A REVIEW OF FOUR SUCCESSFUL RECOVERY PROGRAMMES FOR THREATENED SUB-TROPICAL PETRELS

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SUMMARY

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Recovery programmes have significantly increased the population sizes of four threatened sub-tropical petrels: Zino's Petrel *Pterodroma madeira*, Bermuda Petrel *P. cahow*, Gould's Petrel *P. leucoptera* leucoptera and Hawaiian Petrel *P. sandwichensis*. These recovery programmes were reviewed to examine i) past and present nesting habitat; ii) the nature and commonality of threats; iii) the recovery actions undertaken; iv) the conservation gains; and v) the factors most responsible for these gains. The most significant causes of past population decline were exploitation by humans for food, loss of nesting habitat and the introduction of alien mammals. Primary contemporary threats are predation and disturbance at the breeding grounds by both alien and indigenous species. Current relict populations have restricted distributions and are often confined to nesting habitats that are severely degraded or sub-optimal and dissimilar from those known historically. The crucial attribute of these habitats is the absence or low density of alien predators. The most beneficial recovery actions involved the control or eradication of predators at breeding grounds and the provision of safe artificial nest sites. Recovery actions were more difficult to implement for species on large islands. The success of each recovery programme was due largely to concerted action spanning several decades.

Keywords: Zino's Petrel, *Pterodroma madeira*, Bermuda Petrel, *Pterodroma cahow*, Gould's Petrel, *Pterodroma leucoptera*, Hawaiian Petrel, *Pterodroma sandwichensis*, conservation, Procellariiformes

INTRODUCTION

Many petrels (Procellariiformes) have undergone substantial declines in recent times (Harris 1970, Warham 1990). Conservation efforts to curb this trend that have attracted most publicity are those aimed at decreasing the accidental mortality of seabirds in fishing operations, particularly longlining (Baker *et al*. 2002). This particular threat, however, generally affects only the largest and most charismatic species - the albatrosses, giant petrels and a few of the larger shearwaters (Brothers *et al*. 1999). These species are particularly vulnerable to longlining because of their habit of congregating around ships (Ryan & Moloney 1988) to feed on discarded offal and fish bycatch (Croxall & Prince 1994). Smaller petrels (those less than 600 g) tend not to follow ships and so are generally not at risk from longline fishing (Baker *et al*. 2002).

Many small petrels have suffered substantial declines, due primarily to threats at their breeding grounds (Warham 1990). Unlike the majority of larger petrels that nest on sub-Antarctic islands, many smaller species nest in the tropics or sub-tropics, where the threats are often exacerbated by human population pressures (Enticott & Tipling 1997). Tropical and sub-tropical petrels now constitute a significant proportion of threatened Procellariiformes, particularly among those weighing less than 600 g. The most significant threats for petrels breeding in warmer climes include habitat degradation and predation by alien mammals, loss of habitat through agricultural clearance and urbanisation, and harvesting of eggs or young for food (BirdLife International 2000). Many sub-tropical petrels are known only from single islands, and consequently are particularly susceptible to extinction. At least three species are so rare that their current breeding grounds are unknown: Beck's Petrel *Pseudobulweria becki*, Fiji Petrel *P. macgillivrayi* and Jamaica Petrel *Pterodroma caribbaea*.

Despite the global decline of many tropical and sub-tropical petrels several case histories demonstrate that recovery of such species is possible. This paper reviews the recovery programmes of four sub-tropical petrels: Zino's Petrel *Pterodroma madeira*, Bermuda Petrel *P. cahow*, Gould's Petrel *P. leucoptera leucoptera* and Hawaiian Petrel *P. sandwichensis*. The review aims to i) compare past and present nesting habitat; ii) examine the nature and commonality of threats affecting these petrels; iii) scrutinise the recovery actions that have been implemented; and iv) examine the conservation gains that have been achieved. We then explore the various aspects of these recovery programmes to assess whether there were any specific features that were particularly instrumental in the success of these programmes.

