# Conservation of the Juan Fernandez firecrown and its island habitat

Michael S. Roy, Juan Carlos Torres-Mura, Fritz Hertel, Marina Lemus and Renate Sponer

**Abstract** The Juan Fernandez Islands constitute two distantly separated (182 km) major islands, of which Isla Robinson Crusoe is the closest (667 km) to the Chilean mainland, and a number of smaller surrounding islets. The endemic Juan Fernandez firecrown *Sephanoides fernandensis* once inhabited both major islands and numbered many thousands. Today it exists only on Isla Robinson Crusoe and numbers just a few hundred. Another hummingbird, the green-backed firecrown *S. sephaniodes*, inhabits this island but also occurs on the mainland. The islands are in ecological meltdown as a result of the removal of much of the native (largely endemic) biota. This degradation has been exacerbated by introduced herbivorous and carnivorous mammals, which are extirpating all that remains. In a previous investigation the authors assessed the evolutionary relationships and genetic variation in the Juan Fernandez firecrown population. They showed that the species: (i) is a relative of the high Andean hummingbirds; (ii) is a close sister species of the green-backed firecrown; (iii) dispersed to the islands approximately 0.5–1 million years ago, unlike the green-backed firecrown, which is probably a very recent invader; (iv) maintains some genetic variation, although significantly lower than that found in the green-backed firecrown island population. Because of their relatively recent divergence the authors aimed to find out if the two species compete for resources. In addition, they assessed the conservation options for the Juan Fernandez firecrown and provided recommendations for its management. They concluded that the survival of the Juan Fernandez firecrown is inextricably linked to the holistic restoration of ecosystem/community function of the island. The initial step must involve the removal of introduced mammals, followed by replanting of native flora. Although the authors do not support the use of captive propagation as a general conservation tool, they believe that, because the Juan Fernandez firecrown is composed of only one small population that is under extreme threat of extinction, a captive population should be established.

**Keywords** Conservation, introduced mammals, islands, Juan Fernandez firecrown, restoration.

## Introduction

Species on islands constitute a disproportionate number of the total number of threatened species on this planet as a result of their often small population sizes, and vulnerability to natural and human-induced environmental catastrophes (see Cronk [1997] for a full discussion). Since 1600, 75 per cent of animal extinctions have been of island species (Reid & Miller, 1989). Furthermore, although only 20 per cent of bird species live on islands, 90 per cent of extinct birds (in recent history) were from islands (Myers, 1979). However, the importance of island species for conservation and maintenance of global biodiversity is high because they are often found nowhere else. Although islands contain the most endangered ecosystems, they are also potentially the easiest to conserve and restore. Because they are independent and isolated, permanent removal of non-native organisms and management of resources are relatively easy. However, for full restoration to be successful, extinction of endemic organisms must be avoided and their conservation made a priority.

We visited the oceanic Juan Fernandez Islands (Chile) during the summer months of 1995–96, 1996–97 and 1997–98 with the goal of investigating the evolutionary relationships of the Juan Fernandez avifauna, such as: phylogenetic relationships between island and mainland species, approximate time of dispersal to the islands, and amount of morphological and genetic change accompanied by their isolation on the island. In addition to these questions we have also attempted to: (i) further our understanding of the biology of the islands' endemic flagship species, the Juan Fernandez firecrown (Trochilidae: *Sephanoides fernandensis*), whose preservation is critical if full restoration of the unique and biologically rich Juan Fernandez Islands is to be achieved; and (ii) provide practical

**Michael S. Roy** (corresponding author) **and Renate Sponer** Department of Zoology, University of Otago, Dunedin, New Zealand. E-mail: michael.roy@stonebow.otago.ac.nz

**Juan Carlos Torres-Mura and Marina Lemus** Museo Nacional de Historia Natural, Casilla 787, Santiago, Chile.

**Fritz Hertel** Department of Biology, University of California, Los Angeles, CA 90024, USA.

*Received 21 August 1998. Accepted 2 December 1998*





https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

conservation plans for this end. Already designated as a world biosphere reserve, these islands have massive potential for conservation, biological research activities (comparable to the Galápagos), and sustainable ecotourism, given the correct infrastructure and management goals.

## The Juan Fernandez Islands

The Pacific archipelago of Juan Fernandez, a chain of young oceanic volcanoes, includes two principal exposed peaks: Isla Robinson Crusoe or Masatierra (Fig. 1; 93 sq km, 33°40'S, 78°33'W), which is located 667 km west of the Chilean coast and is estimated to be 3.8–4.2 million years old (Stuessy *et al.*, 1984), and Isla Alejandro Selkirk or Masafuera (85 sq km, 33°45'S, 80°51'W), which is located 182 km west of Isla Robinson Crusoe and is estimated to be 1.0–2.4 million years old (Bourne *et al.*, 1992). The Juan Fernandez Islands have never been connected to the mainland.

The Juan Fernandez Islands contain 142 species of vascular plants of which 69 per cent of species and 18 per cent of the genera are endemic. The endemic plants include the only living relict of the family Lactoridaceae, *Lactoris fernandeziana*, and a remarkable radiation of Compositae, which includes cabbage trees in the genus *Dendroseris*. Unfortunately, a high proportion of this flora is endangered and two species are already extinct. The Juan Fernandez flora has diverse origins; the Lactoridaceae are otherwise known only by fossil remains from South Africa whereas the marine algae have their origins in the Australasian region. Forty-five per cent of the fern species are endemic, with one endemic monotypic genus, *Thryrsopteris* (Ricci, 1996).

