

NEST SITE USE IN SYMPATRIC PETRELS OF THE JUAN FERNÁNDEZ ARCHIPELAGO, CHILE: JUAN FERNÁNDEZ PETREL (*PTERODROMA EXTERNA*) AND STEJNEGER'S PETREL (*PTERODROMA LONGIROSTRIS*)

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Resumen. – Uso de sitio de nidificación en fardelas simpátricas del Archipiélago Juan Fernández, Chile: fardela blanca de Juan Fernández (*Pterodroma externa*) y fardela blanca de Masafuera (*Pterodroma longirostris*). – La fardela blanca de Juan Fernández (*Pterodroma externa*) y la fardela blanca de Masafuera (*Pterodroma longirostris*) son dos especies endémicas pobremente estudiadas, que nidifican simpátricamente en isla Alejandro Selkirk, Archipiélago Juan Fernández, Chile. Investigamos el uso de sitios de nidificación de ambas especies en la colonia principal de Alejandro Selkirk. Definimos seis tipos de hábitat y observamos cuatro grupos de densidad: alta y baja densidad para cada especie. La densidad de fardela blanca de Masafuera (especie más pequeña) fue alta solo en el prado de herbáceas perennes, mientras que en los otros la densidad fue baja probablemente por la presencia de parejas reproductivas de fardela blanca de Juan Fernández o a condiciones desfavorables del suelo para el asentamiento de cuevas. En el hábitat de alta densidad de fardela de Masafuera, los individuos de esta especie tienden a estar más asociados a cuevas de conespecíficos que a cuevas de fardela blanca de Juan Fernández. Esto puede ser atribuido a competencia de interferencia interespecífica por sitios de nidificación, en donde la fardela blanca de Juan Fernández empujaría a la especie más pequeña hacia un hábitat específico. Nuestros hallazgos sobre la restringida distribución de hábitat reproductivo para la fardela de Masafuera pueden tener importantes implicancias para la conservación de esta amenazada especie, especialmente dado el impacto de mamíferos introducidos, depredación (ratas, gatos asilvestrados) y alteración del hábitat (cabras asilvestradas) en Isla Alejandro Selkirk.

Abstract. – Juan Fernández Petrels (*Pterodroma externa*) and Stejneger's Petrels (*Pterodroma longirostris*) are two poorly studied single-island endemic species that nest sympatrically on Alejandro Selkirk Island, Juan Fernández Archipelago, Chile. We investigated nesting site use for both species in the main Alejandro Selkirk colony. We defined six habitat types and observed four density patterns in the colony: high and low density for each species. Burrow density of Stejneger's Petrels (smaller species) was high only in herbaceous perennial grassland habitat, with low densities in other habitat types possibly due to the presence of breeding Juan Fernández Petrels and/or unfavorable soil conditions for burrow establishment. In the high density habitat of Stejneger's Petrels, individuals tended to be more closely associated with conspecific burrows than with Juan Fernández Petrel burrows. This may be attributed to interspecific interference competition for breeding sites, with Juan Fernández Petrels pushing the smaller

species toward a specific habitat type. Our findings of restricted distribution of high density breeding habitat for Stejneger's Petrels may have important implications for conservation of this threatened species, especially given the impacts of introduced mammals, predation (rats, feral cats), and habitat alteration (feral goats) on Alejandro Selkirk Island. Accepted 28 February 2012.

Key words: Alejandro Selkirk Island, habitat use, Procellariidae, *Pterodroma externa*, *Pterodroma longirostris*, sympatric populations.