TABLE 1
Attributes of the four species of *Pterodroma* petrels reviewed

	Zino's Petrel	Bermuda Petrel	Gould's Petrel	Hawaiian Petrel
Conservation status	Critically endangered	Endangered	Vulnerable	Vulnerable
Known residual population (breeding pairs) and year	7 (1969)	18 (1960)	< 250 (1992)	Unknown (1953)
Known current population (breeding pairs)[a]	29	56	911	c. 1000 on Maui; possibly many thousands on other islands
Former breeding distribution	Widespread on Madeira and on the nearby island of Porto Santo	Widespread across the islands of Bermuda	Restricted to Cabbage Tree and Boondelbah Islands, Australia	Abundant on all large islands in the Hawaiian Islands, USA
Location of contemporary nesting grounds	Steep inaccessible ledges in the Central Mountain Massif of Madeira, Portugal	Islets off Nonsuch Island, Bermuda	Areas of rock scree on Cabbage Tree and Boondelbah Islands, Australia	At high elevations on Maui, Hawaii and probably Kauai and Lanai, Hawaiian Islands, USA.
Size of island(s) containing nesting ground(s)	736 km^2	< 0.01 km^2	Cabbage Tree Island, 0.30 km^2; Boondelbah Island, 0.12 km^2	Maui, 1903 km^2; Hawaii, 10 434 km^2; Kauai, 1435 km^2, Lanai 358 km^2
Original nesting habitat	Unknown. Presumed to nest in soil burrows at a range of altitudes in forest and more open country	Soil burrows in forest	Rock cavities among rock-scree slopes in sub-tropical rainforest	Soil burrows in forests and more open country at lower elevations
Current nesting habitat	Soil burrows on isolated steep ledges, high in the central mountains	Rock cavities on rocky islets with sparse vegetative cover	Rock cavities among exposed rock-scree slopes in sub-tropical rainforest with degraded understorey, and nest boxes	Cavities in volcanic debris in sparsely vegetated, volcanic landscapes generally above 2500 m. Possibly also altitudinal wet forest.
Reasons for population decline	Harvested by humans. Predation by rats and cats. Degradation of nesting habitat by sheep and goats	Harvested by humans. Predation by pigs, cats, dogs and rats. Loss of nesting habitat through urbanisation and farming	Habitat degradation by rabbits. Predation by currawongs and raptors. Entanglement in sticky fruits of *Pisonia umbellifera*	Harvested by early Hawaiians. Loss of nesting habitat due to urbanisation and degradation by feral goats and pigs. Predation by introduced mongoose, feral cats, rats and dogs
Current threats	Predation by rats and cats; habitat loss from sheep and goats; ecotourism	Nest-site competition; predation by rats and raptors; storm surge and storm damage to habitat	Predation by currawongs	Predation by rats, cats, mongoose and dogs; habitat disturbance by goats, pigs and cattle; grounding of fledglings by artificial lights
Methods of predator control	Rats poisoned, cats trapped	Rats poisoned, raptors shot	Currawongs shot	Rats poisoned, cats and mongoose trapped, dogs excluded
Recovery actions	Monitor breeding; trap cats; poison rats; search for new nesting ledges; control ecotourism; education	Monitor breeding; exclude competing species; provide artificial nest sites; control rats	Monitor breeding; control currawongs; prevent regeneration of *Pisonia umbellifera* within nesting grounds; translocation	Monitor breeding; exclude goats, pigs, cattle and dogs; control rats, cats and mongoose; retrieval of grounded birds; search for additional breeding grounds

[a] Data as at the 2000 or 2000-01 breeding season

STATUS AND BREEDING BIOLOGY

All four species reviewed differ in population size, distribution and extent of breeding grounds, nesting habitat and conservation status (Table 1). Based on the then criteria of the World Conservation Union (IUCN 1994), Zino's Petrel (ZP) is Critically Endangered, Bermuda Petrel (BP) is Endangered and both Gould's Petrel (GP) and Hawaiian Petrel (HP) are Vulnerable (BirdLife International 2000).

