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Niche breadth and redundancy: Useful indices to analyse fuelwood use in rural communities

María Betina Cardoso*, Ana Haydée Ladio, Mariana Lozada

Laboratorio Ecotono, Instituto de Investigaciones en Biodiversidad y Medioambiente (INIBIOMA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad Nacional del Comahue (UNCo), Quintral 1250, CP:8400, San Carlos de Bariloche, Argentina

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A B S T R A C T

In this work, the concepts of niche breadth and redundancy were used to analyse the use of fuelwood species in rural populations in Patagonia, Argentina. We conducted semi-structured interviews to estimate the fuel niche breadth (FNB). For this, the variables used were as follows: use consensus of native species, use consensus of preferred species and use consensus of pruning species. Moreover, two indices were created to compare socio-environmental fuel redundancy and economic dependence between populations. The most isolated population presented the highest values for FNB, considering principally the use consensus of native species and high environmental redundancy, while the community with most access to urban centres showed the highest FNB value for use consensus of pruning species. The third community presented intermediate values for FNB and low levels of redundancy, showing notable vulnerability. The FNB measured through fuelwood use contributes to the description of socio-ecological factors. Evaluation of redundancy in terms of a resource and its different functional varieties, while not focusing in particular on the functionality of the species, allows the evaluation of the current situation of the resource under study. The indices created in this work can also be used for other variables related to subsistence lifestyles.

1. Introduction

From an interdisciplinary perspective such as ethnobiology, it is understood that the knowledge and use of natural resources by traditional communities depends on the type of environment and the cultural and socio-economic characteristics of each population (Berkes et al., 2000; Varela, 2000).

Interaction between populations and their surroundings is dynamic because of spatial and temporal changes such that in certain contexts of scarcity, the environments offer resources that are relevant to the human populations that depend on them for their subsistence (Berkes, 2008; Hunn, 2014). It is therefore important to value these resources according to the perception of those who use them to understand how changes in their availability influence inhabitants' everyday lives, in both social and ecological terms (Berkes, 2008).

The classical works of Hardesty (1972, 1975) have made an invaluable contribution to studies on the relationship between human beings and the use of natural resources, focusing on the concept of niche breadth as a useful tool for the comparative evaluation of how populations use the elements in their surroundings with varying intensity. This concept includes the idea of multidimensionality, i.e. various dimensions may be analysed in the study of resource use or one particular dimension may be analysed over a certain period of time (Hardesty, 1972, 1975). A community will present higher niche breadth if they display greater diversity or evenness in the use of the dimensions analysed, whereas communities with the dimension of the most selective resource will present narrower niche breadth (Hardesty, 1972, 1975). Certain ethnobiological approaches have used this concept to analyse the use of resources associated with the food dimension (Begossi and Richerson, 1993; Hanazaki and Begossi, 2000; Branco do Nascimento et al., 2010), revealing, for example, that when wild resources are scarce, niche breadth increases, particularly when populations can access external resources (Begossi and Richerson, 1993; Hanazaki and Begossi, 2000; Da Silva and Begossi, 2009).

In addition to this, the concept of ecological redundancy has been evaluated in several ethnobiological studies where various

* Corresponding author.
E-mail address: betinacardoso@comahue-conicet.gob.ar (M.B. Cardoso).

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species may be used for the same function in a socio-ecological system. This has been researched mainly in traditional medicine systems (Borba Nascimento et al., 2015; Soares Ferreira Júnior et al., 2011; Richeri et al., 2013). Currently the relevance of considering the redundancy of certain socio-ecological systems is being evaluated through the utilitarian redundancy model (URM) to study functional systems and generate integrated conservation and biocultural management strategies (Borba Nascimento et al., 2015). However, these strategies have not yet been applied in the study of fuel resources.

Some investigations have analysed the use of wild fuel resources in populations inhabiting hostile environments (Sá e Silva et al., 2008; Cardoso et al., 2012, 2013) and have focused on identifying either new practices developed to compensate for fuelwood scarcity (Jashimuddin et al., 2006) or the physical combustion properties of the woods, which lead to a preference for their use (Abbot et al., 1997; Ramos et al., 2008; Cardoso et al., 2015). It is therefore interesting to analyse the relation between rural subsistence populations and fuel redundancy as a measure of this vital component, which is essential mainly for heating and cooking (Ramos et al., 2008; Cardoso et al., 2012, 2013).

