

Determinants of the diversity of plants, birds and mammals of coastal islands of the Humboldt current systems: implications for conservation

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Abstract Sound conservation plans for islands require understanding the processes underlying to the patterns of species richness and composition. Larger islands are often the targets of conservation assuming that the island area mainly determines species richness, and that species composition is nested across islands. However, in small-island these patterns could be altered because of stochastic processes, and species assemblages could be disharmonious. In addition, human impact could further modify the distribution pattern and diversity. Here we use the case of seven islands from the coastal system of Coquimbo as a model to address the role of environmental variables and human impacts on species richness and assembly rules of plants, birds, and mammals. We hypothesize (a) the existence of a small-island effect, and the prevalence of habitat diversity and anthropogenic impacts as main drivers of species richness, and (b) the existence of disharmonious assemblages, characterized by a low degree of nestedness and random patterns of species co-occurrence. Our results showed that (a) species richness is mainly correlated with habitat diversity, and only weakly related to island area supporting the ‘small-island effect’ and (b) species composition is highly structured, but that such structure may be the result of anthropogenic activities. Nestedness was observed in plants and landbirds, while co-occurrence patterns were only detected in plants. Assemblages in small-islands departed

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from the nestedness pattern and maintain rare species. Currently, only three of the seven islands are protected by national regulations, excluding the smaller ones that are subjected to human disturbance and invasive mammals. Our study suggests that it necessary to include all the islands in a major protected area to preserve both richness and species composition of a number of representative islands of the Humboldt current systems. We showed that conservation plans solely based on island area might not be robust.

Keywords Humboldt current · Conservation · Small-island effect · Island biogeography

Introduction

The theory of island biogeography predicts that species diversity is determined by extinction and colonization processes, which in turn depend on the island size and distance from the source (mainland), respectively (MacArthur and Wilson 1963; Whittaker et al. 2008). Although the theory emphasizes that the area of an island has a direct effect on species richness, indirect effects have also been identified (Barret et al. 2003; Borges 1999; Brown and Kodric-Brown 1977; Lomolino and Weiser 2001; Martin 1981). The importance of the area as predictor of island diversity has been discussed intensively and, recently more attention has been given to the so-called ‘small-island effect’ (Sfenthourakis and Triantis 2009; Dengler 2010; Qie et al. 2011; Spengler et al. 2011). In brief, the small-island effect predicts that below a certain threshold area diversity is independent of island size (Triantis et al. 2006). A variety of processes have been proposed to explain the small-island effect, including stochastic events, habitat diversity, isolation, disturbances, and human impact among others (Triantis et al. 2006, Burns et al. 2009, Spengler et al. 2011).

The species composition on islands can be governed by different assembly rules, revealed by departures from expectations of null models (Whittaker and Fernández-Palacios 2007). Competitive interactions can shape the structure of many species assemblages and therefore, species would present mutually exclusive distributions (Diamond 1975). In contrast, it has been found that several taxonomic groups exhibit non-random patterns of species composition, the so-called nestedness pattern, which occurs when impoverished islands hold mainly species that are also present on adjacent islands with higher species richness (Patterson and Atmar 1986). Nestedness is often used to infer the role of dispersal/extinction processes shaping species composition; for instance, the role of dispersal is inferred from differences in the degree of nestedness among taxa with different vagility (Chown et al. 1998, Spengler et al. 2011). However, all these patterns could be profoundly altered on small-islands, where the stochastic processes may be much more relevant than deterministic dispersal/extinction processes (Spengler et al. 2011). Hence, the species assemblages of small-islands could be markedly disharmonious, exhibiting a low degree of nestedness and/or species co-occurrence.

In the Coquimbo region of Chile (29°00′–32°10′S) there is a group of small coastal islands (<6 km², and <22 km from coast) (Fig. 1) that are under the influence of the Humboldt current system (HCS) (Thiel et al. 2007). The coastal system of Coquimbo (CSC) is constituent of the coastal marine ecosystems of the Humboldt current, an eco-region of interest for the conservation of biodiversity at a global scale (Olson and Dinerstein 1998). In the CSC there are two major upwelling centers that form high primary productivity centers, which permit the existence of a large number of seabirds and marine mammals (Thiel et al. 2007). The seven islands of the CSC support globally and regionally important seabird populations, some of which are endemics to the HCS (Hertel et al. 2005;

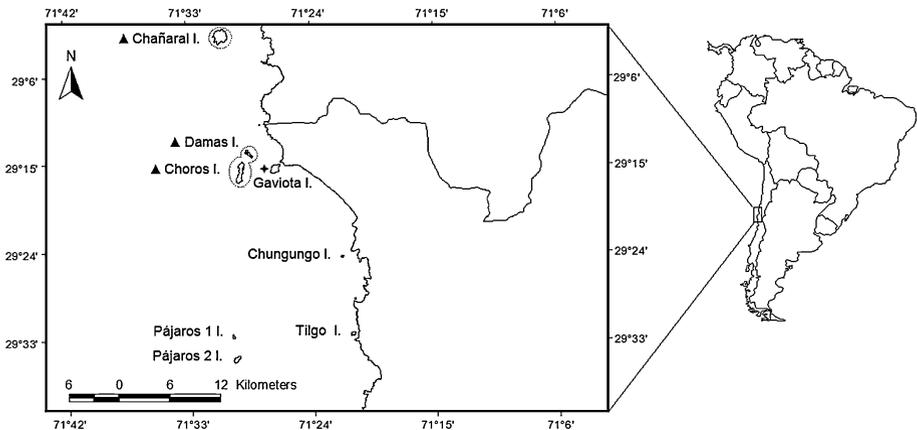


Fig. 1 Map of the studied islands in the coastal system of Coquimbo, Chile. Islands belonging to the Humboldt Penguin National Reserve are identified by *filled triangle*. *Dot lines* around the islands represent the approximated limits of Choros-Damas and Chañaral marine reserve. Gaviota island which was not included in our study is indicated by a *star*

