Status and ecology of gadfly petrels in the temperate North Pacific

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Abstract

The temperate waters of the North Pacific support large populations of gadfly petrels, especially in the boreal summer. In terms of numbers both of species and of individuals, most are trans-equatorial migrants from the New Zealand area or from breeding sites in the eastern or central South Pacific. The three gadfly petrels that breed in the North Pacific (*Pterodroma phaeopygia sandwichensis*, *P. hypoleuca*, and *Bulweria bulwerii*) nest on tropical islands from Hawaii westward.

Alien mammals on breeding colonies are the major threat to all species, with several—*P. p. sandwichensis*, *P. solandri*, *P. neglecta*, and *P. cookii*—showing major declines in breeding range and abundance in prehistoric and historic times and, in most, extinction of some populations. The rarest is *P. p. sandwichensis*, but *P. solandri* and *P. longirostris* are now essentially confined to a single breeding locality and are thus very vulnerable. Diurnal surface-nesting species like *P. neglecta* and *P. ultima* have disappeared from many former nesting sites. Among the most pressing conservation measures needed are continuing predator control on the Hawaiian Islands, immediate protection of Ducie and Oeno islands (U.K.), and control of serious predation on the Desventurados and Juan Fernandez islands (Chile).

Résumé

Les zones tempérées du Pacifique Nord assurent la subsistance de fortes populations de diablotins, surtout pendant l'été boréal. La plupart des espèces et des individus sont des oiseaux migrateurs de l'hémisphère sud, originaires de la Nouvelle-Zélande ou des lieux de nidification dans les régions orientale et centrale du Pacifique Sud. Les trois espèces de diablotins qui se reproduisent dans le Pacifique Nord, *Pterodroma phaeopygia sandwichensis*, *P. hypoleuca* et *Bulweria bulwerii*, nichent dans les îles tropicales d'Hawaï et situées plus à l'ouest.

Les mammifères non indigènes qui ravagent les colonies de reproducteurs sont la plus grande menace pour toutes les espèces, autant les nicheurs que les migrateurs. Plusieurs espèces de diablotins, *P. p. sandwichensis*, *P. solandri*, *P. neglecta* et *P. cookii*, affichent de fortes diminutions de l'aire de reproduction et de l'abondance par rapport aux temps préhistoriques et historiques. Pour la plupart de ces espèces, l'extinction de certaines populations est bien documentée. L'espèce la plus rare est *P. p. sandwichensis*, mais on sait que *P. solandri* et *P. longirostris* sont essentiellement confinés dans un seul lieu de reproduction, ce qui les rend très vulnérables. Des espèces qui nichent de jour en surface, comme *P. neglecta* et *P. ultima*, ont disparu de nombreux lieux antérieurs de nidification. Les mesures de conservation les plus urgentes sont la lutte continue contre les prédateurs dans les îles Hawaï, la protection immédiate des îles Ducie et Oeno (Royaume-Uni) et la lutte contre les prédateurs dans les îles Los Desventurados et Juan Fernández (Chili).

1. Introduction

Both published and unpublished sources have been reviewed to provide a broad picture of the status and ecology of *Pterodroma* and *Bulweria* species in the temperate North Pacific, here defined as north of the Tropic of Cancer (23°28′N). Besides containing all of the huge subtropical gyre, together with the boundary currents (Reid 1962), the area includes extensive subarctic waters and the productive transition zone in between. In the western and central Pacific, tropical waters extend to 30° N (Shuntov 1972), and thus intrude across the southern boundary.

Excluded from this account are several predominantly tropical and equatorial petrels that occur in these waters (Tahiti Petrel *P. rostrata*, Phoenix Petrel *P. alba*, Galapagos Dark rumped Petrel *P. p. phaeopygia*, and New Caledonia Petrel *P. leucoptera caledonica*), as well as some of the subtropical species (Juan Fernandez Petrel *P. externa*, White-necked Petrel *P. cervicalis*, Herald Petrel *P. arminjoniana heraldica*, Black-winged Petrel *P. nigripennis*, and Pycroft's Petrel *P. pycrofti*). The winter-breeding nonmigratory Masatierra Petrel *P. defilippiana* was also excluded. This was once thought to be a possible migrant allied to Cook's Petrel *P. cookii*, but it is now known to be a distinct species (Imber 1985b).

For the nine species included we give information on breeding range and population, nesting habitat, and threats. A full account of the marine distribution in relation to the timing of breeding, migration, and moult of southern hemisphere species may be found in Bartle and Stahl (in press).

2. Breeding species

2.1. Bulwer's Petrel *Bulweria bulwerii*

2.1.1. Breeding localities, population, and habitat

Bulwer's Petrel is an abundant breeder across the tropical Pacific from the coast of China east to the Marquesas Islands (Table 1). However, western populations are apparently now much reduced. The species was formerly on Taiwan, where it is now possibly extinct (Melville 1984).

Table 1
Breeding localities and estimated numbers of pairs of Bulwer's Petrels in the Pacific

Breeding locality	No. of pairs	Reference
China (islands off Fukien)	present	De Schauensee 1984
Ryukyu Is.	few	Hasegawa 1984
Izu Is.	several	Hasegawa 1984
Bonin Is.	many	Hasegawa 1984
Hawaiian Is. (incl. Johnston Atoll)	ca. 100 000	Harrison et al. 1984
Phoenix Is.	100s	Garnett 1984
Marquesas Is.	1000–3000	Holyoak and Thibault 1984

Bulwer's Petrel nests on atolls, rocky islets, and volcanic islands in rock crevices, under rocks, or in shallow depressions in dense vegetation.

2.1.2. Marine distribution in the temperate North Pacific

It is found in the North Pacific over tropical and warm subtropical waters primarily between 10°N and 30°N during the breeding season (April–September), but confined to tropical waters south of 12°N between October and February (Bartle and Stahl, in press).

