BARAU'S PETREL *PTERODROMA BARAUI*: HISTORY, BIOLOGY AND CONSERVATION OF AN ENDANGERED ENDEMIC PETREL

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Received 28 August 2008, accepted 13 March 2009

SUMMARY

PINET, P., SALAMOLARD, M., PROBST, J.M., RUSSELL, J.C., JAQUEMET, S. & LE CORRE, M. 2009. Barau's Petrel *Pterodroma baraui*: history, biology and conservation of an endangered petrel. *Marine Ornithology* 37: 107–113.

The Barau's petrel *Pterodroma baraui* is an endangered gadfly petrel endemic to Reunion Island. It nests in pristine cloud forests between 2200 m and 2800 m above sea level. Although locally abundant, this species is one of the least-studied seabirds in the world. The lack of basic biological information constrains effective conservation action. In this paper, we compile information on past and present status and distribution, ecology, threats and conservation actions. The objectives were to: (i) summarize current knowledge and identify major gaps, (ii) outline major threats to Barau's Petrel and (iii) propose management actions to mitigate those threats. Critical gaps in our knowledge include (i) a lack of precise demographic parameters, (ii) the exact distribution of this species at sea and the factors that influence it, and (iii) habitat requirements associated with nesting. Barau's Petrel is classified endangered (International Union for Conservation of Nature Red List 2008). The major threats include, in order of importance, predation by alien mammals, light-induced mortality and modification of nesting habitat. These threats affect the various age classes of the population (eggs, chicks, juveniles and adults) differently. A recent modelling exercise suggested the extinction of Barau's Petrel in fewer than 100 years, attributable to feral cat predation at breeding colonies in the absence of cat control. The recent establishment of a National Park on Reunion Island should unify conservation and research actions, and prioritise controlling feral cats in breeding colonies. This control should commence as soon as possible in association with a dedicated education program on the effects of feral cats on the Barau's Petrel population.

RÉSUMÉ

Le Pétrel de Barau *Pterodroma baraui* est un pétrel endémique et en danger de l'île de La Réunion nichant dans des terriers à plus de 2200 m d'altitude. Bien qu'elle soit localement abondante, cette espèce est l'une des moins étudiées dans le monde en raison de l'extrême difficulté d'accès des sites de nidification. Le manque crucial d'informations sur la biologie de cette espèce est un frein pour mettre en place des actions concrètes de conservation. Dans cet article, nous avons résumé toutes les informations passées et présentes sur le statut et la distribution, l'écologie, les menaces et les actions de conservation. Les objectifs sont de : (i) compiler l'état des connaissances, (ii) hiérarchiser les menaces majeures et (iii) proposer des actions de conservation pour réduire ces menaces. Il manque des connaissances sur : (i) les paramètres précis démographiques de l'espèce, (ii) la distribution en mer et les facteurs qui l'influencent, et (iii) la sélection des habitats de reproduction. Le Pétrel de Barau est classé « en danger » (l'Union internationale pour la Conservation de la nature Liste rouge 2008) où les menaces majeures sont, par ordre d'importance, la prédation par les mammifères introduits, l'attraction des lumières artificielles des villes et la modification de leurs habitats. Les menaces affectent différemment toutes les classes d'âges de la population (œufs, poussins, juvéniles et les adultes). Une récente étude de modélisation a montré que si des mesures pour contrôler les chats sur les colonies ne sont pas prisent, la population de Pétrel de Barau pourrait disparaitre dans moins de 100 ans. La récente création du Parc National de La Réunion devrait unifier les actions de conservations et de recherches, en insistant sur l'éradication des chats sur les colonies de reproduction. Cette action devrait commencer le plus rapidement possible en association avec un programme de sensibilisation sur l'impact des chats errants sur la population de Pétrel de Barau.