The native terrestrial fauna, derived from the South American mainland, shows comparable endemicity. For example, 35, of 46 species of mollusc and 440 of 687 species of insect are endemic. The native vertebrate fauna consists of land and sea birds and one species of fur seal (there are no native amphibians or reptiles). There are nine terrestrial bird species, three of them endemic to the archipelago: the Juan Fernandez firecrown *Sephanoides fernandensis* (Trochilidae) and the Juan Fernandez tit-tyrant *Anairetes fernandezianus* (Tyrannidae) of Isla Robinson Crusoe (Roy *et al.*, 1999), and the Masafuera rayadito *Aphrastura masafuerae* (Furnariidae) from Isla Alejandro Selkirk. Three avian subspecies are endemic to the Islands: *Falco sparverius fernandezianus* (Falconidae) inhabiting both islands, and *Buteo polyosoma exsul* (Accipitridae) and *Cinclodes oustaleti backstroemi* (Furnariidae) on Isla Alejandro Selkirk. The three other species are also found in mainland Chile: short-eared owl *Asio flammeus*, green-backed

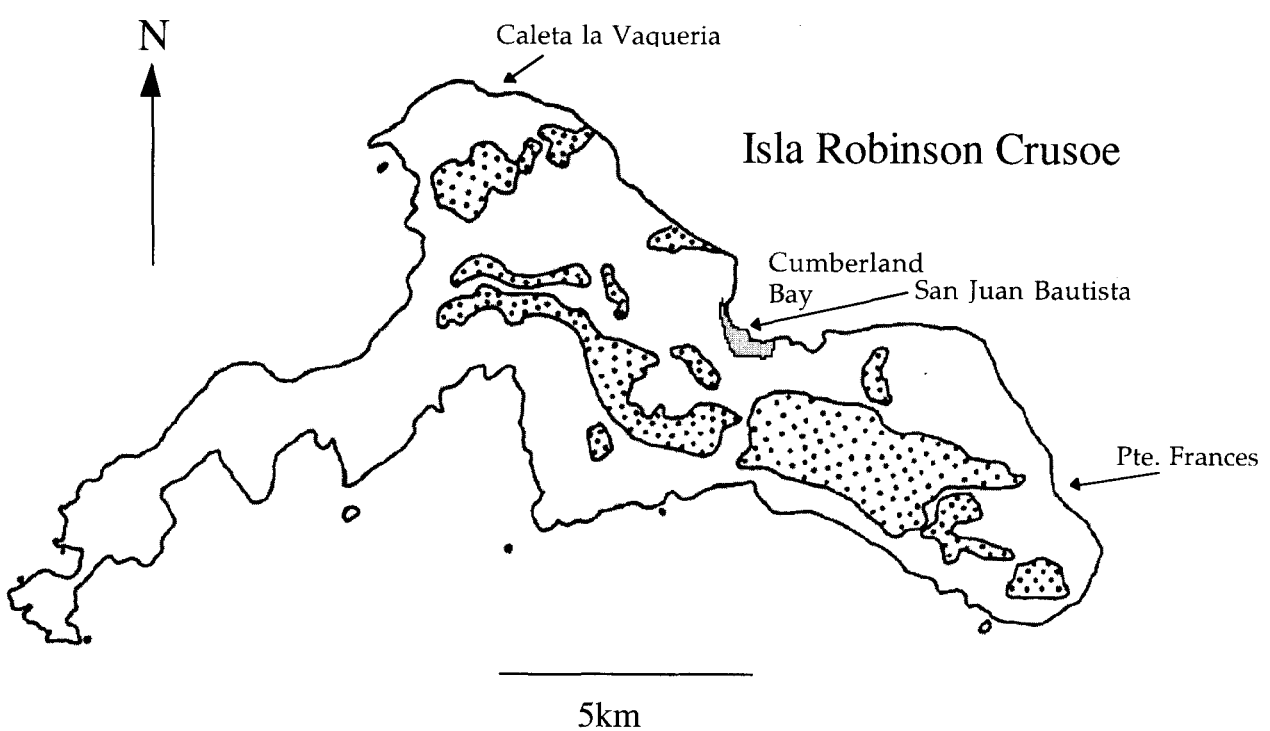


**Fig. 1** Isla Robinson Crusoe (93 sq km). Stippling indicates the principal areas containing native vegetation. They coincide largely with steep hillsides and ridges.



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

**Plate 1** An eroded hillside denuded of topsoil. Native evergreen forest would probably have covered this region just over 100 years ago (*M. Roy*).

firecrown *Sephanoides sephaniodes* and austral thrush *Turdus falcklandicus*. The California quail *Callipepla californica* was introduced to Isla Robinson Crusoe at the beginning of this century but is no longer present. Several species of petrel and shearwater inhabit the waters surrounding the archipelago and nest on the islands: the Juan Fernandez petrel *Pterodroma externa*, Stejneger's petrel *Pterodroma longirostris*, Kermadec petrel *Pterodroma neglecta*, pink-footed shearwater *Puffinus creatopus*, Defilippe's petrel *Pterodroma cooki defilippiana* and white-bellied storm-petrel *Fregetta grallaria*.