2.1.3. Threats and conservation measures

The major threat is imposed by the introduction of alien predators, especially mammals. On Midway Island, Bulwer's Petrels disappeared after the introduction of black rats *Rattus rattus* in 1943 (Harrison et al. 1984). At Johnston Atoll, the natural rock crevices in which birds formerly bred were destroyed by military activities, and the species is now dependent on gaps between rocks and chunks of concrete used to build the causeway (Amerson and Shelton 1976).

2.2. Hawaiian Petrel *Pterodroma phaeopygia sandwichensis*

2.2.1. Breeding localities, population, and habitat

Hawaiian Petrels formerly nested abundantly throughout the main Hawaiian Islands. Hunting and predator introduction by Polynesians exterminated the species from Oahu (Olson and James 1982) and lowland areas elsewhere. Mammals introduced by Europeans probably eliminated it from most high-altitude sites except Haleakala National Park, on Maui (Harrison et al. 1984; Simons 1985). On Mauna Loa, where Banko (1980) had earlier located a colony, birds were heard calling in 1978, and several that had apparently been killed by feral cats were found (J.M. Scott and C.B. Kepler, unpubl. data). This suggests that the colony is threatened by predators from nearby settlements. Other small colonies may exist on Kauai (Banko 1980), Lanai (Shallenberger 1974; Hirai 1978; Pyle 1987), windward Molokai (J.M. Scott and C.B. Kepler, unpubl. data), and elsewhere on Hawaii (Banko 1980; Conant 1980; Pyle 1986). Most breeding activity occurs between April and August, when rainfall is lowest. At Haleakala, birds nest in steep rocky places along the caldera walls where burrows can be dug or lava tubes and cracks are used. The site of this remnant colony may not be representative of the former breeding habitat.

The population at Haleakala was estimated at 1800 birds in 1971 (W. Banko, cited by King 1981), and appears stable. Simons (1984) also estimated the total population at 1800 birds, made up of 48% adults and 52% prebreeders. From 1979 to 1981, Simons (1984) found 575 active burrows, of which 431 were occupied by breeders and 144 by prebreeders. In 1988, 503 burrows were active, and from 42% of these chicks were fledged (Simons, unpubl. data).

2.2.2. Marine distribution and abundance

Delineation of the pelagic range of the Hawaiian Petrel is difficult because the two subspecies of *P. phaeopygia* are not separable at sea. The boundary between the nominate race and *P. p. sandwichensis* appears to lie between about 120°W and 130°W, although Jones (1965) reported a distribution gap between 124°W and 137°W. Abundance and frequency of occurrence increase markedly east of 120°W (Pitman 1986), presumably reflecting the greater abundance of *P. p. phaeopygia* from the Galapagos (35 000 pairs, Coulter 1984, as compared to less than 1000 pairs for *P. p. sandwichensis*).

Small numbers are observed in the Hawaiian region from March until November, with a peak of abundance in May (King 1970). During the breeding season Hawaiian Petrels are usually found north of 17°N (King 1967), with maximum density in Hawaiian waters around 25°N 157°W (King 1970). The range extends north to the southern Gulf of Alaska in July–August, with records to 50°N in waters as cool as 12°C: four seen at 38°N 135′W, August (Bourne 1965); 20 at 45°N 158°W, July (Bourne and Dixon 1975); two near 45°N 154′W, July; one at 50°06′N 146°56′W, August (T.R. Wahl and A.R. DeGange, unpubl. data). Westernmost pelagic records are in the vicinity of 170°W: 1–5 at 17°N 170°W, during March–April (Meeth and Meeth 1986); two at 24°12′N 171°24′W in September (Jones 1965); reported at 172°W, latitude and month not given (Bourne 1989). However, at least some disperse even further west, as Hawaiian Petrels have been collected at Negros Island, Philippines, in March (Rabor et al. 1970) and at Ternate Island, Moluccas, in April (in moult, Bourne 1967a). In view of the collection dates and moult, both specimens were almost certainly nonbreeding birds, suggesting that juveniles migrate into the western tropical Pacific after fledging. There is also a Japanese record of one found in north Honshu on 4 September 1976 (Nakamura 1979). The pelagic range during the nonbreeding season is virtually unknown: in November, *P. phaeopygia* (ssp. unknown) was recorded along 7°N between 139°W and 145°W (Morzer Bruyns 1965) and at 23°N 160°W (Bourne and Dixon 1973); there has been one January sighting at 6°N 131°W (Bourne 1967b).

2.2.3. Threats and conservation measures

The most immediate threat to this species is from feral mammals, primarily cats and mongooses *Herpestes auropunctatus*, which caused more than 60% of the breeding failures in the Haleakala colony in the early 1980s. Continued predation at this level would have driven the colony extinct in 20–30 years. Subsequent mammal trapping has decreased predation and has resulted in increased reproductive success at that colony (Simons 1984, 1985). Conservation of the Haleakala colony requires continuation of the predator control program indefinitely, as well as the restriction of commercial and recreational development nearby. All other nesting sites should be identified and predators controlled as soon as possible.

Artificial lights attract and ground many petrel fledglings annually on Maui (Simons 1983, 1985) and Kauai (Reed et al. 1985). Because of increasing building on Maui, this hazard should be closely monitored (Gassman-Duvall et al. 1988). Possible mitigation could include reducing the use of lights during the month when petrels fledge, as well as

shielding essential outdoor lights, which substantially reduced Newell's Shearwater groundings on Kauai (Reed et al. 1985).

There is now a small body of published and unpublished information (e.g., Scofield 1990a) suggesting that the noise of machinery such as generators can attract or disturb gadfly petrels near colonies. This threat should also be investigated.