INTRODUCTION

Nesting site use patterns are a consequence of the process of breeding habitat selection which describes the actual distribution of breeding individuals across habitat types (Hutto 1985, Hall *et al.* 1997, Jones 2001). However, the presence of conspecifics and/or other species also influences selection and use of a site (Danchin *et al.* 2004, Naves *et al.* 2006). This use can be more competitive when nesting habits involve increased space requirements (area/volume), such as burrow digging. Moreover, two or more species nesting sympatrically in a colony at the same time may divide the niche that they share (Mouquet & Loreau 2002); this may be problematic because individuals of one species may be forced to nest in suboptimal areas (Dale & Manceau 2003, Wilson & Martin 2008). In seabirds that excavate burrows for nesting, like petrels, burrows are established according to a set of physical habitat features that limit burrow distribution and abundance within the breeding colony (Warham 1996). Of those important physical variables correlated with locations of burrows, weather conditions, especially wind exposure and rain, have been strongly associated with soil stability (Thompson & Furness 1991, Varpe & Tveraa 2005). Principal factors include aspect, elevation gradient (Hawke 2001, Hawke & Newman 2004), slope (Schramm 1988), moisture (Warham & Wilson 1982), effective soil depth (Richdale 1963), thermal insulation (Mathiu *et al.* 1992), and composition, structure and density of vegetation (Gillham 1963).

Juan Fernández Petrels (*Pterodroma externa*) and Stejneger's Petrels (*Pterodroma longirostris*) are two single-island endemic species that breed only on Alejandro Selkirk Island, Juan Fernández Archipelago, southwest Pacific (33°78'S, 80°78'W). They breed sympatrically between October and May (Brooke 1987). These species differ significantly in weight and body size, with Juan Fernández and Stejneger's petrels weighing 491 ± 51 g (mean \pm SD, N = 24) and 162 ± 21 g (N = 28) and having tarsus lengths of 41 ± 1.3 mm and 29.4 ± 0.9 mm, respectively (PJH unpubl. data). Estimated body lengths for Juan Fernández Petrel and Stejneger's Petrel are 43 and 26–30 cm, respectively (Goodall *et al.* 1951). There is also an important difference in population sizes, with an estimated number of one million breeding pairs of Juan Fernández Petrel and 131,000 of Stejneger's Petrel in the main colony of the island (Brooke 1987). These species are listed as Vulnerable by the International Union for the Conservation of Nature (Birdlife International 2010a, b), principally because of their restricted breeding range (a single island) and the presence of introduced mammals species, such as goats (*Capra hircus*), which affect the breeding habitat of the petrels by trampling (Bourne *et al.* 1992, Hahn & Römer 2002), and rodents (*Rattus norvegicus*, *Mus musculus*) and feral cats (*Felis catus*) which prey on eggs, chicks, and adults, as described for other petrel species (Jouventin *et al.* 2003).

Studies addressing fundamental aspects in the life history of these two species, i.e., breeding habitat selection, are required not

only to estimate population sizes and track populations trends, but also to implement conservation plans related to the eradication of introduced fauna in these island systems (Gaze 2000, Howald *et al.* 2007). Furthermore, the knowledge of petrel nesting habitats is fundamental for prioritizing areas for protection of these species.

The aims of this study were to: (1) determine patterns of nest site use in potential breeding habitat of Juan Fernández and Stejneger's petrels in Alejandro Selkirk's main colony and (2) evaluate the possible role of competition between the species as a factor driving burrow distribution patterns.

METHODS

Alejandro Selkirk Island (33°45'S, 80°45'W), located in the Juan Fernández Archipelago (Fig. 1) is 834 km offshore the central coast of Chile. The island has an area of 49 km², with a maximum elevation of 1380 m a.s.l. Lower elevations are dominated by grassland composed mainly of *Anthoxanthum odoratum*. Tree ferns (*Dicksonia externa*) cover most of the highlands in the south, while the patchily distributed fern *Lophosoria quadripinnata* predominates in the northern and eastern areas (Brooke 1987).

The study was carried out between 28 February and 19 March 2002, in the Tres Torres and Cordón Inocentes Bajos sectors of the island (1000–1100 m a.s.l.) (Fig. 1). Even though only a fraction of the colony was sampled because of difficulty of access, characterization of the habitat occupied by petrels for nesting (burrow presence) represented the main vegetation components present in the colony (Table 1).