Luna-Jorquera et al. 2003; Simeone et al. 2003; Weichler et al. 2004). Of the seven islands, only Chañaral, Damas, and Choros are legally protected by inclusion in the Humboldt Penguin National Reserve (CONAF 2009); the other islands remain unprotected despite the fact that they are important habitats to a valuable biodiversity (Hertel et al. 2005; Simeone et al. 2003). A high degree of endemism has been reported for the vegetation of the Coquimbo region, where a total of 140 species of endemic plants has been identified of 791 reported for Chile (Squeo et al. 2001). The islands from the national reserve also have a high concentration of endemic plants (Arancio and Lara 2007). On the other four islands several endemic plants have been reported (Hertel et al. 2005). The lack of legal protection, introduction of European rabbit and black rat, and anthropogenic disturbances are increasing the vulnerability of endemic plants and birds (Ellenberg et al. 2006; Fernández and Castilla 2005; Hertel et al. 2005; Simeone et al. 2003). Thus, this combination of small area, minimum isolation, and variable human impacts may mould distinctive patterns of species richness and composition.

Here we use the case of the islands from the CSC as a model system to address the role of environmental variables on the species richness and composition of indigenous plants, birds and mammals. In particular, we hypothesize:

- (a) the existence of a small-island effect, and the prevalence of habitat diversity and anthropogenic impacts as main drivers of species richness, and
- (b) the existence of disharmonious assemblages, characterized by a low degree of nestedness and random patterns of species co-occurrence.

Methods

Characterization of the islands

The CSC as referred here is located in central Chile, between Chañaral Island (29°03'S) and Punta Lengua de Vaca (30°17'S). The islands studied here are enclosed by two important

upwelling centers, which determine higher productivity and standing stocks nearshore decreasing off shores (Marin and Delgado 2007, Thiel et al. 2007). This system supports large colonies of endemic seabirds breeding on the islands and, is also used as foraging ground by a number of other seabirds species and marine mammals (Weichler et al. 2004).

We conducted an extensive review of the available literature, reports, and field notes to describe the environmental characteristics of seven islands belonging to the CSC (Appendix Table 4). We estimated the following environmental variables for each island: area (km²), isolation (km) (i.e., minimum distance from the mainland), habitat diversity, and the level of anthropogenic impact (see below). Area and isolation were obtained from diverse literature sources (Arancio and Lara 2007; CONAF 2009; Hertel et al. 2005; Simeone et al. 2003). The number of geomorphological unit per island was used as a coarse proxy of habitat diversity. Each island was surveyed to recognize the presence or absence of the following geomorphs: dune, plateau, plain, outcrops, cliffs, beaches, dry stream, rocks, and orographic chain. Previously, aerial-photogrammetric images were analyzed using the GIS software Arc View 3.2. In the field, each geomorphological structure was recognized and delimited with the help of a GPS.

The seven islands in the CSC are distributed in a latitudinal gradient of about 62.84 km; three of the islands vary in size from 1.24 (Pájaros 1) to 5.16 (Chañaral) km² and the remaining four islands range from 0.15 (Chungungo) to 0.56 (Damas) km². Two islands are 20.6 and 21.4 km distant from mainland (Pájaros 1 and 2) while the others are within a range of 0.2–6.3 km (see Appendix Table 4). The number of geomorphologic units represented on each island varied from 1 to 6 (see Appendix Table 4). Certain geomorphs were present only in some islands, for example, plateau in Chañaral, plain in Choros, and dune in Damas. In Pájaros 2 island only outcrops was recognized. In general, Chañaral Island showed the highest number of geomorphologic units (6) and the largest size (5.16 km²). Gaviota island (Fig. 1) was not included in our study due to its degraded status. This island is open to the public without any restrictions, being used in a variety of ways, including campsites for tourists and fishermen and sometimes even as foraging ground for goats. At times fishermen disembark on the island accompanied by dogs and cats. Probably, as a consequence of all these factors, at present neither seabirds nor native mammals breed on Gaviota Island.

We classified islands according the level of anthropogenic impacts, using seven binary criteria: current harvesting on bird eggs, past harvesting on bird eggs, record of past local extinctions, presence of exotic plants, presence of exotic animals, unregulated tourism activities, presence of fishermen, and conservation status (i.e., marine reserve/non-marine reserve). There are no permanent human settlements on the islands, so we could not use the total human population as a proxy of the anthropogenic impacts (Chown et al. 1998; McMaster 2005). All this information was compiled from an exhaustive literature search and field observations collected during more than a decade of surveys on the islands. The presence-absence matrix of impacts was used to build a similarity dendrogram (Euclidian distance), with node consistence evaluated using 10,000 bootstrapped values. The classification analysis yielded two groups of islands with different levels of anthropogenic impact (Fig. 2). The first group included the islands Chungungo, Tilgo, and Pájaros 1, with high levels of human impact. The second group included the rest of the islands, and could be considered as low-mid impacted by anthropogenic activities.