2.3. Bonin Petrel *Pterodroma hypoleuca*

2.3.1. Breeding localities and habitat

Bonin Petrels nest only in the northwestern Hawaiian Islands and in the Bonin (Ogasawara) and Volcano (Iwo) islands (American Ornithologists' Union 1983; S.I. Fefer et al., unpubl. data). In the Hawaiian Islands, colonies are found from French Frigate Shoals to Kure Atoll (Harrison et al. 1984), where nests are typically in burrows dug into coral sand, often under bunchgrass *Eragrostris variabilis* or shrubs *Scaevola taccada* (Woodward 1972; Ely and Clapp 1973; Clapp and Wirtz 1975). On Sand Island (Midway Atoll) burrows are in loose sand as well as in consolidated dunes and under lawns (Woodby, pers. obs.), where they may be up to 3 m long and up to 1 m below the surface (Grant et al. 1983). Plant roots provide structural strength to burrows, and Grant et al. (1983) noted that burrows in consolidated sand may last several years, whereas those in loose sand often collapse between breeding seasons. Bonin Petrels may also nest on the surface where cover is available (S.I. Fefer et al., unpubl. data).

2.3.2. Population size

Estimates of the breeding population in the western Pacific are lacking except for "large numbers" on Minami-iwojima (Hasegawa 1984). In the northwestern Hawaiian Islands, there are roughly 1 325 000 birds, of which approximately half are breeding birds. The largest colonies are on Lisianski and Laysan islands, with roughly 300 000–500 000 and 100 000–150 000 breeding birds, respectively. Estimates of the remaining Hawaiian breeding populations are as follows: 5000–10 000 on Midway Atoll, 800–1200 on Kure Atoll, 800–1200 at Pearl and Hermes Reef, and 60–100 on French Frigate Shoals (all estimates from Harrison et al. 1984).

2.3.3. Marine distribution and abundance

Bonin Petrels are confined to the western half of the North Pacific throughout the year, with most sightings from 10°N to 40°N and from 125°E to 160°W (King 1967, 1970; Gould 1983; Tanaka and Kaneko 1983; Tanaka et al. 1985; *Sea Swallow* 1947–1989). They are rare in the Hawaiian region east of 160°W, where scattered birds are sighted from 10°N to 25°N, mostly in October–January and April–May (King 1970; Meeth and Meeth 1986).

Seasonal variation in distribution has been studied east of Japan (Tanaka and Kaneko 1983) but is little known elsewhere. Bonin Petrels are confined south of 36°N from November to April, with the southern limit of range near 24°N until January (Tanaka and Kaneko 1983). In November, the species was recorded commonly (250/day) between Midway Atoll and Laysan Island, but rarely (2/day) between Laysan and French Frigate Shoals (Pyle and Eilerts 1986). It extends further south from February to April, to 12°N between the Philippines and the Marshall Islands (Tanaka and Kaneko 1983) and to 10°N southeast of Hawaii (Meeth and Meeth 1986). At this time of the year, Bonin Petrels are abundant in the East China Sea (several thousand at ca. 30°N 125°E, February, Bourne 1967b), west of the Bonin Islands (Bourne and Dixon 1973; Tanaka and Kaneko 1983), and northeast of the Bonin Islands between 24°N and 32°N (Tanaka and Kaneko 1983). The range shifts further north in June–July, with few records south of 24°N, highest densities between 30°N and 38°N, as well as sightings north to 40°N (Tanaka and Kaneko 1983), and in the Sakhalin region (Harrison 1987). The species seems to return south from August onwards, with highest densities between 28°N and 35°N north and northeast of the Bonin Islands in September–October (Jones 1965; Tanaka and Kaneko 1983).

To the east of Japan, Bonin Petrels are most abundant over sea surface temperatures (SSTs) between 22°C and 23°C in June, and between 27°C and 28°C in July–September (Tanaka et al. 1985).

2.3.4. Threats and conservation measures

Although Bonin Petrel populations are currently large, island populations have fluctuated widely in the past, and at least two are currently threatened by introduced rats. Populations at Laysan and Lisianski are probably now stable following drastic declines in the 1910s (Harrison et al. 1984). At that time, introduced rabbits completely devegetated both islands, causing widespread collapse of petrel burrows (Ely and Clapp 1973; Clapp and Wirtz 1975).

The importation of soil and vegetation to the formerly barren Sand Island (Midway Atoll) promoted a population boom of petrels early this century, and at least 500 000 were estimated to nest there by the late 1930s (Hadden 1941). The subsequent drastic population decline there as well as on Eastern Island was caused in part by runway construction in the early 1940s, and by black rats introduced in 1943 (Fisher 1949; Ludwig et al. 1979; Grant et al. 1981; Harrison et al. 1984). Rat control has been partially effective at Sand Island, where in 1987 there was limited hatching success (Woodby 1988). At nearby Kure Atoll, Polynesian rats *R. exulans* have been abundant at least since 1870 (Read 1912, p. 42) and were the apparent cause of complete breeding failure from 1964 to 1968 (Woodward 1972).

Wedge-tailed Shearwaters *Puffinus pacificus* kill a significant number of Bonin Petrel chicks, either by direct attack when these larger shearwaters claim petrel burrows in the spring, or by starvation when petrel chicks are evicted (S.I. Fefer et al., unpubl. data). A small numbers of petrels die each year by colliding against buildings on Midway, attracted by bright lights (P. Sievert, pers. commun.; P. Pyle, pers. obs.).

3. Trans-equatorial migrants

3.1. Providence Petrel *Pterodroma solandri*

3.1.1. Breeding localities, population, and habitat

Norfolk Is: The Providence Petrel is now extinct on the main island as a result of human and alien mammal predation. At least 170 000 adults were taken for food by starving convicts in 1790, hence their vernacular name (Lindsey 1986). This slaughter, together with the impact of an estimated 15 000 introduced pigs by 1796, ensured the extinction of Providence Petrels on Norfolk by 1800 (Schodde et al. 1983). The species is not previously recorded on much-modified Nepean and Phillip islands (Schodde et al. 1983), but small numbers (4+ pr.) have now become established on Phillip Island (Hermes et al. 1986).

