

Distance to flood meadows as a predictor of use of *Nothofagus pumilio* forest by livestock and resulting impact, in Patagonia, Argentina

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Abstract Seedling browsing by livestock has been indicated as major threat for forest sustainability use. *Nothofagus pumilio* forests are part of the livestock raising system in Patagonia, but because of the sparse understory cover, livestock graze mainly on flood meadows within the forest matrix. The complexity of the environment under study (forests and flood meadows) means that an adaptive predictor is needed to evaluate the intensity of resource use by livestock in order to assess its effect on the forest. Distance to flood meadows was evaluated as a predictor of the use intensity of the forest by livestock and its effect on the understory. The study was conducted at three sites in

Chubut Province, Patagonia–Argentina. We established transects in the forest 320 m long, starting at the edge flood meadow-forest. In these transects, the livestock presence indicators (soil compaction, density of feces and trails) and composition of the understory were evaluated. Generalized Linear Model for repeated measures for longitudinal data were used. The indicators showed that distance is efficient for estimating forest use intensity by livestock. The understory varied with distance, the cover of exotic herbaceous was higher near the flood meadow. Far from the flood meadow, the cover was entirely composed of native species. The results support the use of distance to flood meadows as a tool for decision making in livestock and forest management in *N. pumilio* forests, and for further research on livestock effect on the forest.

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Introduction

Herbivory by large exotic ungulates is one of the main anthropic disturbances in the Patagonian Andes forests (Kitzberger et al. 2005; Vázquez 2002; Relva et al. 2010; Relva and Veblen 1998). In 1880 began a period of massive European settlement in northern Patagonia and the establishment of livestock occurred during the

coming decades (Veblen and Lorenz 1988). Livestock pressure on these forests may reduce and even prevent the regeneration of some tree species and alter the composition of the vegetation, increasing the predominance of thorny bushes and the importance of exotic species (Kitzberger et al. 2005; Relva and Veblen 1998; Blackhall et al. 2008).

The use of resources by livestock is determined by habitat characteristics (Bailey et al. 1996; Coughenour 1991). For example, gradient and distance to water sources may result in some areas being intensively used, while others are not used at all. Similarly, biotic factors such as species composition, availability and forage quality of the vegetation affect the spatial arrangement of the animals and the use of the understory (Senft et al. 1987). Large herbivores produce direct and indirect alteration in plant communities, affecting their biodiversity and structure (Cingolani et al. 2008; Coughenour 1991). Changes in the abundance of different plant species according to how palatable they are constitute one of the direct alterations (Vázquez 2002; Perry 1994). On the other hand, an example of indirect alteration is the introduction of alien invasive species by livestock that may displace native plants communities by competition (Holmgren 2002). Other examples of indirect alteration are changes in the root structure of vegetation, and water and soil nutrients distribution by physical soil compaction through trampling (Milchunas et al. 1998; Cingolani et al. 2008).

This study focuses on ‘lenga’ forests [*Nothofagus pumilio* (Poepp. et Endl.) Krasser], one of the tree species with greatest ecological, economic and landscape value in Patagonia (Bava and Rechene 2004; Martínez Pastur et al. 2000). *N. pumilio* forests are important for traditional livestock raising, which uses the high cordillera pastures during summer and steppe pastures during winter (Guitart 2004). These summer pastures are located within a forest landscape matrix, which includes flood meadows with high palatable species productivity, locally known as ‘mallines’. In spite of the existence of these flood meadows cattle also uses forest resources; cattle use in the forest cause serious damage, particularly on natural regeneration (Rebertus and Veblen 1993; Vázquez 2002). Because the environment under study (forest-flood meadows) is spatially complex, resources are heterogeneously used by selecting not only forage, but also resting areas, shade, shelter and watering sites (Bailey et al.

1996; Coughenour 1991). Where herbivores are more abundant or stay longer (in search of food, water, shelter or protection), increased presence indicators are found (Martínez Pastur et al. 1999). Herbivore abundance or stocking rate (number of animals/surface area) is adequate for estimating the intensity of resource use in homogeneous environments; but in these heterogeneous environments, stocking rate is difficult to describe and has little explanatory power (Coughenour 1991).

The understory is an essential component of forest ecosystems because it contributes nutrients to the soil, protects soil from erosion, forms the basis of trophic networks and provides wildlife habitat, thus regulating many ecosystem functions (Ellum 2009; Kerns and Ohmann 2004). In particular, it is the stratum where the forest regenerates from seedlings and saplings (Rebertus and Veblen 1993). The understory in *N. pumilio* forests is made up mainly of herbaceous species and sparse shrubs (Boelcke et al. 1985; Lencinas et al. 2008), and has low cover and diversity in the southern part of its distribution (Moore 1983; Lencinas et al. 2008) as compared to other similar temperate forests around the world (Christensen and Emborg 1996). There are studies evaluating the understory according to forest structure (Damascos and Rapoport 2002; Sánchez-Jardón et al. 2010; Lencinas et al. 2008; Bastías Fuentes 2005), and studies of the synergic effect of grazing and fire on recent post-fire forests (Raffaele et al. 2011); however, little is known about the impact of livestock use on the understory in natural forests. This information could be used to develop tools for sustainable forestry, taking into account both biodiversity conservation and livestock as a factor in the production pattern. The aims of this study were to evaluate (a) whether the distance to flood meadows is an efficient predictor of how intensively livestock use forest resources and (b) the effect of livestock use intensity on diversity, composition and understory structure.