To date, no studies that integrate the concept of niche breadth with the use and consumption of fuel plants have been executed. Moreover, the concept of functional redundancy has not been analysed in relation to woody resources. The rural steppe communities of northwest Patagonia have traditionally farmed sheep and goats for a living, in conjunction with the gathering of wild edible, medicinal, and fuelwood plants and small-scale horticulture (Ladio and Lozada, 2004; Molares and Ladio, 2012; Cardoso et al., 2012; Eyssartier et al., 2013). Fuelwood gathering is practically a daily exercise, and it is directed mainly to bushy species of the predominantly arid environments to the east of the Andean cordillera. This natural resource is complemented with the purchase of firewood of external origin (Cardoso and Ladio, 2011; Cardoso et al., 2012, 2013). It has been documented that populations that share similar ecological environments present higher similarities in their subsistence practices than populations settled in different environments (Ladio and Lozada, 2001; Ladio et al., 2007). Thereby, it is interesting to evaluate fuel niche breadth amongst communities of Mapuche ancestry, considering their use and management of fuelwood resources as the main dimension of analysis. Furthermore, the evaluation of fuel redundancy will offer another perspective, contributing to the understanding of niche breadth and comparison between populations.

The general objective of this work is to analyse how fuel niche breadth, i.e. combustible plant use, varies between neighbouring rural populations in an arid region of northeast Patagonia. The communities of Pilquiniyeu del Limay, Laguna Blanca and Comallo have the same cultural roots but differ in other aspects such as the presence of woody plants in their immediate surroundings and relative access to urban centres. Our study focuses mainly on the quantitative analysis of the woody species, but socio-economic aspects are also assessed. The data were recorded using the ethnographic methodology, which is widely used to estimate qualitative and quantitative results obtained through interviews (Guber, 2001, 2004); methods of specific plant sampling were therefore not used.

The study of an essential resource like woody species allows us to estimate, in a relative way, the current situation of these populations in their environment. We hypothesise that (1) even though the populations are close in geographical terms and share a subsistence way of life in an arid region, the relative richness of available woody species will lead to differences in the use of fuel resources and therefore variance in the fuel niche breadth; (2) the most isolated communities, which are located in less anthropised environments, with a higher offer of wild resources will present greater socio-environmental redundancy; (3) communities with more access to urban centres will use a higher diversity of biofuel resources, which is associated with greater availability of external resources and economic dependence.

2. Methods

2.1. Study area

The study was implemented in the northwest of Patagonia, Argentina, in three rural communities lying in the last foothills of the Andean Cordillera, from west to east, in an ecotone and Patagonian steppe zone (León et al., 1998). The communities involved were Pilquiniyeu del Limay (250 inhabitants) (40° 31′ S and 70° 02′ W; 898 m.a.s.l.), belonging to the Monte-Patagonia ecotone region where shrub-steppe vegetation predominates; Laguna Blanca (180 inhabitants) (40° 43′ S and 69° 50′ W; 1251 m.a.s.l.), situated to the west in a shrub-steppe region that borders a zone of uncultivated land; and Comallo (2000 inhabitants) (41° 02′ S and 70° 16′ W; 782 m.a.s.l.), situated in a grass-shrub steppe region (León et al., 1998) (Appendix 1 version electronic only, Table 1). The landscape is distinguished by its valleys, wetlands and rocky outcrops. The climate is predominantly arid and cold, with annual precipitation of between 150 and 300 mm, which is concentrated in autumn and winter as rain and snow, and the average annual temperature is 8–10 °C (Bran et al., 2000).

These populations are made up of peasants of Mapuche ancestry who speak the dominant Spanish language; very few speak the native Mapuzungun. The principal economic activity is sheep and goat farming for the sale of wool and family sustenance. The women do craft work with the wool, and these products are sold in regional markets (Cardoso et al., 2012, 2013).

The closest urban centre to these communities in northwest Patagonia is the city of San Carlos de Bariloche (130.000 inhabitants) at a distance of approximately 220 km. In all cases, the families depend on fuelwood for cooking and heating their homes, and fuelwood gathering is generally carried out on foot or horseback. The main differences between these populations are presented in Table 1.

