.2322	0.00351	0.0099	22	1078.6342
site+oil+FM	4125.776	9.7165	0.00275	0.0078	22	1079.1186
1st(rehab only)	4133.190	17.1314	0.00007	0.0002	20	1090.6586
.	4133.234	17.1745	0.00007	0.0002	19	1092.7598
Oil	4135.153	19.0941	0.00003	0.0001	20	1092.6213
1st(rehab only)+site	4135.237	19.1783	0.00002	0.0001	21	1090.6444
Site	4135.241	19.1816	0.00002	0.0001	20	1092.7089
site+oil	4137.174	21.1148	0.00001	0.0000	21	1092.5810

<sup>a</sup> Candidate models for factors influencing post-release survival

<sup>b</sup> Akaike's Information Criterion corrected for bias (AICc) and adjusted for overdispersion (c-hat =1.25)

<sup>c</sup> Difference in QAIC<sub>c</sub> value from the best model

<sup>d</sup> Akaike weight attributed to the models, indicating the relative support for each model

<sup>e</sup> QAICc weight in relation to the best model

<sup>f</sup> Number of parameters in each model

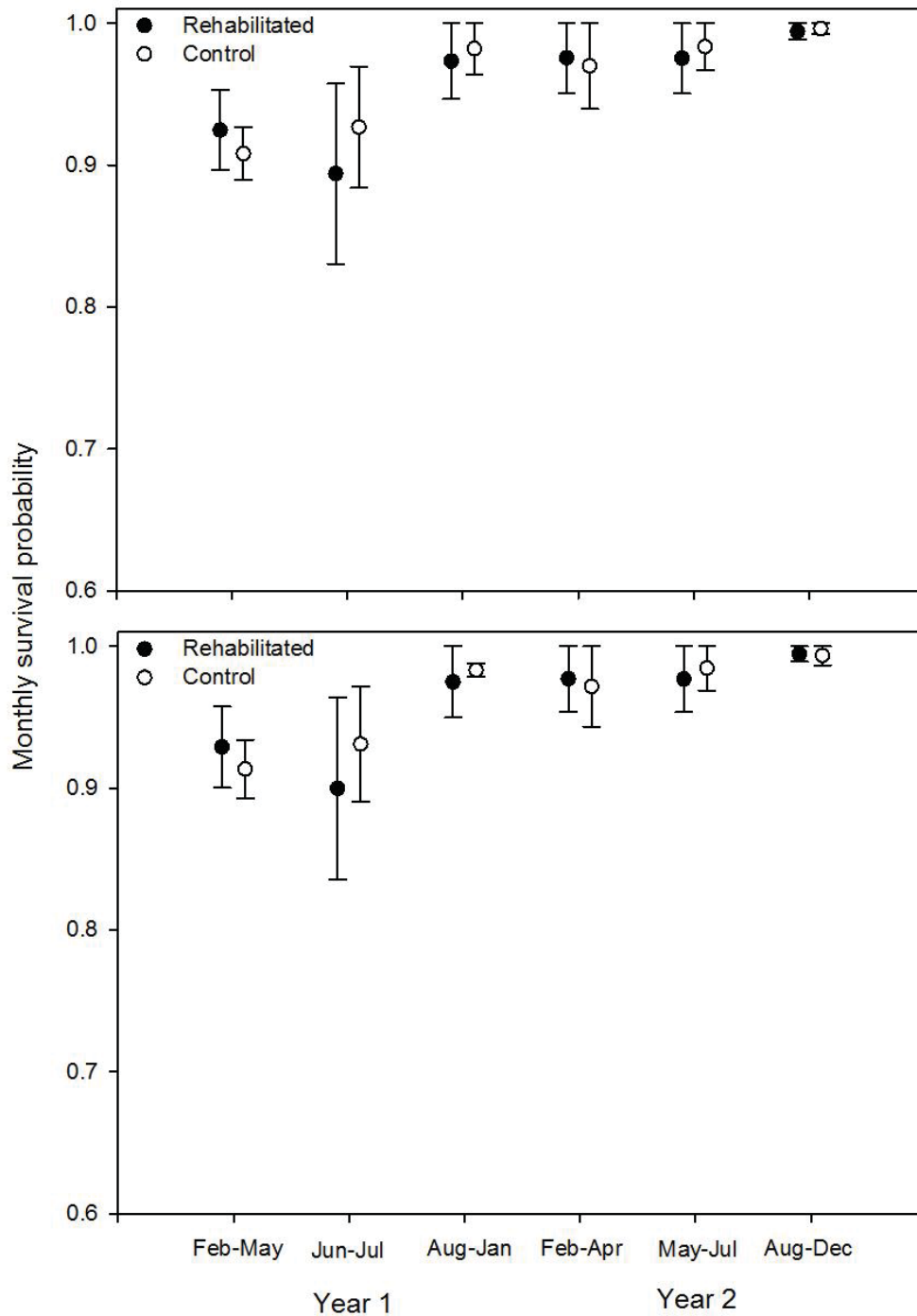
<sup>g</sup> Model deviance

**Table 3.3.** Comparisons of monthly survival probabilities for rehabilitated and control penguins and for penguins from the mainland and offshore island sites under models  $\{\phi_{oil}\}$  and  $\{\phi_{site}\}$  (Table 3.2).

Variable	Monthly survival ( $\phi$ )
Rehabilitated	$0.950 \pm 0.006$
Control	$0.953 \pm 0.004$
Mainland	$0.953 \pm 0.004$
Offshore	$0.951 \pm 0.007$

**Table 3.4.** Annual survival probabilities for control and rehabilitated penguins under the best post-hoc model  $\{\phi_{breed+year}\}$ . The annual survival probabilities are not for true calendar years as the first “year” is between February 2012 and January 2013, and the second “year” is between February and December 2013.

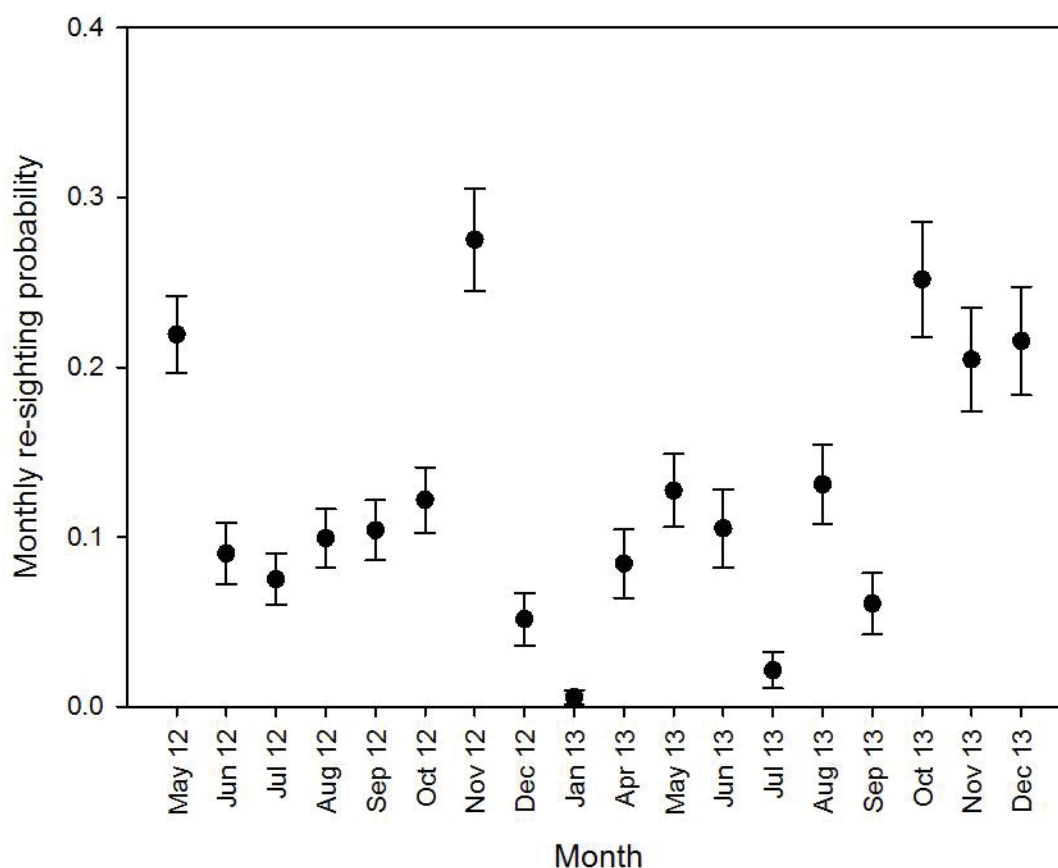
Year	Annual survival ( $\phi$ )
1	$0.52 \pm 0.102$
2	$0.84 \pm 0.129$



**Figure 3.2.** Monthly survival probabilities for rehabilitated and control penguins at the mainland sites surveyed (Mount Maunganui and Leisure Island) (top graph) and the offshore island site surveyed (Rabbit Island) (bottom graph). Upper and lower standard error bars are shown. Upper errors are constrained to one as the survival probability cannot be greater than one. In the first year (2012) Feb-May is the first interval surveyed (as well as the moult/post-moult foraging period), Jun-Jul is a non-breeding period, and Aug-Jan is the breeding season. In the second year (2013) Feb-May is the moult/post-moult foraging period, May-Jul is a non-breeding period and Aug-Dec is the breeding season.