The four species have similar breeding biology. Like most other Procellariiformes, they are highly pelagic, long-lived, mate for life, breed once a year (some other species breed biennially), and lay a single egg that is not replaced if lost (Warham 1990). Nest-site fidelity is strong, with pairs returning to the same burrow year after year. They feed principally on fish, squid and crustaceans at foraging areas that are largely unknown (Warham 1990).

HISTORIC DISTRIBUTION, HABITAT AND CAUSES OF DECLINE

Zino's Petrel

ZP occurs only on the heavily populated north Atlantic island of Madeira (32° 45' E, 16° 28' N) off the coast of North Africa, 900 km from Portugal, to which the island belongs. Since the island was discovered in 1419, humans have heavily exploited its abundant avifauna as a source of food (Bannerman & Bannerman 1965). The first specimens of ZP were collected in 1903 (Schmitz 1905). By 1934, when the species was first described (Mathews 1934a), it was already rare (Mathews 1934b). In the early 1940s two freshly fledged juveniles were found within the walls of the governor's palace in Funchal, presumably attracted there by lights. The species was not seen again until 1969.

Fossil records indicate that ZP was once widespread and common on Madeira (Zino & Zino 1986) and on the nearby island of Porto Santo (Zino *et al*. 2001). The main island of Madeira (736 km^2) is principally volcanic in origin with precipitous sea cliffs, a central mountain massif (rising to 1860 m) and steep gorges (Maul 1965). The island was once much more forested than it is today (Bannerman & Bannerman 1965) and it is thought that ZP had then nested in a broader range of habitats.

Initially, ZP was almost certainly exploited as a source of food, but would have also been adversely affected by predation from introduced Black Rats *Rattus rattus* and domestic cats *Felis catus*. Its nesting habitat has been eroded through overgrazing, and its burrows have been trampled by domestic stock (sheep *Ovis aries* and goats *Capra hircus*). ZP are now restricted to small cliff ledges that are inaccessible to large mammals.

Bermuda Petrel

BP has only ever been recorded from the Atlantic islands of Bermuda (64º 45' W, 32º 17' N), isolated in the western reaches of the Sargasso Sea, 1200 km north-east of the Caribbean and 900 km east of the United States coastal area of North Carolina (BirdLife International 2000). Bermuda consists of one main island and numerous smaller nearby islands - a total land area of only 53 km^2, supporting a human population of 60 000. The terrain is predominantly hilly, and soils are derived from calcareous sediments of aeolionite (Land & Mackenzie 1970).

Fossil evidence indicates that BP was once common and widespread across much of the main island, as well as on many of the smaller, vegetated islands (Wetmore 1962) where it bred in burrows dug into the soil. BP was first reduced in numbers by domestic pigs Sus scrofa released by Spanish voyagers about 1560 (Wingate 1985). Colonisation of Bermuda by the British in 1612 led to a further decline of the species. Not only was BP exploited as a food source by the early settlers, it was also subjected to heavy predation from introduced domestic cats, domestic dogs Canis domesticus and Black Rats (Lefroy 1877). The species was all but extirpated by around 1630 (Zimmerman 1975) and for more than 300 years was thought to be extinct (Verrill 1902, Murphy & Mowbray 1951).

Gould's Petrel

GP breeds only on two islands - Cabbage Tree Island (152º 14' E, 32º 41' S) and Boondelbah Island (152º 14' E, 32º 42' S) at the entrance to Port Stephens on the east coast of New South Wales, Australia (Priddel & Carlile 1997a). Cabbage Tree Island (0.3 km^2), the principal nesting site, is dominated by sub-tropical rainforest growing on volcanic-derived soils of toscanite. GP nests in natural rock cavities within the forested rock scree slopes of two large gullies on the western side of the island (Hindwood & Serventy 1943). Soil suitable for burrowing is available, but GP does not nest in soil burrows. A few pairs also breed on nearby Boondelbah Island where there is no forest or canopy cover. Here the petrels nest in small, exposed rock piles (Priddel & Carlile 1997a).

