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Effect of drought disturbance in a sclerophyll forest on the micromammal community in the Río Clarillo National Park, Metropolitan Region, Chile

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Abstract

Background Micromammals play an important role in mediterranean ecosystems. The "megadrought" in the sclerophyll forest has caused a "browning" that implies, among other things, the reduction of canopy cover. The effects of forest browning on the taxonomic and functional diversity of micromammals were evaluated.

Methods Forests with high and low disturbance degree were characterized based on the level of browning and canopy cover. To study the community of micromammals in these forests, the Capture-Mark-Recapture method was used with Sherman traps. Community indices such as Shannon–Wiener and Pielou were calculated. The Coefficient of Variation was used to study functional diversity for each trait separately. Multivariate measures FRic, FEve and FDiv were used to determine multidimensional diversity.

Results We observed differences in species composition and in richness, diversity, and cover variables between forest types. However, micromammal communities were similar in taxonomic and functional diversity in highly and slightly disturbed forests.

Discussion The micromammal community appears to show some resistance to forest changes due to disturbance, which could be related to their generalist diet and high dispersal capacity. The presence of the genus *Rattus* could entail a decrease in native rodent diversity and could have a greater effect than the disturbance of the forest due to drought. These results are an invitation to conduct long-term studies to better understand the potential vulnerability of the different micromammal species to disturbed sclerophyll forests affected by drought.

Keywords Browning, Functional Diversity, Mediterranean Forest, Taxonomic Diversity

Background

Environmental disturbances, such as drought, reduce habitat availability and increase habitat isolation, which reduces species richness and can modify community structure [49, 71]. In the mediterranean area of Chile, one of the 25 biodiversity "hotspots" worldwide, the effects of climate change have caused a severe drought has impacted sclerophyll forests [19], producing a visual phenomenon called "browning". This phenomenon translates into the reduction of greenness and drying of the foliage of the trees, ending with the falling of the

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leaves, thus reducing canopy coverage. Between the north of Santiago and the southern limit of the Cantillana range, at least a third of the sclerophyll forest is decreasing in greenness and vigor [48], and this situation is expected to be aggravated as the rainfall deficit continues [68]. These habitat structural changes involve the loss or degradation of ecosystem components that are used by animals to meet different requirements, such as reproductive sites, resting sites, shelters and feeding grounds [69]. Thus, habitat alteration can alter biological diversity, which has been documented for micromammal communities in Chile [32, 49, 71, 72]. In some cases, disturbances reduce the overall abundance and density of small mammals, because of a lower habitat quality [18, 49, 59, 72] and body mass and size decrease as well [5]. Moreover, regarding trophic guilds, omnivores and herbivores vary according to a landscape gradient that goes from areas with greater disturbance with little vegetation (predominance of omnivores) to forests with denser vegetation where herbivores tend to be more abundant [58].

To assess the impact of these changes in sclerophyll forests, it is important not only to understand how the number and abundance of species are altered, but also to be able to identify what traits make species more vulnerable, to come closer to understanding the functions that may be at risk of being lost [16, 17]. For this, the use of functional diversity (FD) is useful as it can reflect the variation of traits within a community and tends to be more susceptible than species richness to environmental perturbations [9]. There are three main measures of FD that incorporate multiple traits: functional richness (FRic), which reflects the amount of functional space occupied by the species of a community regardless of their abundances; functional evenness (FEve), which represents the homogeneity in the distribution of the abundances of the species of a community in a functional space; and functional divergence (FDiv), which is a measure of functional similarity between the dominant species of a community [41]. These metrics provide complementary information regarding the FD, are independent of each other and do not depend on the number of species, evenness, nor on taxonomic diversity [10].

Among forest animals, micromammals are relevant because they can greatly influence the structure and composition of plant communities and the ecological processes of the ecosystem [50]. In general, micromammals contribute to the ecological succession processes of plants in ecosystems through dispersal, predation, and seed recruitment [22]. In addition, they are important prey for raptors and carnivorous mammals [28, 29, 60], therefore being key species in food webs.