Materials and methods

Study area and experimental design

The study area is located in northwest Chubut Province (Patagonia, Argentina), between 42°38' and 43°23' latitude South, 71°14' and 71°31' longitude West, at an elevation between 1,290 and 1,370 m a.s.l.

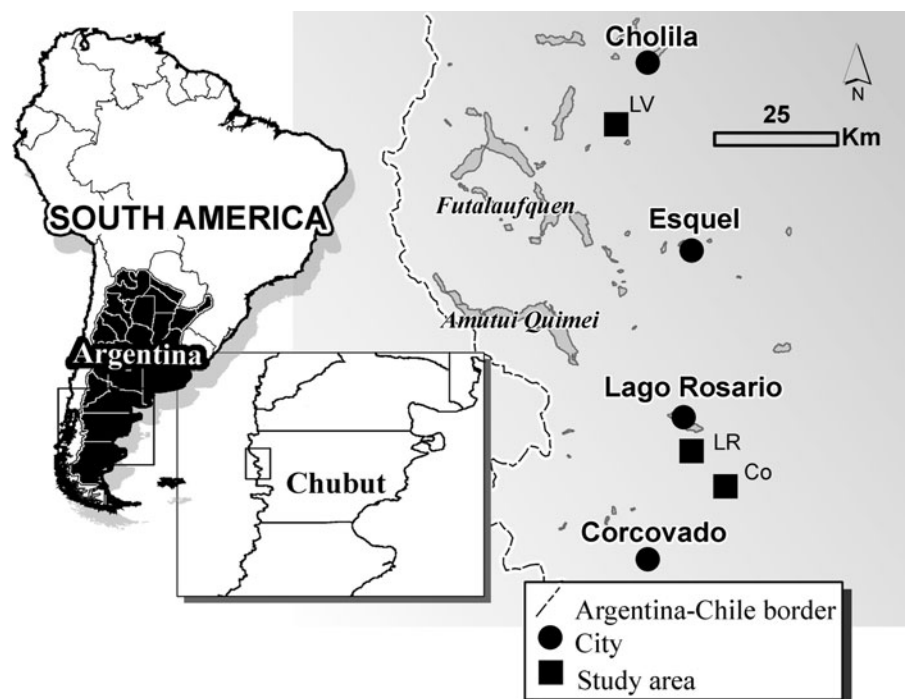
(Fig. 1). It is a mountainous area with cold-temperate to cordilleran moist-cold climate, with rainy winters, dry summers and prevailing westerly winds (Dimitri 1972). The soils are of volcanic origin and rich in organic matter. Within the forest matrix there are flood-prone depressions where the proximity of the water table to the surface prevents trees from growing (flood meadows or ‘mallines’) (Cassola 1988). Their vegetation includes herbaceous species of good forage quality, such as sedges (*Carex gayana*, *Carex subantarctica*, *Eleocharis albibracteata*), reeds (*Juncus balticus*, *Juncus depauperato*) and other typical wetland species (Ayesa et al. 1999). These flood meadows usually have a thin ecotone, not greater than 10 m, and concentrate most of livestock grazing (Raffaele 1999; Flueck et al. 1999; Cassola 1988).

Three study sites were selected with flood meadows surrounded by *N. pumilio* forest, which were used for forestry with selective cutting of the best specimens for timber (high-grading), between 1970 and 1990: Laguna Villarino (LV), Corcovado (Co) and Lago Rosario (LR). Cattle use is similar throughout the study area, where forests are grazed from about 50 years ago with about 0.1 head/ha. Livestock management at these sites is extensive and seasonal (use as summer pastures), and cattle are present only from December

to April. At each site, three transects were established at least than 300 m away from each other, beginning at the edge of the flood meadow and extending 320 m into *N. pumilio* forest. Six main plots measuring 20 × 60 m were located on each transect (10, 20, 40, 80, 160 and 320 m away from the edge of the flood meadow), with the longer side perpendicular to the transect. Altitude above sea level was measured with GPS in each plot and expressed as m a.s.l. The following variables were recorded in these plots (Fig. 2):

- *Indicators of livestock presence*: evaluated in the main 20 × 60 m plots (*i*, in Fig. 2). Feces and trails were surveyed and expressed as number/m². Soil compaction was measured at a depth of 15 cm, once on each trail and at three systematically selected points off each trail, using a cone-tipped impact penetrometer (30° cone–INTA Villegas Model), and expressed in Kg/cm². Soil compaction was also measured off the trails to have complete data of all plots, since in some of them there were no trails, also in some sectors widely used soil forest was disturbed and trails were undistinguished (Gallopín et al. 2005).
- *Characterization of understory*: presence and cover of all vascular plant species were visually estimated in five systematically arranged 2 m²

Fig. 1 Map showing location of the study area in north-west Chubut province, Patagonia, Argentina