GP was first described in 1844 as breeding on Cabbage Tree Island "in great numbers" (Gould 1844), but one hundred years later the population was noticeably less numerous (D'Ombrain 1943). Underlying this decline has been the long-term degradation of the nesting habitat by the introduced European Rabbit *Oryctolagus cuniculus* (Priddel *et al*. 2000). By removing the rainforest understorey, rabbits have removed the vegetative cover that concealed and protected the petrels from avian predators. Removal of the undergrowth also exposed GP to another threat – entanglement in the fruits of the Birdlime Tree *Pisonia umbellifera* (D'Ombrain 1970, Fullagar 1976). This tall, indigenous shrub produces sticky fruits that readily adhere to the feathers of birds, rendering flight impossible (Priddel & Carlile 1995b). In a forest without rabbits, most of the fallen fruits lodge in the understorey plants where they pose little threat to GP. With the understorey removed, the *Pisonia* fruits fall to the ground where they are a significant threat to GP moving about the forest floor.

Hawaiian Petrel

HP breeds only on the Hawaiian Islands in the central Pacific Ocean (Richardson & Woodside 1954). This archipelago is made-up of eight large islands (between 154° W 19° N, and 160° W, 22° N) and 124 smaller islands (between 180° W and 30° N) (Juvik & Juvik 1998). The islands are all volcanic in origin, the most easterly of which are still active. Fossil evidence indicates that HP occurred on numerous islands within the archipelago (Olson & James 1982a, Olson & James 1982b), nesting in soil burrows within altitudinal wet forest (Bryan 1908). Breeding colonies, however, no longer occur on many islands.

The arrival of Polynesians at the Hawaiian Islands some 1800 years ago introduced humans as a major predator of HP. Along with humans came dogs, pigs and the Pacific Rat *R. exulans* (Simons

1985). HP on Oahu was probably exterminated by these alien predators prior to the arrival of Europeans (Olson & James 1982a). Additional mammalian predators that accompanied Europeans, such as domestic cats, Black Rats and Norway Rats *R. norvegicus*, accelerated the declime of HP. The introduction of the Small Indian Mongoose *Herpestes auropunctatus* by the sugar industry added yet another predator (Hodges 1994).

CONTEMPORARY DISTRIBUTION, HABITAT AND THREATS

Zino's Petrel

It was not until 1967 that concerted efforts were made to locate the breeding grounds of ZP (Zino & Zino 1986). In 1969, a relict population was discovered nesting on a series of remote cliff ledges in the Central Mountain Massif (Zino & Zino 1986). These ledges are inaccessible to sheep and goats, and so support floral communities that differ from those on surrounding lands (Zino *et al*. 2001).

Contemporary threats to ZP were initially thought to involve the incidental consumption of birds and eggs by local shepherds and the occasional removal by collectors (Zino & Zino 1986). However, when nests were first monitored (in the early 1980s) it soon became apparent that high levels of predation on eggs and chicks by Black Rats was the predominant threat to the species (Zino & Zino 1986). A further threat was identified in 1991 when feral cats killed 10 petrels on a single ledge (Zino 1992).

Bermuda Petrel

Following many failed attempts to locate living specimens, BP was eventually discovered breeding on several small islets off Nonsuch Island in 1951 (Murphy & Mowbray 1951). It was not until 10 years later, however, that the size of the relict population, just 18 breeding pairs, became known (Zimmerman 1975). The petrels were restricted to four small rocky islets totalling less than 0.01 km^2. These islets are essentially devoid of vegetative cover (Wingate 1988) and contain only small pockets of skeletal soil (Murphy & Mowbray 1951) that are too shallow to support burrows. Without the opportunity to burrow, BP nests in natural rock cavities (Wingate 1985). Many of these cavities are close to sea level and are subject to inundation by surging seas during storms. In addition, hurricanes and rising sea levels are gradually destroying these cavities, reducing further the few nest sites available (Wingate 1995).

The loss of nest sites is compounded by the associated increase in competition from the White-tailed Tropicbird *Phaethon lepturus* (Wingate 1985). This tropicbird, which remains common on Bermuda, is larger and more aggressive than BP and consequently competition for nest sites invariably results in the petrel chick being killed. In some years, mortality of BP chicks has been as high as 60% (Wingate 1985).