Key words: Barau's Petrel, *Pterodroma baraui,* history, status, conservation, biology

INTRODUCTION

Unlike most of the larger petrels nesting on sub-Antarctic islands, smaller species from tropical and temperate regions have suffered from substantial declines or extinction. Increasing human presence creates negative impacts, which primarily consist of threats at their breeding grounds (Warham 1990). Tropical and subtropical petrels now constitute a significant proportion of threatened Procellariiformes, particularly among those weighing less than 600 g (e.g. Table 1 in Le Corre 2008). The most significant threats for petrels breeding at lower latitudes include predation by alien mammals; loss of habitat through clearance of vegetation for

agriculture; urbanization; and harvesting of eggs, young or adults for food (BirdLife International 2000). Because many tropical petrels are predicted to become extinct in the near future, knowledge of their biology and ecology is urgently needed to provide effective conservation actions.

In the southwest Indian Ocean, Reunion Island (Fig. 1) holds two endemic gadfly petrels: the Mascarene Petrel *Pseudobulweria aterrima* and the Barau's Petrel *Pterodroma baraui.* As a result of human colonization and expansion on Reunion Island over the last 400 years, and the concomitant introduction of alien mammals (cats, rats and goats), Barau's Petrel is currently listed as an endangered species (International Union for Conservation of Nature Red List 2008). The conservation of a threatened species usually requires detailed understanding of its basic biology, distribution and habitat use (Guisan & Zimmermann 2000). Such data provide a foundation for (i) assessment of the status of and threats to existing populations, (ii) planning of future management actions, and (iii) ongoing monitoring of population status and recovery. The current lack of basic biological information for Barau's Petrel and the few identified colonies (fewer than 10) constrains effective conservation strategies. The recent establishment of a national park on Reunion Island, encompassing most known breeding colonies of Barau's Petrel, is the first step in securing the future survival of this species. This step also provides opportunities for more intensive research on the species.

Table 1
Linear measurements (mm) and body mass (g) of adult Barau's petrels (captured on colonies) and fledglings (from rescue campaigns) on Reunion Island. Data shown are mean ± s.d. (2003-2008, SEOR data).

Characteristic	ADULTS (n=74)	FLEDGINGS (n=100)
Wing	295.4 ± 5.3	285 ± 17.5
Tarsus	38.7 ± 1.3	38.9 ± 1.1
Culmen	33.5 ± 1.2	32.5 ± 1.2
Bill depth	12.4 ± 0.5	11.2 ± 0.5
Bill length	19.8 ± 1.1	19.4 ± 0.9
Mass	433.6 ± 36.2	361.9 ± 52.1

Over the past few decades, a number of observations and studies have been conducted, but much of this material has not been yet published. The present paper reviews all available data on the biology and ecology of this species in order to (i) identify knowledge gaps, (ii) highlight major threats and (iii) identify priorities for conservation action. The assembled information on past and present status, distribution, ecology, threats and management actions is intended to provide a comprehensive framework for future research and conservation of Barau's Petrel.