## Re-sighting probability

Under  $\{P_t\}$ , the post-release re-sighting model used, monthly re-sighting probabilities (Figure 3.3) ranged between 0.005 (se=0.004, 95% CI=0.01-0.02) and 0.26 (se=0.026, 95% CI=0.22-0.32), with a mean value of 0.12 (se=0.078, 95% CI=0.06-0.12).



**Figure 3.3.** Monthly re-sighting probabilities of little blue penguins at the three study sites combined (Mount Maunganui, Leisure Island and Rabbit Island). Upper and lower standard error bars are shown.

## Variables influencing survival

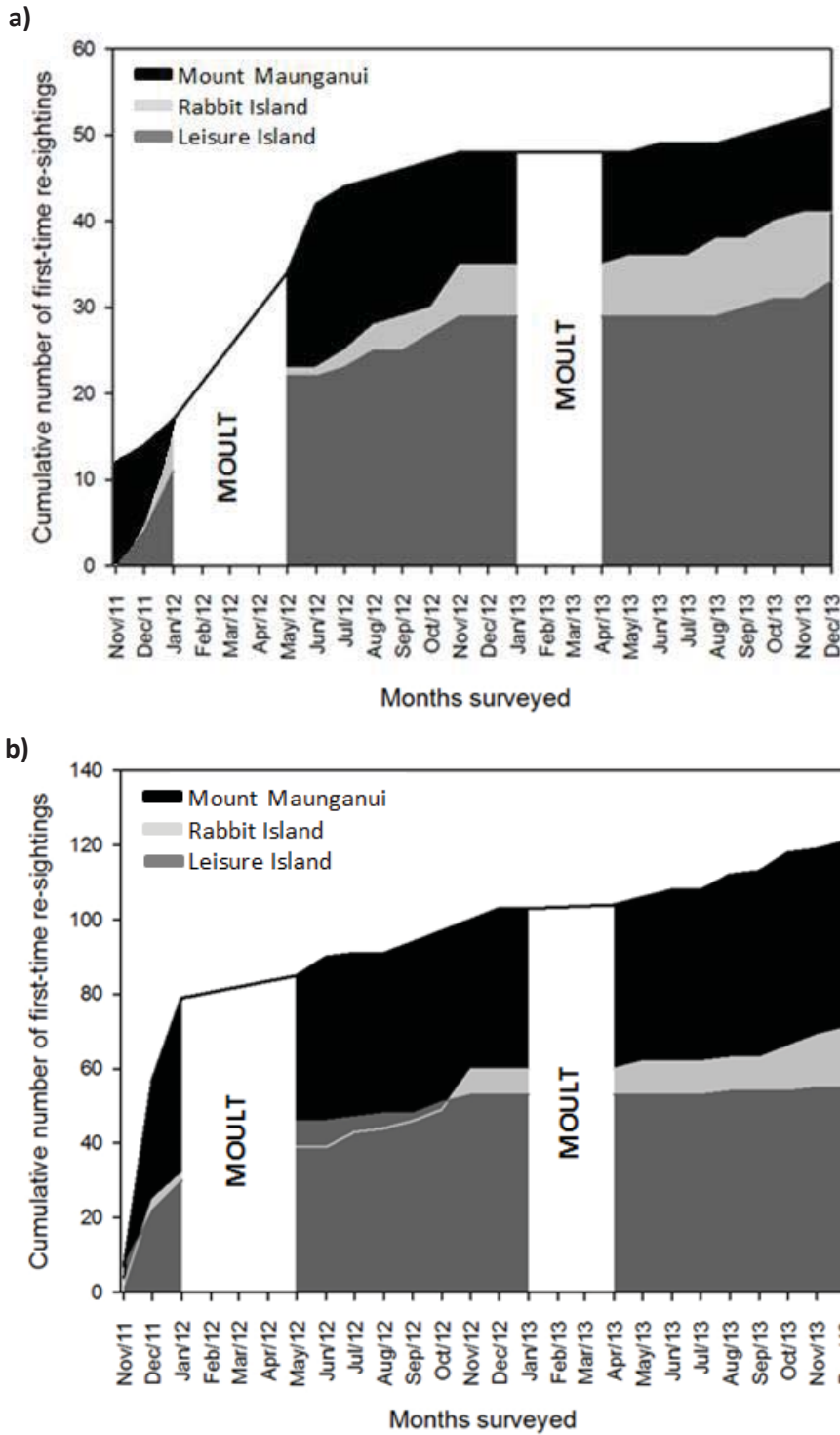
Mann-Whitney U-tests and Student T-tests conducted following Shapiro-Wilk normality tests showed no significant differences in physiological, oil- and captive-related parameters (oiling degree, admission BMI (body mass index), admission PCV (packed cell volume), admission TP (total protein), admission BG (blood glucose), presence of pododermatitis,

release BMI, and captive duration) between rehabilitated and control penguins seen and not seen during survival monitoring surveys.

## **Re-sighting rates**

The cumulative number of rehabilitated penguins re-sighted for the first-time since release during post-release survival monitoring surveys progressively increased at the three study sites until November 2012 (approximately 10 months after the last penguins were released from captive care). Thereafter, no new re-sightings of rehabilitated penguins were made at any of the monitored sites until May 2013. In May and June only a few first-time re-sightings were made at Mount Maunganui and Rabbit Island; none however were made at Leisure Island. From August 2013 (the start of the egg laying period) re-sighting rates of penguins seen for the first time since release began to increase again at all three sites and by the end of December 2013 (the end of the study period) an asymptote of first-time re-sightings of rehabilitated penguins was yet to be reached (Figure 3.4). Overall, 62.2% of the rehabilitated penguins were re-sighted during the study period (Table 3.5).

The number of marked control penguins re-sighted for the first time since micro-chipping was high during December 2011 and January 2012. Following the 2012 moult period the rate reduced but a steady increase was still obvious at all three sites until November 2012. Thereafter new records continued to increase at Mount Maunganui until the end of December 2013. At Rabbit Island very few first-time re-sightings were made following the 2013 moult period, however an increase in the re-sighting rate was observed from September through to December 2013 (peak of the breeding season). When survival monitoring finished at the end of December 2013, an asymptote of first-time re-sightings was yet to be reached at both of these sites. At Leisure Island, first-time re-sightings of control penguins appears to have almost reached an asymptote as from November 2012 to December 2013 only two control penguins were re-sighted for the first-time since being micro-chipped (Figure 3.4). By the end of the study period, 68.4% of the control penguins had been re-sighted (Table 3.5).



**Figure 3.4.** The cumulative number of rehabilitated (a) and control (b) little blue penguins re-sighted each month for the first-time since release from captivity. Data are based on encounters of penguins during survival monitoring surveys at the three study sites. Note that as rehabilitated penguins were released between November 2011 and February 2012 and control penguins were micro-chipped between November 2011 and January 2012, the months before the moult are not strictly comparable between the two groups.

## Recapture rates and inter-colony movements

Many penguins encountered during survival monitoring surveys, particularly those from Leisure Island, were recaptured more than once (Table 3.5). Inter-colony movements were rare for both rehabilitated and control penguins (Table 3.6).

**Table 3.5.** Post-release recapture rates of rehabilitated and control little blue penguins encountered during survival monitoring surveys at the three study sites.

Recaptures	Rehab (n=217)	%	Control (n=361)	%
0	82	37.8	114	31.6
1	52	24.0	83	23.0
2	31	14.3	57	15.8
3	18	8.3	41	11.4
4	20	9.2	31	8.6
5	8	3.7	21	5.8
6	2	0.9	7	1.9
7	3	1.4	2	0.6
8	1	0.5	2	0.6
9	0	0.0	3	0.8

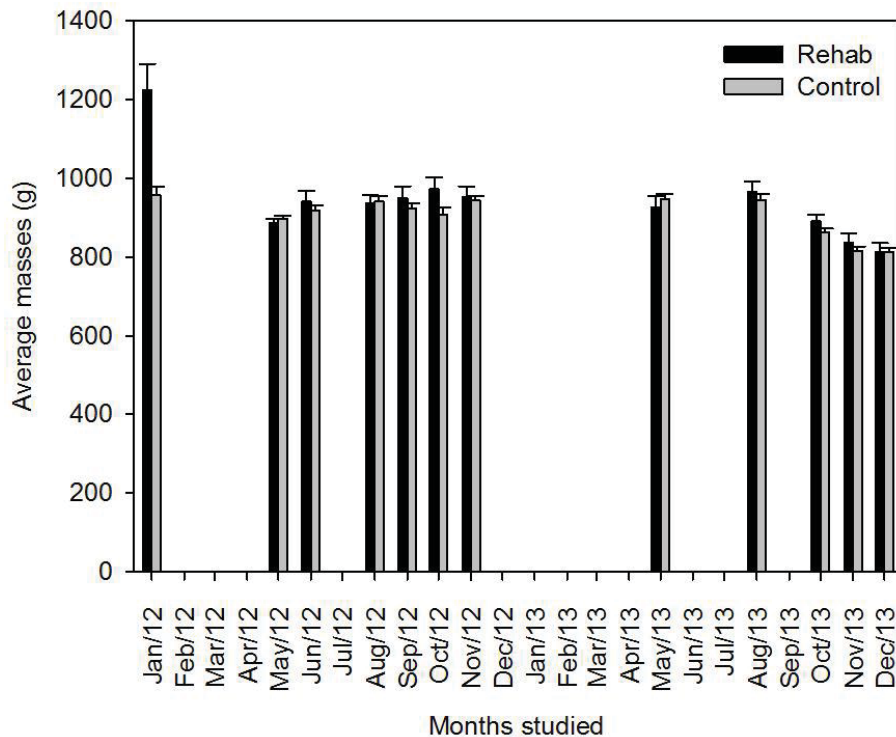
**Table 3.6.** Inter-colony movements made by rehabilitated and control little blue penguins re-sighted more than once during survival monitoring surveys at the three study sites.

