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ECOSYSTEMS

The diversity and structure of plant communities in the maritime Antarctic is shaped by southern giant petrel's (*Macronectes giganteus*) breeding activities

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Abstract: Southern giant petrels (*Macronectes giganteus*) are found in the Antarctic. They build their nests with rock fragments, disturbing large areas during incubation and chick feeding periods; however, their impact on vegetation is unknown. Thus, we aimed to evaluate the effect of Petrel nests and associated breeding activities on the diversity and structure of cryptogam communities of Stinker Point, Elephant Island. We selected 13 nests in February and March 2012 and continue the monitoring in 2018. The area of direct influence of breeding activities was photographed to calculate plant community coverage. The results demonstrated that species richness, community coverage and composition, and beta diversity showed significant differences between active and inactive nests. The linear mixed-effect models revealed that the positive effect of nest area mainly caused variation in community coverage, but had a negative effect on beta diversity. *Sphaerophorus globosus* (lichen) grew around the inactive nests, sometimes forming a ring up to 1 m in diameter. This ring was then surrounded by the *Chorisodontium acyphyllum* moss colonized by *S. globosus,* and a final ring of *Sanionia uncinata,* colonized by the same lichen. Recently constructed nests are generally surrounded by *Prasiola crispa* and *Sanionia uncinata* carpets.

Key words: formations, phytogeography, plant, succession.

INTRODUCTION

The Antarctic (continental and maritime) is home to various seabird species, such as penguins, seagulls and petrels (Petry et al. 2018). These nest areas can affect plant communities (i.e., species richness, community composition, and structure of cryptogams), acting as microhabitats or habitat filters. However, these microhabitat factors are still poorly understood since previous studies have been restricted to evaluating the relationship of nutrient input and soil properties with plant communities (Poelking et al. 2015, Schmitz et al. 2018, 2020a, b, 2021). Furthermore, most studies in Antarctica are confined to changes in species richness and composition of cryptogam communities shaped by environmental filtering, such as soil texture, soil fertility, and topographical factors (Poelking et al. 2015, Schmitz et al. 2020a, b, 2021), with limited studies on habitat filtering (i.e., microhabitats such as rocks and nests of birds).

Under the habitat filtering approach, microsite conditions can shape plant communities and filter species with similar attributes to colonize and grow in these microhabitats (Bao et al. 2019, Campos et al. 2020, Cifuentes-García et al. 2020). Thus, the patterns of diversity (richness and composition) and structure (coverage) of cryptogam communities in Antarctica are scale-dependent according to habitat filtering and promote high species turnover (beta diversity) along habitats such as pedoenvironments (Schmitz et al. 2020a, b, 2021). Beta diversity explains the temporal and spatial changes in plant community composition (Bao et al. 2019, Campos et al. 2020, Nunes et al. 2020); for example, the percentage of dissimilarity in the species composition of two communities (Koleff et al. 2003, Anderson et al. 2011, Anderson & Walsh 2013).

Macronectes giganteus (southern giant petrel) reproduces in the Maritime Antarctic, and little is known of its impact on vegetation near the nesting area. Its breeding range extends from approximately 40°S (Gough Island) to 68°S in West Antarctica and sub-Antarctic islands and areas around the Antarctic Peninsula (Creuwels et al. 2005). Only a small number (~1%) of the population breeds on the coast of the Antarctic continent or certain South American island shores (Woehler et al. 2003, Patterson et al. 2008). The nests are mainly built in colonies established in open spaces of variable size. On the South Shetland Islands, the petrel's sole egg hatches during the first weeks of January, with the rookery period slightly longer than three months; parental care rarely extends longer than the fourth week of life (Cooper et al. 2001, Conroy 1972, Otovic et al. 2018). This period causes various impacts on vegetation in the surrounding nesting area, mainly by feces deposition, rock removal, landing and departure movements, and other adult and chick disturbances that have not yet been evaluated.

In this study, we aimed 1) to evaluate the pattern of species richness, community composition, and structure of cryptogam communities around southern giant petrel (*Macronectes giganteus*) nests (inactive and active), and 2) to test the main effects of nest area on community coverage, species richness, and beta diversity on Stinker Point, Elephant Island, Maritime Antarctica.

MATERIALS AND METHODS

This study was carried out at Elephant Island, Maritime Antarctica (61°07′ S 55°03′ W) in February/March 2012 and continue the monitoring in February/March 2018. The central area is completely ice-covered and the coastal areas are ice-free, although access is difficult because of the steep cliffs and strong wind and wave action. Specifically, the sampling area was at Stinker Point (61°13′25″ S 55°21′35″ W), one of the largest coastal ice-free areas (4.5 × 1.8 km) with the richest flora and fauna of the island. This area is limited on the north by the Sultan Glacier and on the south by the Endurance Glacier (Pereira & Putzke 1994). The Emílio Goeldi Refuge, a Brazilian facility, named after the Swiss-Brazilian naturalist and zoologist Emílio Augusto Goeldi. It was built in 1988, being the structure located on Stinker Point, Elephant Island (61° 3′ 0′ S 55° 12′ 0″ W). The refuge can accommodate up to six people (Figure 1).

A survey was done using drone photography and visiting the areas) to record all active nests when the group first arrived at the area and then kept monitoring to see which nests were abandoned. This was done to avoid impact over the giant petrel population. We have chosen to this study 13 nests in 2011/2012 early abandoned by the southern giant petrels (called active nests) found on the Brazilian refuge plateau area (750 × 462 m) or nests abandoned for more years (called inactive). The same nests studied in 2012 were also studied in 2018, being photographed to calculate the coverage

