

Article

Understory Forage Quality for Grazing Animals in Chilean Patagonian Forests

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Abstract: Native forests provide forage for grazing animals. We investigated whether native and exotic vegetation promotes the potential animal load (PAL, ind ha⁻¹ yr⁻¹) for cattle (*Bos taurus*, ~700 kg) and sheep (*Ovis aries*, ~60 kg) in contrasting native forest types and canopy cover (closed, semi-open, open). This study was conducted in Chilean Patagonia (−44° to −49° SL). Vegetation cover (%) and growth habit data (trees, shrubs, forbs, graminoids, ferns, lianas, lichens, and bryophytes) were collected from 374 plots (>5 ha) in different environments: coihue (*Nothofagus dombeyi*, CO), lenga (*N. pumilio*, LE), mixed *Nothofagus* forests (MI), ñirre (*N. antarctica*, ÑI), evergreen forest (SV), and open land (OL). We combine this data with literature and laboratory analyses (e.g., crude protein, %) to develop PAL values for seasons. Data sampling was evaluated using descriptive analyses and uni- and multi-variate analyses (ANOVA, MCA, GLM). Results showed that closed forests had more native species (~56.6%) compared to open forests (~33.3%), while OL had higher cover of exotic species (~68.6%). LE presented the highest native species cover (~58.0%) and ÑI presented the highest exotic species cover (~53.0%). Closed forests had fewer exotic species than semi-open and open forests, which supported higher cover of native plants ($p < 0.01$). Forbs were the dominant growth habit in closed forests, while graminoids were dominant in OL (~45.8%). Multivariate analyses showed that LE and CO were associated with lower PAL values, explaining 91.2% variance. GLMs showed that the PAL increased in ÑI and the spring season, with forbs and graminoids having positive effects and shrubs and trees having negative effects ($r^2 = 0.57$ – 0.67). Our analyses also showed that exotic species dominated environment types with a high PAL, particularly during spring and summer, when cover increased. This indicates a trade-off between forage production in forests with exotic plants.



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1. Introduction

There is worldwide interest in integrating sustainable forest management and maintaining biodiversity, giving rise to the controversial divide between integration and separation of conservation with production systems. In a separation scenario, the available land is divided into areas focused on maximizing productive capacity (e.g., intensive livestock farming), while other areas are dedicated to maintaining biodiversity. In an integration scenario, a lower production level is maintained in exchange for biodiversity to be conserved throughout the landscape [1].

Native forests are vital by providing multiple ecosystem services for the people [2,3]. These services are diverse, including biodiversity, water regulation, and non-timber products (e.g., provision of forage), among others [4,5]. Forests and their goods and services (e.g., forage quality) largely depend on vegetation biodiversity [6,7]. In this study, forage quality refers to the nutritional value and palatability of plant species for livestock, which we assess using species-level protein content, phenology, and intake potential. Assessing how vegetation responds to integrating human uses is imperative to reconcile sustainable land use and biodiversity [8,9]. Then, vegetation changes are the starting point for research on land management from an integration perspective of the production system.

Evidence at regional and global scales showed that most species are declining because of human activities (losers) and are being replaced by far fewer expanding species that thrive in human-altered environments (winners) [10]. A few generalists' replacements of numerous specialist species generate biotic homogenization [10,11] that can reflect stable states (e.g., exotic plant species that dominate in cover). These changes can occur in native forests with integrated livestock [5,12,13]. Forest canopy openings influence the amount of light reaching the understory, which affects vegetation composition [14–16]. The degree of canopy cover can negatively impact some plant species, while others significantly increase their cover [17,18]. Despite its key ecological role, the understory remains poorly characterized in terms of its seasonal productivity and nutritional quality across forest types and canopy gradients. This knowledge gap limits the assessment of the true potential of native forests to support livestock production while preserving biodiversity. Previous studies suggest livestock can produce different effects on vegetation because of herbivore selectivity to specific plant species, e.g., cattle prefer grasses while sheep prefer legumes and other broadleaf species [19–23]. Furthermore, the nutritional potential of native and exotic species in these systems has rarely been addressed, despite its relevance for evaluating integration scenarios. Understanding how vegetation origin (native vs. exotic) and forest structure influence forage quality and carrying capacity is essential for informing sustainable land use.

Native and exotic species coverage may depend not only on the forest's structural and ecological processes but also on the associated open lands (e.g., grasslands and shrublands) [24,25], such as the entry of native or exotic species from surrounding environments [26,27]. Vegetation in different environment types (e.g., forest types or open lands) can exhibit phenological stages (e.g., forage) throughout different seasons, which is a crucial factor in herbivory feeding [19,28–30]. Vegetation growth peaks in spring and summer across different environment types, while autumn and winter bring changes as vegetation enters senescence, during which domestic herbivores increase their consumption of forest vegetation (e.g., tree seedling, sapling, shrubs) [31]. In this context, revealing the role of

native and exotic vegetation can provide a pathway in land integration for productive potential (e.g., livestock systems) in native forests. In this context, it is essential to quantify how canopy structure, plant composition, and nutritional characteristics converge to define potential animal load (PAL). This approach can reveal opportunities and limitations for livestock integration in native forests.

Here, we investigated the causal relationships between native and exotic vegetation cover (%) and the potential animal load (PAL, ind ha⁻¹ yr⁻¹) for a common type of livestock worldwide (cattle and sheep) in contrasting native forests and canopy cover (closed, semi-open, open) in Chilean Patagonia. Our objective was to integrate vegetation composition with estimates of nutritional quality to assess the extent to which native forests can provide forage of adequate quality and quantity for livestock. We hypothesize that differences in vegetation origin (native vs. exotic), growth habit, and forest canopy structure lead to measurable differences in forage quality, which we define as the combination of nutritional content and livestock palatability and ultimately affect the potential animal load. This hypothesis does not assume a priori that native forests provide lower quality forage but instead test whether exotic species contribute differently to silvopastoral capacity across canopy gradients. These relationships were assessed through a multi-seasonal field approach, allowing us to derive ecological insights relevant to land-sharing scenarios.

2. Materials and Methods

2.1. Study Area

Our study area focused on the Aysén region (108,494 km²) in Chilean Patagonia between -44° and -49° SL. The research concentrated on the eastern side of the Andes, which is more suitable and accessible for livestock systems, with the Carretera Austral as the central road system (Figure 1). We excluded the western side due to its extensive protected areas (National Parks and Reserves), where agricultural development and livestock farming are mostly prohibited. The forests contain 18 predominant forest types featuring various tree species [32]. The genus *Nothofagus* is the most representative, including evergreen forests with *N. dombeyi* and *N. betuloides* and deciduous forests with species such as *N. pumilio* and *N. antarctica*. The climate is warm temperate mesothermal, varying by location and elevation. Precipitation ranges from ± 3000 to ± 4000 mm yr⁻¹ on the western side and ± 500 to ± 1500 mm yr⁻¹ on the eastern side. Summer temperatures (December to February) range between 10 and 18 °C, while winter temperatures (June to August) drop below 0 °C, with conditions including heavy rain, snow, and strong winds [33]. During the last century, large areas of the region were deliberately burned as part of broader colonization policies aimed at expanding livestock grazing. These fires resulted in extensive open forest structures and facilitated the establishment of exotic forage species. Consequently, the current landscape can form a mosaic of native forests and open lands, offering a unique context for studying land-sharing scenarios under diverse canopy conditions.

2.2. Sampling Design and Data Taking

We first explored potential study sites with native forests and open lands using ArcGIS Desktop 10.8.2 [34]. To capture representative gradients of canopy cover and vegetation composition, we generated a set of 500 points randomly distributed on the CONAF land shapefile layer [35], which contains spatially explicit land-cover data for the study area. Then, ground-truthing was conducted at these points during the round year (four seasons) between 2022 and 2024. After field verification, we selected 374 plots representing the target native forest types and associated open lands in ranches, national parks, and reserves.

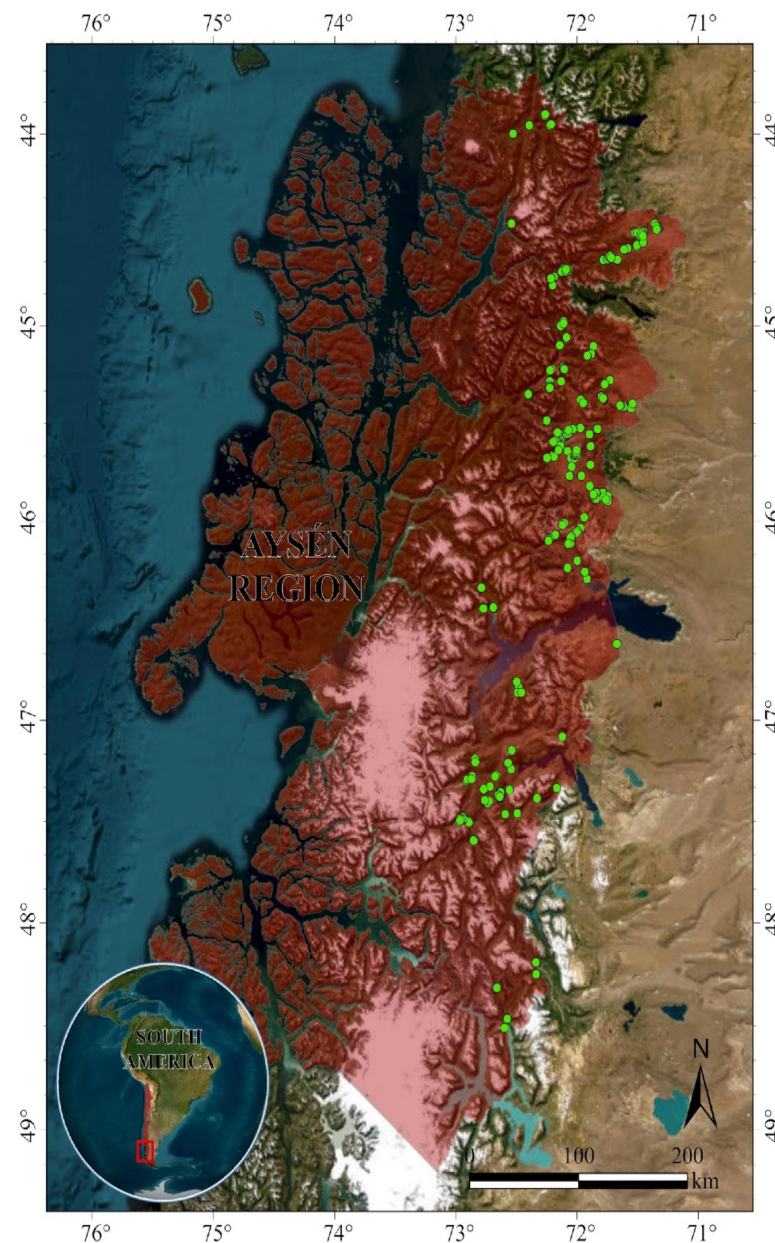


Figure 1. Study area indicating the Aysén region (red) and the studied plots (green). Basemap source was extracted from ArcGIS Desktop 10.8.2 [34]. Background image was obtained from Google Earth (<https://earth.google.com/web/> [accessed 15 November 2024]).