To evaluate changes in FD in micromammals, it is necessary to identify relevant traits of their response to environmental changes, such as morphological traits and trophic guild traits [58]. These traits cover aspects of the spatial dimension and the resources used by these species, allowing us to obtain an approximation of the role of species, biodiversity and ecosystem functions [23].

In this study, the responses of a micromammal community to the damage and loss of canopy resulting from drought in a sclerophyll forest were assessed. Aspects related to the taxonomic and functional diversity of micromammals were studied. We hypothesized that the disturbance resulting from severe drought in the sclerophyll forest of central Chile is causing a decrease in taxonomic diversity (lower richness and abundance of native species), a lower variation in morphological traits (exclusion of individuals with larger body size) and in trophic guilds (predominance of omnivory and insectivory) of the community of micromammals.

Methods

Study area

The sampling was carried out in the Río Clarillo National Park located in the municipality of Pirque, Metropolitan Region, Chile The area is under the influence of the semi-Andean mediterranean climate [56] where the mediterranean Andean sclerophyll forest of *Quillaja saponaria–Lithraea caustica* occurs [40]. Existing park records of the micromammal community are based on direct observations or bone remains contained in raptor pellets. The reported community is made up of a marsupial and 12 rodents, out of which three are exotic species (Table 1).

Sampling design

To select the sampling sites, a satellite image interpretation was carried out through the Google Earth software.

Table 1 Statistical summary of browning level and vegetation cover in both forest categories

Forest category	Statistical	Browning (%)	Cover (%)
LDD	Mean	8.75	69.5
	SD	10.3	3.45
	Min	0	66.6
	Max	20	73.3
HDD	Mean	55	37.55
	SD	2.9	8.2
	Min	52.5	28.6
	Max	57.5	48.3
ANOVA	$F_{1,6}$	49.54	20.94
	p	0.0004	0.00379

In this image, changes in color and texture of the vegetation cover were reviewed to identify the places where the forest presented browning and the places that did not. Once the areas were selected, field work was carried out to inspect the polygons, which were selected if they met the following criteria: (1) presence of native forest, and (2) presenting a homogeneous unit of vegetation of at least of 8.100 m^2 for sampling micromammals. Plant and micromammal sampling was conducted during the autumn in the Southern Hemisphere, between March and April 2022.

Plant community

At each sampling site, five 20 × 20 m plots were randomly selected. For each plot, the level of browning and vegetation cover was determined. Browning was obtained by visually estimating the percentage of the affected canopy (0%: no browning; $< 25\%$: low level; $\geq 25\%$ and $< 50\%$: medium level; $\geq 50\%$ and $< 75\%$: high level and $\geq 75\%$: very high level). Vegetation cover was obtained by determining the proportion (%) of land in the plot occupied by the perpendicular projection of the canopy of the woody species [7]. To examine the potential differences in the structure of the forest categories, the cover values of the woody species recorded in the 40 sampling plots were used. Dissimilarity between samples was visualized by non-metric multidimensional scaling (nMDS) using the metaMDS function in the *vegan* package in R and differences in composition between forest categories were assessed using a PERMANOVA with Bray–Curtis distances.

To characterize the specific diversity among the forest categories, the diversity of plant species was determined using Shannon–Wiener's diversity index $[H' = -\Sigma^{s} (p_i \log_2 p_i)]$. Pielou's evenness index was also estimated for each forest category (J') $[J' = H'/H'_{max}]$. To determine whether plant species richness, diversity, and evenness differ significantly among the forest categories, an analysis of variance was conducted.

Forest classification according to degree of disturbance

The disturbance degree of the forest was determined based on the proportion of canopy affected by browning and the vegetation cover in the sampling plots. To establish the categories, we considered the following criteria: (i) Forest with a low disturbance degree (LDD): proportion of canopy browning $< 50\%$ and vegetation cover $\geq 50\%$, (ii) Forest with a high disturbance degree (HDD): proportion of canopy browning $\geq 50\%$ and vegetation cover $< 50\%$. We therefore selected four sampling sites with LDD and four sites with HDD (Fig. 1).