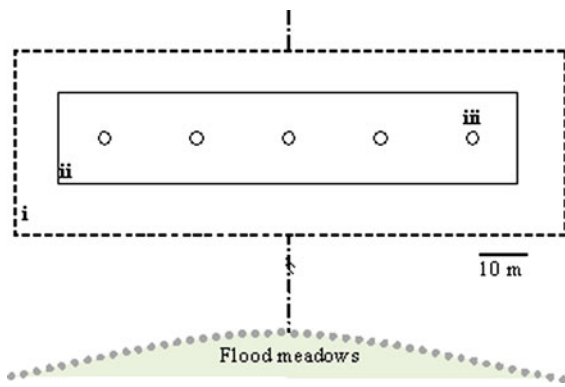


Fig. 2 Diagram of a main plot and sub-plots, *i* rectangular 20 × 60 m plot for characterizing use by livestock, *ii* rectangular 10 × 50 m sub-plot for characterizing forest structure, and *iii* circular 2 m² sub-plot for characterizing understory

circular sub-plots ($n = 5 \times 54 = 270$) (*iii*, in Fig. 2). Species were determined according to *Catálogo de Plantas Vasculares del Cono Sur* (Catalog of Vascular Plants of the Southern Cone) (Zuloaga et al. 2008) and their origin (native or exotic) and habit (herb, shrub or tree) were assigned following Ezcurra and Brion (2005). *N. pumilio* regeneration was counted as tree habit. Species richness (r) y Shannon-Wiener's diversity index (H) were calculated for the main plots ($n = 54$). The values for cover of the species recorded in each circular plot were grouped according to origin and habit.

Due to the absence of *N. pumilio* forests with no livestock grazing, a control site was not established. Instead, we measured some variables which could be related to understory changes. These forest variables were taken in a rectangular 10 × 50 m sub-plot (*ii*, in Fig. 2), and included:

- Canopy cover expressed in percentage, calculated from 4 hemispheric photographs of each plot, and analyzed with Gap Light Analyzer Version 2.0,
- Density of adult trees (diameter at breast height >10 cm) expressed in n/ha ,
- Basal area expressed in m^2/ha ,
- Dominant height expressed in m,

Data analysis

The following differences according to distance to flood meadows were analyzed: (1) forest structure

and altitude, (2) intensity of use by livestock (soil compaction, density of feces and trails) and (3) understory (r , H , total cover, and cover according to habit and origin). Considering the lack of independence of the main plots measured on the same transect, a generalized linear model for repeated measures for longitudinal data was used, in which distance was entered as a repeated factor with 6 levels, the transects were entered as subjects and the sites were considered as blocks. The analysis was performed with significance level $P < 0.05$, and Fisher posteriori test was applied. The sphericity of covariance matrix was proved by Mauchly test. When sphericity was discarded, freedom degrees were adjusted by Huynn-Field Method (SPSS Inc. 2006).

The soil compaction on trails variable was not evaluated using this technique because data were not available for all distances and transects, so a descriptive analysis was performed.

A principal component analysis (PCA) was performed on the cover of species present in over 2% of the understory sub-units evaluated, using the InfoStat statistical package version 2009. Covers were standardized and distance to flood meadows was considered as a classification variable. A biplot was produced with the first two axes explaining greatest variability.

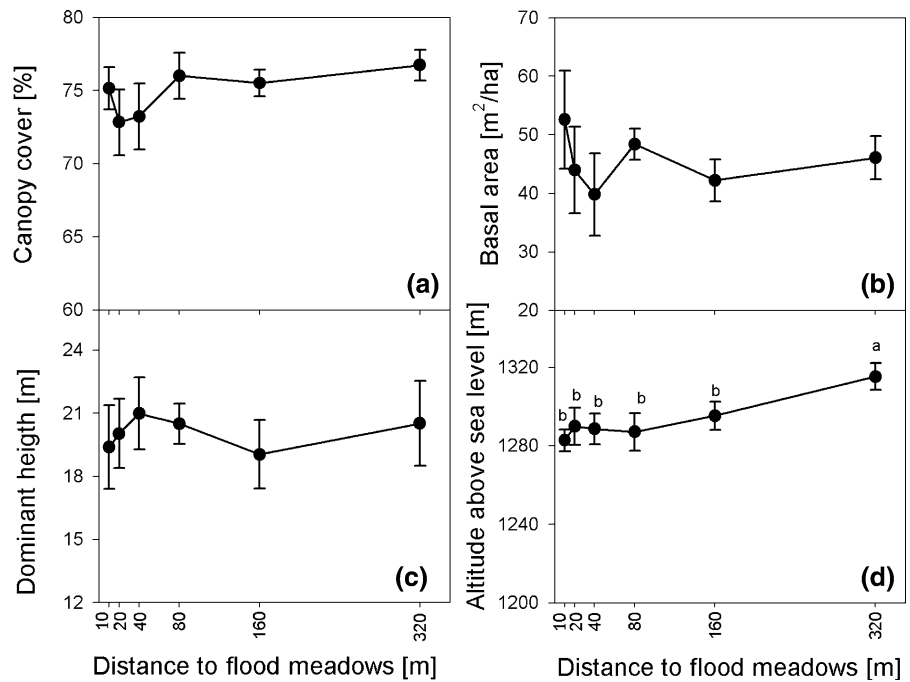
Results

Site characterization and general description of the understory

None of the forest variables significantly changed with the distance to flood meadows, which indicates that the forest studied has a homogeneous structure. The cover canopy was $74.9 \pm 1.16\%$ ($F_{gl:2.56}: 2.56, P: 0.62$), basal area was $40 \pm 3 m^2/ha$ ($F_{gl:5}: 0.70, P: 0.62$), dominant height was $20 \pm 0.7 m$ ($F_{gl:5}: 0.21, P: 0.95$) and there were approximately 500 ± 42 trees/ha. In contrast, altitude was higher at 320 m than at the other distances to flood meadows studied ($F_{gl:5}: 7.03, P < 0.001$). Altitude at 320 m from flood meadow is $1,315 \pm 6.8 m$ a.s.l., while at 10 m, altitude is $1,282 \pm 5.4 m$ a.s.l. (Fig. 3), (all values mean \pm standard error).