These plots (>5 ha) were homogeneous in composition and intensity of use. Forest types were defined based on dominant tree species in the upper canopy, following Huertas Herrera [32]. They were categorized into the following types: coihue (*Nothofagus dombeyi*, CO), lenga (*N. pumilio*, LE), mixed *Nothofagus* forests (MI), ñirre (*N. antarctica*, ÑI), evergreen forest (SV), and open land (OL), which includes grasslands, shrublands, and peatlands with little to no continuous canopy but occasional isolated trees. In the forest plots, we measured the canopy cover using hemispherical photographs with a Nikon 35 mm digital camera (Nikon D800, Japan), a tripod at 1 m up to the floor, and an 8 mm fisheye lens (Sigma, Japan). Photographs were oriented so that the top edge of the lens faced magnetic north, and direct sunlight was avoided. Gap Light Analyzer v.2.0 software [36] was used to analyze photographs and calculate the percentage of forest canopy cover (CC). Using this data, we classified the plots as closed (>70% CC), semi-open (40% to 70% CC), and open (<40% CC) (Figure 2A).

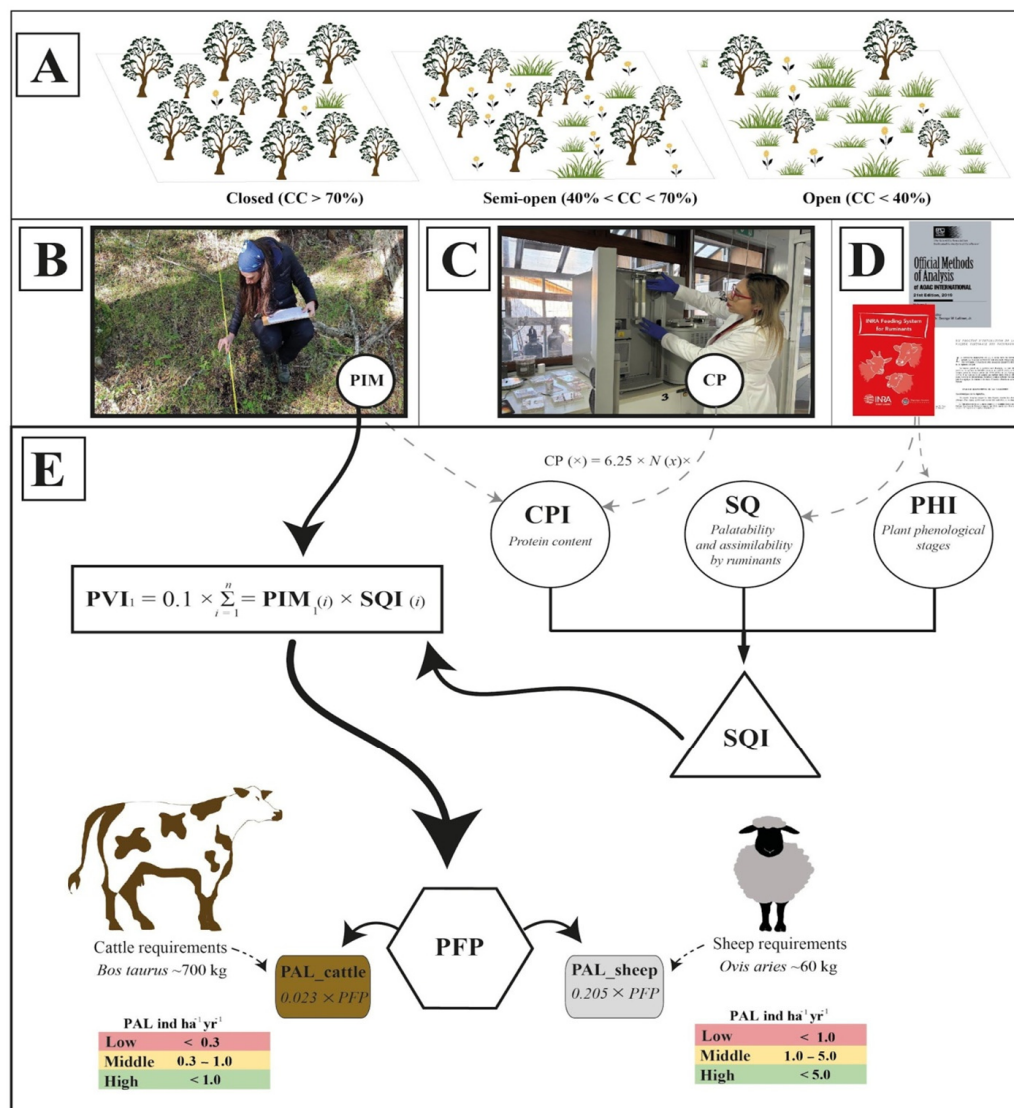


Figure 2. Data analysis framework for index calculation. (A) Forest treatments based on canopy cover (CC); (B) plant composition measured by point-interception method (PIM); (C) plant nitrogen content measurements to calculate crude protein (CP); (D,E) index determination based on crude protein index (CPI), phenological index (PHI), plant specific quality (SQ), specific quality index (SQI), pastoral value index (PVI), potential forage production (PFP), and potential animal load (PAL).

Vegetation metrics were measured in 1.0 ha plots during the spring and summer (flowering period) to accurately identify species in each plot across the different environment types. Vegetation cover (%) was determined using the point-interception method (PIM) [37], with a 50 m transect marked at every meter (Figure 2B). Vegetation was classified by plant origin (native or exotic) and growth habit (trees, shrubs, forbs, graminoids, ferns, lianas, lichens, and bryophytes), including coarse woody debris and bare soil. The plants were sampled for subsequent chemical composition analyses using a 0.5 m² quadrant randomly placed at each plot. All plants within the quadrant were collected at the base; labeled with the location, site identification number, and sampling date; and transported to the laboratory promptly. In the laboratory, plants were analyzed using gravimetric destructive random sampling (kg dry matter ha⁻¹), weighed with an analytical balance (± 0.0001 g) (Boeco, Hamburg, Germany), and dried in an oven at 60 °C (Binder, Camarillo, CA, USA) until constant weight. Plant nitrogen content was measured using the LECO TruSpec[®] CHN simultaneous elemental determinator (USA) with the Dumas direct combustion method (Figure 2C). Following AOAC [38], plant nitrogen content (% and mg) was used

to calculate crude protein (CP, % dry matter) by multiplying it by a factor of 6.25. Nitrogen percentage measurements were obtained for each analyzed season (summer, autumn, spring, and winter), resulting in distinct CP values for each plant species.

2.3. Plant Nutritional Data Approach

We propose the following indices to analyze plant nutritional quality [39]:

- (i) Crude protein index (CPI) based on average CP levels (Figure 2C) as follows: 0–10% (very low CP), 10–12% (low CP), 12–15% (medium CP), 15–18% (high CP), and >18% (very high CP).
- (ii) Phenological index (PHI) (Figure 2D), where plant phenological stages were classified and rated (rPHI) as follows: absent (rPHI = 0.00) when the plant species was not available, 0 (rPHI = 0.25) when the plant species occurred at the beginning or the end of the growing phase, intermediate stage (rPHI = 0.50) when the plant species was fruiting or drying; near-complete development (rPHI = 0.75) when the plant species was near to or continuing flowering; and complete development (rPHI = 1.00) when the plant species was at maximum flowering expression.
- (iii) Specific quality index (SQI) was calculated following Daget and Poissonet [40] (Figure 2D). This index integrates phenological stage, species palatability, and digestibility for ruminants. Each species was assigned a specific quality value (SQ) from 0 (no zootechnical interest) to 10 (maximum interest). For validation, our SQI values were compared with existing literature for the region [5,40,41].

These indices were used to calculate a pastoral value index (PVI), which integrates the nutritional and ecological value of each species with their relative cover (%) in the understory (Figure 2E). PVI provides insights into pasture quality by ranking the importance of plant species based on their zootechnical interest, vegetation composition, and plant understory cover (%). The index ranges from 0 (environments with no zootechnical value) to 100 (environments of maximum zootechnical relevance). We used the PVI as a proxy for the plot's potential animal load (PAL), following Daget and Poissonet [40]. This approach assumes that one livestock unit (LU) requires one specific number of milk forage unit (MFU) per year. Also, the PAL included 0.02 PVI for European standard cattle (*Bos taurus*, ~700 kg) consuming a total of 3000 MFU yr⁻¹. Finally, we calculated the potential forage production (PFP) as $x = PVI \times 0.2 \times 3000$, reflecting the plot's output in MFU ha⁻¹ yr⁻¹. We calculated these values for all the plots, where cattle required 2555 MFU yr⁻¹, and sheep required 292 MFU yr⁻¹. This rationale was used to determine the final data of potential animal load (PAL) (Figure 2E) following Daget and Poissonet [40] and INRA [39]. The PAL was calculated as PFP/2555 for cattle, resulting in an average value of 0.023 PVI (PAL cattle, ind ha⁻¹ yr⁻¹). The sheep (*Ovis aries*) calculation was based on PFP/292, achieving to 0.205 PVI (PAL sheep, ind ha⁻¹ yr⁻¹). We utilized PAL values as focus data for our analyses (cattle and sheep) across different seasons. For better interpretation of these data, PAL values were classified into the following: (A) for sheep—<1.0 (low), 1.0–5.0 (medium), and >5.0 (high); (B) for cattle—<0.3 (low), 0.3–1.0 (medium), and >1.0 (high).

2.4. Data Analyses

We quantified the occurrence frequency of plants (%) at each interception point (Appendix A, Table A1), and we standardized these values on a scale from 0 to 100 to calculate vegetation cover. One-way ANOVAs were used to highlight how vegetation and ground cover varied between native and exotic species, and across different environment types (CO, LE, MI, ÑI, SV, OL) and canopy cover (closed, semi-open, open, compared to OL) as the main factors. PAL values for sheep and cattle were analyzed using one-way ANOVAs to evaluate their variation across seasons and environment types and to test how

plant origin and canopy openness influence forage availability and livestock integration. We calculated ratios for PAL values to visualize variations of each factor across the different seasons. The variables were log-transformed to meet ANOVA assumptions, which were assessed using the Shapiro–Wilk and Levene tests; however, non-transformed means were presented. Comparisons of the means were conducted using Tukey’s post hoc test ($p < 0.05$). These analyses were performed using Statgraphics Centurion XVI Version 16.1.11 (StatPoint Technologies, Warrenton, VA, USA). Finally, we conducted two multiple correspondence analyses (MCAs): (i) The first one analyzed the association between environment types and canopy cover with PAL for sheep and cattle. (ii) The second one aimed to detect the factors related to variations in canopy cover (%) of native and exotic plant species across the forest types, using PAL values during the growing season (spring and summer). Both MCAs were performed in R using the FactoMineR (Version 2.11) library following Lê et al. [42]. Dimension reduction was based on eigenvalues, and category associations were interpreted from the first two axes. Additionally, we conducted a generalized linear model (GLM) analysis to further explore the factors influencing the PAL. To evaluate the effects of environment types, canopy cover, season, and the growth habit of the understory on the potential animal load (PAL) for sheep and cattle, a GLM with a normal distribution was fitted using InfoStat software 2014 version (<https://www.infostat.com.ar>, [accessed 15 November 2024]). The model included environment types, canopy cover, and season as fixed factors. Quantitative covariates comprised the relative cover (%) of four dominant understory growth habits: forbs, graminoids, shrubs, and trees. Other understory growth habits (e.g., ferns, bryophytes, lichens, and lianas) were excluded due to their low frequency.