Inter-colony movements (n)	Rehabilitated (n=83)	%	Control (n=164)	%
0	78	94.0	157	95.7
1	5	6.0	6	3.7
2	0	0	1	0.6

## Post-release masses

Body masses of rehabilitated penguins were higher than masses of control penguins in December 2011 (Mann-Whitney  $U=1$ ,  $p=0.0140$ ) and January 2012 (Mann-Whitney  $U=99.5$ ,  $p=0.0001$ ), the months after initial release back to the wild. In May, after the moulting and post-moult foraging period (February-April 2012), the masses of rehabilitated penguins had

reduced to levels very similar to those of control penguins (control penguins include those in the micro-chipped group as well as penguins encountered with no microchip) (Mann-Whitney  $U=3810.5$ ,  $p=0.496$ ). Throughout the remainder of the study there were no significant differences in mass between rehabilitated and control penguins (Figure 3.5).



**Figure 3.5.** Average monthly masses of little blue penguins encountered during survival monitoring surveys. Masses are only shown for months in which more than 10 control penguins and 10 rehabilitated penguins were encountered. No masses were recorded in the moult and post-moult foraging period (February to April in 2012 and February to March in 2013) as survival monitoring surveys were not conducted during these periods.

### Post-release behaviour

When first re-captured the proportion of behaviours expressed by rehabilitated and control penguins when approached (stayed, moved <2 m, ran) and when handled (docile, resists, aggressive) differed (Table 3.7). These proportions still differed on the second re-capture. On the third re-capture behaviour on approach was still significantly different between the two groups, however, behaviour in hand was not; the opposite was true for the fourth re-capture. In general rehabilitated penguins were more likely to stay when approached,

whereas control penguins were more likely to move or run. In hand, rehabilitated penguins were more docile than control penguins and generally somewhat less aggressive; there were no clear trends in the expression of resistant behaviour between the two groups (Tables 3.7 and 3.8).

There was no systematic change in the behaviour of control and rehabilitated penguins, both in hand and on approach, as handling frequency increased (Tables 3.7 and 3.8).

**Table 3.7.** Behaviour of rehabilitated and control penguins when approached during survival monitoring surveys. The behaviours of penguins as capture number increases are compared between the two groups. The behaviours of penguins when first approached are also compared to the behaviours expressed as handling number increases. Significant differences are indicated by an asterisk (\*). All Chi-square tests have two degrees of freedom.

	Approach	Rehab behaviour (%)			Control behaviour (%)			Chi-square test	
	# Captures	Stayed	Moved <2m	Ran	Stayed	Moved <2m	Ran	$\chi^2$	P
<b>Behaviour</b>	1	51	31	18	41	41	18	11.8393	0.0027*
	2	56	31	13	34	51	15	33.9725	4.197e <sup>-8*</sup>
	3	45	48	7	42	36	22	32.9263	7.082e <sup>-8*</sup>
	4	44	41	15	33	46	21	2.8092	0.2455
	5	42	58	0	34	45	21	65.8012	2.2e <sup>-16*</sup>
<b>Chi-squared test</b>									
<b>Significance</b>		$\chi^2$	P		$\chi^2$	P			
	1 vs. 2	1.4708	0.4793		6.0007	0.0497*			
	1 vs. 3	0.0302	0.0302*		1.6194	0.4450			
	1 vs. 4	0.5733	0.5733		1.2785	0.5277			
	1 vs. 5	0.0772	0.0772		0.5805	0.7481			

**Table 3.8.** Behaviour of rehabilitated and control penguins when caught and handled during survival monitoring surveys. The behaviours of penguins as capture number increases are compared between the two groups. The behaviours of penguins when first handled are also compared to the behaviours expressed as handling number increases. Significant differences are indicated by an asterisk (\*). All Chi-square tests have two degrees of freedom.

	In hand	Rehab behaviour (%)			Control behaviour (%)			Chi-square test	
	# Captures	Docile	Resists	Aggressive	Docile	Resists	Aggressive	X <sup>2</sup>	P
<b>Behaviour</b>	1	31	54	15	28	49	23	13.3325	0.0013*
	2	44	44	12	30	55	15	11.3212	0.0035*
	3	36	54	10	34	50	16	5.7964	0.0551
	4	36	46	18	25	58	17	21.8392	1.813e <sup>-5</sup> *
	5	-	-	-	21	61	18	-	-
<b>Chi-squared test</b>									
<b>Significance</b>		X <sup>2</sup>	P	X <sup>2</sup>	P				
	1 vs. 2	5.4949	0.0641	6.8898	0.03191*				
	1 vs. 3	1.4624	0.4813	3.0877	0.2136				
	1 vs. 4	8.9214	0.0116*	2.0428	0.3601				
	1 vs. 5	-	-	1.6614	0.4357				

## Discussion

### Results summary

There was no evidence that rehabilitated penguins suffered mass mortality in the initial period following release from captivity, and throughout the study survival rates did not differ between rehabilitated and control penguins or between the mainland and offshore island sites studied. Survival was reduced in the first six months following micro-chipping and release from captivity for rehabilitated penguins and following micro-chipping for control penguins (0.92); thereafter survival rates were high and remained fairly consistent over time (0.97-1.0). Annual survival rates were thus reduced in the first year studied, but high in the second year. These survival rates however represent minima as, among other factors, an asymptote of first-time re-sightings of control and rehabilitated penguins was not reached by the end of the study.

Upon release, and during the first two months monitored post-release, rehabilitated penguins were heavier than control penguins. After the moult/post-moult foraging period, rehabilitated penguins had similar masses to control penguins, and thereafter remained so. The behaviour of rehabilitated and control penguins differed when first re-captured and over time with rehabilitated penguins more likely to stay when approached and more docile when handled. Both groups expressed no systematic change in behaviour as handling frequency increased.

### Post-release survival

- **Mass mortality**

No evidence of post-release mass mortality of rehabilitated (and control) penguins was observed. If such mortality did occur it is highly unlikely it would have gone by unnoticed as Tauranga beaches, particularly Mount Maunganui, are very popular in summer, the season when the releases took place. Other studies have had varying results. Mass mortality was not reported for Cape gannets (*Morus capensis*) rehabilitated after the *Castillo de Bellver* oil spill (Altwegg et al. 2008) or for African penguins (*Spheniscus demersus*) rehabilitated after

the *Apollo Sea*, Dyer Island and Cape Town Harbour oil spills (Whittington 2002). In contrast, mass mortalities within the first few days or weeks after release have been reported for rehabilitated surf scoters (*Melanitta perspicillata*), common guillemots (*Uria aalge*), western grebes (*Aechmophorus occidentalis*) and velvet scoters (*Melanitta fusca*) (Sharp 1996; De la Cruz et al. 2013). Causes of death included handling/capture-associated stress (De la Cruz et al. 2013) and unsuccessfully treated oil-induced physiological problems such as immunosuppression (Wernham et al. 1997), and kidney, liver, and intestinal damage (Sharp 1996). As mass mortality did not occur in this study it appears that the rehabilitation process avoided these issues.

- **Survival during the first six months**

Although survival was generally high, there was a six-month period following release/micro-chipping where survival was reduced for both control and rehabilitated penguins. A number of potential factors may have contributed to this apparent reduced survivability; some may have affected rehabilitated and control penguins separately, whereas others may have had a common effect (Table 3.9).

**Table 3.9.** Factors potentially contributing to reduced apparent survival of control and rehabilitated penguins in the first six months. ‘True’ (direct) mortality effects are shaded, as opposed to potentially confounding (indirect) factors.

Factors	Rehab	Control
Incomplete rehabilitation	✓	
Adverse environmental conditions	✓	✓
Residual oil effects within the environment	✓	✓
High mortality of juvenile penguins		✓
Mortality of sub-adult penguins	✓	
Increased workload from loss of mate		✓ ✓
Disruptions to previous breeding season	✓	✓
Emigration out of study sites	✓	
Vagrant nature of juvenile penguins	✓	
Vagrant nature of sub-adult penguins		✓
Tag loss soon after implantation		✓
Subcutaneous tag migration away from insertion site	✓	✓
Tag failure	✓	✓
Inadequate detection techniques	✓	✓

▪ **Factor explanations**

Of the factors listed in Table 3.9, some may have given rise to ‘true’ mortality whereas other indirect factors may have had a confounding influence on mortality estimates, and these are not necessarily applicable to each group of penguins equally.