Lord Howe: Here there are an estimated 96 000 pairs (Fullagar 1985; Lindsey 1986). The species breeds in burrows (ca. 1 m), often with substantial nests of *Dracophyllum*

fitzgeraldii and shredded palm fronds (Fullagar 1985). Entrances to occupied burrows are often blocked by dried leaves (Fullagar 1976) kicked in by the outgoing partner, as in some other *Pterodroma* (Bartle 1968) and *Procellaria* (Bartle, unpubl. data) species; perhaps this is a sign of past (avian) predation on colonies.

3.1.2. Marine distribution in the temperate North Pacific

The status and ecology of Providence Petrels in the temperate North Pacific are somewhat enigmatic. Recent identification of the similar Murphy's Petrel *P. altima* as a regular migrant to the northeast Pacific and Hawaiian area (summarized in Bailey et al. 1989 and later in this paper) has cast doubt on many earlier sightings of Providence Petrel east of the dateline. An added complexity is that although Providence Petrels breed in the austral winter (March–November), most observations of the species in the North Pacific are in the boreal summer, and are therefore of nonbreeders. A full discussion of these issues appears in Bartle and Stahl (in press), and is summarized here.

Information from Tanaka (1986, and unpubl. data) has shown that Providence Petrels are widely distributed in the northwest Pacific from November to March. They are not usually found in the southern hemisphere at that time (Bartle and Stahl, in press). During these months they occur in relatively warm subtropical waters (>12.0°C), especially in February (>16.0°C), in low densities eastwards from Japan to 170°E, northwest of Kure Atoll (Tanaka 1986).

Nonbreeding Providence Petrels are more widely distributed in the temperate North Pacific in the boreal summer, mostly well north of their range in the same seas in the boreal winter. They are abundant (0.2–3.0 birds/km^2) in confluence, transition zone, and subarctic frontal waters east of Japan and the Kuril Islands to 180°E in June–October (Kuroda 1955; Nakamura and Tanaka 1977; Wahl et al. 1989; Tanaka 1986, unpubl. data). In spring, Providence Petrels favour cool waters further than 160 km offshore (Kuroda 1955; Y. Tanaka, unpubl. data) with a temperature range of 6–11°C (Nakamura and Tanaka 1977; Wahl 1978; Tanaka 1986). Later in the year, as temperatures rise in the subtropical waters of the transition zone, a wider range of SSTs is occupied, from 12°C to 26°C (Tanaka 1986). However, at that time there are also birds in subarctic waters as cold as 3.5°C north of the Subarctic Front (Nakamura and Tanaka 1977; Wahl et al. 1989).

From July, Providence Petrels are concentrated mainly along the Subarctic Front (Kuroda 1955; Tanaka 1986, unpubl. data) from the Kuril Islands to 150°W, south of Kodiak Island. The species occurs in the south-central Gulf of Alaska north to 55°N 145°W in July–August (T.R. Wahl, unpubl. data).

Hawaiian area and eastern Pacific: Controversy surrounds published sightings in the Hawaiian area and off the Pacific coast of North America, as most of these lack adequate documentation (American Ornithologists' Union 1983, 1989; Pyle 1988; Bailey et al. 1989). The possibility of confusion with Murphy's Petrel is high. Most specimens taken or found dead in the Hawaiian area or eastern Pacific have been Murphy's Petrels; however, a Providence Petrel was collected at 40°N 150°W 900 nautical miles north-northeast of Hawaii by R.L. Pitman in July (Los Angeles County Museum 102806) and two others were seen nearby by him at 41°N 137°W in May (Bailey et al. 1989). Further confirmed sightings are reported by Bailey et al. (1989) from the eastern tropical Pacific (May–November) and 465 nautical miles south-southwest of Pt. Conception, California, in December.

In summary, it seems that nonbreeding Providence Petrels occur together with Murphy's Petrels in temperate waters east of the dateline but in lesser numbers, except in the subarctic.

3.1.3. Threats and conservation measures

Although the main breeding population is now confined to a single island where predators are present, no immediate threat has been identified, and there is no evidence of further decline (Fullagar 1985). Nevertheless, the Providence Petrel must be classified as "vulnerable," in accordance with IUCN (World Conservation Union) guidelines. Black rats have been present on Lord Howe since 1918 (Hindwood 1940), but this species does not seem to provide as great a threat to gadfly petrels as do Norway rats *R. norvegicus*, which must be prevented from reaching Lord Howe Island. Breeding success of Providence Petrels should be monitored on a long-term basis to assess the impact of rat predation on eggs and young chicks, and of feral cats on adults and chicks. Continuation of the control program on goats and, especially, pigs is also important. Predation on Providence Petrel eggs by the Woodhen *Tricholimnas sylvestris*, itself an endangered species, has also been recorded (Fullagar 1976).

3.2. Kermadec Petrel *Pterodroma neglecta*

3.2.1. Breeding localities, population, and habitat

This species has a widespread breeding distribution in subtropical South Pacific, but it is now greatly reduced in numbers. Apart from the unknown numbers (high) on Ducie and Oeno islands (Pitcairn group), the world population of Kermadec Petrels is now only about 10 000 pairs, of which 60% are on the 15-ha Meyer Island, one of the Kermadec Islands (Table 2).

Kermadec Petrels are diurnal surface breeders under forest. Shade is apparently an important factor in nest site selection (Merton 1970; Holyoak and Thibault 1984), though protection from sudden heavy rainfall, when many eggs can be lost (Merton 1970), may also be important. It nests in long grass on islets off Easter Island (Johnson 1965). On the Lord Howe group (main island and Ball's Pyramid) the species nests at high altitudes (>400 m) on the surface or in shallow holes, and on tussock ledges on steep faces (Hindwood 1940; Brown 1979). Cliffs are preferred nesting sites on islands either where predators are present (Austral Islands, Holyoak and Thibault 1984; Juan Fernandez, Johnson 1965) or where other gadfly petrels predominate (Macauley Island, Tennyson et al. 1989). On Ducie, Kermadec Petrels nest at the base of cliffs, whereas Herald and Phoenix petrels favour flatter terrain (E.H. Quayle, unpubl. data). Nests are made by first scratching out a hollow in the ground (Oliver 1955) and then building a nest of leaves and twigs or grass, sometimes of a substantial size (Murphy and Pennoyer 1952; Oliver 1955; Johnson 1965). This species apparently never burrows (Hindwood 1940; Holyoak and Thibault 1984).