Even on the islets where BP currently survives, eggs and chicks were probably lost occasionally to Black and Norway Rats, before measures were taken to control those individuals that manage to reach the islets (Wingate 1978). Occasional predation by owls and falcons (D.B. Wingate unpubl. data) has reduced the rate of recovery of BP.

Gould's Petrel

Monitoring of GP began in 1989. It was soon apparent that the population was declining due to poor breeding success and high adult mortality (Priddel & Carlile 1995b). In 1992, the breeding population numbered less than 250 breeding pairs. Breeding success was poor (<20%) and adult mortality (>50 individuals a year) exceeded fledgling production.

Degradation of the nesting habitat by rabbits had made GP vulnerable to entanglement in the sticky fruits of the Birdlime Tree, and to attack by Pied Currawongs *Strepera graculinaa*, a large, indigenous crow-like bird (Priddel & Carlile 1995b). In addition, sporadic predation by transient raptors and owls occasionally caused significant mortality of breeding adults.

Hawaiian Petrel

Contemporary breeding grounds of the HP were unknown until 1953 when a population was discovered on Maui (Richardson & Woodside 1954). Since then, additional populations have been located on the same island (Harrison *et al*. 1984, Simons 1985, Simons & Hodges 1998, Hodges & Nagata 2001), and on the island of Hawaii (Hu 1995). Haleakala National Park, on the island of Maui, contains the largest known colony of about 1000 breeding pairs (Haleakala National Park unpubl. data). Early reports of Polynesian hunting parties having to travel to the crater of Haleakala to collect fledglings (Henshaw 1902) suggest that HP was already restricted to its current breeding range at the time Europeans arrived in the Hawaiian Islands.

Monitoring of known nests at Haleakala has been conducted annually since 1988, and additional nests are found each year (Hodges & Nagata 2001). In some years more than 60% of all egg and chick mortality was caused by cats and mongooses (Simons 1983). Although rats prey on HP eggs, the major threat that rats pose is that they provide a prey base for cats and mongooses (Simons 1985).

The few sites where HP are currently known to breed are in sub-humid, sub-alpine, volcanic landscapes at altitudes generally above 2500 m (Simons & Hodges 1998). Boulders and debris from volcanic activity dominate this dry, barren landscape where soil and vegetative cover are sparse (Simons 1985). Here HP nests on volcanic cliffs and steep slopes in burrows formed from deep natural cracks between buried rocks, volcanic boulders and bedrock (Richardson & Woodside 1954) or dug into erosional debris or, occasionally, sod-covered soil (Simons 1985).

Based on at-sea observations, Spear *et al*. (1995) estimated the world population of HP to be about 19 000 birds. Nocturnal calls and the occurrence of grounded fledglings suggest that the species may breed on the islands of Kauai and Lanai, but difficult terrain has so far frustrated attempts to locate any colonies (Hirai 1978, Conant 1980, Ainley *et al*. 1997). Based on the number of birds observed returning inland the as-yet-undiscovered population on Kauai may exceed several thousand individuals (Ainley *et al*. 1997) and may still nest in soil burrows within forest (Simons & Hodges 1998). This population may be relatively abundant because Kauai is free of mongooses.

OTHER POTENTIAL THREATS

Pollutants

Of the four petrel species considered in this review, pollution is known to affect only one. BP was discovered to have high levels of residual DDT in chicks and eggs (Wurster & Wingate 1968). This residual insecticide was implicated in the low reproduction success recorded between 1958 and 1970. Although plastic pollution is a significant threat to many seabirds, it does not appear to be a threat for any of the four species of petrel reviewed. Opportunistic examinations of the regurgitated crop contents of ZP, HP and GP found no evidence of synthetic material (Zino *et al*. 1989, C. Natividad & D. Priddel unpubl. data). There are no records of oil contaminating any of the four species.

