Biogeography, diversity, and conservation of the birds of the Juan Fernández Islands, Chile

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> Kurzfassung

Die Avifauna Fernandeziana wird hinsichtlich Artenreichtum, Habitatwahl und Brutstatus beschrieben und analysiert. Taxonomische Komposition und biogeographische Herkunft werden bestimmt. Abschließend wird der gegenwärtige Gefährdungsstatus der Vögel aus einer geographischen Perspektive mittels „Eigenplace Index“ nach Walter analysiert. Die Avifauna umfasst nur 55 nachgewiesene Arten, etwa ein Drittel regelmäßige Brutvögel und zwei Drittel nicht brütende Besucher. Die meisten Artnachweise kommen von der Insel Robinson Crusoe (41), gefolgt von Alejandro Selkirk (26) und dem kleinen Santa Clara (8). Elf Arten brüten auf Crusoe und sieben auf Selkirk, aber kein Endemit brütet auf beiden Inseln. Insgesamt sind auf dem Archipel 14 Vogelordungen, 29 Familien und 41 Gattungen vertreten. Die artenreichsten Ordnungen sind die Procellariiformes (18 Arten) gefolgt von den Passeriformes (7) und den Charadriiformes (7). Im arithmetischen Mittel kommen 1,3 Arten je Gattung vor, 2,0 Gattungen je Familie und 1,7 Familien je Ordnung. Die meisten Seevögel entstammen subantarktisch/temperierten Regionen, die meisten Landvögel der Neotropis (zusammen 65 %). Unter Anwendung des Eigenplace Indexes erscheinen alle Endemiten in den beiden Schutzklassen, welche die stärkste Bedrohung anzeigen. Die sechs endemischen Landvogeltaxa sind hochgradig gefährdet, besonders *Sephanoides fernandensis* und *Aphrastura masafuerae*. Für den geringen Artenreichtum könnten unterschiedliche Faktoren verantwortlich sein: geringe Beobachtungsintensität, geringe Einwanderungsraten aufgrund hoher Isolation, Konkurrenz aufgrund begrenzter Ressourcen und Prädation bei fehlenden Rückzugsgebieten. Die Ergebnisse stützen die theoretische Annahme, dass nah verwandte Taxa dazu tendieren sich auf Inseln gegenseitig zu reduzieren/auszuschließen und dass ein Generalist dazu tendiert mehrere Spezialisten zu ersetzen.

> Abstract

The Avifauna fernandeziana is described and analysed according to species richness, habitat choice, and breeding status. Taxonomic composition and biogeographical origin are identified. Finally the current conservation status of birds is analysed from a geographical point of view using Walter’s eigenplace index. The avifauna is represented by only 55 recorded species, one third regular breeders and two thirds visitors. Most species records come from the island Robinson Crusoe (41), followed by Alejandro Selkirk (26) and small Santa Clara (8). Eleven species breed on Crusoe and seven on Selkirk, but they share no endemics. In total 14 bird orders, 29 families and 41 genera are present. Richest orders are Procellariiformes (18 species) followed by Passeriformes (7) and Charadriiformes (7). On average 1.3 species are found per genus, 2.0 genera per family, and 1.7 families per order. Most seabirds originate from Subantarctic/Temperate zones, most landbirds from the Neotropis (together 65 %). Using the eigenplace index, all endemics appear in the two highest scored conservation classes. The six endemic landbird taxa are highly threatened, especially *Sephanoides fernandensis* and *Aphrastura masafuerae*. For the low species richness diverse factors may be responsible: low observation intensity, low immigration rates by isolation, competition for limited resources, and predation without retreat areas. The findings support the theoretical suggestion that on islands closely related taxa tend to reduce each other and that one generalist tends to replace several specialists.

> Key words

Avifauna fernandeziana, biodiversity, island birds, island theory, endemics, endangered species, conservation, eigenplace index, Neotropical realm, Juan Fernández Islands.

Introduction

The Juan Fernandez Islands are amongst the most threatened natural areas around the globe (ALLEN, 1984, HULM, 1995). Their flora and fauna is generally known to be highly endemic (SKOTTSBERG, 1956, STUESSY & ONO, 1998), limited to three relatively small islands (~ 95 km²) that have faced severe conservation threats since the year 1574, when the first human set foot on them. Birds are the islands' only native land vertebrates and the avifauna holds more than 30 % of the endemic bird taxa of Chile (comp. ARAYA *et al*., 1992). Although indications of severe conservation problems have been presented (BOURNE *et al*., 1992, CUEVAS & VAN LEERSUM, 2001), basic data of the diversity of the avifauna and related biogeographical background is still lacking. However, knowledge of the occurring species is one of the very fundamental requirements for any successful conservation work, at best accompanied by knowledge of species ecology and their distribution patterns. In this context the basic importance of ecological species lists is widely accepted, but the geographical analysis of species' distribution pattern for conservational use is often neglected (STOTZ *et al*., 1996, WHITTAKER, 1998).

The avifauna of the Juan Fernández Islands is poorly known in general. A number of early species accounts have been published (SCLATER, 1871, REED, 1874, SCHALOW, 1899, LÖNNBERG, 1921, MURPHY, 1936, JOHNSON, 1965, 1967, TORRES, 1970, TORRES & AGUAYO, 1971, BOURNE, 1983); they are valuable but deal only with a limited part of the total spectrum of species. Then SCHLATTER (1987) gave a first overview of Chilean island avifaunas based on a literature survey; BROOKE (1987a) and MEZA (1988) added their field observations in study reports. In their "bird guide" ARAYA *et al*. (1992) provided some additional data based on literature and personal observations. Beginning in 1992 and continuing until 2002, intensive field investigations have yielded a wealth of new avifaunal data relevant for zoogeographical analysis and evaluation.

