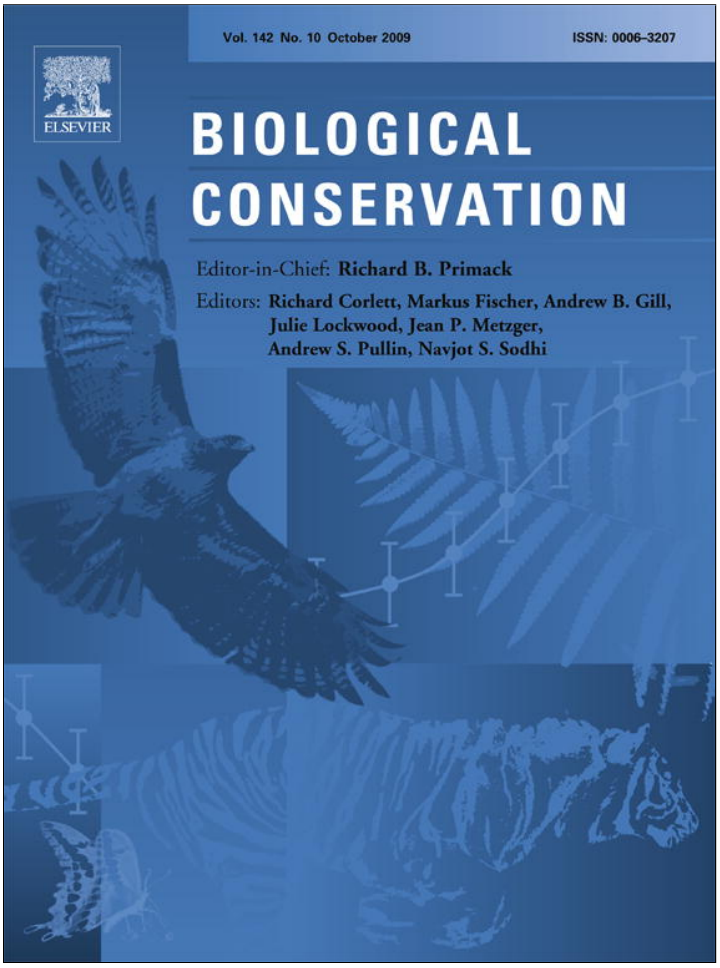
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Review

Translocations of eight species of burrow-nesting seabirds (genera *Pterodroma*, *Pelecanoides*, *Pachyptila* and *Puffinus*: Family Procellariidae)

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A B S T R A C T

Development of seabird translocation techniques is required to meet species recovery objectives, to improve conservation status, and to restore ecological processes. During 1997–2008 we undertook translocation trials on eight petrel species of four genera within the New Zealand region: common diving petrel (*Pelecanoides urinatrix*), fairy prion (*Pachyptila turtur*), grey-faced petrel (*Pterodroma macroptera gouldi*), Pycroft's petrel (*Pterodroma pycrofti*), Chatham petrel (*Pterodroma axillaris*), Chatham Island taiko (Magenta petrel; *Pterodroma magentae*), fluttering shearwater (*Puffinus gavia*), and Hutton's shearwater (*Puffinus huttoni*). A total of 1791 chicks within 5 weeks of fledging were moved up to 240 km, placed in artificial burrows and hand-fed until they fledged. Of these, 1546 fledged, and so far at least 68 have returned as adults to the translocation sites. Most birds were crop-fed a puree based on tinned sardines and fresh water. This diet worked well for all species regardless of their typical natural diet (planktonic crustaceans, squid, or fish) with all species fledging above or close to mean natural fledging weights.

Contents

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1. Introduction

Burrow-nesting and surface-nesting petrels (Families Procellariidae, Hydrobatidae and Oceanitidae) have been extirpated from many traditional breeding sites through human-induced impacts, especially the introduction of new predators to islands (Moors and Atkinson, 1984; BirdLife International, 2000). Local extinctions and severe population declines have resulted in over half the world's petrel species being recognised as threatened, with 11 species ranked as critically endangered (Croxall et al., 1984; Hirschfeld, 2007). In addition to impacts on the birds themselves, local extinctions and population declines of petrels can have severe impacts on the ecology of breeding sites, as burrow-nesting seabirds (in particular) are often ecological drivers of the terrestrial ecosystems where they breed (Smith, 1976; Mulder and Keall, 2001; Markwell and Daugherty, 2002). Petrels typically nest in dense colonies that may be of enormous size (Croxall et al., 1984; Warham, 1996; Brooke, 2004), and can dominate the ecology of breeding sites through their burrowing activity, trampling of vegetation, collection of ground-cover vegetation for nest linings, and especially the importation of vast quantities of marine-sourced nutrients deposited at colonies as droppings, regurgitations, failed eggs and corpses (Smith, 1976; Furness, 1991; Okazaki et al., 1993; Warham, 1996). Local extinctions of petrels can therefore have profound effects on other biota, including vegetation, invertebrates, herpetofauna, and terrestrial birds (Hawke et al., 1999; Worthy and Holdaway, 2002).

Management of threatened petrels has, to date, largely focussed on control and eradication of introduced predators (Veitch and Bell, 1990; Veitch and Clout, 2002). This has been successful for species that persisted at those sites (e.g. Imber et al., 1994; Cooper et al., 1995; Pierce, 1998), but there are few known examples of petrels naturally recolonising sites following their total extirpation. This is largely because petrels are typically highly philopatric, returning near the vicinity of their natal nest site when they reach breeding age (Warham, 1990), but also because their very low rate of intrinsic population growth (maximum of one chick per pair per year; Warham 1990, 1996) means that few populations are increasing rapidly enough to seek new (or vacated) breeding grounds.

New Zealand has at least 36 extant species of burrow-nesting and surface-nesting petrels, 33 of which are believed to have suffered human-induced breeding range reductions, and six of which are considered to have a conservation status of nationally critical or nationally endangered (Taylor, 2000a; Miskelly et al., 2008). Two further species are believed to be globally extinct (Miskelly et al., 2006; Tennyson and Martinson, 2006). The need to establish or re-establish additional breeding colonies to improve conservation status has been explicitly identified for at least 17 species of petrels in the New Zealand region (Taylor, 2000a; Aikman et al., 2001; Veitch et al., 2004), and several island restoration plans have identified the desirability of restoring petrel colonies due to their ecological benefits to other species (Miskelly, 1999; Department of Conservation, 2000; Whitaker, 2002).

There is, therefore, an urgent need to develop conservation management techniques for burrow-nesting petrels, both to achieve recovery objectives for critically endangered species, and to allow their reintroduction or attraction to restoration sites where they can resume their role as ecological drivers. Several previous workers have attempted to translocate petrel chicks (Table 1), but when we began our research programme in 1997, only the fluttering shearwater (*Puffinus gavia*) transfer to Maud Island (Bell, 1994; Bell et al., 2005) showed some evidence that new petrel colonies could be formed by chick translocations. This situation is starting to change, with recent successes reported for common diving petrel (*Pelecanoides urinatrix*; Miskelly and Taylor, 2004) and Gould's petrel (*Pterodroma leucoptera*; Priddel et al., 2006).

We here describe a series of research and management trials undertaken with eight species of burrow-nesting petrels around New Zealand during 1997–2008. These trials have focussed on development of techniques for translocation and attraction of petrels to new (or vacated) colony sites. Species selected for these trials initially were non-threatened or less threatened species (Tables 2 and 3); in two cases (grey-faced petrel *Pterodroma macroptera gouldi* and Pycroft's petrel *Pterodroma pycrofti*) these were specifically selected as surrogate species to develop techniques for application to more threatened near-relatives (Chatham Island taiko *Pterodroma magentae*, and Chatham petrel *Pterodroma axillaris*, respectively). We chose to attempt chick translocations of common diving petrels because they have an unusually quick life cycle for a petrel (Table 2). We hoped that lessons learnt from the diving petrels could be applied to more threatened species, and to species with much longer life cycles. Chatham petrels, Chatham Island taiko and Hutton's shearwaters (*Puffinus huttoni*) were translocated in order to establish additional breeding populations, as identified in their respective species recovery plans (Aikman et al., 2001; Department of Conservation, unpubl.). We selected fairy prions (*Pachyptila turtur*) and fluttering shearwaters (*Puffinus gavia*) for translocation as part of an ecological restoration programme for the recipient site, recognising their role as ecological drivers (Miskelly, 1999). The primary goal of the grey-faced petrel translocation to Matakohe Island was to establish a self-sustaining population of a locally threatened native bird species (Friends of Matakohe – Limestone Island Society, unpubl.). The potential ecological benefits of restored petrel colonies was identified as an added benefit for translocations of common diving petrels, Pycroft's petrels, Chatham petrels and grey-faced petrels.

2. Methods

2.1. Ecological research on species selected for translocation

Research and monitoring of basic breeding ecology was undertaken by the authors and co-workers for four of the study species before translocation or hand-rearing trials were initiated. All known breeding burrows of both Chatham Island taiko and Chatham petrel have been closely monitored since 1987 and 1990, respectively, as part of their recovery programmes (Aikman et al., 2001). Data collection has been most comprehensive for the Chatham petrel at their sole breeding site on Rangatira (South East) Island, where over 100 pairs nest in artificial nest boxes and are readily monitored. Relevant information collected has included hatching dates, frequency of provisioning visits by adults feeding chicks, meal sizes, chick growth and development, length of parental desertion before fledging, chick emergence period from the burrow before fledging, fledging dates, and age at fledging, first return

Table 1
Summary of known petrel chick translocations. Twelve hand-reared grey-faced petrel chicks translocated from the National Wildlife Centre, Mount Bruce, New Zealand back to two natural colonies are not shown (one of these birds has been recorded back at its release site).