Micromammal community

A 60 × 135 m grid was installed in each sampling site using 50 240 × 80x90 mm Sherman traps (43 Sherman and 7 Sherman modified) placed every 15 m, covering an area of about 8.100 m^2. The traps were installed at 4:00 p.m. and checked early the next day. All traps were kept active for three consecutive nights. Crushed oats

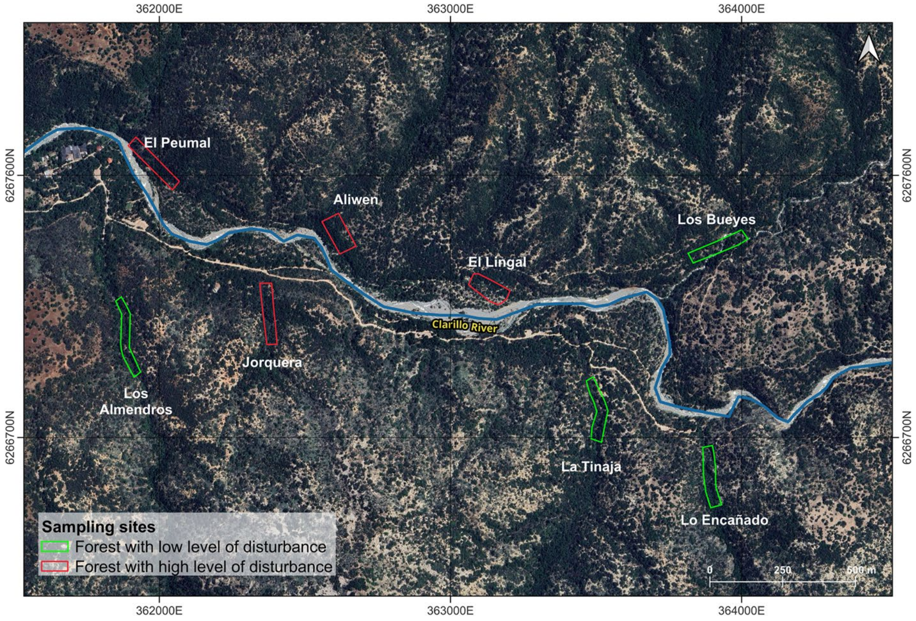

Fig. 1 Sampling sites categorized according to level of browning in the study area of Río Clarillo National Park, Metropolitan Region, Chile

with vanilla essence were used as bait. For every captured animal, the species was identified, and standard body measurements were taken following to the proposal of Hall [25]: total length, vertebral tail length, hind leg length with claw, and ear length. All measurements were expressed in mm and weight in g. We also recorded the sex of the animals, and determined the age (i.e., juvenile or adult) based on body measurements and coat characteristics. Before releasing them, an individual tag was placed on the ear: ear tag model 1005-1L1, one cm long and 0.25 g in weight. Biosafety equipment approved by the Chilean Ministry of Health was used to handle the animals (Fig. 2). The taxonomy used for scientific names and species classification was based on the list by D'Elía et al. [11]. We only considered micromammals whose weight did not exceed 500 g. The captures required permission from the Metropolitan Agricultural and Livestock Service (*Servicio Agrícola y Ganadero (SAG) región Metropolitana*), through Exempt Resolution No. 197/2022, and with the approval of the Bioethics Committee of the Faculty of Life Sciences of the Andrés Bello University, Act No. 008/2022.

icromammal community analysis

Community indices (richness, relative abundance, diversity and evenness) were calculated for both forest categories. Alpha (α) diversity was determined by Shannon–Wiener's diversity index and evenness was estimated with Pielou's index. Subsequently, an analysis of variance was used to evaluate differences between both forest categories. Dissimilarity in community structure between the forests with low and high degree of disturbance was visualized with a nMDS using the metaMDS function, and differences in species composition were assessed by a PERMANOVA using Bray–Curtis distances.