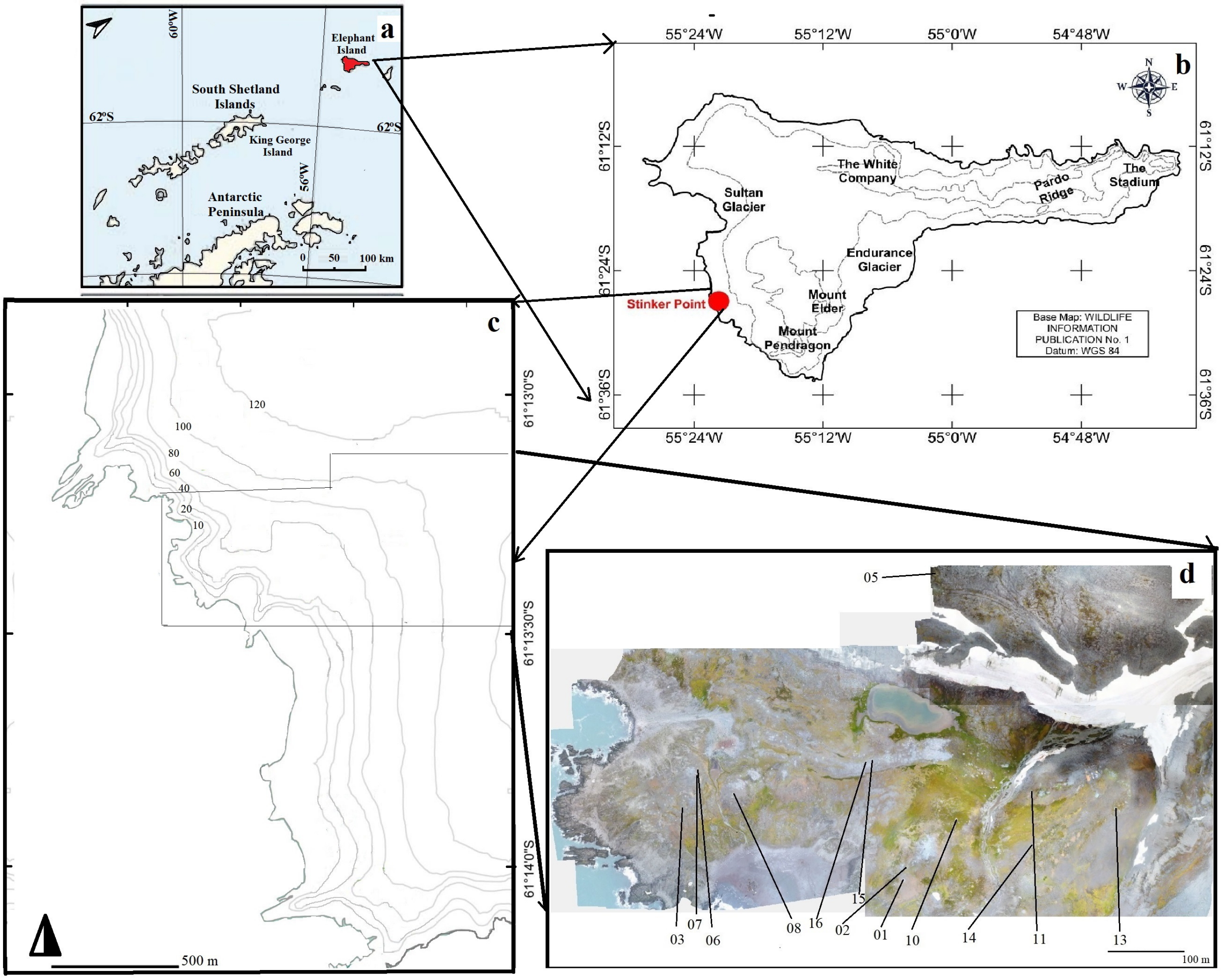


Figure 1. Schematic map of the South Shetland Islands (a), Elephant Island (b), Stinker Point (c), and the area studied (d).

of each plant/lichen species and to determine vegetal composition. From the nests found, the 13 chosen to do this study were also distanced from active nests still occupied by adults. This was done just to avoid disturbance to the reproductive populations. Some nests studied were abandoned for more than one year, since almost all the rock fragments were covered by vegetation, indicating no recent disturbance. These nests were also photographed to understand the plant succession around these nests after stopping disturbance (Table I). So, the nests were classified as inactive (abandoned for more than one season, with rocks of the main structure of the nest almost completely covered by vegetation, named P1, P2, P10, P11, P13, P14) or active (nests actively used for bird breeding each year, since rocks were clean of vegetation and clearly moved to structure the nest; named P3, P5, P6, P7, P8, P15 and P16).

A square was delimitated from the area surrounding the nest (named the area of direct influence) using the disturbances provoked by the parents and chick, such as dislocated stones, landing marks, deposited feces and disrupted vegetation. The images were taken in 2012 from a one-meter-high positioned camera (Canon EOS 550D – 14 Megapixels) and fused to form one large and complete image of the nest and surroundings. In 2018, the same nests studied in 2012 were photographed using a drone Phantom F-4 and the Agisoft software to generate a complete figure and a map of nest distribution. To better understand plant organization, the dominant species were colored using the original photos as a reference to draw a diagram of the plant distribution surrounding the nest, and CobCal software was used to calculate the covered area and percentage.

Plant species were identified using specific literature such as Putzke & Pereira (2001), Ochyra (1998) and Ochyra et al. (2008) for mosses and Redón (1985), Øvstedal & Lewis-Smith (2001) and Olech (2004) for lichens. The collected specimens were dried and deposited at the Bruno Edgar Irgang Herbarium (HBI) of the Universidade Federal do Pampa (UNIPAMPA - São Gabriel – Rio Grande do Sul state - Brazil).

Data analysis

From the 13 nests studied to identify plant species associated (named P1 to P16), there were classified 6 nest as inactive (P1, P2, P10, P11, P13 and P14) and 7 as active (P3, P5, P6, P7, P8, P15 and P16). Data analysis was conducted mainly using R 3.6.0 Environment (R Development Core Team 2019). The PC-Ord 5.15 software (McCune & Mefford 2006) was used to analyze the similarity of species between nests. "ggplot2" package (Hadley 2015) was used to create graphical illustrations of the results. In general, we analyzed the data by comparing communities between active and inactive nests as described above. To compare the means of cover between the two types of nests using the Wilcoxon test, we first tested the normal distribution using the Shapiro-Wilk test and evaluated the Q-Q graph. Then we evaluated the homogeneity of variances using the Bartlett test (Crawley 2013).

Species richness, community composition, and dissimilarity

The sampled-based rarefaction and extrapolation approach (Chao et al. 2014) was used based on 100 replicate bootstrap runs to estimate 95% confidence intervals of interpolated

Table I. Geographical location, area directly affected and altitude of the nest studied.