3. Results

A total of 163 species were surveyed, 73% natives and 27% exotic, where the most frequent growth habit was forb (45%), shrub (21%), and graminoid (17%). When we analyzed vegetation cover (%) by plant origin and growth habit across the different environment types, ANOVAs showed that native species predominated most forest types (~45%), particularly in the LE forest (~58%). In contrast, exotic species increased in ÑI and OL ($p < 0.01$, Table 1). The CO, MI, and SV forest types exhibited more than 40% native species cover, with fewer exotic species. ÑI (~38%) and OL (~20%) displayed the lowest native species coverage. Exotic species had their highest coverage in ÑI (~53%), like OL (~68%). ÑI was the only forest type where exotic species exceeded native species, while LE had the lowest exotic species cover (~16%). Graminoids dominated the OL and ÑI regarding growth habits, covering 44% and 30%, respectively. Other forest types were primarily composed of forbs, shrubs, and tree ground cover (e.g., natural forest regeneration). Ferns contributed around 5% of the total cover in the studied environments, while the mean cover of bryophytes was significant for CO, which reached nearly 8% coverage. ÑI and OL showed over 90% ground coverage by vegetation, with lower proportions of woody debris or bare soil than other forest types. In contrast, woody debris covered over 20% in LE and CO, while SV exhibited similar coverage of woody debris and bare soil.

ANOVAs also indicated that the degree of forest canopy cover significantly affected the cover of native and exotic species in the understory (Table 2). The growth habits of understory species in OL differed from open or semi-open forests, as OL doubled the coverage percentage of exotic species ($p < 0.01$). In contrast, native species dominated closed forests, covering over 55% of the ground. Graminoids primarily covered OL and semi-open forests more than open forests and were less prevalent in closed forests. Forbs predominated in closed forests, followed by shrubs, while other coverage consisted of woody debris, which accounted for over 20% of ground cover. Forbs were the dominant

growth habit in open and semi-open forests, greater than graminoids. Open forest types had 26% of bare soil cover, while closed forests had only 2.4%. All canopy categories had less total vegetation coverage than OL.

Table 1. One-way ANOVA results for vegetation cover (%) classified by plant origin and growth habit, including woody debris and bare soil, in different environment types (CO = coihue, LE = lenga, MI = mixed, ÑI = ñirre, SV = evergreen, OL = open land).

Variables	ÑI	LE	CO	MI	SV	OL	F(p)
Native species	38.0 b	58.4 c	46.1 b	42.2 b	40.5 b	21.6 a	27.44 (<0.01)
Exotic species	53.4 b	16.4 a	22.6 a	34.4 ab	33.2 ab	68.6 c	52.85 (<0.01)
Trees	2.7 b	6.7 c	6.3 c	2.1 b	2.8 ab	0.3 a	12.38 (<0.01)
Shrubs	15.3 c	12.8 b	13.4 b	11.1 ab	11.5 ab	6.4 a	5.98 (<0.01)
Forbs	35.5 b	34.7 b	23.1 a	28.8 ab	28.1 ab	31.9 b	2.83 (0.02)
Graminoids	30.1 b	11.9 a	10.7 a	21.5 ab	16.9 ab	44.8 c	37.20 (<0.01)
Ferns	5.4	3.5	6.5	7.1	5.9	3.3	2.06 (0.07)
Lianas	0.1 a	-	1.0 b	-	1.1 b	-	14.08 (0.01)
Lichens	0.4 b	0.8 c	0.1 a	-	0.2 b	0.1 a	3.03 (0.01)
Bryophytes	1.9 a	4.4 b	7.6 c	6.0 bc	7.2 c	3.4 ab	5.16 (0.01)
Total	91.4 b	74.8 a	68.7 a	76.6 a	73.7 a	90.2 a	29.57 (<0.01)
Coarse-woody debris	4.1 a	21.0 c	27.4 c	17.4 bc	14.0 b	3.7 a	34.05 (<0.01)
Bare soil	4.5 a	4.2 a	3.9 a	6.0 a	12.3 b	6.1 a	2.80 (0.02)

F = Fisher test; (p) = significance level. Different letters for each row indicate differences by Tukey tests at $p < 0.05$.

Table 2. One-way ANOVA results for vegetation cover (%) classified by plant origin and growth habit, including woody debris and bare soil, in different forest canopy cover levels (closed, semi-open, open) and open land (OL).

Variables	Closed	Semi-Open	Open	OL	F(p)
Native species	56.6 c	36.2 b	33.3 ab	21.5 a	51.70 (<0.01)
Exotic species	20.4 a	51.9 c	39.6 b	68.6 d	77.84 (<0.01)
Trees	6.1 c	2.7 b	1.2 a	0.2 a	18.63 (<0.01)
Shrubs	15.1 c	11.8 b	11.8 b	6.2 a	10.45 (<0.01)
Forbs	31.4 a	37.0 b	31.0 a	31.1 a	2.73 (0.04)
Graminoids	12.6 a	30.1 b	27.6 b	45.8 c	61.33 (<0.01)
Ferns	6.1 c	3.3 b	0.3 a	3.3 b	5.77 (0.01)
Lianas	0.2	0.1	-	-	2.17 (0.09)
Lichens	0.6	0.5	-	0.1	2.26 (0.08)
Bryophytes	4.9 c	2.6 b	1.0 a	3.4 b	3.94 (0.01)
Total	77.0 a	88.1 b	72.9 a	90.1 b	22.91 (<0.01)
Coarse-woody debris	20.6 c	5.9 b	0.8 a	3.7 b	44.05 (<0.01)
Bare soil	2.4 a	6.0 b	26.3 c	6.2 b	40.06 (<0.01)

F = Fisher test; (p) = significance level. Different letters for each row indicate differences by Tukey tests at $p < 0.05$.

Differences in PAL among forest types and OL were similar for sheep and cattle, with no significant differences compared to the mean for sheep and forest types (Figure 3). However, PAL values significantly differed across forest types ($p < 0.01$). ÑI showed PAL similarities with OL, unlike the LE and CO types, which markedly decreased. MI forest types were almost equal to the total mean values. In addition, PAL values diminished in summer, being marked in autumn and winter. PAL values decreased notably in summer, with further reductions in autumn and winter. Canopy cover significantly ($p < 0.01$) affected the PAL of cattle and sheep in the analyzed environment types (forests vs. OL) (Figure 4). In spring, OL had a higher PAL compared to forests with varying levels of canopy cover. Semi-open and open forest types showed a more similar group to OL, and they were dissimilar in terms of PAL from closed forests. These differences were more evident for sheep, where the PAL in closed forests was lower than any level of forest cover and especially lower than in OL. In contrast, for cattle, although significant differences were observed among the

various canopy cover levels in spring ($p < 0.01$), these differences were almost equal to the total mean among the groups.

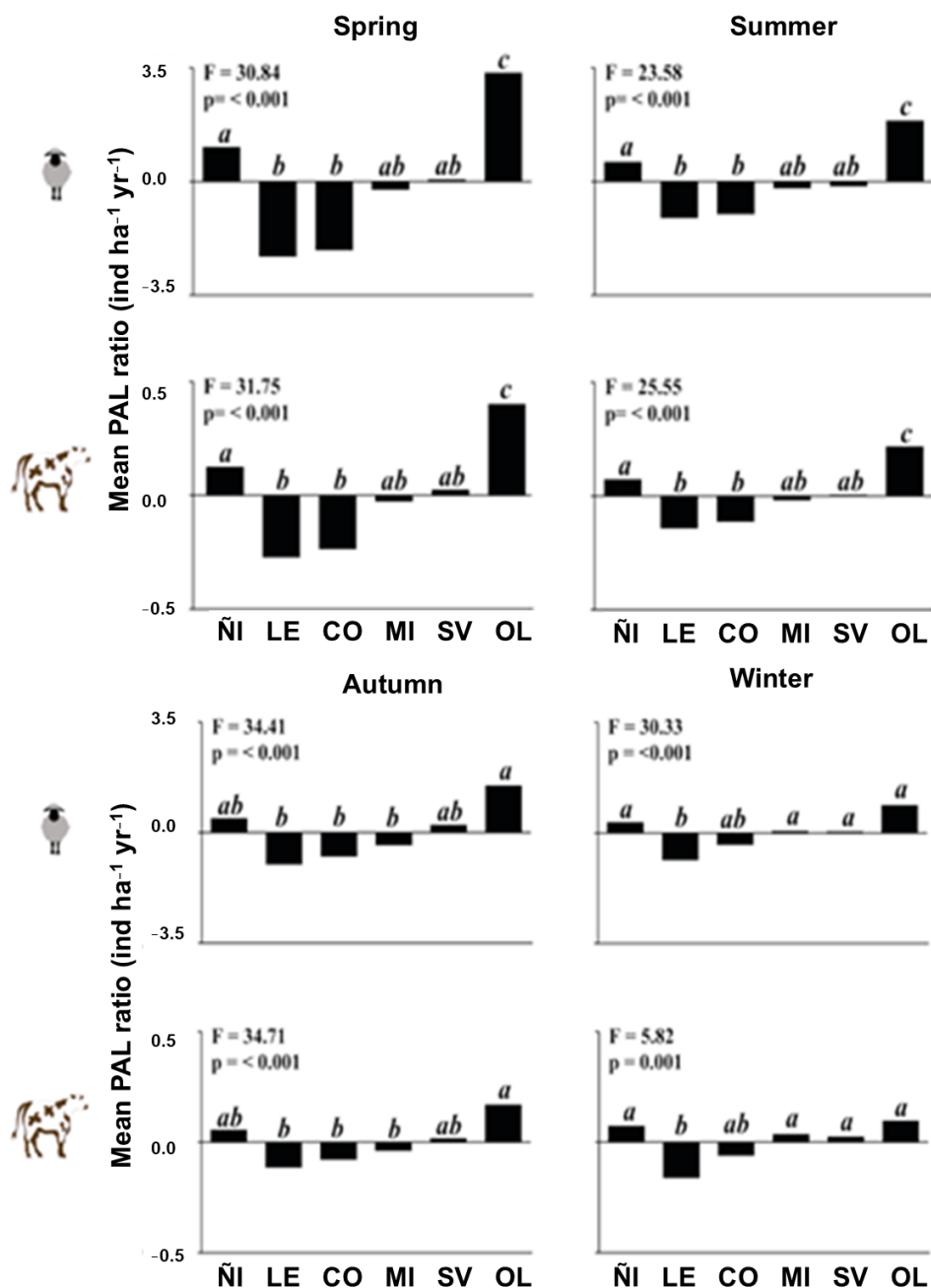


Figure 3. ANOVAs for potential animal load (PAL) ratio (ind ha⁻¹ yr⁻¹) for sheep and cattle (indicated by sheep and cattle icons) across different seasons and environment types. Different lowercase letters above each bar indicate significant differences between the levels (Tukey test at $p < 0.05$). ÑI = ñirre, LE = lenga, CO = coihue, MI = mixed, SV = evergreen, OL = open land.