The Juan Fernandez Islands are environmentally degraded and are among the 11 most seriously threatened protected natural areas in the world (Allen, 1984). Their botanical heritage (Sandars *et al.*, 1982; Perry, 1984) was the reason for protection as a national park in 1935 and as a World Biosphere Reserve in 1977. The national park now includes the entire archipelago except for the town of San Juan Bautista and its immediate surroundings, and is overseen by the Chilean Corporacion Nacional Forestal (CONAF). Herbivorous mammals, introduced to the islands as early as 1574, and logging activities of the previous four centuries caused the loss of much of the native forest on the islands (Plates 1 and 2): on Isla Robinson Crusoe (9300 ha) only about 10 per cent is left undegraded to slightly degraded (Fig. 1; Plates 1 and 2), 15 per cent denuded or severely eroded and the rest either moderately eroded or covered by introduced weeds. Regeneration of natural vegetation is hampered by the grazing of introduced goats, rabbits and rodents (*Rattus rattus*, *R. norvegicus* and *Mus musculus*), and by introduced plants such as the maquis shrub *Aristotelia chilensis* (Eleocarpaceae, introduced from central Chile), the shrub *Ugni molinae* (Myrtaceae, introduced from the south of Chile) and the bramble *Rubus ulmifolius* (Rosaceae, introduced from Europe to continental Chile and then to the islands). Ricci (1996) suggested little change in the distribution of native ferns since the first botanical collections were made in 1823 (Graham, 1824), 1824 (Douglas, 1836) and 1830 (Bertero, 1830), 250 years after the islands' discovery. This is surprising given the gross anthropogenic changes made to the environment since then and their effects on the angiosperm flora. The native fauna is directly affected by introduced mammals such as rodents and coatis *Nasua nasua*, which have been implicated in the predation of birds.

## The demography and biology of the hummingbirds

The Juan Fernandez Islands are listed as a priority 1 (critical) Endemic Bird Area of the World (Stattersfield *et al.*, 1998). Rottmann & Lopez-Calleja (1990) listed *Sephanoides fernandensis* as one of the most endangered bird species in Chile. Listed as Critically Endangered in the IUCN red list (Collar *et al.*, 1994; IUCN, 1996), it is estimated that only 250–400 individuals remain,

**Plate 2** Remnant native forest along the high ridges of the volcanic terrain (*M. Roy*).



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

and the species is restricted to Isla Robinson Crusoe (Colwell, 1989). Recent population estimates have varied from several thousand (Mann, 1975) to 200 (Colwell, 1989). However, our estimates, based on mist-netting capture rates and field observations, suggest that a figure in the low hundreds is correct. One of the problems inherent with these estimates is the mobility of individuals; for instance, one male that we captured and marked in the town of San Juan Bautista was recaptured 2 days later on the other side of the island. This suggests that an individual could potentially be counted more than once, depending on the census technique used. The Juan Fernandez firecrown once inhabited both islands (last recorded on Isla Alejandro Selkirk in 1908 [de Brooke, 1987]), with an estimated population size of several thousand individuals in the 19th century (de Brooke, 1987; Colwell, 1989). The major reasons for its decline are not clear but are thought to be due primarily to habitat degradation and perhaps predation of eggs by introduced rodents and coatis. The green-backed firecrown *Sephanoides sephaniodes* inhabits both islands, with an estimated population between 4000 (Colwell, 1989) and 6000 (de Brooke, 1987) individuals on Isla Robinson Crusoe. This hummingbird has been abundant on Isla Robinson Crusoe only since the late 19th century and was first observed on Isla Alejandro Selkirk in 1981, where it was reported to have become widespread (Bourne *et al.*, 1992). However, CONAF rangers have noted that they are no longer seen on Isla Alejandro Selkirk and we saw none in a 1-week stay in 1997. In mainland Chile this species has a wide distribution south of the Atacama Desert to an altitude of 2000 m (Fjeldså & Krabbe, 1990).

Morphologically, the two firecrown species resemble each other in that the males of both species and the female of the Juan Fernandez firecrown have a brightly coloured, iridescent crown (Plates 3 and 4). However, the Juan Fernandez firecrown is strikingly sexually dimorphic: the male (Plate 3) is more or less brick coloured all over and is approximately 66 per cent larger than the female (Hertel *et al.*, unpublished data) which has a white breast dappled with black spots, and an iridescent blue back and wings (Plate 4). The dimorphism is so great that the two sexes were initially classified as separate species (King, 1831; Sclater, 1871). Both sexes of the green-backed firecrown are olivaceous above and whitish below with green spots; apart from the male's irridescent crown, sexes are minimally dimorphic and differ only slightly in size.

Traditionally the two species have been considered sister taxa, related to the high Andean radiation of hummingbirds; our study using DNA techniques (Roy *et al.*, 1998) supported this relationship (Fig. 2) and also suggested that they became isolated from each other relatively recently, 0.5–1 million years ago. Further, our study suggested that colonization by the green-backed firecrown was recent. As a result of apparent ecological similarities, competition between the two species may be confounding the potential for the Juan Fernandez firecrown to recover.