2.2. Data collection

Fieldwork was executed according to the guidelines presented in the Code of Ethics of the International Society of Ethnobiology (ISE, 2006). During the years 2011 and 2012, visits were made to each of the communities and the interviewees' homes. In this case, the ethnographical methodology consisted in contextualised dialogue with each of the families visited, each one being taken as a sampling unit. Semi-structured interviews, free listing and participant observation (Guber, 2001, 2004) were carried out. The semi-structured interviews were based on an open questionnaire. Free listing involved a question being asked and the interviewee responding by giving all possible answers. For participant observation, the researcher spent time with members of the community in an everyday context. During this shared time, the researcher interacted with the interviewee and recorded the activities carried out.

Twenty-eight inhabitants were interviewed in the Laguna Blanca community, 35 in Comallo and 28 in Pilquiniyeu del Limay. An individual from each domestic unit was interviewed. Questions were related mainly to the use of domestic firewood; the phenomenon of the interviewee's perception of their surroundings and

Table 1
Environmental and socio-economic characterization of three rural communities studied in NW Patagonia, Argentina.

	Characterization of Communities		
Name	Pilquiniyeu del Limay	Laguna Blanca	Comallo
Geo-coordinates	40° 31′ S and 70° 02′ O	40° 43′ S and 69° 50′ O	41° 02′ S and 70° 16′ O
Altitude	898 m.a.s.l.	1251 m.a.s.l.	782 m.a.s.l.
Phytogeographical environment	Shrub-steppe	Shrub-steppe and Wasteland area	Shrub-steppe with grass
Dominant plant communities	Shrubland mainly composed of *Larrea nitida*, *Colliguaja integerrima*, *Schinus* spp. and *Lycium* spp.	Grass and shrub-steppe mainly composed of *Pappostipa* spp., *Festuca argentina*, *Festuca pallescens, Mulinum spinosum*, *Senecio filaginoides*, *Senecio subulatus*	Grass and shrub-steppe mainly composed of *Senecio subulatus and Mulinum spinosum*.
Total population	50 dwellings (dispersed rural population)	40 dwellings (dispersed rural population)	90 dwellings (semi-rural population)
Close to water course	Yes	No	There was once a river, but it is now dry
Institutions	Primary school, Health care service, traditional authority, Evangelical church	Primary school, Health care service, traditional authority, Evangelical church	Primary school, Secondary school, Train station, non- traditional authority, Evangelical church
Authorities	Indigenous authority (Lonko) and government authority	Indigenous Authority (Lonko) and government authority	Government authority
Economic activities	Small sheep and goat farms, state employment, household crops	Small sheep and goat farms, state employment	Small sheep farms, state employment, household crops, brickmaking, retail trade
Street lighting	Absence	Absence	Presence
Horticultural activities	Home gardens and tree cropping	Absence	Home gardens and greenhouse
Public transport	Absence	Once a week	Daily
Distance between homes	10 to 20 km	In the town, homes are close, in the surroundings, they are dispersed over 7 km	Adjacent, as in a town
Pruning species used as firewood	*Salix fragilis, Ulmus minor*	*Salix fragilis*	*Ulmus minor, Salix fragilis*, *Populus* sp.
Liquified petroleum gas	Absence	Absence	Presence
Purchase of fuelwood	Little	A very large amount	A considerable amount

the availability of combustible species were explored, and the socio-economic aspects of everyday activities were also recorded.

Topics related to gathering practices, such as usage patterns and search distances, are documented in detail in Cardoso et al. (2012, 2013). A herbarium was built, where each species was identified by its scientific name, and it can be found at the Ecotono Laboratory, Universidad Nacional del Comahue.

2.3. Data analysis

The data were analysed qualitatively. Information from the field work was reinterpreted systematically and quantitatively, and the data were categorised and then analysed statistically (Siegel and Castellan, 1995). The richness of woody species used in each community was compared using the Jaccard similarity index. This index is based on plant presence or absence, taking the number of species in common as a proportion of the total number of species present. This is expressed as $JSI = [c/(a + b + c)] \times 100$, where c is the number of species common to two communities, a is the number of unique species in a given community, and b is the number of species unique to the other community (Höft et al., 1999). In addition, the consensus of use index (CUI) was calculated for each species mentioned in each community, taking the number of species mentioned per person over the total number of informants to represent the use frequency of the species. The CUI of each species was compared between communities with a Kruskal-Wallis analysis, followed by paired comparisons with the Mann-Whitney test (Siegel and Castellan, 1995). The equation used to estimate fuel niche breadth (FNB) is the niche breadth diversity index used in other related studies (Hardesty, 1975; Begossi, 2006; Branco do Nascimento et al., 2010) and is represented by the following expression:

$$Fuel\ Niche\ Breadth = 1 \Big/ \sum_{i}^{n} (pi)^2 \quad (1)$$

where pi is the proportion of the total subsistence contributed by resource i in a given dimension, in this case, fuelwood. This combination of terms relates the richness of fuel species used to the frequency of cites, also taking into account the total number of informants interviewed in each community. This dimension was analysed as a function of other sub-dimensions identified in management of the fuelwood resource: use consensus of native species, use consensus of preferred species and use consensus of pruning species.

To estimate variation in fuel redundancy between populations, we created the socio-environmental fuel redundancy index (SEFRI) using the following equation:

$$Socio-Environmental\ Fuel\ Redundancy\ Index = \sum environmental\ fuel\ resources / external\ fuel\ resources$$

where environmental fuel resources is the sum of resources that form part of environmental fuel redundancy, which includes the percentage of households that collect wild species, the percentage of households that collect manure and the percentage of households that use prunings. External fuel resources is the sum of external fuel sources: the percentage of households that buy firewood.

To this analysis, we added the variable of economic activities. We considered that any economic variation observed in a household would influence their ecological autonomy in the use and replacement of fuel resources. Categories were arranged in

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ascending order and quantified according to income levels: 1-casual work, 2-craft weaving, 3-home gardens, 4-State employment, 5-small-scale livestock and 6-commerce. The domestic unit may depend on one or more of these options. To analyse this dimension, we created the economic dependence index (EDI), represented by the following equation:

$$Economic\ Dependecy\ Index = \sum_{i}^{n} Economic\ activities\ for\ each\ household\ /\ n$$

where the value of activities in a domestic unit is summed up in relation to n, which is the total number of domestic units in each community.

Because the indices used in this study have no upper limit, the averages of the results were compared statistically between the three communities through chi-square test.

3. Results and discussion

3.1. Why are there similarities and differences in the use of fuel species?

The total richness of woody species gathered in the communities was 19 native species, and, to a lesser extent, the pruning products of exotic tree species (*Ulmus minor*, *Salix fragilis* and *Populus* sp.) (Fig. 1; Table 1). Similarities between Comallo and Laguna Blanca in the use of wild woody species presented the highest value, with 64% of species shared. In both communities, there is a scarcity of fuelwood resources (Table 1). Comallo uses products of peri-domestic pruning (exotic trees) as a complement when firewood is scarce, and this helps to alleviate pressure of use on native species. In Laguna Blanca, woody vegetation is limited, and most shrubs are low-growing cushion plants (Table 1); this community shares 55% of fuel species used with Pilquiniyeu del Limay.

The similarity between Comallo and Pilquiniyeu del Limay was 52%. The latter community is the most isolated and is situated among a shrub stratum (Table 1) with more plant coverage and greater heterogeneity in terms of daily gathering. Both this environmental heterogeneity and long distances between dwellings have an effect on gathering, in that certain species are favoured over others. Comallo is the least isolated community of the three in terms of access to urban centres, and here dwellings are closer together. The people have access to external fuel sources such as liquid petroleum gas and the purchase of firewood. In these environments, the richness of woody plants is lower than in other semi-arid environments, which offer a greater diversity of wild woody species available for gathering (Kaschula et al., 2005; Lucena et al., 2007).

According to surveys conducted in the area, in the vegetation close to the domestic units, which consists of trees cultivated for wind protection, fruit and ornamental purposes (Eyssartier et al., 2013), there is very little variety used for fuel, mainly from wild species. On the one hand, inhabitants look for their preferred wild fuelwood species, which provide most heat energy, such as *Chuquiraga erinaceae, Berberis microphylla, Prosopis denudans and Schinus johnstonii* (Cardoso et al., 2015). This preference is not