Diversity of plants, birds, and mammals

We obtained information of the species richness of vascular plants, mammals, and birds recorded for on the islands. Only non-exotic species were considered for further analyzes.

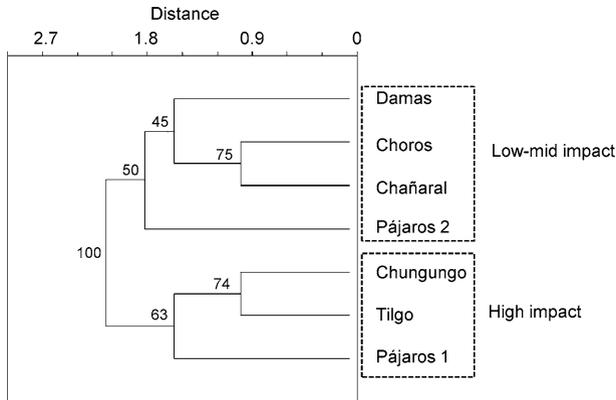


Fig. 2 Classification of islands according to different levels of anthropogenic impacts, based on a cluster analysis. The numbers show the consistency of nodes based on 10,000 bootstrapped values

Data for vegetation were collected from field reports and lists of plant species on the islands (Arancio and Lara 2007; Hertel et al. 2005; Squeo et al. 2001). Information about the presence of birds (both seabirds and landbirds) and mammals comes from our field records taken at several excursions conducted over 11 years (1999–2010). During this period we regularly surveyed the islands to monitor populations of seabirds and record the presence of terrestrial birds. The data set was complemented from published papers and technical reports of government services (Arancio and Lara 2007; CONAF 2009; CONAMA and SERNAPESCA CONAMA 2009; Hertel et al. 2005; Simeone et al. 2003; Vilina et al. 1994). The species list used in this study including plants, birds, and mammals is the present day diversity and the most complete that have been assembled so far. In the case of seabirds, we have recorded the calls from an unidentified small petrel arriving on Choros Island during the night, and thus it is not included in our inventories.

Statistical analysis

Species diversity

The relationship between species richness and the four environmental variables measured was analyzed using generalized linear models (GLM), after a \log_{10} transformation of richness, area, and isolation, and assuming a Gaussian error structure. The maximum complexity of the models was limited by the low number of islands, so we only considered additive models up to a second-order. All possible models (11) were explored using the library *glmulti* in R. Best models were selected according to the weighted values of the Akaike information criterion (AIC). The coefficients associated to each variable and its relative importance was assessed using through a multi-model average. Analyzes were repeated for plants and birds by separated. Because mammals were absent from two islands, separate analyzes were not carried out on this taxon.

Species composition

We evaluated the role of different environmental variables explaining differences in species composition among islands (for all species combined and for plants and birds by

separate). This was carried out using a permutational analysis of variance (PERMANOVA) based on the Jaccard index of similarity and 10,000 runs. Analyzes were performed using the routine *adonis* in the library *Vegan* in R. The results were visualized using a non-metric multidimensional scaling (nMDS). We also evaluated the degree of nestedness and species co-occurrence. Nestedness pattern refers to the tendency of species-depauperated sites to being random subsets of richer sites. Nestedness analysis was evaluated using the recently proposed nestedness metric based on overlap and decreasing fill (NODF) (Almeida-Neto et al. 2008; Ulrich et al. 2009). Among the different nestedness indices proposed in the literature, NODF is the most robust, and less prone to type I and II statistic errors (Ulrich et al. 2009; Ulrich and Gotelli 2007b). Species co-occurrence was measured as the mean C-score metric (Ulrich and Gotelli 2007a). The observed values of NODF and C-score were contrasted against 10,000 values obtained in random matrices built by retaining the same number of presences for sites and species, using the swap algorithm. All analyzes were carried out using the routine *oecosimu* in the library *Vegan* in R. Analyzes were repeated for plants and birds by separated.

Results

A total of 127 non-exotic species of plants, birds, and mammals were recorded on the seven islands studied. The total species richness varied from 5 to 68 species across islands (Appendix Table 5). The most diverse island is Damas with 68 species including land and seabirds, mammals and plants; and the less diverse is Pájaros 2 Island, which harbors only seabirds. Plants were the most diverse group (61 species), followed by birds (58 species) and mammals (8 species). No islands contain island endemic species. We also recorded ten exotic species that were not included in further analysis (Appendix Table 5).

In general, species richness varied positively with island area and habitat diversity and human impact, and negatively with isolation (Table 1). The most important variable explaining species richness variability across island was habitat diversity (Fig. 3), according to the multi-model average, with a relative importance of 0.68 for all species combined and 0.61 for plants only (Table 1). For birds and mammals, the relative importance was lower (0.32–0.21, respectively), but other variables received much less support (<0.07). In all cases, best models included only the habitat diversity as the best predictor of richness.