Species	Date	Release site	No. translocated	No. fledged	No. returned	References
Short-tailed shearwater *Puffinus tenuirostris*	1954	Fisher Island	50	?[a]	0	Serventy et al. (1989)
Short-tailed shearwater	1960–1971	Fisher Island	157	?[a]	5	Serventy et al. (1989)
Leach's storm petrel *Oceanodroma leucorhoa*	1980	Eastern Egg Rock	20	20	0	Kress (1980) and S. Kress (pers. comm.)
Manx shearwater *Puffinis puffinus*	1980–1984	Cardigan Island	250	?[a]	?[b]	Brooke 1990 and M. Brooke (pers. comm.)
Black petrel *Procellaria parkinsoni*	1986–1990	Little Barrier Island	249	?[a]	2	Imber et al. (2003)
Fluttering shearwater *Puffinus gavia*	1991–1996	Maud Island	334	273	34	Bell et al. (2005) and M. Bell (pers. comm.)
Gould's petrel *Pterodroma leucoptera*	1995	Cabbage Tree Island	30	30	3	Priddel and Carlile (2001)
Common diving petrel *Pelecanoides urinatrix*	1997–1999	Mana Island	239	118	20	Miskelly and Taylor (2004 and this study)
Gould's petrel *Pterodroma leucoptera*	1999–2000	Boondelbah Island	200	195	13	Priddel et al. (2006 and pers. comm.)
Grey-faced petrel *Pterodroma macroptera*	1999	Mount Maunganui	30	13	3	This study. Project leader GAT
Pycroft's petrel *Pterodroma pycrofti*	2001–2003	Cuvier Island	232	227	19[c]	This study. Project leader GAT
Fairy prion *Pachyptila turtur*	2002–2004	Mana Island	240	240	19[c]	This study. Project leader CMM
Chatham petrel *Pterodroma axillaris*	2002–2005	Pitt Island	200	198	6[c]	This study. Project leader HG
Cahow *Pterodroma cahow*	2004–2007	Nonsuch Island	81	79	3[c]	Jeremy Madeiros (pers. comm.)
Grey-faced petrel	2004–2008	Matakohe Island	174	114+	–[c]	This study. Project leaders: C. Bishop and C. Mitchell
Hutton's shearwater *Puffinus huttoni*	2005–2008	Kaikoura Peninsula	291	270	1[c]	This study. Project Leaders: S. Cranwell and P. McGahan
Fluttering shearwater	2006–2008	Mana Island	225	211	–[c]	This study. Project Leaders: L. Adams and HG
Chatham Island taiko *Pterodroma magentae*	2006–2008	Sweetwater CC[d]	22	22	–[c]	This study. Project Leaders: D. Houston, D. Palmer and GAT
Common diving petrel	2007–2008	Motuora Island	91	86	–[c]	This study. Project Leaders: Robin Gardner-Gee and HG
Chatham petrel	2008	Sweetwater CC[d]	47	47	–[c]	This study. Project leaders: D. Houston and HG

[a] Chicks not monitored closely after translocation.
[b] Evidence of birds occupying up to eight burrows, but no band recoveries.
[c] Translocation too recent for any/all birds to return.
[d] Sweetwater Conservation Covenant, south-west Chatham Island.

to the natal colony, and first breeding (Gardner, 1999, and authors, unpubl.). Breeding data were also collected from a colony of about 300 pairs of grey-faced petrels on Kauwahaia Island, Bethells Beach, Auckland west coast from 1989 to 2008 (G. Taylor, unpubl.), and Gangloff and Wilson (2004) provided comparable data for Pycroft's petrel. For the four remaining species (common diving petrel, fairy prion, fluttering shearwater, and Hutton's shearwater), we drew on previous studies by Richdale (1943, 1944, 1945, 1965a,b), Thoresen (1967, 1969), Harper (1976), Bell (1994), Miskelly et al. (2001), Cuthbert and Davis (2002a,b), Bell et al. (2005), and Peter Hodum (pers. comm.), supplemented by information on growth rates, and emergence and fledging dates gathered during the translocations.

2.2. Study sites

These trials were undertaken at 19 sites throughout northern and central New Zealand and the Chatham Islands (Fig. 1). These are here arranged in a roughly north-to-south sequence, grouped together by the species of petrel studied at each site. The numbers of birds moved are given in Table 3, except for where more than one source site was used (diving petrels to Mana Island).

Matakohe (Limestone) Island (38 ha; 35°48′ S 174°22′ E) is a scenic reserve situated in the upper reaches of Whangarei Harbour, Northland. It is the focus of a revegetation project run by the Friends of Matakohe – Limestone Island Society. Grey-faced petrel chicks from Hen Island were translocated to the island in 2004–2008.

Hen Island (Taranga) (500 ha; 35°58′ S 174°43′ E) is a forested nature reserve 14 km east of Whangarei Heads. Grey-faced petrel chicks were translocated to Matakohe Island from Hen Island on 1 December 2004, 3 December 2005, 8 December 2006, 15 December 2007 and 5 December 2008.

Motuora Island (85 ha; 36°31′ S 174°47′ E) is a recreation reserve jointly managed by the Motuora Restoration Society and Department of Conservation. Lying in the Hauraki Gulf 5 km off Mahurangi Harbour, north of Auckland, the island was formerly farmed, and is now the focus of an ecological restoration programme. Common diving petrel chicks were translocated to Motuora Island from Wooded Island, 12 km away, in 2007 and 2008.

Table 2
Status and breeding ecology of the eight study species. All are burrow-nesters that form long-term monogamous pair bonds, and typically lay a single egg each year (but see Taylor and Miskelly, 2007). Breeding dates for common diving petrel, fairy prion and fluttering shearwater are from Cook Strait populations (central New Zealand). Conservation status as assigned by New Zealand Department of Conservation (Miskelly et al., 2008).

Name	Common diving petrel *Pelecanoides urinatrix*	Fairy prion *Pachyptila turtur*	Pycroft's petrel *Pterodroma pycrofti*	Chatham petrel *Pterodroma axillaris*	Grey-faced petrel *Pterodroma macroptera*	Chatham Island taiko *Pterodroma magentae*
Status	NZ native	NZ native	NZ endemic	NZ endemic	NZ endemic subspecies	NZ endemic
Conservation status	Relict	Relict	Recovering	Nationally vulnerable	Not threatened	Nationally critical
NZ breeding distribution	Islands around NZ	Islands around NZ	Northern islands	Rangatira, Chatham Is	Northern NZ	Chatham I.
NZ population (pairs)	700,000+	1,000,000+	2500–4000	200–300	200,000+	*c.*15
Adult bodyweight (g)	110–150	100–150	130–190	190–230	400–700	420–500
Lay date	August–September	October–November	November–December	December–February	June–July	November–December
Incubation length (days)	53	44–54	*c.*45–47	42–58	51–58	*c.*55
Hatch date	October–November	December	January	February–March	August–September	January
Chick period (days)	44–59	43–56	77–84	76–96	108–128	*c.*105
Fledging date	December	January–February	March–April	May–June	December–January	April–May
Mean fledge weight (g)	125	106	162	213	542	424
Age of return (years)	1–2	2–3	2–4	2–3	3–5	3–5
Age of first breeding (years)	1–3	3–4	3+	3+	5+	5+
References	Marchant and Higgins (1990), Heather and Robertson (1996), Taylor (2000b), Miskelly and Taylor (2004, 2007)	Marchant and Higgins (1990), Heather and Robertson (1996), Taylor (2000b), Graeme Loh (pers. comm.), authors (unpubl.)	Marchant and Higgins (1990), Heather and Robertson (1996), authors (unpubl.)	Marchant and Higgins (1990), Taylor (1994), Heather and Robertson (1996), Taylor (2000a), Aikman and Miskelly (2004), authors (unpubl.)	Imber (1976), Marchant and Higgins (1990), Heather and Robertson (1996), Taylor (2000b)	Heather and Robertson (1996), Taylor (2000a), Aikman and Miskelly (2004), Imber et al. (2005), authors (unpubl.)

Name	Fluttering shearwater *Puffinus gavia*	Hutton's shearwater *Puffinus huttoni*
Status	NZ endemic	NZ endemic
Conservation status	Relict	Declining
NZ breeding distribution	Islands around NZ	Kaikoura mountains
NZ population (pairs)	100,000+	106,000
Adult bodyweight (g)	230–415	305–370
Lay date	September–October	October–November
Incubation length (days)	51–52	46–56
Hatch date	November	December–January
Chick period (days)	71–79	75–94
Fledging date	January–February	March–April
Mean fledge weight (g)	411	404
Age of return (years)	4–6	2–4
Age of first breeding (years)	5–7	4–6
References	Marchant and Higgins (1990), Heather and Robertson (1996), Taylor (2000b), Bell et al. (2005), Peter Hodum (pers. comm.)	Marchant and Higgins (1990), Heather and Robertson (1996), Taylor (2000a), Cuthbert and Davis (2002a,b), authors (unpubl.)