Emigration from the study site is likely to have been a factor contributing to the reduced apparent survival of rehabilitated penguins, as there is uncertainty about which colonies these penguins were resident at. When oiled, penguins come ashore at the nearest landmass, regardless of whether or not it is the colony they reside at (Underhill et al. 1999). Oiled penguins recovered at the three study sites were assumed to have originated from those sites and were subsequently released back to the same area. If some of these birds

were actually from other sites, it is likely that after release they would return to their historical 'home'. In that situation, emigration is indistinguishable from mortality and a drop in apparent survival could partly reflect dispersal of some oiled birds out of the study area (Gilroy et al. 2012). This is unlikely to be a factor for control penguins, which were micro-chipped coming ashore during the breeding season. As little blue penguins are generally site-faithful when breeding (Reilly and Cullen 1981; Bull 2000; Johannesen et al. 2002a), it is highly likely that these penguins belonged to these colonies and were returning to their nests.

True survival of rehabilitated penguins may have also been low during the first six months if some individuals were unable to adjust to life back in the wild foraging and fending for themselves. Furthermore, shortly after release most rehabilitated penguins underwent their annual moult, a stressful, energetically demanding period of the annual cycle (Wolfaardt 2007); any negative effects of oiling that may have persisted, despite cleaning and rehabilitation, may have manifested during this period, compromising the survival of some individuals. However, the stress of moult might have been lessened by the fattening of penguins while in captivity (which were on average heavier than control penguins when released).

Survival of both rehabilitated and control penguins may have also been genuinely reduced during this period (which included moult, post-moult foraging and two winter months) due to adverse environmental conditions (Wernham et al. 1997; Golet et al. 2002), limited food availability (Monnett et al. 1990) and/or the persistence of residual oil within the marine environment (Monson et al. 2000; Bodkin et al. 2002; Golet et al. 2002). If so, this may have further compromised survival during this stressful and energetically demanding period of the annual cycle.

True mortality of control penguins may have also occurred due to some adults having to incubate and rear chicks alone during the 2011-12 breeding season due to the loss of their partners through oil-related mortality or through their removal for rehabilitation. This increased workload may have resulted in some control penguins dying as well as possibly having a confounding effect on survival by causing some penguins to forego breeding in the subsequent breeding season; as non-breeding penguins do not come ashore often, the

probability of re-sighting these penguins would have been reduced. This latter effect may have also occurred in rehabilitated penguins as a result of the disruption of pair bonds and high breeding failure during the breeding season of the oil spill (Fry et al. 1986; Giese et al. 2000; Wolfaardt 2007).

Reduced apparent survival of control and rehabilitated penguins may also be attributed to the varying ages of these penguins. An unknown proportion of juvenile penguins (less than a year old) may have been micro-chipped and included within the control group due to recently fledged chicks being misidentified as adults. Sub-adult penguins (older than a year but not yet sexually mature) are unlikely to have been included as they generally do not return to the breeding colonies (the site of micro-chipping) until they are ready to breed at two to three years of age (Dann and Cullen 1990; Dann et al. 1992; Dann et al. 1995). No juvenile penguins were included in the rehabilitated group as the oil spill occurred during the incubation stage of the breeding season, however some sub-adult penguins that were oiled and came ashore will be included. As both juvenile and sub-adult penguins spend a lot of time at sea and rarely make landfall (Reilly and Cullen 1981) until sexually mature (Dann and Cullen 1990; Dann et al. 1992; Dann et al. 1995), it is unlikely that these penguins would have been re-sighted during monitoring surveys; this would have had a confounding effect on survival estimates. Juvenile and sub-adult little blue penguins also have lower survival rates than adult penguins (18% during the first year of life compared to 71% during the second year, 78% in the third year and 83% thereafter until they reach senescence at approximately nine years of age and survivability decreases) (Sidhu et al. 2007); this may have resulted in true mortality of these penguins and therefore reduced calculated survival rates of control and rehabilitated penguins throughout the study.

PIT-tag loss could have influenced the apparent survival of control penguins. Varying rates of tag loss have been reported for birds (14%, Jackson and Bunger 1993; 21%, Elbin and Burger 1994; 4-47%, Becker and Wendeln 1997; 3-30%, Clarke and Kerry 1998; 5%, Carver et al. 1999; 5%, Jamison et al. 2000; 0%, Low et al. 2005) with rates lowest when surgical glue is used to seal insertion sites (Becker and Wendeln 1997; Clarke and Kerry 1998). Glue was not used in this study therefore PIT-tags may have been lost if penguins returned to the sea prior to wound closure (Low et al. 2005). PIT-tags can also be lost if inserted caudal to cranial (towards the head) as gravity may cause caudal migration of the tags back out of the

insertion site (Clarke and Kerry 1998); insertion was cranial to caudal in this study thus loss in this manner is not likely. Rehabilitated penguins are unlikely to have lost tags as insertion sites healed while in captivity and all tags were present upon scanning prior to release.

For both rehabilitated and control penguins two potential factors contributing to reduced apparent survival include subcutaneous PIT-tag migration away from insertion sites (which reduces detection rates) and tag failure. Tag migration is a likely factor as reasonably high migration rates have been reported in studies, such as 40% in brown trout (*Salmo trutta*) (Clarke and Kerry 1998; Jamison et al. 2000; Gheorghiu et al. 2010; Wyneken et al. 2010). Tag failure however is likely only a minor contributing factor as the tags are designed to stay active beyond the life expectancy of the host (providing the tags are not damaged) (J. Rutherford, pers. comm.). On average, cats and dogs, the intended hosts of these tags, live longer than penguins (Taylor et al. 1995; Dann et al. 2005) therefore most tags should still be functional. This expectation is supported by a study on Adelie penguins (*Pygoscelis adeliae*) in which only 5/314 PIT-tags (1.6%) failed between the first and fourth winter of the study (Clarke and Kerry 1998).

Inadequate detection of marked penguins may have also resulted in an underestimation of survival. This is demonstrated by the finding that 5% of the rehabilitated penguins and 3% of the control penguins, whose breeding success were monitored during the breeding season and were regularly seen during nest checks, were not detected during survival monitoring surveys. If surveys had been of a longer duration (i.e. 3–4 hours rather than 2 hours) and conducted more frequently (i.e. fortnightly at Mount Maunganui and Leisure Island rather than fortnightly-monthly, and monthly at Rabbit Island rather than approximately monthly), it is likely that detection rates would have increased (particularly at Rabbit Island as approximately one-third of the marked penguins are thought to belong to this site). It would have been difficult however to increase the re-sighting effort as a core group of volunteers was relied upon to undertake surveys, many of whom are too busy to undertake longer and more frequent surveys. Furthermore, the trade-off between survey intensity (and thus data accuracy) and penguin disturbance had to be considered (Vertigan et al. 2012), as conducting additional surveys may have adversely affected the penguins and altered their behaviour, particularly at Leisure Island as this is a small site with high re-encounter rates.

Overall, it cannot be concluded which factors contributed to the reduced apparent survival in each group during the first 6-months. It is therefore unknown whether this reduced survival was a result of 'true' mortality factors, 'confounding' mortality factors or a combination of both. If confounding factors were the main contributors, it is thus possible that survival during this 6-month period may have actually been higher than reported.

- **Survival during the rest of the study**

After the first six months survival rates of control and rehabilitated penguins increased and remained high and reasonably constant throughout the rest of the study. Annual survival was low (52%) in the first year but high in the second year (84%). This latter rate is within the range reported for a well-studied colony of little blue penguins at Phillip Island (66-85.8%) (Reilly and Cullen 1979; Dann and Cullen 1990), suggesting that control and rehabilitated penguins were fit, healthy, and capable of foraging, maintaining mass and ultimately surviving.

It was a positive sign that survival was not lower for rehabilitated penguins during most of the first breeding season and during the second breeding season and moult period as these times are energetically demanding periods of the annual cycle during which any persistent deleterious effects of oiling may have manifested and compromised survival (Giese et al. 2000; Wolfaardt et al. 2009a); rehabilitation was thus reasonably success at reversing these effects. Furthermore, as survival was not reduced in the second moult period it can be concluded that survival is not routinely reduced during moult. This suggests that the reduced survival in the first interval was likely not due to the stress of moult but instead may be attributed to one or a number of aforementioned potentially contributing factors.

It is evident that 'new' tagged penguins were still being recorded for the first time towards the end of the study (an asymptote of cumulative first-time re-sightings of both control and rehabilitated penguins had not been reached) indicating that the survival estimates represent minima. Other studies have found that re-sightings are influenced by study duration. For example re-sightings of African penguins in the three years after the *Treasure* oil spill increased from 55% to 80% to 92% respectively (Wolfaardt et al. 2008b). Furthermore, after five years of intensive study following the *Apollo Sea* oil spill, African

penguins were still being re-sighted for the first time since release (Whittington 2002). In the present study it is therefore likely that in future surveys previously unrecorded penguins will be encountered; survival estimates may thus increase and thereby more accurately reflect true survival.