The first multiple correspondence analysis (MCA) showed that environment types, forest canopy cover, and PAL (sheep and cattle) were closely related (Figure 5). Axis 1 (eigenvalue = 0.527, horizontal line) and Axis 2 (eigenvalue = 0.141, vertical line) explained 98.6% of the cumulative variance of the model. Axis 1 alone explained 91.2% of data variation, presenting the highest inertia ($\lambda = 0.278$). The MCA model revealed discrimination between axes, where LE and CO forest types and the closed canopy cover categories contributed most to the lowest PAL values across different seasons for both sheep and

cattle. Additionally, SV was close to the origin of Axes 1 and 2, which was associated with medium PAL values. ÑI and MI forest types contributed to the middle PAL values, as well as open and semi-open canopy covers. In contrast, OL differed from the other environment types and canopy cover categories, comprising and grouping the highest PAL values for all the seasons and livestock types (sheep and cattle). The second MCA highlighted the relationship between the PAL and understory cover of native and exotic species (Figure 6). Axis 1, with an eigenvalue of 0.959, explained 48.6% of the cumulative variance, exhibiting the highest inertia ($\lambda = 0.921$), while Axis 2, with an eigenvalue of 0.859, contributed with an inertia of 0.738. This resulted in a cumulative percentage variance of 87.6% when both axes were considered. This second MCA conformed to a conspicuous group of low PAL associated with high cover percentages of native species (indicated by green numbers), which emphasizes the disparity in the cover between native and exotic species and high PAL values for cattle and sheep.

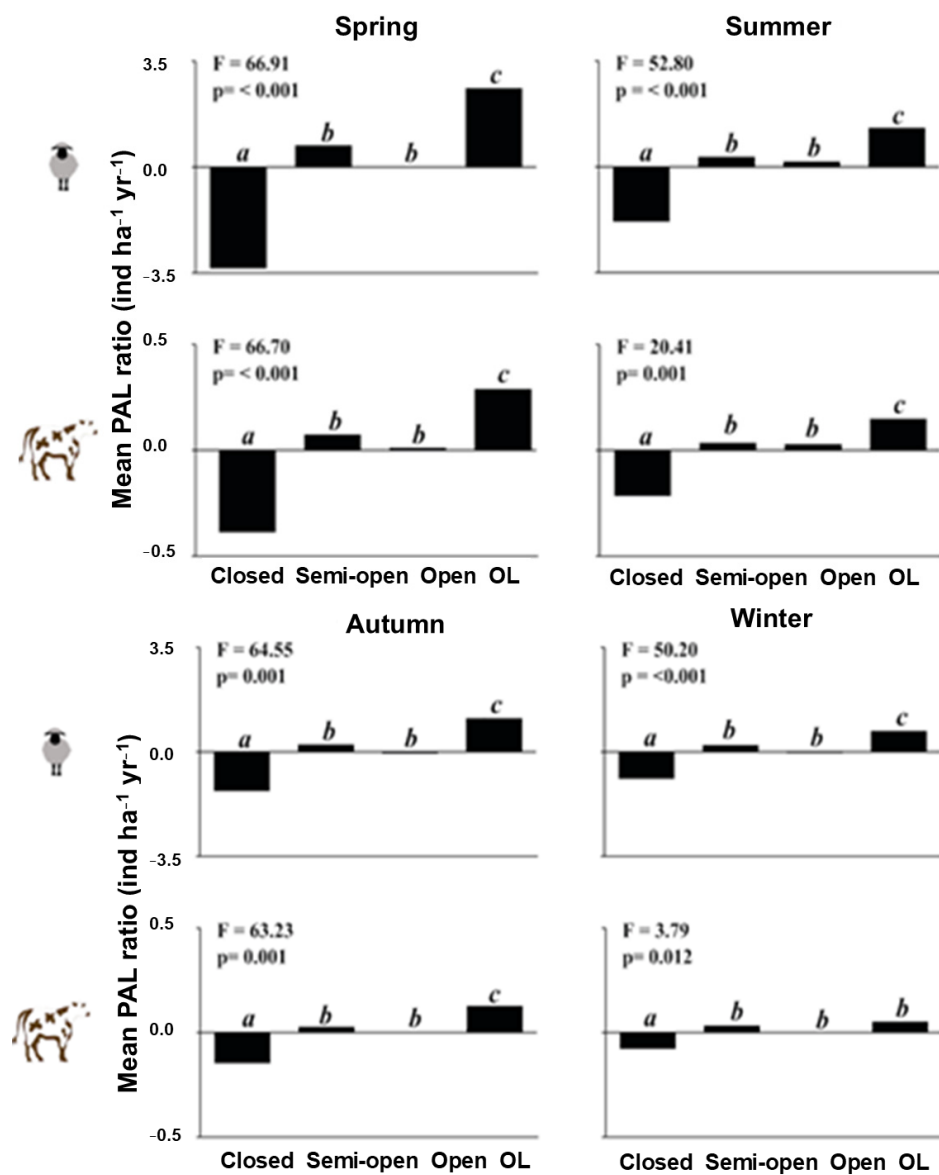


Figure 4. ANOVA for mean potential animal load (PAL) ratio (ind ha⁻¹ yr⁻¹) for sheep and cattle (indicated by sheep and cattle icons) across different seasons and forest canopy cover (closed, semi-open, open) and open land (OL). Different letters above the bars indicate significant differences between the levels (Tukey test at $p < 0.05$).

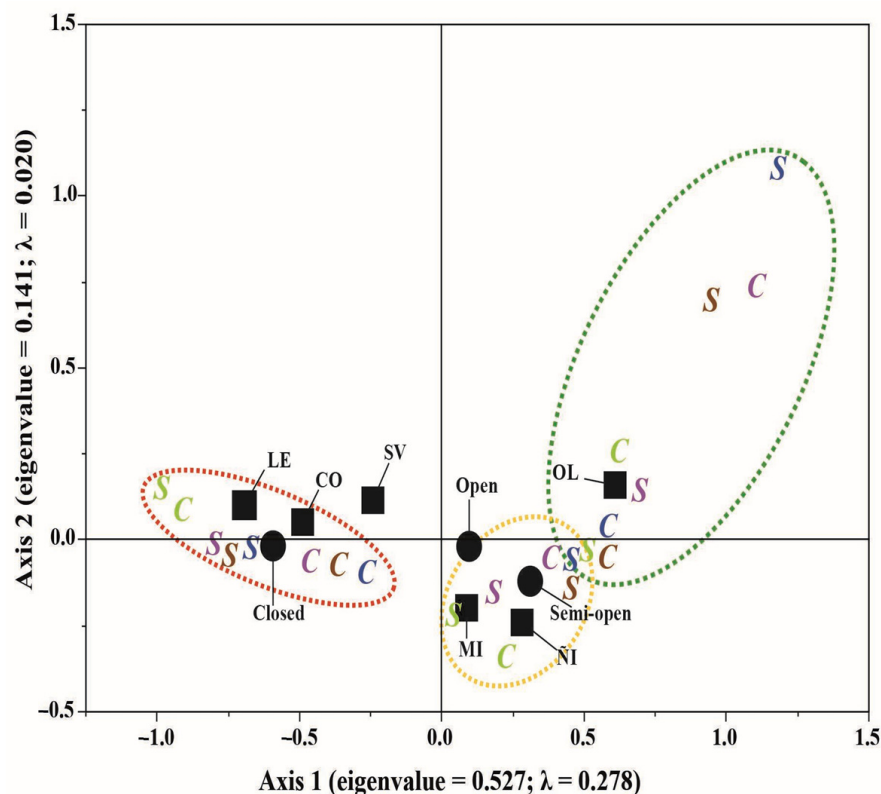


Figure 5. Multiple correspondence analysis showing the relationship between the analyzed environment types ($\tilde{N}I$ = ñirre, LE = lenga, CO = coihue, MI = mixed, SV = evergreen, OL = open land), canopy cover (closed, semi-open, open) and OL, and the potential animal load (PAL, ind $ha^{-1} yr^{-1}$) categories: low (red dotted oval), medium (yellow dotted oval), and high (green dotted oval) for sheep (S) and cattle (C). Colored letters represent their PAL data across different seasons (light green for spring, purple for summer, brown for autumn, blue for winter).

The GLM fitted for sheep (Table 3), using PAL as the dependent variable, was highly significant ($F = 142.2$, $p < 0.01$), with a coefficient of determination r^2 of 0.574 and an AIC of 4656.1. Environment type had a significant effect, with $\tilde{N}I$ showing a higher PAL compared to the reference category, which was CO ($p < 0.01$), while LE was associated with a decrease in the PAL ($p = 0.03$). Open canopy cover was positively associated with PAL ($p < 0.01$). Season also had significant effects, where the PAL was higher during spring and summer compared to autumn seasons ($p < 0.01$), and winter had a marginal negative effect ($p = 0.05$). Regarding understory growth habits, the cover of forbs and graminoids was positively associated with the PAL ($p < 0.01$), whereas the presence of shrubs and trees had significant negative effects ($p < 0.01$).

For cattle, the GLM was highly significant ($F = 219.0$, $p < 0.01$), with a coefficient of determination r^2 of 0.674 and an AIC of 3415.1 (Table 4). The PAL was significantly higher in $\tilde{N}I$, whereas LE exhibited a negative effect ($p = 0.01$). Open canopy cover promoted greater forage availability ($p < 0.01$). Among seasonal effects, spring had the most positive influence on the PAL ($p < 0.01$), followed by summer, while winter significantly reduced the PAL ($p < 0.01$). The relative cover of forbs and graminoids was positively associated with the PAL ($p < 0.01$). In contrast, shrubs and trees had strong negative effects, with trees representing the most limiting factor for potential forage availability in the understory ($p < 0.01$).

