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Assessing avian mortality during oil spills: a case study of the New Zealand MV 'Rena' oil spill, 2011

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ABSTRACT: Determining the effects of oil spills on wildlife can be difficult. The collection and publication of data on wildlife impacts and mortalities from oil spills are vital steps to help understand overall effects. However, the way wildlife are collected and processed affects the results and how information can be used. Information for threatened and endangered species is particularly important, as effects on small population size or range-restricted species need to be evaluated as accurately as possible. This paper outlines the procedures for the collection of wildlife, both alive and dead, during the first 6 wk following the MV 'Rena' incident in New Zealand and discusses these processes in terms of assessing mortality. The container ship MV 'Rena' struck the Astrolabe Reef, 22 km off Tauranga, New Zealand, spilling an estimated 350 t of heavy fuel oil on 5 October 2011. An oiled-wildlife response team undertook search and collection of all live oiled and all dead birds in the affected area. In the first 6 wk of the response, 428 live birds were taken into the rehabilitation facility, and 1376 oiled and 687 unoiled bird carcasses (representing 49 species) were assessed. To maximise information gathering from oil spill mortalities, we recommend the development of clear collection procedures and documentation, experts for species identification and, where possible, necropsies of carcasses. Direct counts of mortality and post-release (for rehabilitated wildlife) monitoring studies of oiled wildlife are still rare; however, this is critical research that should be undertaken during and after oil-spill events.

KEY WORDS: Seabird mortality · Oil spill response · Impact · Wildlife

1. INTRODUCTION

Marine oil spills impact environments and wildlife populations throughout the world (Burger 1993, Camphuysen & Heubeck 2001, Henkel & Ziccardi 2018). The effects of oil spills commonly extend over wide spatial scales and may combine with environmental factors to cause fluctuations in wildlife populations, particularly those already endangered or range restricted (Votier et al. 2005, 2008). Oil spills can cause large wildlife, and particularly avian, mortality events, as was the case, for example, with the 'Torrey Canyon' spill in 1967 in France and England; the 'Exxon Valdez' spill in Alaska in 1989; and the 'Prestige' spill in Spain in 2002 (Bourne et al. 1967, Ford et al. 1996, Piatt & Ford 1996, Velando et al. 2005, Moreno et al. 2011). Research into oil spill effects shows a variety of immediate (Eppley & Rubega 1990, Burger 1993, Piatt & Ford 1996, Golet et al. 2002, Wolfaardt et al. 2008, Antonio et al. 2011, Munilla et al. 2011) and long-term effects

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for wildlife (Monson et al. 2000, Golet et al. 2002, Alonso-Alvarez et al. 2007, Altwegg et al. 2008). However, the overall effects of oil spills on wildlife populations are still poorly understood. Oil spills are geospatially and temporally unpredictable events, and reliable publication of raw data on their effects is vital to allow researchers, industry and government authorities to understand trends, impacts and biological effects across multiple spill events.

Exposure of birds to petroleum products alters feather structure, causing birds to lose buoyancy, insulation and flight capability (Leighton 1993, O'Hara & Morandin 2010, Matcott et al. 2019). Most birds exposed to and contaminated by oil will likely die from drowning, hypothermia or starvation (Jessup & Leighton 1996, Clark 2001), and if birds die at sea, often their carcasses are never recovered (Piatt & Ford 1996). Estimating the long-term impact and direct mortality on avian species caused by an oil spill is technically difficult, as it is often not possible to observe or collect every individual affected by oil. As a consequence, estimates of the immediate avian mortality from oil spills are most frequently derived from the number of birds found dead on shorelines following a spill (e.g. Piatt & Ford 1996, Flint et al. 1999, Munilla et al. 2011).

The number of oil-affected bird carcasses found on shorelines represents a minimum estimate of the likely mortality from an oil spill. From these numbers, either a probability-based expansion factor is used in a mortality model to account for birds that are killed but not collected (Wiese 2003, Wiese & Robertson 2004, Munilla et al. 2011), or an estimated mortality based on the numbers of birds present and vulnerable to lethal exposure is used to estimate total mortality (Wilhelm et al. 2007, Haney et al. 2014). Both estimates (a mortality model or an estimated mortality model) theoretically account for birds that die but disappear before arriving on shore (Wiese 2003, Wiese & Robertson 2004, Munilla et al. 2011), and those on shore that go undetected by spill responders (Van Pelt & Piatt 1995, Byrd et al. 2009). However, models of seabird mortality during an oil spill must be able to handle missing data and many sources of uncertainty; for example, estimating seabird mortality based on the numbers of birds present and vulnerable to lethal exposure assumes the availability of biological data from before the spill (Wilhelm et al. 2007, Haney et al. 2014). For the majority of the world's coastal areas, and many endangered or threatened species, particularly truly pelagic avian species, such biological data either do not exist, or are not available in sufficient detail to be useful for this sort of estimate.

On 5 October 2011, the container ship MV 'Rena' struck the Astrolabe Reef (37° 33′ 37″ S, 176° 23′ 47″ E), 22 km off Tauranga, New Zealand, and spilled an estimated 350 t of heavy fuel oil (HFO 380). This paper outlines the process and procedures for the collection and identification of birds that were brought into the facility for rehabilitation and those that died or were found dead during the first 6 wk following the 'Rena' incident in New Zealand and reports the known geographically traceable mortality related to the spill event. On a global scale, the volume of oil spilt during the 'Rena' incident was relatively small; however, the oil leaked for several weeks and the spill occurred close to important wildlife breeding and foraging areas, affecting both resident and migratory, common and threatened avian species (Schiel et al. 2016). Based on the 'Rena' experience, we make recommendations for the development of clear collection procedures, including careful documentation, pre-identification of experts who can identify species and the necropsies of carcasses wherever possible to help determine likely cause(s) of death.

2. MATERIALS AND METHODS

The MV 'Rena' struck the Astrolabe Reef on 5 October 2011 (Fig. 1). A coordinated oil spill response led by Maritime New Zealand, including New Zealand's National Oiled Wildlife Response Team led by Wildbase, Massey University, was deployed on the same day as the spill, including the establishment of an oiled-wildlife rehabilitation facility and post-mortem processing centre. Searches of beaches in the area of the spill began on the morning of 7 October for live oiled birds and all dead birds, after ensuring health and safety plans and procedures were in place, allowing appropriate field personnel with personal protection equipment to be deployed.

2.1. Collection methods

Birds (alive and dead) were collected in 2 ways: (1) using targeted coastal searches of the Bay of Plenty and its islands and; (2) following reports from the public of locations of live and dead birds. Additionally, dead birds were either collected opportunistically by oil-spill responders or died while under care in the wildlife rehabilitation facility.