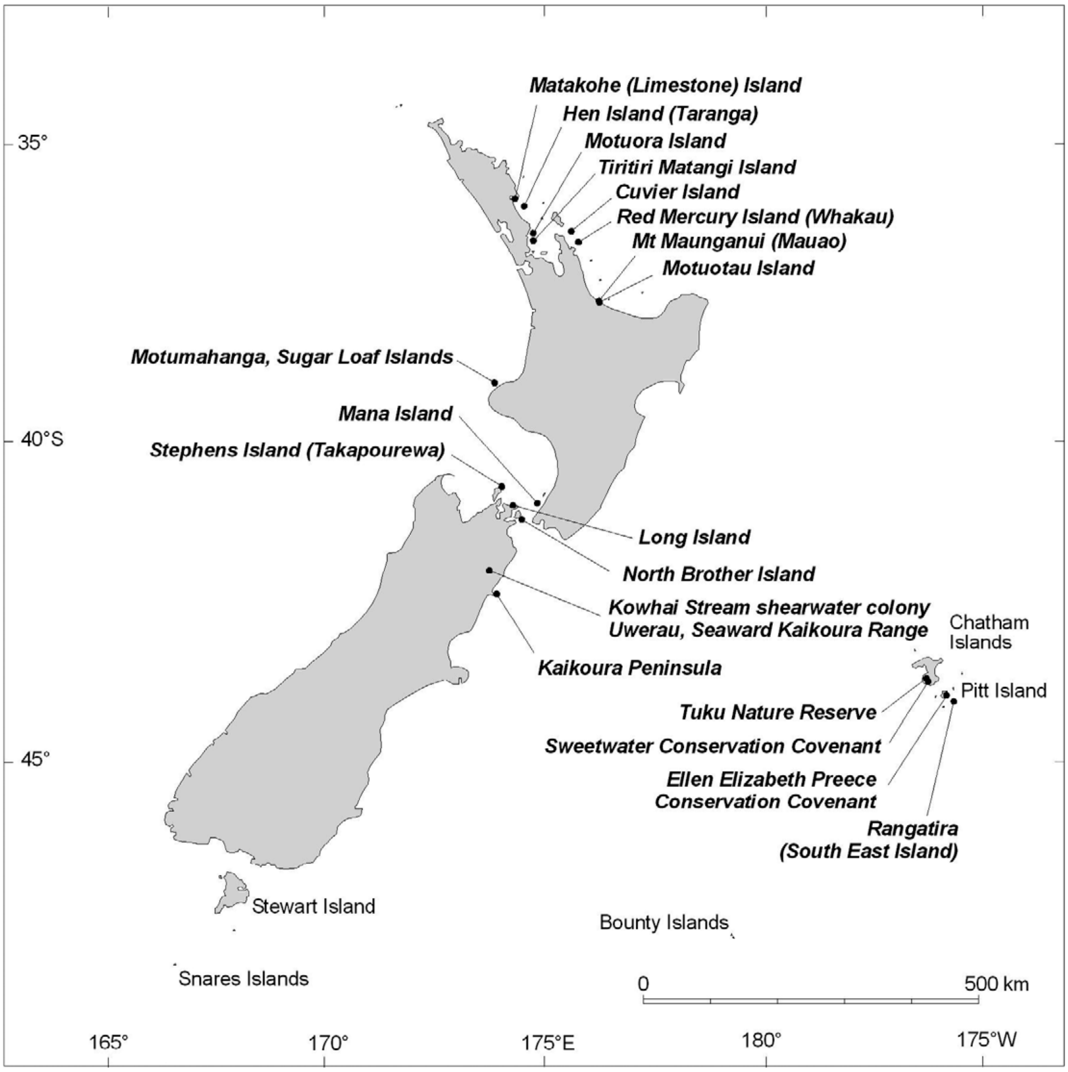

Fig. 1. New Zealand, showing the locations of the 19 study sites.

Wooded Island (1.0 ha; 36°35′ S 174°53′ E) lies 200 m north of Tiritiri Matangi Island in the Hauraki Gulf. It holds a dense colony of common diving petrels, with a few fluttering shearwaters (Taylor and Tennyson, 1999). Diving petrel chicks were translocated to Motuora Island from Wooded Island on 27 November 2007, and 13 November and 21 November 2008.

Cuvier Island (170 ha; 36°26′ S 175°46′ E) is a nature reserve that is now free of introduced mammals following the eradication of goats (*Capra hircus*) in 1961, cats (*Felis catus*) in 1964, and Pacific rats (*Rattus exulans*) in 1993 (Veitch and Bell, 1990; Towns and Broome, 2003). The only petrel species known to be present are grey-faced petrels and a few common diving petrels. Pycroft's petrel chicks were translocated to Cuvier Island from Red Mercury Island in 2001–2003.

Red Mercury Island (*Whakau*) (203 ha; 36°37′ S 175°56′ E) is a forested nature reserve that holds the largest known breeding colony of Pycroft's petrels, with an estimated 2000–3000 pairs in 1998 (Taylor, 2000a). The island is free of introduced mammals following the eradication of Pacific rats in 1992 (Towns and Broome, 2003). Pycroft's petrel chicks from Red Mercury Island were translocated to Cuvier Island, 24 km to the north–north-west, on 16 March 2001, 14 March 2002, and 5 and 7 March 2003.

Mt. Maunganui (*Mauao*) (75 ha; 37°38′ S 176°10′ E) is a recreation reserve that forms the eastern headland to Tauranga Harbour. Over 100 pairs of grey-faced petrels breed on the northern flanks. Grey-faced petrel chicks were translocated here from Motuotau Island in November 1999.

Motuotau Island (2.5 ha; 37°38′ S 176°12′ E) is a scenic reserve 2 km offshore from Mt. Maunganui. It is free of introduced mammals, although a single stoat (*Mustela erminea*) invaded (and was trapped) in 1996 (Clifford, 1997). At least 500 pairs of grey-faced petrels breed on Motuotau. Grey-faced petrel chicks were translocated from Motuotau to Mt. Maunganui on 19 November 1999.

Motumahanga, Sugar Loaf Islands (1.7 ha; 39°03′ S, 174°01′ E) lies off the Taranaki coast and holds a colony of several thousand common diving petrels (Merton, 1961). Introduced mammals have never been present. Motumahanga was the source of common diving petrel chicks translocated to Mana Island, 235 km to the south–south-east, on 11 December 1997 (52 chicks) and 21 November 1998 (63 chicks; Miskelly and Taylor, 2004).

North Brother Island (4 ha; 41°06′ S, 174°26′ E) is a nature reserve in the outer Marlborough Sounds and has a colony of about 600 pairs of common diving petrels (Gaston and Scofield, 1995). Introduced mammals have never been present. The island was the source of common diving petrel chicks translocated to Mana Island, 28 km to the east, on 24 November 1997 (39 chicks), 27 November 1998 (40) and 26 November 1999 (49; Miskelly and Taylor, 2004).

Table 3
Petrel translocation trials undertaken by the authors and co-workers 1997–2008. All chicks were hand-fed following translocation. Pre-translocation trials included supplementary feeding of 10 Pycroft's petrel chicks in natal burrows on Red Mercury I. in March 2000, and hand-feeding seven Chatham petrels to fledge on Rangatira I. in May 2001.

Year	Months	Species	No. of chicks	Translocated to
1997	November–December	Common diving petrel	90	Mana I
1998	November–December	Common diving petrel	100	Mana I
1999	November–December	Grey-faced petrel	30	Mt. Maunganui
	November–December	Common diving petrel	49	Mana I
2001	March	Pycroft's petrel	30	Cuvier I
2002	January–February	Fairy prion	40	Mana I
	March–April	Pycroft's petrel	100	Cuvier I
	April–May	Chatham petrel	41	Pitt I
2003	January–February	Fairy prion	100	Mana I
	March–April	Pycroft's petrel	102	Cuvier I
	April–May	Chatham petrel	49	Pitt I
2004	January–February	Fairy prion	100	Mana I
	April–May	Chatham petrel	55	Pitt I
	December–January	Grey-faced petrel	40	Matakohe I
2005	April	Hutton's shearwater	10	Kaikoura Peninsula
	April–May	Chatham petrel	55	Pitt I
	December–January	Grey-faced petrel	31	Matakohe I
2006	January–February	Fluttering shearwater	40	Mana I
	March–April	Hutton's shearwater	86	Kaikoura Peninsula
	May	Chatham Island taiko	1	Sweetwater Conservation Covenant
	December–January	Grey-faced petrel	40	Matakohe I
2007	January–February	Fluttering shearwater	91	Mana I
	March–April	Hutton's shearwater	95	Kaikoura Peninsula
	April–May	Chatham Island taiko	8	Sweetwater Conservation Covenant
	November–December	Common diving petrel	25	Motuora I
	December–January	Grey-faced petrel	22	Matakohe I
2008	January–February	Fluttering shearwater	94	Mana I
	March–April	Hutton's shearwater	100	Kaikoura Peninsula
	April–May	Chatham Island taiko	13	Sweetwater Conservation Covenant
	April–May	Chatham petrel	47	Sweetwater Conservation Covenant
	November–December	Common diving petrel	66	Motuora I
	December–January	Grey-faced petrel	41	Matakohe I

Mana Island (217 ha; 41°06′ S, 174°46′ E) is a scientific reserve off the Wellington west coast. The island was farmed for over 150 years before the last stock were removed in 1986. Following eradication of house mice (*Mus musculus*) in 1989, the island has been free of introduced mammals. Mana Island is the site of a comprehensive ecological restoration programme, including attempts to re-establish seabird colonies (Miskelly, 1999). Diving petrel chicks were translocated to Mana Island in 1997–1999 (Miskelly and Taylor, 2004), fairy prion chicks in 2002–2004 (Miskelly and Gummer, 2004), and fluttering shearwater chicks in 2006–2008. The sites chosen for attracting and translocating petrels are on the south-western cliff-top (80 m asl), near a colony of *c*.100 pairs of sooty shearwaters (*Puffinus griseus*).

Stephens Island (Takapourewa) (150 ha; 40°40′ S 173°60′ E) is a nature reserve off the northern tip of D'Urville Island, western Cook Strait. It has New Zealand's largest colony of fairy prions, estimated at 1 million pairs (Brown, 2001). Cats were eradicated in 1925 (Veitch, 1985); since then the island has been free of introduced predators. Stephens Island was the source of fairy prion chicks translocated to Mana Island, 80 km to the south-east, on 13 January 2002, 14 January 2003 and 17 January 2004.

Long Island (117 ha; 41°07′ S 174°17′ E) is a scenic reserve in outer Queen Charlotte Sound, Marlborough Sounds. There is a large fluttering shearwater colony near the northern tip of the island. Fluttering shearwaters were translocated from Long Island to Mana Island on 15 January 2006, 4 January 2007, and 5 January 2008. The same source colony was used for translocations to Maud Island (Bell et al., 2005).

Kowhai Stream shearwater colony, Uwerau, Seaward Kaikoura Range (24 ha; 42°16′ S 173°36′ E) Set among steep snow tussock (*Chionochloa pallens* and *C. flavescens*) covered slopes at 1200–1800 m asl within Mt. Uwerau Nature Reserve, the Kowhai Stream colony is the largest of the two known colonies of Hutton's shearwaters (Sherley, 1992; Cuthbert and Davis, 2002a). Chicks were translocated from here to Kaikoura Peninsula on 2 April 2005, 8–9 March 2006, 7–9 March 2007, and 5–6 March 2008.

Kaikoura Peninsula (42°26′ S 173°43′ E) is adjacent to the town of Kaikoura on the north-east coast of the South Island. The 1 ha cliff-top site chosen for the new Hutton's shearwater colony site was recently grazed pasture (stock now fenced out) on the outer peninsula. Potential predators (cats, ferrets *Mustela furo*, and stoats) were controlled by trapping, shooting and a temporary fence whilst chicks were present. It is intended that a predator-proof fence be constructed around the site. Chicks from the Kowhai Stream colony were translocated to Kaikoura Peninsula in 2005–2008.