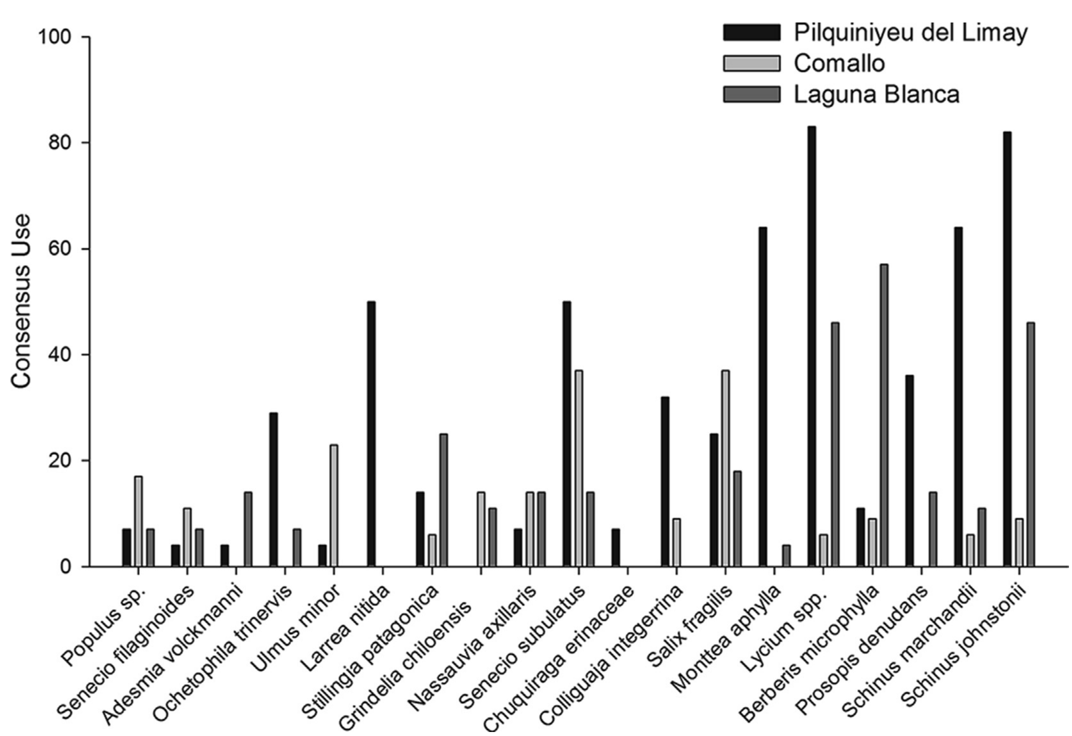

Fig. 1. Comparison of the use consensus of fuelwood species between three rural communities of NW Patagonia.

random and is a result of cultural transmission of knowledge relating to use of the environment and making the most efficient use of its resources. On the other hand, because of fuel shortage, all species present are used as an energy source, thus restricting the selection process. This also generates a search for new alternatives and promotes constant resilience processes.

The bar chart in Fig. 1 shows that although there are inter-population differences, a notable number of fuel species are shared by the three communities, with high use consensus at regional level and in terms of exotic cultivated species. In Pilquiniyeu del Limay, the most frequently used species were *Schinus marchandii*, *Schinus johnstonii*, and *Monttea aphylla* and the genus *Lycium*; in Laguna Blanca, most frequently used species were *Schinus johnstonii* and *Berberis microphylla* and the genus *Lycium*; in Comallo, the most used species were *Senecio subulatus* and *Salix fragilis* (Fig. 2). Similarly, the study of fuelwood resource use in the past (e.g. Caruso Fermé and Civalero, 2014) reveals that the selection processes were just as detailed, and their evaluation helps us interpret the socio-ecological importance of these woody species in the lives of inhabitants.

A comparative analysis of the CUI of the species between the three communities shows that Piquiniyeu del Limay has the highest number of species with high use consensus, followed by Laguna Blanca and then Comallo. Although Pilquiniyeu del Limay presented higher levels of use consensus than Laguna Blanca, these results were only marginally significant (Mann-Whitney, $p = 0.081$; Fig. 1). No significant differences were found between the CUI of the species of Laguna Blanca and Comallo (Mann-Whitney, $p = 0.469$). This could indicate that both settlements share a large number of species that are used in similar ways. It was found that Pilquiniyeu del Limay had more significant use consensus values than Comallo (Mann-Whitney, $p = 0.026$). Variation in the CUI of the fuel species in Pilquiniyeu del Limay presented frequency values that were higher and had a wider range than the other communities. The results obtained agree with hypothesis 1, which predicts that different communities will present differences in their use patterns, principally because of the differences in their immediate environment.