Field teams that undertook coastal searches were instructed to collect any dead bird and any visibly

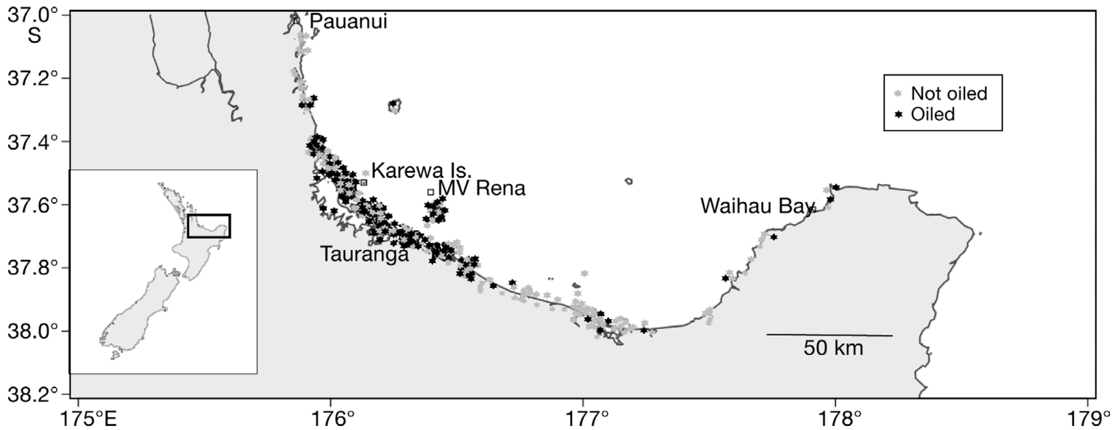

Fig. 1. Location and oiling status of bird carcasses recovered during the first 6 wk of the MV 'Rena' spill response, 11 October to 18 November 2011. The location of the 'Rena' wreck is also indicated

oiled live birds (any live bird oiled >5% externally was considered visibly oiled) or any unoiled birds that showed signs of starvation/exhaustion or were for other reasons unable to fly (i.e. pre-existing injuries) if they could be safely collected (Sievwright et al. 2019). All accessible coastlines between Pauanui, Coromandel Peninsula, and Waihau Bay, Bay of Plenty (Fig. 1), were searched within the first week, with priority given to areas where oil trajectory modelling predicted and/or aerial surveillance confirmed that oil had reached. After the first week, collections primarily occurred while searching areas where oil response beach clean-up crews were working or where the public called in locations of carcasses or live oiled birds, except in the fourth week, when the ship broke up and therefore searching was again concentrated on areas where aerial surveillance confirmed new oil had washed ashore. Field teams carried collection equipment, including pre-printed waterproof tags with spaces for recording band numbers (if the animal was banded); capture method; species (if known); capture date, time and location; name of the collector; status (alive or dead) at time of capture; degree of oiling; and date and time of departure from the capture location. Field teams comprised a minimum of 2 persons, and each person wore rubber boots, nitrile gloves and Tyvek® (Dupont) suits to protect themselves from oil contamination. In the first 2 d of collection, in areas with high densities of dead birds, carcasses were collected and were combined in retrieval bags due to restricted initial resources; however, this practice was discontinued on Day 3 to minimise cross contamination of oiled and unoiled carcasses.

During the 'Rena' response, areas known to be habitat for little blue penguins *Eudyptula minor* were monitored for approximately 30 min before and 2 h after sunset by field teams, primarily to collect live, oiled penguins coming to or leaving the shore; any dead birds found were also collected. Additionally, any animal that died while in care at the oiled-wildlife rehabilitation facility was collected and necropsied (Gartrell et al. in press). All collected dead animals were processed at the oiled-wildlife facility post-mortem area. For further results and discussion on live bird treatment, see Gartrell et al. (in press).

2.2. Species identification and data collection

All birds, live or dead, were processed at the oiled-wildlife facility. All dead birds brought to the facility were identified to species by an expert ornithologist, and when available, data on location and date of collection were recorded. Similarly, the species of all live birds was identified, location and date of capture were documented, and animals were then subject to a triage and rehabilitation process as outlined by Gartrell et al. (in press). All individuals that died in the wildlife rehabilitation facility were necropsied by a veterinary pathologist, along with as many carcasses as possible collected from shoreline searches to help determine cause of death.

3. RESULTS

In total, 428 live seabirds were admitted to the oiled-wildlife facility (Gartrell et al. in press) and 2063 bird carcasses, from 49 species, were processed between 11 October and 18 November 2011, with 1376 (67%) of the carcasses recorded as oiled. The majority of live birds admitted were little blue penguins (n = 394), with lower numbers of other seabirds including common diving petrels *Pelecanoides urinatrix* (n = 10), pied shags *Phalacrocorax varius* (n = 5), and grey faced petrels *Pterodroma macroptera* (n = 5; Gartrell et al. in press). Most live seabirds admitted (393/428; 91.8%) had contamination of their plumage with heavy fuel oil, while the remainder (35/428, 8.2%) were found without oil but were starving/exhausted or had pre-existing injuries (Gartrell et al. in press).

The numbers of animals brought in live and as carcasses, based on species and percentage of oiled birds, are presented in Table 1. The majority (67%) of the carcasses were found in the first week after the grounding of the MV 'Rena', with another 15% found in the fourth week (Fig. 2). The number of bird carcasses processed each week, and the numbers of oiled and unoiled carcasses processed, are presented in Fig. 2. For the 4 most common species impacted by this spill (combined total n = 1697), the numbers of carcasses of each species processed each week, along with numbers of oiled and unoiled birds, are presented in Fig. 3. There are no records, and therefore there is no way of determining, the number of birds that could have been cross-contaminated in the first 2 d when non-oiled carcasses may have been combined in retrieval bags with oiled carcasses. The geographic locations of bird carcasses recovered with geographic data (n = 1657), and whether they were oiled or not, are presented in Fig. 1. Carcasses (n = 327) from 26 species were necropsied, with the primary diagnosis of extensive oiling (likely causing hypothermia and or drowning) applying to 71% of all necropsied oiled birds, followed by dehydration/starvation (21%) for oiled birds (Table 2). For unoiled carcasses, the primary diagnosis for cause of death was dehydration/starvation (39%, Table 2); in addition, 32% were classified as decomposed, but their state of decomposition made it unlikely that these deaths were caused by the spill or response. Trauma was only found in unoiled birds, while 'other' known causes of death represented 8 and 10%, respectively, for oiled and unoiled birds (Table 2). Examples of 'other' causes were the swallowing of fish hooks or fishing line, egg peritonitis and broken bones. All animals that were brought into the rehabilitation facility and that died, or were euthanized, were animals that had been oiled; therefore, their necropsy results are included in the oiled wildlife results (Table 2). Of the individuals for which sex was determined, there was a slight bias towards higher numbers of females (Table 2).