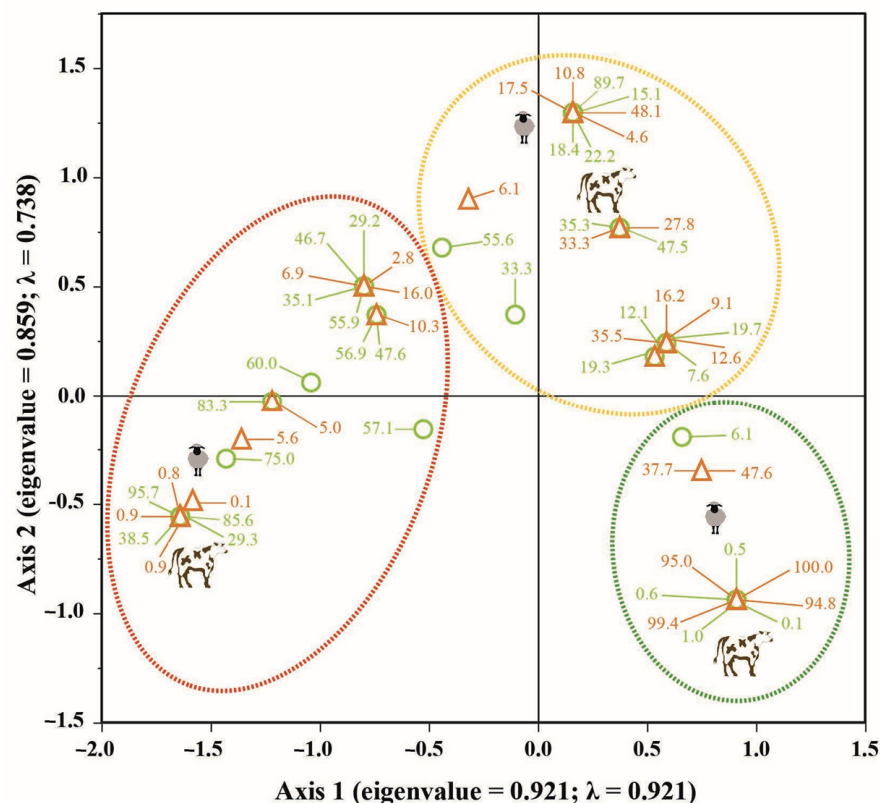


Figure 6. Multiple correspondence analysis showing the relationship between the understory cover (%) of native (light green) and exotic (orange) species across the analyzed environment types and the potential animal load (PAL, ind ha⁻¹ yr⁻¹) categories: low (red dotted oval), medium (yellow dotted oval), and high (green dotted oval) for sheep and cattle. The cattle and sheep symbols represent the centroids for low, medium, and high PAL categories.

Table 3. Generalized linear model (GLM) predicting potential animal load (PAL) for sheep, based on environment type (CO = coihue, LE = lenga, MI = mixed, ÑI = ñirre, SV = evergreen, OL = open land), canopy cover, season, and growth habit. The *p*-value indicates significant differences when *p* < 0.05.

Variable	Estimate	Standard Error	Z-Value	<i>p</i> -Value
Intercept	−11.79	0.142	−8.32	<0.001
Environment types (LE)	−0.29	0.135	−2.18	0.030
Environment types (MI)	0.22	0.192	1.13	0.259
Environment types (OL)	0.31	0.221	1.43	0.157
Environment types (EV)	−0.06	0.198	−0.29	0.766
Environment types (ÑI)	0.69	0.140	4.93	<0.001
Canopy cover (open)	0.62	0.174	3.58	<0.001
Season (spring)	1.27	0.083	15.21	<0.001
Season (summer)	0.64	0.083	7.62	<0.001
Season (winter)	−0.16	0.083	−1.96	0.050
Forbs	0.01	0.001	5.54	<0.001
Graminoid	0.01	0.001	13.75	<0.001
Shrubs	−0.01	0.003	−4.81	<0.001
Trees	−0.03	0.005	−6.07	<0.001

Table 4. Generalized linear model (GLM) predicting potential animal load (PAL) for cattle, based on environment type (CO = coihue, LE = lenga, MI = mixed, ÑI = ñirre, SV = evergreen, OL = open land), canopy cover, season, and growth habit. The p -value indicates significant differences when $p < 0.05$.

Variables	Estimate	Standard Error	Z-Value	p -Value
Intercept	−26.28	0.094	−28.07	<0.001
Environment types (LE)	−0.24	0.089	−2.66	0.008
Environment types (MI)	0.21	0.127	1.62	0.105
Environment types (OL)	0.17	0.146	1.14	0.257
Environment types (EV)	0.05	0.131	0.41	0.681
Environment types (ÑI)	0.45	0.093	4.85	<0.001
Canopy cover (open)	0.51	0.115	4.39	<0.001
Season (spring)	0.89	0.055	16.13	<0.001
Season (summer)	0.25	0.055	4.60	<0.001
Season (winter)	−0.17	0.055	−3.06	0.002
Forbs	0.01	0.001	5.35	<0.001
Graminoid	0.01	0.001	18.22	<0.001
Shrubs	−0.01	0.002	−4.26	<0.001
Trees	−0.04	0.003	−14.14	<0.001

4. Discussion

4.1. Plant Origins and Growth Habits

Our research showed that the composition and structure of the understory in Patagonian forests reflect a gradient of human influence and canopy openness, with variable contributions of native and exotic species across forest types and seasons. This gradient also mirrors historical land-use legacies, where extensive fires set for grazing expansion altered forest structure and species composition. It is expected that several species introduced in Patagonia were intended primarily for ruminant foraging (e.g., *Taraxacum officinale*, *Dactylis glomerata*, *Holcus lanatus*), with a few designated for human consumption (e.g., *Rosa eglanteria*) or aesthetic purposes (e.g., *Lupinus polyphyllus*). The dominance of native species in LE forests aligns with expected less disturbed ecosystems, emphasizing the resilience of native species in closed canopy stands. In contrast, the high exotic species cover in ÑI and OL suggests a correlation between canopy cover and plant invasion vulnerability, generating significant environment homogenization. This supports previous findings that land-sharing, such as logging or grazing, often promotes the establishment of exotic species [27]. Previous studies have indicated the connection between plant composition and the diversity of structures in these native forests [25]. Preserving diverse canopy structures is crucial for maintaining plant diversity [15,16,43]. Plants are essential for energy transfer and nutrient cycling in ecosystems [44] and respond in complex ways to natural and human-induced disturbances [6]. Then, various factors, such as species-specific autoecology, canopy structure and composition, site and microsite conditions, and interactions with dominant trees, shape plant abundance and distribution [45–47]. Additionally, the variation in growth habits of studied environments highlight the structural shifts in plants in response to integrated natural forests with livestock conditions. We also observed that PAL values were higher in forest types and canopy conditions with more exotic graminoids and forbs, whereas closed forests dominated by native shrubs and forbs had consistently lower PAL values. This aligns with our hypothesis that vegetation origin and growth habits influence forage quality and carrying capacity. The higher exotic species cover in more open environments highlights the vulnerability of these areas to exotic species. The reduced bare soil cover in closed forests suggests healthier soil conditions, while the increase in bare soil in open environments indicates degradation processes, such as erosion. This raises concerns about how further canopy disturbances could alter these dynamics, potentially

decreasing forest resilience. Light availability within the forest is essential, influenced by tree density and canopy cover [48]. The forest type also plays a significant role, where deciduous trees shedding their leaves in autumn create high seasonal variation in light availability for understory plants. On the other hand, evergreen trees maintain their leaves year-round, leading to a need for plants to adapt to low light conditions throughout the year [14–16]. The differences in understory plant communities across different forest types underscore the need for tailored conservation strategies considering local conditions and species distributions [49].

4.2. Nutritional Subsidies for Grazing Animals

The MCA results and PAL trends support the idea that exotic species contribute significantly to potential forage availability in forests affected by human activities. This supports the conclusion that exotic species can act as nutritional “winners” in silvopastoral systems. We found associations between factors (environment types and canopy cover) and a low, medium, and high potential animal load (PAL). The marked differences in PALs across the different environments reveal the pressure that livestock exerts on ÑI and OL, especially during autumn and winter when plant regeneration is slower. The fact that the PAL is lowest in LE and CO forests highlights the protective role of intact forest canopies in limiting grazing pressure. Here, we showed the relationships between the PAL, forest types, and species composition. Our data reveal that OL consistently supports higher PAL ratios for sheep and cattle than in forested areas, notably closed forests. This supports the conclusion that exotic species can act as nutritional “winners” in more open or disturbed environments. For sheep, restricted grazing opportunities in certain forest types, especially LE, indicate a need for management strategies that optimize livestock foraging while conserving native biodiversity. Cattle, however, display greater adaptability, utilizing forage across various environments with only minor differences in the PAL. Additionally, PAL is often associated with high native species coverage, indicating that as livestock pressure increases, native species are likely to be displaced by exotic species, particularly in open and semi-open forest settings. In this context, analyzed environments provide pivotal understory species to support livestock forage [7]. This extensive activity involves cattle and sheep species and combines native forests with open grasslands [22,50,51]. However, previous studies indicate that livestock grazing changes understory plant communities within these forests (e.g., dominance in coverage of native or exotic species) [25]. Pointing out that developing forests managed for livestock use raises questions about their forest ecological perspective to promote a balance between productive alternatives and ecological values [52]. In forests with livestock uses (e.g., silvopastoral systems), the plant forage value and animal occurrence varied significantly across management alternatives and associated environments [13]. Prior work suggests that habitat diversity plays a crucial role in shaping the dietary patterns of herbivores. Soler et al. [53] found that the diverse habitats and plant species within *Nothofagus* forests significantly influence the seasonal dietary patterns of native mammals. Moreover, different authors [4,5,22,25,51] underscore the importance of understanding the varying responses of forage production to environmental drivers (e.g., droughts) in different systems, as this knowledge can inform management practices that improve the resilience of livestock production in the face of increasing climate variability. Considering the phenological stage is also essential when evaluating plant availability for livestock feeding, as different species have distinct growing times, affecting their accessibility to livestock throughout the year (Figures 3 and 4). Previous studies show that both palatable and non-palatable plants, whether dead or alive, present estimations of change and nutritional contributions [31]. Our data highlights that the plant exotic component is fundamental to understanding the forage potential of the studied forests and

associated OL. Furthermore, our results support the hypothesis that differences in forest structure and plant origin influence variations in forage quality and PAL. This confirms the predictive value of our conceptual framework and highlights the novelty of combining species composition and nutritional metrics in native forests under silvopastoral use. For example, the GLMs confirmed that the PAL was strongly influenced by environment type, canopy cover, and season. The PAL increased in ÑI forests and under open canopy cover, especially in spring and summer. Forbs and graminoids were positively associated with the PAL, while shrubs and trees had negative effects, reinforcing the role of understory structure in forage availability.