- **Comparisons to other studies and factors influencing survival**

Post-release survival rates of rehabilitated birds have been highly variable between studies (Table 1.1). In general, lower post-release survival rates have been associated with smaller rehabilitated birds including species of murre (Newman et al. 2004), auk, and guillemot (Sharp 1996; Camphuysen et al. 1997; Wernham et al. 1997), whereas higher rates have been reported for larger birds, particularly penguin species (Crawford et al. 2000; Whittington et al. 2000; Whittington 2002; Altwegg et al. 2008). Penguins respond well to rehabilitation efforts (Randall et al. 1980; Underhill et al. 1999; Heubeck et al. 2003) and seem more robust birds than murre, auks, and guillemots (Altwegg et al. 2008; Wolfaardt et al. 2009b), less prone to injury whilst in care (Newman et al. 2004), and more tolerant of the stress of rehabilitation, handling and captive confinement (Altwegg et al. 2008). Penguins also have short feathers that can be more vigorously and thus more effectively cleaned than long flight feathers (Morant et al. 1981). Furthermore, penguins are capable of fasting for up to three weeks (they do so annually during the moult period) and possess greater internal reserves than smaller bird species; these factors may enable oiled penguins to better maintain mass and condition prior to capture and cleaning and thus ultimately result in higher captive survival and post-release survival rates (Wolfaardt et al. 2009b) as documented in this study.

Besides species differences (Heubeck et al. 2003; Russell et al. 2003), other factors that vary between spills and geographic locations may also contribute to the variable post-release survival rates reported for oil-rehabilitated animals. Such factors include: the preparedness, skill and expertise of rescue and rehabilitation teams (Frink and Miller 1995; Wernham et al. 1997; Heubeck et al. 2003); proximity to a properly equipped rehabilitation centre (Heubeck et al. 2003; Wolfaardt et al. 2008a); effectiveness of treatment and rehabilitation techniques (Wernham et al. 1997); durations between oiling and capture, capture and rehabilitation, and rehabilitation and release; condition of oiled animals; distance between

the release site and the site of initial capture (Wernham et al. 1997); oil type, toxicity and quantity spilled (Wernham et al. 1997; Saba and Spotila 2003; Barham et al. 2007); climatic conditions (Wernham et al. 1997); food availability (Whittington 2002); and the intensity, duration, and geographic range of post-release monitoring surveys (Wolfaardt et al. 2009b). An unfavourable combination of these factors may result in low captive and post-release survival rates of rehabilitated animals. If possible, in future spills it would be useful to document these factors (Wernham et al. 1997) so it can be determined which combination of factors result in highest post-release survival.

Post-release survival of rehabilitated animals may also be influenced by specific oil- and captive-related variables (Sharp 1996; Goldsworthy et al. 2000b; Ben-David et al. 2002). In this study such variables measured included oiling degree, admission body mass index, admission packed cell volume, total protein, and blood glucose values, the presence or absence of pododermatitis, release body mass index and captive duration. As no significant differences in these variables were found between rehabilitated penguins re-sighted during survival monitoring surveys and not re-sighted, it seems that none of these factors influenced post-release survival. With respect to the variables packed cell volume, total protein and blood glucose, this may be because these parameters were used to selectively triage and euthanize oiled penguins with low levels (K. Morgan, pers. comm.).

Other studies have had both similar and varying results and have tested variables not considered in this study (Table 3.10). Overall, there is no general consensus as to which variables can accurately predict the probability of post-release survival; this is probably due to the paucity of data. This highlights the importance of continuing to conduct post-release monitoring studies so that more definitive conclusions can be made about the predictive ability of these variables to assist in triaging oiled birds based on their likelihood of future survival.

**Table 3.10.** Ability of different variables to predict post-release survival of oil-rehabilitated animals. PCV is packed cell volume, TP is total protein and BG is blood glucose.

<b>Variable</b>	<b>Good predictor of post-release survival</b>	<b>Poor predictor of post-release survival</b>
<b>Oiling degree</b>	Little blue penguin <sup>1</sup> Guillemot, Western grebe, Surf scoter, Velvet scoter <sup>2</sup>	African penguin <sup>4</sup> Little blue penguin <sup>8</sup>
<b>Sex</b>	Little blue penguin <sup>1</sup>	Surf scoter <sup>7</sup>
<b>Capture mass and condition</b>	Little blue penguin <sup>1</sup> African penguin <sup>3,4</sup> American coot ( <i>Fulica americana</i> ) <sup>5</sup>	Guillemot, Western grebe, Surf scoter, Velvet scoter <sup>2</sup> Little blue penguin <sup>8</sup>
<b>Admission PCV, TP and BG values</b>	-	Little blue penguin <sup>8</sup>
<b>Release mass and condition</b>	Little blue penguin <sup>1</sup> American coot <sup>5</sup>	Guillemot, Western grebe, Velvet scoter <sup>2</sup> Surf scoter <sup>2,7</sup> River otter ( <i>Lontra canadensis</i> ) <sup>6</sup> Little blue penguin <sup>8</sup>
<b>Presence of pododermatitis</b>	-	Little blue penguin <sup>8</sup>
<b>Captive duration</b>	-	Little blue penguin <sup>1,8</sup>
<b>Release PCV and TP values</b>	-	Guillemot, Western grebe, Surf scoter, Velvet scoter <sup>2</sup>
<b>Release haemoglobin level</b>	River otter <sup>6</sup>	-
<b>Duration between oiling and capture</b>	African penguin <sup>3</sup>	-

**Sources:** <sup>1</sup>(Goldsworthy et al. 2000b). <sup>2</sup>(Sharp 1996). <sup>3</sup>(Kerley and Erasmus 1987). <sup>4</sup>(Parsons and Underhill 2005). <sup>5</sup>(Anderson et al. 2000). <sup>6</sup>(Ben-David et al. 2002). <sup>7</sup>(De la Cruz et al. 2013). <sup>8</sup>(This study).

## Re-sighting rates

Re-sighting probabilities for control and rehabilitated penguins were reasonably low throughout the study ranging between 0.005 and 0.26 per month. The lowest probability was in January 2013; fewer penguins may have been encountered coming ashore during this period as many would have been at sea fattening up after breeding in preparation for moult, or alternatively they may have already been on land moulting (Gales and Green 1990; Williams 1995). The highest probabilities were in May 2012 and in some chick rearing months (November 2012, October 2013, November 2013 and December 2013). This peak in

May possibly reflects the high survey intensity during this month as this was the first month surveyed after release/micro-chipping and many people were keen to assist in monitoring. The re-sighting peaks in some of the chick rearing months is likely due to breeding penguins coming ashore regularly during this period to feed and guard chicks (Williams 1995) and thus being more frequently encountered during surveys. The generally low re-sighting probabilities throughout the study may be due to surveys not being conducted frequently enough and/or not being of a long enough duration. These low rates may also be due to penguins returning to colonies beyond those being studied. To increase re-sighting rates in future surveys it is thus recommended that more surveys of a longer duration are conducted and that, if feasible, additional colonies within the oil-affected area should be monitored.

### **Post-release masses**

Following release rehabilitated penguins were significantly heavier than control penguins, presumably due to low energy demands and provision of ample food while in captivity. However, with the loss of these benefits of captive care, their masses reduced post-release and following the moult and post-moult foraging period, were similar to that of control penguins. Thereafter, masses remained similar between the two groups, even during energetically expensive breeding and moult periods (Wolfaardt 2007). These results indicate that rehabilitated penguins adjusted well to life back in the wild and thus suggest that any negative effects of oiling on the ability of rehabilitated penguins to forage and maintain mass were reversed by the rehabilitation process.

Only a few studies have reported post-release masses of oil-rehabilitated animals and whether these masses are within normal ranges for the species concerned. One such study involving rehabilitated American coots found that after release, rehabilitated coots lost more weight than control coots. However after six weeks, masses were comparable for rehabilitated and control birds and throughout the remainder of the study masses varied similarly between the two groups (Anderson et al. 2000). Another study found that little blue penguins rehabilitated after the *Iron Baron* oil spill weighed more than control penguins upon release. Thereafter, they lost mass, however in contrast to this study, their

average mass did not stabilise once it reached that of control penguins but continued to decrease; within 20 days of release rehabilitated penguins weighed less than control penguins. On average it took 60-100 days for these penguins to increase their mass to release levels suggesting that they struggled to adjust to life back in the wild. At one study site, rehabilitated penguins weighed significantly less than control penguins on seven different occasions during the 20 months monitored; five of these occasions were within five months of release. During the rest of the study no significant mass differences were found between control and rehabilitated penguins (Goldsworthy et al. 2000b). These results indicate that following the initial delay in transitioning to the wild, rehabilitated penguins thereafter were also generally able to maintain their weight and forage as efficiently as control penguins.