This study aims to accomplish four principal goals. Firstly, it wants to present an ecological approach to the avifauna of this archipelago and its surrounding waters. Species richness by island, habitat use, and breeding status will be presented and analysed on the basis of available records from the past 150 years and recent field observations from the three islands. Secondly, the taxonomic composition of the avifauna will be analysed in order to know which bird genera, families, and orders are present on the islands and in which proportion. Thirdly, the historical areography of all species and, in case of insular endemics, that of their next relatives will be analysed (MÜLLER, 1981). We wish to identify which geographical influences are most significant for the sea- and landbird fauna. Fourthly, the breeding avifauna shall be evaluated in terms of its current aerographic conservation status for the first time. WALTER (2004) presented a classification system (eigenplace index) which makes it possible to analyse species' "functional spatial complex of existence" and to evaluate their distribution character according to six geographical parameters. We aim to identify those bird species whose areographic characteristics confer to them high conservation importance and urgency.

Study area and biogeographical background

The Juan Fernández Archipelago in the south-eastern Pacific Ocean off Chile (33° 28' 48'' S to 33° 47' 57'' S and 78° 47' 12'' W to 80° 47' 44'' W) is of volcanic origin. It consists of the islands Robinson Crusoe, Alejandro Selkirk, Santa Clara, and several small rocky islets. The easternmost Robinson Crusoe (47.11 km², 915 m elevation above sea level) is 567 km distant from the continent, the westernmost Alejandro Selkirk (44.64 km², 1340 m) another 167 km to the west of Robinson Crusoe, and the much smaller Santa Clara (2.23 km², 375 m), only 1.5 km to the south-west of Robinson Crusoe (area measures according to official government information). The entire archipelago is a Chilean national park since 1935 and a UNESCO Biosphere Reserve since 1977, with the exception of the human settlement. More detailed geographical descriptions can be found from CASTILLA (1987) and SKOTTSBERG (1956).

The archipelago is located between Polynesia and South America and differs from all others by a unique combination of environmental factors: neither entirely belonging to the Neotropical flora nor to the Subantarctic, but representing a separate floristic region. Various factors are responsible for the archipelago's biogeographical isolation and high endemism rate: the lack of neighbouring islands within 500 km, long distance to the mainland, the cool Humboldt Current flowing northward parallel to the South American continent, and the mainly southerly to westerly winds. Because of the considerable island elevations above sea level, alpine vegetation is found as well. The islands belong to the few places in the Pacific (Galápagos Islands, Revillagigedo Archipelago) that remained untouched by humans until the discovery by European sailors post-Columbus; the Polynesians did not reach further than Easter Island and the Native Americans stayed on and near the South American mainland.

Compared to may others, the Juan Fernández Archipelago is characterised by a high number and proportion of endemic plants: Sohmer (pers. comm. to Stuessy, 1992) states that its number of endemic plant species per area unit is the highest of all oceanic island systems. The flora contains at least 127 endemic species, eleven endemic genera and one endemic family (Stuessy, 1992). Most of them show relations to southern South America (about 80 % of the vascular flora). Some 10 % have their origin in the western Pacific (e.g. New Zealand, Australia), 7 % have immigrated from the Neotropic, and about 3 % originate from more distant regions (Stuessy, 1992). The diaspores were probably primarily transported to the islands by birds; since 1574 a variety of additional species has been introduced by man from different geographical regions (Skottsberg, 1928, 1953, Stuessy, 1992).

Data collection and evaluation

Four field campaigns were undertaken from 1992 to 2002 (Hahn *et al*., 2005). Data collection based on optical and acoustic identification of birds. All available and relevant data sources are given in the list of references. Systematic classification follows Dickinson (2003) and Jaramillo (2003). The biogeographical association of recorded bird species according to their distribution areas and/or regions of origin is conformed to two groups. Seabirds are classified according to climate zone and ocean. For freshwater-/landbirds the terrestrial system of biogeographical realms can be applied (Müller, 1973, 1977). The latter includes transition zones, like the Austral subdivision of southern South America, being positioned between the Neotropical and the Archinotical realms. The term freshwater bird is used for limnocolous species (rails, lapwings, egrets, geese, grebes etc.).

Results

A total of 55 bird species have been recorded on the Juan Fernández Archipelago and its surrounding waters, of which 17 are considered to be regular breeders (Table 1). Thus more than two thirds of the recorded species are non-breeders. Most species belong to seabirds (31), the rest to landbirds (16); freshwater birds (8) were also observed on the archipelago, but all were non-breeding visitors. Among the current breeding avifauna, landbird species (11) are more numerous than seabird species (6). Most species records come from Robinson Crusoe (38), followed by Alejandro Selkirk (24) and small Santa Clara (8). Seven bird species regularly breed on Alejandro Selkirk, eleven on Robinson Crusoe, and seven on Santa Clara.

Of the six breeding seabird species three are found on Alejandro Selkirk, and two of them are endemic breeders of this island only. The same four species breed on Robinson Crusoe and Santa Clara. These latter ones can be classified as endemic to the south-eastern Pacific of Chile, as they also breed on Mocha, Desventuradas and/or Easter Island but nowhere else. One species, the White-bellied Storm-Petrel *Fregetta grallaria segethi* Vieillot, is probably the only seabird species breeding on all three Juan Fernández islands. Definite breeding records exist for Santa Clara only, but repeated sightings in the waters around the two major islands provide evidence of breeding there also (its cliff nest sites are difficult to reach; see Murphy, 1936, Brooke, 1987a).