**Plate 3** A male Juan Fernandez firecrown (*M. Roy*).

## Competition and division of resources

Observations were made of Juan Fernandez firecrowns that were feeding and defending particular nectar

**Plate 4** A female Juan Fernandez firecrown (*M. Roy*).



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

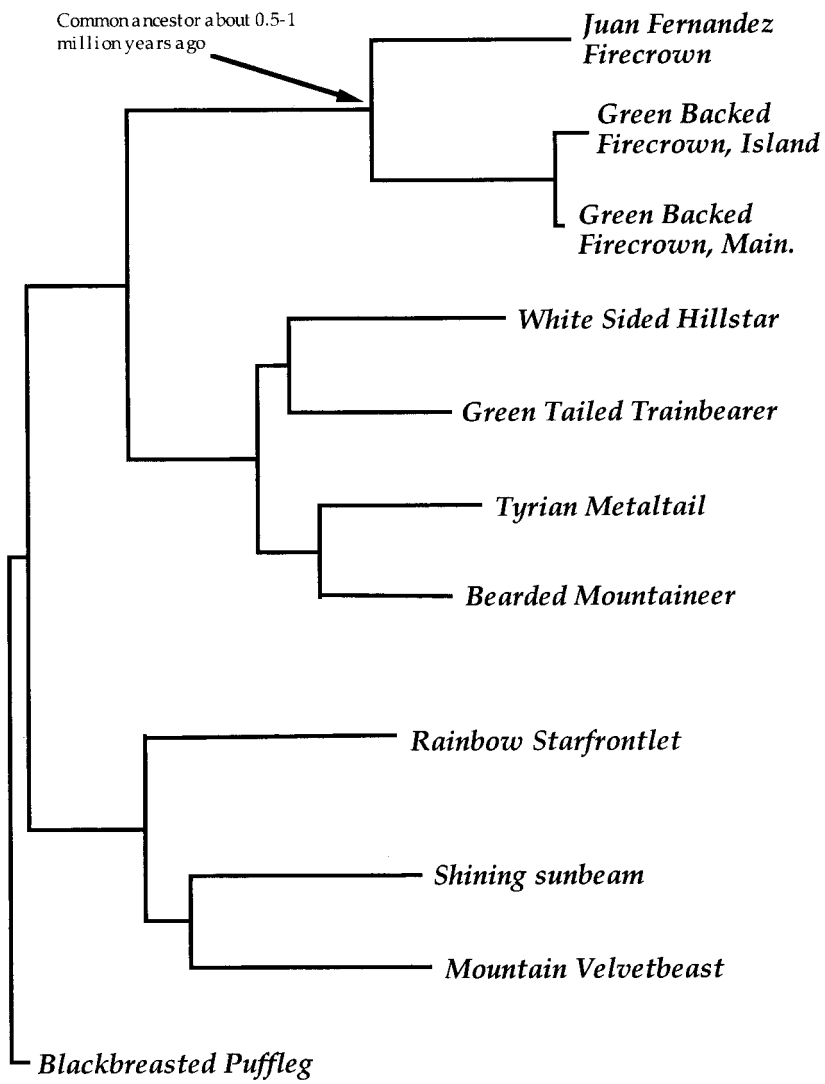


**Fig. 2** A phylogenetic tree based upon mitochondrial genetic markers, describing evolutionary relationships of several Andean hummingbirds. The Juan Fernandez firecrown is shown to be a close relative of the green-backed firecrown, which in turn is closely related to the High Andean hummingbird taxa such as the hillstars and metaltails. Based on our data, the Juan Fernandez firecrown and the green-backed firecrown shared a common mainland ancestor approximately 0.5–1 million years ago, which would have dispersed to the Juan Fernandez Islands sometime after this.

sources. Observations were relatively simple because flowering plants were well separated and feeding territories well defined. Observations were made in December 1996, throughout the day and over 3 days.

Pollen recovered from the beaks of both *Sephanoides fernandensis* and *S. sephaniodes* suggested both to be equally important pollinators of native flowering plant species (Table 1), although this was not found to be true for introduced plants (Table 1). Both hummingbird species were observed feeding on 11 native and 14 introduced plant species; of the latter, male Juan Fernandez firecrowns used only seven species and females 10 instead of all 14 used by the green-backed firecrown. Seasonal availability of food appears to be a key factor because during winter, just one native species, *Raphithamnus venustus*, flowers. As a result of the scarcity of this resource, most of the Juan Fernandez firecrown population is concentrated in San Juan Bautista during winter, feeding on introduced plants such as *Eucalyptus* sp. and garden flowers (e.g. abutilon *Malva nicaensis*; pers. obs.). At sites outside San Juan Bautista, male Juan Fernandez firecrowns, when found, would always be near a *R. venustus* tree. One instance of a female defending a *Cardo* sp. flower was observed in the Vaqueria region. *Dendroseris litoralis* produces seasonal flowers that are an important resource for the Juan Fernandez firecrown.

Males are aggressive and territorial (de Brooke, 1987; Colwell, 1989) spending much of their time calling and pursuing green-backed firecrowns and, sometimes, female conspecifics. On one occasion, two males were seen feeding in the same territory (an abutilon bush) and individually pursuing incoming hummingbirds. Only one intraspecific male-to-male conflict was witnessed. Male Juan Fernandez firecrowns spent significantly more time chasing green-backed firecrowns than conspecifics (142 vs. 4 recorded chases, respectively) although this can partly be explained by the difference



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

in population sizes of the two species (approximately 20 : 1). One female defended a territory for several hours against green-backed firecrowns and, later, another female Juan Fernandez firecrown. Aggression and chasing occurred between all individuals, although green-backed firecrowns were chased more often. The Juan Fernandez firecrown females eventually left the site leaving the green-backed firecrowns to the resource.