Nest number	Location	Area directly affected by the nest	Altitude (m)
01	61° 13' 25,18" S and 55° 21' 50,78" W	5.5 x 4.93	41
02	61° 13' 23,89" S and 55° 21' 51,59" W	4.1 x 4.94	47
03	61° 13' 21,72" S and 55° 22' 11,92" W.	2.5 x 3.05	61
05	61° 13' 7,73" S, 55° 21' 50,81" W	2.6 x 4.6	121
06	61° 13' 20,3" S and 55° 22' 09,02" W.	1.8 x 2.9	62
07	61° 13' 20,04" S and 55° 22' 09,02" W.	1.8 x 2.2	63
08	61° 13' 21,03" S and 55° 22' 06,5" W.	1.6 x 2	68
10	61° 13' 22,4" S and 55° 21' 46,9" W.	4 x 5.4	57
11	61° 13' 21,1" S and 55° 21' 39,6" W.	7.1 x 6.5	57
13	61° 13' 21,5" S and 55° 21' 32,91" W	2.1 x 2.6	77
14	61° 13' 23,04" S and 55° 21' 40,13" W	4.05 x 5	55
15	61° 13' 19,47" S and 55° 21' 54,31" W	2.4 x 4.5	98
16	61° 13' 19,52" S and 55° 21' 54,83" W	3.3 x 3.4	98

and extrapolated curves (Colwell et al. 2012) for species richness comparisons between sampling active and inactive nestsinactive using the "*iNEXT*" package (Hsieh et al. 2016). Thus, whenever the 95% confidence intervals did not overlap among rarefaction and extrapolation curves, there were significant differences ($p < 0.05$) (Colwell et al. 2012).

A non-metric multidimensional scaling (NMDS) analysis based on Jaccard dissimilarities using the "*metaMD*"' function (Clarke 1993, Oksanen et al. 2018) and permutational multivariate analysis of variance (PERMANOVA, 9999 permutations) based on the "*adonis*" function was used to compare community composition between nests groups. Furthermore, we used the "*MDSrotate*" function, which rotates an external environmental variable (coverage and area) to be parallel to the first multidimensional scaling dimension (Oksanen et al. 2018). All different functions of NMDS are available within the "vegan" package (Oksanen et al. 2018).

A two-way cluster analysis (also known as biclustering based on Jaccard dissimilarity) was used to assess similarities and differences in species composition between nest groups using PC-Ord 5.15 software (McCune & Mefford 2006).

Beta diversity between nests

The beta diversity analysis (calculated based on the average species composition of each nest) proposed by Anderson (2006) was used to evaluate the differences of taxonomic composition between nests based on Jaccard dissimilarities with incidence data using the "betadisper" function, and permutational analysis of multivariate dispersions (PERMDISP) of the *vegan* package (Oksanen et al. 2018). In this analysis, greater dispersal of data points indicated greater species composition variability between groups using PERMANOVA (based on Monte-Carlo with 9999 permutations), which can then be considered a measure of beta diversity (Anderson 2006, Anderson & Walsh 2013, Nunes et al. 2020).

Linear mixed models

We used linear mixed-effects models (LMMs, with random and fixed effects) to test the main effects of nest area (explanatory variables) on community coverage, beta diversity, and species richness (response variables). Sample sites were considered random effects (1|plots) in all models. The most suitable residuals distribution and link function (i.e., normality was confirmed by the Q-Q graph and Shapiro–Wilk test) was evaluated (Zuur et al. 2009, Crawley 2013).

RESULTS

The disturbance area by southern giant petrels through trampling, feces deposition, and rock movements (the area directly affected) was found to be from 3.2 (nest 8) to 46.1 m^2 (nest 11, which had another nest adjacent), accounting for 194.3 m^2 of the area under the direct influence of the 16 nests (Figures 2 and 3, Table I). Considering the mean value found (13.9 m^2/nest), it was estimated that the total nests (n = 320) accounted for 4.448 m^2 of directly affected plateau, corresponding to 1.3 % of the total plateau area (346.5 m^2 total area investigated) (Figure 3).

Five mosses, one fruticose lichen, one foliose lichen, one Antarctic grass (*Deschampsia antarctica*), one alga (*Prasiola crispa*) and various unidentified muscicolous lichens were found growing associated with the 16 studied southern giant petrel nests. The lichen species *Sphaerophorus globosus* (with a total occupied area of 31.8 m^2, was found in six nests) and the moss *Chorisodontium acyphyllum* (19.5 m^2,