3.2.2. Marine distribution and abundance in the temperate North Pacific

Analysis of patterns of marine distribution and migration for Kermadec Petrels is particularly difficult because some populations breed in summer and others in winter. Plumage, moult, and gonadal data can, however, be used to clarify the status of migrants as summer or winter breeders or nonbreeders. Results of a review of the distribution and

Table 2
Breeding localities and estimated number of pairs of Kermadec Petrels

Breeding locality	No. of pairs	Reference
Lord Howe group	>100	Brown 1979
Kermadec Is.	>6 000	Merton 1970
Austral Is.	1000	Holyoak and Thibault 1984
Tuamotu Is.	—	R.H. Beck, unpubl. data
Pitcairn group	>50 000	E.H. Quayle, unpubl. data
Easter I.	<100	Johnson 1965
Juan Fernandez Is.	—	Johnson 1965
Los Desventurados Is.	—	Johnson 1965

migrations of *P. neglecta* (Bartle and Stahl, in press) are summarized.

Information from the tropical western Pacific and Japan (Y. Tanaka, pers. commun.) suggests a regular migration of winter breeders to the temperate North Pacific. Kermadec Petrels occur widely in warm Kuroshio Current and confluence waters east of Japan from June to November.

Records from the Hawaiian area and central Pacific transition domain also fit best with an austral winter-breeding population. The preponderance of light-phase birds (King 1970) suggests an origin in Polynesia or the southwest Pacific. To the north, Gould (1983) saw Kermadec Petrels to 39°N in subtropical waters across the subarctic boundary (SSTs 16–25°C). Wahl et al. (1989) also recorded them nearby. To the east, there are three records off California: December (Bailey et al. 1989), January, and March (R. Veit, pers. commun.).

3.2.3. Threats and conservation measures

The virtual elimination of Kermadec Petrels from Raoul Island, Kermadec Islands, provides the best documented example of how vulnerable surface-nesting gadfly petrels are to alien mammals. This account is from Merton (1970). In the 19th century Kermadec Petrels were very abundant on Raoul, with up to 12 000 chicks per year harvested for food by settlers. In 1908 the population was estimated at about "half a million individuals," nesting at densities of up to 4000/ha. In addition to human predation and volcanic ash deposits, Kermadec Petrels had to contend with Polynesian rats (probably present for several centuries), goats (since 1836), and cats (mid-19th century onwards). However, the spectacular decline of Kermadec Petrels on Raoul began with the arrival of Norway rats in 1921. By 1937, Kermadec Petrels were "very scarce." Breeding continued to 1944, but had effectively ceased by 1954. Only a few pairs have bred in recent years. Although cat predation on adults was an important factor, it appeared that egg and chick predation by Norway rats quickly reduced productivity to zero, and prevented recruitment.

Rats now occur on most breeding places of *P. neglecta* (cf. Wodzicki and Taylor 1984). The exceptions are Ball's Pyramid, Herald Islands (Kermadec group), possibly islets off Rapa and Easter Island, and perhaps San Ambrosio (though fishermen now camp there, Millie 1963). In addition, Macauley, Ducie, and Oeno are free of *R. rattus* and *R. norvegicus*. Cats are on Lord Howe, Raoul, and Robinson Crusoe islands. The latter also suffers from the effects of introduced coatimundis *Nasua narica*, goats, and rabbits, and from egg collecting for food by the local population, despite being a World Heritage site (Schlatter 1984). Cats on San Felix Island in the Desventurados (Jehl 1973) probably exterminated *P. neglecta* there. Of the predator-free islands where this species now breeds, only Ball's Pyramid and the Herald Islands have protected status and restricted access.

Other than the Hawaiian Petrel, the Kermadec Petrel appears to be the most highly threatened of the North Pacific gadfly petrels. Like *P. phaeopygia*, the population has been decimated in historic times, and threats continue from predation by alien mammals in the now much reduced breeding habitat. As a diurnal surface-nesting species, the Kermadec Petrel is especially vulnerable. The outlook for Isla Robinson Crusoe and San Ambrosio is not bright (Schlatter 1984), and an active conservation and human development program urgently needs to be implemented under the auspices of the Chilean authorities. Ducie and Oeno (and Macauley) appear pristine except for the presence of Polynesian rats (Wodzicki and Taylor 1984) and they, together with Rapa, deserve World Heritage status and, more importantly, proper protection.

3.3. Murphy's Petrel *Pterodroma ultima*

3.3.1. Breeding localities, population, and habitat

Murphy's Petrel is restricted to French Polynesia (Austral, Tuamato, and possibly Gambier islands, Thibault 1973), where the total population is now estimated at only hundreds of pairs (Thibault 1988), and the Pitcairn group (Murphy and Pennoyer 1952), where the population appears to be much higher.

The species breeds on coral islands, atolls, rocky islets, and volcanic islands (Holyoak and Thibault 1984). It is a surface nester, under trees, shrubs, or low vegetation or in cliff cavities; its nest is built from vegetation or is a simple depression in sand (Lacan and Mougin 1974; Holyoak and Thibault 1984). It is mostly if not exclusively diurnal on breeding grounds (Holyoak and Thibault 1984).