We used burrow entrance height and width, measured using a Vernier caliper (0.1 mm), to identify burrows for both petrel species. To validate the use of entrance dimensions to assign burrows to a species, we

determined burrow contents by using a burrow scope and/or an excavated access tunnel that allowed identification and confirmation of the occupying species. Both methods are widely used for burrowing seabirds and have been shown to have minimal disturbance on the individual (Jones *et al.* 2003). The two species breed roughly synchronously and have comparable incubation and nestling periods; incubation periods are approximately 45–50 days and 55–60 days for Stejneger's and Juan Fernández petrels, respectively, and nestling periods are approximately three months (Brooke 1987). At the time that the study period began, breeding birds of both species were at the end of the incubation period or had chicks no older than two weeks of age. The difference between the sizes of entrances of two species was evaluated with a *t*-test. Basic statistics are presented as mean \pm SD.

We evaluated the use of nesting habitat type by establishing eight randomly distributed (Bibby *et al.* 2000) 100 m² quadrats in each designated habitat category within the colony (except in herbaceous perennials grassland where $n = 4$, totaling $5 \times 8 + 4 = 44$ quadrats). In each quadrat, we recorded the total number of burrows per species and converted them to density values. Density data for both species as dependent variables were analyzed using a two-way ANOVA with unbalanced design (Quinn & Keough 2002), with species and habitat as fixed factors, once the assumptions of the parametric analysis were fulfilled through square root transformation (Zar 1999).

We estimated the maximum possible occupancy of burrows by randomly marking five burrows per species in each quadrat ($5 \times 2 \times 44 = 440$ burrows) and checking them daily for five continuous days. Occupancy of quadrats with less than five burrows was estimated by using all burrows within the quadrat (Table 2). At the entrance of each burrow, we placed a barricade of toothpicks as a metric of

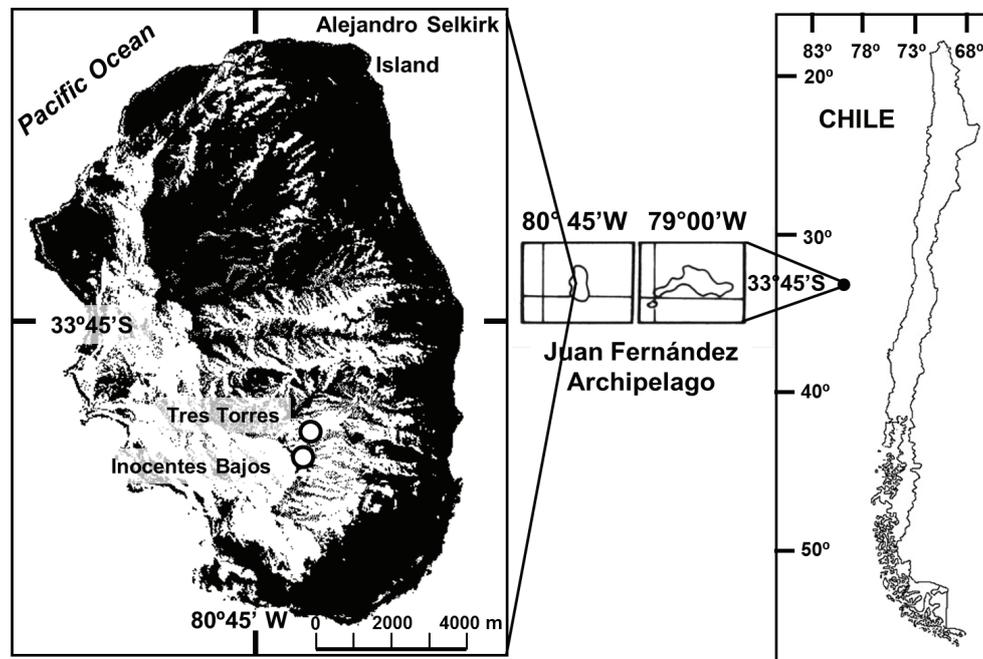


FIG. 1. Alejandro Selkirk Island (Juan Fernández Archipelago, Chile) and study sites.

burrow visits (i.e., toothpicks knocked down) (Bibby *et al.* 2000). Burrows with at least three visits during the five days were classified as occupied. This method allowed us to monitor a larger number of burrows and to evaluate occupancy in areas of the colony with muddy soils and standing water, which made the use of the infra-red burrow scope impractical. It is important to note that this estimate represents a maximum possible occupancy given that activity at the entrance could be due to multiple causes: breeding adult petrels, non-breeding petrels, cats, or rats. The occupancy ratio of the total counted burrows per quadrat was estimated using the maximum possible occupancy of selected burrows. We considered only burrows classified as occupied for analyses of occupancy.