The functional traits were selected following the work of Gómez-Ortiz and Moreno [21] and Paniccia et al. [58]. Importance was given to those functional traits of the "response" type, since these are the ones with which species respond (functional change) to environmental changes [39]. We also considered the traits that were measured in situ at the time of capture (body measurements). A total of seven functional traits were selected, one related to the life history of the species (omnivorous, herbivorous and insectivorous trophic guild) and the other six, related to morphology (standard body measurements). Trophic guild: to estimate the functional diversity of the trophic guild trait, Shannon–Wiener's diversity index, Simpson's dominance index and Pielou's evenness were used. To test the difference in functional diversity of the trophic guild trait between the forests with low and high degree of disturbance, an analysis of variance was used. Morphological traits: the functional diversity of morphological traits was estimated using the coefficient of variation of each trait separately within the community identified in both forest categories. Only adult individuals were considered for this analysis, excluding juveniles due to small sample sizes. Analyses of variance were used to test whether there were differences

Fig. 2 Working procedure with micromammals: **A** Capture (*Octodon lunatus*); **B** Morphometric recording (*Thylamys elegans*); **C** Ear tagging (*Abrothrix longipilis*) and (**D**) Release (*Phyllotis darwini*)

in trait variation between the two forest categories. Functional diversity (FD): in order to analyze the FD of the traits as a whole, we considered three multivariate FD metrics: functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv) [41]. These indices were calculated using R software with the dbFD function of the FD package. To test whether there were differences between each FD index between the two forest categories, analyses of variance were used as well.

Results

Plant community

Differences in the level of browning and coverage between the two forest categories were confirmed (Table 1 and Fig. 3). The sites Lo Encañado, La Tinaja, Los Almendros and Los Bueyes were categorized as forest with a low degree of disturbance, where browning levels did not exceed 20% and canopy cover exceeded 70%. The Jorquera, El Lingal, El Peumal and Aliwen sites were categorized as forests with a high degree of disturbance, with browning levels that started at 52.5% and cover values that did not exceed 50% (Fig. 4).

The species that make up both the forests with low degree of disturbance (LDD) and those with high degree of disturbance (HDD) are the species that commonly make up the Andean mediterranean sclerophyll forest. The most abundant species were *Cryptocarya alba* and *Lithraea caustica*. We observed differences in the composition of plant species between the two forest categories (ANOVA $F_{1,39} = 18.36$; $p = 0.027$). Moreover,

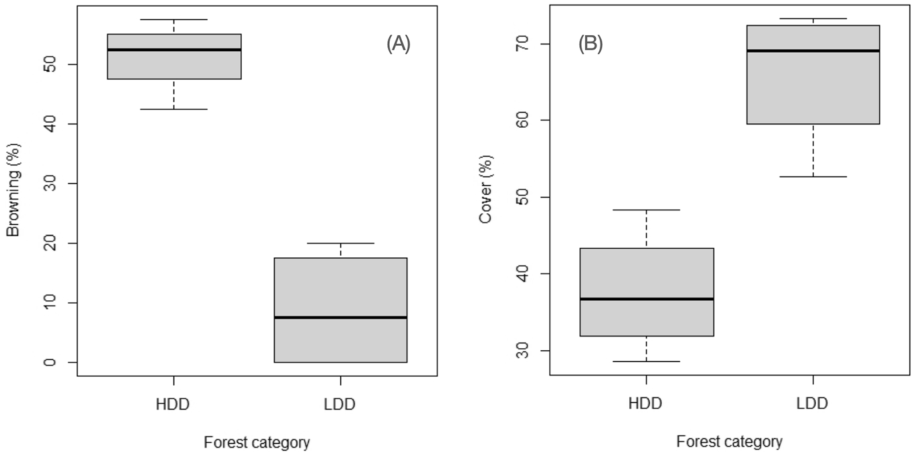

Fig. 3 Boxplot representing the level of browning (**A**) and vegetation cover (**B**) of the two forest categories: low disturbance degree (LDD) and high disturbance degree (HDD)

Fig. 4 General view of the condition of the low disturbance forest (left) and the high disturbance forest (right)

plant diversity (i.e., cumulative richness and Shannon–Wiener's diversity index) differed significantly between the forest categories, with higher values in the forest plots with LDD. There were no significant differences in the evenness of plant species (Table 2).