3.3.2. Marine distribution and abundance in the temperate North Pacific

Murphy's Petrel is an austral winter breeder which migrates to the eastern half of the temperate North Pacific, apparently occupying similar zones of surface water to Providence Petrels in the west (Bartle and Stahl, in press). Also, like *P. solandri*, nonbreeding Murphy's Petrels are present in the northeast Pacific throughout the year (sightings in all months except December, January, and August; Bartle and Stahl, in press).

The regular presence of Murphy's Petrel off California between April (up to 71/day), June, and possibly July is now fairly well established (Bailey et al. 1989). In July, Murphy's Petrels were observed in the southern Gulf of Alaska, north to 54°27'N 144°52'W, with four collected at 50°N 145°W (Pitman and Wahl, in Bailey et al. 1989). They were recorded in the Hawaiian region in September–November: French Frigate Shoals, in September (Amerson 1971); one was collected 7 nautical miles southwest of Oahu in October (Gould and King 1967); two collected at Kure Atoll, in October (Gould and King 1967). One bird found alive on Kauai in November was confirmed Murphy's Petrel (Bailey et al. 1989), not Providence Petrel as originally identified (Pyle 1987). The chronological sequence of observations off California (April–June/July), in the southern Gulf of Alaska (July), and in the Hawaiian region (Sept.–Nov.) suggests an anticlockwise movement of these birds during the breeding season. This is supported by records of birds heading north off California in April (Bailey et al. 1989), and of birds identified as Providence Petrels (but suspected to be Murphy's Petrels, Bailey et al. 1989) heading south in the Hawaiian region in October (King 1970).

3.3.3. *Threats and conservation measures*

Predation by humans, feral cats, and pigs may have eliminated Murphy's Petrel from Pitcairn Island (Williams 1960). Polynesian rats are present on Henderson, Ducie, and Oeno islands (Williams 1960), but there is no evidence that they represent a threat, as they were introduced to Henderson at least 400 years ago (Steadman and Olson 1985). No breeding site of Murphy's Petrel other than Henderson Island has protected status at present. On Mururoa and Fangataufa atolls, nuclear tests probably have an impact on Murphy's Petrel, though no information is available.

3.4. Mottled Petrel *Pterodroma inexpectata*

3.4.1. *Breeding localities, population, and habitat*

Mottled Petrels breed in short burrows (±1 m) or in rock crevices sometimes under forest. Historical records (Stead 1932; Falla 1934; Bartle, unpubl. data) and subfossil deposits (Millener 1981, 1984; McGovern-Wilson 1986) indicate a widespread breeding distribution inland on mainland New Zealand south of 38°S. Dated deposits (Worthy and Mildenhall 1989), which include Mottled Petrels, extend back to 20 600 B.P. ± 450 years. Most mainland colonies were apparently wiped out by mammals introduced by Polynesians and Europeans over the last 1000 years, although some survived on remote inland mountains until at least 1963 (Bartle, unpubl. data). Mottled Petrels still breed on rat-free islets in Lake Hauroko, 13 nautical miles from the nearest sea, in the Fiordland district of southern South Island (Cooper 1983), but today most nest on islands off southern New Zealand. Table 3 lists breeding places in north–south order.

These figures are based on vague statements and indicate only orders of magnitude. They suggest that the world population is probably less than 100 000 and possibly near 50 000 breeding pairs, remarkable in view of the abundance of this conspicuous species in antarctic and subarctic waters.

3.4.2. *Marine distribution and abundance in the temperate North Pacific*

Bartle and Stahl (in press) give details of the marine distribution and abundance of Mottled Petrels in the Indian Ocean and South Pacific and of their migration into the North Pacific. Information on favoured marine habitats in all oceans is also given. This brief report on the distribution and abundance of Mottled Petrels in the temperate North Pacific is based on that account.

Northwest and central Pacific: Mottled Petrels are widespread and abundant in offshore confluence, transition zone, and especially subarctic waters in the northwest and central Pacific from June until October. During this period they are also abundant south of the Aleutians (Nakamura and Tanaka 1977; Wahl 1978; Wiens et al. 1978; Gould 1983). Some of these birds enter the Bering Sea from June and become numerous up to 59°N from July (T.R. Wahl, unpubl. data) to October (Gould et al. 1982). Mottled Petrels are more common in the Bering Sea than reported by Ainley and Manolis (1979), perhaps because many earlier observations had been concentrated over shelf waters. Densities of up to 3.0 birds per square kilometre are usual for the oceanic waters of the Bering Sea in July, with maximum numbers in the Central Bering Gyre (Wahl et al. 1989).

Gulf of Alaska and eastern Pacific: Nonbreeders present in the Pacific coast offshore zone from November to May (Loomis 1918; Ainley and Manolis 1979) vacate these waters in favour of the Alaska Gyre during May–October. Differing dates of moult (breeders July, Gulf of Alaska; nonbreeders February, New Zealand; subadults November, California) show that breeding birds swell numbers in the gulf from June onwards. Gould et al. (1982) found that the gulf's oceanic and shelf-break waters support as many as 110 000 Mottled Petrels in the summer. They occur from 4 May until 30 October, with maximum numbers from June to October (Gould et al. 1982).

Table 3
Breeding localities and estimated numbers of Mottled Petrels

Breeding localities	Numbers	Reference
Islets off Fiordland	100s	Jackson 1972
Islands around Stewart I.	10 000s	Blackburn 1965
Snares Is.	10 000s	Warham et al. 1977

3.4.3. *Threats and conservation measures*

Mottled Petrels are vulnerable to mammalian predators on nesting sites. Predation by Polynesian, black, or Norway rats has not been recorded, although it no doubt occurs. Mottled Petrel adults have survived in high numbers on Big South Cape Island, despite the irruption of black rats in 1962 which effectively wiped out 40% of the island's land bird fauna (Atkinson 1985). There is no room for complacency, however, as there are no data on breeding success. Mottled Petrels also survived on the mainland until recent times, despite the presence of Polynesian rats for ca. 1000 years, Norway rats since 1770, and black rats since 1858 (Atkinson 1985). The decline and probable extinction of Mottled Petrels on mainland New Zealand coincided with the introduction and spread of mustelids. A mustelid trapping program (W.J. Cooper, pers. commun.) is necessary to maintain the nearshore island colonies in Lake Hauroko and in Dusky Sound and Preservation Inlet.