4. DISCUSSION

During the MV 'Rena' incident response, 1376 oiled and 687 unoiled bird carcasses were assessed from 49 species, with 16% of the carcasses necropsied. There are several mechanisms by which oil-related mortality can go unobserved during and after a spill, and equally, mechanisms by which non-oil-related mortality could be mistaken for oil-related mortality, such as seen in the first 2 d of this spill response where combining carcasses in retrieval bags may have caused cross-contamination between oiled and unoiled birds. During an oil spill, coastlines will contain carcasses of animals that died before the oil spill, and animals that died during the oil spill. An animal that has died during an oil spill may or may not be discovered by searchers. Animals that die during an oil spill could have died as a direct (e.g. lethal direct exposure to oil or fumes, or consumption of oiled prey) or indirect (e.g. starvation from a lack of prey, if prey are directly killed by oil) consequence of the oil spill (Jessup & Leighton 1996), or from other causes as indicated above and in Table 2. Additionally, for ship-based oil spills, additional materials transported by the vessels may also cause deaths. For example, milk powder and microplastic beads were both cargo in containers that were lost overboard during the 'Rena' incident for which there was concern for the environment and impacts on wildlife (Battershill et al. 2016). For at least 1 necropsy, a bird was recorded as having ingested milk powder, and this was recorded as its primary cause of death, likely due to metabolic acidosis; however, no necropsied bird was identified as having died from ingestion of microbeads. Mortality from the oil spill and the response does not mean that an animal will be visibly oiled. Other factors such as inhalation of fumes, ingestion of oil, death from response activities or starvation from changes in the ecosystem or prey species due to the oiling event could all be reasons for an individual's death without evidence of external oiling.

During the period of a spill, and the spill response, natural and other anthropogenic deaths of birds will also occur, and these carcasses can be found on shorelines by oil spill responders. If possible, this background mortality should be separated from spill-related mortality, by necropsying as many carcasses as practicable of both oiled and unoiled carcasses to try to determine the cause of death. Similar to many spills, there was no documented known background mortality data for avian species for this area before the spill. Distinguishing between non-spill and spill-related mortality is difficult, usually requiring data on

Table 1. Species, threat classification and number of birds brought in live or dead and processed at the oiled-wildlife facility during the first 6 wk of the MV ‘Rena’ spill response from 11 October to 18 November 2011. New Zealand threat status from Robertson et al. (2017); IUCN status from https://www.iucnredlist.org/. Percentage of birds in last column shows % oiled live / % oiled dead; however, if no live birds were brought in, the value given is for dead birds only

Common name	Species	New Zealand threat status	IUCN threat status	Number live	Number of carcasses	% of birds oiled live/carcass
Black swan	*Cygnus atratus*	Not threatened	Least Concern	0	1	0
Mallard + hybrid	*Anas platyrhynchos*	Introduced	Least Concern	0	2	0
Paradise shelduck	*Tadorna variegata*	Not threatened	Least Concern	0	1	0
Canada goose	*Branta canadensis*	Introduced	Least Concern	0	2	50
Little blue penguin[a]	*Eudyptula minor*	At risk	Least Concern	394	114	96/79
Wandering albatross	*Diomedea exulans*	Naturally uncommon	Vulnerable	0	1	100
Chatham Island mollymawk	*Thalassarche eremita*	Naturally uncommon	Vulnerable	0	1	0
White-capped mollymawk	*Thalassarche cauta steadi*	At risk	Near Threatened	0	1	100
Northern giant petrel	*Macronectes halli*	Recovering	Least Concern	0	3	100
Cape petrel	*Daption capense*	Migrant	Least Concern	0	5	40
Grey-faced petrel	*Pterodroma gouldi*	Not threatened	Least Concern	5	5	60/60
White-headed petrel	*Pterodroma lessonii*	Not threatened	Least Concern	0	1	0
Mottled petrel	*Pterodroma inexpectata*	Relict	Least Concern	0	3	33
Blue petrel	*Halobaena caerulea*	Migrant	Near Threatened	0	23	52
Prion sp.	*Pachyptila* sp.	–	–	0	3	0
Antarctic prion	*Pachyptila desolata*	Naturally uncommon	Least Concern	0	7	71
Fairy prion	*Pachyptila turtur*	Relict	Least Concern	0	16	63
White-chinned petrel	*Procellaria aequinoctialis*	Not threatened	Least Concern	0	2	0
Buller’s shearwater	*Ardenna bulleri*	Naturally uncommon	Vulnerable	1	222	100/70
Flesh-footed shearwater	*Ardenna carneipes*	Nationally vulnerable	Near Threatened	0	69	7
Sooty shearwater	*Ardenna grisea*	At risk	Near Threatened	3	211	33/19
Little shearwater	*Puffinus assimilis*	Recovering	Least Concern	0	21	95
Fluttering shearwater	*Puffinus gavia*	Relict	Near Threatened	3	270	100/89
White-faced storm petrel	*Pelagodroma marina*	Relict	Least Concern	0	73	70
Common diving petrel	*Pelecanoides urinatrix*	Relict	Least Concern	10	880	60/80
Storm petrel sp.	Subfamily Oceanitinae	–	–	1	7	0/100
Australasian gannet	*Morus serrator*	Not threatened	Least Concern	3	34	0/12
Shag sp.	*Phalacrocorax* sp.	–	–	0	2	50
Black shag	*Phalacrocorax carbo*	Naturally uncommon	Least Concern	0	2	0
Little shag	*Phalacrocorax melanoleucos*	Not threatened	Least Concern	0	2	0
Spotted shag	*Phalacrocorax punctatus*	Not threatened	Least Concern	0	4	50
Little black shag	*Phalacrocorax sulcirostris*	Naturally uncommon	Least Concern	0	3	0
Pied shag	*Phalacrocorax varius*	Recovering	Least Concern	5	15	60/5
White-faced heron	*Egretta novaehollandiae*	Not threatened	Least Concern	1	1	0/0
Bar-tailed godwit	*Limosa lapponica*	At risk	Near Threatened	0	1	100
Pukeko	*Porphyrio porphyrio melanotus*	Not threatened	Least Concern	0	4	0
Variable oystercatcher	*Haematopus unicolor*	Not threatened	Least Concern	0	1	100
Oystercatcher sp.	*Haematopus* sp.	–	–	0	1	0
Red-billed gull	*Chroicocephalus scopulinus*	At risk	Least Concern	1	8	0/25
Black-backed gull	*Larus dominicanus*	Not threatened	Least Concern	0	7	29
White-fronted tern	*Sterna striata*	Nationally vulnerable	Near Threatened	1	1	0/0
Rock pigeon	*Columba livia*	Introduced	Least Concern	0	10	20
Tui	*Prosthemadera novaeseelandiae*	Not threatened	Least Concern	0	2	50
Sacred kingfisher	*Todyramphus sanctus*	Not threatened	Least Concern	0	1	100
Australian magpie	*Gymnorhina tibicen*	Introduced	Least Concern	0	5	0
Blackbird	*Turdus merula*	Introduced	Least Concern	0	2	50
Starling	*Sturnus vulgaris*	Introduced	Least Concern	0	3	67
House sparrow	*Passer domesticus*	Introduced	Least Concern	0	1	0
Unidentified	Unidentified	–	–	0	9	33
Total and overall percentage oiled				428	2063	67