As there are no pre-spill mass data of penguins at the three study sites to which direct comparisons can be made, it is unknown whether the masses recorded during this study are similar to pre-spill averages. Masses of both control and rehabilitated penguins were generally lower throughout the annual cycle than masses reported at other little blue penguin colonies in New Zealand and Australia (Table 3.11). Direct oiling effects are unlikely to be the cause of these low masses as control penguins were also affected. One possible cause could be reduced food availability during the study period as an indirect consequence of toxic effects of oil on prey species (Golet et al. 2002). Another possible explanation is that little blue penguins at these colonies (as well as colonies studied in Northland and at Tiritiri Matangi Island) simply weigh less than penguins at other colonies (D. Brunton, pers. comm.; Kinsky and Falla 1976; Jones 1978). Conditions are warmer in these areas than in the South Island of New Zealand (NIWA 2001), and masses of little blue penguins generally decrease with decreasing latitude (Gales 1987). Regardless of the reason for these reduced masses, as masses were similar between rehabilitated and control penguins throughout the majority of the study, it appears that rehabilitation was successful at returning penguins back to the wild that were capable of maintaining mass throughout the annual cycle.

**Table 3.11.** Average masses of little blue penguins at colonies in New Zealand and Australia.

Colony	Year/s	Mass (month unknown)	Average monthly mass (g)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Mount Maunganui, Leisure Island, Rabbit Island, Tauranga (rehabilitated penguins)	2012		1225				888	941	930	936	951	974	952		
Mount Maunganui, Leisure Island, Rabbit Island, Tauranga (control penguins)	2012		957				898	919	976	941	923	908	945	895	
Mount Maunganui, Leisure Island, Rabbit Island, Tauranga (rehabilitated penguins)	2013					927	991		967		891	836	814		
Mount Maunganui, Leisure Island, Rabbit Island, Tauranga (rehabilitated penguins)	2013				921	948	949	995	945	893	863	817	814		
Northland <sup>1</sup>	-		902												
Tiritiri Matangi Island, Auckland <sup>2</sup>	-		910												
Tiritiri Matangi Island, Auckland <sup>3</sup>	2011		1015	868	847	875									
Cook Strait <sup>1</sup>	-		1117												
Motuara Island <sup>4</sup>	1998											1021			
Banks Peninsula <sup>1</sup>	-		1327												
Oamaru <sup>4</sup>	1998								1138						
Otago Peninsula <sup>1</sup>	-		1169												
Otago Peninsula <sup>3</sup>	1999														
Otago Peninsula <sup>3</sup>	2000		1199	1255	1181	1207	1249	1197	1160	1252	1239	1304			
South Westland <sup>1</sup>	-		1004												
South Westland <sup>7</sup>	2008-09									1241					
Bulle <sup>7</sup>	2008-09									1117					
Phillip Island, Victoria <sup>8</sup>	-		1207												
Fremantle, Western Australia <sup>9</sup>	-		1390												
Penguin Island, Western Australia <sup>10</sup>	-		1403												
Bowen Island, New South Wales <sup>11</sup>	1987-90		1380	1150	1120	1010	1060	1070	1010	1050	1090	1100	1100	1090	
Albatross Island, Tasmania <sup>12</sup>	1984										1180				1200
Albatross Island, Tasmania <sup>13</sup>	1985		1080		1380		1060			1100					1150
Albatross Island, Tasmania <sup>12</sup>	1985				1220			1200		1180					1280
Fort Direction, Tasmania <sup>12</sup>	1984				1280					1080					1180
Fort Direction, Tasmania <sup>12</sup>	1985		1200	1220	1020	1300	990	1200	1020	1000	1260	1270	1250	1300	
Marion Bay, Tasmania <sup>12</sup>	1984		1160		1040					1050					1380
Marion Bay, Tasmania <sup>12</sup>	1985		1220	1620	1100	1220	1080	1190	1100	1120	1020	1170	1190	1170	

**Sources:** <sup>1</sup>(Kinsky and Falla 1976). <sup>2</sup>(Jones 1978). <sup>3</sup>(D. Brunton pers. comm.). <sup>4</sup>(Numata et al. 2000). <sup>5</sup>(Johannesen et al. 2002b). <sup>6</sup>(Braidwood 2009). <sup>7</sup>(Montague 1982b). <sup>8</sup>(Montague 1982a). <sup>9</sup>(Klomp 1987). <sup>10</sup>(Fortescue 1991). <sup>11</sup>(Gales and Pemberton 1990). <sup>12</sup>(Gales and Green 1990).

## Post-release behaviour

There is an indication that some behaviours of rehabilitated penguins were influenced by their time spent in captivity. Following release, rehabilitated penguins were more likely to stay when approached during survival monitoring surveys and when handled were more docile than control penguins. However, as handlings increased, there was no systematic change in the behaviour of control and rehabilitated penguins. These results suggest that during captivity some rehabilitated penguins became somewhat habituated to the presence of people, which may have reduced their fear and instinctual perception that identified humans as a threat (Csermely 2000). This behavioural change may have persisted post-release for some individuals. However as post-release survival rates were similar between control and rehabilitated penguins, it seems that this captive-induced behavioural change did not influence the ability of penguins to forage effectively, identify and avoid predators and ultimately survive post-release.

To the best of my knowledge no other studies have looked at the effect of captivity on post-release behavioural responses of oil-rehabilitated animals whilst being approached and handled by researchers. Most behavioural studies instead compare movement patterns and spatial use of rehabilitated and control animals. Such studies have reported contrasting results. No detectable behavioural differences were found for rehabilitated western gulls (*Larus occidentalis*) (Golightly et al. 2002), common murrelets (Newman et al. 2003) and four species of freshwater turtle (*Chrysemys picta*, *Chelydra serpentina*, *Trachemys scripta*, *Pseudemys rubriventris*) (Saba and Spotila 2003). In contrast, significant differences were found for brown pelicans (*Pelecanus occidentalis*), with rehabilitated pelicans remaining sedentary and forgoing migration to breeding grounds (Anderson et al. 1996), and rehabilitated guillemots, with disproportionate numbers remaining in close proximity to the release site rather than dispersing (Sharp 1996). Another study compared the frequency and duration of different behaviours (such as feeding and preening) expressed by control and rehabilitated American coots, and found significant differences between the two groups (Anderson et al. 2000). It therefore appears that in some cases rehabilitated animals behave in an aberrant manner, however there is uncertainty as to whether these behaviours are altered due to time spent in captivity, untreated effects of oiling, or a combination of both

factors. Such factors were not considered in this study, but could be researched in future studies.

## **Limitations**

A limitation of this post-release survival study was that only three penguin colonies within the oil-affected area were monitored. Thirty-eight percent of the oiled penguins were rescued from and returned to areas in the Bay of Plenty beyond those being studied (such as Motiti Island, Matakana Island, Papamoa, Waihi, Maketu, and Omanu). Overall survival rates could have been more accurately reported if post-release monitoring had occurred at these areas. It is also possible that some penguins assumed to be from the three study sites actually belonged to other additional, more distant colonies such as Karewa Island and Mayor Island; oiled penguins were not rescued from these sites, however this does not mean that oiled birds were not part of these colonies. Time, financial and logistical constraints unfortunately rendered additional surveys at these sites during the present study unfeasible therefore a decision was made to focus on only three study sites (Mount Maunganui, Leisure Island and Rabbit Island) that were close together, easily accessible and from which the majority of the oiled penguins were rescued from and all of the control penguins were tagged at.

## **Conclusion**

In summary, no post-release mass mortality of rehabilitated penguins was recorded and survival rates were similar between rehabilitated and control penguins throughout the study period. Upon release and during the subsequent two months rehabilitated penguins were heavier than control penguins, however thereafter masses were similar between the two groups. Behaviourally, rehabilitated penguins were more likely to stay when approached and were more docile in hand than control penguins, however as survival was similar between the two groups it appears these behavioural changes did not compromise their ability to forage and detect predators.

These results suggest that the products, treatments, and techniques used during the rehabilitation process were effective at treating and counteracting the negative effects of oil contamination on the post-release survival of rehabilitated little blue penguins.

## Chapter Three Appendix

Appendix Table 3.1. Design matrix created in MARK to construct the global model.

B1: Inter- cept	B2: Oil	B3: FM	B4: Oil*FM (Oil*1 <sup>st</sup> )	B5: FM*year	B6: Year	B7: Site	B8: Breed	B9:	B10:	B11:	B12:	B13:	B14: Parm	B15:	B16:	B17:	B18:	B19:	B20:	B21:	B22:	B23:	B24:	B25:	B26:	B27:	B28:
1	1	1	1	1	0	0	0	0	0	0	0	0	1.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	2.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	3.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	1	0	0	0	0	0	4.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	1	0	0	0	0	0	5.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	1	0	0	0	0	0	6.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	1	0	0	0	0	0	7.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	1	0	0	0	0	0	8.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	9.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	0	1	0	0	0	0	0	0	0	10.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	0	0	0	0	0	0	11.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	0	0	0	0	0	0	12.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	0	0	0	0	0	0	13.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	14.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	15.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	16.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	17.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	0	0	0	0	18.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	0	1	0	0	0	0	0	0	19.Phi	0	0	0	0	0	0	0	0	0	0	0	0	0	0







# Chapter Four

## General discussion



Image credit: MNZ 2011

An increase in the frequency and severity of marine oil spills has resulted in a concomitant increase in oil-contamination of marine animals (Clark and Gorney 1987; Wolfaardt et al. 2009b). This has brought to attention the global debate of whether or not oiled animals should be rehabilitated, the main arguments of which centre on the cost, effectiveness and conservation value of undertaking rehabilitation (Estes 1991; Anderson et al. 1996; Sharp 1996; Jessup 1998; Wolfaardt et al. 2008b; Wolfaardt et al. 2009b; De la Cruz et al. 2013). The debate is yet to be resolved, highlighting the importance of assessing rehabilitation success. Currently such assessment is made by monitoring the post-release survival and productivity of oil-rehabilitated animals (Giese et al. 2000; Parsons and Underhill 2005; Wolfaardt et al. 2009b).