Species composition was highly variable across islands (Jaccard's index, mean similarity = 0.42). For all species combined, the PERMANOVA showed that level of anthropogenic impact was the only significant variable explaining the variation in species composition ($r^2 = 0.24$, $P = 0.04$, Table 2). The difference in composition according the level of anthropogenic impact was evident by the existence of two separate clusters islands in the nMDS analysis (Fig. 4). Similar results were found for plants (Table 2), but not for birds, in which case no variable was significant. The NODF analysis showed that assemblages were significantly nested (z -value = -7.007 , $P < 0.001$), but there were large differences among taxa (Table 3); nestedness was significant only for plants. Similarly, the mean C-score was higher than expected by chance for all species and plants ($P < 0.001$ in both cases, Table 3), but for birds the level of co-occurrence was not different than expected by the null model (Table 3).

Discussion

This study synthesizes all the relevant existing information about the diversity of plants, birds, and mammals of islands belonging to the CSC. Our results showed that

Table 1 Summary of the generalized linear models (GLM) for the relationship between species richness and different environmental variables across islands

	Best model			Multi-model average		
	Model	AIC _c	AIC _w	Variable	Coefficient	Importance
All species	Intercept + habitat diversity	23.23	0.67	Anthropogenic impact	0.0002	0.01
	Intercept	24.94	0.29	Area	0.0051	0.02
	Area	30.60	0.02	Isolation	−0.0036	0.02
				Habitat diversity	0.3131	0.68
Plants	Intercept	2.4555	1.00	Intercept	2.4555	1.00
	Intercept + habitat diversity	28.54	0.59	Anthropogenic impact	−0.0043	0.01
	Intercept	29.64	0.34	Area	0.0069	0.02
	Intercept + isolation + habitat diversity	35.11	0.03	Isolation	−0.0139	0.04
				Habitat diversity	0.3903	0.61
Intercept	1.1080	1.00	Intercept	1.1080	1.00	
Birds	Intercept	20.44	0.60	Anthropogenic impact	0.0042	0.02
	Intercept + habitat diversity	21.70	0.32	Area	−0.0023	0.02
	Intercept + area	26.26	0.03	Isolation	0.0073	0.03
				Habitat diversity	0.0960	0.32
				Intercept	2.7351	1.00

Only the three models with the lowest AIC_c are showed. The relative importance of each variable and the estimated coefficients were estimated across all fitted models (11) using a multi-model average approach. Mammals were also included in the combined analysis with all species

- species richness is mainly correlated with habitat diversity, and only weakly related to island area supporting the ‘small-island effect’ and
- species composition is highly structured, but that such structure may be the result of anthropogenic activities.

These results highlight the importance of combining analyzes of insular biogeography and patterns of species distribution for conservation purposes.

Species richness

Habitat diversity was the best predictor to explain the species richness on islands, in agreement with the assumption that more diverse habitats support a more diverse biota (Williams 1964). This was consistent with the results of several studies showing that habitat diversity can be a better predictor for species richness than area or isolation (Abbott 1974; Power 1972, 1976; Reed 1981; Ricklefs and Lovette 1999). The lack of a significant relationship between richness and island area has been reported by previous studies (Gentile and Argano 2005; Kelly et al. 1989; Losos 1986; Power 1972) and it could be explained by the so-called ‘small-island effect’ (Lomolino and Weiser 2001): indeed, five out of the seven islands existing in the CSC are below the smallest area of ca. 1 km², suggested as the minimum to explain richness of species as a function of island size (Lomolino and Weiser 2001). The diversity in smaller islands could be maintained by subsidies from outside the system (i.e., mainland) (Barret et al. 2003), a likely possibility

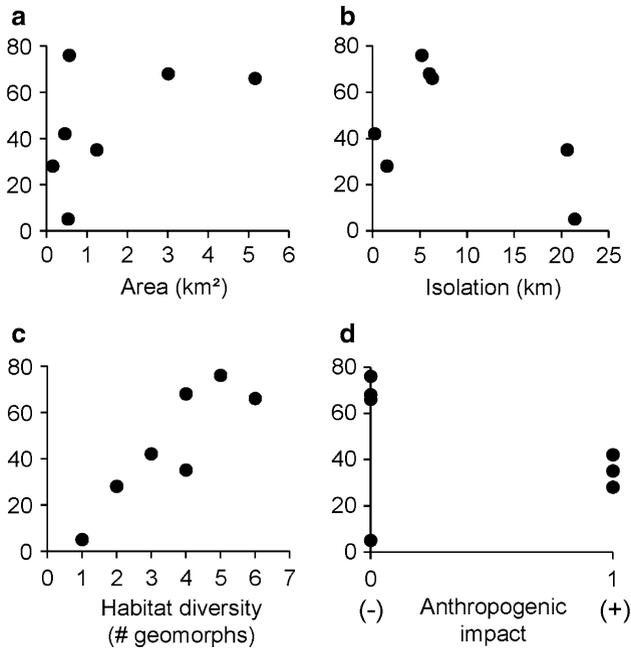


Fig. 3 Relationship between species richness and **a** area, **b** isolation (distance from the coast), **c** habitat diversity (number of geomorphs), and **d** anthropogenic human impact. See *text* for details

given the close proximity of islands from mainland. However, the relationship between isolation (i.e., distance from the coast) and species richness, although negative, was non-significant.