Our observations lead us to conclude that Juan Fernandez firecrown males are large enough to defend territories against most other individuals and may use a single resource (flowering bush or tree) for many days. Juan Fernandez firecrown females defend territories against all but male Juan Fernandez firecrowns. On the other hand, non-territorial green-backed firecrowns tend to travel from one resource to another, avoiding resident defenders as much as possible. This strategy promotes opportunism in green-backed firecrowns, exemplified by their readiness to quickly make use of artificial feeders that we provided. Juan Fernandez firecrowns seldom used these feeders.

These data suggest that green-backed firecrowns cannot directly outcompete Juan Fernandez firecrowns for nectar resources. It also appears that, because of their size, male Juan Fernandez firecrowns can defend highly productive resources whereas females often find themselves with lower quality resources that may not necessarily be worth defending. Another point of interest is an apparently skewed male : female of about 3 : 1 (Torres-Mura *et al.*, unpublished data). Is this a natural ratio or are females being indirectly outcompeted for resources by the green-backed firecrown? The female's crown morphology may have evolved with territoriality and resource defence in the female—perhaps because resources were originally scarce and clumped. Presumably, females would have defended resources only against other females because males would easily take over resources from females as a result of their greater size (Colwell, 1989). Females would then be more likely to make use of resources that were of insufficient quality to attract males. The colonization of the islands by the green-backed firecrown may now be forcing the female Juan Fernandez firecrown into an increasingly smaller resource niche.

**Table 1** Species of pollen recovered from the beaks of hummingbirds caught in mist nets (X) and feeding observations from the field (√)

| | *Sephanoides fernandensis* | | | | *Sephanoides sephaniodes* | |
|---|---|---|---|---|---|---|
| | Male | | Female | | Male/Female | |
| Native plant species | | | | | | |
| *Ochagavia elegans* | X | √ | X | √ | X | √ |
| *Phrygilanthus berteroi* | X | √ | X | √ | X | √ |
| *Escallonia callcottiae* | X | √ | X | √ | X | √ |
| *Sophora fernandeziana* | X | √ | X | √ | X | √ |
| *Eryngium bupleuroides* | X | √ | X | √ | X | √ |
| *Raphithamnus venustus* | X | √ | X | √ | X | √ |
| *Cuminia fernandeziana* | X | √ | X | √ | X | √ |
| *Nicotiana cordifolia* | X | √ | X | √ | X | √ |
| *Centaurodendron dracaensis* | X | √ | X | √ | X | √ |
| *Dendroseris litoralis* | X | √ | X | √ | X | √ |
| *Dendroseris macrantha* | X | √ | X | √ | X | √ |
| Introduced species | | | | | | |
| *Lobelia tupa* | X | √ | X | √ | X | √ |
| *Cynara cardunculus* | | | X | √ | X | √ |
| *Dipsacus sativus* | | | X | √ | X | √ |
| *Crinodendron patagua* | X | √ | X | √ | X | √ |
| *Tristerix corymbosus* | X | √ | X | √ | X | √ |
| *Malva nicaensis* | X | √ | X | √ | X | √ |
| *Althaea rosea* | | | | | | √ |
| *Albizia lophantha* | X | √ | X | √ | X | √ |
| *Rubus ulmifolius* | | √ | X | √ | X | √ |
| *Nicotiana tabacum* | | | | | X | √ |
| *Crocosmia crocosmiiflora* | | | | | X | √ |
| *Eucalyptus globulus* | X | √ | X | √ | X | √ |
| *Silybum marianum* | | | | | | √ |
| *Cardo* sp.? | | | | √ | | √ |



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

## Genetic considerations of small population size

As populations decline there is an increasing tendency for an individual to breed with a close relative. This inbreeding increases the level of homozygosity in the short term and decreases effective population number. The long-term effect is a loss of genetic variation. For a species that normally outbreeds, inbreeding will almost certainly have a negative impact (Saccheri *et al.*, 1998) as a result of an increase in homozygosity of deleterious alleles causing inbreeding depression. However, the extent to which inbreeding threatens the continued existence of a species has been widely debated. For the Juan Fernandez firecrown, inbreeding may not have such a deleterious effect because population size has always been limited and perhaps it has been through several previous bottlenecks as a result of stochastic environmental or demographic changes. This may have had the effect of 'purging' the population of deleterious alleles, thereby allowing a highly homozygous population to suffer no ill effects. Island populations are generally regarded as being inbred (e.g. Channel Island fox—Wayne *et al.*, 1991), sometimes with no obvious deleterious effects. Recent analyses have, however, suggested that island species, especially endemics, are at greater risk of extinction from genetic effects than their mainland relatives (Frankham, 1998). Preliminary analysis of the Juan Fernandez firecrown population revealed some genetic variation, although this was significantly less than that found in the green-backed firecrown (Roy *et al.*, 1998). If a captive population were to be raised, inbreeding should be minimized by encouraging a high rate of population increase and ensuring equitable founder representation and parentage in lineages (Templeton & Read, 1984).

## Restoration: pest control

Habitat restoration coincident with the removal of introduced mammals is a realistic, and perhaps the only appropriate, conservation strategy that may save Juan Fernandez firecrown from extinction. If its preservation is to be achieved, immediate implementation of a well-conceived conservation management plan is necessary.