[a]The number of little blue penguins collected is likely to be biased upwards as their habitat was specifically monitored by field teams to collect live and retrieve oiled penguins coming ashore, which did not occur for any other species

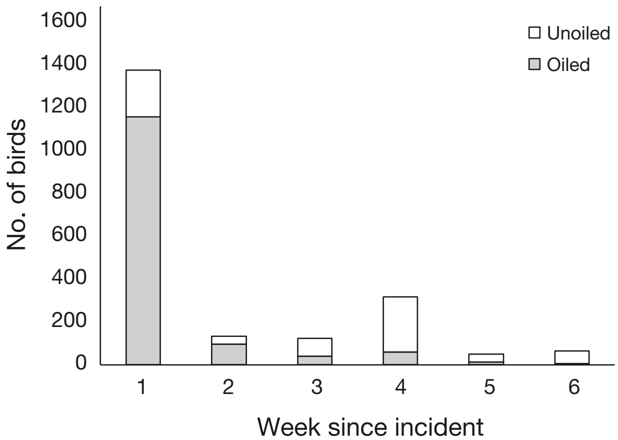

Fig. 2. Total number of bird carcasses processed at the oiled-wildlife facility by week during the first 6 wk of the MV 'Rena' spill response, 11 October to 18 November 2011

individual age and reproductive class, species composition, location of carcasses and timing of decomposition. Additionally, there are numerous anatomical and physiological effects of oil ingestion or inhalation that can be difficult to detect, or to differentiate from other possible causes of death, even upon necropsy. Data compiled from a variety of spills indicate that using visible oiling as the primary criterion for linking the spill to bird injury probably underestimates spill-related injuries by a factor of about 50% (Helm et al. 2015). However, for most oiled seabirds, the proximal causes of death are likely to be hypothermia, drowning (caused by extensive external oiling) and starvation, as found in the present study (Table 2).

Other spill events have confirmed that oiled carcasses at sea can sink or are scavenged, preventing them from reaching shore and therefore preventing their collection (Wiese 2003, Munilla et al. 2011, Wiens et al. 2011). Thus, the 'Rena' carcass assessment figures are likely to be a minimum estimate of the mortality caused in the first 6 wk the oil spill. A number of conditions can influence the successful retrieval of live and dead birds from coastlines during an oil spill. These can include prevailing winds and currents, the search effort and the area searched. Experiments using drift blocks have reported recovery rates ranging from 0.7 to 61%, depending on the combination of these factors (Hlady & Burger 1993, Flint et al.

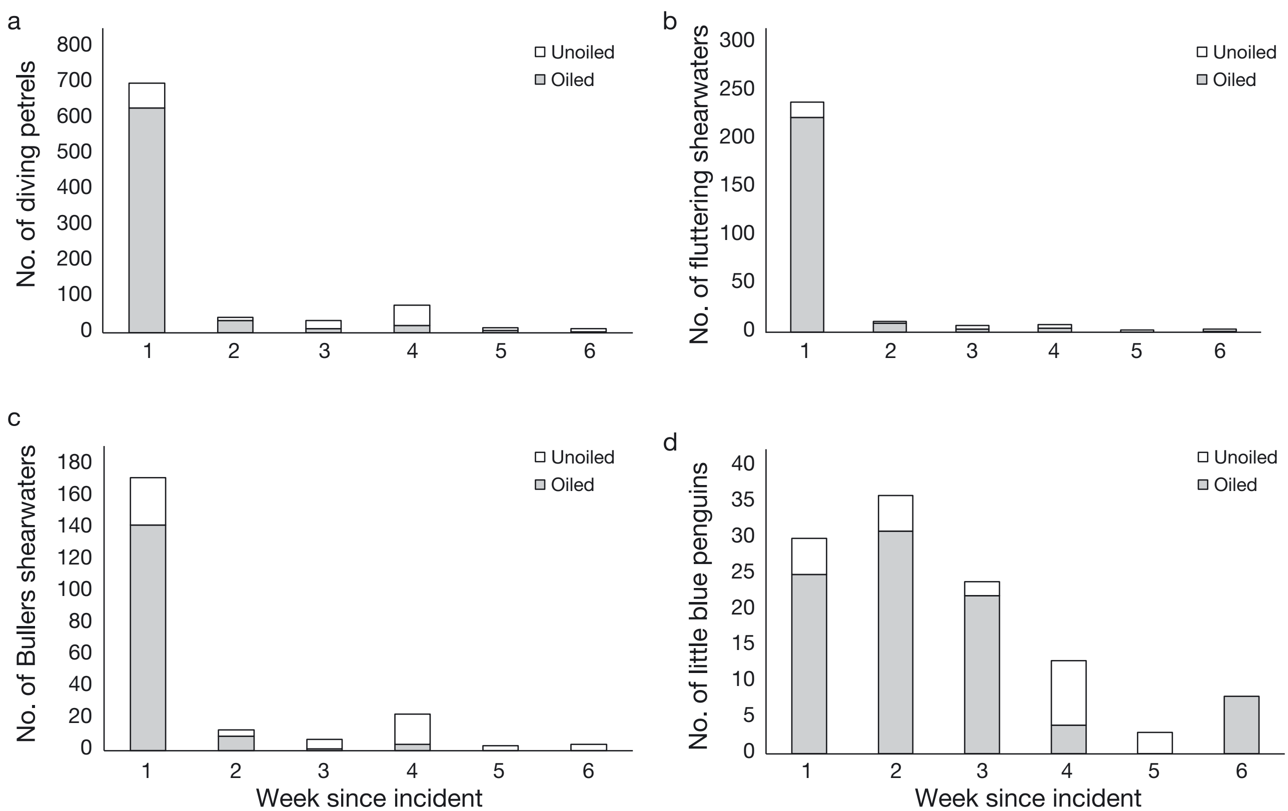

Fig. 3. Total number of bird carcasses processed at the oiled-wildlife facility in the first 6 wk of the MV 'Rena' response by week for the 4 most prevalently oiled species: (a) common diving petrel, (b) fluttering shearwater, (c) Buller's shearwater and (d) little blue penguin. Note different *y*-axis scales