Notably, human impacts had a no significant effect on species richness. Previous studies on oceanic islands have reported a positive, although taxa-dependent, relationship between species richness, and human population on islands (Chown et al. 1998). The same positive relationship between species richness and human population was found for vascular plants of Eastern north America (McMaster 2005). The existence of such a positive relationship has been attributed to the effect of species invasions may compensate the extinctions on islands (Hall 2010; Sax and Gaines 2008). However there are only one species locally extinct from the islands (Peruvian diving-petrel from Chañaral; Araya and Duffy 1987), and there are only ten exotic species described for the islands. Indeed, the percentage of exotic forms varied between 0 and 8% across islands. In addition, the number of exotic species is strongly related to the number of native species ($r = 0.91$, $n = 7$, $P = 0.002$) and habitat diversity ($r = 0.94$, $n = 7$, $P = 0.004$), suggesting that the success colonization of invading species may be also controlled by the same environmental factors determining the richness of native species.

Species composition and assembly rules

Unlike species richness patterns, variation in species composition among islands was weakly related to environmental variables. The only significant variable was the level of anthropogenic impact, although the larger number of plants drove this effect on the islands. Human impacts on species composition on islands have been often associated to the

Table 2 Summary of the permutational analysis of variance (*PERMANOVA*, 10,000 runs) of species composition (based on Jaccard’s similarity index) according different environmental characteristics of the studied islands

Taxa	Factors	MSS	F-value	r ²	P-value
All species	Anthropogenic impact	0.295	2.649	0.239	0.047
	Area	0.189	1.697	0.153	0.153
	Isolation	0.243	2.184	0.197	0.128
	Habitat diversity	0.285	2.554	0.230	0.079
	Residuals	0.111		0.180	
Plants	Anthropogenic impact	0.567	3.454	0.473	0.046
	Area	0.179	1.091	0.149	0.439
	Isolation	0.229	1.392	0.191	0.365
	Habitat diversity	0.060	0.366	0.050	0.891
	Residuals	0.164		0.137	
Birds	Anthropogenic impact	0.154	1.720	0.175	0.148
	Area	0.151	1.687	0.172	0.155
	Isolation	0.158	1.765	0.180	0.289
	Habitat diversity	0.236	2.639	0.269	0.121
	Residuals	0.089		0.204	

Mammals were also included in the combined analysis with all species. Significant values in *bold*

Fig. 4 Non-metric multidimensional scaling (nMDS) for the species composition across islands according two levels of anthropogenic human impact

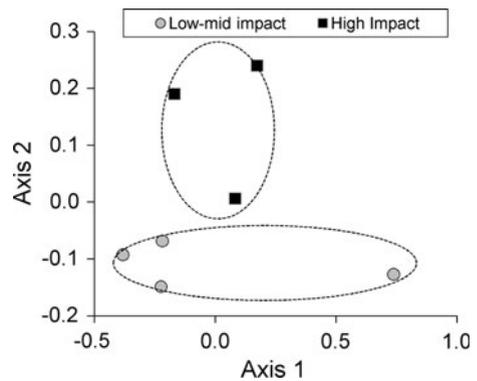


Table 3 Analyzes of nestedness (*NODF*) and co-existence (*C-score*) across islands

Group	NODF		C-score	
	Statistic (z-value)	P-value	Statistic (z-value)	P-value
All Species	-7.00	0.0009	4.45	0.0009
Plants	-5.77	0.0009	4.45	0.0009
Birds	-0.37	0.5904	1.01	0.3006

Mammals were also included in the combined analysis with all species. Significant values in *bold*

homogenization effects via extinctions/invasions of exotic forms (Sax and Gaines 2008). However, the CSC is not characterized by the presence of many exotic forms, so human impacts are rather affecting the composition of indigenous species.

Despite the existence of a small-island effect, assemblages were highly harmonious or structured, as could be predicted in a system governed by stochastic processes. Moreover, and contrary to expectations, nestedness was significant only in plants, but not in birds. Previous studies have shown that the among taxa variation in the degree of nestedness is related to their dispersal abilities (Chown et al. 1998, Spengler et al. 2011). We suggest that the particular configuration of the islands of the CSC, combined with the human impacts may account for this pattern. Nestedness is most likely related to selective extinction, when species with more area or habitat requirements should disappear earlier than less specialized species. Nonetheless, immigration rates should also have an effect on this pattern organization (Whittaker and Fernández-Palacios 2007). We found that neither area nor isolation exerted a significant relationship on species richness, so it could be difficult to suggest which process of extinction/colonization should have the strongest effect on the nestedness structure. Nevertheless, it is suspected that the nestedness pattern observed in vegetation is not explained by colonization rates that are frequently related to high dispersal abilities (Weiher and Keddy 2004). If selective extinction is operating, although it was not clearly identified, it is probably that plants have low requirements of area and resources on the islands. However, alternatively, it has been suggested that the non-random pattern can be explained by “habitat nestedness”, where species may present nested distribution because the habitats they occupy are also nested (Wright et al. 1998). Accordingly, plant species composition could be explained by habitat nestedness and species richness could be determined by habitat diversity (Whittaker and Fernández-Palacios 2007). However, habitat diversity was weakly related to the variation in species composition, even in plants. Alternatively, we suggest that nestedness could be explained by the frequent human visiting of islands by local fishermen and tourists, which may increase the chances of propagule dispersal. The lack of nestedness observed in birds may be explained by the close proximity of islands with the mainland, and among them; most of the birds would have enough dispersal capabilities to inhabit any islands, so stochastic processes would regulate its distribution.