Without doubt, an uncontrolled rabbit population on Isla Robinson Crusoe will prevent the regeneration of native vegetation in degraded areas, thereby reducing the likelihood of success of any conservation programme designed to preserve the Juan Fernandez firecrown and other native species. Arguably, rabbits constitute the biggest conservation threat to Isla Robinson Crusoe. No census of rabbits has been undertaken but we found them in all non-forested regions we visited, in large numbers and at high densities. We suggest that there are many tens of thousands of individuals on the island. Rabbits are selective feeders on shrub seedlings and hence many valuable native perennial plants are simply being browsed away. Because rabbits keep the ground bare, they contribute greatly to erosion, particularly during drought. The true picture of the impact of rabbits on the landscape will be hard to measure until they have been controlled for some years. Erosion caused initially by logging, followed by domestic grazers and now feral rabbits, has desertified large regions and soil erosion has laid bare much of the lower slopes outside the San Juan Bautista–Cumberland Bay region (Bourne *et al.*, 1992). This area was also denuded of endemic evergreen forest about 100 years ago, but has since been replanted with non-grazeable exotics (mostly *Pinus* and *Eucalyptus*), which are spreading.

The removal of rabbits must occur if Isla Robinson Crusoe is to be restored and its native species preserved. Until now CONAF has resisted using myxomatosis because it causes high morbidity in rabbits and has been perceived to have potential secondary effects on non-target native species. CONAF has relied solely on shooting and trapping but this is completely ineffective because hunting expeditions are not continuous and are concentrated in only a few localities.

International experience of rabbit control has recently been marked by some success in Australia and New Zealand. The reason for this is the introduction of Rabbit Calicivirus Disease (RCD), which was first reported in the People's Republic of China in 1984 as the cause of a new, highly transmissible and lethal pandemic of rabbits (ANZRCDP, 1996) and is now present in more than 40 countries. The virus can be spread in a number of ways, including rabbit-to-rabbit contact or mechanically by birds, insects and even people. However, the movement of the virus is primarily linked to an insect vector and climatic patterns. Tests have found the RCD virus to be rabbit specific. Species tested include hares, koala, echidna, wombat, endangered native New Zealand bats and kiwis, bringing the number of species tested to 48 (31 in Australia, two in New Zealand and 15 elsewhere), including domestic animals. For full efficacy and 100 per cent rabbit removal, intensive trapping, poisoning, shooting, use of dogs and fumigation of warrens should be undertaken in addition to the RCD release (B. Bell, pers. comm).

Other introduced mammals include cats and coatis—both of which are implicated in the predation of native ground nesting seabirds (Bourne *et al.*, 1992). One male Juan Fernandez firecrown was found killed by a household cat in San Juan Bautista. Two other encounters with feral cats on remote parts of the island confirm a

small population that probably depends entirely on wild-caught food. Coatis probably hunt rabbits and may take bird eggs. It is unclear whether they are directly implicated in the demise of the Juan Fernandez firecrown. Prey switching of cats and coatis from rabbits to native fauna is a problem that needs to be assessed before rabbit control is undertaken. The perceived low population of cats and coatis may not present too much of a risk, but a trapping programme should be undertaken for some time prior to rabbit control for it to be minimized. Control of cats and coatis may co-occur with rat control (see below) as a result of the secondary effects of rat poison (e.g. 1080) on other mammals.

Although not directly observed on the Juan Fernandez Islands, rats will eat bird eggs and seeds of native plants. They are therefore an impediment to the conservation of the Juan Fernandez firecrown and island restoration, and must be controlled. Although rodent control on Isla Robinson Crusoe will not be easy, rodent eradication on islands, especially in New Zealand, has been undertaken with great success (Towns & Ballantine, 1993). Control of rodents, perhaps leading to their eventual eradication, is a realistic goal for Isla Robinson Crusoe (B. Bell, pers. comm.).

The grazing of domestic animals is not permitted in the national park but cattle were occasionally observed there, often in the most degraded areas. Apparently there has not been enough money to compensate farmers for the removal of cows and horses (Bourne *et al.*, 1992).

Holistic ecological restoration, through the removal of mammalian pest pressure, may provide a cost-effective alternative to individual single-species conservation projects. In addition, ecosytem recovery may reinvigorate community function. Opportunities to study the regeneration of ecosystems are few and the restoration of Isla Robinson Crusoe could provide a unique and important opportunity for such studies (e.g. Simberloff, 1990).

## Habitat and Juan Fernandez firecrown restoration

The Juan Fernandez firecrown should serve as a flagship species, given that the restoration of the island depends entirely on revegetation with native flora on which the Juan Fernandez firecrown depends. After a survey of the Juan Fernandez firecrown population, de Brooke (1987) made the following recommendations: (i) record the utilization of flowers throughout the year; (ii) undertake a study of population dynamics; (iii) establish feeding stations in native forest; (iv) plant a 10-ha plot with flowering shrubs that flower throughout the year; and (v) establish a captive breeding population (see below).

The first two propositions have been acted upon by CONAF through a 2-year study on population estimates (using censuses) and food preferences over four seasons (Meza, 1988, 1989). We strongly urge CONAF to consider implementing the other three recommendations as soon as possible. In addition we recommend the measures listed below.