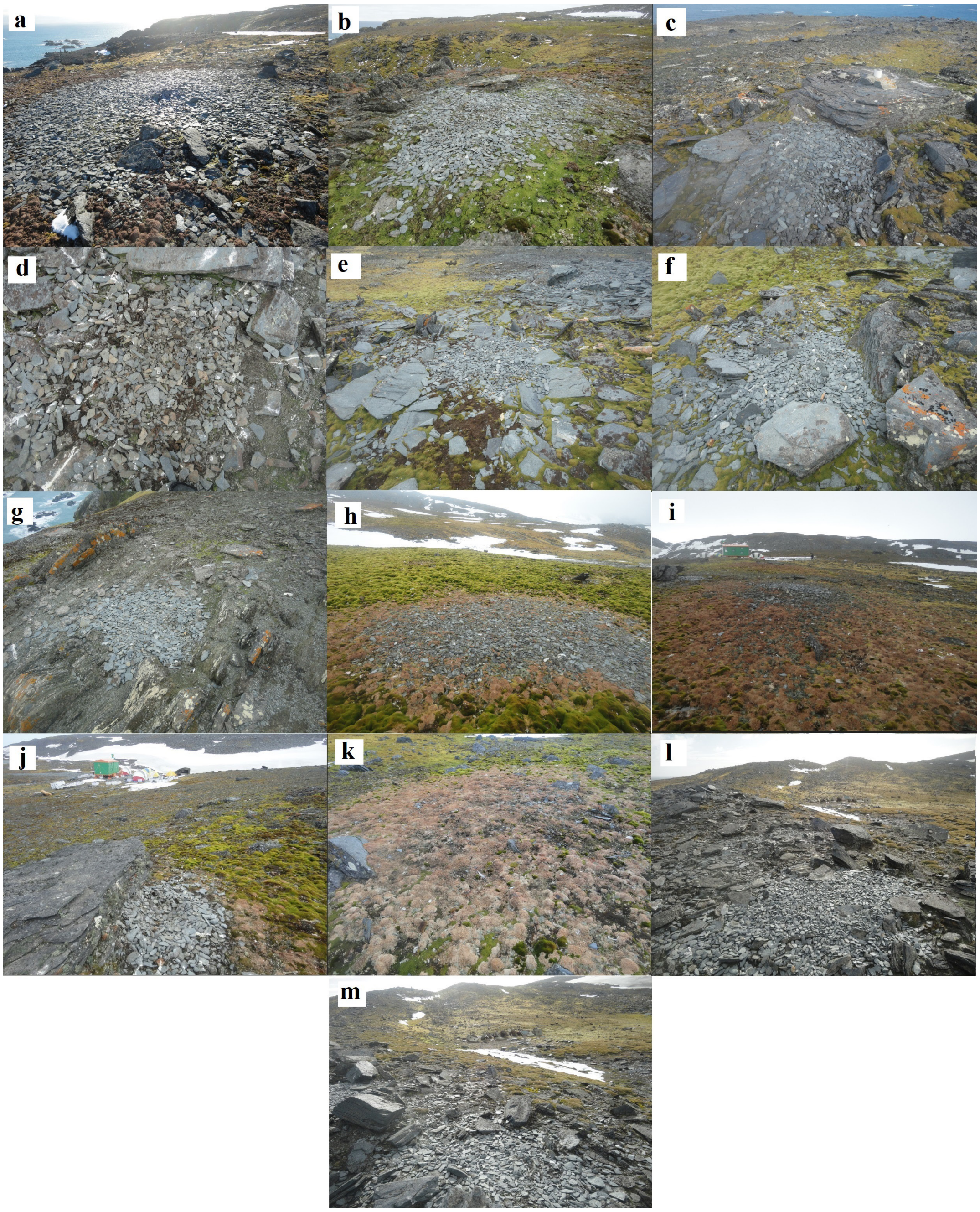


Figure 2. General view of the 13 nests studied: a = P1; b= P2; c= P3; d= P5; e= P6; f= P7; g= P8; h= P10; i= P11; j= P13; k= P14; l= P15; m= P16.

found in 8 nests) showed the highest coverage (Table II). The greatest number of species found in a single nest was five (nest 3), and the lowest was a single species (*Prasiola crispa* – nest 8).

Community coverage showed significant differences between nest types, where the inactive nest coverage was twice as high as that of active nests (Figure 4). The community species richness differed between the two nest types. However, the results showed an overlap in the confidence interval of the curves, indicating that the differences were not significant (Figure 5a). Conversely, when the community composition variability was analyzed, significant differences were observed between nest types (Permanova: $F_{1,11} = 5.25$, $p < 0.001$), with marked variation in

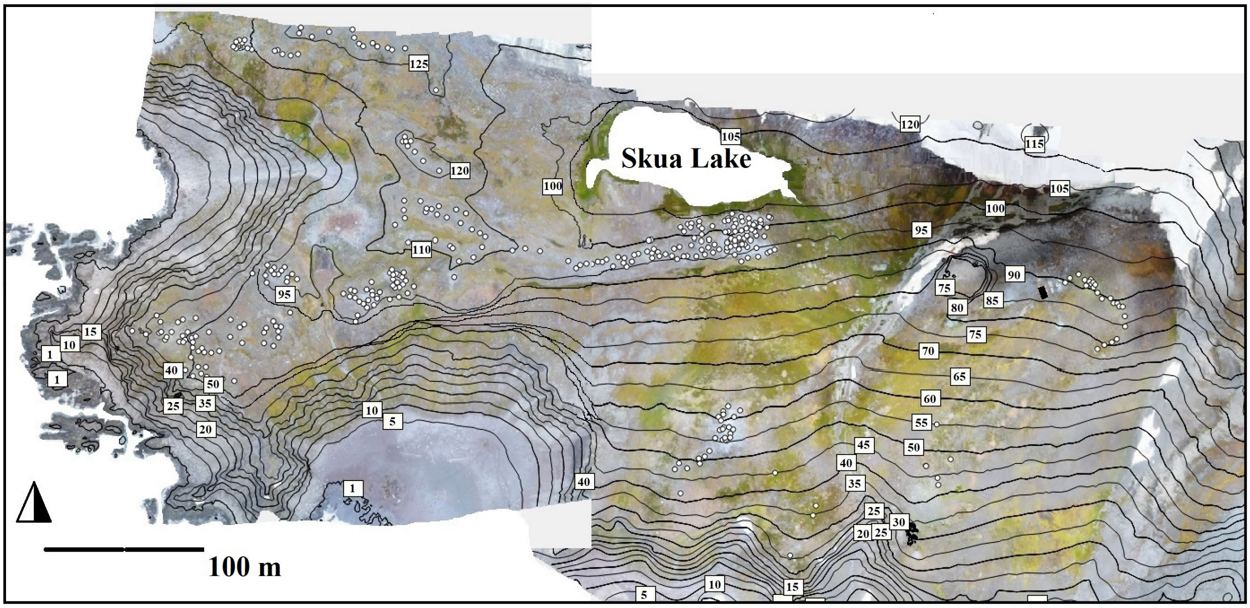


Figure 3. **Map of all the southern giant petrel nests found in the Refuge Plateau of Stinker Point (white dots = petrel nests; black square = Brazilian Goeldi Refuge; squares with a number = altitude).**

area and coverage (Figure 5b–c). This result was corroborated by comparing species distribution between nest types using a two-way cluster dendrogram, where a marked species-specific difference was observed (Figure 6).

The results on the beta diversity approach showed that the sample points in inactive nests clustered in the multidimensional space, with less distance from the centroid in comparison to active nests, which showed a scattered pattern (Figure 7a). Thus, changes in beta diversity between nest groups (Permanova: $F_{1,11} = 4.04$, $p < 0.001$; Figure 7b) were observed.

The best linear mixed-effect models showed that variation in community coverage (Est. = 1.11, t = 5.11, p <0.001) was mainly explained by nest area, which had the strongest positive effect (Figure 8a) and negative effect (Est. = -0.10, t = 0.51, p <0.001) on beta diversity (Figure 8b). However, no significant effect (Est. = 0.03, t = 1.47, p = 0.17) was observed on species richness (Figure 8c).