3.2. Fuel niche breadth in relation to fuel use and preferences

On comparing the FNB index between communities in terms of use consensus of native fuel species, a significant difference was found ($X_i{}^2$ for one sample, $0.01 < p < 0.001$) (Siegel and Castellan, 1995); the highest value corresponded to Pilquiniyeu del Limay (Table 2), followed by Laguna Blanca, with Comallo coming far behind. Pilquiniyeu del Limay, the most isolated community, therefore presents a more even and diverse use of wild woody species for fuel, reflecting a close relationship with the availability of fuel species in the immediate surroundings.

The FNB found for the use consensus of native species in Pilquiniyeu del Limay is almost double that of Laguna Blanca (Table 2). The differences between these populations in the immediate context could be due mainly to an environment with more pronounced scarcity of woody species around Laguna Blanca. It can be observed here that use consensus varies between neighbouring populations and highlights the importance of experience in the differential use of resources, according to the immediate context. On the other hand, Pilquiniyeu del Limay presents a FNB value almost 10 times that of Comallo (Table 2). This value indicates that the exploitation of native resources in Pilquiniyeu del Limay is 10 times higher in terms of evenness, and this is due to the less dependence on wild fuel resources in Comallo, where use is directed at certain species. This may be related to a less heterogeneous environment, similar to Laguna Blanca.

The use of peri-domestic pruning products to satisfy the need for energy is encouraged in the Comallo community. It is in the dimension use consensus of pruning species that this community presents the highest value of the three communities for FNB (Table 2), which is an indication of resilience. The difference in this dimension between communities is not significant ($X_i{}^2$, $0.90 < p < 0.80$), possibly because only four species of exotic trees, including *Ulmus minor*, *Salix fragilis* or the *Populus* sp., are generally used in the three communities. The plots of land in Pilquiniyeu del Limay are very large, and inhabitants use the pruning remains of old trees as fuel to complement native firewood, whereas Laguna Blanca uses almost no tree prunings because of the dryness of their surroundings and the scarcity of trees. In contrast, Comallo has peri-urban wooded areas and more favourable environmental conditions for tree growth; therefore, in the absence of a heterogeneous environment with a diversity of woody plants, they use pruning products with more frequency.

The results presented here indicate that the higher the FNB value in a community, the higher is the number of vulnerable plants as they are under constant pressure of use as a fuel resource. Therefore, if there is more pressure on certain species, coupled with livestock browsing and the drought suffered in recent years, (Golluscio and Mercau, 1995; Paruelo et al., 2006), use consensus becomes a variable that can predict exploitation and thereby the existing dynamics in relation to use of the environment.

As shown in Table 2, FNB results for the use consensus of preferred species presented no significant differences between communities ($X_i{}^2$, $0.90 < p < 0.80$). Pilquiniyeu del Limay had the highest value for this dimension, and the other communities had similar values. The preferred species are native species with the

Table 2
Comparison of fuel niche breadth, socio-environmental fuel redundancy index and economic dependency index values among three rural communities in NW Patagonia.

Fuel niche breadth was measured with the following equation: $Fuel\ Niche\ Breadth = 1/\sum_i^n (pi)^2$. The variables compared are the subdomains related to fuel resource.

Description of subdomains	Pilquiniyeu del Limay	Laguna Blanca	Comallo
Use consensus of native species	11.96	6.14	0.08
Use consensus of pruning species	2.23	1.87	2.71
Use consensus of preferred species	2.95	1.85	1.73

Comparison of fuel redundancy values using the following index:
$Socio-Environmental\ Fuel\ Redundancy\ Index = \sum environmental\ fuel\ resources / external\ fuel\ resources$

Pilquiniyeu del Limay	Laguna Blanca	Comallo
22.62	1.12	1.28

Comparison of economic dependency values using the following index: $Economic\ Dependecy\ Index = \sum_i^n Economic\ activities\ for\ each\ household / n$

23.24	26.67	30.76

hardest wood, chosen by inhabitants on the basis of experience and cultural esteem (Cardoso et al., 2015). Because the preferred species belong to the native flora, it could be expected that environmental heterogeneity, which generates differences in use consensus in general, will also lead to differences in selection. However, because of their shared history and species in common, preference always points to the same species in general, such as *Schinus* spp., *Lycium* spp., *Berberis microphylla* and *Prosopis denudans*. Although these are the preferred species, not all are found at each site; shared history and interchange contribute to shared knowledge. This knowledge goes beyond the range of fuel species used in these populations, revealing a socio-ecological coupling as a kind of cultural landscape.