4.3. Limitations of the Present Study

Additional information on limitations helps contextualize our findings. It is commonly believed that the autumn and winter seasons are critical for the functionality of these landscapes (Figure 7), at least in terms of nutritional offerings to support sheep and cattle, the main livestock species. We found that the analyzed exotic species contribute to the forage potential of the studied forests, underscoring the complex interplay between native and exotic vegetation in the studied environment types. This is fundamental because animals can rely on this food availability during scarcity or winter. In this context, winter and the forest type are essential in managing the forest with livestock use. For this reason, some species acquire greater importance, as they are available during these periods. Moreover, other components like lichens appear, which animals may utilize as food; this ultimately becomes an essential component during winter in the forests. Our study did not incorporate other relevant biological and ecological factors, such as differences in ruminant digestion, the physiological status of livestock, or behavioral aspects related to grazing selectivity. Furthermore, while we focused on domestic herbivores, native species such as *Lama guanicoe* and *Hippocamelus bisulcus* also depend on these forests and may experience similar or contrasting ecological pressures. Future research could integrate these perspectives to provide a more holistic understanding of silvopastoral dynamics.

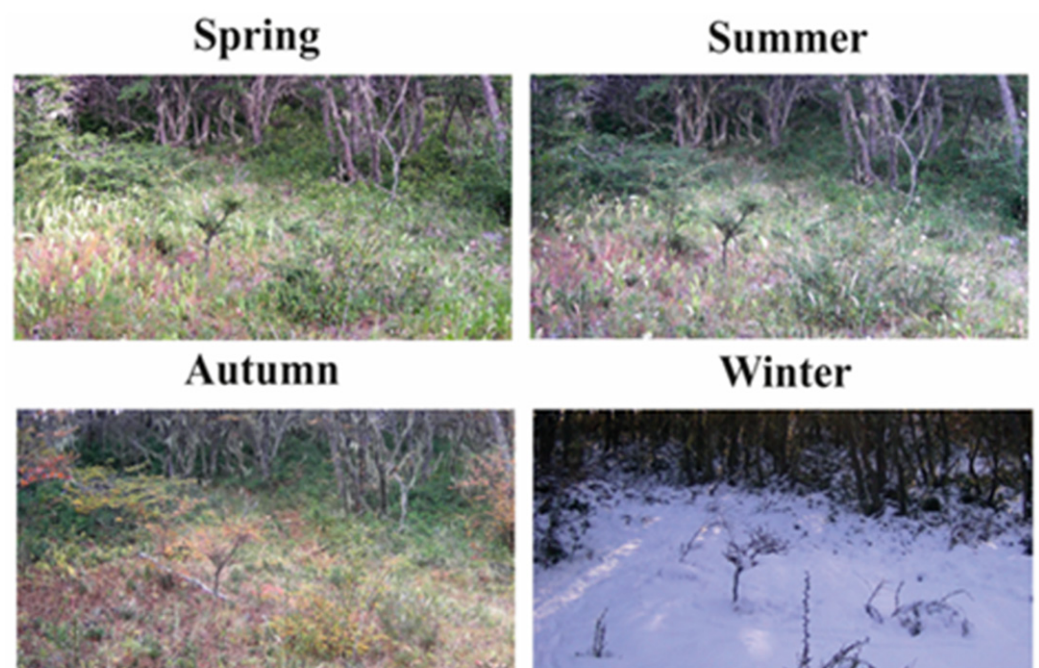


Figure 7. Example of the seasonal influence on vegetation cover at one plot of the study site.

Clarifying our findings to provide practical management recommendations is crucial. Although there are evident changes due to climate shifts across the seasons, where snow plays a vital role in the functionality of different types of forests and environments, plants can still be utilized for human interests, such as animal nutrition. The idea is that these environment types can offer differentiated functionalities throughout the seasons, providing multiple benefits of interest for human production systems, such as livestock. Here, we compare the potential productivity of native forests from a global perspective, contrasting Patagonian forests with highly productive systems such as grasslands, primarily composed of exotic species used in productive systems worldwide as forage for livestock. In this context, our results, obtained through an approach that used a developed index of potential forage for the studied environment types, demonstrate the comparability of these environment types with others worldwide using standardized parameters, e.g., 700 kg for cattle and 60 kg for sheep. This means all the environment types that we analyzed can support livestock production, though some more effectively than others, such as OL and ÑI forest types. The other environments can also support animal forage, although our study did not consider cattle or sheep age classes (e.g., calf, yearling, heifer, cow, lamb) or smaller livestock species (e.g., goat, pig, chicken).

5. Conclusions

Our hypothesis supported the idea that the differential influence of native and exotic vegetation affects forage quality and its impact on potential animal load. Closed native forests are unsuitable for livestock forage; therefore, it is advisable to conserve them in their current state to maintain other ecosystem services. Promoting closed canopies can enhance the coverage of native species while limiting the growth of exotic species. While seasonal changes influence potential animal load, the specific environment type and canopy cover are critical factors. Enhancing forage production for livestock often necessitates the introduction of exotic plant species, which can support a higher potential animal load. This situation suggests a trade-off between forage production within the forest and the prevalence of exotic plants. After all, here, we showed that in native forests with integrated livestock, exotic “winners” can homogenize diverse environment types for production systems. Furthermore, our study showed that sheep relied more on open terrain and semi-open forests, whereas cattle were more adaptable and could access forage in all forest types, including closed-canopy forests with a lower overall PAL. Therefore, from a management perspective, conservation efforts should prioritize the protection of closed-canopy forests due to their high ecological value, while more open forest types could be adapted for silvopastoral use, balancing production and biodiversity.

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Appendix A

Table A1. Occurrence of understory plants (%) in the studied environment types (CO = coihue, LE = lenga, MI = mixed, ÑI = ñirre, SV = evergreen, OL = open land) and forest canopy cover (closed, semi-open, open).

Code	Species	Origin	Growth Habit	Environment Type						Total	Canopy Cover			Total
				CO	LE	MI	ÑI	SV	OL		Closed	Semi-Open	Open	
ACIN	<i>Acaena integerrima</i>	Native	Forb	0.0	0.5	0.0	1.3	0.3	1.3	3.5	0.4	1.8	0.7	2.9
ACMA	<i>Acaena magellanica</i>	Native	Forb	0.0	1.1	0.0	0.0	0.0	0.8	1.9	1.1	0.4	0.0	1.4
ACMI	<i>Achillea millefolium</i>	Exotic	Forb	0.0	1.6	0.3	5.1	0.0	7.5	14.4	3.6	5.4	0.4	9.4
ACOV	<i>Acaena ovalifolia</i>	Native	Forb	2.7	15.2	3.2	8.8	2.4	5.6	38.0	30.1	12.7	1.1	43.8
ACPI	<i>Acaena pinnatifida</i>	Native	Forb	1.3	6.4	1.1	9.1	0.0	2.7	20.6	9.4	13.0	1.8	24.3
ADCH	<i>Adenocaulon chilense</i>	Native	Forb	2.4	17.6	1.9	4.3	0.0	0.5	26.7	29.7	5.4	0.4	35.5
AGCA	<i>Agrostis capillaris</i>	Exotic	Graminoid	0.5	6.1	0.0	5.9	0.0	12.6	25.1	8.0	8.3	0.7	17.0
AGLE	<i>Agrostis leptotricha</i>	Native	Graminoid	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.4	0.0	0.4
AGST	<i>Agrostis stolonifera</i>	Exotic	Graminoid	0.0	0.3	0.3	2.9	0.5	1.1	5.1	1.8	3.3	0.4	5.4
AICA	<i>Aira caryophyllea</i>	Exotic	Graminoid	0.3	0.3	0.0	1.1	0.0	4.3	5.9	0.0	1.8	0.4	2.2
AMLU	<i>Amomyrtus luma</i>	Native	Tree	0.5	0.0	0.3	0.0	0.8	0.0	1.6	1.4	0.7	0.0	2.2
ANOD	<i>Anthoxanthum odoratum</i>	Exotic	Graminoid	0.0	0.0	0.0	2.4	0.0	0.0	2.4	1.8	1.4	0.0	3.3
ANMU	<i>Anemone multifida</i>	Native	Forb	0.0	4.0	0.8	10.2	0.3	1.1	16.3	6.9	12.3	1.4	20.7
ARCH	<i>Aristotelia chilensis</i>	Native	Tree	0.0	0.3	0.0	0.0	0.3	0.5	1.1	0.7	0.0	0.0	0.7
ARMA	<i>Armeria maritima</i>	Native	Forb	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
AZLA	<i>Azara lanceolata</i>	Native	Tree	2.7	0.3	0.5	0.0	2.1	0.0	5.6	5.8	1.8	0.0	7.6
BAMA	<i>Baccharis magellanica</i>	Native	Shrub	0.0	1.3	0.8	5.3	0.0	0.8	8.3	3.6	5.8	0.7	10.1
BEDA	<i>Berberis darwinii</i>	Native	Shrub	2.1	5.1	1.6	4.0	1.6	7.2	21.7	12.7	6.2	0.7	19.6
BEEM	<i>Berberis empetrifolia</i>	Native	Shrub	0.0	0.3	0.0	0.3	0.0	0.0	0.5	0.0	0.4	0.4	0.7
BEMI	<i>Berberis microphylla</i>	Native	Shrub	1.9	6.1	0.8	17.6	0.8	5.3	32.6	18.8	16.7	1.4	37.0
BESE	<i>Berberis serratotdentata</i>	Native	Shrub	0.3	3.7	0.5	0.3	0.3	0.0	5.1	6.5	0.4	0.0	6.9
BLMO	<i>Blechnum mochaenum</i>	Native	Fern	0.3	0.0	0.0	0.0	0.3	0.0	0.5	0.7	0.0	0.0	0.7
BLCL	<i>Blechnum chilense</i>	Native	Fern	0.3	0.0	0.0	0.0	0.5	0.0	0.8	1.1	0.0	0.0	1.1
BLPE	<i>Blechnum pennamarina</i>	Native	Fern	4.5	12.3	2.4	13.9	2.1	9.1	44.4	33.3	14.1	0.4	47.8
BRSE	<i>Bromus setifolius</i>	Native	Graminoid	0.3	5.9	0.3	0.5	0.0	0.3	7.2	7.2	2.2	0.0	9.4
BRUN	<i>Bromus unioloides</i>	Native	Graminoid	0.0	0.8	0.0	0.0	0.0	0.5	1.3	1.1	0.0	0.0	1.1
CABI	<i>Calceolaria biflora</i>	Native	Forb	0.0	2.1	0.0	2.9	0.0	0.0	5.1	2.2	4.0	0.7	6.9
CAVA	<i>Capsidium valdivianum</i>	Native	Liana	0.3	0.0	0.0	0.0	0.5	0.0	0.8	1.1	0.0	0.0	1.1
CABA	<i>Carex banksii</i>	Native	Graminoid	0.0	0.0	0.0	2.7	0.0	0.5	3.2	2.2	1.4	0.0	3.6
CADA	<i>Carex darwinii</i>	Native	Graminoid	0.3	0.3	0.0	0.3	0.0	2.4	3.2	0.4	0.7	0.0	1.1

Table A1. Cont.