With the extinction of the introduced California Quail *Callipepla californica* Shaw the number of breeding landbirds dropped down to eleven. At present eight of them breed on Robinson Crusoe, four on Alejandro Selkirk, and three on Santa Clara. All three from Santa Clara are found as well on neighbouring Robinson Crusoe, but not on the more distant Alejandro Selkirk. Only one landbird species, the Austral Thrush *Turdus falcklandii magellanicus* King, breeds on Robinson Crusoe as well as on Alejandro Selkirk. All other landbird species occur on one of the two mayor islands only, although some (*Falco sparverius fernandensis* Chapman, *Buteo polyosoma exsul* Salvin, *Sephanoides sephaniodes* Lesson & Garnot, *Cinclodes oustaleti baeckstroemii* Lönnberg) have been observed as single individuals or in small numbers at the respective other island. However, they were not able to establish a permanent population (if they bred at all) and disappeared again soon.

Two other introduced bird species persist on the islands: feral Rock Doves *Columba livia* f. *domestica* Gmelin are nowadays restricted to Robinson Crusoe and Santa Clara. Previously there was a population on Alejandro Selkirk too (Martin, 1909), but in 1917 Bäckström (Lönnberg, 1921) could not find them any more. House Sparrows *Passer domesticus* Linnaeus were also introduced to Robinson Crusoe in 1943. In 1983 they had reached Alejandro Selkirk (Bourne, 1983), but became extinct again in 1994 (Hahn *et al*., 2005). Today they are limited to the settlement San Juan Bautista of Robinson Crusoe. These two species have also been introduced to Easter Island (Fig. 1b). Thus, the latter's avifaunal similarity to Juan Fernández is entirely based on introductions. By contrast, the similarity to the landbird faunas of the islands Mocha and Chiloe (both 19 %) is largely a result of native bird distribution. The similarity of the landbird fauna

Tab. 1. Bird taxa recorded from the Juan Fernández Archipelago and its surrounding waters.

		Biogeo.	Island records				Inform.
Scientific name	**Common name**	**category**	**RC**	**SC**	**AS**	**JF**	**source**
Rollandia rolland	White-tufted Grebe	NT	b w				2
Diomedea exulans	Wandering Albatross	sAnt cp	w				5
Thalassarche bulleri	Buller's Albatross	sAnt Pac	w		w		2,5
Thalassarche cauta	White-capped Albatross	sAnt cp	w				5
Thalassarche melanophris	Black-browed Albatross	sAnt cp	w		w		2,5,6
Macronectes giganteus	Southern Giant Petrel	sAnt cp			w	x	1,3,5
Fulmarus glacialoides	Southern Fulmar	sAnt cp				x	3,5,6
Daption capense	Cape Petrel	sAnt cp	w		w	x	1,2,5,6
Pterodroma defilippiana	**Másatierra Petrel**	sTem Pac	wb c	wb c			1,3,5,6
Pterodroma longirostris	**Stejneger's Petrel**	sTem Pac			u so		1,3,5,6
Pterodroma externa	**Juan Fernández Petrel**	sTem Pac			um so		1,3,5,6
Pterodroma neglecta juana	**Imber's Petrel**	sTem Pac	wb c	wb c			1,3,5,6
Puffinus creatopus	**Pink-footed Shearwater**	sTem seP	wb co	wb co			1,3,5,6
Puffinus carneipes	Flesh-footed Shearwater	sTem cp				x	3
Puffinus griseus	Sooty Shearwater	sTem Pac	w				5
Procellaria aequinoctialis	White-chinned Petrel	sAnt cp	w				5
Procellaria cinerea	Brown Petrel	sAnt cp	w				5
Pelagodroma marina	White-faced Storm-Petrel	sAnt cp			w		8
Fregetta grallaria segethi	**White-bellied Storm-Petrel**	sTem cp	w	wb o	w	x	1,3,5,6
Spheniscus humboldti	Humboldt Penguin	sTem seP	w				4,5
Spheniscus magellanicus	Magellanic Penguin	sAnt seP				x	3,5
Pygoscelis papua	Gentoo Penguin	sAnt cp			w		2
Phaethon rubricauda	Red-tailed Tropicbird	S/T cp	w		w		5
Phaethon lepturus	White-tailed Tropicbird	S/T cp	w		w		5
Sula dactylatra	Masked Booby	S/T cp	w	w			1
Phalacrocorax bougainvillii	Guanay Cormorant	NT	w				5
Bubulcus ibis	Cattle Egret	O-W	b o		b o		1,2
Cygnus melancoryhus	Black-necked Swan	NT	w		w		2,3
Chloephaga picta	Upland Goose	sSA	c o				7
Cathartes aura	Turkey Vulture	NT/NA	b o				5
Buteo polyosoma exsul	**Másafuera Hawk**	NT	bm os		b-a os		1,3,5,6
Falco sparverius fernandensis	**Juan Fernández Kestrel**	NT/NA	bm co	bm o			1,3,5,6
Falco peregrinus tundrius	Peregrine Falcon	Cos	bm co		bm o		3,5
Callipepla californica	California Quail	NA	b os †		b os †		2,3,5
Pardirallus maculatus	Spotted Rail	NT	b x				3
Fulica armillata	Red-gartered Coot	sSA			b x		2
Fulica rufifrons	Red-fronted Coot	NT	b x		b x		2,3
Vanellus chilensis chilensis	Southern Lapwing	NT	b o		b o		2,3,5
Haematopus ater	Blackish Oystercatcher	sTem Pac	wb o				5
Phalaropus fulicaria	Red Phalarope	sArc cp				x	3,5
Stercorarius longicaudus	Long-tailed Jaeger	sArc cp	w			w	3,5
Sterna paradisaea	Arctic Tern	sArc cp				w	1,3,5
Sterna fuscata	Sooty Tern	S/T cp				w	3
Procelsterna cerulea	Grey Noddy	S/T Pac	w			w	3,5
Columba livia* f. *domestica	**Rock Dove**	O-W	b co	b co	b co†		1,3,5
Asio flammeus suinda	**Short-eared Owl**	Cos	bm os	bm co			1,3,5,6
Sephanoides sephaniodes	**Green-backed Firecrown**	sSA	bm sf		bm sf		1,3,5,6
Sephanoides fernandensis	**Juan Fernández Firecrown**	sSA	bm sf				1,3,5,6
Cinclodes oustaleti baeckstroemii	**Másafuera Cinclodes**	sSA			b-a o		1,3,5,6
Aphrastura masafuerae	**Másafuera Rayadito**	sSA			ua sf		1,3,5,6
Anairetes fernandezianus	**Juan Fernández Tit-Tyrant**	NT	bm sf				1,3,5,6
Turdus falcklandii magellanicus	**Austral Thrush**	sSA	bm sf		b-a sf		1,3,5,6
Curaeus curaeus	Austral Blackbird	sSA	b osf		b os		2,5
Zonotrichia capensis	Rufous-collared Sparrow	NT	b os				2
Passer domesticus	**House Sparrow**	O-W	b os		b os†		1,3,5,6
Sum of recorded bird taxa		**55**	**41**	**8**	**26**	**11**	