### **Assessment of rehabilitation effectiveness**

Results of post-release monitoring studies have varied between oil spills and species as no two spills are the same and responses to oiling and rehabilitation vary inter-specifically (Goldsworthy et al. 2000; Wolfaardt et al. 2009b). The most relevant comparisons to the *Rena* are those conducted on little blue penguins rehabilitated after the *Iron Baron* oil spill in Australia. This vessel struck the Hebe Reef in northern Tasmania on 10 July 1995 (Giese et al. 2000; Goldsworthy et al. 2000a; Goldsworthy et al. 2000b), spilling 325 tonnes of bunker fuel oil spilled into the marine environment of which half washed ashore (Goldsworthy et al. 2000a). This was a similar amount and fuel type to that spilled during the *Rena* oil spill. While on a global scale the *Iron Baron* (and *Rena*) spill was considered a small spill, as the oil contaminated important seabird foraging and breeding grounds, the impact on wildlife was profound. Many seabirds of a variety of species were oiled, with little blue penguins the most visibly affected species (Goldsworthy et al. 2000b). Considerably more oiled penguins were rescued and rehabilitated after the *Iron Baron* spill (1894 birds) than the *Rena* (383 birds). Captive survival rates were similar between the two spills (approximately 95%: Giese et al. 2000; Goldsworthy et al. 2000a; Goldsworthy et al. 2000b), but post-release survival and reproductive success were lower for rehabilitated penguins after the *Iron Baron* spill than the *Rena* spill (Table 4.1). The post-release monitoring results of this spill provide a good comparison to those from the *Rena* spill as although some spill conditions differed, the study species is the same.

**Table 4.1.** Post-release survival and productivity variables studied during the *Iron Baron* and *Rena* oil spills. Productivity information presented for the *Iron Baron* spill is only from the first year studied so comparisons can be made to the one-year *Rena* study. A cross indicates that a significant difference was found between control and rehabilitated penguins (in all cases this represents a reduction, delay or protraction in the variable for rehabilitated penguins relative to control penguins). A tick indicates that a variable was similar (p-value >0.05) for rehabilitated and control penguins. A cross and a tick together indicates that there were both differences and similarities between the two groups.

Variable	<i>Rena</i> oil spill	<i>Iron Baron</i> oil spill
<b>Breeding study</b>		
Timing of egg laying	✓	X
Duration of egg laying	✓	X
Clutch size	✓	n/a
Hatching success	X	✓
Fledging success	✓	n/a
Egg success	✓	X
Pre-fledging chick masses	✓	X
<b>Survival study</b>		
Post-release survival	✓	X
Breeding season survival	✓	X
Moult period survival	✓	✓
Post-release masses	✓	X / ✓

These comparisons indicate that in general penguins rehabilitated after the *Iron Baron* oil spill had lower survival and reproductive success than control penguins, whereas after the *Rena* oil spill most parameters assessed were similar between the two groups. This suggests that the rescue, treatment and rehabilitation process conducted during the *Rena* oil spill was possibly more successful than that during the *Iron Baron* oil spill; this may be attributed to a few factors that differed between the two spills. Firstly, the *Rena* spill occurred 16 years after the *Iron Baron* spill therefore increased survival and productivity of rehabilitated

penguins may be due to improvements in oiled wildlife rehabilitation; animal husbandry and care may have also improved (Ben-David et al. 2002; Kuyper and Williams 2004; Newman et al. 2004; Ziccardi 2008; Wolfaardt et al. 2009b).

The response and preparedness of the oiled wildlife rescue operation may have also improved over time. Goldsworthy et al. (2000b) state that during the *Iron Baron* oil spill, island sites were visited 4-26 days after the spill. As one of their main study sites was an island (Ninth Island) this delay in rescuing oiled penguins increased the duration between the oiling and treatment of individuals, resulting in penguins losing mass and condition. Negative effects of oil contamination may have also manifested. Consequently, penguins from Ninth Island may have been more adversely affected by oiling and possibly less receptive to rehabilitation, resulting in the survival and productivity of these penguins being compromised by persistent oiling effects. During the *Rena* oil spill, the rescue operation was prompt and daily targeted night searches for oiled penguins were conducted. This minimised durations of oil exposure and thus possibly enabled more effective treatment of toxic oiling effects. This may have contributed to the increase in post-release survival and breeding success of rehabilitated penguins.

Lastly, following the *Rena* oil spill, rehabilitated penguins were released at their site of capture, whereas following the *Iron Baron* spill 53% of the rehabilitated penguins were translocated prior to release (20% were released 210 km from Low Head (one of the main sites oiled penguins were rescued from) and 33% were released 410 km away from Low Head)); survival of these translocated individuals may have been reduced due to unfamiliarity with the foraging grounds and the extra energy expenditure required to return 'home' (Goldsworthy et al. 2000b). Higher post-release following the *Rena* oil spill may therefore be partially explained by rehabilitated penguins being released at their capture site.

## Study contributions

As illustrated by the high level of success of the rehabilitation process conducted during the *Rena* oil spill (relative to the *Iron Baron* oil spill), one of the main contributions of this study is that it confirms that the oil-rehabilitation process used in New Zealand is effective at treating oiled little blue penguins. This success is evident both within the rehabilitation process (with 94.3% of penguins being released back to the wild) and post-release, with similar survival and restoration rates between rehabilitated and control penguins. The study supports other findings and the general conclusion that penguins are the group of animals that respond best to rehabilitation (Randall et al. 1980; Crawford et al. 2000; Goldsworthy et al. 2000; Whittington et al. 2000; Whittington 2002; Barham et al. 2007; Wolfaardt et al. 2008a). This growing evidence therefore suggests that in future oil spills, if present, penguin species should be targeted for rehabilitation.

The finding of significantly reduced hatching success in rehabilitated pairs provides additional feedback on the effectiveness of the rehabilitation process used in New Zealand and highlights an avenue where future research could be directed. Evidently, the rehabilitation process could not completely overcome all negative impacts of oiling, and understanding the mechanism by which hatching success is affected could help inform the captive management of oiled penguins. It may be possible to determine which rehabilitation and treatment techniques need to be improved to increase post-release breeding success, and thereby increase rehabilitation efficacy in future oil spills.

Another important aspect of this study is that it contributes to the debate about the overall value of rehabilitation, which is contentious given the mixed rehabilitation outcomes historically, and the large amounts of money required to treat oiled animals. The rehabilitation of little blue penguins following the *Rena* oil spill can be considered to have had a number of positive outcomes:

- Recovery of oiled penguins from the wild for rehabilitation (or euthanasia) reduced the suffering of oiled penguins and rehabilitation successfully treated most negative effects of oiling that may have compromised post-release survival and productivity.

- Of the behaviours assessed, upon re-capture from the wild, rehabilitated penguins expressed no abnormalities or differences to control birds that may have compromised their survival.
- Most rehabilitated penguins whose breeding success was monitored were successfully restored to the local penguin population (observed breeding after release) and thus resource competition between unrestored rehabilitated individuals and the rest of the breeding population was low.
- The removal of oiled animals during the oiled wildlife response resulted in little damage to habitat at Mount Maunganui and Leisure Island or disturbance of unoiled animals as nearly all penguins were found on rocks or on the beach and reasonably low densities of seabirds inhabit the rocky shorelines of these sites. In contrast, on Rabbit Island some habitat damage and disturbance occurred as rescue teams had to walk through the bush to access the back of the island and in doing so trampled plants and disturbed some ground-nesting seabirds; these negative effects were reduced however by making a track.

Some additional factors supporting the rehabilitation having been done include that, although expensive, funding for wildlife rehabilitation during an oil spill response is generally covered by the spiller through insurance, therefore the money spent on wildlife during the *Rena* was not available for any other purpose, including other conservation and management efforts that could have benefitted the population as a whole (such as pest control) (K. Morgan, pers. comm.). Furthermore, this money was not spent on rehabilitating just a few individuals but rather almost 20% (216/1200) (D. Richards, pers. comm.) of the penguins estimated to breed at the three study colonies. The rehabilitated penguins are therefore likely to contribute to and increase the speed of the post-spill recovery of these colonies, which indicates that undertaking rehabilitation had conservation value. From a societal perspective, rehabilitation can be considered both justifiable and necessary, as due to public interest, involvement and demand, there really was no option but to attempt to rehabilitate oiled wildlife. The health and welfare of these animals had been compromised due to human-induced actions, and therefore there was a moral obligation and demand to try to right the wrong by at least attempting to rescue and rehabilitate oiled animals (no matter the cost) rather than leaving them in a distressed state, with many eventually dying

(Frink and Miller 1995). The alternative option would have been to collect and euthanize oiled animals to end their suffering (and prevent them from contaminating other individuals in the population and becoming incorporated into the food chain) (K. Morgan, pers. comm.), however money, facilities, equipment, and skilled personnel were available to preferentially attempt rehabilitation. Based on these arguments it can be concluded that rehabilitating oiled *Rena* penguins was justified and it can be justified on individual, population, ethical, humanitarian, and conservation grounds.