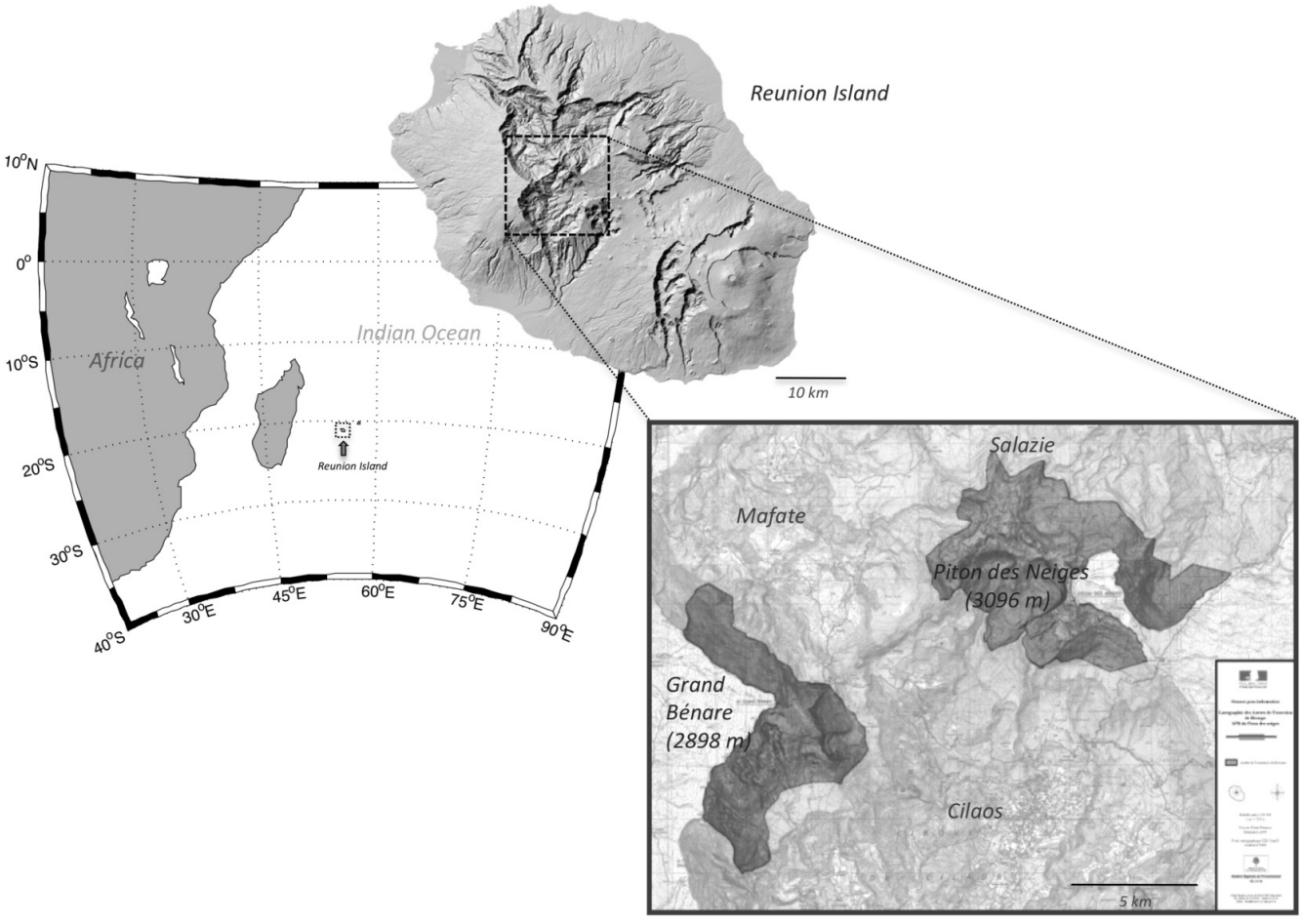

Fig. 1. Location of Reunion Island in the Indian Ocean, and the areas of Barau's Petrel *Pterodroma baraui* colonies on Reunion. The black frame indicates the boundaries of the special reserve, which includes most known Barau's Petrel colonies.

HISTORY AND STATUS

The first written observations of Barau's Petrel at Reunion Island were made in 1804 by Bory de Saint Vincent (Jouanin 1987, Barré *et al.* 2005). During one of his explorations, he reported the presence of "Taille vent," which is the common Creole name for Barau's Petrel that is still used today (Gill 1967). "Taille vent" describes the whistling noise emitted by the birds in flight.