Table 2. Primary necropsy diagnoses from carcasses collected and processed at the oiled-wildlife facility during the first 6 wk of the MV 'Rena' spill response from 11 October to 18 November 2011. Shown are species, total numbers necropsied (N), divided into those that died in the facility (on site)/those that were collected dead (dead on arrival, DOA) for species where appropriate, numbers of each sex (where known); and percentages (number of individuals (n) in parentheses) of each primary diagnosis for oiledor unoiled birds. 'Other' refers to causes of death that were not oil-spill related, such as egg peritonitis or swallowing fish hooks

Species	Birds necropsied			Primary necropsy diagnosis, % (n)						
				Oiled			Unoiled			
	N (died on site/DOA)	Males (n)	Females (n)	Dehydration/ starvation	Extensive oiling	Other	Dehydration/ starvation	Trauma	Other	Decomposed &/or unknown
Australasian gannet	9 (3/6)	4					33 (3)	33 (3)		33 (3)
Little blue penguin	63 (28/35)	23	34	15 (7)	67 (29)	22 (10)	41 (7)	18 (3)		41 (7)
Blue petrels	7	1	1	100 (3)			50 (2)		25 (1)	25 (1)
Buller's shearwater	44 (1/43)	16	4	5 (1)	95 (18)		64 (16)		4 (1)	32 (8)
Cape petrel	2	1					50 (1)			50 (1)
Chatham Island albatross	1		1				100 (1)			
Common diving petrel	78 (10/68)	17	24	22 (12)	72 (39)	6 (3)	18 (4)	4 (1)	20 (5)	58 (14)
Fairy prion	1									100 (1)
Flesh-footed shearwater	17	3	14					77 (13)	18 (3)	5 (1)
Fluttering shearwater	46 (2/44)	10	9	10 (4)	90 (35)		28 (2)	14 (1)	14 (1)	44 (3)
Sacred kingfisher	1		1	100 (1)						
Little shearwater	1									100 (1)
Australian magpie	1									100 (1)
Mallard duck	1									100 (1)
Mottled petrel	1	1					100 (1)			
Northern giant petrel	2	1			50 (1)	50 (1)				
Pied shag	9 (2/7)	2	5	100 (1)			50 (4)	25 (2)		25 (2)
Pukeko	1							100 (1)		
Red-billed gull	3 (1/2)	1	2	100 (1)					50 (1)	50 (1)
Sooty shearwater	25 (3/22)	14	10	100 (2)			65 (15)	21 (5)	9 (2)	5 (1)
Spotted shag	2		1	100 (1)			100 (1)			
Storm petrel sp.	1	1							100 (1)	
Wandering albatross	1	1		100 (1)						
White-chinned petrel	2		2				100 (2)			
White-faced storm petrel	7		3	40 (2)	60 (3)					100 (2)
White-fronted tern	1 (1/0)	1								100 (1)
Totals / averages	327 (51/276)	29%	34%	21%	71%	8%	39%	19%	10%	32%

1999). Other studies have demonstrated that these drift block experiments overestimate recovery rates, as many birds are lost due to sinking, scavenging or predation, all of which are unlikely to affect a block (Wiese 2003, Munilla et al. 2011, Wiens et al. 2011). However, due to the considerable sources of uncertainty estimating or modelling total mortality in other ways, we have not attempted to determine total mortality here. For future spill events, to facilitate the modelling of mortality, clear, documented carcass collection procedures, including search effort should be followed, to allow for temporal and geographical identification of carcass recovery.

One of the indicators that the actual mortality during the 'Rena' oil spill was likely to be higher than presented here is the type of species known to live and breed in the area. For example, diving petrels and shearwaters are all pelagic seabird species that spend the majority of their lives at sea, only coming ashore to breed and raise young. Oil trajectory maps from the 'Rena' showed that a major slick of heavy fuel oil circulated in the Bay of Plenty and surrounding areas for many days immediately after the grounding, before being driven ashore by prevailing winds and tides (Gartrell et al. in press). Therefore, there was ample opportunity for these species to be exposed to oil, and if oiled, for their carcasses to sink or be scavenged at sea, long before winds and tides would have washed their carcasses (and the oil) ashore. Unfortunately, some of the petrel and shearwater species identified during the 'Rena' response are also species with the highest threat classifications (many with 'vulnerable', 'at risk' and 'relict' classifications in New Zealand; Table 1). Thus, not being able to fully track or record individual mortality, and therefore underestimating mortality, could be an even greater problem for these species than for non-threatened species (Table 1).

4.1. Temporal and spatial distribution

Of the carcasses, 67% were found in the first week after the grounding of the 'Rena', with another 15% in the fourth week, when the vessel undergoing salvage was affected in a storm and there was a significant additional release of oil from the vessel (Figs. 2 & 3). Many seabirds die or are unable to fly immediately after contact with oil, and it is common for live and dead birds to begin beaching within hours of a nearshore spill (Ford 2006). Typically, the number of seabirds recovered ashore peaks within days of the initial release and then declines steadily over a period, assuming no further releases of oil (Ford 2006). This is particularly true for the smaller pelagic seabirds such as diving petrels and shearwaters, whereas the carcasses of the larger, more robust little blue penguins were more evenly spread over the 6 wk (Fig. 3). It should also be noted that the number of little blue penguins collected is likely to be biased upwards, as their habitat was specifically monitored by field teams to retrieve live oiled penguins coming ashore; this was not the case for any other species.

Carcasses were found over a large coastal area of approximately 360 km (Fig. 1). Some of this spread would have been due to the fact that the 'Rena' grounding was 22 km from shore and therefore the influence of winds, tides and currents could spread the oil and carcasses over a larger area than if it was closer to shore. Some seabirds can fly or swim significant distances when lightly oiled or affected by inhalation or ingestion that is not immediately lethal (Fig. 1; Campbell et al. 1978, Ford 2006). However, the highest density of oiled carcasses was found along the shorelines closest to the 'Rena' grounding site (Fig. 1).