These results highlight the relevance of biotic factors (i.e., disturbance by breeding birds) in shaping the structure and composition of cryptogam communities in the Antarctic. Generally, in inactive nests *Sphaerophorus globosus* grows around southern giant petrel nests forming a ring up to 1 m in diameter. It grows in diameter depending on feces disposal, being more developed when oriented in the predominant wind direction. The *Sphaerophorus* ring is surrounded by the moss *Chorisodontium acyphyllum*, which is colonized by *Sphaerophorus globosus*, usually located in the North/Northwest quadrant, and by a ring of *Sanionia uncinata* colonized by the same lichen (but not as frequently). Finally, newer active nests are generally surrounded by *Prasiola crispa* and *Sanionia uncinata* carpets, which are already growing in the area. *Chorisodontium acyphyllum* is the last moss species that colonizes the surroundings of nests.

Table II. **Plant species cover (%), area of rocks covering the soil used in the nest building and surroundings (%) and total area (m^2) around giant petrel nests in Stinker Point – Elephant Island.**

	1	**2**	**3**	**5**	**6**	**7**	**8**	**10**	**11**	**13**	**14**	**15**	**16**	**Total m^2**
Sphaerophorus globosus	33.1	20.5	-	-	-	-	-	8.7	19.6	17.6	34.2	-	-	
	9	4.1						1.9	9	1	6.9			31.8
Chorisodontium acyphyllum	-	-	0.4	0.1	-	-	-	53.5	11.5	46.4	-	-	-	
			0.03	0.01				11.6	5.3	2.6				19.54
Chorisodontium +Sphaeorophorus	14.7	38.5	-	-	-	-	-	4.4	33.6	10.4	32.6	-	-	
	4	7.8						0.9	15.5	0.6	6.6			35.4
Chorisodontium + muscic. lichens	-	-	-	2.9	-	-	-	-	-	-	-	-	-	
				0.35										0.35
Sphaerophorus + *Sanionia*	18.4	-	-	-	-	-	-	-	22.7	-	30.0	-	-	
	5								10.5		6.1			21.6
Sanionia uncinata	-	2.9	21.9	-	27.2	30.7	-	3.5	-	-	-	-	-	
		0.6	1.7		1.4	1.2		0.8						5.7
Sanionia + muscic. lichens	-	-	-	2.8	-	-	-	-	-	6.2	-	-	5.4	
				0.3						0.3			0.6	1.2
Prasiola crispa	-	19.5	-	1.1	-	-	2.4	-	-	-	-	0.5	0.3	
		4		0.1			0.1					0.05	0.03	4.28
Mastodia tesselata	-	-	1.6	-	-	-	-	-	-	-	-	-	-	
			0.1											0.1
Muscicolous lichens	-	-	7.3	-	-	3.4	-	-	-	-	-	-	-	
			0.6			0.1								0.7
Deschampsia antarctica	-	-	0.3	-	-	-	-	-	-	-	-	6.6	5.2	
			0.02									0.7	0.6	1.32
Muscicolous lichens	-	-	-	-	1.4	-	-	-	-	1.9	-	-	-	
					0.07					0.1				0.17
Bryum argenteum	-	-	-	-	-	-	-	-	-	-	-	0.2	-	
												0.02		0.02
Polyrichastrum alpinum	-	-	-	-	-	-	-	-	-	-	-	-	0.9	
													0.1	0.1
Half ring fungi	-	-	-	-	0.1	0.3	-	-	-	-	-	-	-	
					0.005	0.01								0.015
Rocks used for nest building	33.8	12.3	9.8	21.6	11.3	12.4	15.5	29.9	6.5	9.2	-	14.9	10	
	9.1	2.5	0.7	2.6	0.6	0.49	0.5	6.4	3	0.5	-	1.6	1.1	29.09
Rocks around the nest		6.3	58.7	71.5	60	53.2	82.1		6.1	8.3	2.2	77.8	78.2	
		1.3	4.5	8.6	3.1	2.1	2.6		2.8	0.4	0.4	8.4	8.7	42.9
Total m^2	27.1	20.3	7.6	11.96	5.2	3.9	3.2	21.6	46.1	5.5	20	10.8	11.1	194.3

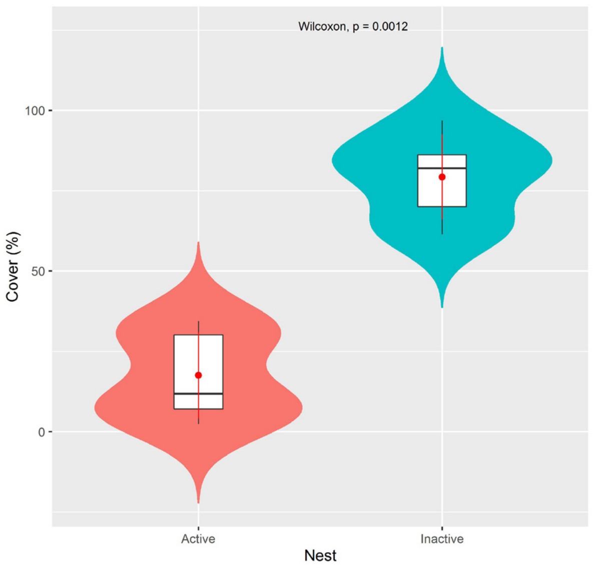


Figure 4. Differences in community coverage between nests. The red dots indicate the average values and the shape of the violin indicates the distribution of data variability.