The first living Barau's Petrel specimen, found on one of the northern beaches of Reunion Island, was described by Jouanin (1963) and initially named *Bulweria baraui* (in recognition of the local ornithologist Armand Barau). Imber (1985) reclassified this specimen as belonging to the genus *Pterodroma* based on morphologic parameters. Bretagnolle & Attié (1991) concluded that *P. baraui* was phylogenetically close to *P. inexpectata* (endemic to New Zealand), and to a lesser extent, to *P. phaeopygia* (from Galapagos and Hawaii), based on vocalizations. Not long after, Bretagnolle *et al.* (1998) confirmed by genetic analysis the classification of Barau's Petrel within the *Pterodroma* genus, with the closest link being to *P. nigripennis.*

The main distinguishing characteristics of Barau's Petrel are the back and upper-wing coverts, which are pale grey with a vague bluish tinge, contrasting with a prominent dark mid-wing panel M formed by blackish brown-grey outer primaries (Jouanin & Gill 1967, Probst 1996a, Barré *et al.* 2005). Coloration of plumage is slightly different between adults and fledglings, with the adult's upper wing being more brown-grey. Table 1 shows the main morphometric data.

Many historical writings (e.g. Bory de Saint-Vincent 1804) reported that local people used to eat chicks of Procellarids. Indeed, osteologic research, supported by local oral history, reveals evidence for past exploitation of Barau's Petrel by humans (Mourer-Chauvire *et al.* 1999). This species has been protected only since 1989; until then, individuals were still killed for food, and some illegal shooting may have taken place since 1989. Bretagnolle and Attié (1993) described this illegal activity and found that a hunting culture existed beyond 1989, when hunters may have shot at least 50 birds per day (Bretagnolle & Attié 1997). Consumption by humans was also reported in 1995, when an abandoned campsite was discovered within a breeding colony (Probst *et al.* 2000). Several human artefacts were found, including bones of various species such as goats, rats and Barau's Petrels (Probst *et al.* 2000).

Barau's Petrel breeds only on Reunion Island, although one nest was discovered on Rodrigues Island in 1974 (Cheke 1987) and some birds have been observed prospecting in the Valley of Black River National Park in Mauritius Island. No evidence of breeding has been found at both islands recently, however.

It was hypothesized that the species also previously bred on Amsterdam Island, because a large number of bones were found at several sites (Worthy & Jouventin 1999). Before 1995, knowledge of Barau's Petrel breeding colonies on Reunion Island came from limited *ex situ* observations because the colonies could not be accessed (Jouanin & Gill 1967, Brooke 1978, Barré & Barau 1982, Bretagnolle & Attié 1991). Those observations suggested that this petrel is colonial and nested 25 km inland in burrows located on cliffs 2200–2800 m above sea level (asl). The adults reach their nesting sites by soaring on rising air currents (Bretagnolle & Attié 1991). The first colony was discovered in 1995 along the ridge joining Grand Bénare to Piton des Neiges at *c.* 2400 m asl, immediately above an area called Col du Taibit (Probst 1995, Probst *et al.* 2000). A larger colony was then found in 2001 in a remote area, above 2200 m, on the Piton des Neiges. It remains the largest known colony (around 900 burrows) and has been monitored annually since 2004, just before the peak of fledgling departure (April). Several small breeding colonies have been discovered since then and have been identified as Important Bird Areas (Le Corre & Safford 2001). Most known colonies have been included within a special reserve since 2001 (Fig. 1). Recently, increased search effort around one of the highest peaks (Grand Bénare, approximately 2900 m asl) revealed a new and easily accessible breeding colony in 2006. This new colony in a less remote area provides a good opportunity for more intensive studies on the ecology of Barau's Petrels. Currently, two breeding sites are monitored: 160 and 130 burrows at Piton des Neiges and Grand Bénare respectively (Fig. 1).

There are no data on population sizes or trends before 1990. Ship-borne surveys estimated the population to be between 15 000 and 20 000 birds (Stahl & Bartle 1991). Annual coastal counts to monitor the size and trend of the population have been undertaken once annually since 1996 by the local ornithological society [Société d'études ornithologiques de la Réunion (SEOR)]. However, as an index, these counts are difficult to reliably interpret. Because of the high variability, no evidence of population change in recent years has been found (Salamolard 2007). Probst *et al.* (2000) estimated the population to consist of fewer than 3800 breeding pairs. The most recent estimate in 2001, based on the discovery of the new breeding colonies, gives a number of 4000 to 6500 breeding pairs spread over 10 colonies (Le Corre & Safford 2001).