Because of their lower relative abundance, the grouping of Stejneger's Petrel burrows

was determined in relation to both conspecific and Juan Fernández Petrel burrows, in order to evaluate the occurrence of subcolonies. We defined subcolonies as discrete breeding aggregations (Hipfner *et al.* 2007) that form a clearly separated social unit (Dittman *et al.* 2007). First, we performed a goodness of fit analysis for the Poisson distribution of the Stejneger's Petrel burrows using a chi-square test in order to test the null hypothesis of random distribution of this species. For random distribution to be supported, the ratio between variance and mean of the total burrows counted in all quadrats ($n = 44$) must equal 1 ($\sigma^2/\mu = 1$). If this hypothesis is rejected, the burrow distribution may be uniform ($\sigma^2/\mu < 1$) or clustered ($\sigma^2/\mu > 1$). Second, to evaluate the grouping of Stejneger's Petrels with respect to Juan Fernández Petrels, we constructed a contingency table,

TABLE 1. Described habitat types in the principal colony of Juan Fernández (*Pterodroma externa*) and Stejneger's (*Pterodroma longirostris*) petrels, Alejandro Selkirk Island, with soil, vegetation, and slope characteristics.

Habitat type	Soil characteristic	Vegetation type	Height of vegetation (m)	Slope (°)
Fern humus	Deep and spongy humus layer	Remains of <i>Dicksonia externa</i> , <i>Blechnum cycadifolium</i> , <i>Lophosoria quadripinnata</i> , soil covered by <i>Marchantia polymorpha</i>	< 2	15–30
Vernal grassland	Shallow ground, with basaltic rock base	<i>Anthoxanthum odoratum</i> , scarce presence of <i>L. quadripinnata</i>	< 30	< 5
Tree fern forest	Deep humus layer	<i>D. externa</i> with scarce presence of <i>B. cycadifolium</i>	100–250	15–25
Canelo forest	Well-constituted soil	Patches of <i>Drimys winteri</i> , few <i>D. externa</i> and <i>L. quadripinnata</i>	200–500	45
Patches of low fern	Deeply rooted soil	<i>Histiopteris incisa</i> covering densely patches	30	< 15
Herbaceous perennials grassland	Rocky soil, deeper than vernal grassland soil	<i>Rubus geoides</i> , <i>Rumex acetosella</i> , and <i>Myrteola nummularia</i> ; <i>M. polymorpha</i> and <i>A. odoratum</i> in lower densities	< 5	10–20

using a chi-square test, to evaluate the null hypothesis that each Stejneger's Petrel burrow is close to an intra- or inter-specific burrow in the same proportion. We measured distances to the five nearest neighbors (to the nearest 1 cm) for 40 randomly chosen burrows in perennial grassland habitat (because of the abundance of both species). The contingency table contained one column (Stejneger's Petrel factor) and two rows (neighbor factor with two levels: number of neighbors of both species).

RESULTS

Differentiation of burrows. The burrows of Juan Fernández Petrels were taller (145.8 ± 29.2 cm) and wider (111.7 ± 20.8 cm) ($n = 25$) than those of Stejneger's Petrels (height = 98.9 ± 14.6 cm, width = 88.5 ± 18.9 cm) ($n = 13$) ($t_{0.05(2)} = 3.3$, d.f. = 36, $p < 0.001$; $t_{0.05(2)} = 5.4$, d.f. = 36, $p < 0.001$, respectively).