Micromammal community

The comparison of the micromammal community between the two forest categories did not show any significant differences for any of the variables of taxonomic diversity: abundance, richness, Shannon–Wiener's diversity index, Pielou's evenness index and Simpson's dominance index. Six species were recorded in each of the forest categories, one marsupial and five rodents (Table 3). Furthermore, there were no significant differences in species composition of micromammals (ANOVA $F_{1,7}=0.38$; $p=0.82$).

Regarding functional diversity, in both forest categories, the same trophic guild classes were recorded: three omnivorous species, two herbivores and one insectivore. The variables of diversity (H'), dominance (D) and evenness (J') of trophic guilds did not show significant differences between forests with LDD and forest with HDD (ANOVA H': $F_{1,4}=0.01$; $p=0.92$, D: $F_{1,4}=0.009$; $p=0.93$ and J`: $F_{1,4}=0.006$; $p=0.81$).

Regarding morphological traits, although we observed greater variation (CV) of morphological traits in the forest with a low disturbance degree, no significant differences in the CV or in the mean values of the morphological traits were found between the two forest categories (ANOVA $F_{1,10}=0.16$; $p=0.695$; Table 4).

The results of the analysis of functional diversity of traits of micromammal communities using three multivariate indices (i.e., FRic, FEve, FDiv), did not show any significant differences between the two forest categories (Table 5).

Table 2 Values of Shannon–Wiener's diversity index (H'), Pielou's evenness index (J') and the richness (S) of plant species recorded in the two forest categories, low disturbance degree (LDD) and high disturbance degree (HDD)

Variable	LDD	HDD	ANOVA	
			$F_{1,6}$	*p*
S	34	30	12.49	0.0123
H´	2.758	2.190	9.179	0.0231
J´	0.782	0.643	0.333	0.585

Table 3 Micromammal species recorded in the two forest categories: low disturbance degree (LDD) and high disturbance degree (HDD)

Species	LDD	HDD		
	n	n		
Thylamys elegans	13	8		
Octodon lunatus	3	1		
Abrothrix longipilis	0	1		
Abrothrix olivacea	1	0		
Phyllotis darwini	4	2		
Rattus norvegicus	3	1		
Rattus rattus	7	5		
			ANOVA	
Abundance (N)	31 ± 4.8	18 ± 1.2	$F_{1,6}=1.67$	$p=0.243$
Richness (S)	6 ± 1.2	6 ± 1.2	$F_{1,6}=0.077$	$p=0.791$
Diversity (H')	1.527 ± 0.5	1.442 ± 0.5	$F_{1,6}=0.218$	$p=0.657$
Evenness (J')	0.852 ± 0.4	0.804 ± 0.4	$F_{1,6}=0.082$	$p=0.784$
Dominance (D)	0.73 ± 0.3	0.70 ± 0.3	$F_{1,6}=0.295$	$p=0.607$

The studied variables are presented with their respective results and analysis of variance (± SD)

Discussion

The browning of the forest does not seem to be affecting the micromammal community for the moment, since our analyses showed no significant differences in the taxonomic and functional diversity of the community between forests with low and high degree of disturbance, although significant differences were observed in the composition, cover, species richness and diversity between forest categories. The life history characteristics of most native micromammal species present in the study area, such as short generation times and high fertility rates [66], dispersal capacity [34, 51], generalist resource use with a wide variety of food habits [26, 46, 50, 57], and flexibility in physiological mechanisms [6], favor a

Table 4 Coefficient of variation (CV) values and the mean of each morphometric trait measured in the micromammal community for the two forest categories, low disturbance degree (LDD) and high disturbance degree (HDD)

Trait	LDD		HDD	
	CV	Mean	CV	Mean
Total length	0.26	247.54	0.23	252.92
Tail length	0.27	135.18	0.28	135.35
Body length	0.30	112.36	0.21	117.57
Leg length	0.47	26.13	0.43	26.64
Ear length	0.27	18.5	0.20	19.00
Weight	0.85	84.52	0.74	81.17