Threats at sea

The range and extent of threats at sea are essentially unknown for all four species, largely because very little is known about the extent or whereabouts of their foraging areas. Spear *et al*. (1995) conducted at-sea observations of HP and other Procellariiformes between 1980 and 1994. While valuable information was gathered on distribution, density and population size, little was revealed about possible threats.

Although there is no evidence of any current threats at sea for any of the four species, two observations highlight their sensitivity to conditions at sea. Firstly, a dramatic reduction in breeding success of GP (<20% compared to the norm of >50%) occurred during 1995 (Priddel & Carlile 1997b) coincident with an Australia-wide die-off of Pilchards *Sardinops sagax neopilchardus*, believed to be the result of an alien pathogen introduced to Australian waters in frozen pilchards fed to farmed fish (Hyatt *et al*. 1997). Secondly, the percentage of HP that come ashore to nest is significantly less during *El Niño* years (c. 40% compared to the norm of c. 65%; C.N. Hodges *in litt*.). These responses suggest that sub-tropical petrels may be particularly vulnerable to an increase in the extent or frequency of environmental perturbations caused by further degradation of the marine environment or by global climate change.

RECOVERY ACTIONS

Actions completed

For each recovery programme, a suite of recovery actions has been implemented to ameliorate each of the threats identified, minimise adult mortality and maximise reproductive output. Although the collective benefit of these actions has been measured, the relative contribution of each individual action has not been assessed.

Although the breeding grounds of ZP were rediscovered in 1969, it was not until 1986 that the Freira Conservation Project was established to protect the species. This programme was a joint initiative between the Funchal Museum of Natural History, Parque Natural da Madeira and the local community, with financial assistance provided by several European benefactor agencies. Responsibility for development, coordination and implementation of the programme has rested with concerned local ornithologists. The programme aimed to monitor the breeding population, ameliorate threatening processes as they were identified and to investigate further possible breeding sites (Zino *et al*. 2001). In 1986 a programme of rat baiting was instigated (Buckle & Zino 1989). Following a bout of cat predation in 1991 an intensive cat-trapping programme was also initiated (Zino 1992).

BP has had the longest programme of recovery, beginning in 1951 and, up until recently, under the stewardship of a single individual. Actions to conserve BP have focused on reducing competition for nest sites, providing artificial nest sites and rat control. Initial recovery action involved fitting each nest site with a wooden baffle that restricted entry by tropicbirds but permitted access by the slightly smaller petrels (Zimmerman 1975). Subsequently, artificial nest sites were also created. These structures, comprising a long tunnel terminating in an enlarged chamber, were constructed largely of concrete (Wingate 1978). Construction of these artificial nests has continued to ensure that there are at least 10 nests surplus to requirements each year. Following each major storm, substantial remedial work is needed to shore up eroding sections of the smaller islets and prevent the loss of nest sites. Rats have been eradicated from the small islets, but occasionally this needs to be repeated because of re-invasion from adjacent headlands of the main island (Wingate 1985). Baiting of these headlands to reduce the likelihood of recolonisation is now a routine part of the recovery programme.

The plight of GP came to light only as recently as 1989 (Priddel *et al*. 1995). In 1993, concerned scientists initiated an experimental recovery programme to remove Birdlime Trees from within the GP breeding habitat and to control Pied Currawongs (Priddel & Carlile 1997b). In 1997, rabbits were eradicated from Cabbage Tree Island (Priddel *et al*. 2000). Over the next few years, two hundred near-fledged birds were translocated from Cabbage Tree Island to Boondelbah Island, one kilometre to the south, and placed in habitat created from artificial nest boxes (Priddel & Carlile 1995a). The aim was to establish a second colony as a safeguard for the species should the main colony on Cabbage Tree Island suffer catastrophic loss due to wildfire or the arrival of an alien predator. Earlier trials demonstrated the validity of the techniques used (Priddel & Carlile 2001), but it is too soon to know if the translocation has been successful.