**1** Remove all introduced mammals, initially within an intensively managed, fenced, feasibility-study site.

**2** Enforce grazing restrictions on national park land.

**3** Replant native flora, initially within the feasibility-study site but also at forest edges.

**4** Replant fast-growing, soil-binding trees along highly eroded slopes for short-term relief (with removal of self-seeded individuals when necessary).

**5** Implement systematic introduced-plant control zonally. In regions where bramble control is carried out, flowering native plants should be planted to make up for the lost resource.

**6** Monitor and reassess management at every step.

In order to begin a restoration project, we suggest a feasibility-study site (200–300 ha), surrounded by a fence (2.2-m high made with galvanized high tensile woven wire and a 6-mm mesh) within which introduced mammals and plants would be monitored and removed continually, and native flowering plants planted, especially the all-year-round flowering *R. venustus*. Such a strategy would provide logistical information for further restoration projects. Gradual enlargement of this area may provide a means by which eradication and ecosystem restoration can eventually be achieved over the entire island, without having to ensure pest eradication in the entire island in one go. This site could initially be situated at the eastern, moister end of Robinson Crusoe Island (Fig. 1) where some native forest remains.

Isla Robinson Crusoe is the best island on which to focus conservation efforts. Because Juan Fernandez firecrowns are already there, conservation efforts can be monitored and easily managed, and the impact in terms of tourism and publicity is likely to be beneficial. The distinct subspecies of Juan Fernandez firecrown that once inhabited Isla Alejandro Selkirk (*leyboldi*) is now extinct. Reasons for its extinction are probably a result of many factors, including those that now threaten the remaining population. An important future goal is to establish a secondary population of Juan Fernandez firecrown in case the Isla Robinson Crusoe population becomes extinct. As a means to this end, a captive population of Juan Fernandez firecrowns should be maintained with the goal of releasing them on to the islands in the near future. This facility should



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press

probably be housed in Santiago to aid public awareness and information dissemination, but aviaries with a good history of hummingbird husbandry would be required to undertake this important task.

### The people

The small fishing community of San Juan Bautista, which once relied heavily on domestic livestock as a supplement to its fishing activities, has not benefited from the attention given to conservation of the islands. Wood collection and grazing of animals are severely restricted. There is a small tourist industry but there has been little planning and there is poor supporting infrastructure. As a result of the remoteness and wildness of the environment, a tourist niche has yet to be realized. However, with wise planning and ecological restoration, there is no reason why the Juan Fernandez Islands cannot benefit from the same eco- and adventure tourism as is promoted in the Galápagos Islands. This would directly benefit the local population and provide a positive attitude to the conservation of the local environment.

### Costs

Costs of such a restoration programme would be large. It has been estimated that to remove cats and rats from a 3000-ha island 5 km off New Zealand would cost $US50,000 (Kennedy, 1998). The logistical problems arising from the Juan Fernandez Islands' remoteness are extreme, and conservatively we suggest a figure of $US0.5–1 million to rid Robinson Crusoe Island of mammalian pests and initiate the restoration process. However, these islands contain a rich human fictional and factual history and are a biological treasure chest that represents a vast untapped potential for tourism, whose returns may far outweigh the cost of removing the pests and restoring the native vegetation. Action must be taken now—time is running out for the Juan Fernandez firecrown because at its present rate of decline, it is set to become extinct within 5 years.

## Acknowledgements

This study was funded by Fondecyt (Chile) grant number 195087, and grants to MSR by the University of London Central Research Fund (UK) and Fauna & Flora International's 100% Fund. Permits were kindly provided by Corporacion Nacional Forestal (CONAF) for fieldwork in national parks in Chile and Servicio Agricola y Canadero (SAG) for work with protected species. We are indebted to Sr Ivan Leiva, Sr Alberto Bordeaux and other CONAF personnel who made this study possible.

## References

Allen, D. (1984) Threatened 'Protected Natural Areas' of the world. *Environmental Conservation*, **12**, 76–77.

ANZRCDP (1996) Australia and New Zealand Rabbit Calicivirus Disease Program: a biological control initiative against the European wild rabbit. http://www.csiro.au/communication/rabbits/qarabbit.htm

Bertero, C. (1830) Notice sur L'Histoire Naturelle de l'ile Juan Fernandez, extraite d'une lettre de M. Bertero. *Annals Scientifica Naturelles*, **1**(21), 344.

Bourne, W.R.P., Brooke, M., de, L., Clark, G.S. & Stone, T. (1992) Wildlife conservation problems in the Juan Fernandez Archipelago, Chile. *Oryx*, **26**, 43–51.

de Brooke, M.L. (1987) *The Birds of the Juan Fernandez Islands*.. Study report No. 16. International Council for Bird Preservation, Cambridge, UK.

Collar, N.J, Crosby, M.J & Stattersfield, A.J. (1994) *Birds to Watch 2: The World List of Threatened Birds*. Birdlife Conservation Series, **4**, 1–407.

Colwell, R.K. (1989) Hummingbirds of the Juan Fernandez Islands, natural history, evolution and population status. *Ibis*, **131**, 548–566.

Cronk, Q.C.B. (1997) Islands: stability, diversity, conservation. *Biodiversity and Conservation*, **6**, 477–493.