The understory cover was $29.7 \pm 1.9\%$; species richness 9 (with a range from 2 to 19 species) and Shannon-Wiener's diversity index 1.27 ± 0.05 . Sixty-one vascular plant species were recorded in all sites,

Fig. 3 Forest variables mean (\pm standard error): **a** Canopy cover (%), **b** Basal area (m^2/ha), **c** dominant height (m); and **d** altitude above sea level (m) as a function to distance to flood meadows. Different letters represent significant differences at $P < 0.05$ by Fisher test



belonging to 29 families, among which Asteraceae (21%) and Poaceae (12%) were dominant (Table 1). Of all the plants surveyed, 59 were identified at species level, 1 at genus level (*Carex* sp.) and 1 at family level (Poaceae) due to the lack of taxonomically relevant features. Out of the total number of species, 48 were native, 34 herbs, 12 shrubs and 2 trees including *N. pumilio* and *Nothofagus antarctica* regeneration, although the latter was found at one sampling unit. There were 11 exotic species, all of them herbs (Table 1).

Distance to flood meadows as predictor of livestock use intensity

The indicators of the presence of livestock (soil compaction, density of feces and trails) were higher near flood meadows, although they followed different patterns (Fig. 4). Soil compaction on the trails decreased with distance, indicating more intensive use near flood meadows (Fig. 4a). Soil compaction off the trails showed variation at different assessed distances (Fig. 4a, $F_{gl:5}: 4.85, P: 0.02$), but showed no variation patron related to the distance to flood meadows. Feces density was higher in areas near flood meadows (10 m) than farther away from them (40, 80, 160 and 320 m) (Fig. 4b, $F_{gl:4.8}: 7.82, P < 0.001$), while at 80, 160 and

320 m it was almost null. Trails density was lower at sites farther to flood meadows (320 m) than at nearer ones (10 m) (Fig. 4c, $F_{gl:5}: 2.4, P: 0.05$). The set of indicator variables shows that use of the forest by livestock tends to stabilize at its lowest values from a distance of 80 m away to flood meadows.

Livestock use and resulting impact on understory

The intensity of livestock use, estimated by distance from flood meadows, had different kinds of influence on the understory variables analyzed (Figs. 5, 6 and 7). The values for richness and diversity did not significantly vary with distance ($F_{gl:5}: 0.75, P: 0.59$ and $F_{gl:5}: 1.38, P: 0.25$, respectively), although there was a tendency to lower diversity as intensity of use increased (Fig. 5). Similarly, understory total cover showed no pattern of variation according to distance to flood meadows ($F_{gl:5}: 1.31, P: 0.26$), it was composed mainly of herbaceous species and, to a lesser extent, of shrubs and trees (*N. pumilio*). It attained its maximum values at 320 and 20 m (Figs. 6a, 7a).

Cover according to habit showed that, regardless of distance, herbs represented about 50% of the cover, with no significant trend regarding distance to flood meadows (Fig. 6b, $F_{gl:5}: 1.77, P: 0.12$), with somewhat higher values in parts of the forest more

Table 1 List of species of understory *N. pumilio*

Family	Species	Abbreviation	Origin	Habit
Apiaceae	<i>Osmorhiza chilensis</i> Hook. & Arn	Osm chi	n	h
Asteraceae	<i>Adenocaulon chilense</i> Less.	Ade chi	n	h
	<i>Baccharis magellanica</i> (Lam.) Pers.		n	s
	<i>Chilotrichum diffusum</i> (G. Forst.) Kuntze	Chi dif	n	s
	<i>Gamochoeta spiciformis</i> (Sch. Bip.) Cabrera		n	h
	<i>Hypochaeris radicata</i> L.		e	h
	<i>Lagenophora nudicaulis</i> (Comm. Ex Lam.) Dusén		n	h
	<i>Leucheria thermanum</i> Phil. (Phil.)	Leu the	n	h
	<i>Perezia bellidifolia</i> (Phil.) Reiche		n	h
	<i>Senecio baccharidifolius</i> DC.		n	h
	<i>Senecio chilensis</i> Less.	Sen chi	n	h
	<i>Senecio neaei</i> DC. var. <i>Neaei</i>		n	h
<i>Taraxacum officinale</i> Weber ex F.H. Wigg.	Tar off	e	h	
Berberidaceae	<i>Berberis empetrifolia</i> Lam.		n	s
	<i>Berberis microphylla</i> G. Forst.	Ber mic	n	s
	<i>Berberis serratodentata</i> Lechl.	Ber sed	n	s
Blechnaceae	<i>Blechnum penna-marina</i> (Poir.) Kuhn	Ble pe-m	n	h
Brassicaceae	<i>Cardamine variabilis</i> Phil.		n	h
	<i>Noccaea magellanica</i> (Comm. ex Poir) Holub		n	h
Caryophyllaceae	<i>Cerastium arvense</i> L.	Cer arv	e	h
	<i>Stellaria media</i> (L.) Cirillio	Ste med	e	h
Celastraceae	<i>Maytenus chubutensis</i> (Speg.) Lourteig & O'Donell & Sleumer		n	s
	<i>Maytenus disticha</i> (Hook. f.) Urb.		n	s
Cyperaceae	<i>Carex caduca</i> Boott	Car cad	n	h
	<i>Carex</i> sp.			h
Empetraceae	<i>Empetrum rubrum</i> Vahl ex Willd.		n	s
Ericaceae	<i>Gaultheria mucronata</i> (L. F.) Hook. & Arn.	Gau muc	n	s
	<i>Gaultheria pumila</i> (L. f.) D.J. Middleton	Gau pum	n	s
Fabaceae	<i>Trifolium repens</i> L.	Tri rep	e	h
	<i>Vicia nigricans</i> Hook. & Arn.		n	h
Geraniaceae	<i>Geranium sessiliflorum</i> Cav.		n	h
Hydrophyllaceae	<i>Phacelia secunda</i> J.F. Gmel		n	h
Iridaceae	<i>Sisyrinchium cuspidatum</i> Poepp.		n	h
Juncaceae	<i>Luzula chilensis</i> Nees & Meyen ex Kunth		n	h
Lycopodiaceae	<i>Lycopodium paniculatum</i> Desv.		n	h
Nothofagaceae	<i>Nothofagus antarctica</i> (G. Forst.) Oerst.		n	t
	<i>Nothofagus pumilio</i> (Poepp. & Endl.) Krasser	Not pum	n	t
Orchidaceae	<i>Codonorchis lessonii</i> (Brongn.) Lindl.		n	h
	<i>Gavilea lutea</i> (Pers.) M.N. Correa		n	h
Oxalidaceae	<i>Oxalis adenophylla</i> Gillies ex Hook. & Arn.	Oxa ade	n	h