4.2. Known mortality and biological impacts

Accurately estimating the biological impacts of seabird mortality from an oil spill on seabird populations is difficult. Factors such as the area exposed to oiling, the species' population range and size, as well as the foraging range and the overall proportion of the species occurring within the range of the oil spill are all parameters that need to be known. Impacts of oil spills are most severe for isolated or small populations, or when other natural or anthropogenic factors are acting concurrently on the species or population. For example, a common murre *Uria aalge* breeding colony near San Francisco (California, USA) was extirpated by the 'Apex Houston' oil spill after the colony had been substantially impacted from 2 yr of high mortality due to a coastal gill net fishery and reduced productivity from 2 consecutive El Niño years (Carter et al. 2003). This is one of the reasons why New Zealand dotterels *Charadrius obscurus* were pre-emptively captured in the area of the 'Rena' spill to prevent their oiling (Gartrell et al. 2014). New Zealand dotterels are a sparsely distributed, 'at risk' species (Robertson et al. 2017), which suffers from extensive predation by domesticated and introduced pest predators in New Zealand. The pre-emptive capture of this species likely accounts for the absence of their carcasses from beach searches in our mortality data, despite substantial range overlaps with the oiled area. It is also noted in other studies that small-bodied birds (like dotterels) may be found at a much lower rate than larger birds (e.g. Ford & Zafonte 2009).

All of the national and global population estimates for the species of which at least 50 carcasses were found (Table 1), are near, or exceed, 1 million individuals or pairs, except flesh-footed shearwaters *Puffinus carneipes* and little blue penguins. This indicates that for those species with large populations, losing a relatively low number of individuals (100s) is likely to have restricted immediate effects; however, this cannot be truly determined without an understanding of all likely mortalities. For flesh-footed shearwaters, a nationally vulnerable species in New Zealand and classified by the IUCN as Near Threatened globally and with only an estimated 8000 breeding pairs in New Zealand (BirdLife International 2017), the loss of 69 individuals (Table 1) could have significant short- and long-term effects on the species, especially given that the majority of those necropsied were female (Table 2). Little research has been undertaken on this species in the area affected by the 'Rena' spill, but the species is known to breed in large numbers on the islands near where the spill occurred during the months of September to May, with egg-laying occurring in December each year, which overlaps with the timing of the spill and the ongoing response (Taylor 2013).

Little blue penguins were the species rehabilitated in the highest numbers (Gartrell et al. in press) during the 'Rena' event, as well as having a high number of known mortalities (n = 114, including individuals that died or were euthanized in the rehabilitation facility; Table 1). For this species, post-release monitoring studies have been conducted to evaluate survival and reproduction, (Sievwright et al. 2019, in press), post-spill diving and foraging behaviour (Chilvers et al. 2015) and for understanding corticosterone stress responses to determine if responses of oiled and rehabilitated birds differed from those of birds not oiled or rehabilitated but from the same area (Chilvers et al. 2016). Little blue penguins are recorded as a declining species, with unknown numbers in New Zealand, although they are widely distributed throughout New Zealand and Southern Australia, with an estimated total population of mature individuals of >400 000; BirdLife International 2017). Findings from the post-release research show that rehabilitated birds have survival rates, reproductive success, diving behaviour and stress response behaviours within the range of other reported little blue penguin populations around New Zealand and Australia (Chilvers et al. 2015, 2016, Sievwright et al. 2019, in press). These results are encouraging, as despite a likely immediate decrease in numbers caused by the mortality of individuals during the oil spill, the population in the area should be able to recover given sufficient time and protection.

4.3. Necropsy results

Publications of necropsy results from wildlife that died or suspected of dying during an oil spill are rare. During the 'Rena' response, 327 carcasses from 26 species were necropsied. Trauma and decomposition as primary diagnoses were recorded only in unoiled carcasses. Birds collected in the first week of the response with decomposition as a diagnosis (preventing true identification of cause of death) were likely to have died before the oil spill occurred and their deaths were not related to the oil spill itself. Trauma as a primary diagnosis, including damage by fish hooks, stabbing injuries and blunt trauma to the head, back and neck, was a common diagnosis for shearwater species. These injuries are unlikely to be related to the oil spill, although blunt trauma could be related to an oil spill response if the birds were unfortunate enough to get caught up in heavy machinery during the spill clean-up and boat salvage efforts.

For oiled carcasses, extensive oiling (71%), likely causing hypothermia and/or drowning, was by far the most frequent primary diagnosis, and it is likely that all of these deaths can be attributed directly to exposure to oil from the spill. For both oiled and unoiled carcasses, dehydration/starvation (21/39%) were common primary diagnoses, and these too are likely to be both directly (external oiling reducing ability to forage) and indirectly (with reduced prey availability or distribution disrupting foraging reported during many spill events; Jessup & Leighton 1996) related to oil spill and clean-up activities. The 'other' category for both oiled and unoiled carcasses included animals that had died or had to be euthanized in the facility as a result of 'common' captivity complications such as aspergillosis infections (even though all individuals were given itraconazole as a prophylaxis against aspergillosis from the first day they arrived at the facility), and diagnosable conditions such as egg peritonitis and broken bones. Although many of the 'other' category diagnoses may not be directly linked with the oil spill and response, for some of the oiled animals at least, they are indirectly linked, as without becoming oiled, birds would not have been brought into the facility and exposed to conditions they would not normally come across in the wild.

Here, we report only primary diagnoses, although many necropsies also included secondary diagnoses/complications related to cause of death. For example, for oiled carcasses, trauma was a common secondary diagnosis, particularly for extensively oiled carcasses. There are most likely links between these primary and secondary diagnoses with, for example, minor trauma, possibly increasing the birds' likelihoods of becoming oiled or decreasing their ability to avoid oil. For any primary diagnosis, secondary complications or conditions need to be taken into consideration when linking cause of death to the oil spill and the oil spill response; however, reporting all of these connections is difficult to present for so many necropsy results.