Douglas, D. (1836) A sketch of a journey to the north western parts of the continent of North America during the years 1824, 1825, 1826 and 1827. W. J. Hooker's Companion to the Botanical Magazine II, pp. 84–86. In *Report of The Scientific Results of The Voyage of* H.M.S. Challenger. Vol. I (Botany) W. Hemsley (1885) pp. 1–75. London, Edinburgh, Dublin.

Fjeldså, J. & Krabbe, N. (1990) *Birds of the High Andes*. Zoological Museum, Copenhagen, and Apollo Books, Svendborg.

Frankham, R. (1998) Inbreeding and extinctions: island populations. *Conservation Biology*, **12**(3), 665–675.

Graham, M. (1824) *Diario de mi Residencia en Chile y Brasil*. Editorial Cervantes, Santiago de Chile, Chile.

IUCN (1996) *1996 IUCN Red List of Threatened Animals*. IUCN, Gland, Switzerland.

Kennedy, C.S. (1998) *The conservation potential of Great Mercury Island (New Zealand)*. Hons. thesis, Dept. Zoology, Otago University.

King, P.P. (1831) Notes on birds collected by Capt. King in Chile. *Proceedings Zoological Society London*, **1830–1831**, 29–30.

Mann, G. (1975) Observaciones sobre el estado actual de algunos representantes de fauna y flora en el parque nacional Juan Fernández. *Boletin Museo Nacional de Historia Natural (Chile)*, **34**, 207–216.

Meza, J. (1988) *Informe Anual del Proyecto Conservaciôn del Picaflor de Juan Fernández* Sephanoides fernandensis, *Otomno 1987–Verano 1988*. Unpublished report, Corporacion Nacional Forestal V Region.

Meza, J. (1989) *Informe Anual del Proyecto Conservaciôn del Picaflor de Juan Fernández* Sephanoides fernandensis, *Invierno 1988–Otomno 1989*. Unpublished report.

Myers, N. (1979) *The Sinking Ark: A New Look at the Problem of Disappearing Species*. Pergamon Press, New York.

Perry, R. (1984) Juan Fernandez Islands: a unique botanical heritage. *Environmental Conservation*, **11**, 72–76.

Reid, W.V. & Miller, K.R. (1989) *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity*. World Resources Institute, Washington, DC.

Ricci, M. (1996) Variation in distribution and abundance of the endemic flora of the Juan Fernandez Islands, Chile. Pteridophyta. *Biodiversity and Conservation*, **5**, 1521–1532.

Rottmann, J. & Lopez-Calleja, M.V. (1990) *Estrategia nacional de conservaciôn de aves. Serie Técnica Servicio Agrícola y Ganadero*, **1**.

Roy, M.S., Torres-Mura, J.C. & Hertel, F. (1998) Evolution and history of hummingbirds (Aves: Trochilidae) from the Juan Fernandez Islands, Chile. *Ibis*, **140**, 265–273.

Roy, M.S., Torres-Mura, J.C. & Hertel, F. (1999) Molecular phylogeny and evolutionary history of the Tit-Tyrants (Aves: Tyrannidae). *Molecular Phylogeny Evolution*, **11**(1), 67–76.

Saccheri, I., Kuussaari, M., Kankare, M., Vikman, P., Fortelius, W. & Hanski, I. (1998) Inbreeding and extinction in a butterfly metapopulation. *Nature*, **392**, 491–494.

Sandars, R.W., Stuessy, T.F. & Marticorena, C. (1982) Recent changes in the flora of the Juan Fernandez Islands, Chile. *Taxon*, **3**, 284–289.

Sclater, P.L. (1871) On the land birds of Juan Fernandez. *Ibis*, **1**, 178–183.

Simberloff, D. (1990) Reconstructing the ambiguous: can island ecosystems be restored? In *Ecological Restoration of New Zealand Islands* (eds D. R. Towns, C. H. Daugherty and I. A. E Atkinson), pp. 37–51. Department of Conservation, New Zealand.

Stattersfield, A.J., Crosby, M.J., Long, A.J. & Wege, D.C. (1998) *Endemic Bird Areas of the World*. BirdLife Conservation Series N7, BirdLife, Cambridge, UK.

Stuessy, T.F., Foland, K.A., Sutter, J.F., Sanders, R.W. & Silva, O.M. (1984) Botanical and geological significance of potassium–argon dates from the Juan Fernandez Islands. *Science*, **225**, 49–51.

Templeton, A.R. & Read, B. (1984) Factors eliminating inbreeding depression in a captive herd of Speke's gazelle (*Gazella spekei*). *Zoo Biology*, **3**, 177–199.

Towns, D.R. & Ballantine, W.J. (1993) Conservation and restoration of New Zealand island ecosystems. *Trends in Ecology and Evolution*, **8**(12), 452–457.

Wayne, R.K., George, S.B., Gilbert, D., Collins, P.W., Kovach, S.D., Girman, D. & Lehman, N. (1991) A morphologic and genetic study of the island fox *Urocyon littoralis*. *Evolution*, **45**, 1849–1868.

## Biographical sketch

Michael S. Roy is a lecturer in conservation, evolution and genetics. His research centres on the conservation of small populations, defining conservation units and conservation areas, and investigating speciation processes and biogeography in terrestrial and marine environments. He also works on mammalian social structure and its evolution. Please visit http://www.otago.ac.nz/Zoology/staff/mr.html for further details.



https://doi.org/10.1046/j.1365-3008.1999.00067.x Published online by Cambridge University Press