C-score values were higher than expected by the null model, suggesting that species co-existence may be determined by competitive interactions. However, this was significant only for plants, which are much more diverse and are probably competing for resources like water and nutrients. Also, and despite the low diversity of exotic species, they could additionally exert pressure on native and endemic plants for space (Corbin and D’Antonio 2004; Newsom and Noble 1986). The observed presence of nestedness and co-occurrence in plants, has been suggested as possible since they can coexist but are restricted by their similarities, especially because of the minimum morphological distance reached among them (Burns 2007; Weiher et al. 1998; Worthen 1996). The absence of co-occurrence among birds could be explained due to the scale of investigation: competitive interactions (i.e., nesting competition) could be detected among species birds but only at smaller spatial scales.

Implications for conservation

From a conservation viewpoint, the small areas of the islands of the CSC cannot be used to judge their importance; indeed, the existence of a ‘small-island effect’ anticipates a much

larger diversity than expected by the island biogeography theory. The lack of nestedness in birds strongly suggests that the protection of a few islands will not warrant the protection of the many species. For instance, it is known that Chungungo Island is the only recorded place where a particular seabird species nests, the White-vented storm-petrel (Hertel and Torres-Mura 2003) which is found in the category “Data Deficient” according to IUCN (2010). Also, Pájaros 2 Island, where a small colony of Peruvian diving-petrel was recently found, is the second colony after the largest established on Choros Island. This last species is listed as endangered by the IUCN (2010).

The endemic flora inhabiting the studied islands represents ~4% of endemic plants reported both for the region of Coquimbo and for Chile. For plants, islands would act as a reservoir in view of human disturbances that usually take place in the continent, such as mining and thermoelectric projects, urban growth, agriculture, grazing by domestic animals, and pests. Among the total number of birds reported, eight seabirds species are endemic to the HCS from 13 species reported by Schlatter and Simeone (1999). Four species are of special concern, the White-vented storm-petrel (Data deficient), Humboldt penguin (Vulnerable), Red-legged cormorant (Near threatened) and Peruvian diving-petrel (Endangered) (IUCN 2010). Among the landbird species, *Mimus tenca* and the terrestrial mammal *Phyllotis darwini* are endemic to Chile (Simonetti et al. 1995), and for marine mammals the marine otter *Lontra felina* is endangered (IUCN 2010). Thus, we strongly suggest that Chungungo, Tilgo, Pájaros 1 and 2 islands, as well as the islands of the Humboldt Penguin National Reserve (Choros, Damas, and Chañaral) should be included in a major protected area that ensures the preservation of a number of related islands that are representative of the HCS.

The protection of the islands of the CSC will have multiple benefits at the regional and national level. For example, will contribute to the national policies for the protection of the biodiversity. The inclusion of all the islands in the Humboldt Penguin National Reserve, involves the incorporation of only 2.37 ha. This figure is very small, and does not significantly contribute to the goal of the country of protecting 10% of marine habitats. However, will promote and justify the allocation of funds to eradicate invasive species that affect both endemic plants and seabirds. Additionally, the islands holds important colonies of endemic seabirds, as well as plants, invertebrates, reptiles, land birds, and micro-mammals, so that the protection of their habitats would help in the conservation of species of regional and global significance (Squeo et al. 2001; Simeone et al. 2003; Hertel et al. 2005; Arancio and Lara 2007; CONAF 2009; IUCN 2010).

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Appendix

See Tables 4, 5, 6, and 7.

Table 4 Island locations, main geographical features and species richness of plants and animals found on islands of North-central Chile

Variables	Islands							
	Chañaral	Damas	Choros	Chungungo	Tilgo	Pájaros 1	Pájaros 2	
Latitude	29°01'S	29°13'S	29°15'S	29°24'S	29°32'S	29°35'S	29°32'S	
Longitude	71°34'W	71°31'W	71°32'W	71°21'W	71°20'W	71°33'W	71°33'W	
Size area (km ²)	5.16	0.56	3.01	0.15	0.45	1.24	0.53	
Isolation (km)	6.3	5.2	6	1.5	0.2	20.6	21.4	
Geomorphological Units	6	5	4	2	3	4	1	
Seabirds	6	1	7	5	4	7	5	
	3	10	6	3	4	5	0	
Landbirds	1	1	4	5	1	1	0	
	17	18	24	7	14	17	0	
Plants	38	49	27	8	18	6	0	
Mammals	6	2	4	1	2	1	0	

Seabirds and landbirds diversity were divided into two groups. *B* breeding and *NB* Non breeding

Table 5 Landbirds and seabirds found on islands of North-central Chile

Scientific name (Common name)		Islands															
		Chañaral		Damas		Choros		Chungungo		Tilgo		Pájaros 1		Pájaros 2			
		B	NB	B	NB	B	NB	B	NB	B	NB	B	NB	B	NB		
Seabirds																	
1	<i>Arenaria interpres</i> (Ruddy turnstone)			1	1												1
2	<i>Charadrius alexandrinus</i> (Snowy plover)			1													
3	<i>Charadrius modestus</i> (Rufous-chested dotterel)			1													
4	<i>Cinclodes nigrofumosus</i> (Seaside cinclodes)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	<i>Haematopus ater</i> (Blackish oystercatcher)			1													
6	<i>Larosterna inca</i> (Inca tern)					1											
7	<i>Larus dominicanus</i> (Kelp gull)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	<i>Numenius phaeopus hudsonicus</i> (Whimbrel)			1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	<i>Oceanites gracilis</i> (White-vented storm-petrel)					1											
10	<i>Pelecanus thagus</i> (Peruvian pelican)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	<i>Pelencanoides garnoti</i> (Peruvian diving-petrel)					1											
12	<i>Phalacrocorax bougainvillii</i> (Guanay cormorant)			1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	<i>Phalacrocorax gaimardi</i> (Red-legged cormorant)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	<i>Spheniscus humboldti</i> (Humboldt penguin)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	<i>Phalacrocorax brasilianus</i> (Neotropic cormorant)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
16	<i>Sula variegata</i> (Peruvian booby)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	<i>Sula nehouxii</i> (Red footed booby)																
	Total seabirds	6	3	1	10	7	6	5	3	4	4	4	4	7	5	5	0
Landbirds																	
18	<i>Agriornis livida</i> (Great shrike-tyrant)	1				1	1	1	1	1	1	1	1	1	1	1	1
19	<i>Agriornis montana</i> (Black-billed shrike-tyrant)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	<i>Ardea alba</i> (Great egret)	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 5 continued