In 1976, a perimeter fence was erected around the main colony of HP to exclude feral goats and pigs. Although the purpose of this fence was to protect the endemic vegetation (Hodges 1994), it also benefited HP by preventing burrows from being trampled (Simons 1983). The fence also reduced the number of dogs entering the colony (Hodges & Nagata 2001). Trapping to control rats began in 1968. Since 1981, cats and mongooses have also been targeted following studies which highlighted the impact of these species. Trapping of all three species is now undertaken year-round, with the additional use of rodenticides since 1997. Urban lighting on Kauai has been modified to reduce the number of young HP and Newell's Shearwater *Puffinus auricularis newelli* that become disorientated and ground on the island (Ainley *et al*. 1995, Simons & Hodges 1998).

Proposed actions

ZP is far from secure, and although over time the threat of illegal collecting has diminished, ecotourism from ornithologists and mountaineers is expanding and needs to be appropriately managed (Zino *et al*. 2001). With the assistance of international funding, the land containing the ledges on which ZP breeds are being purchased as a conservation measure. Grazing has already been excluded. Together these actions will control erosion, restore the vegetative cover, and expand the extent of suitable nesting habitat. Initially, the expansion of nesting habitat may involve the creation of artificial burrows. A study of burrow usage by breeding adults, using remote electronic techniques, is soon to commence.

A programme of banding BP has recently been instigated to collect detailed information regarding the demography of this species. Initiatives to attract sub-adults to other islands or to translocate fledglings from some of the smaller islets to Nonsuch Island (0.06 km^2) are currently being developed. Nonsuch is maintained predator free, contains a regenerated forest environment and has excellent potential to allow the petrels to recommence their natural burrowing activities (Wingate 1985).

The recovery of GP is progressing at such a rate that no additional recovery actions are planned (NSW National Parks and Wildlife Service 2001). A study is currently being undertaken to examine the energetics of breeding adults and nestlings. The findings of this study may provide options to maximise reproductive output should food resources again be in short supply.

Further surveys are needed to locate colonies of HP on Kauai and additional colonies on the island of Hawaii. Despite best efforts, the control of predators at Mauna Loa on the island of Hawaii needs to be improved. Current practices of predator control at Haleakala on Maui appear adequate, but research to improve the efficiency of the techniques used is likely to be beneficial (Simons & Hodges 1998).

CONSERVATION ACHIEVEMENTS

In the first year of monitoring (1986) the breeding success of ZP, only six burrows on the main nesting ledge were occupied, and no pairs bred successfully (Zino & Zino 1986). Rat baiting began soon after and in 1987 a single chick survived through to fledging (Buckle & Zino 1989). Since 1990, breeding success has been variable, but the number of known breeding pairs on this ledge has increased to 12 (Zino *et al*. 2001), with a further 17 pairs discovered on other ledges.

Recovery of BP was variable in the early years. Breeding success increased to 66% (18 breeding pairs) in 1960 but dropped to a low of 28% in 1966 (21 pairs) (Wurster & Wingate 1968). By 1977, the number of breeding pairs had risen to 26 and breeding success had stabilised at approximately 50–60% (Wingate 1978). The population has continued to increase steadily, reaching 35 breeding pairs in 1983 (Wingate 1985), 49 in 1995 (Wingate 1995) and 56 in 2000 (D.B. Wingate unpubl. data). The presence in recent years of additional birds prospecting for nest sites suggests that the increasing trend will continue into the foreseeable future.

In 1992, the population of GP was less than 250 breeding pairs, breeding success was less than 20% and fewer than 50 young fledged a year (Priddel *et al*. 1995). Recovery actions have been implemented since 1993, and the number of breeding pairs has increased steadily to 911 pairs breeding in 2000 (D. Priddel & N. Carlile unpubl. data). Breeding success has, in all but one year, exceeded 50%. Reproductive output has increased markedly, and in 2000 a total of 474 birds fledged.