Table 1 continued

Family	Species	Abbreviation	Origin	Habit
Poaceae	<i>Agrostis capillaris</i> L.		e	h
	<i>Bromus coloratus</i> Steud.	Bro col	n	h
	<i>Festuca magellanica</i> Lam.		n	h
	<i>Poa nemoralis</i> L.		e	h
	<i>Poa pratensis</i> L.	Poa pra	e	h
	<i>Poa alopecurus</i> (Gaudich. ex Mirb.) Kunth	Poa alo	n	h
	<i>Phleum alpinum</i> L.		n	h
	<i>Poaceae 1</i>			h
Polemoniaceae	<i>Microsteris gracilis</i> (Hook.) Greene		e	h
Polygonaceae	<i>Rumex acetosella</i> L.	Rum ace	e	h
Ranunculaceae	<i>Ranunculus peduncularis</i> Sm.		n	h
Rosaceae	<i>Acaena ovalifolia</i> Ruiz & Pav.	Aca ova	n	h
	<i>Acaena pinnatifida</i> Ruiz & Pav.	Aca pin	n	h
	<i>Potentilla chilensis</i> (L.) Mabb.	Pot chi	n	h
	<i>Geum magellanicum</i> Comm. ex Pers.		n	h
Rubiaceae	<i>Galium hypocarpium</i> (L.) Endl. ex Griseb.		n	h
Santalaceae	<i>Myoschilos oblongum</i> Ruiz & Pav.	Myo obl	n	s
Saxifragaceae	<i>Ribes cucullatum</i> Hook. & Arn.	Rib cuc	n	s
Scrophulariaceae	<i>Calceolaria crenatiflora</i> Cav.	Cal cre	n	h
	<i>Veronica serpyllifolia</i> L.	Ver ser	e	h
Violaceae	<i>Viola maculata</i> Cav.	Vio mac	n	h

List of species by family, including origin (*n* native, *e* exotic), habit (*h* herb, *s* shrub, *t* tree), and abbreviation of species were used in the PCA

intensively used by livestock (10, 20 m). Shrub cover showed no pattern of variation regarding distance to flood meadows (Fig. 6c, $F_{gl:5}$: 1.41, P : 0.22), and attained its maximum values at 40 and 320 m. Forest regeneration cover (*N. pumilio*) showed no variation regarding distance (Fig. 6d, $F_{gl:5}$: 1.33, P : 0.25), the lowest value being at 40 m.

Regarding origin, native species cover was greater at 320 m (32%), than at 10, 20 and 40 m away to flood meadows (15%) (Fig. 7b, $F_{gl:5}$: 3.94, P : 0.002). Exotic herbaceous species cover was greater where the forest was more intensively used by livestock (10 and 20 m), where cover reached 17%, and low or null where the forest was less used (160 and 320 m), with cover lower than 1% (Fig. 7c, $F_{gl:4.4}$: 8.88, P < 0.001).

Livestock use and resulting impact on species composition

In the PCA, 4 principal components (PC) with eigenvalues greater than 1 were extracted which

explained 92% of the variability. The first two PCs, which explain 68.7% of the variability, were used to construct a biplot (Fig. 8) showing the species associated to areas near to or far to flood meadows. To the right of the biplot are the exotic herbaceous species *Poa pratensis*, *Taraxacum officinale*, *Stellaria media*, *Rumex acetosella* and *Trifolium repens*, which had greater cover in parts of the forest near to flood meadows (10, 20 and 40 m). In these parts exposed to intensive use by livestock, maximum cover values were also found for the native herbaceous species *Acaena pinnatifida*, *Potentilla chilensis*, *Bromus coloratus* and the shrub species *Berberis microphylla* and *Chilothrichum diffusum*. To the left of the biplot, associated to areas far to flood meadows (80, 160 and 320 m), are the native herbaceous species *Viola maculata*, *Osmorhiza chilensis*, *Blechnum penna-marina*, *Poa alopecurus*, *Carex caduca*, *Acaena ovalifolia*, *Adenocaulon chilense*, *Leucheria thermarum*, *Calceolaria crenatiflora*, *Senecio chilensis*, *Oxalis adenophylla*, native shrubs