3.3. Fuel redundancy and fuel niche breadth

The results obtained for the SEFRI showed significant differences between communities (X_i^2, $0.01 < p < 0.001$) (Table 2): Laguna Blanca 1.12, Comallo 1.28 and Pilquiniyeu del Limay 22.62. The lowest values for SEFRI were found for Laguna Blanca and Comallo. Taking into account all the variables that form part of this index, both these populations present a high percentage of families that buy firewood externally, and this reduces the redundancy value. The difference between values for these two populations and the result for Pilquiniyeu del Limay is related to the large number of families buying firewood in Comallo and Laguna Blanca, where firewood growing in the wild is scarcer. In contrast, Pilquiniyeu del Limay is the community that most collects native woody species in a more heterogeneous environment, and the external purchase of firewood is almost non-existent.

In agreement with hypothesis 2, the highest level of fuel redundancy was found in Pilquiniyeu del Limay, where the community is more isolated and the wild firewood resource is more widely available. This is in line with FNB results obtained for the use consensus of native species and for the use consensus of preferred species (Table 2).

The utilitarian redundancy model suggests that a population with systems in place for the use of their most redundant resources can be a more resilient population (Borba Nascimento et al., 2015). In this sense, and considering the results obtained for SEFRI, Pilquiniyeu del Limay may be considered a population with greater resilience in terms of fuelwood management, given that the impact is shared amongst several species. Nevertheless, we can also observe resilience processes in Comallo, e.g. in the FNB for the use consensus of pruning species as an alternative to the use of native species (Table 2). In Comallo, inhabitants use the prunings of peri-domestic woodlands and of the willows along the riversides close to the town. Although this data could increase the environmental redundancy of Comallo, environmental scarcity and the large percentage of families that buy fuelwood reduces the redundancy value. These results show the importance of including the ingression of external products in the redundancy calculation and the integral importance of this index.

In Laguna Blanca, 83% of the population buy firewood from outside the community, compared to 63% in Comallo and 4% in Pilquiniyeu del Limay. This difference reveals the scarcity of woody resources; moreover, the fact that Patagonian winters are long and the demand for firewood throughout the whole year is high explains why the purchase of firewood becomes a regulator of the domestic economy. It should be noted that considering all the resources used to obtain energy, cow and horse dung is an important element in the region (Cardoso et al., 2012, 2013). The percentage of families that collect dung is similar in the three communities because this resource is used as a complementary fuel and is therefore of interest to include as a variable in the SEFRI.

Woody plants have been valued by human populations since ancient times. In relation to this, anthracological studies focus on the analysis of carbon remains produced by wood in fires used to provide light and heat energy (Carrión Marco, 2005; Hastorf et al., 2005). In Argentina, the use of different taxons of tree and shrub species as firewood has been documented in different regions of the country (Capparelli and Raffino, 1997; Marconetto and Gordillo, 2008). These investigations complement current ethnobiological studies and help in the interpretation of the importance, redundancy and value of wood used in subsistence activities in both the past and the present.

3.4. Economic activities and their relationship with the use of fuelwood for subsistence

As mentioned previously, the principal economic activity is sheep and goat farming. Nevertheless, the diversification of activities varies between populations, and this can depend partly on their level of isolation. In Pilquiniyeu del Limay and Laguna Blanca, extensive livestock farming is the only main activity sustaining the households. To a lesser extent, the inhabitants obtain work in the state sector, as health workers or government officials, or they work in the school.

When we compare the relation between communities in terms of this dimension using the EDI created for this study, we find no significant differences between the three populations (X_i^2, $0.5 < p < 0.7$). The lowest values for EDI are seen in Pilquiniyeu del Limay, 23.24, and Laguna Blanca, 26.67 (Table 2), whereas Comallo presented the highest value with 30.76. This indicates that Comallo is showing greater diversification in its economic activities; it is the community closest to urban centres and also the one that depends least on native resources and traditional ways of life. Although livestock farming is important, the presence of shops and state employment expands the economic structure. These results agree with hypothesis 3, indicating that the population with the greatest breadth for economic activities has the lowest breadth for use of native resources and the highest values for the use of other resources, e.g. the use of pruning species.