Scientific name (Common name)	Islands													
	Chañaral		Damas		Choros		Chungungo		Tilgo		Pájaros 1		Pájaros 2	
	B	NB	B	NB	B	NB	B	NB	B	NB	B	NB	B	NB
21 <i>Asthenes humilis</i> (Dusky-tailed canastero)														
22 <i>Athene culicillaria</i> (Burrowing owl)	1		1	1										
23 <i>Bubo magellanicus</i> (Magellanic horned owl)									1					
24 <i>Buteo polyosoma</i> (Red-backed hawk)	1		1	1					1					
25 <i>Caracara plancus</i> (Crested caracara)	1		1	1					1					
26 <i>Carduelis barbatus</i> (Black-chinned siskin)														1
27 <i>Cathartes aura</i> (Turkey vulture)	1		1	1	1	1	1	1	1	1	1	1	1	1
28 <i>Cinclodes fuscus</i> (Buff-winged cinclodes)					1									
29 <i>Cinclodes oustaletii</i> (Grey-flanked cinclodes)				1	1	1	1	1	1	1	1	1	1	1
30 <i>Phrygilus gayi</i> (Grey hooded sierra-finch)														1
31 <i>Coragyps atratus</i> (Black vulture)	1		1	1	1	1	1	1	1	1	1	1	1	1
32 <i>Diuca diuca</i> (Common diuca finch)	1		1	1	1	1	1	1	1	1	1	1	1	1
33 <i>Egretta thula</i> (Snowy egret)				1	1	1	1	1	1	1	1	1	1	1
34 <i>Falco femoralis</i> (Aplomado falcon)														
35 <i>Falco peregrinus</i> (Peregrine falcon)	1		1	1	1	1	1	1	1	1	1	1	1	1
36 <i>Geositta cunicularia</i> (Common miner)	1		1	1	1	1	1	1	1	1	1	1	1	1
37 <i>Geositta cunicularia deserticolor</i> (Desert-colored miner)	1													
38 <i>Hirundo rustica</i> (Barn swallow)														1
39 <i>Leptasthenura aegithaloides</i> (Plain-mantled tit-spinetail)														1
40 <i>Milvago chimango</i> (Chimango caracara)				1										
41 <i>Mimus tenca</i> (Chilean mockingbird)				1	1	1	1	1	1	1	1	1	1	1
42 <i>Muscisaxicola macloviana</i> (Dark-faced ground-tyrant)				1	1	1	1	1	1	1	1	1	1	1

Table 5 continued

Scientific name (Common name)	Islands													
	Chañaral		Damas		Choros		Chungungo		Tilgo		Pájaros 1		Pájaros 2	
	B	NB	B	NB	B	NB	B	NB	B	NB	B	NB	B	NB
43 <i>Nycticorax nycticorax</i> (Black-crowned night heron)							1							
44 <i>Oreopholus ruficollis</i> (Tawny throated dotterel)		1												
45 <i>Patagona gigas</i> (Giant hummingbird)							1		1					
46 <i>Phrygilus fruticeti</i> (Mourning sierra-finch)					1								1	
47 <i>Pygochelidon cyanoleuca</i> (Blue-and-white swallow)							1							
48 <i>Sephanoides sephanooides</i> (Green-backed firecrown)														
49 <i>Sicalis luteola</i> (Misto yellow-finch)				1										
50 <i>Tachycineta meyeni</i> (Chilean swallow)						1							1	
51 <i>Theristicus melanopus</i> (Black-faced ibis)		1		1		1								
52 <i>Thinocorus rumicivorus</i> (Least seedsnipe)		1			1									
53 <i>Troglodytes musculus</i> (House wren)		1		1		1							1	
54 <i>Tyto alba</i> (Barn owl)													1	
55 <i>Upucerthia dumetaria</i> (Scale-throated earthcreeper)				1		1								
56 <i>Vallenus chilensis</i> (Southern lapwing)				1		1								
57 <i>Zenaidra auriculata</i> (Chilean eared dove)													1	
58 <i>Zonotrichia capensis</i> (Rufous-collared sparrow)		1		1		1							1	
Total landbirds	1	17	1	18	4	24	5	7	1	14	1	17	0	0
Total sea and land birds	7	20	2	28	11	30	10	10	5	18	8	22	5	0