Tuku Nature Reserve, Chatham Island (1239 ha; 44°04′ S 176°37′ W) The Tuku Nature Reserve and some immediately adjacent privately-owned land are the only known breeding sites of the Chatham Island taiko. All known breeding burrows are under dense forest 4–5 km from the coast. Feral cats and rats (*Rattus* spp.) are intensively controlled near nests to limit their impacts on the critically endangered taiko (Imber et al., 1994; Aikman and Miskelly, 2004). Taiko chicks were translocated to the nearby Sweetwater Conservation Covenant on 1 May 2006, 20–28 April 2007, and 14 April–2 May 2008.

Sweetwater Conservation Covenant, Chatham Island (4 ha; 44°05′ S 176°38′ W) is a privately-owned forest remnant adjacent to the Tuku Nature Reserve. A 4 ha predator-proof fence to exclude all mammalian pests was completed by the Chatham Island Taiko Trust in 2006, with the intention of creating a secure breeding site for taiko. Taiko chicks from the nearby Tuku Nature Reserve were translocated to this site in 2006–2008. A further translocation is planned for April 2009. An initial translocation of Chatham petrel chicks to a nearby hilltop within the predator-proof fence was undertaken in April 2008.

Ellen Elizabeth Preece Conservation Covenant, Pitt Island, Chatham Islands (53 ha; 44°17′ S 176°11′ W) is a privately-owned forest remnant near the north-east coast of Pitt Island, 6 km from Rangatira. About 40 ha of the covenant have been surrounded by a predator-proof fence, designed to exclude feral cats, weka, and feral pigs, to allow reintroduction of vulnerable bird species. House mice are the only mammals present inside the fence. Chatham petrel chicks were translocated here from Rangatira in 2002–2005.

Rangatira (*South East Island*), *Chatham Islands* (219 ha; 44°21′ S 176°10′ W) is a predator-free nature reserve with over 1.3 million pairs of burrow-nesting petrels (West and Nilsson, 1994). Until this study, Rangatira was the only known breeding location for Chatham petrel. Chatham petrel chicks were translocated from Rangatira to Ellen Elizabeth Preece Conservation Covenant, 6 km to the north, on 30 April and 14 May 2002, 1 May 2003, 28 April 2004, and 1 May 2005, and from Rangatira to Sweetwater Conservation Covenant, 46 km to the northwest, on 21–29 April 2008. Further translocations to Sweetwater are planned for 2009 and 2010.

2.3. Translocation of petrel chicks

Diving petrel, Pycroft's petrel, fairy prion, Hutton's shearwater and fluttering shearwater chicks were located by hand-searching burrows by day and/or night. Chicks of grey-faced petrels, Chatham petrels and Chatham Island taiko were mainly taken from existing study burrows. Precise ages of chicks of all species were generally not known (with the exception of Chatham petrel in some years) as observers were not present at the source colonies during hatching. Wing length was considered the best predictor of how far each chick was from fledging (Richdale, 1945; Gangloff and Wilson, 2004; authors, unpubl.). For diving petrels and fairy prions, chicks of a range of ages 0–6 weeks (diving petrel) or 0–3 weeks (fairy prion) off fledging were sought, as we did not know at what age chicks developed a strong attraction to their natal site, although both species fledge less than 4 days after their first emergence from their burrows (Richdale, 1965a; Miskelly and Gummer, 2004). For the other species we sought chicks that were 2–5 weeks from fledging, as we assumed that birds that had emerged from their natal burrows would have become fixed on their natal site. Pycroft's petrels emerge for up to 15 nights before fledging (mean 7 nights; Gangloff and Wilson, 2004); Chatham petrels for up to 21 nights (mean 11 nights; authors, unpubl.); grey-faced petrels for up to 33 nights (mean 16 nights; authors, unpubl.); Hutton's shearwaters for up to 27 nights (mean 7 nights; authors, unpubl.); fluttering shearwaters for up to 15 nights (mean 7 nights; authors, unpubl.), and Chatham Island taiko for up to 27 nights (Johnston et al., 2003). Half of the emergence data were from translocated chicks (exceptions were diving petrel, Pycroft's petrel, Chatham petrel, and Chatham Island taiko).

At sites without ongoing study populations, chicks were measured and weighed (and generally banded) when first encountered, and any burrow containing a chick suitable for translocation was tagged and mapped. For all species other than Chatham Island taiko, we tried to select chicks that had high bodyweights in relation to wing-length, as an estimator of good condition.

The chicks were collected from their burrows on the day of translocation and placed in ventilated cardboard boxes for transport. For most translocations we used pet carry boxes (approx. 39 × 21 cm × 26 cm deep) with newspaper or leaf litter lining. For fairy prions, Pycroft's and Chatham petrels, and Hutton's and fluttering shearwaters, we inserted a diagonal divider, allowing two chicks to be carried per box. For the diving petrels (the smallest species) we used larger boxes, with up to 16 compartments, each about twice the size of the chicks (Miskelly and Taylor, 2004). A handful of nest litter and shed chick down was collected from Pycroft's and Chatham petrel and Chatham Island taiko nests to provide a familiar smell in their new burrows and to encourage chicks to recognise their own nest entrance by olfaction once they emerged. The biosecurity impacts of this action were considered negligible, as in each case the little-modified source location was the model for the more-modified recipient site, and translocation of nest fauna and flora was considered acceptable. Transport was by boat (all Pycroft's and Chatham petrel chick translocations, the 1999 and 2005–2008 grey-faced petrel chick translocations, and the 2007–2008 diving petrel translocations) or helicopter (all fairy prion, and Hutton's and fluttering shearwater translocations, the 2004 grey-faced petrel translocation, and the 1997–1999 translocations of diving petrel chicks from North Brother Island), or a combination of helicopter, motor vehicle and/or commercial airline and boat (remaining diving petrel translocations). Chatham Island taiko chicks were hand-carried in boxes then shifted by quad bike. Most chicks were placed into artificial burrows at release sites on the day of translocation. Exceptions were the 1997 diving petrel translocation from Motumahanga (transit time 22 h), the 2001 and 2002 Pycroft's petrel translocations (birds kept in carry boxes for up to 3 days whilst artificial burrows were being prepared and during heavy rain), and the last four Chatham petrel chicks translocated in 2008 (birds kept in carry boxes for one night).

With the exception of diving petrels, translocated chicks were generally not fed on the day of transfer. However, after recognising the susceptibility of grey-faced petrel and diving petrel chicks to heat stress and dehydration in 1998 and 1999, we initiated a regime of giving translocated chicks 5–20 ml of cooled boiled water (volume dependent on species) via a syringe and crop needle or tube (see below) on arrival at the release site. Each chick was then placed into its own marked artificial burrow. Blockades (usually of plastic mesh) were placed over the burrow entrances to keep the chicks in the burrows until they were sufficiently developed to start emerging (and usually for a minimum of 2 days, with the exception of ten well-advanced Chatham petrel chicks and one Pycroft's petrel chick that were constrained for one night only). Plastic mesh gates were later considered important to install at the chamber end of the tunnel in burrows accommodating the two shearwater species, to prevent chicks getting stuck inside tunnels with blockaded entrances (see below).

2.4. Artificial burrow design

The artificial burrows used for diving petrels on Mana Island in 1997–1999 were a simple trench with a side chamber, covered with lengths of wood, and with a 20–40 cm length of 11 cm diameter PVC drainage pipe for the entrance tunnel (Miskelly and Taylor, 2004). These burrows were later re-used for fairy prions in 2002–2004, as at the time only a single pair of diving petrels was nesting in an artificial burrow (this latter burrow was not used during the prion translocations).

By 2005, burrow designs for species nesting on hill slopes were modified to improve durability, insulation from the sun, and drainage, whilst still allowing prospecting adults to extend burrows. Burrows consisted of a 3-sided rectangular box (two long sides) set into the slope, with one end (the chamber) deeper below the surface, with an earthen back wall to allow further digging by birds, and the other end emerging from the surface and fitted with an access lid. Tunnels were 30–40 cm lengths of 11 cm diameter PVC drainage pipe that were sunk horizontally into channels along the slope leading from the front-side of the box. Birds have to enter a trench below ground level to enter the pipe, which effectively extends the tunnel, sheltering the entrance from wind, and keeping the burrow darker. For the shearwaters, chambers had internal dimensions 45 × 25 cm and 20 cm deep, constructed from 20 × 5 cm rough-sawn planks or plywood. Long lengths of pipe were avoided for these shearwater species as large chicks can get stuck inside them. Similar but smaller burrows (internal dimensions of 35 × 20 cm and 15 cm deep) were used for diving petrels on Motuora Island.

For the forest-nesting Chatham petrels, we used buried 4-sided wooden nest boxes (approx. 35 × 35 × 25 cm deep) similar to study burrows at the source colony on Rangatira. For Pycroft's petrels on Cuvier Island, 30 moulded plastic artificial burrows approx. 38 × 35 cm × 35 cm deep were buried alongside 72 earth burrows. Burrows were set on flat or slightly sloping ground and were fitted with 30–40 cm lengths of 11 cm diameter PVC drainage pipe entrance tunnels. Similar buried plywood nest boxes (approx. 40 × 45 × 40 cm deep) were used for grey-faced petrels on Matakohe Island and for Chatham Island taiko chicks. For these two larger species, the entrance tunnels were made with 16 cm diameter drainage pipe, or as earth tunnels dug by hand.

For all translocations since 2004, we improved drainage of artificial burrows by placing gravel under the chamber floor during construction, before adding dry grass (cliff-nesters) or leaf litter (forest-nesters) as nest lining. Where necessary, sandbags were employed to provide additional insulation to individual burrows, particularly at northern locations where burrows were more vulnerable to overheating.

2.5. Development of artificial diets

Previous hand-rearing trials for grey-faced petrels (Taylor et al., in prep.) were based around a diet used for rehabilitating seabirds (see Bell, 1994). The natural diet of parent-reared grey-faced petrel chicks was assessed in 1997 to determine the importance of different fats, proteins and trace elements in their natural diet of squid, fish and krill (Hendriks et al., 2000). A new artificial diet for petrels was proposed, based around a commercially available canned cat-food (details below). As diving petrels and fairy prions feed almost entirely on planktonic crustaceans (Marchant and Higgins, 1990), we developed a diet for these species based on pureed Antarctic krill (*Euphausia superba*) with added calcium and vitamins. Trials with grey-faced petrels (Taylor et al., in prep.) and fairy prions (2002, see below) showed that a diet based on tinned 'sardines' (juvenile Antarctic herrings *Clupea harengus*) in soya oil resulted in higher survival and growth rates than the fish and squid diet and the krill diet (results presented here), and so we then used this sardine-based diet for further trials with four *Pterodoma* petrels (all predominantly squid feeders), plus the krill-feeding fairy prion and common diving petrel, and the two predominantly piscivorous *Puffinus* shearwaters.