Habitat use for nesting and burrow occupancy. The total numbers of burrows for Stejneger's and Juan Fernández petrels were 241 and 1721 (ratio 1:7), respectively (Table 2). Juan Fernández Petrel burrow counts were higher in all quadrats except in herbaceous perennial grassland. The two-way ANOVA (fixed factors) showed highly significant differences in burrow density for each factor and the interaction between them (species factor: $df = 1$, $F = 510.3$, $p < 0.01$; habitat factor: $df = 5$, $F = 80.4$, $p < 0.01$; sp. * habitat: $df = 5$, $F = 98.1$, $p < 0.01$). Results indicated a high and low density group for both species (Fig. 2). The high density group for Juan Fernández Petrels was comprised of fern humus, canelo (*Drimys winteri*) forest, and tree fern forest habitat types, with the low density being formed by vernal grassland, herbaceous perennials grassland and patches of low fern. The high density group for Stejneger's Petrels was characterized by herbaceous perennials grassland, with the low

TABLE 2. Maximum possible occupancy (%) of Juan Fernández Petrel (JFP) and Stejneger's Petrel (SP) burrows by habitat type. The top row per species is the total of all burrows found in quadrats per habitat (8 quadrats per habitat, except for herbaceous perennial grassland which contained only 4). The % occupancy for each habitat type (bottom row) was estimated from 40 burrows per species in each habitat, except for herbaceous perennial grassland with 20 burrows per species. Occupancy of quadrats with less than five burrows was estimated using all burrows within the quadrats.

	Fern humus	Vernal grassland	Canelo forest	Patches of low fern	Tree fern forest	Herbaceous perennials grassland
JFP burrows	434	99	487	27	617	57
% occupancy	97.5	90	82.5	100	100	100
SP burrows	19	2	6	0	0	214
% occupancy	5.6	0	0	0	0	100

density group composed of the five other habitats.

Juan Fernández Petrels exhibited high percentages of maximum possible burrow occupancy (over 90%) in all habitat types except for canelo forest (83%). In contrast, Stejneger's Petrels had high maximum possible occupancy (100%) only in herbaceous perennials grassland. Other habitats contained either no burrows or few burrows with low occupancy levels (Table 2).

Burrow grouping by Stejneger's Petrel. Stejneger's Petrel burrows were distributed non-randomly ($\chi^2 = 3928$, $\chi^2_6 = 16.81$, $p < 0.01$), with a clear tendency for the burrows to be arranged in a clustered distribution ($\sigma^2/\mu = 246.8/5.5 = 44.8 > 1$). Furthermore, Stejneger's Petrels showed a strong tendency to associate with individuals of the same species rather than with Juan Fernández Petrels ($\chi^2 = 81.92$, $\chi^2_1 = 6.635$, $p < 0.01$).

DISCUSSION

This is the first work since Brooke (1987) to explore the breeding habitat use of these two little-known species endemic to Alejandro Selkirk Island. As an identification tool, we have demonstrated a clear difference in the

dimension of burrow entrances of Juan Fernández and Stejneger's petrels. Thus, burrow entrance size is a characteristic feature that allows quick identification and accurate assignment of burrows to one of the species and provides a useful tool for carrying out population censuses, searching for burrows to include in monitoring, and establishing relationships between habitat and settlement patterns of individuals.

Overlap in nest sites between colonial species may result in interspecific competition (Ramos *et al.* 1997, Rodenhouse *et al.* 1997, Kokko *et al.* 2004). To avoid competition, a separation of nesting sites use may evolve over time (Burger & Gochfeld 1988, Ramos *et al.* 1997). Since Stejneger's Petrel burrows are small, they can potentially dig more of them in the same area relative to Juan Fernández Petrels. However, burrow density in Juan Fernández Petrels was higher in every studied quadrat, except for the one established on perennial grassland (Fig. 2). In the Alejandro Selkirk colony, the high density of Juan Fernández Petrel burrows is associated with tree fern forest, canelo forest, and fern humus habitat types, all of which have soft, wet, deep, and penetrable soils with slopes that facilitate nesting and minimize flooding of the nest chamber by water accumulation