Code	Species	Origin	Growth Habit	Environment Type						Total	Canopy Cover			Total
				CO	LE	MI	ÑI	SV	OL		Closed	Semi-Open	Open	
CAFU	<i>Carex fuscula</i>	Native	Graminoid	0.0	0.0	0.0	1.1	0.0	0.3	1.3	0.4	1.1	0.0	1.4
CAGA	<i>Carex gayana</i>	Native	Graminoid	0.0	0.0	0.0	0.5	0.0	0.5	1.1	0.0	0.7	0.0	0.7
CEAR	<i>Cerastium arvense</i>	Exotic	Forb	0.0	4.0	0.8	8.3	0.0	1.9	15.0	5.4	10.5	1.8	17.8
CEGL	<i>Cerastium glomeratum</i>	Exotic	Forb	0.3	1.6	0.3	4.0	1.1	3.5	10.7	4.7	5.1	0.0	9.8
CHCU	<i>Chusquea culeou</i>	Native	Shrub	2.4	1.9	0.3	1.1	2.4	0.5	8.6	8.0	2.9	0.0	10.9
CHDI	<i>Chiliotrichum diffusum</i>	Native	Shrub	0.0	4.3	0.0	3.2	0.0	1.1	8.6	5.8	4.0	0.4	10.1
CIVU	<i>Cirsium vulgare</i>	Exotic	Shrub	0.5	1.1	0.0	2.1	0.5	0.5	4.8	2.5	3.3	0.0	5.8
COBI	<i>Collomia biflora</i>	Native	Forb	0.0	0.0	0.0	1.1	0.0	0.0	1.1	0.0	1.4	0.0	1.4
COES	<i>Colletia spinosa</i>	Native	Shrub	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.4	0.0	0.4
COHY	<i>Colletia hystrix</i>	Native	Shrub	0.0	0.0	0.0	1.1	0.0	0.0	1.1	0.0	1.1	0.4	1.4
COIN	<i>Colliguaja integerrima</i>	Native	Shrub	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.0	0.4	0.4	0.7
COLE	<i>Codonorchis lessonii</i>	Native	Forb	0.3	4.8	0.3	0.0	0.0	0.3	5.6	6.9	0.4	0.0	7.2
CRCA	<i>Crepis capillaris</i>	Exotic	Forb	1.1	0.8	0.0	3.5	0.0	3.5	8.8	2.5	4.3	0.4	7.2
DAGL	<i>Dactylis glomerata</i>	Exotic	Graminoid	0.5	7.2	0.8	8.3	2.1	13.9	32.9	9.8	14.5	1.4	25.7
DEDE	<i>Dendroligotrichum dendroides</i>	Native	Bryophyte	0.0	0.0	0.3	0.3	0.3	0.0	0.8	0.7	0.0	0.4	1.1
DICH	<i>Discaria chacaye</i>	Native	Shrub	0.0	0.0	0.0	3.5	0.0	0.0	3.5	1.8	2.9	0.0	4.7
DIPA	<i>Diplolepis pachyphylla</i>	Native	Liana	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
DIPU	<i>Digitalis purpurea</i>	Exotic	Forb	0.5	0.0	0.0	0.0	0.3	0.0	0.8	0.7	0.4	0.0	1.1
DRVE	<i>Draba verna</i>	Exotic	Forb	0.0	0.0	0.0	1.6	0.0	0.0	1.6	0.7	1.4	0.0	2.2
DRWI	<i>Drimys winteri</i>	Native	Tree	0.3	0.0	0.0	0.0	0.5	0.0	0.8	1.1	0.0	0.0	1.1
DYGL	<i>Dysopsis glechomoides</i>	Native	Forb	0.5	1.6	0.3	0.8	0.5	0.3	4.0	2.9	1.8	0.4	5.1
ECVU	<i>Echium vulgare</i>	Exotic	Forb	0.0	0.0	0.3	0.3	0.0	0.8	1.3	0.4	0.4	0.0	0.7
ELAN	<i>Elymus angulatus</i>	Native	Graminoid	0.0	0.0	0.0	1.3	0.0	0.0	1.3	1.1	0.7	0.0	1.8
ELPA	<i>Eleocharis pachycarpa</i>	Native	Graminoid	0.0	0.8	0.0	0.0	0.0	0.0	0.8	1.1	0.0	0.0	1.1
ELRE	<i>Elymus repens</i>	Exotic	Graminoid	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.4	0.0	0.4
EMCO	<i>Embothrium coccineum</i>	Native	Tree	0.8	0.3	0.0	0.3	0.0	0.0	1.3	0.7	1.1	0.0	1.8
EMRU	<i>Empetrum rubrum</i>	Native	Shrub	0.0	0.8	0.0	2.7	0.0	0.5	4.0	2.9	1.8	0.0	4.7
ESAL	<i>Escallonia alpina</i>	Native	Shrub	0.0	0.0	0.0	0.5	0.0	0.3	0.8	0.4	0.4	0.0	0.7
ESRU	<i>Escallonia rubra</i>	Native	Shrub	0.3	0.0	0.0	0.3	0.0	0.0	0.5	0.4	0.4	0.0	0.7
ESVI	<i>Escallonia virgata</i>	Native	Shrub	0.0	0.0	0.0	3.2	0.0	1.6	4.8	2.5	1.8	0.0	4.3
FEMA	<i>Festuca magellanica</i>	Native	Graminoid	0.3	4.5	0.3	1.3	0.0	0.3	6.7	6.2	2.5	0.0	8.7
FEP	<i>Festuca pallascens</i>	Native	Graminoid	0.0	2.7	0.0	5.6	0.0	1.1	9.4	1.8	7.2	2.2	11.2
FERU	<i>Festuca rubra</i>	Native	Graminoid	0.0	0.3	0.0	2.1	0.0	5.3	7.8	0.4	2.9	0.0	3.3
FRCH	<i>Fragaria chiloensis</i>	Native	Forb	0.3	7.8	0.3	11.5	0.0	2.1	21.9	12.7	13.0	1.1	26.8
FUMA	<i>Fuchsia magellanica</i>	Native	Shrub	1.3	0.8	0.0	0.0	2.1	3.5	7.8	4.3	1.4	0.0	5.8
GAAP	<i>Galium aparine</i>	Exotic	Forb	0.0	0.3	0.0	1.3	0.0	0.0	1.6	1.4	0.7	0.0	2.2
GAHY	<i>Galium hypocarpium</i>	Native	Forb	0.3	1.6	0.3	0.8	0.0	2.4	5.3	1.4	2.5	0.0	4.0
GALU	<i>Gavilea lutea</i>	Native	Forb	0.3	4.3	0.0	1.3	0.0	0.3	6.1	6.5	1.4	0.0	8.0
GAMU	<i>Gaultheria mucronata</i>	Native	Shrub	2.4	9.9	0.8	4.8	0.0	7.5	25.4	17.4	6.2	0.7	24.3
GERMA	<i>Geranium magallanicum</i>	Native	Forb	1.1	5.1	0.0	5.6	0.0	5.1	16.8	9.1	6.5	0.4	15.9
GEMO	<i>Geranium molle</i>	Exotic	Forb	0.0	0.0	0.0	1.1	0.0	2.1	3.2	0.4	1.1	0.0	1.4
GEUMA	<i>Geum magallanicum</i>	Native	Forb	0.3	2.4	0.3	0.8	0.0	0.0	3.7	3.3	1.8	0.0	5.1
GRRU	<i>Griselinia ruscifolia</i>	Native	Shrub	1.1	0.0	0.0	0.0	0.8	0.0	1.9	2.2	0.4	0.0	2.5
GRSP	<i>Greigia sphacelata</i>	Native	Forb	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0

Table A1. Cont.

Code	Species	Origin	Growth Habit	Environment Type						Total	Canopy Cover			Total
				CO	LE	MI	ÑI	SV	OL		Closed	Semi-Open	Open	
GUMA	<i>Gunnera magellanica</i>	Native	Forb	0.0	2.1	0.8	0.3	0.0	0.0	3.2	3.6	0.7	0.0	4.3
GUTI	<i>Gunnera tinctoria</i>	Native	Forb	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
HOLA	<i>Holcus lanatus</i>	Exotic	Graminoid	2.1	8.0	3.2	21.7	1.6	21.9	58.6	22.1	26.4	1.1	49.6
HYDE	<i>Hymenophyllum dentatum</i>	Native	Forb	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.4	0.0	0.0	0.4
HYRA	<i>Hypochaeris radicata</i>	Exotic	Forb	3.2	4.0	0.5	8.8	1.1	16.3	34.0	8.3	14.9	0.7	23.9
HYSE	<i>Hydrangea serratifolia</i>	Native	Liana	0.3	0.0	0.0	0.0	0.5	0.0	0.8	1.1	0.0	0.0	1.1
JUPR	<i>Juncus procerus</i>	Native	Graminoid	0.5	0.3	0.0	1.1	0.0	1.6	3.5	0.4	2.2	0.0	2.5
LAHA	<i>Lagenophora harioti</i>	Native	Forb	0.3	2.1	0.3	0.0	0.8	0.0	3.5	4.0	0.7	0.0	4.7
LAMA	<i>Lathyrus magellanicus</i>	Native	Forb	0.0	0.0	0.0	2.1	0.3	0.0	2.4	1.1	2.2	0.0	3.3
LAPH	<i>Laureliopsis philippiana</i>	Native	Tree	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
LESC	<i>Leptinella scariosa</i>	Native	Forb	0.5	0.5	0.0	0.0	0.8	4.8	6.7	1.1	1.4	0.0	2.5
LETH	<i>Leucheria thermanum</i>	Native	Forb	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
LEVU	<i>Leucanthemum vulgare</i>	Exotic	Forb	0.0	0.5	0.0	0.0	0.0	3.5	4.0	0.0	0.7	0.0	0.7
LOFE	<i>Lomatia ferruginea</i>	Native	Tree	1.1	0.0	0.3	0.3	0.3	0.0	1.9	2.2	0.4	0.0	2.5
LOPE	<i>Lotus pedunculatus</i>	Exotic	Forb	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.4	0.0	0.4
LURA	<i>Luzula racemosa</i>	Native	Forb	0.3	0.3	0.0	0.0	0.5	0.0	1.1	1.1	0.4	0.0	1.4
LUPO	<i>Lupinus polyphyllus</i>	Exotic	Forb	0.0	0.5	0.0	1.1	0.0	1.9	3.5	0.0	2.2	0.0	2.2
MADI	<i>Maytenus disticha</i>	Native	Shrub	0.5	10.2	0.5	5.3	0.0	0.0	16.6	15.2	6.9	0.4	22.5
MAGR	<i>Macrachaenium gracile</i>	Native	Forb	0.3	2.7	0.3	0.0	0.0	0.0	3.2	4.3	0.0	0.0	4.3
MESA	<i>Medicago sativa</i>	Exotic	Forb	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
MICO	<i>Mitraria coccinea</i>	Native	Liana	0.3	0.0	0.0	0.0	1.6	0.0	1.9	1.8	0.7	0.0	2.5
MUDE	<i>Mutisia decurrens</i>	Native	Liana	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.4	0.4	0.0	0.7
MUSP	<i>Mulinum spinosum</i>	Native	Shrub	0.0	1.6	0.3	3.5	0.3	1.9	7.5	1.1	4.7	1.8	7.6
MUSPI	<i>Mutisia spinosa</i>	Native	Liana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MYCH	<i>Myrceugenia chrysocarpa</i>	Native	Shrub	0.3	0.3	0.0	0.3	0.0	0.0	0.8	0.0	1.1	0.0	1.1
MYOP	<i>Myoschilos oblonga</i>	Native	Shrub	0.0	0.5	0.3	0.8	0.0	0.0	1.6	1.1	0.7	0.4	2.2
MYPL	<i>Myrceugenia planipes</i>	Native	Shrub	0.5	0.0	0.0	0.0	0.5	0.0	1.1	1.1	0.4	0.0	1.4
NEGR	<i>Nertera granadensis</i>	Native	Forb	1.1	0.5	0.8	0.0	1.9	0.0	4.3	3.6	2.2	0.0	5.8
NOAN	<i>Nothofagus antarctica</i>	Native	Tree	0.0	0.0	0.0	13.9	0.0	0.3	14.2	6.5	11.2	1.1	18.8
NOBE	<i>Nothofagus betuloides</i>	Native	Tree	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.4	0.0	0.0	0.4
NODO	<i>Nothofagus dombeyi</i>	Native	Tree	1.9	0.3	0.0	0.0	0.8	0.8	3.7	2.5	1.4	0.0	4.0
NOPU	<i>Nothofagus pumilio</i>	Native	Tree	0.0	18.2	0.5	1.1	0.0	0.8	20.6	21.7	4.3	0.7	26.8
OLJU	<i>Olsynium junceum</i>	Native	Forb	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.0	0.7	0.0	0.7
OSCH	<i>Osmorrhiza chilensis</i>	Native	Forb	1.6	20.6	1.1	9.1	1.1	0.5	34.0	32.2	12.3	0.7	45.3
OSDE	<i>Osmorrhiza depauperata</i>	Native	Forb	0.0	2.1	0.0	0.0	0.0	0.3	2.4	2.9	0.0	0.0	2.9
OVAN	<i>Ovidia andina</i>	Native	Shrub	0.3	0.3	0.0	1.1	0.0	0.3	1.9	0.0	2.2	0.0	2.2
OVPI	<i>Ovidia pillopollo</i>	Native	Shrub	0.0	0.0	0.5	0.3	0.0	0.0	0.8	0.7	0.4	0.0	1.1
OXEN	<i>Oxalis enneaphylla</i>	Native	Forb	0.0	0.0	0.0	2.1	0.0	0.0	2.1	0.4	2.5	0.0	2.9
PAVI	<i>Parentucellia viscosa</i>	Exotic	Forb	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.4	0.0	0.4
PHAL	<i>Phleum alpinum</i>	Native	Graminoid	0.0	0.5	0.0	2.4	0.0	2.1	5.1	1.1	2.2	0.7	4.0