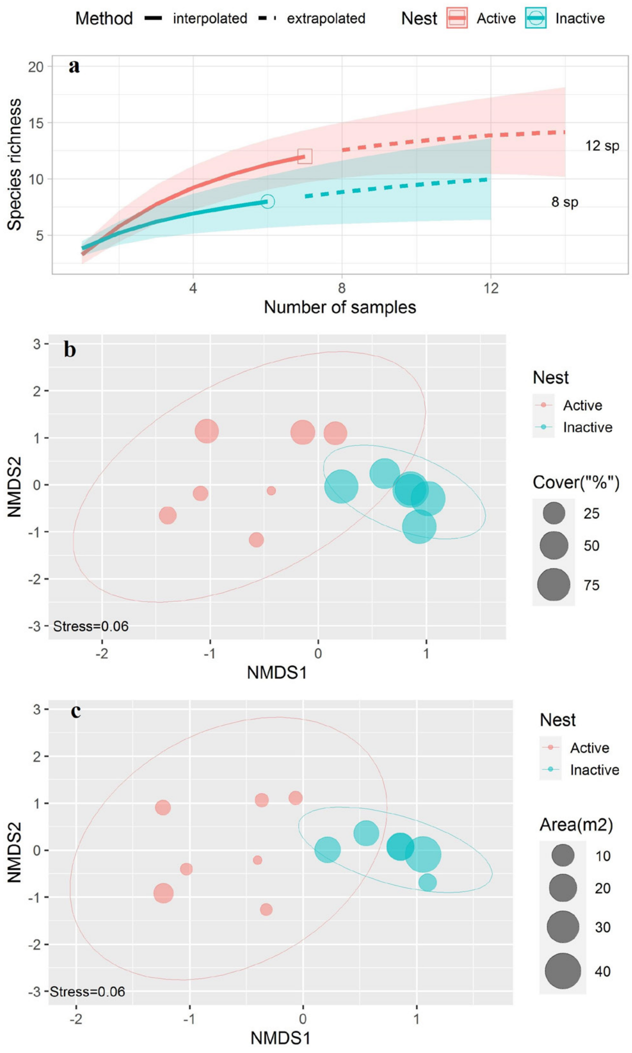
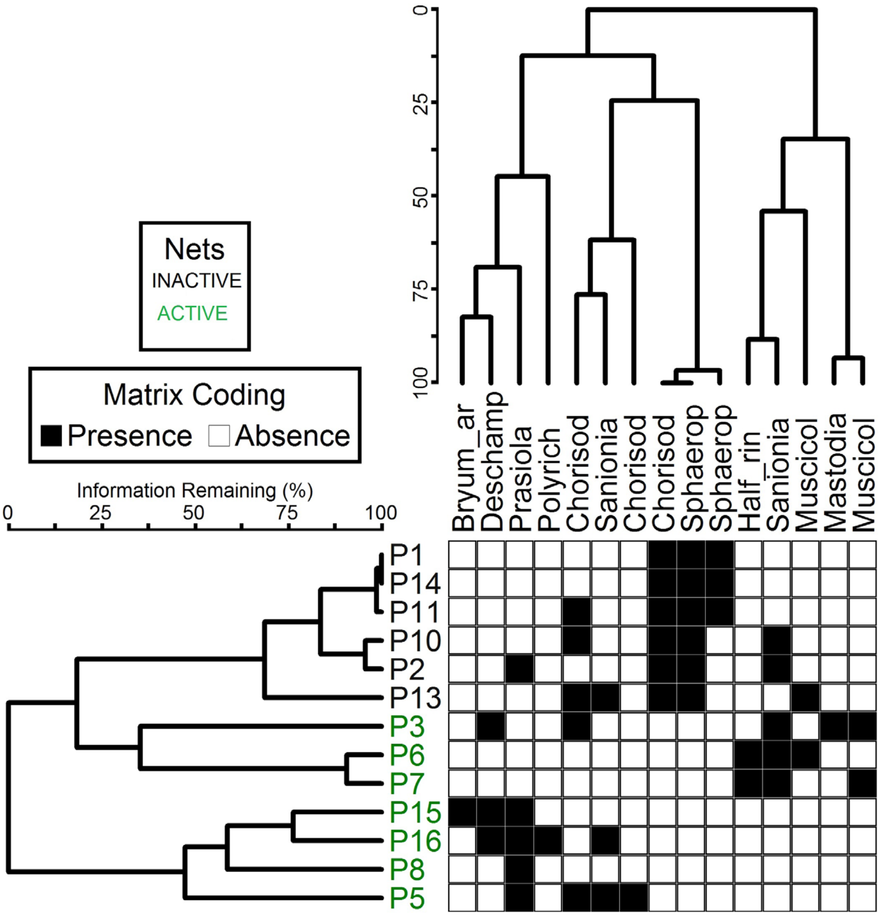


Figure 5. Sampled-based rarefaction (solid lines) and extrapolation curves (dashed lines) of species richness (a) between sampled nests. Rarefaction and extrapolation curves present the lines that represent the mean values and the bands the standard deviation with 95 % confidence intervals. Non metric multidimensional scaling (NMDS) based on species composition from different nests along a coverage gradient (b) and area of nests (c) in Maritime Antarctica.



	Bryum_ar	Deschamp	Prasiola	Polyrich	Chorisod	Sanionia	Chorisod	Chorisod	Sphaerop	Sphaerop	Half_rin	Sanionia	Muscicol	Mastodia	Muscicol
P1	□	□	□	□	□	□	□	■	■	■	□	□	□	□	□
P14	□	□	□	□	□	□	□	■	■	■	□	□	□	□	□
P11	□	□	□	□	■	□	□	■	■	■	□	□	□	□	□
P10	□	□	□	□	■	□	□	■	■	□	□	■	□	□	□
P2	□	□	■	□	□	□	□	■	■	□	□	■	□	□	□
P13	□	□	□	□	■	■	□	■	■	□	□	□	■	□	□
P3	□	■	□	□	■	□	□	□	□	□	□	■	□	■	■
P6	□	□	□	□	□	□	□	□	□	□	■	■	■	□	□
P7	□	□	□	□	□	□	□	□	□	□	■	■	□	□	■
P15	■	■	■	□	□	□	□	□	□	□	□	□	□	□	□
P16	□	■	■	■	□	■	□	□	□	□	□	□	□	□	□
P8	□	□	■	□	□	□	□	□	□	□	□	□	□	□	□
P5	□	□	■	□	■	■	■	□	□	□	□	□	□	□	□

Figure 6. Species distribution between nests using two-way cluster dendrogram based on the Jaccard dissimilarity metric.