Mottled Petrel adults and fledglings suffer extensive mortality from natural predation by Southern Skuas *Catharacta skua lonnbergi* on southern breeding islands (Stead 1932; Warham et al. 1977). Prior to their eradication in 1986 (New Zealand Wildlife Service, unpubl. data), introduced wekas *Gallirallus australis* were also a major problem on Codfish Island (Blackburn 1965; M.J. Imber, unpubl. data). Harvesting of many Mottled Petrel fledglings together with the much more numerous Sooty Shearwater fledglings by Maori on Big South Cape Island was described by Stead (1932) and continued until recent times (Richdale 1964). Traditional birding rights were guaranteed to Maori by the British government in the Treaty of Waitangi (1840). Fortunately there is no evidence that birding has reduced the population size of Mottled Petrel on this island, and in other respects all breeding places of Mottled Petrels are fully protected reserves with restricted access.

3.5. Cook's Petrel *Pterodroma cookii*

3.5.1. *Breeding localities, population, and habitat*

Subfossil deposits show that *P. cookii* was a widespread breeding species on mainland New Zealand before the arrival of Polynesians, ca. 1000 B.P. (Millener 1981, 1984). The numbers of bones found at 10 North Island cave sites indicate that breeding colonies must have been extensive (Millener 1981). These caves are mostly at about 300 m above sea level and well inland (>50 km from the nearest coast). Radiocarbon dates from deposits in the Oparara Valley, northwest South Island (Worthy and Mildenhall 1989), suggest occupancy of this site by breeding Cook's Petrels from 20 600 B.P. ± 450 years until at least 11 250 B.P. ± 150 years. In the Waikato caves (North

Island) investigated by Millener (1981), dated deposits extend from 24 800 B.P. ± 500 years right up to 1075 B.P. ± 75 years. The present breeding distribution at Little Barrier and Great Barrier islands in the Hauraki Gulf (36°S) and Codfish Island in Foveaux Strait (47°S) straddles the prehistorical extent of Cook's Petrels in New Zealand.

About 50 000 pairs breed on Little Barrier Island, the stronghold of the species today (Imber 1985a). Their long burrows, usually 1–3 m, but up to 5 m (Imber 1985a), are on steep forested slopes from ca. 300 m to the top of the island (720 m), with the greatest numbers at mid-altitudes (about 500 m) under tall (10 m) broadleaf forest. On Great Barrier Island, there are probably fewer than 20 breeding pairs (Imber 1985a), nesting at mid-altitudes (200–400 m) under tall (10 m) forest (Bartle 1967; Scofield 1990b). On Codfish Island, numbers declined from a rough estimate of 20 000 pairs in 1934 (Stead 1936) to about 100 pairs today (Imber 1985a), probably because of predation by the introduced weka. On Codfish they breed nearer the sea, 30–200 m in altitude, under forest.

3.5.2. Marine distribution and abundance in the temperate North Pacific

Detailed information on distribution, abundance, preferred marine habitats, and breeding status is now available for migrant Cook's Petrels. This is given in Bartle and Stahl (in press) in full, and summarized here.

Cook's Petrels are present in offshore waters of western Mexico and, to a lesser degree, California, with most seen during April–November. Some disperse westwards and northwards in June to the temperate and subarctic central Pacific. They are seemingly localized within this huge region over areas of upwelling and along the Subarctic Boundary. Cook's Petrels occur off California in all months, with peaks of abundance in April–May and in August (McCaskie 1980, 1986, 1987, 1989; Roberson 1986; Bailey et al. 1989; P. Pyle and R. Veit, pers. obs.), reflecting movements to and from subarctic waters. In the central North Pacific the earliest sighting is 1 June at 46°N 169°E (Wahl 1978), about 600 nautical miles south of the Commander Islands. This is also the westernmost record. In July, Cook's Petrels have been recorded at widely separate locations in the central North Pacific. Fall records from the central Pacific include five southbound nonbreeders between Midway and Laysan islands in November (Pyle and Eilerts 1986).

Greatest densities of Cook's Petrels in the North Pacific are off Baja California. Dates of occurrence and timing of moult there indicate that this is the major area for breeding migrants (Bartle and Stahl, in press). Relative numbers of Cook's Petrel in the central Pacific in summer compared with the offshore zone off California and Baja are difficult to assess, but all experienced observers crossing the Subarctic Boundary east of 180° have recorded this species, though not in high densities.

3.5.3. Threats and conservation measures

Little Barrier and Codfish islands are reserves where access is limited and strictly controlled. Great Barrier Island is inhabited and breeding sites have only partial protection. Polynesian rats occur on all three breeding places of Cook's Petrel and are responsible for low-level predation of eggs and chicks only (Imber 1985a). Wekas, thought to be wholly responsible for the apparent catastrophic decline of Cook's Petrels on Codfish Island between 1934 and 1965, were eliminated from the island between 1980 and 1986 (New Zealand Wildlife Service, unpubl. data). The population of *P. cookii* is now recovering slowly (G. West, pers. commun.).

On Little Barrier Island cats preyed heavily on fledgling and adult Cook's Petrels between their introduction (before 1895) and their extermination in 1982 (Moors and Atkinson 1984). This population now seems secure. However, on Great Barrier Island nearby, cats continue to kill adults, and it is probable that black rats and pigs cause some additional mortalities. The Great Barrier population, which is separable from the other two populations based on measurements (Bartle, unpubl. data), is therefore endangered.