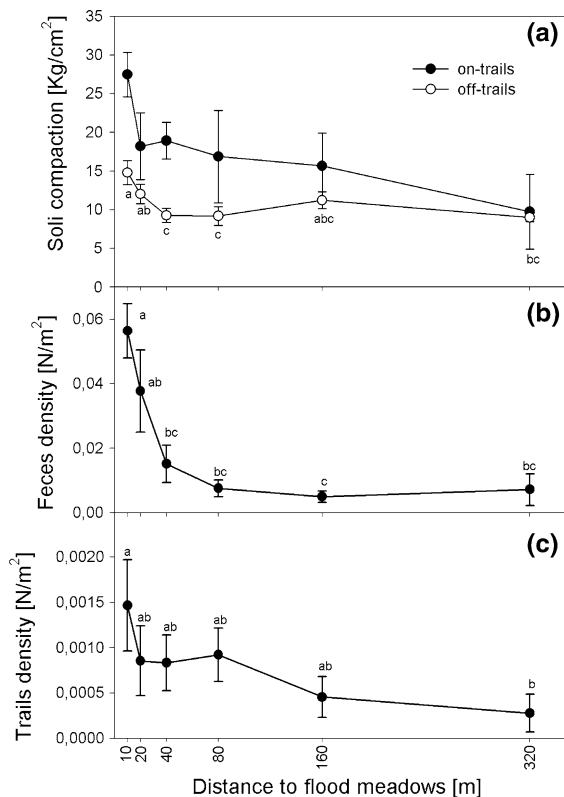


Fig. 4 Indicators of livestock presence: **a** Soil compaction on-trails and off-trails, **b** feces density, **c** trails density (mean and standard error) as a function to distance to flood meadows. Different letters represent significant differences at $P < 0.05$ by Fisher test

Gaultheria mucronata, *Berberis serratodentata*, *Ribes cucullatum* and *Myoschilos oblongum* and forest regeneration (*N. pumilio*).

Discussion

Distance to flood meadows as a predictor of intensity of use by livestock

The dynamics of livestock use in forest ecosystems is complex because the resources are heterogeneously distributed. This uneven distribution spatially conditions herbivores abundance, and therefore the use of resources in different areas (Coughenour 1991; Bailey et al. 1996). In Patagonian forests it has also been mentioned that large herbivores use is heterogeneous (Gallopín et al. 2005; Flueck et al. 1999). In this region, the number of animals per area is therefore a

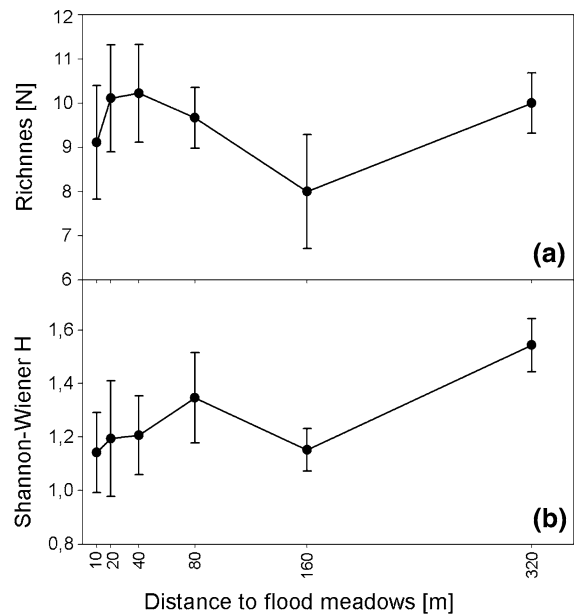


Fig. 5 Species richness (r) and Shannon-Wiener's diversity (H) as a function to distance to flood meadows (mean and standard error)

value which does not sufficiently explain how intensively livestock use the forest. Although the stocking rate in the study area was low—in the order of 0.1 animals per hectare—the heterogeneous landscape means that indirect indicators are needed to understand how space is used. On the scale analyzed, the distance to flood meadows strongly conditions the spatial use of the forest by livestock, as shown by the pattern estimated from the indicators studied (soil compaction on trails, feces and trails density). A similar pattern was found in semi-arid ecosystems where a concentrated effect of grazing pressure was observed in the areas near the watering site (Todd 2006). The high availability of palatable species in flood meadows (Cassola 1988; Flueck et al. 1999) and the fact that flood meadows are the main source of water, in contrast to the low supply of forage typical of the *N. pumilio* understory (Flueck et al. 1999; Guitart 2004), determine a trend towards greater use of forest resources near to flood meadows. Flueck et al. 1999 found that livestock select flood meadows from among various types of environment, including *N. pumilio* forest, similar as reported by Manacorda et al. (1996) in ecosystems of *N. antarctica* and flood meadows.