Table 5 Values of multivariate indices of functional diversity of morphological traits measured in the micromammal community in the two forest states, low disturbance degree (LDD) and high disturbance degree (HDD)

Forest	Sites	Fric	Feve	Fdiv
LDD	Los Almendros	1.86	0.30	0.73
	La Tinaja	3.20	0.67	0.59
	Lo Encañado	0	0	0
	Los Bueyes	0	0	0
HDD	Jorquera	3.35	0.97	0.88
	EL Lingal	1.86	0.45	0.75
	El Peumal	2.67	0.87	0.74
	Aliwen	0	0	0
ANOVA:		$F_{1,6}=0.43$ $p=0.533$	$F_{1,6}=1.48$ $p=0.269$	$F_{1,6}=0.89$ $p=0.38$

Fric Riqueza funcional, *Feve* Equitatividad funcional y Fdiv, Divergencia funcional

Fric Functional richness, *Feve* Functional evenness and *Fdiv*, Functional divergence

rapid response to environmental changes [27, 35, 36, 44], which could enable species to continue inhabiting habitats affected by browning. In addition, the presence of vegetation patches less affected by drought, with greater forest coverage and connectivity, is another factor that could be minimizing the effect of browning on micromammals, especially on taxonomic diversity [30, 53, 64]. An important aspect to highlight is that the community of micromammals recorded in the study area consists mainly of a group of species (*A. olivacea*, *A. longipilis*, *P. darwini*, *T. elegans*) that are abundant, with a wide distribution and large home ranges [26, 45, 51]. This, together with the other characteristics already mentioned, seems to form a group of fauna with sufficient conditions to cope with browning.

For now, according to our results, there is no loss of micromammal species as a result of browning, which could indicate that the forest ecosystem continues to receive the environmental services that this type of fauna provides. That the micromammal community still maintains its characteristics despite the level of disturbance of the sclerophyll forest is important considering that these species contribute positively to the ecological processes of the ecosystem (seed dispersal, spore dissemination and insect predation [22, 43]), facilitating the maintenance, good functioning and productivity of native vegetation, which could help the resistance and resilience of the forest against disturbances such as drought [67]. It would be relevant to continue monitoring the micromammal community, hopefully on a larger time scale, to identify possible future effects of browning.

The diversity (in terms of richness and abundance) of micromammal species tends to decrease in the face of habitat disturbance that implies a reduction in vegetation cover [30, 53, 65, 72], which may also cause the displacement of species more specialized in forest habitats [8]. Although the canopy cover of the forest with the highest degree of disturbance was lower than in the forest low disturbance degree, no significant differences became evident in terms of richness and abundance of the micromammal community. This result could be partially explained by the fact that the community is represented mostly by sigmodontine rodents, which are habitat generalists [50] and have a wide variety of feeding habits, from herbivorous species to variable degrees of omnivory [26, 50, 57]. The studies of Arroyo-Rodríguez et al. [2] and Paniccia et al. [58] and the studies of Silva [63] and Zúñiga Rau et al. [72] in Chile show that in disturbed environments, there is a predominance of omnivorous species over insectivores and herbivores. However, Guabloche et al. [24] indicate that the diet of a small rodent may be more varied and complex than the standard trophic categories (herbivore or insectivore), which could explain the lack of difference in the trophic guild in both forest categories.

Moreover, it is possible that the effect of drought, specifically the browning of the forest, does not have a strong enough effect on the availability of resources yet, especially food and shelter, as to reduce the diversity of micromammals that inhabit the forest with the highest degree of disturbance. As browning is associated with environmental changes related to climatic variables [48] that could modify the availability of resources, which in turn causes changes in the abundance of certain populations of micromammals [1, 27, 35, 52, 55, 72], it is necessary to conduct further sampling in the study area to detect possible interannual variations of the communities that inhabit the forest disturbed by drought, since only one season of the year was sampled in this study, which could be insufficient to demonstrate the effects of browning.