The dimensions chosen here may not be sufficient to illustrate clearly the different economies of the three populations. Other parameters should perhaps have been included, such as annual income from the sale of wool or subsidies received by rural inhabitants. Inhabitants of this region traditionally survived on livestock farming alone, maintaining an economic niche that, although reduced in size, persisted over time. In contrast, at the present time, the drought suffered during recent years and the ash from volcanic eruptions have led to a lack of good grazing land and the death of thousands of animals, possibly reducing further the width of this economic niche.

Diversification of economic activities affects fuel use. Use of the fuelwood resource is based on the gathering of wild firewood, the purchase of external firewood and the products of pruning. In Comallo, peri-domestic woodlands are associated with external agents who promote urban planting; they provide the plants and collaborate in their maintenance. This is an advantage as items that belong to the subsistence lifestyle are replaced and this niche is broadened (Table 2). Other studies have also reported that in socio-environmental contexts presenting scarcity of wild resources and access to external sources, the niche is broadened in the dimensions analysed (Begossi and Richerson, 1993; Cavallini and Nordi, 2005; Da Silva and Begossi, 2009). This indicates that subsistence populations with greater access to non-traditional economies weaken their close relationship with their immediate surroundings because of the scarcity of resources and the ingression of external sources that can replace existing items (Godoy and Bawa, 1993). This tendency towards the use of external sources, which are perhaps distant from the wild context but can make a positive contribution, form part of the resilience process; certain ways of life can be sustained, and others replaced, according to the current context.

3.5. Local, spatial and temporal perception

Perception is directly influenced by context and is therefore prone to transformation when the surrounding environment changes, although certain aspects may remain constant, depending on the different cultural contexts (e.g. MacLaury, 1987). At the same time, knowledge is a result of the capacity to understand and is experienced within a domain of consensual action and cultural history (Varela et al., 1997; Varela, 2000). It has been documented in the Patagonian region that the study from a local perspective of spatial and temporal perception of the surroundings and their state of conservation constitutes an essential tool for the understanding of management practices and resource use (Molares and Ladio, 2012).

In this study, where we focus on the fuelwood resource, we found that inhabitants perceive that the distances travelled for firewood gathering become longer every year and that decades ago the availability of these species was greater and therefore procuring firewood was not the problem it is now. Interviewees expressed their concern about the general scarcity of firewood, and in particular the preferred species, which are no longer found. This fact agrees with firewood supply strategies registered in this and other studies (Cardoso et al., 2012, 2013), which reveal the money spent on the purchase of firewood from the annual income of locals or the use of dung as a last resource in view of this scarcity.

4. Conclusions

In these communities, fuelwood gathering is the principal source of the biomass required to satisfy the need for heat and cooking. The fuel niche breadth measured through fuelwood use and redundancy contributes to the description of socio-ecological contexts that are close in both geographic and cultural terms. Evaluation of redundancy in terms of a resource and its different functional varieties, not focusing in particular on the functionality of the species, allows us to analyse the current situation of the resource under study. Use consensus as a predictive variable of FNB becomes an important factor that together with fuel redundancy describes supply and demand in a given context.

Greater diversity and evenness of fuel use was observed both in Pilquiniyeu del Limay, with more heterogeneity in the use of wild resources, and Comallo, through pruning, use of liquid petroleum gas and purchase of fuelwood. However, in Laguna Blanca we observe a community with lower fuel niche breadth relating to use and low fuel redundancy, mainly due to scarce environmental and economic resources. If we add to this the high number of families that purchase external fuelwood and immediate surroundings of a hostile nature for human dwellers, we can identify a population with a high vulnerability index.

Owing to the hostility of these environments where regional climatic changes bring floods, drought and volcanic eruptions along the Andean Cordillera, a state of vulnerability can be clearly identified in these populations, which are surprising in their assimilation of regional disturbances, possibly indicating long-term processes of ecological-social resilience.

The indices created in this study can also be used for other variables related to subsistence lifestyles. We believe it is important to consider local perspectives that place a high value on rural inhabitants' background experience, which influences processes of cognition and perception–action, which are intimately interwoven with the immediate ecological and socio-cultural environment.

Conflict of interest

We declare that we have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2017.05.007.

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