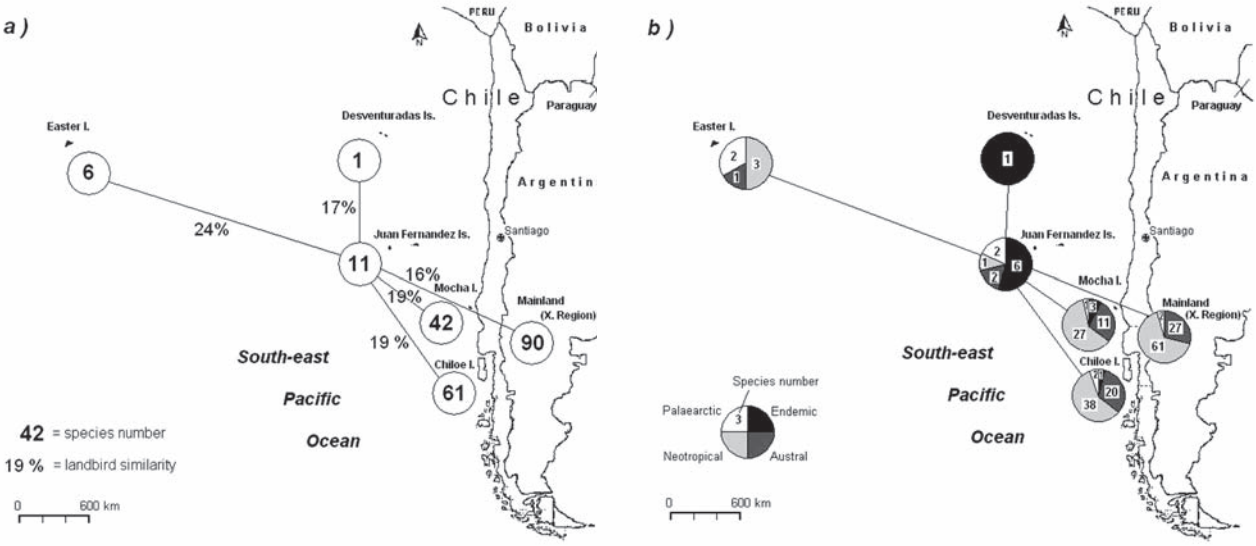

Fig. 1. Biogeographical data of the avifauna of the Juan Fernández Archipelago and its next related regions in the Southeast-Pacific; **a**) species number and similarity (% = Sørensen quotient) of breeding landbirds on species level; **b**) biogeographical origin and endemism of breeding landbirds on subspecies level. Data = Easter and Desventuradas Is.: SCHLATTER (1987), Juan Fernandez and Mocha Is.: own field data 1992-2003; Chiloe I. and (Valdivian and Patagonian forest area of the) X. Region de los Lagos: evaluated from Jaramillo (2003).

of Juan Fernández to the Chilean mainland is little less (16 %) than to the mentioned coastal islands. The similarity of the landbird fauna to Mediterranean Chile or more distant regions of the Neotropic is even less. This confers a high isolation of the Avifauna fernandeziana, and supports the archipelago's status as a separate biogeographical province.

The pre-human endemism of the avifauna is likely to have been even higher, not only because of the recent introductions but also because of a possible case of extinction. The taxonomic status and previous existence of another hummingbird taxon is uncertain. After KING (1831) had described the Juan Fernández Firecrown *Sephanoides fernandensis* from Robinson Crusoe, GOULD (1870) described a similar one from Alejandro Selkirk (comp. also COLWELL, 1989). This was classified later as the subspecies *Sephanoides fernandensis leyboldi* (GOULD, 1870). Since Gould had not collected it by himself, he described it on the basis of information and specimens from LEYBOLD. However, it is unclear if LEYBOLD had actually been on the island and if he was the original collector. Besides this, female differences between the uncertain taxon *leyboldi* to *fernandensis* are small (and the characters vary within *fernandensis*). JOHOW (2003) presented reasonable doubts on the correctness and previous existence of this taxon based on unpublished material from his great-grandfather, one of the first natural scientists visiting the archipelago in the late 19th century who had not reported a single specimen during his field work (JOHOW, 1896).