BIOLOGY AND ECOLOGY

Nesting habitats

Reunion Island (21°S, 55°33′E) is part of the Mascarene archipelago. It is a mountainous volcanic island covering 2512 km^2 in the tropical southwest Indian Ocean (Fig. 1). The central part of the island consists of a volcanic massif comprising three collapsed craters called Mafate, Cilaos and Salazie, dominated by the highest central peak Piton des Neiges, 3069 m. Colonies are associated mainly with upland cloud forest in which endemic shrubs such as *Erica reunionensis* (Ericaceae), and *Sophora denudata* (Fabaceae), are the dominant plants (Cadet 1977, Probst *et al.* 2000). This forest is among the least altered ecosystems of the Mascarene archipelago (Thébaud & Strasberg 1997).

Barau's Petrels nest in earth burrows, in crevices or under rocks. Burrows are on average 98 cm long, 19 cm wide and 11 cm high (Probst *et al.* 2000). Sticks (mostly *Erica reunionensis*) are used as nesting material (Probst *et al.* 1995, 2000). Depending on habitat, the density of burrows ranges from 0.03/m^2 to 0.35/m^2, on the ridge and on the plateau respectively (Probst *et al.* 2000). These results suggest that a thick humus layer may be a prerequisite to burrow establishment for Barau's Petrel, and factors that may influence nest selection seem to be vegetation cover, slope and altitude (Probst *et al.* 2000).

Life history and breeding phenology

Little is known of the breeding biology of Barau's Petrels and very few data are available on their reproductive and demographic

parameters. What is known suggests that their biology is similar to that of the high-altitude-nesting Hawaiian Dark-rumped Petrel *P. sandwichensis* (Simons 1984, 1985). Barau's Petrel fledglings are attracted by urban light and this phenomenon causes massive and seasonal light-induced mortality [Le Corre *et al.* 2002 (see "Threats" section)].

Using the number of fledglings attracted by urban lights (Fig. 2) as a proxy of fledging dates, we constructed a breeding phenology of the species (Fig. 3). The fledging peak occurs in mid-April (Fig. 2) and shows that Barau's Petrels are highly synchronous summer breeders. Assuming an incubation period of 45 days and a chick-rearing period of three months [as for the Hawaiian Dark-rumped Petrel (Simons 1984, 1985)], we estimated that the mean laying period is in November, which is consistent with observation of displaying, burrowing and activities at colonies (Bretagnolle & Attié 1991, authors unpub. data).

Marine biology

Distribution at sea

Few data are available on the distribution and behaviour of Barau's Petrels at sea. No tracking has been down so far, and so knowledge about its at-sea distribution is based on ship surveys only. The species has a tropical and subtropical distribution throughout the Indian Ocean (Fig. 4), where individuals tends to select areas of intermediate salinity and warm water (Pocklington 1979). Records at sea tend to show a seasonal variation in distribution (Fig. 4), with most birds observed in the southwest Indian Ocean (200 km to 2000 km south of Reunion Island) between September and April—the breeding season (Gill 1967, Jouanin & Gill 1967, Frost 1981, Bourne 1989, Stahl & Bartle 1991). During the non-breeding period (May–August), most records are from the northern Indian Ocean (Fig. 4).

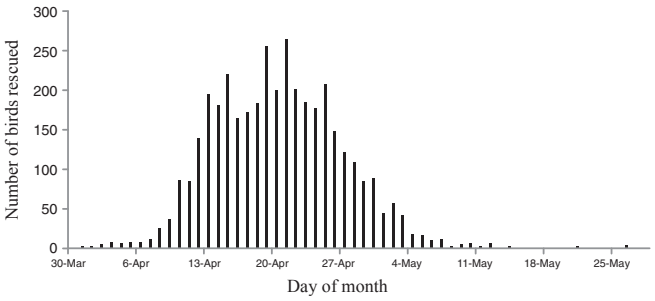

Fig. 2. Daily schedule of Barau's Petrel *Pterodroma baraui* fledglings rescued during the rescue campaign between 1995 and 2007 (Société d'études ornithologiques de la Réunion data).