Table A1. Cont.

Code	Species	Origin	Growth Habit	Environment Type						Total	Canopy Cover			Total
				CO	LE	MI	ÑI	SV	OL		Closed	Semi-Open	Open	
PHPR	<i>Phleum pratense</i>	Exotic	Graminoid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PHSE	<i>Phacelia secunda</i>	Native	Forb	0.0	1.9	0.0	1.1	0.0	0.0	2.9	2.5	1.4	0.0	4.0
PIPO	<i>Pinus ponderosa</i>	Exotic	Tree	0.0	0.0	0.3	0.0	0.0	0.5	0.8	0.0	0.0	0.4	0.4
PLLA	<i>Plantago lanceolata</i>	Exotic	Forb	0.3	1.3	0.3	0.8	1.3	6.7	10.7	1.4	3.6	0.4	5.4
PLMA	<i>Plantago major</i>	Exotic	Forb	0.5	0.0	0.8	1.9	0.5	0.8	4.5	3.3	1.8	0.0	5.1
POAL	<i>Poa alopecurus</i>	Native	Graminoid	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.4	0.4	0.0	0.7
POAN	<i>Poa annua</i>	Exotic	Graminoid	0.0	0.0	0.0	1.1	0.0	0.3	1.3	0.7	0.7	0.0	1.4
POAU	<i>Polypogon australis</i>	Native	Forb	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.4	0.4
POBU	<i>Poa bulbosa</i>	Exotic	Graminoid	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
POPR	<i>Poa pratensis</i>	Exotic	Graminoid	1.3	5.1	1.3	13.6	1.1	11.0	33.4	10.5	18.1	1.8	30.4
POMU	<i>Polystichum multifidum</i>	Native	Fern	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.4	0.0	0.0	0.4
PONU	<i>Podocarpus nubigenus</i>	Native	Tree	0.3	0.3	0.0	0.0	0.0	0.0	0.5	0.0	0.7	0.0	0.7
PRMA	<i>Protousnea magellanica</i>	Native	Lichens	0.5	5.9	0.0	2.1	0.3	0.8	9.6	6.9	5.1	0.0	12.0
PRVU	<i>Prunella vulgaris</i>	Exotic	Fern	1.1	0.5	0.5	4.3	1.6	1.3	9.4	5.8	5.1	0.0	10.9
QUCH	<i>Quinchamalium chilense</i>	Native	Forb	0.0	0.0	0.0	0.8	0.0	0.5	1.3	0.7	0.4	0.0	1.1
RAMI	<i>Ranunculus minutiflorus</i>	Native	Forb	0.5	0.0	0.0	0.5	0.0	0.0	1.1	1.1	0.4	0.0	1.4
RALA	<i>Raukaua laetevirens</i>	Native	Shrub	1.6	0.0	0.3	0.0	0.5	0.3	2.7	2.9	0.4	0.0	3.3
RARE	<i>Ranunculus repens</i>	Exotic	Forb	0.8	1.1	1.3	0.5	2.1	0.5	6.4	4.3	3.6	0.0	8.0
RHSP	<i>Rhaphithamnus spinosus</i>	Native	Shrub	0.5	0.0	0.0	0.0	0.8	0.0	1.3	1.1	0.7	0.0	1.8
RIRU	<i>Ribes rubrum</i>	Exotic	Shrub	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
RICU	<i>Ribes cucullatum</i>	Native	Shrub	0.0	2.9	0.0	10.2	0.0	0.5	13.6	6.5	9.8	1.4	17.8
RIMA	<i>Ribes magellanicum</i>	Native	Shrub	0.5	4.8	0.8	1.9	0.5	0.0	8.6	8.7	2.2	0.7	11.6
ROEG	<i>Rosa eglantheria</i>	Exotic	Shrub	0.0	0.0	0.3	0.5	0.0	0.3	1.1	0.4	0.4	0.4	1.1
RUAC	<i>Rumex acetocella</i>	Exotic	Forb	0.0	4.3	0.8	15.2	0.8	10.7	31.8	9.1	18.1	1.4	28.6
RUCR	<i>Rumex crispus</i>	Exotic	Forb	0.0	0.0	0.0	0.8	0.5	2.1	3.5	0.4	1.1	0.4	1.8
RUGE	<i>Rubus geoides</i>	Native	Forb	0.8	1.6	1.3	1.1	1.3	1.9	8.0	6.2	2.2	0.0	8.3
RURA	<i>Rubus radicans</i>	Native	Forb	0.8	0.0	0.0	0.0	0.8	0.0	1.6	2.2	0.0	0.0	2.2
SACO	<i>Saxegothaea conspicua</i>	Native	Tree	0.5	0.0	0.0	0.0	0.5	0.0	1.1	1.1	0.4	0.0	1.4
SAGR	<i>Sanicula graveolens</i>	Native	Forb	0.0	0.0	0.0	1.1	0.0	0.0	1.1	0.0	1.4	0.0	1.4
SARE	<i>Sarmienta repens</i>	Native	Liana	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
SCAN	<i>Schoenus andinus</i>	Native	Forb	0.0	0.5	0.0	0.0	0.0	0.5	1.1	0.7	0.0	0.0	0.7
SCPA	<i>Schinus patagonicus</i>	Native	Shrub	0.0	0.0	0.0	0.0	0.3	0.5	0.8	0.0	0.0	0.4	0.4
SEFI	<i>Senecio filaginoides</i>	Native	Shrub	0.0	1.9	0.5	0.5	0.0	0.5	3.5	2.5	1.1	0.4	4.0
SEPA	<i>Senecio patagonico</i>	Native	Shrub	0.0	0.0	0.0	1.1	0.0	0.5	1.6	0.4	0.7	0.4	1.4
STME	<i>Stellaria media</i>	Exotic	Forb	0.0	0.5	0.0	0.5	0.0	0.0	1.1	0.4	0.7	0.4	1.4
TAOF	<i>Taraxacum officinale</i>	Exotic	Forb	2.7	12.6	0.8	26.2	1.3	16.8	60.4	25.0	31.2	2.9	59.1
TRPR	<i>Trifolium pratense</i>	Exotic	Forb	0.8	1.3	0.8	5.1	0.0	13.9	21.9	1.8	8.7	0.4	10.9
TRRE	<i>Trifolium repens</i>	Exotic	Forb	2.1	6.4	1.6	18.7	2.1	16.8	47.9	16.7	23.9	1.4	42.0
UNTE	<i>Uncinia tenuis</i>	Native	Graminoid	0.0	0.5	0.0	0.0	0.3	0.0	0.8	1.1	0.0	0.0	1.1
URDI	<i>Urtica dioica</i>	Exotic	Forb	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
VACA	<i>Valeriana carnosa</i>	Native	Forb	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0
VAFO	<i>Valeriana fonckii</i>	Native	Forb	0.0	0.5	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.7	0.7
VALA	<i>Valeriana lapathifolia</i>	Native	Forb	0.0	1.3	0.0	0.0	0.0	0.0	1.3	1.8	0.0	0.0	1.8
VEPE	<i>Veronica peregrina</i>	Exotic	Forb	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.4	0.0	0.0	0.4
VESE	<i>Veronica serpyllifolia</i>	Exotic	Forb	0.0	0.5	0.0	1.9	0.0	0.0	2.4	2.5	0.7	0.0	3.3
VIBI	<i>Vicia bijuga</i>	Native	Forb	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.4
VIHI	<i>Vicia hirsuta</i>	Exotic	Forb	0.0	1.1	0.0	0.0	0.0	0.0	1.1	1.4	0.0	0.0	1.4
VINI	<i>Vicia nigricans</i>	Native	Forb	0.0	1.3	0.0	0.0	0.0	0.0	1.3	1.8	0.0	0.0	1.8
VIRE	<i>Viola reichei</i>	Native	Forb	0.0	11.8	0.5	2.9	0.0	0.3	15.5	15.6	4.7	0.4	20.7

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