Many nesting grounds of HP remain undiscovered, so the size of the population and the rate of recovery are difficult to estimate. In 2000, the known breeding population was estimated to be 450–650 pairs (Hodges & Nagata 2001). Annual surveys have now located a total of more than 900 HP nests around the summit of Haleakala alone (Hodges & Nagata 2001). Further nests are likely to be discovered as more potential sites are searched. Estimates of population size based on observations of birds at sea (Spear *et al*. 1995) and birds flying inland on Kauai Island (Ainley *et al*. 1995) range up to 35 000 birds. In 1979, breeding success (based on the proportion of active burrows that produce fledglings) at Haleakala was 24%, with most breeding failure being due to predation (Simons 1985). Since recovery actions have been implemented breeding success appears stable at about 40% (Simons 1985, Hodges 1994, Hodges and Nagata 2001).

DISCUSSION

Current populations of all four petrels now have greatly restricted distributions and are confined to habitats that differ markedly from their original nesting habitat (Table 1). By inhabiting uncharacteristic or sub-optimal habitats petrels can be exposed to threats that they would not normally encounter. BP, for example, now breeds on islets where it suffers nest competition with the cliff-nesting tropicbird and inundation of nests by seas during storms. Neither of these problems would have occurred in the original breeding habitat.

Although current nesting habitats bear little resemblance to those used in the past, they share one crucial attribute: the absence or low density of alien predators. Thus, whereas forest may be a component of the optimal nesting habitat for these petrels, the principal factor in conserving each species is maintaining their current nesting habitat free of alien predators. It is not surprising then that the recovery action that featured most prominently in each of the four recovery programmes was the control of predators. The species of predator differed between programmes, so the means of control also varied (Table 1).

Predation of nesting adults, chicks and eggs is probably the single most significant threat to petrel populations around the globe, and is particularly prevalent at tropical and sub-tropical latitudes (Enticott & Tipling 1997, BirdLife International 2000). Troublesome predators can also include indigenous species that have assumed pest status. Both BP and GP have suffered significant losses from indigenous bird species, these threats having arisen in response to the changing circumstances associated with displacement from, or degradation of, optimum habitat.

Each of the recovery programmes focused on enhancing small relict populations of species that were once far more numerous. Relict populations can be particularly difficult to locate, thereby delaying or frustrating efforts to commence recovery action. Three species (ZP, BP, HP) were eventually discovered in habitats dissimilar from those in which they previously occupied when more abundant. Surveys for other populations and other relict species should extend beyond those habitats known from historical records.

All four species of petrel showed substantial increases in breeding success soon after action was taken to ameliorate the threats identified. However, because petrels are long-lived and can take many years to reach breeding age (usually in excess of five years; Warham 1990), increases in the size of the breeding population can be slow, and may not be evident for many years. It is essential, therefore, that recovery programmes for seabirds are planned and funded in terms of decades rather than years. Often financed by short-term political budgets, conservation agencies around the world have difficulty in planning and maintaining such long-term programmes. An important feature of each of the programmes reviewed is their relative longevity, due in large part to a few dedicated individuals. It is noteworthy that the successes associated with these recovery programmes have been achieved primarily by individuals who worked to some extent independently of conventional funding and organisations, and without the guidance of a recovery team or any formal review process. Although many nations now have a formal recovery planning process in place, usually involving the formulation of a recovery plan overseen by a recovery team, this procedure is clearly not essential to achieving a successful conservation outcome. Of those species reviewed, BP and GP have the smallest breeding distributions. Being restricted to small, uninhabited islands, however, has meant that recovery actions could be more focused and more effective. The total area requiring management is comparatively small, making tasks such as the control or eradication of alien predators both achievable and affordable. On the other hand, species that nest on large islands generally require management that is both more extensive and more frequent, thus necessitating greater overall effort to achieve the same results. HP and ZP breed on relatively large islands (Table 1) and will require greater vigilance and more widespread action for the population to reach and maintain sustainable levels.

Knowledge of the foraging range and feeding behaviour of all four species is needed to assess the importance of human-induced mortality factors at sea. With the apparent onset of climate change, further threats at sea are possible. Future population trends of each species will have to be viewed in the light of changing weather patterns, yet discerning the effects of climate change will always be difficult in species with populations that are either small or under rapid recovery. Any subtle decreases in breeding success brought about by gradual changes in climate may be swamped by the increases associated with successful recovery actions at their nesting grounds.

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