2.6. Foods given to petrel chicks

Where appropriate, meal sizes are given as mean ± s.e. (sample size, range).

(i) Fish and squid diet. Whole pilchards (*Sardinops* spp.; 45%) and squid (*Nototodarus* spp.; 45%) were minced then pureed with fresh water (10%), and a Mazuri™ vitamin tablet. This diet was considered an approximation of the natural diet of grey-faced petrels, and was used for 12 chicks during the 1999 translocation (120 g per meal). Due to poor weight gains, olive oil (10%) was added after 13 days. A further three chicks received the same diet but with additional 10% fish oil throughout.

(ii) Krill diet. A smooth paste was prepared by blending, in a food processor, 320 g of thawed krill (purchased as a frozen 24 kg block) with 160 ml of cooled boiled water, along with one sixth of a teaspoon of Bonegro™ calcium supplement. Every second day a quarter of a Mazuri™ vitamin tablet was added. The mixture was strained through a fine kitchen sieve to remove pieces of exoskeleton that could block the feeding apparatus. The krill diet was used for 239 diving petrels (1997–1999) and 20 fairy prions (2002). Meal sizes for diving petrels averaged 27.3 ± 0.2 g (n = 4298, range 1–75 g). Meal sizes for fairy prions averaged 28.4 ± 0.9 g (n = 127, range 6–52 g).

(iii) Cat-food diet. Following a nutritional analysis of the diet of wild grey-faced petrels (Hendriks et al., 2000), we trialed three versions of a diet based on tinned cat-food. Most of these trials were undertaken with neonate grey-faced petrel chicks raised in captivity (Taylor et al., in prep.). However, in November–December 1999, eight grey-faced petrel chicks at Mt. Maunganui were fed on Whiskas™ cat-food (chicken, beef, lamb and pork-based) mixed with 10% fresh water, and another seven were fed on Chef Salmon and Turkey™ cat-food (chicken, beef, salmon and turkey-based) mixed with 10% fresh water; meals averaged 120 g. In March 2000 we fed a mixture of Chef Salmon and Turkey™ cat-food (70–85%), olive oil (5%) and fresh water (10–25%) to ten Pycroft's petrel chicks left in their natal burrows on Red Mercury Island (i.e. they were potentially receiving parental feeds also). Meal sizes for Pycroft's petrels averaged 18.7 ± 1.6 g (n = 54, range 3–51 g).

(iv) Piecemeal sardine diet. Chunks of Brunswick™ sardines (=juvenile Antarctic herrings *Clupea harengus*) in soya oil were fed to 30 Pycroft's petrels and three Chatham petrels in 2001, and 17 Pycroft's petrels (one initial meal each only) in 2002. The average meal sizes received were: Pycroft's petrel (2001) 27.5 ± 0.7 g (n = 150, range 6–68 g); and Chatham petrel 20 g (8–30 g).

(v) Pureed sardine diet. The standard pureed sardine diet was based on 106 g tins of Brunswick™ sardines in soya oil. When we first used this brand, it was labelled as containing 77% sardines, 22% soya oil, and ⩽1% added salt; from mid-2004 onwards, we found the labelled contents of the same brand had changed to 89% sardines, 10% oil and 1% salt. The contents of each tin were pureed in a food processor with 50–60 ml cold (pre-boiled) water. In 2003 we trialed 16 of 100 fairy prion chicks on a diet based on 425 g tins of Ocean Catch™ sardines in natural oil, pureed with cooled boiled fresh water (approx. 240 ml of liquid in total before blending). Meal sizes for fairy prions fed the Ocean Catch™ sardine diet averaged 33.4 ± 1.0 g (n = 160, range 6–64 g).

The pureed Brunswick™ sardine diet was used for 1454 chicks of eight species since 2002, with the only subsequent exceptions being 20 fairy prions in 2002, and 16 in 2003 (see Table 3). Meal sizes for the pureed Brunswick™ sardine diet are given in Table 4.

2.7. Hand-feeding chicks

The main method we used for feeding petrel chicks was delivery of a puree into the crop via a crop needle (1997–2004) or crop tube (2005–2008) inserted down the oesophagus (Fig. 2). Crop needles are manufactured specifically for hand-feeding birds; they are

Table 4
Meal sizes for the standard pureed Brunswick™ sardine and fresh water diet as given to eight species of burrow-nesting seabirds between 2002 and 2008 (excludes initial small "introductory" meals).

Species (dates)	No. chicks	No. meals	Mean	s.e.	Min.	Max.
Meal size (g)						
Fairy prion (2002–2004)	204	1914	26.6	0.3	1	60
Pycroft's petrel (2002–2003)	202	1211	15.3	0.2	1	46
Chatham petrel (2002–2008)	247	1066	16.5	0.2	1	35
Chatham Island taiko (2002–2008)	22	69	31.9	2.5	5	105
Grey-faced petrel (2004–2007)	133	1347	108.0	0.9	10	180
Hutton's shearwater (2005–2008)	291	4700	37.0	0.2	5	135
Fluttering shearwater (2006–2008)	225	4904	61.7	0.2	10	90
Common diving petrel (2007–2008)	91	890	25.0	0.2	10	30

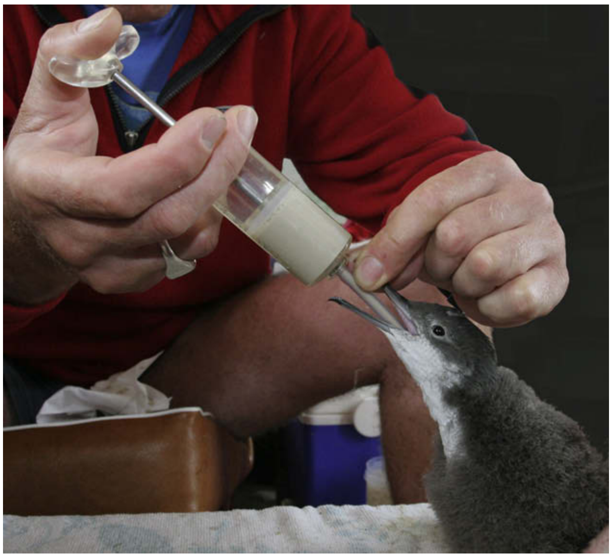

Fig. 2. Fluttering shearwater chick being fed the pureed sardine diet via a syringe and crop tube (Photo: D. Cornick).

bulb-tipped, curved metal tubes that can be pushed onto disposable syringes, or screwed into syringes that have Luer-lock fittings™. Crop tubes are similar in function to crop needles, but are made of clear Teflon™; they are a wider gauge (6.3 mm outside diameter) and can be cut to length to suit each species. Teflon tubes were screwed directly into 30 or 50 ml Plexiglass™ syringes.

For some smaller trials we have hand-fed pieces of thawed mackerel or preserved sardine. Small pieces of fish were placed at the back of the chicks' throats, which were then massaged from the exterior to encourage swallowing. Cooled boiled water (typically 5–10 ml) was also administered via a syringe and crop needle.

To reduce the risk of food spoilage, food mixtures were kept cool in an insulated bin until needed. Food mixtures were heated in small batches in a water bath to 30–35 °C before feeding. Feeding typically required two people, with one person holding the upper mandible and operating the syringe and crop needle/tube, whilst the other person restrained the chick and cleaned up any spillage to prevent soiling of the plumage. The chick's neck was carefully extended up and outwards (approx. 45° angle) to open the oesophagus, then the crop needle or tube was introduced, taking care to avoid the opening to the trachea at the base of the lower mandible. Once in place, the plunger was gently pushed (Fig. 2). If the bird showed signs of vomiting or became distressed, the crop needle or tube was carefully removed and the chick allowed to settle. Large volumes of food were typically delivered in two or three attempts, allowing the chick to rest in between. Chicks of some species were more prone to regurgitation close to fledging; food was more successfully delivered to these chicks by giving small amounts of food in the back of the throat and allowing them to swallow unaided.

Feeding regimes differed for each species reflecting, to some degree, the natural parental visitation rates observed in the wild. To achieve appropriate daily weight changes diving petrels, fairy prions, Hutton's and fluttering shearwaters were fed once a day (twice daily for diving petrels in 1998 and 1999; Miskelly and Taylor, 2004). *Pterodroma* petrels were typically fed every second or third day, though more frequently if chicks were underweight.

Chicks were fed only 10–20 g on the first day of feeding, to allow adjustment to the new diet and feeding technique. For grey-faced petrels, the first meal was diluted 50:50 with fresh water. From day 2, meal sizes were increased until by day 4 chicks of all species were generally fed as much as they would readily take up to experimentally determined maximum amounts. Chicks began to resist feeding as they approached fledging, consequently the amount of food that they received declined until many chicks took less than 10 g of food on the day of departure. With the exception of *Pterodroma* chicks (which need to lose weight, and are prone to regurgitation), chicks were generally offered more food than they accepted in the week before fledging. After 2004, meal plans were developed for each bird using chick weight and wing-length data as well as information recorded at the previous feeding event, to reduce incidences of regurgitation.

Care was taken to maintain high levels of hygiene. Following indications that some diving petrel chicks were suffering from candidiasis (*Candida albicans* yeast infection) in 1999, we developed a standard methodology of immersing crop needles and tubes in chlorhexidine solution after each bird was fed, after rinsing the needles and tubes in boiled water to remove particulate matter.

Chicks of all species were weighed before and after each meal, and wing lengths were recorded every third day (initially), then daily as chicks approached fledging. The departure date was recorded for each translocated chick, except some Pycroft's petrels in 2001 and 2003.

2.8. Trials comparing artificial diets

Three trials were undertaken to compare survival and growth rates under different diet regimes at the same time: (i) during the 1999 translocation of grey-faced petrel chicks to Mt. Maunganui, 12 chicks were fed on a fish and squid diet, three chicks had the fish and squid diet with additional fish oil, eight chicks were fed Whiskas™ cat-food, and seven chicks were fed Chef™ cat-food; (ii) during the 2002 fairy prion translocation, 20 chicks were fed the krill diet, and 20 were fed the standard pureed sardine diet; (iii) during the 2003 fairy prion translocation, 84 chicks were fed the standard pureed (Brunswick™) sardine diet, and 16 were fed the pureed Ocean Catch™ sardine diet.