DISCUSSION

We found five mosses, one fruticose lichen (*Sphaerophorus globosus*), one foliose lichen (*Mastodia tesselata*), *Deschampsia antarctica* (Antarctic grass), *Prasiola crispa* (alga), and various unidentified muscicolous and saxicolous nitrophilous lichens associated with the 13 studied nests. The species are regularly arranged in a definite pattern of zonate circles or semi-circles, never before described around petrel nests in Antarctica. For southern giant petrel nests, likely due to the high nitrogen supply, these succession patterns were found in most nests evaluated. This pattern is not expected to occur in sub-Antarctica breeding sites, as plants are used for nest building in Southern South America and in the South Georgia Islands (Poncet et al. 2020). Other Antarctic flying seabirds also do not display this nest construction method, instead of using available plant materials. The skuas (*Catharacta* spp.) and kelp gull (*Larus dominicanus*) use mosses and lichens (sometimes also angiosperms) for nest building, while shag (*Phalacrocorax atriceps*) uses algae and mud (Quintana & Travaini 2000). Penguins use only rock fragments but gentoo penguins (*Pygoscelis papua*) are sometimes in slender colonies and close to vegetal formations (Quintana 2001). The interference of those species on plant formation surrounding their nests still need to be evaluated.

Southern giant petrel nests in Antarctica are built using pebbles, with no collection of the surrounding vegetation, unlike other birds such as the skuas (*Catharacta* spp.) (Albuquerque et

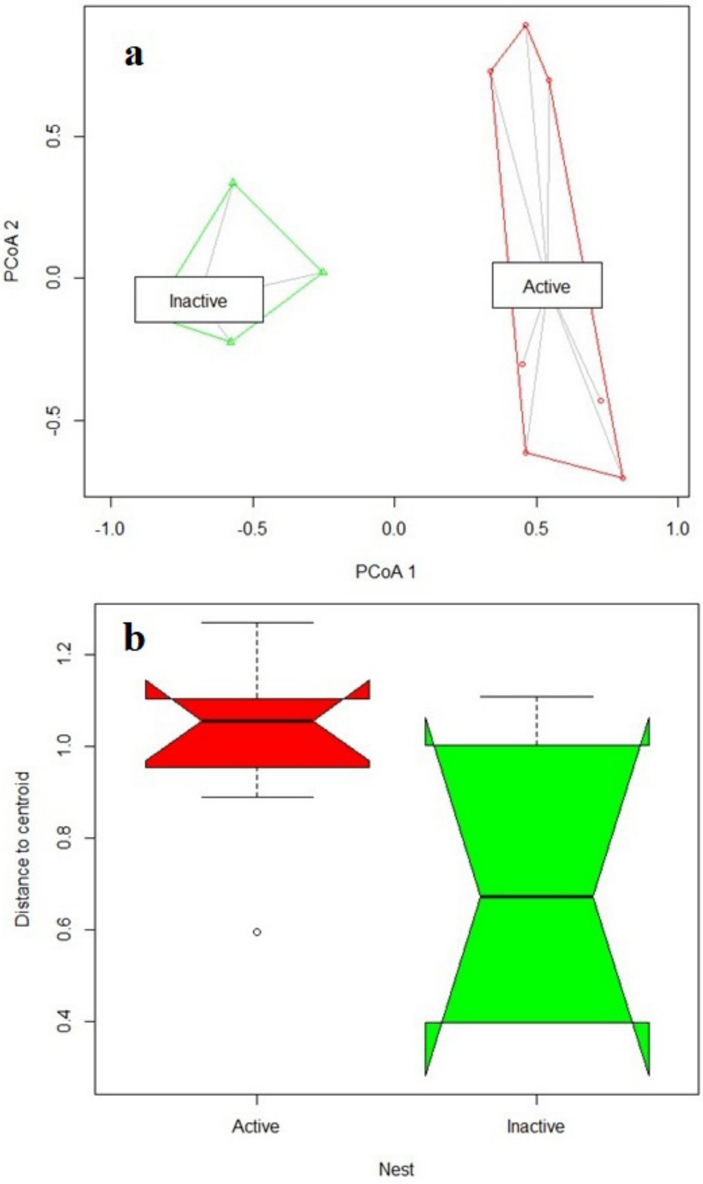


Figure 7. Principal coordinate analysis (PCoA) based on the Jaccard dissimilarity metric (a), and differences in beta diversity (b) between sampled nests.

al. 2012). Therefore, the vegetation around the nesting area is relatively well preserved, despite the long period (approximately three months) of residence of breeding birds in the area (Cooper et al. 2001). Sometimes, the permanence of females is longer than that of males, despite the imminent failure in reproduction, females can stay on the nest up to one month after male abandonment (Schulz et al. 2014). However, non-breeding individuals and failed breeders also stay in the colony and even on nests during the breeding season. Therefore, the direct impact (when taking non breeders into account) is restricted to trampling during nest building (repair and maintenance), landing and departure, and feces deposition.

In this context, the results of this study corroborate that the nests use or maintenance during breeding bird's dynamic can be considered a biotic filter that determines marked changes in community coverage, community composition, and species turnover.