4.4. Limitations and recommendations

This research only reports known carcass recoveries from the field and deaths from within the rehabilitation facility, which will likely represent a minimum estimate of the total mortalities caused by the MV 'Rena' spill event and therefore restricts our understanding of likely total effects on species. Numerous factors influence the accuracy of seabird mortality estimates inferred from carcass recovery counts (Ford et al. 1996, Flint et al. 1999, Ford 2006, Byrd et al. 2009, Ford & Zafonte 2009). Additionally, factors such as biased sex ratios of mortalities, or the proportion of adults versus juvenile deaths, would also influence the effects on, and the recovery of, species after an incident (Nevins & Carter 2003). For avian species, unless fully necropsied, it is almost impossible to determine sex, and in many cases age, of individuals, particularly when subjects are covered in oil; therefore, for the majority of individuals in this study, these parameters were not known. We also faced the known initial problem of bagging together oiled and unoiled carcasses in the first 2 d. Together, all of these factors affect determining oil versus non-oil mortality. For example, Powlesland & Powlesland (1994) documented avian carcasses on New Zealand's beaches during 1993 and reported some Southern Ocean pelagic species such as petrels, e.g. *Pachyptila* and *Haloboena* spp., entering the Bay of Plenty mainly in winter, often dying of starvation and exhaustion. It is possible that carcasses of such species were mummified and recovered during the oil spill response beach searches some months later, as seen in the high number of diagnoses of decomposed/cause of death unknown for many of these species, particularly unoiled carcasses (Table 2).

From our previously established response protocols and lessons learnt from the 'Rena' spill, it is clear that preparedness and planning before a spill is the most critical recommendation not only for oiled-wildlife spill responses in general, but also for assessing avian mortality during an oil spill. In particularly, we recommend:

(1) Prior development of health and safety protocols, stockpiles of personal protective equipment, capture and collection equipment, and previously identified and trained personnel for recovery of live and dead wildlife;

(2) Development of clear collection procedures (i.e. single carcass per collection bag), clear documentation and location information recorded with the collection bag (see Section 2 for example information to be recorded);

(3) Documentation of search effort, including priority searches of areas where oil trajectory modelling predicts and/or aerial surveillance confirms that oil has washed ashore;

(4) Pre-determination and ability to employ experts during a spill response to identify affected species;

(5) Necropsies of carcasses wherever possible to collect additional important information such as sex and primary diagnosis of cause of death.

4.5. Conclusions

Collection and assessment of dead wildlife, both oiled and unoiled, is a critical part of any oiled-wildlife response, not only for record keeping but also importantly to reduce indirect mortality associated with other animals scavenging oiled bodies, to prevent remobilisation of oil and to reduce risks to human health and safety. Collection and assessment of carcasses also allows a likely minimum estimate of mortality caused by the spill and the response. Estimated spill mortality is only weakly correlated with the absolute volume of oil spilled; other factors, such as oil type, avian population density in the affected area, wind and wave action, distance of the spill site from the shore and temperature are all known to affect total mortality burdens during oil spills (Page et al. 1990, Burger 1993). As oil is removed from the environment, the direct impacts from the oil lessen, although long-term impacts may affect species survival rates over a scale of years to decades, and only become apparent with detailed demographic assessment (e.g. Monson et al. 2000). Relative to the number of oil spills that occur annually, oiled-wildlife response efforts, direct counts of mortality and post-spill/post-release (for rehabilitated wildlife) monitoring studies are still rare; however, this type of research needs to be undertaken during and after oiling events to fully understand the total and long-term impacts of oil spills on wildlife.

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LITERATURE CITED

Alonso-Alvarez C, Munilla I, López-Alonso M, Velando A (2007) Sublethal toxicity of the *Prestige* oil spill on yellow-legged gulls. Environ Int 33:773–781

Altwegg R, Crawford RJM, Underhill LG, Williams AJ (2008) Long-term survival of de-oiled Cape gannets *Morus capensis* after the *Castillo de Bellver* oil spill of 1983. Biol Conserv 141:1924–1929

Antonio FJ, Mendes RS, Thomas SM (2011) Identifying and modeling patterns of tetrapod vertebrate mortality rates in the Gulf of Mexico oil spill. Aquat Toxicol 105:177–179

Battershill CN, Ross PR, Schiel DR (2016) The MV *Rena* shipwreck: time-critical scientific response and environmental legacies. NZ J Mar Freshw Res 50:173–182

BirdLife International (2017) IUCN Red List for birds. www.birdlife.org

Bourne WRP, Parrack JD, Potts GR (1967) Birds killed in the Torrey Canyon disaster. Nature 215:1123–1125

Burger AE (1993) Estimating the mortality of seabirds following oil spills: the effects of spill volume. Mar Pollut Bull 26:140–143

Byrd GV, Reynolds JH, Flint PL (2009) Persistence rates and detection probabilities of bird carcasses on beaches of Unalaska Island, Alaska, following the wreck of the M/V *Selendang Ayu*. Mar Ornithol 37:197–204

Campbell LH, Standring KT, Cadbury CJ (1978) Firth of Forth oil pollution incident, February 1978. Mar Pollut Bull 9:335–339

Camphuysen CJ, Heubeck M (2001) Marine oil pollution and beached bird surveys: the development of a sensitive monitoring instrument. Environ Pollut 112:443–461

Carter HR, Lee VA, Page GW, Parker MW and others (2003) The 1986 *Apex Houston* oil spill in central California: seabird injury assessments and litigation process. Mar Ornithol 31:9–19

Chilvers BL, Morgan KJ, Finlayson G, Sievwright K (2015) Diving behaviour of wildlife impacted by an oil spill: a clean-up and rehabilitation success? Mar Pollut Bull 100: 128–133

Chilvers BL, Finlayson G, Candy EJ, Sriram A, Morgan KJ, Cockrem JF (2016) Corticosterone stress hormone responses in oil rehabilitated and non-rehabilitated little penguins. Mar Pollut Bull 113:312–315

Clark RB (2001) Marine pollution. Oxford University Press, New York, NY

Eppley ZA, Rubega MA (1990) Indirect effects of an oil spill: reproductive failure in a population of South Polar skuas following the 'Bahia Paraiso' oil spill in Antarctica. Mar Ecol Prog Ser 67:1–6

Flint PL, Fowler AC, Rockwell RF (1999) Modeling bird mortality associated with the M/V Citrus oil spill off St. Paul Island, Alaska. Ecol Modell 117:261–267

Ford RG (2006) Using beached bird monitoring data for seabird damage assessment: the importance of search interval. Mar Ornithol 34:91–98

Ford RG, Zafonte MA (2009) Scavenging of seabird carcasses at oil spill sites in California and Oregon. Mar Ornithol 37:205–211

Ford RG, Bonnell ML, Varoujean DH, Page GW and others (1996) Total direct mortality of seabirds from the Exxon Valdez oil spill. Am Fish Soc Symp 18:684–711