2.9. Pre-fledging emergence

Blockades were removed from burrow entrances at varying periods after translocation, based on known emergence data at natural colonies. We removed blockades to diving petrel and fairy prion burrows as close as possible to the estimated fledging dates for each bird, generally when the chicks reached a specific wing length and had little down remaining. For shearwaters, the timing of blockade removal required balancing the risk of chicks wandering prematurely, and minimising stress to birds that endeavoured to exit their burrow. We removed blockades for *Pterodroma* chicks generally 3–4 days after transfer, as these chicks rapidly developed a strong affinity to their own burrows. However, light chicks were constrained for longer periods to ensure they received necessary meals.

Following removal of burrow entrance blockades, stick fences were set at burrow entrances to allow monitoring of any chick movement out of burrows before fledging. Any records of fences knocked down before or in the middle of a series of intact recordings were discarded as likely to have been knocked over by other means (e.g. wind, lizards or another bird). Chicks of some *Pterodroma* and *Puffinus* spp. were prone to wander during the emergence period, sometimes ending up in other study burrows, or hidden under dense vegetation. Whilst most birds were found and were given further meals, some chicks were not located. If a missing chick was of sufficient weight that it would have exceeded minimum known fledging weight at its estimated fledging date (based on wing length and growth rate), then we assumed that it fledged successfully (eight grey-faced petrels, 27 Chatham petrels, and 16 fluttering shearwaters in Tables 1 and 5), otherwise they were assumed to have died. We departed Cuvier Island before all the translocated Pycroft's petrel chicks had fledged in 2001 and 2003; the remaining 49 chicks are assumed to have fledged successfully as they were in good condition when last checked, and no skeletal remains were found inside study burrows on subsequent trips. As the fledging dates for these 100 individuals are unknown, they have not been included in graphs presented here (Figs. 3 and 4).

2.10. Acoustic attraction systems

Automated solar-powered sound systems were installed on Mana Island in April 1993 and November 2006, Cuvier Island in March 2001, at Ellen Elizabeth Preece Conservation Covenant, Pitt Island in April 2002, at Sweetwater Conservation Covenant, Chatham Island in October 2006 and December 2008, on Motuora Island in March 2008, and on Matakohe Island in April 2008. These broadcast calls of the target species, and were configured to switch on at dusk and off at dawn, to match the nocturnal colony attendance patterns of all eight species. A sound system is scheduled to be installed on Kaikoura Peninsula in 2009.

2.11. Searching for returning chicks

Searches for returning chicks generally did not begin until chicks were expected to return, based on previous studies (Table 2); however, for some species we had ongoing studies at the release site, meaning that checks began from the year after fledging. Initially we searched for birds on the surface, and for droppings or feathers near the loudspeakers, and also checked artificial burrows for signs of occupation. Burrow checks were facilitated by placing fences of small sticks across artificial burrow entrances. From November 1999 on Mana Island we searched for diving petrels by turning off the sound system temporarily (to reduce background noise) and then inducing birds in natural burrows to call by mimicking their calls.

Of the species translocated before 2005, four (diving petrel, Pycroft's petrel, fairy prion, Chatham petrel) have had sufficient translocated chicks fledge to justify search effort at the source colonies. Few of these colonies have been searched for returning translocated chicks due to access constraints, cost, and, on North Brother Island and Motumahanga, the risk of burrow damage on these small, intensively burrowed islands. However, we have undertaken searches on Stephens Island (fairy prion source) and Rangatira (Chatham petrel source) as part of ongoing work. These searches began in 2004, the first year that either species was expected to return. On Stephens Island there were 8 evenings of searches at the source site in 2004, 6 evenings in 2005, and 10 evenings in each of 2006–2008. On Rangatira, a team searched for prospecting adult Chatham petrels for 21 nights during 20 November–12 December 2005, and for 7 nights during 12–19 February 2009, and over 130 study burrows are monitored annually.

3. Results

3.1. Survival rates

Survival rates for well-developed chicks between translocation and fledging varied between 62% and 100% for each of the eight species (Table 5). The lowest survival rates occurred during the first four diving petrel and grey-faced petrel translocations (1997–1999), when deaths were mainly due to dehydration, food poisoning and candidiasis yeast infection (Miskelly and Taylor, 2004). These problems were largely overcome by modifying our translocation and feeding methodology by: (a) keeping birds shaded from direct sunlight at all times during transfer, (b) giving water on arrival at the new colony site, to reduce dehydration stress during transfer, (c) heating small batches of food at the feeding site, rather than preheating larger quantities that allowed bacterial build-up over time, and (d) soaking rinsed feeding equipment in chlorhexidine solution after each chick was fed. Most subsequent translocations used a single diet, based on tinned Brunswick™ sardines. Between 2000 and 2008, 66 of 1481 translocated chicks died (4.5%), compared to 48.7% of 269 chicks during 1997–1999.

Even with these precautions, the winter and spring-nesting diving petrels and grey-faced petrels appeared more prone to dehydration and nutritional problems than the other species, which are all summer nesters. The small size of diving petrel chicks and their dense plumage may make them more prone to heat stress. The poor condition of some grey-faced petrel chicks at the time of transfer in 2004, and to a lesser extent in 2005 may have resulted from more difficult feeding conditions over the winter/spring months. Grey-faced petrels were also fed for longer than most other species (Fig. 3), and this long period on an artificial diet, perhaps lacking the right nutritional balance (Taylor et al., in prep.), may have contributed to renal failure and gastrointestinal problems of six chicks close to fledging.

Other causes of death included predation (19 Hutton's shearwaters), hypothermia during severe weather events (11 diving petrels, 2 Pycroft's petrels), chicks wandering from burrows and becoming lost when considered too young to fledge without further feeding (9 fluttering shearwaters, 2 grey-faced petrels), chicks becoming stuck in artificial burrow entrances (4 fluttering shearwaters), flooding of burrows during heavy rain (1 Pycroft's petrel, 1 Chatham petrel), aspergillosis (1 fluttering shearwater), and over-feeding (1 diving petrel). Two grey-faced petrel chicks were euthanased when they failed to recover from pre-existing injuries and infections. Ten previously healthy chicks died when close to fledging, with no cause of death able to be determined (3 grey-faced petrels, 3 diving petrels, 2 Hutton's shearwaters, 1 Pycroft's petrel, 1 Chatham petrel).

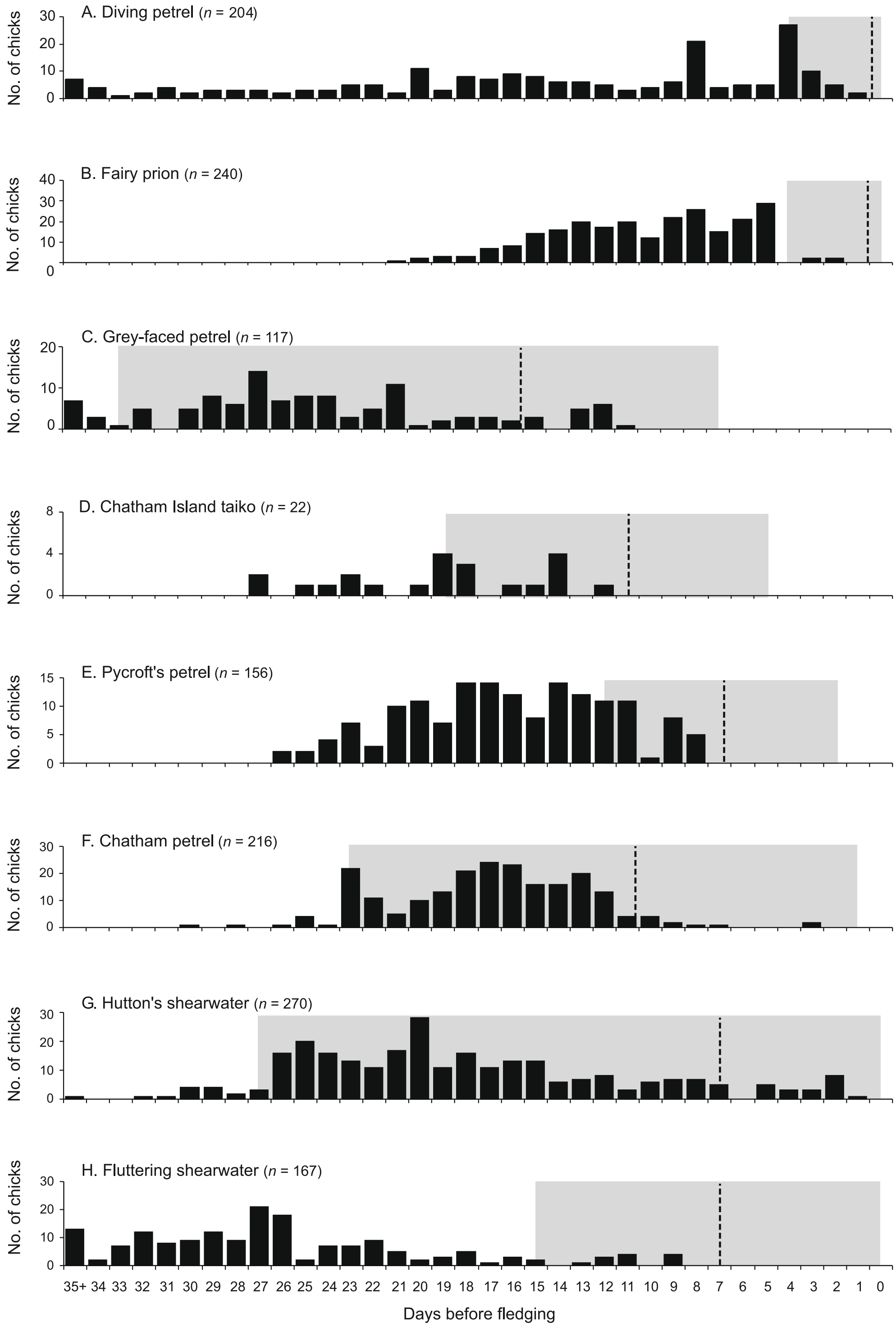

Fig. 3. Length of time that translocated chicks were at their release sites before fledging. Shading shows the range of dates that translocated chicks started to emerge from burrows at night, with vertical lines showing the mean emergence date in relation to fledging.