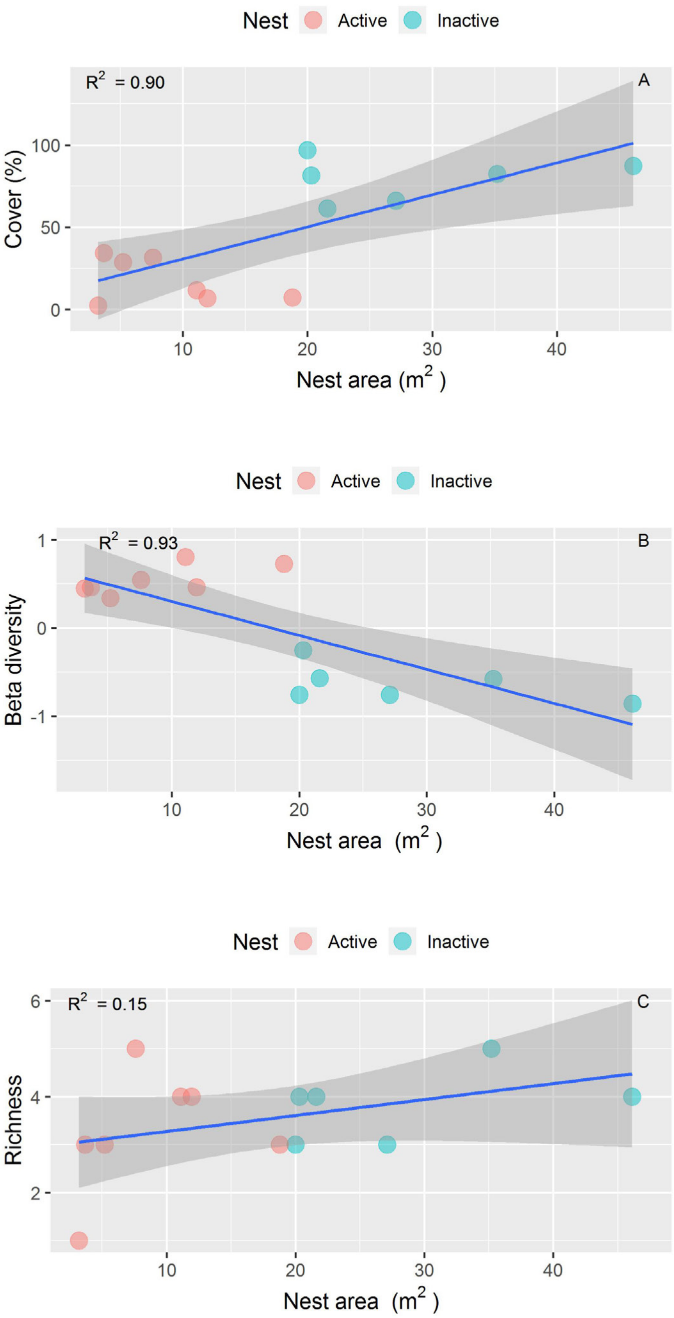


Figure 8. Relationships between the nest area and coverage (a), beta diversity (b), species richness (c) and nest groups (inactive and active). Solid lines represent fitted (predicted) values of the models, and the shaded polygons represent the 95 % associated with the modeled predictions.

Specifically, a microhabitats differentiation induced by the nest's construction (active nests) and abandonment (inactive) dynamics of southern giant petrel is evident, which probably determines the dynamics of colonization, growth and species turnover along succession. Despite not having evaluated the specific cryptogam communities along a succession dynamic, it is assumed that the reproductive behavior variations of southern giant petrel may induce differences on chemical and physical properties of substrates; consequently, it may generate an abiotic filtering and promotes high β-diversity and low species similarity between active and inactive nests. Previous studies showed that pedoenvironmental and soil fertility have significant effects on species composition and beta diversity of cryptogam communities in Antarctica (Schmitz et al. 2020a, 2020b, 2021). Based on gradient analysis, the pedoenvironmental filtering of cryptogam communities has been previously tested on Maritime Antarctica (Schmitz et al. 2020a, b, 2021). However, there are still gaps in knowledge about the effects of bird nest dynamics on cryptogam communities.

Surprisingly, the fruticose lichen *Sphaerophorus globosus* can survive in the first ring of plants surrounding southern giant petrel nests. Petrels can weigh up to 5.4 kg (Warham 1962). In Stinker Point, a sample of 23 birds had a mean weight of 4.3 kg (Krüger et al. 2018) and movements of adults and chick could easily break this thallus. Lichens are frequently associated with *Chorisodontium acyphyllum* in Antarctica (Øvstedal & Lewis-Smith 2001), including in regions near nests.

The results of beta diversity allow presuming that a deterministic pattern shape by habitat filtering (i.e., Schmitz et al. 2020a, 2021) is possible, which must be proven through the co-variation of nest categories (active and inactive) and nest distribution along environmental gradients. Moreover, the positive relationship of coverage and nests area, and the negative relationship of beta diversity and nests area, may indicate that recently active nests promote higher species richness, community composition variability and beta diversity due to the high resources availability (i.e., nutrients, space) for coexistence during initial successional stages. Conversely, during advanced successional stages on abandoned inactive nests there is lower species richness and turnover due to the high dominance of few species (i.e., higher coverage) and limited resources.

The cryptogam communities in the new area near Goeldi Refuge is mainly composed by the pioneer algal species *Prasiola crispa*. This macroscopic alga colonizes nests because it is an extremely nitrophilous taxon, found in nesting areas of birds in the north pole, being common in all habitats rich in organic nitrogen (Broady et al. 2012, Richter et al. 2014, 2015). Unfavorable habitat conditions caused by constant treading by birds change the algal mat to a monostromatic lamellar, cracked form, which was also observed in our study (Pietryka et al. 2016). In our study 38,5% of the nests a ring of this alga is found in the first ring together with the rock fragments of the nest (including inactive nests), where feces deposition is higher.

The Antarctic moss turf generally contains the characteristic species *Chorisodontium aciphyllum*, *Polytrichastrum alpinum*, *Polytrichum piliferum* Hedw. and *Polytrichum juniperinum* Hedw. (Ochyra et al. 2008). *C. aciphyllum* grows directly on rock fragments; however, as the soil is formed, it is replaced by *Sanionia uncinata*, which is clearly seen on Stinker Point, Elephant Island. This was also the case around the nests, where species occurred according to the presence of soil.

Compared with the plant composition found around the skuas nests (Albuquerque et al. 2012), the diversity rates in southern giant petrel nests are slightly lower (4.2 species/nest for skuas and 3.71 for petrels). The main mosses found in skua nests typically occur in plant communities from Antarctic ice-free areas at higher frequencies (Victoria et al. 2009), such as *Sanionia uncinata*, which are often observed in association with muscicolous lichen species *Cladonia borealis* S. Stenroos, *Usnea antarctica* Du Rietz, and *Leptogium* sp. This moss species is considered the most abundant associated lichen, occurring together with other fruticose lichen species (Victoria et al. 2006). For southern giant petrel nests, all species found, mainly in the inactive nests, are common in sites with the highest nitrogen content, such as penguin rookeries (Putzke & Pereira 1990).

CONCLUSIONS

The results demonstrate that southern giant petrel (*Macronectes giganteus*) nest (inactive and active) determine differences in diversity, composition and structure (i.e., community coverage) of cryptogam communities on Stinker Point, Elephant Island, Maritime Antarctica. The concentric rings generated by species composition are exclusive in the nest directly influenced area and may contribute to general vegetation coverage.

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