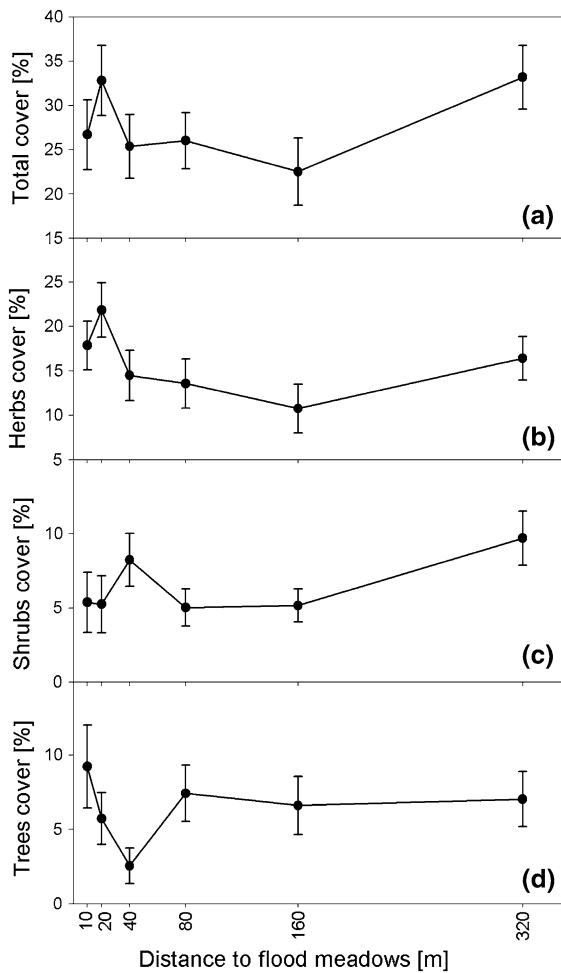


Fig. 6 Total cover (a), herbs cover (b), shrubs cover (c) and trees cover (d, *N. pumilio* seedlings) as a function to distance to flood meadows (mean and standard error)

Impact on the understory

Total richness species recorded in this study (61 sp.) was higher than that found in other sites in *N. pumilio* forests (Sánchez-Jardón et al. 2010; Lencinas et al. 2008; Damascos and Rapoport 2002), and did not vary with distance. Shannon-Wiener’s diversity index did not vary with distance, but showed a higher value at 320 m to flood meadows, where native plants dominate the understory. Total cover was relatively low (28%), similar as reported by Bastías Fuentes (2005), and there was native herbaceous species predominance, as reported by Moore (1983) and Lencinas et al. (2008) in Tierra del Fuego. Total cover did not vary with distance, but showed the highest values at 20 and

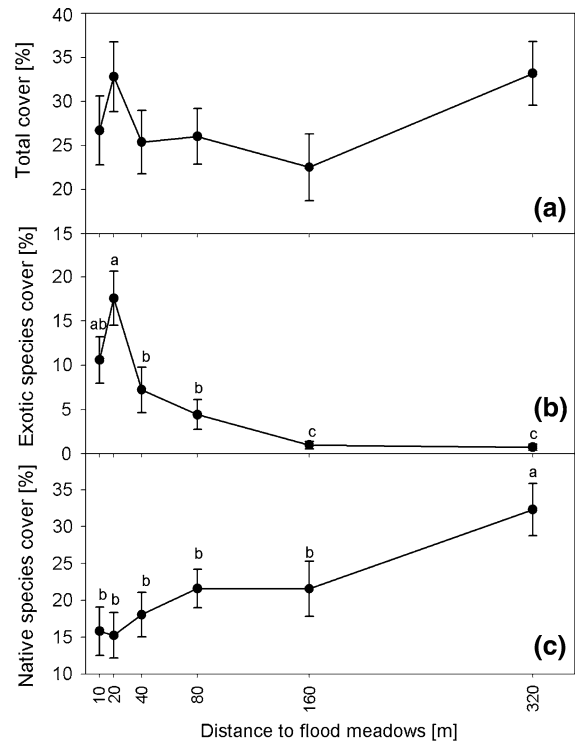
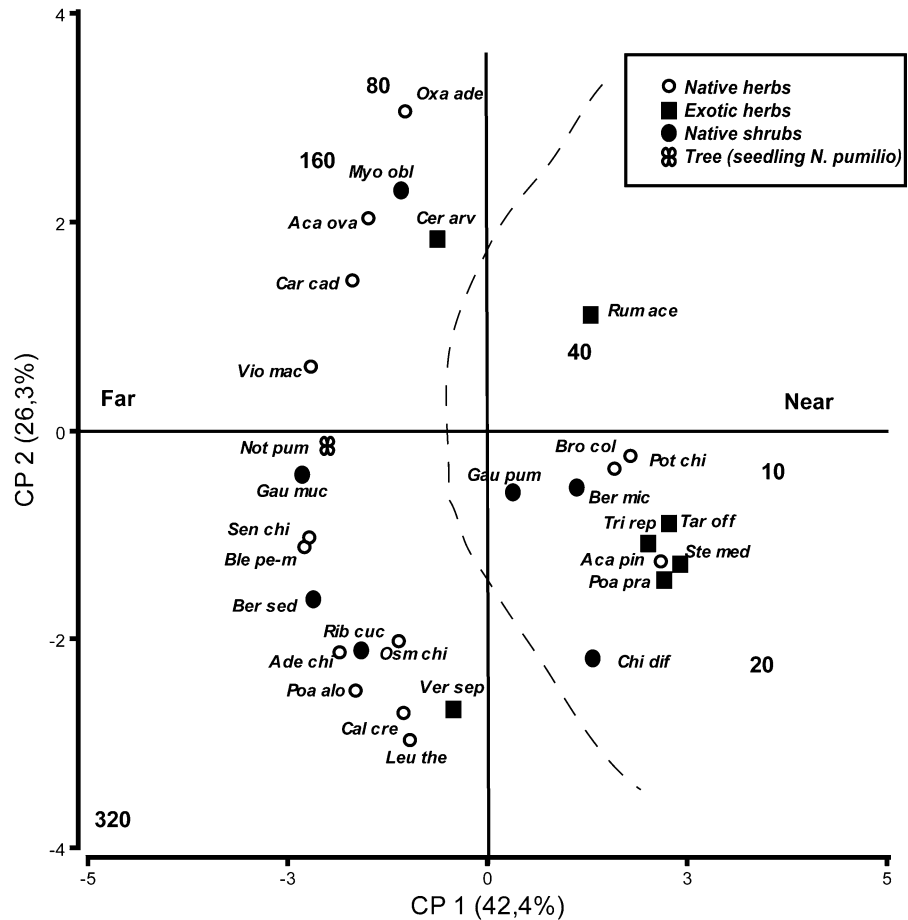