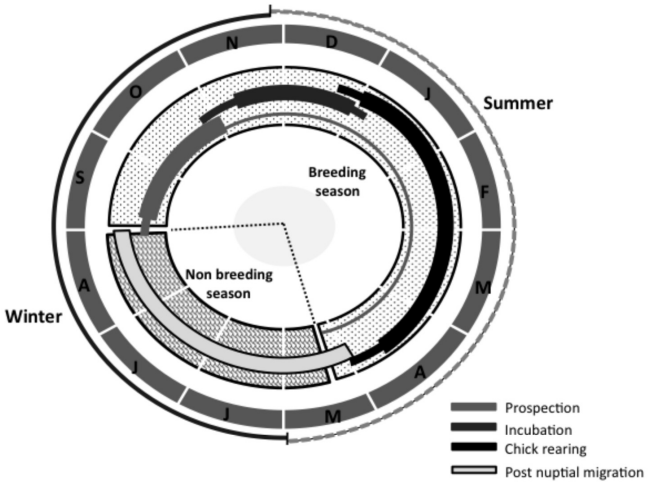

Fig. 3. Annual breeding cycle of Barau's Petrel *Pterodroma baraui* at Reunion Island. Thick lines show peak activity; thin lines, off-peak activity.

TROPHIC ECOLOGY

Barau's Petrel is a pelagic seabird that feeds at the sea surface by surface-seizing, dipping and surface-plunging. They take mostly squid and fish (Stahl & Bartle 1991, Ballance & Pitman 1999, authors unpub. data). Barau's petrels forage alone or in small flocks and are often associated with Sooty Terns *Sterna fuscata* and Audubon Shearwaters *Puffinus lherminieri* (Stahl & Bartle 1991, Jaquemet *et al.* 2004). A recent study showed differences in $\delta^{13}C$ and $\delta^{15}N$ values in liver between young and adult Barau's Petrels (Kojadinovic *et al.* 2008), suggesting that young and adults consume different prey.

Threats

The two main threats to Barau's Petrels both occur on land during the breeding period:

- predation by alien mammals, and
- artificial-light-induced mortality.

Predation

Introduced predators are a major threat to seabirds worldwide (Chapuis *et al.* 1994) and Procellariiforms that attend colonies for long periods and breed on the ground or in burrows are particularly vulnerable. Cats *Felis catus* were probably introduced to Reunion Island in the early 17th century as a biologic control for rats and are

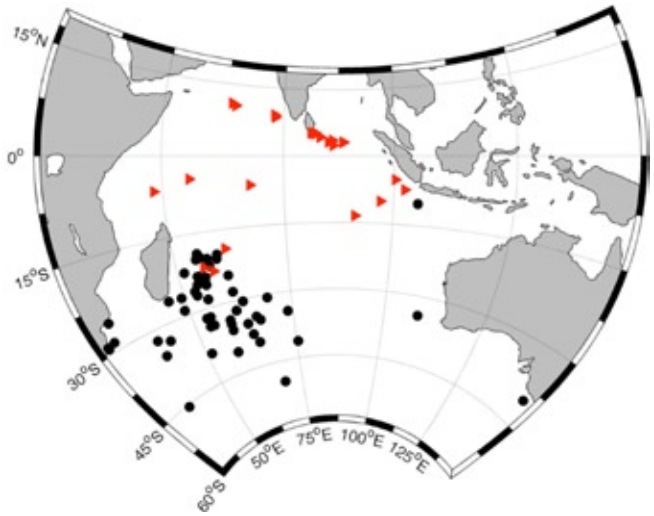

Fig. 4. At-sea observations of Barau's Petrel *Pterodroma baraui* since 1988. Black dots represent records during breeding season, and triangles represent records during non-breeding season. (Data from Gill 1967, Jouanin & Gill 1967, Frost 1981, Bourne 1989, Carter *et al.* 1989, Stahl & Bartle 1991, Lambert 2001, J.W. Enticott in Lambert 2001, van Marle & Voous 1988, van den Berg *et al.* 1990, Chapman & Cheshire 1987, Dunlop *et al.* 1988.)