A final contribution of this study is that we support the use of PIT-tags as a method of marking penguins for mark-recapture and productivity studies. Alternative identifiers, such as flipper bands, have been extensively used in penguin studies, however these external markers can negatively affect penguins by increasing energy expenditure whilst swimming and reducing survival (Culik et al. 1993; Stonehouse 1999; Jackson and Wilson 2002). Furthermore, if flipper bands are fitted too loosely, they may be lost, or alternatively, if fitted too tightly, there is a risk of gangrenous poisoning when penguins increase in size during the moult period (Underhill 1995). PIT-tags, which are implanted subcutaneously, cannot affect survival in such ways (Becker and Wendeln 1997; Jamison et al. 2000) and as they are internally inserted, tag loss is highly unlikely, providing that the correct insertion technique has been used (Castro-Santos et al. 1996; Clarke and Kerry 1998; Zydlewski et al. 2006). Additional advantages of PIT-tags are that they are long-lasting, tag detection is quick and easy (Dutton and McDonald 1994; Elbin and Burger 1994; Clarke and Kerry 1998; Gibbons and Andrews 2004), and they provide a passive method of identifying marked breeding penguins as scanning can be undertaken with minimal disturbance to the nesting penguin. PIT-tags however are not without disadvantage; the main problem is that visual observation of marked animals is not possible (Elbin and Burger 1994). This was not a big issue in the context of our formal monitoring as penguins are flightless birds and thus could be easily approached on land and scanned for the presence of a tag. However, this lack of visual marking meant that PIT-tagged penguins found dead by the public were not identified as being of special interest and thus may not have been reported to us for scanning and collection. Overall, however it seems that the benefits of marking penguins with PIT-tags outweigh the costs associated with this marking method and we recommend their use in

future penguin studies; they are however unlikely to be a suitable marking method for volant birds which can be difficult to approach for scanning and identification.

### **General study limitations and recommendations**

A general limitation of this study is that, although the control penguins represent a true control group for looking at the direct effects of oiling itself and the effects of the rehabilitation process, these penguins do not represent a true 'control' group that enable assessment of the overall effect of the oil spill on the penguins. This is because, although classified as non-oiled and non-rehabilitated, these penguins still resided and foraged in habitat within the oil-affected area and thus may have been indirectly affected by the presence of oil within the marine ecosystem. There were also no pre-spill data on survival and productivity rates of penguins at our study sites to which comparisons could be made, to help make this assessment. To somewhat compensate for this, breeding success parameters were indirectly compared to those from on-going studies of little blue penguins at other colonies in New Zealand and Australia; survival rates were not compared. We recommend continuing to monitor these three study sites so that baseline survival and productivity data can be collected so that if future oil spills occur at this location (which is possible due to the busy nature of the nearby port of Tauranga) some comparative pre-spill information will be available to enable the spill impact to be assessed.

Another general limitation of this study was the inability to distinguish whether the toxic effects of oiling or the chronic stress associated with captivity and rehabilitation (or a combination of both factors) caused the reduced hatching success of some rehabilitated pairs. In future studies, to separate such effects, a group of control birds would need to be caught and treated in the same manner as oiled birds. Through this these birds would experience the rehabilitation process and the stress of captive confinement and thus once released if these birds also had reduced breeding success it could then be confirmed that captive stress contributes to reduced hatching success. Conversely, if breeding success was not found to decrease in these penguins this would suggest that for oil-rehabilitated birds the toxic effects of oiling were the main cause of reduced productivity rather than captive stress. It would however only be feasible to include such a group if time, money and resources were sufficient to tend to this group as well as the oiled animals, otherwise the

survival of the oiled animals may be compromised as well as the efficacy of the rehabilitation process.

### **Future research suggestions**

If any other oil spills requiring an oiled wildlife response occur in New Zealand, it is recommended that post-release monitoring of the most affected species should also be conducted. This will enable further assessment of the oil-rehabilitation process, and if birds, besides little blue penguins, are monitored, the effectiveness of rehabilitating other species could also be determined. It is also recommended that efforts are made to determine ways in which such studies can be conducted so that they are cost-recoverable.

In addition to post-release monitoring studies, a number of other potential research topics regarding oil-rehabilitated wildlife could be investigated in future studies. Some suggestions include: determining whether the diet, distance and duration of foraging trips, and frequency and length of burrow visits (during the breeding season) differ between oil-rehabilitated and control birds; undertaking hydrocarbon analyses of abandoned eggs to determine the persistence of oil residues in oil-affected environments; undertaking post-mortem examinations and tissue analyses of dead rehabilitated birds (and their chicks) to identify their causes of death and to look for the presence of residual hydrocarbons; taking measurements of chicks raised by rehabilitated birds to enable sexing so that it can be assessed whether there is a skew in the proportion of male to female chicks produced by rehabilitated pairs; gaining pre-emptive information on the survival and productivity history of seabird populations near busy or prominent ports and shipping areas so that pre-spill data is present if a spill were to occur; and gaining a better understanding of the effects of captive stress on post-release survival and productivity of rehabilitated animals.

### **Importance of reducing the frequency of oil spills and conducting post-release monitoring**

Although techniques to rehabilitate oiled wildlife are improving, as demonstrated by an increase over time in post-release survival and productivity rates of oil-rehabilitated animals, these techniques are only ever reactive mitigation methods that in general save

only a small proportion of oiled wildlife. In reality many more birds die from oil contamination than can be ever be saved by rehabilitation (Goldsworthy et al. 2000b). This highlights the importance of focusing efforts on reducing the frequency and severity of oil spills in general (Morant et al. 1981; Fowler et al. 1995; Sharp 1996; Altwegg et al. 2008) but particularly in busy shipping areas in close proximity to seabird colonies and their foraging grounds (Wolfaardt et al. 2009b). It is an unrealistic goal however to stop oil spills from occurring, as so long as oil is transported by sea it is inevitable that accidental oil spills will occur despite legislations, policies, care and policing (Partridge 1997). It is also inevitable that due to public demand, rehabilitation of oiled wildlife will still be performed (Estes 1998). This reinforces the need to prioritise protection of wildlife habitat during an oil spill response to minimise the number of animals that become oiled, although it should be acknowledged that there will always be competing resources at risk, including environmental, cultural and economic. Appropriate protection methods for wildlife habitat will be entirely dependent on the spill circumstances, but may include techniques such as booming (in particular of estuaries and inshore harbour areas); dispersant use (where the net environmental benefit analysis indicates its use is appropriate); and various shoreline clean-up techniques (K. Morgan, pers. comm.). It is also very important to have oil spill contingency plans and preparations in place to enable prompt, efficient and hopefully more successful rescue and rehabilitation operations to be conducted. Furthermore, it is imperative that time, money, and effort are continued to be invested in conducting post-release monitoring studies of oil-rehabilitated wildlife so the effectiveness of oil-rehabilitation can continue to be assessed and improved over time to maximise success (Wernham et al. 1997; Newman et al. 2004).

## **Thesis conclusion**

In summary, the main findings of the survival component of this study indicated that there was no post-release mass mortality of oiled little blue penguins rehabilitated after the C/V *Rena* oil spill, and that the survival of rehabilitated penguins was similar to that of control penguins throughout the study period. Furthermore, post-release survival of rehabilitated penguins was not influenced by oiling degree, admission and release BMI (body mass index), admission PCV (packed cell volume), TP (total protein), and BG (blood glucose), or captive

duration. It was also found that upon release rehabilitated penguins had higher masses than control penguins, however four months after release their masses had reduced and were similar to control penguins, and thereafter remained so. Behaviourally, rehabilitated penguins were generally more likely to stay when approached by people and were more docile than control penguins, although no systematic changes in behaviour were observed as handling frequency increased.

The main findings of the post-release productivity component of this study indicated that rehabilitated penguins were capable of breeding, and doing so successfully as with the exception of hatching success, all reproductive parameters measured were similar between rehabilitated and control pairs. Hatch, fledge and egg success rates were also within ranges (sometimes towards the higher end) reported for other little blue penguin colonies in New Zealand and Australia. Pre-fledging chick masses were also similar between control and rehabilitated pairs, but low when compared to masses reported at other colonies. This reduction may have been due to reduced food availability during the breeding season or it is possible that little blue penguins (both adults and chicks) generally weigh less in the Bay of Plenty than at other colonies due to geographic and/or climatic factors. Sample sizes were too small to determine whether any predictor variables had an effect on hatching and fledging success.

Overall, these results suggest that the rehabilitation process used in New Zealand following the *C/V Rena* oil spill was reasonably effective at treating any negative effects of oiling on the post-release survival and productivity of oiled little blue penguins. This indicates that treating and rehabilitating the penguins was a worthwhile conservation action as the rehabilitated birds were able to survive and reproduce and thus contribute to the recovery of the oil-affected populations. These findings support the continued conductance of oiled wildlife rehabilitation in New Zealand and highlight the importance of undertaking post-release monitoring of rehabilitated animals so that the efficacy of this process can continually be assessed and improved over time to maximise success.

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