A total of 14 bird orders and 29 families are represented by all species recorded (Table 1 & Fig. 2). With respect to the regular breeding species, only six of these orders (43 %) and eleven families (38 %) are present. Most frequent are the Procellariiformes within the avifauna, with 33 % of all recorded and 35 % of the breeding species. Second are the Passeriformes with 13 % of all recorded and 29 % of the breeding species.

Biogeographical categories describe the principal origin and present breeding distribution range. For island endemics distributional information of the most closely related species is given. Seabirds (code left): **sAnt** = sub-Antarctic, **sTem** = southern Temperate, **S/T** = Subtropical and/or Tropical, **sArc** = sub-Arctic; (code right): **seP** = south-eastern Pacific / southern South America only, **Pac** = Pacific more widespread, **cp** = circum-polar / throughout all oceans. Land- and freshwater birds (code for core distribution): **sSA** = southern South American / Austral distribution only within the Neotropical realm, **NT** = Neotropical more widespread, **NA** = Neoarctic, **O-W** = Old-World, **Cos** = Cosmopolitan / worldwide. Island records: **RC** = Robinson Crusoe, **SC** = Santa Clara, **AS** = Alejandro Selkirk, **JF** = Juan Fernández Archipelago (source without details to island). Altitude level (code left): **w** = waters/sea-level, **b** = basal (0–300m), **m** = montane (300–800m), **u** = sub-alpine (800–1100m), **a** = alpine (1100–1340m). Habitat type (code right): **c** = cliffs and rock boulders along the shore, **o** = open terrain and grassland, s = shrub-like vegetation (layer height 0.5–3m), **f** = forest-like vegetation (layer height > 3m), **x** = record without data, † = extinct. Information sources are: **1** = own observations (1992–2002), **2** = SCHILLER & ARAYA (CONAF; pers. comm. 1995 & 2002), **3** = ARAYA *et al*. (1992), **4** = MEZA (1988), **5** = SCHLATTER (1987), **6** = BROOKE (1987a), **7** = GUICKING & FIEDLER (2000), **8** = JOHOW (2000). Bold typing indicates present breeding birds.

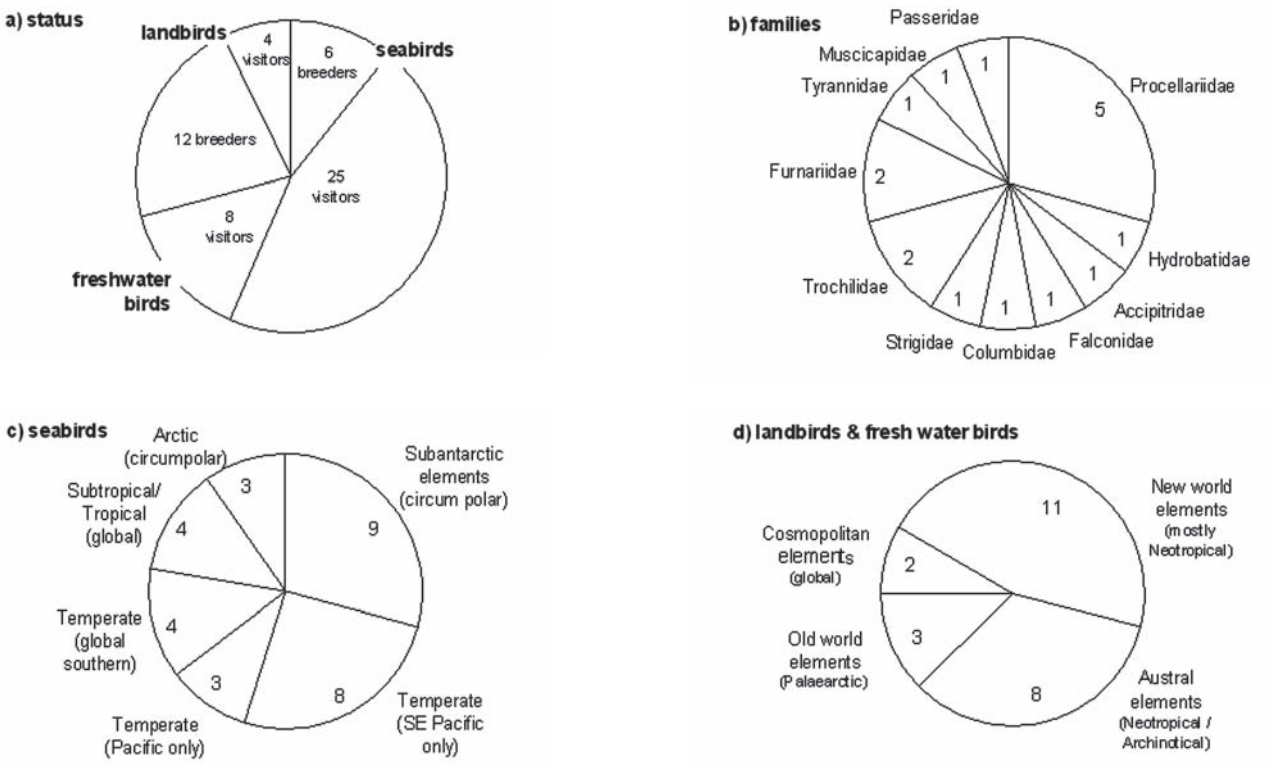

Fig. 2. Status, family affiliation, and biogeographical distribution of the Avifauna fernandeziana; **a**) Breeders and visitors among the landbird, freshwater bird, and seabird fauna. The formerly introduced (and here included) *Callipepla californica* has become extinct; **b**) current breeding species according to family affiliation; **c**) recorded seabird species according to their biogeographical distribution range; **d**) recorded freshwater - and landbird species according to their biogeographical distribution range.