now widespread across all habitats, from the coast to the highest mountains. They have contributed to the extinction of several Reunion's bird species (Barré *et al.* 1996).

To date, only one study has analyzed the impact of alien predators on Barau's Petrel. Faulquier *et al.* (in press) quantified predation by cats within two monitored colonies. Feral cats preyed mostly on Barau's Petrels, given that 57% of cat scats contained petrel remains. Although data are lacking on the number of cats in the colonies, a conservative estimate suggests that more than 900 birds are killed by cats annually in these two studied colonies (Faulquier *et al.* in press). Cats kill adults (58% of carcasses) and fledglings (42%) alike. The presence of only a few cats may be a major conservation problem for this species. A recent modelling exercise suggested the potential extinction of Barau's Petrel in less than 100 years if cats are not removed or effectively controlled (Russell *et al.* in press).

Rats are uncommon within Barau's Petrel colonies (Fontaine 2006). Faulquier *et al.* (in press) suspect that this situation is not the result of top-down control by cats, but of bottom-up control by food resources available to rats. If rats do prey on Barau's Petrel, they are likely to take only eggs and chicks, not adults as cats do. A consequence of this stage-specific predation is that the Barau's Petrel population is more sensitive to cat predation (which reduces adult survival) than to rat predation (which reduce breeding success) (Keitt *et al.* 2002, Le Corre 2008, Russell *et al.* in press). Thus, if cat control leads to an increase in rat density (as a result of a mesopredator release), the result would not necessarily be a decline in the petrel population (Le Corre 2008).

Urban light-induced mortality

The increasing number of lights associated with the ongoing urbanization of Reunion Island is a serious threat to Barau's Petrels. Since 1995, SEOR has implemented rescue campaigns each year to census grounded birds and to save as many birds as possible. Between 1995 and 2008, more than 5000 fledglings were rescued (Fig. 5), of which 90% were ringed and released successfully (Le Corre *et al.* 2003, Salamolard *et al.* 2007). Each year, around 429 ± 212 birds (excluding the small sample size from 1995, Fig. 5) were found grounded after being attracted by lights (with a maximum of 835 rescued birds in 2001, Fig. 5). Le Corre *et al.* (2002) estimate that these figures may represent an average of 20% of the fledglings produced each year. The number of fledglings found grounded each year is highly variable (Fig. 5) and probably reflects variability in breeding success at colonies.

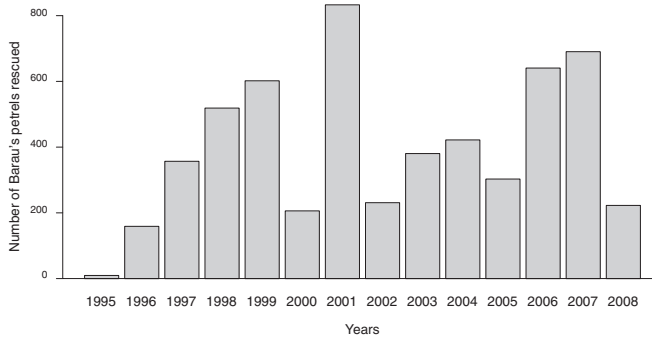

Fig. 5. Number of Barau's Petrel *Pterodroma baraui* found grounded during the rescue campaigns between 1995 and 2008 on Reunion Island (Société d'études ornithologiques de la Réunion data).