3.2. Diet comparisons

The 1999 grey-faced petrel feeding trial at Mt. Maunganui was compromised by the deaths of a third of the chicks due to presumed heat stress in artificial plastic burrows. The affected sites were all under a section of forest exposed to long periods of warm afternoon sun and their diet may have lacked sufficient water to compensate for overheating in burrows. Of the 13 chicks that fledged, four were fed on fish and squid, five were fed Chef™ cat-food, and four were fed Whiskas™ cat-food. However, our observations plus those from grey-faced petrels raised in captivity (Graeme Taylor et al., in prep.) revealed that chicks fed on a cat-food diet grew more slowly and required more food than those fed either on fresh fish and squid or the pureed sardines used for all species since 2002. The birds fed on the cat-food diet clearly had problems processing this food as the nests rapidly filled with excessive faeces and required constant cleaning of the nests and birds.

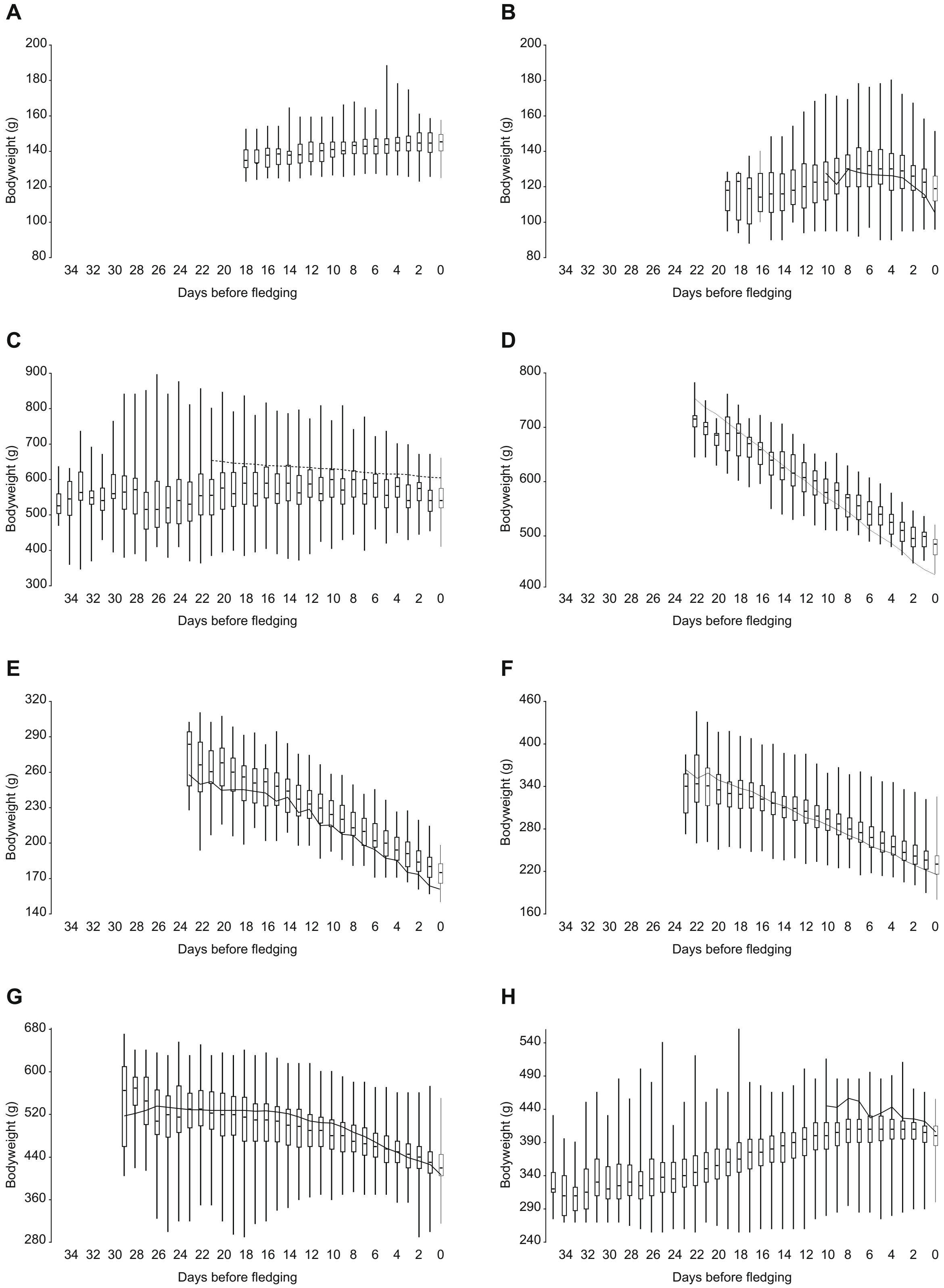

Fig. 4. Box and whisker plots of weight changes of translocated chicks fed the pureed sardine diet before fledging. A = common diving petrel; B = fairy prion; C = grey-faced petrel; D = Chatham Island taiko; E = Pycroft's petrel; F = Chatham petrel; G = Hutton's shearwater; H = fluttering shearwater. The dashes inside each box show the median, the boxes contain the upper and lower quartiles, and the whiskers show the range (maxima and minima). Curves show the mean weights of natural, parent-fed chicks for each species. Samples sizes varied, as some chicks were present at the release sites for only a few days; compare with Fig. 3 to determine sample sizes per day. Natural chick weights were based on regular (typically daily) measurements of study chicks for fairy prion (C. Miskelly, unpubl.), Pycroft's petrel (Benoit Gangloff, pers. comm.), Chatham petrel (H. Gummer, unpubl.), fluttering shearwater (Peter Hodum, pers. comm.) and Hutton's shearwater (Richard Cuthbert, pers. comm.). Grey-faced petrel natural weight changes were modelled from chick weights in relation to expected fledging date based on wing length (G. Taylor, unpubl.). Chatham Island taiko natural weight changes were derived from spot-weights of 67 parent-fed chicks 1991–2006 (G. Taylor and C. Miskelly, unpubl.).

Table 5
Fledging success of translocated chicks.

Species	Year	No. translocated	No. fledged
Common diving petrel			
Pelecanoides urinatrix	1997	90	52
	1998	100	40
	1999	49	26
	2007	25	24
	2008	66	62
	Total	330	204
Grey-faced petrel			
Pterodroma macroptera	1999	30	13
	2004	40	28
	2005	31	26
	2006	40	39
	2007	22	21
	2008	41	38
	Total	204	165
Pycroft's petrel			
Pterodroma pycrofti	2001	30	30
	2002	100	97
	2003	102	100
	Total	232	227
Chatham Island taiko			
Pterodroma magentae	2006	1	1
	2007	8	8
	2008	13	13
	Total	22	22
Fairy prion			
Pachyptila turtur	2002	40	40
	2003	100	100
	2004	100	100
	Total	240	240
Chatham petrel			
Pterodroma axillaris	2002	41	41
	2003	49	49
	2004	55	54
	2005	55	54
	2008	47	47
	Total	247	245
Hutton's shearwater			
Puffinus huttoni	2005	10	10
	2006	86	79
	2007	95	83
	2008	100	98
	Total	291	270
Fluttering shearwater			
Puffinus gavia	2006	40	34
	2007	91	91
	2008	94	86
	Total	225	211

All 240 translocated fairy prion chicks fledged successfully, and so the three artificial diets used made no difference to pre-fledging survival. Eighteen chicks fed on a krill-based diet in 2002 fledged at a mean weight of 104 ± s.e. 2.4 g, which was significantly lighter than 20 chicks fed on a Brunswick™ sardine diet in the same year (115 ± 1.5 g; $t = 4.412$, $P < 0.001$). Sixteen chicks fed on an Ocean Catch™ sardine diet in 2003 had significantly lighter fledging weights (105 ± 1.5 g) than 84 chicks fed on a Brunswick™ sardine diet in the same year (123 ± 1.2 g; $t = 6.691$, $P < 0.001$). The Brunswick™ sardine-based diet was used subsequently for all eight petrel species.

3.3. Fledging condition of chicks fed on pureed sardines compared to parent-fed chicks

The translocated petrel species exhibited markedly different growth strategies during the last weeks before fledging. The three summer-breeding *Pterodroma* spp. all lost weight rapidly during the last 3 weeks, losing 31–33% of their median bodyweight over this time (Fig. 4d–f). Hutton's shearwater had a similar pattern, although the rate of weight loss over the last 3 weeks was only 20% (Fig. 4g). Fairy prion and fluttering shearwater both showed gradual weight gains until the last week, then lost 2.4–8.5% over the last 7 days before fledging (Fig. 4b and h). Diving petrels and grey-faced petrels had negligible variation in mean bodyweight between translocation and fledging (Fig. 4a and c).

Most of the translocated chicks exhibited similar growth patterns to parent-fed chicks of the same species (the superimposed curves on Fig. 4b–h), although there is limited data on natural chick development for several species, and none at all for common diving petrels from northern and central New Zealand. Of the six species for which there were comparable data for parent-fed chicks, translocated chicks of four species fledged at significantly higher bodyweights (fairy prion, Pycroft's and Chatham petrel, Hutton's shearwater), and there was no significant difference in fledging weights for fluttering shearwater and common diving petrel (Table 6).

Weight loss curves for parent-fed grey-faced petrel and Chatham Island taiko chicks were modelled from accumulated data from 122 and 67 chicks, respectively (superimposed curves on Fig. 4c and d), rather than daily measurements of a sample of chicks. The regression line for parent-fed grey-faced petrel chicks indicated a mean weight loss of 7% over the last 3 weeks before fledging (Fig. 4c). However, it is thought that grey-faced petrel chicks lose weight rapidly in the last 3–4 days, to fledge at a mean weight similar to the mean of 545 g recorded for translocated chicks (Imber, 1976; G. Taylor, unpubl. data). If so, then weight loss over the last 3 weeks would be *c.*18%. This rapid weight loss over the last few days was masked by collection of too few 'natural' data, and because wing-length was used as an estimator for age with respect to fledging date. Grey-faced petrel chicks are also fed by their parents right up to fledging, and chicks can lose weight rapidly by processing these freshly delivered meals. By contrast, the natural Chatham Island taiko weight changes were graphed in relation to actual fledging dates. Adults of this species stop visiting their chicks 1–3 weeks before departure, and so chick weight loss is more predictable.