Gartrell BD, Collen R, Dowding JE, Gummer H and others (2014) Captive husbandry and veterinary care of northern New Zealand dotterels (*Charadrius obscurus aquilonius*) during the CV Rena oil-spill response. Wildl Res 40: 624–632

Gartrell BD, Battley P, Clumpner C, Dwyer W and others (in press) Captive husbandry and veterinary care of seabirds during the MV Rena oil spill response. Wildl Res (in press)

Golet GH, Seiser PE, McGuire AD, Roby DD and others (2002) Long-term direct and indirect effects of the 'Exxon Valdez' oil spill on pigeon guillemots in Prince William Sound, Alaska. Mar Ecol Prog Ser 241:287–304

Haney JC, Geiger HJ, Short JW (2014) Bird mortality from the *Deepwater Horizon* oil spill. I. Exposure probability in the offshore Gulf of Mexico. Mar Ecol Prog Ser 513: 225–237

Helm RC, Carter HR, Ford RG, Fry DM, Moreno RL, Sanpera C, Tseng FS (2015) Overview of efforts to document and reduce impacts of oil spills on seabirds. Fingas M (ed) Handbook of oil spill science and technology. John Wiley & Sons, Hoboken, NJ, p 431–448

Henkel LA, Ziccardi MH (2018) Life and death: How should we respond to oiled wildlife? J Fish Wildl Manag 9:296–301

Hlady DA, Burger AE (1993) Drift-block experiments to analyse the mortality of oiled seabirds off Vancouver Island, British Columbia. Mar Pollut Bull 26:495–500

Jessup DA, Leighton FA (1996) Oil pollution and petroleum toxicity to wildlife. In: Fairbrother A, Locke LN, Hoff GL (eds) Non-infectious diseases of wildlife. Iowa State University Press, Ames, IA, p 141–156

Leighton FA (1993) The toxicity of petroleum oils to birds. Environ Rev 1:92–103

Matcott J, Baylis S, Clarke RH (2019) The influence of petroleum oil films on the feather structure of tropical and temperate seabird species. Mar Pollut Bull 138: 135–144

Monson DH, Doak DF, Ballachey BE, Johnson A, Bodkin JL (2000) Long-term impacts of the *Exxon Valdez* oil spill on sea otters, assessed through age-dependent mortality patterns. Proc Natl Acad Sci USA 97:6562–6567

Moreno R, Jover L, Diez C, Sanpera C (2011) Seabird feathers as monitors of the levels and persistence of heavy metal pollution after the *Prestige* oil spill. Environ Pollut 159:2454–2460

Munilla I, Arcos JM, Oro D, Álvarez D, Leyenda PM, Velando A (2011) Mass mortality of seabirds in the aftermath of the *Prestige* oil spill. Ecosphere 2:1–14

Nevins HM, Carter HR (2003) Age and sex of common murres *Uria aalge* recovered during the 1997–98 Point Reyes Tarball Incidents in central California. Mar Ornithol 31: 51–58

O'Hara PD, Morandin LA (2010) Effects of sheens associated with offshore oil and gas development on the feather microstructure of pelagic seabirds. Mar Pollut Bull 60: 672–678

Page GW, Carter HR, Ford RG (1990) Numbers of seabirds killed or debilitated in the 1986 *Apex Houston* oil spill in central California. Stud Avian Biol 14:164–174

Piatt JF, Ford RG (1996) How many seabirds were killed by the *Exxon Valdez* oil spill? Am Fish Soc Symp 18:712–719

Powlesland RG, Powlesland MH (1994) Seabirds found dead on New Zealand beaches in 1993, with a review of *Sterna albostriata, S. caspia* and *S. striata* recoveries, 1943–1992. Notornis 41:275–286

Robertson HA, Baird K, Dowding JE, Elliott GP and others (2017) Conservation status of New Zealand birds, 2016. NZ Threat Classification Series 19. Department of Conservation, Wellington

Schiel DR, Ross PM, Battershill CN (2016) Environmental effects of the MV *Rena* shipwreck: cross-disciplinary investigations of oil and debris impacts on a coastal ecosystem. NZ J Mar Freshw Res 50:1–9

Sievwright KA, Battley PF, McConnell HM, Armstrong DP, Morgan KJ (2019) Survival rates of oil-rehabilitated and non-rehabilitated little penguins after the C/V *Rena* oil spill, New Zealand. Mar Pollut Bull 146:317–325

Sievwright KA, Battley PF, McConnell HM, Chilvers BL, Morgan KJ (in press) Post-release breeding success of oil-rehabilitated and non-rehabilitated little penguins following the M/V Rena oil spill, New Zealand. Mar Pollut Bull (in press)

Taylor GA (2013) Flesh-footed shearwater. In: Miskelly CM (ed) New Zealand birds online. www.nzbirdsonline.org.nz/species/flesh-footed-shearwater

Van Pelt TI, Piatt JF (1995) Deposition and persistence of beachcast seabird carcasses. Mar Pollut Bull 30:794–801

Velando AD, Mouriño AJ, Arcos F, Barros A (2005) Population trends and reproductive success of the European shag *Phalacrocorax aristotelis* on the Iberian Peninsula following the *Prestige* oil spill. J Ornithol 146:116–120

Votier SC, Hatchwell BJ, Beckerman A, McCleery RH, Hunter FM (2005) Oil pollution and climate have wide-scale impacts on seabird demographics. Ecol Lett 8: 1157–1164
Votier SC, Birkhead TR, Oro D, Trinder M, Grantham MJ (2008) Recruitment and survival of immature seabirds in relation to oil spills and climate variability. J Anim Ecol 77:974–983
Wiens JA, Day RH, Murphy SM (2011) Oil and marine birds in a variable environment. In: Wiens JA (ed) Oil in the environment: legacies and lessons of the *Exxon Valdez* oil spill. Cambridge University Press, Cambridge, p 318–347
Wiese FK (2003) Sinking rates of dead birds: improving estimates of seabird mortality due to oiling. Mar Ornithol 31: 65–70
Wiese FK, Robertson GJ (2004) Assessing seabird mortality from chronic oil discharges at sea. J Wildl Manag 68:627–638
Wilhelm SI, Robertson GJ, Ryan PC, Schneider DC (2007) Comparing an estimate of seabirds at risk to a mortality estimate from the November 2004 *Terra Nova* FPSO oil spill. Mar Pollut Bull 54:537–544
Wolfaardt AC, Underhill LG, Altwegg R, Visagie J, Williams AJ (2008) Impact of the *Treasure* oil spill on African penguins *Spheniscus demersus* at Dassen Island: case study of a rescue operation. Afr J Mar Sci 30:405–419

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