Charadriiformes also make up 13 % of the overall avifauna but 0% of the breeding avifauna.

The mean number of all bird taxa by taxonomic category is 1.3 species per genus, 2.0 genera per family, and 1.7 families per order. Among all recorded species, two typical southern hemisphere seabird families are present (Diomedeidae, Spheniscidae) and five New World landbird families (Cathartidae, Trochilidae, Furnariidae, Tyrannidae, Icteridae). Thus 15 species (27 %) of the avifauna are represented by members of families that are limited to the most closely related biogeographical regions, the Archinotical and Neotropical realms.

Looking at the climate zone of all recorded seabird species (Fig. 2c), analyses of their areal systems show that nine (29 %) have a circumpolar Subantarctic distribution range. Fifteen taxa (48 %) have a temperate range, of which eight (26 %) have an exclusive distribution in the south-eastern Pacific, three (10 %) have a wider Pacific and four (13 %) a global southern temperate distribution. Another four taxa (13 %) have a global tropical/subtropical range and three (10 %) have a circumpolar Arctic one. Looking at the biogeographical origins of all recorded freshwater-/landbirds (Fig. 2d), eleven taxa (46 %) are New World elements (mostly Neotropic). Eight taxa (33 %) also belong to the Neotropical realm, but can be further classified as Austral elements (transition zone to Archinotical realm in southern South America). Three taxa (13 %) are Old World elements (Palaearctic) and two (8 %) have a nearly cosmopolitan distribution range.

Altogether, a clear dominance of elements from the Subantarctic/temperate climate zone (seabirds) and from the Austral/Neotropical biogeographical region (freshwater-landbirds) is detected. These categories (comp. Fig. 2d-e) are represented by 36 species or 65 % of the overall avifauna. The remaining 19 species belong to six other, geographically more distant categories.

Recently it has been shown that not only ecological factors (like habitat, reproduction, competition, predation etc.) but also geographical factors can provide essential information on the conservation value and need of a given taxon. WALTER's (2004) six eigenplace index parameters (history, area, dispersion, vagility, isolation, and location reliance) represent an integrative methodological approach. The 17 breeding bird species are investigated according to their eigenplace values, and are ranked in four conservation classes (Table 2).

The lowest conservation class (I) is represented by species with Old World origin and widespread distribution range. *Columba livia* and *Passer domesticus* have been introduced as alien invaders from the

Tab. 2. Geographical conservation status of the Juan Fernández breeding birds.

Eigenplace parameters	History	Area	Dispersion	Vagility	Isolation	Location	Sum	Cons. class
Bird taxon	**H**	**A**	**D**	**V**	**I**	**L**		
Columba livia f. *domestica*	1	1	3	1	1	2	**9**	I
Passer domesticus	1	1	3	**1**	1	2	9	
Asio flammeus suinda	2	2	3	2	1	2	12	
Sephanoides sephaniodes	4	**3**	1	3	2	3	16	II
Turdus falcklandii magellanicus	4	3	1	3	2	3	16	
Pterodroma externa	**5**	**5**	**1**	1	**5**	**5**	**22**	III
Pterodroma longirostris	**5**	**5**	**2**	**1**	**5**	**5**	**23**	
Puffinus creatopus	5	5	3	**1**	5	4	23	
Pterodroma defilippiana	5	5	4	1	5	4	**24**	
Pterodroma neglecta juana	**5**	5	4	1	5	4	24	
Fregetta grallaria segethi	5	**5**	4	1	5	4	24	
Buteo polyosoma exsul	**5**	**5**	**2**	**4**	**5**	**5**	**26**	IV
Falco sparverius fernandensis	**5**	**5**	**3**	**4**	**5**	**4**	**26**	
Anairetes fernandezianus	5	**5**	**2**	**4**	**5**	**5**	**26**	
Cinclodes oustaleti baeckstroemii	**5**	**5**	**3**	**4**	**5**	**5**	**27**	
Sephanoides fernandensis	**5**	**5**	**4**	4	**5**	**5**	**28**	
Aphrastura masafuerae	**5**	**5**	**5**	**4**	**5**	**5**	**29**	

Taxa are analysed in regard to their conservation status basing on six geographical parameters (for methodological details see eigenplace index after Walter 2004). These are: **H** = History, **A** = Area, **D** = Dispersion, **V** = Vagility, **I** = Isolation, **L** = Location reliance. For each taxon and parameter a minimum score of 1 to a maximum of 5 is given, and therefore the sum ranges from 6 to 30. Four score classes are distinguished (Latin numbers): **I** = 6–12, **II** = 13–18, **III** = 19–24, **IV** = 25–30. Bold typing indicates taxa being endemic to the archipelago.