Fig. 7 Total cover (a), exotic species cover (b) and native species cover (c), as a function to distance to flood meadows (mean and standard error). Different letters represent significant differences at $P < 0.05$ by Fisher test

320 m to flood meadows. In areas near flood meadows (10–20 m), where there was higher livestock use impact, a high cover of herbaceous species was recorded. These were mainly the exotic herbaceous species *P. pratensis*, *S. media*, *T. repens*, *T. officinale* and *R. acetosella*, and some native ones such as *B. coloratus*, *A. pinnatifida* and *P. chilensis*, cited for *N. pumilio* forests with presence of livestock (Sánchez-Jardón et al. 2010). In contrast, in areas far from flood meadows (320 m), higher cover of native herbaceous species such as *P. alopecurus*, *O. chilensis*, *A. chilense*, *C. crenatifolia*, *L. thermarum*, *S. chilensis*, *B. penna-marina*, and native shrubs such as *G. mucronata*, *R. cucullatum*, *B. serrato-dentata* were recorded, while no exotic species were present.

Despite the high levels of native species cover recorded, exotic species were also found, as noted for other Patagonian forests under the impact of large ungulates (Vázquez 2002; Blackhall et al. 2008; Relva and Veblen 1998). In fact, exotic species are rare in *N. pumilio* forests. In a *N. pumilio* forest with no

Fig. 8 PCA performed on values for cover of understory species (present in over 2% of the sub-plot), using distance to flood meadow as classification variable. Broken line separate species with greater cover near flood meadow (10, 20, 40 m), from the greater cover far from flood meadows (80, 160, 320 m). Species habit and origin are indicated. See abbreviations in Table 1



livestock use, 8–14% of species are exotic, Damascos and Rapoport (2002) and Lencinas et al. (2008), respectively; while Sánchez-Jardón et al. (2010) found 42% of exotic species in the understory of *N. pumilio* forest with livestock use. In this work 19% of exotic species were recorded, which were concentrated in the first 40 m to flood meadows. The increase in cover of exotic herbaceous species in these disturbed parts may be due to the introduction of seeds of new species carried by livestock (Holmgren 2002; Collado et al. 2008), and/or to nutrient input caused by livestock (Todd 2006).

The shrub stratum displayed complex behavior along the livestock use intensity gradient, with maximum cover at 40 and 320 m away to flood meadows. Livestock selectivity may induce changes in the species composition of the understory according to forage quality (Veblen et al. 1989; Relva and Veblen 1998; Vázquez 2002). The highest shrub cover at sites used intensively by livestock is

provided by *B. microphylla*, a frequent species in overgrazed areas (Gallopín et al. 2005) and *C. diffusum*, which adapts to grazing by increasing its chemical defense when there is greater herbivory (Braun et al. 2003). The increase in shrub cover in areas located far from the flood meadow is provided by *G. mucronata*, *M. oblongum*, *R. cucullatum* and *B. serrato-dentata*, which may be more palatable or intolerant to grazing; however, no prior information is available on the subject.

Cover provided by regeneration of *N. pumilio* did not change according to the intensity of livestock use, although in the PCA it was associated to greater distance to flood meadows. Other studies have reported negative impact of livestock on the natural regeneration process of *N. pumilio* (Bava and Rechene 2004; Cavieres and Fajardo 2005; Martínez Pastur et al. 2000; Collado et al. 2008; Raffaele et al. 2011), which may be observed by adding information on abundance, frequency, age-state of regeneration and

diet microhistologic analysis (Quinteros et al. unpublished data).

Conclusions

Livestock raising using *N. pumilio* forest pastures in summer is an important economic activity in the region, its effects are related to the livestock use intensity. This can be estimated using distance to flood meadows, which could be a useful tool for planning sustainable livestock and forestry management. The understory has low cover, mainly made up of herbs. Major impact on the understory concentrate near flood meadows, and it is almost imperceptible beyond a distance of 80 m. Species composition is more affected where livestock use is more intense, causing an increase in the cover of exotic herbaceous species. In the least intensively used areas the understory presents exclusively species native.

The contribution made by this study may provide guidance for managing *N. pumilio* forests, e.g. for establishing buffer zones without forestry activities around flood meadows. However, the processes involved are so complex that there is a need for greater knowledge of other aspects of the ecosystem, such as the natural regeneration process, that would contribute to sustainable use.

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