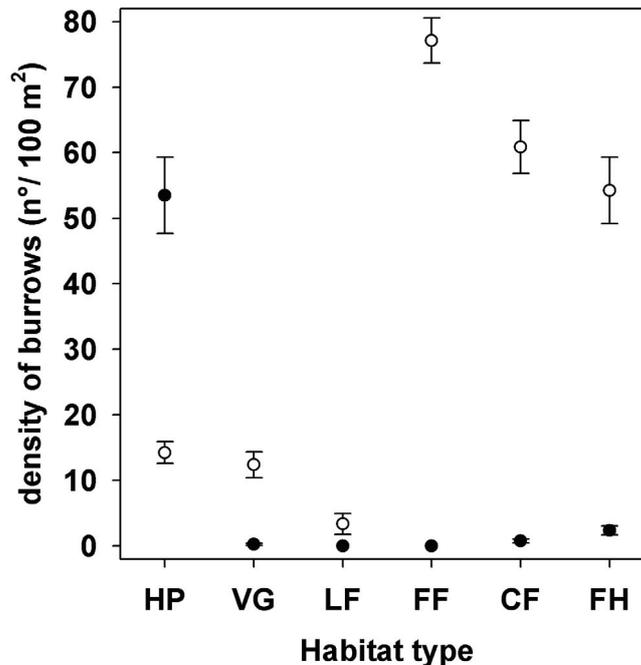


FIG. 2. Mean and standard errors for burrow densities of Juan Fernández Petrel (white circles) and Stejneger's Petrel (black circles) by habitat type in the breeding colony. Key for the characterized habitats: herbaceous perennials grassland (HP), vernal grassland (VG), patches of low fern (LF), tree fern forest (FF), canelo forest (CF), fern humus (FH). For all habitat types $n = 8$, except for HP with $n = 4$.

(Schramm 1988). In addition, tree ferns can exceed 2 m in height and do not have dense fronds at ground level, thus allowing the birds to move easily on the ground. In contrast, habitat types with low Juan Fernández Petrel burrow density (i.e., vernal grassland, herbaceous perennials grassland, and patches of low fern) either did not have optimal soil conditions (e.g., shallow, rocky surface) or had a vegetation structure that prevent petrels from digging.

However, Stejneger's Petrels are largely to completely absent from the three same viable habitats, breeding primarily in the herbaceous perennials grassland. Why do Stejneger's Petrels nest principally in this habitat? One possible explanation is that interspecific interference competition may result in displace-

ment of subordinate smaller/vulnerable species from the optimal areas for nesting, favoring occupancy by bigger species, as seen in other seabird communities (Oro *et al.* 2009). If this occurs on Alejandro Selkirk Island, available habitats for Stejneger's Petrels are those utilized less by Juan Fernández Petrels. Of the habitats available to Stejneger's Petrels, only one appears to be suitable (abundance, accessibility, and procurability; Jones 2001), namely herbaceous perennials grassland since its soil may not be deep enough for the larger species. This interference competition could cause Stejneger's Petrels to be constrained to form breeding assemblages in these areas. Based on density of the Stejneger's Petrel in the six designated habitat types, we propose that the degree of

grouping showed by this species could represent a series of small subcolonies restricted to a particular habitat type within a large colony dominated by the Juan Fernández Petrel. However, further studies need to examine the specific spatial structure of both species within the colony and conduct behavioral studies to determine possible agonistic interactions.

The information provided by our study will allow future work to focus on the protection and management of critical terrestrial areas for these species, especially given that there appear to be considerable impacts of introduced mammals through predation and soil alteration (Bourne *et al.* 1992, Hahn & Römer 2002). Introduced mammals can affect them differentially because rats and mice can exert a higher impact on smaller than on larger species. Besides their size, small seabird species, like those of the family Hydrobatidae (storm petrels), meet the main criteria for susceptibility to rats, i.e., they are burrow or cavity nesters, and are likely to be preyed upon in all life stages (i.e., eggs, chicks, adults) (Ruffino *et al.* 2009). In contrast, feral cats are too big to enter burrows and attack small petrels, taking adult birds only on their arrival or departure from the colony (Jouventin & Micol 1995) and/or late-stage nestlings when they exit the burrows to exercise their wings late in the season. Finally, in the study site, trampling by goats can disproportionately affect soils with deep and spongy humus layers like fern humus, where a large density of Juan Fernández Petrel burrows is present; rocky soils, where the largest density of burrows of Stejneger's Petrels was found, should be less vulnerable to direct trampling effects by goats.

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