Palaearctic. These species have reached an enormous dispersion potential and a global distribution through their adaptation to human settlements and activities. *Asio flammeus* Vieillot has a wide distribution in the entire Holarctic and in parts of the Neotropic. The second class (II) contains two species which have a limited Austral distribution range, but where they are equally and densely present. *Sephanoides sephaniodes* and *Turdus falcklandii* have probably immigrated on their own after habitat conditions had changed on the islands as a consequence of human activity. The third class (III), indicating high conservation importance, is composed of the six native seabird species. The two endemic *Pterodroma* species that exclusively breed on Alejandro Selkirk are ranked lower than the four remaining ones breeding on Robinson Crusoe and Santa Clara, although the latter have additional breeding populations on some other islands. The reason for this is a difference in dispersion/population patterns (Brooke, 1987b, Hodum & Wainstein, 2003). The highest conservation class (IV) consists of all six endemic landbird taxa. *Sephanoides fernandensis* of Robinson Crusoe and *Aphrastura masafuerae* Philippi & Landbeck of Alejandro Selkirk have the highest scores. They also differ from the other four species by being dispersed unevenly and extremely rare overall.

Discussion

The avifauna of the Juan Fernández Archipelago is represented by a relatively small number of bird species. Seabirds are more frequent than landbirds, probably because most seabirds have large foraging, wandering and dispersal areas, and the Juan Fernández waters are extremely rich in fish and other marine food sources (Schlatter, 1984, Ojeda & Avilés, 1987). Among the breeding avifauna, however, landbird species are more numerous than seabirds. The low number of landbird visitors can be explained by the isolated geographical position away from the mainland and off the usual migration routes. The northward flowing Humboldt Current and the oceanic south-westerly winds seem to be further geographical reasons limiting landbird dispersal from mainland Chile through anemochore and hydrochore processes (Hajek & Espinoza, 1987). Freshwater birds were recorded as visitors in higher numbers than landbirds, but lack any breeding records. This may be due to the absence of lakes or lagoons, poor food sources in creeks, and high predation risk by raptors. Regardless of the sparse ornithological record for the islands in general, the low observation frequency of visiting freshwater-/landbirds stands out; many of the species have been recorded only once. Thus,

Fig. 3. The Masafuera Rayadito, *Aphrastura masafuerae,* is Chile's most threatened bird species, both according to population size as well as to geographical range.

Fig. 4. Feral goats, *Capra aegagrus* f. *hircus*, have been introduced by Capitan Juan Fernandez shortly after the islands' discovery in the year 1580. They continue to destroy the natural vegetation and by that cause severe habitat loss for *Aphrastura masafuerae*.

Fig. 5. *Aphrastura masafuerae* is endemic to Alejandro Selkirk Island, where it is restricted to high altitude areas with intact ferns (1000 ha). About 140 individuals survive in these *Dicksonia* and *Lophosoria* stands.

Fig. 6. The Juan Fernandez Firecrown, *Sephanoides fernandensis*, is endemic to Robinson Crusoe Island. It may have vanished from Alejandro Selkirk. Its population size has declined during the last decade and is around 1000 individuals now.

the islands are not considered to be important stop-over locations for migrant freshwater species (PHILIPPI, 1950, ZIMMER, 1938).

The overall bird richness within the archipelago is clearly higher for Robinson Crusoe than for Alejandro Selkirk. This needs explanation since both islands

share a similar latitude, size, flora, and belong to the same phytogeographical province (Blake & Atwood, 1963, Morrone, 2000). This difference, expressed most clearly in the visiting seabirds, may partially be an artefact related to frequency of observer visits: many observers did not reach Alejandro Selkirk since the only permanent settlement is located on Robinson Crusoe which lies closer to the mainland. Nevertheless, these two islands differ in orography as well as geographical shape and more of the dispersing, migrating, or vagrant birds from South America will probably arrive on Robinson Crusoe. Skottsberg (1925) suggested lower immigration rates for Alejandro Selkirk and noted that accidental visitors rarely reached this island because of its remoteness. It is likely, however, that numerous birds visiting both major islands have not been documented in the past because of the low observation intensity. Therefore further species records are to be expected in the future.

The data situation of the resident avifauna is quite different: both islands have been surveyed intensively and in similar proportion, and no breeding appear to have been overlooked. The higher species number for Robinson Crusoe compared to Alejandro Selkirk seems to be related to two other factors: (1) human impact on Robinson Crusoe (introductions, habitat alteration) and (2) presence of the opportunistic and bird-hunting *Buteo polyosoma exsul* on Alejandro Selkirk. On Robinson Crusoe Island, the combination of human-modified and still undisturbed habitats provides a landscape for introduced as well as for native landbird species (Sax *et al*., 2000). Moreover, the higher frequency of ship passages to Robinson Crusoe from the mainland additionally means a potential for higher bird immigration rates, an important factor for establishing permanent colonisation status (MacArthur & Wilson, 1967). On Alejandro Selkirk, there is proof that the *Buteo* population has been a major factor in the extirpation of Rock Doves, House Sparrows, California Quails, and rabbits (Torres & Aguayo, 1971, Hahn *et al*., 2004). The behaviourally opportunistic *Buteo* may be able to eliminate a badly protected prey species, partly as it inhabits all habitat types of the island in relatively high abundance.

Interestingly the majority of breeding species does only inhabit one of the two major islands, although dispersing to the other island does not appear to be the critical factor: several specimens of *Buteo polyosoma exsul*, *Falco sparverius fernandensis*, *Asio flammeus suinda*, and *Cinclodes oustaleti baeckstroemii* were seen on the other major island (e.g. Torres, 1970, Brooke, 1987a), but have never been breeding there. Thus the number of breeders is not limited by immigration, but also by ecological island factors such as presence of suitable habitat, competition with resident species, and successful antagonistic strategies.