3.4. Pre-fledging emergence behaviour

The pre-fledging emergence patterns observed for translocated chicks ranged from individuals fledging on the first night that they emerged from their burrows through to others spending up to 33 nights on the colony surface (Fig. 3). Diving petrels and fairy prions typically fledged on the first night they emerged, or they emerged for a single night before fledging (mean 0.4 and 0.7 nights, respectively), with a maximum four nights on the surface for both species (Fig. 3a and b). Pycroft's petrels, Hutton's and fluttering shearwaters all spent a mean of seven nights on the surface, but maxima ranged from 12 to 27 nights (Fig. 3e, g and h). Chatham Island taiko and Chatham petrels spent a mean of 11 nights on the surface (Fig. 3d and f), though had different ranges, with all taiko chicks spending at least 5 nights on the surface, whilst some advanced Chatham petrel chicks fledged on their second night out. Translocated Chatham petrel chicks spent a similar amount of time on the surface (10.7 ± s.e. 0.2 nights, $n = 220$) as 'natural' chicks (11.2 ± 0.4, $n = 84$; $t = 1.202$, $P = 0.23$).

Translocated grey-faced petrel chicks had the longest emergence period, spending 7–33 nights on the colony surface (mean 16 nights; Fig. 3c).

3.5. Evidence of chicks returning to translocation sites and source sites

The expected age of first return to breeding colonies for the eight study species ranges from 1 to 6 years (Table 2). Of the 11

Table 6
Student's *t*-test comparison of fledging weights (g) of parent-fed chicks versus translocated chicks fed on pureed Brunswick[TM] sardines. Data presented as mean ± s.e. (*n*). Natural data sourced from Imber (1976), grey-faced petrel; Cuthbert and Davis (2002a), Hutton's shearwater; Gangloff and Wilson (2004), Pycroft's petrel; Peter Hodum (pers. comm.), fluttering shearwater; otherwise authors' unpubl. data.

Species	Natural, parent fed	Translocated	*t*	Probability
Fairy prion	105.9 ± 2.1 (30)	119.5 ± 0.7 (204)	6.499	<0.001
Pycroft's petrel	168.1 ± 2.9 (31)	174.0 ± 11.5 (79)	2.124	0.036
Chatham petrel	215.1 ± 4.0 (36)	232.2 ± 1.5 (244)	4.151	<0.001
Hutton's shearwater	408.8 ± 7.4 (40)	424.0 ± 2.1 (269)	2.502	0.013
Fluttering shearwater	406.7 ± 10.4 (23)	399.0 ± 1.6 (203)	−1.333	0.18
Common diving petrel	135.5 ± 2.0 (50)	134.7 ± 0.9 (86)	−0.390	0.70
Grey-faced petrel	542 (range 470–605)	544.9 ± 4.5 (93)		
Chatham Island taiko	423.9 (modelled)	480.9 ± 5.0 (21)		

discrete translocation projects reported here, only two (diving petrels 1997–1999 and grey-faced petrels in 1999) were completed long enough ago that we do not expect any further translocated chicks to be recovered as adults at the translocation sites (Table 1). Sixty-eight translocated chicks of six species have so far been recovered as adults at their translocation sites (Table 1), and five species have been confirmed to be breeding. Of the two species yet to be recovered as adults, one (fluttering shearwater) has been successfully translocated previously (Bell et al., 2005), and the other (Chatham Island taiko) is closely related to species that have returned following translocation.

There has been little effort to search for translocated birds back at the source colonies, largely due to access constraints to the remote island breeding colonies, and the difficulty of searching large petrel colonies without damaging fragile burrows. So far only two of our study species has been recovered at the source colony, with 25 translocated fairy prions recovered on Stephens Island (compared to 19 at the translocation site on Mana Island), and 2 translocated Chatham petrels recovered on Rangatira Island (compared to 6+ at the translocation site on Pitt Island).

4. Discussion

4.1. A universal artificial diet for translocated petrel chicks

The most unexpected outcome of this long series of trials was that petrel chicks of all species in the last third of their nestling period thrived on a single, simple artificial diet regardless of species size, phylogeny, or their typical natural diet. The species that we translocated typically fed on euphausiid crustaceans and copepods (diving petrel and fairy prion), squid (all four *Pterodroma* petrels), or fish and euphausiids (the two *Puffinus* shearwaters) (Marchant and Higgins, 1990), yet all eight species had post-translocation survival rates to fledging of 86–100% (and typically > 93%) when fed on pureed sardines (=juvenile Antarctic herrings) in soya oil.

Along with high survival rates, chicks of all species fledged in good condition when fed on pureed sardines. Mean fledging weights were significantly higher than natural weights for four species, and probably also for a fifth (Chatham Island taiko, where samples of natural fledging weights were insufficient for statistical comparison). Three further species (grey-faced petrel, diving petrel and fluttering shearwater) fledged at weights similar to natural weights. In the one robust trial comparing the sardine diet with a quasi-natural diet (fairy prions fed on pureed krill in 2002), chicks fed on pureed sardines fledged at a significantly higher mean bodyweight than those fed on krill. High fledging weights are correlated with high survival to adulthood in petrels (Perrins et al., 1973; Sagar and Horning, 1998), and this proved to be the case for the first species that we translocated (Miskelly and Taylor, 2004).

In addition to its effectiveness, the pureed sardine diet was more practical than any of the diets based on fresh or frozen fish, squid or krill. The main ingredient was readily available through retail or wholesale outlets, and could be purchased in small quantities if required, and stored almost indefinitely without refrigeration or freezing. The fish and oil content of every tin was consistently and reliably the same, and was easily prepared with water to a consistency that could be extruded through the feeding apparatus. Many of our translocation sites did not have reticulated electricity, yet we were able to prepare the petrel food using a kitchen blender powered by a petrol-powered generator or solar-charged batteries, and using portable gas cookers to heat water as required. Delivery of the puree via a crop tube was quicker and cleaner than piecemeal feeding of sardine chunks, although the logistics of feeding up to 100 chicks per day should not be underestimated.

We expect that the pureed sardine diet will prove effective for translocations of well-developed chicks of all burrow-nesting procellariid petrels, including those genera not yet tested (*Lugensa*, *Halobaena*, *Bulweria*, *Pseudobulweria*, *Procellaria*, and *Calonectris*).

4.2. Pre-fledging emergence behaviour

Natural emergence patterns had been studied in six of the translocated species (all but grey-faced petrel and fluttering shearwater), but the quality of data varied from video monitoring of a few burrows (Johnston et al., 2003), through monitoring of stick fences at a large number of burrow entrances in relation to changes in chick bodyweights indicating parental feeding visits (Gangloff and Wilson, 2004; H. Gummer, unpubl. data for Chatham petrel), to general statements about observed fledgling behaviour at burrow entrances and on the colony surface (Richdale, 1943, 1965a,b; Harper, 1976; Cuthbert and Davis, 2002a). Parent-reared chicks exhibited a wide range of pre-fledging emergence behaviour among the species translocated, with some typically fledging on the first night that they emerged from the burrow (Richdale, 1943, 1965a) and others coming to the surface and even climbing trees for up to 27 nights before fledging (Johnston et al., 2003; Gangloff and Wilson, 2004; H. Gummer, pers. obs.).

The pre-fledging emergence patterns observed for translocated chicks (Fig. 3) were generally similar to those described for parent-reared chicks. 'Natural' diving petrels and fairy prions also typically fledged either on the first night they emerged, or they emerged for up to 2 nights before fledging (Richdale, 1943, 1965a,b; Harper, 1976). 'Natural' Pycroft's petrel emergence patterns (mean 7 nights, range 1–15 nights; Gangloff and Wilson, 2004) were very similar to those we observed for translocated chicks, as were Chatham petrel emergence patterns ('natural' mean 11.2 nights, translocated mean 10.7 nights; n.s.).

Translocated Hutton's shearwater chicks appeared to spend more nights on the surface (mean 7 nights, ranging up to 27 nights) than the 4–5 nights at the burrow entrance suggested by Cuthbert and Davis, 2002a), but this aspect of natural chick behaviour has not been studied in detail.

The 22 translocated Chatham Island taiko chicks all had much shorter emergence periods than the three 'natural' chicks studied by Johnston et al. (2003), which emerged for 16, 24 and 27 nights before fledging. We suspect that the hilltop location and clear airspace at Sweetwater Conservation Covenant allowed translocated chicks to fledge rapidly (mean 11 nights of emergence) compared to the difficulty that wild chicks had becoming airborne from valley-floor sites with a dense, uniform-height canopy above, where they often had to be rescued after failed fledging attempts (Johnston et al., 2003).

4.3. Return of translocated chicks to release sites

Most of the translocations reported here have been undertaken too recently to allow full analysis of return rates, particularly in relation to fledging weights and the length of time that individual chicks were at the release sites (but see Miskelly and Taylor, 2004). However, the 68 translocated chicks of six species so far recovered as adults at the release sites add to the growing body of evidence that it is possible to reset the strong homing ability of petrels, and to use this as a tool to restore depleted or extinguished petrel colonies, or to establish them at new sites. To date, 11 species of petrel of five genera have been recovered back at release sites following translocations (Serventy et al., 1989; Priddel and Carlile, 2001; Priddel et al., 2006; Imber et al., 2003; Miskelly and Taylor, 2004; Bell et al., 2005; Jeremy Madieros, pers. comm.; this study), and a further species is due back during 2009–2011 (Table 1). In the case of the endangered Chatham petrel, the small colony now breeding within Ellen Elizabeth Preece Conservation Covenant on Pitt Island is the first recorded breeding away from Rangatira Island since the species' discovery in 1892.

In addition to the returning translocated chicks, unbanded prebreeders have been found at each of the monitored sites, typically arriving simultaneously with the returning (banded) chicks, and often found near the loud speaker systems. In the case of common diving petrels on Mana Island, the number of unbanded birds recovered at the colony ($n = 80$ by December 2008) greatly exceeded the 20 translocated chicks that returned (C. Miskelly, unpubl. data; Miskelly and Taylor, 2004). We suggest that use of sound attraction, in addition to translocation of chicks, is an important component in the successful establishment of new petrel colonies.

Development of a reliable methodology for petrel translocation and attraction offers new hope for a group of birds that have suffered huge losses in numbers, diversity and breeding ranges due to direct and indirect human impacts.

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