3.6. Stejneger's Petrel *Pterodroma longirostris*

3.6.1. Breeding localities, population, and habitat

Stejneger's Petrel currently breeds only on Isla Alejandro Selkirk (previously known as Mas Afuera Island), Juan Fernandez group. The estimated breeding population is 131 000 pairs (Brooke 1987). It nests in short burrows (Johnson 1965), on a restricted area of steep ridges near the southern end of the island. Elevation is between 850 and 1100 m, and burrows are under a dense tree-fern *Dicksonia externa* forest. Burrows of Stejneger's Petrel are found intermingled with large numbers of nesting Juan Fernandez Petrel (Brooke 1987).

3.6.2. Marine distribution and abundance in the temperate North Pacific

Little was known until recently. An account of migration routes to and from the South Pacific and of the distribution, marine habitat, and breeding status of migrant Stejneger's Petrels is given in Bartle and Stahl (in press). This shows that Stejneger's Petrel is primarily a migrant to the northwest Pacific, becoming very abundant and widespread by early June over an area from 30° N to 35° N and between 160° E and 180° E, with up to 3000 birds seen in a single day at a rate in excess of 80 per hour (Tanaka et al. 1985; K. Nakamura, pers. commun.). In late July and August they are abundant to the east of Honshu in the warm Kuroshio Current (Tanaka et al. 1985). In late September, the main concentration of Stejneger's Petrels is further east than in July–August (Tanaka et al. 1985), mostly 35–40° N and 150–160° E, flocking (>200) along fronts east of the Kuroshio Current.

Stejneger's Petrel is also known from the eastern North Pacific, but all records are thought to be of nonbreeders, as most are in moult during the breeding season. There are undated records from Lanai, Hawaii (Clapp 1984), and probably from 28° N 138° W (Pitman 1986). In October, two were seen off Hawaii by Pyle (1986); in November, one or more were seen over the Davidson Seamount, 65 nautical miles southwest of Point Sur, California (McCaskie et al. 1980); five were seen 225–300 nautical miles off southern California on 9–14 November (P. Pyle and D. Sibley, pers. obs.); and five were collected about 650 nautical miles west of California between 14 and 19 November (Moffitt 1938).

3.6.3. Threats and conservation measures

Feral cats on the breeding grounds kill large numbers of Stejneger's Petrel (Brooke 1987). Because there are no winter-breeding petrels on Alejandro Selkirk (unlike Isla Robinson Crusoe), Brooke thought that cats might never become numerous enough to reduce petrel numbers. However, there is much evidence elsewhere to suggest that cats can eradicate burrowing petrels (Moors and Atkinson 1984). In addition to cats, both Norway and black rats are present (Torres and

Table 4
Conservation status of temperate North Pacific gadfly petrels

Actually or potentially threatened species	Some populations threatened	All or most populations now safe
Now very rare:		
P. p. sandwichensis	*P. neglecta*	*B. bulwerii*
	P. ultima	*P. inexpectata*
		P. hypoleuca
		P. cookii
Abundant, but confined to a single island:		
P. solandri		
P. longirostris		

Aguayo 1971; Atkinson 1985), although Brooke (1987) could see no evidence that they are a problem. Continued protection of the Stejneger's Petrel breeding site high on Isla Alejandro Selkirk and control of predators, especially cats, may be necessary to ensure the survival of this still-numerous species.

3.7. Conservation priorities

Elsewhere in this volume, DeGange et al. show that driftnets and gill nets pose no threat to surface-feeding gadfly petrels, and Bailey and Kaiser demonstrate that predation by introduced mammals on breeding islands presents the gravest threat to North Pacific seabirds. This is particularly true for gadfly petrels, where the introduction of predators on South Pacific islands has led to the extinction of many populations, probably totalling millions of individuals, as described in the species accounts.

Although only one of the gadfly petrel species of the temperate North Pacific is known to be threatened (Table 4), others are very vulnerable because they breed on only one island (Providence and Stejneger's petrels). Protection of their South Pacific breeding grounds is necessary to ensure maintenance of the present level of North Pacific populations. Already some species have greatly declined (e.g., Providence, Kermadec, and Cook's petrels). A pan-oceanic conservation strategy is desperately needed for protection of trans-equatorial migrant gadfly petrels on their isolated and little-known breeding places. Several key islands constitute significant parts of Pacific territories with inadequate conservation legislation and enforcement, and rapidly expanding human populations.

Our review has shown that although steps have been taken to control predators on islands administered by New Zealand, Australia, and the United States, the situation elsewhere is one of inaction. Britain and France have singularly failed to take initiatives in nature conservation in the Pacific. In some cases the islands have protected status, such as the Juan Fernandez Islands (Chilean National Park and World Heritage site), but the local situation is such that the involvement of outside conservation agencies is essential. In other instances, islands of global importance for seabirds, such as Ducie and Oeno (Pitcairn group, U.K.), have no protected status as far as we can determine. Accidental or deliberate introductions of mammals could occur at any time. Of the many examples of predation chronicled in the species accounts, those of Norway rats, cats, and pigs are the most severe. We recommend that specific protective measures be taken on all islands supporting an endemic species, and on those where Kermadec and Murphy's petrels are still breeding, as these surface-nesting diurnal birds are particularly susceptible to predation. Until protective measures are in place, the outlook for Pacific gadfly petrels is very uncertain.

3.7.1. Specific recommendations

(1) The Pacific Seabird Group (PSG) should request that the British government apply to the IUCN for World Heritage listing for Ducie and Oeno islands. Additionally, the PSG should recommend to the British authorities appropriate legislation and practical measures to protect Ducie and Oeno. These could include regular overflight by long-distance patrol planes from New Zealand and/or French Polynesia or elsewhere to prevent itinerant settlement and possible introduction of predators and fire.

(2) The PSG should ask the national parks authority of Chile whether assistance would be welcomed in controlling alien predators on the Desventurados and Juan Fernandez islands and, if so, then the PSG should arrange for assistance to be given by appropriate national and international bodies.

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