The presence of the genus *Rattus* in a protected area such as the Río Clarillo National Park is an important precedent to set, and further studies would be necessary to assess the prevalence of the genus since it triggers ecological impacts such as predation, transmission of parasites, diseases, habitat modification and alteration of food webs [38]. The fragility of Mediterranean ecosystems, especially those exposed to disturbances, such as our study area, make apparent that the presence of invasive exotic species such as those of the genus *Rattus* constitutes a high-risk element for the conservation of native fauna [3, 33, 37, 38, 64], as they can displace or prey on other small mammals, as documented in Argentina, where *Rattus* has become a predator of the mole mouse *Chelemys macronyx* [62].

If a similar impact of *Rattus* is occurring on the community of native micromammals in our study area, it could be interfering with the efforts to detect the effects of browning on the community.

The response of different micromammal species to disturbance depends on their morphological characteristics [15, 53, 61]. For example, leg length is related to vegetation cover [53], and large rodent size is related to predation risk [30, 31, 47]. On the other hand, body size influences the capacity for survival and reproduction in the face of changes in habitat; larger body size in disturbed environments with low canopy cover increases the probability of predation [30, 31, 47]. Thus, species that inhabit disturbed habitats are often associated with a small body size [4]. In our study, there was no evidence that morphological characteristics of the species were related to their response to disturbance. The browning of the forest has not impacted any species of micromammals, regardless of their traits.

The use of the functional diversity (FD) indices FRic, FEve and FDis is recommended since it reveals the impact of disturbances on biotic communities in the best possible way [70]. These indices analyze the functions of organisms in the ecosystem, achieving a better reflection of their role in their habitat [14]. Our results allow us to infer that some of the potentially available resources could currently be unexploited and could result in a reduction in the productivity of an ecosystem [41]. In our study, no differences were detected in the DF of the micromammal community between forest categories, so we can infer that browning has not exerted an effect on the role of micromammal species inhabiting the BAP. In turn, as there is no loss of species in the BAP, it is expected that there is no loss of DF either [17]. The non-identification of DF response in the BAP could reveal the existence of species turnover and low ecological plasticity of species [16]. Some parts of the functional niche would be occupied but underutilized. This could increase the opportunity for potential invaders to establish [41], something that was perceived in our study with the important presence of the genus Rattus. Finally, it should be noted that browning does not exert pressure on competition between species, as no differences in functional divergence were identified [15].

Appendix

Table 6 Table A1 Micromammal species (< 500 g) recorded in Río Clarillo National Park

Species	Díaz [12]	Díaz et al [13]	Zurita et al. [73]
Thylamys elegans (Waterhouse, 1839) /E	+ (e)	+ (e)	0
Abrocoma bennettii (Waterhouse, 1837) /E	+ (e)	+ (e)	+ (e)
Octodon degus (Molina, 1782) /E	0	0	+ (e)
Octodon lunatus (Osgood, 1943) /E	+ (e)	+ (e)	0
Spalacopus cyanus (Molina, 1782) /E	0	+ (d)	0
Abrothrix longipilis (Waterhouse, 1837) /N	+ (e)	+ (e)	+ (e)
Abrothrix olivacea (Waterhouse, 1837) /N	+ (e)	+ (e)	+ (e)
Oligoryzomys longicaudatus (Bennett, 1832) /N	+ (e)	+ (e)	+ (e)
Loxodontomys micropus (Waterhouse, 1837) /N	0	+ (e)	0
Phyllotis darwini (Waterhouse, 1837) /N	+ (e)	+ (e)	0
Mus musculus (Linnaeus, 1758) /I	0	0	+ (e)
Rattus norvegicus (Berkenhout, 1769) /I	+ (e)	+ (e)	+ (e)
Rattus rattus (Linnaeus, 1758) /I	+ (e)	+ (e)	+ (e)

Record: +(e): by bone remains in pellets; +(d): by direct observation; 0: not recorded, *N* Native species; *E* Species endemic to Chile, *I* Introduced species

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Authors' contributions
SF, CS, GS and VQ designed the experiment. SF and CS conducted the sampling. SF, GS and VQ conducted the analyses and wrote the original draft. All authors read and approved the final version of the manuscript.

Data availability
All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
Does not apply.

Consent for publication
Does not apply.

Competing interests
The authors have no competing interests to declare.

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