The relatively low ratio of Juan Fernández taxa belonging to the next higher taxonomic category (species per genus, genera per family, families per order) is suggested to be the result of isolation by distance, small area (and limited habitats), and increased competition for limited resources. It corresponds to the theoretical suggestions that closely related taxa tend to reduce each other and that one generalist of a (taxonomic or ecological) group tends to replace two or more specialists on islands (Lack, 1969, Diamond, 1974, Abbott, 1980). The resident landbirds provide excellent support for these hypotheses. (The taxonomically more closely related seabird species are mostly non-breeders; breeders among them are distinguishable by different feeding sources, waters, strategies, islands.) All six endemic landbird taxa originate from generalist species which are widely distributed (area and habitat range) on the Chilean mainland, not from specialists or continental restricted endemics. Especially the mainland sister species of endemics at the species level, *Aphrastura spinicauda* Gmelin, *Anairetes parulus* Kittlitz and *Sephanoides sephaniodes*, are among the most abundant bird species in southern Chile from the Valdivian to the Patagonian and Magellanic forests (Vuilleumier, 1985, Armesto *et al*., 1996, Jimenez, 2000).

The dominance of Subantarctic/temperate seabirds and Neotropical/Austral freshwater-/landbirds in the avifauna of the Juan Fernández Islands corresponds to the climatic conditions and the geographical position of the archipelago. It is an oceanic temperate wet climate with a relatively dry summer (Skottsberg 1953 applying Köppen's system) that is significantly colder than that of the Chilean coast at the same latitude (impact of the cold Humboldt Current). Therefore the avifauna resembles more to that of southern Chile around 40° S than to that of central Chile around 33° S.

Amongst the seabird fauna primarily taxa are found that have a wide distribution range covering all southern oceans, and secondarily those being restricted to the south-eastern Pacific (Tuck & Heinzel, 1980). The freshwater-/landbird fauna is characterised by comparatively few widespread elements, indicating the generally lower vagility of this group as well as the high insular isolation. The Austral/Neotropical elements are therefore the most numerous within the latter group, representing the closest biogeographical realm. Elements of the central or eastern Neotropic are entirely absent, possibly caused by difficulties in crossing the formidable barrier of the High Andes and then to survive the follow-up dispersal over the open sea (Müller, 1973, Fjeldså & Krabbe, 1990). Land-/freshwater birds of the distant Australian and/or Polynesian regions are absent as well (Mayr, 1945).

For the first time an areographic conservation ranking was assessed for all breeding birds of the Juan

Fernández Islands (Table 2). The natural distribution areas and island habitats are generally very limited on this small archipelago. The destruction of native habitat is particularly detrimental to the endemic taxa since their habitat preferences are more selective than those of non-endemics (HAHN *et al*., 2005, 2006). All of the endemic species are threatened today (restricted area and low abundance) and appear in the two highest conservation classes (III & IV). The lower conservation ranking of seabirds (all in class III) compared to landbirds (in class IV) may be related to habitat loss suffered by the latter. This is a more critical factor for landbirds since they depend on suitable habitat for feeding and breeding. Seabirds are independent of terrestrial foraging sites and may use any kind of suitable island surface or rock wall as nest site, regardless of habitat alteration (SCHLATTER, 1984, comp. also BROOKE, 1987b). Further threats for both groups seem to be the new invasive competitors and predators on the Juan Fernández Islands (see BOURNE *et al*., 1992, ROY *et al*., 1999, HAHN & RÖMER, 2002).

Juan Fernández Firecrown and Másafuera Rayadito possess a range which each is smaller than 15% of the archipelago area and have small population numbers. The Juan Fernandez Firecrown (total population around 1000 individuals) faced various threats during the past centuries: intensive collecting by humans, comprehensive habitat loss, competition by immigrated Green-backed Firecrown, and predation by introduced mammals (COLWELL, 1989; BOURNE, *et al*. 1992; ROY, *et al*. 1999). To our observations, the most critical factors (beneath general habitat loss) are disappearance of native hummingbird plants from the wild, plantation of small/low flowering plants in the settlement (even if native), and especially the domestic cat population in the settlement.

The Másafuera Rayadito has faced similar threats, and has to be classified as the most threatened bird species of the archipelago, now showing a population size being as low as 140 individuals. Habitat destruction, mainly through man-made fires and introduced goats *Capra aegagrus* f. *hircus* LINNAEUS, is valued as the most serious concern for its critical situation. During field work feral cats *Felis silvestris* f. *catus* LINNAEUS, Ship rats *Rattus rattus* LINNAEUS, Norway rats *Rattus norvegicus* BERKENHOUT, and House mice *Mus musculus* LINNAEUS were detected within its 1000 ha species range. These are likely to have a negative effect on adult rayaditos as well as broods. Conservation management for the Masafuera Rayadito must include the total eradication of introduced goats, cattle, cats, mice, and rats. More detailed studies of the breeding ecology are urgently needed, especially reproduction success is evident. On an archipelago level, priority should be put on the eradication of goats on Alejandro Selkirk, rabbits on Robinson Crusoe/Santa Clara, and cats in the settlement San Juan Bautista.

In spite of the recent species inventories and behavioural observations (HAHN & RÖMER, 2002, HAHN *et al*. 2004, HAHN *et al*. 2005, 2006) very little is known about the specific ecology of all endemic species. Such knowledge is urgently needed in order to further develop conservation policies and regulations for the preservation of this unique bird assemblage. Detailed ecological studies are needed for the six endemics of conservation class IV, especially *Aphrastura masafuerae*, the species most prone to extinction.

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