B breeding and NB Non breeding

Table 6 Plant diversity found on islands of North-central Chile

Plants	Islands						
	Chañaral	Damas	Choros	Chungungo	Tilgo	Pájaros 1	Pájaros 2
1 <i>Alstroemeria philippii</i>	1	1	1				
2 <i>Amblyopappus pusillus</i>	1	1	1				
3 <i>Atriplex mucronata</i>	1	1					
4 <i>Atriplex semibaccata</i>					1		
5 <i>Bromus berterianus</i>	1						
6 <i>Calandrinia cachinalensis</i>	1	1					
7 <i>Chenopodium murale</i>	1	1					
8 <i>Chenopodium petiolare</i>		1			1		
9 <i>Chorizanthe frankenioides</i>	1	1					
10 <i>Cistanthe coquimbensis</i>		1					
11 <i>Colliguaja odorifera</i>					1		
12 <i>Copiapoa coquimbana</i>	1	1	1		1		
13 <i>Copiapoa marginata</i>		1	1				
14 <i>Copiapoa pseudocoquimbana</i>	1						
15 <i>Crassula connata</i>		1					
16 <i>Cristaria aspera</i>	1	1	1				
17 <i>Cristaria glaucophylla</i>		1					
18 <i>Cryptantha kingii</i>		1					
19 <i>Cuscuta chilensis</i>	1	1	1		1		
20 <i>Cuscuta purpurata</i>	1	1	1				
21 <i>Cyclosporum laciniatum</i>		1					
22 <i>Echinopsis litoralis</i>					1		
23 <i>Ephedra gracilis</i>		1					
24 <i>Eriosyce chilensis</i>				1	1		
25 <i>Eriosyce subgibbosa</i>	1	1	1				
26 <i>Erodium cicutarium</i>		1					
27 <i>Eryngium pulchellum</i>		1					
28 <i>Eulychnia breviflora</i>				1	1		
29 <i>Eulychnia acida</i> var. <i>procumbens</i>	1	1	1		1	1	
30 <i>Fagonia chilensis</i>		1				1	
31 <i>Frankenia chilensis</i>	1	1	1	1			
32 <i>Gamochaeta monticola</i>		1					
33 <i>Heliotropium huascoense</i>	1	1	1				
34 <i>Heliotropium stenophyllum</i>					1		
35 <i>Loasa elongata</i>	1	1	1				
36 <i>Malva nicaensis</i>	1						

Table 6 continued

Plants	Islands						
	Chañaral	Damas	Choros	Chungungo	Tilgo	Pájaros 1	Pájaros 2
37 <i>Mesembryanthemum cristalinum</i>	1	1	1	1	1	1	
38 <i>Mesembryanthemum nodiflorum</i>	1	1	1				
39 <i>Microphyes litoralis</i>		1					
40 <i>Montiopsis capitata</i>				1			
41 <i>Myrcianthes coquimbensis</i>					1		
42 <i>Nolana acuminata</i>	1						
43 <i>Nolana crassulifolia</i>	1	1	1		1		
44 <i>Nolana divaricata</i>		1					
45 <i>Nolana sedifolia</i>	1	1	1	1	1		
46 <i>Oenothera coquimbensis</i>		1					
47 <i>Ophryosporus triangularis</i>	1	1	1		1		
48 <i>Opuntia</i> sp.				1			
49 <i>Oxalis gigantea</i>					1		
50 <i>Oxalis megalorrhiza</i>	1	1	1				
51 <i>Oxalis micrantha</i>	1		1				
52 <i>Oxalis virgosa</i>	1						
53 <i>Perityle emoryi</i>	1						
54 <i>Polyachyrus fuscus</i>	1	1	1				
55 <i>Rhodophiala bagnoldii</i>		1					
56 <i>Schinus molle</i>		1					
57 <i>Sicyos baderoa</i>	1	1	1	1	1	1	
58 <i>Solanum albiflorum</i>		1					
59 <i>Solanum remyanum</i>	1	1	1		1	1	
60 <i>Sonchus tenerrimus</i>	1						
61 <i>Spergularia pycnantha</i>	1						
62 <i>Stipa speciosa</i>		1					
63 <i>Suaeda foliosa</i>	1	1	1			1	
64 <i>Tetragonia espinosae</i>	1	1	1				
65 <i>Tetragonia maritima</i>	1	1	1				
66 <i>Tetragonia ovata</i>	1	1	1				
67 <i>Tristerix aphyllus</i>	1	1	1				
68 <i>Zephyra elegans</i>		1					
Total plants	38	49	27	8	18	6	0

Table 7 Diversity of mammals found on islands of North-central Chile

Mammals	Islands						
	Chañaral	Damas	Choros	Chungungo	Tilgo	Pájaros 1	Pájaros 2
1 <i>Phyllotis darwini</i> (Darwin's leaf-eared mouse)					1		
2 <i>Abrothrix olivaceus</i> (Olive grass mouse)		1			1		
3 <i>Arctocephalus australis</i> (Fur seal)	1						
4 <i>Desmodus rotundus</i> (Common vampire bat)	1						
5 <i>Lontra felina</i> (Marine otter)	1	1	1				
6 <i>Mirounga leonina</i> (Southern elephant seal)	1		1				
7 <i>Oryctolagus cuniculus</i> (European rabbit)	1		1				
8 <i>Otaria flavescens</i> (South American sea lion)	1		1	1			
9 <i>Thylamys elegans</i> (Mouse opossum)	1						
10 <i>Mus musculus</i> (House mouse)			1				
11 <i>Rattus rattus</i> (Black rat)				1		1	
Total mammals	7	2	5	1	2	1	0

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