MANAGEMENT AND RESEARCH NEEDS

Since the late 1990s, conservation awareness has improved greatly on Reunion Island, leading to the establishment of a large protected area (national park) that encompasses most known breeding sites of Barau's Petrel. Despite these achievements, several conservation actions have yet to be implemented.

First, control of cats at Barau's Petrel colonies should be undertaken year round, particularly during the non-breeding season, when petrels are absent and cats have to turn to other food sources, increasing the likelihood of them taking baits. Given the steep and treacherous nature of the terrain where Barau's Petrel breed, the most labour- and cost-efficient means of cat control is target-specific poisoning. Checking live traps daily would be almost impossible over the large areas where cats are likely to range and require targeting. A number of suitable toxins and delivery methods have recently been developed, which would be appropriate for cat control on Reunion Island (see Hetherington *et al.* 2007, Murphy *et al.* 2007, Algar & Brazell 2008). Like other oceanic islands, Reunion benefits from the absence of native mammals (excluding three insectivorous bat species), allowing a wider array of methods to be used for mammalian predator control. Counterproductively, however, French legislation affords equal protection to both domestic and feral cats (Faulquier *et al.* in press). Thus, the eradication of cats at Barau's Petrel colonies is currently illegal! Legislation has to change to allow provisions for controlling feral cats at sites where they are a conservation threat. This should be undertaken in association with a rigorous education program on the impacts of feral cats.

In addition, a rescue program for grounded fledglings has been operating effectively since 1995. The peak of the fledgling period covers less than one month, generally in some restricted areas. Shielding or switching off the lights that regularly attract large numbers of birds during this period should be a priority conservation action. Discussions are currently ongoing with local authorities to implement seasonal reductions of urban light in these areas.

Research is needed to more precisely estimate population size, demographic parameters and trends in the population. Long-term banding studies are needed to determine adult and juvenile survival and age of first reproduction. All rescued fledglings are routinely banded, but very few band have been recovered, and consequently, the survival rate of rescued fledglings after their release is unknown. At-sea data on Barau's Petrel are also needed to understand how these birds use the marine environment. Direct and indirect competition with fisheries should both be evaluated to highlight potential mortality or threats at sea.

CONCLUSIONS

In summary, the priorities regarding Barau's Petrel conservation on Reunion Island are (i) removal or control of cats at colonies and development of a regulatory framework to achieve this control within the French legislative system; (ii) a continued rescue campaign for grounded birds; and (iii) expansion of the protected area to include all colonies. The priorities for research include (i) intensified survey and population monitoring efforts to determine population size, survivorship, mortality and the effects of environmental factors; (ii) acquisition of data on nest-site selection and breeding productivity for understanding the relationship between environmental parameters and breeding success, (iii) study

of the distribution of Barau's Petrel at sea during both the breeding and non-breeding seasons to understand how these birds use the marine environment and (iv) evaluation of the impact of other potential threats (e.g. rats, poaching, industrial fisheries).

ACKNOWLEDGEMENTS

P. Pinet benefited from a PhD grant given by the Region Réunion and the European Social Fund. The authors thank all the volunteers who have contributed to Barau's Petrel conservation, research and rescue of downed birds: Lucie Faulquier, Thomas Ghestemme, Martin Riethmuller, Rémi Fontaine, Nelly Minatchy, Thomas Duval, Christophe Caumes, Fabien Jan, Minou Monta, Audrey Valery and the many volunteers who participated over the years. We also thank the Brigade de La Nature of the Indian Ocean and the Peloton de Gendarmerie de Haute Montagne of Cilaos for their useful field assistance and their motivation since 2001. We thank David Priddle and Chris Powell for their thorough comments and corrections. We acknowledge SEOR and the Museum d'Histoire Naturelle for their contributions and their hard work on the protection of this endangered bird and the collection of data. Funding from Direction Régionale de l'Environnement Réunion, EDF (Electricité de France) and Réunion Region has supported the rescue campaigns. FEDR (Fonds européen de développement regional) has funded the conservation plan.

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