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Research paper

Preference and calorific value of fuelwood species in rural populations in northwestern Patagonia

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ABSTRACT

Traditional knowledge of fuel species was evaluated, associating species preferences with the physical properties of wood and its combustibility. The physical characteristics of 21 popular firewood species were analyzed in three rural communities in the northwest of Patagonia. Semi-structured interviews were carried out in 91 homes, as well as free listing and walks; samples of the woody species were collected in each of the homes visited. We have hypothesized that the experience of gathering and using fuelwood species, as cognitive know-how, over generations will have enabled local people to know species have best fuel attributes, such as hot coals, low spark and low smoke emission. Thus, for each sample, calorific value, density, moisture content and ash content were measured as predictive variables of combustibility. The fuel attributes of the different woods represent physical properties for which were analyzed by means of the classification for Fuel Value Index (FVI) priority species in the area. Results indicate that the species with the highest FVI values are those mostly preferred by local people such as *Berberis microphylla*, *Prosopis denudans*, *Schinus johnstonii*, *Lycium* spp., *Senecio subulatus* and *Schinus marchandii*. This work recommends the cultivation of energy crops of the preferred native species with high combustibility, to be used as bioenergy and multipurpose species.

1. Introduction

Wood can be used for different purposes, but the most extensive is as fuel in the world's rural communities which still depend on this energy source for heating their homes and cooking their food [1]. In general, human communities use and prefer local wood for fuel, that is, species native to their own area [2–4]. In the selection process carried out by local people, the attributes which characterize good fuel are inherent in each type of wood, established by the physical and chemical properties of each plant species [5]. Thus, certain physical properties of the wood are commonly valued by people for different activities [6–8].

The close relationship between local populations and their environment has been widely studied by the science of ethnoecology, which has been defined as the inter-disciplinary study of the knowledge systems, practices and beliefs of human groups relating to their environment [9,10]. One of the fundamental aspects of ethnoecology is the concept of interculturality, favoring dialogue between the academic realm and local wisdom. Current research, however, dealing with the importance of traditional knowledge and comparing it with empirical results shows that they have much in common [11].

Previous ethnobotanical investigations have focused on gathering and consumption patterns of fuelwood plants, such as how these gathering activities are distributed within the family [2,12,13], how plant gathering patterns change in hostile landscapes [14–19], what new practices are learnt in order to cope with wood resource shortage, for example the use of the byproducts of agricultural activities [20,21], which physical properties of fuelwood influence locals' preferences and the cultural significance of certain plant species [6,22,23].

For thousands of years the practice of gathering firewood has grown out of observation and experimentation with the qualitative and quantitative combustibility characteristics of woody resources [24]. Not all woods types are the same and therefore different attributes have conferred on certain species the character of a preferred resource in comparison with others. Amongst the qualitative characteristics that seem to be considered by different

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traditional societies are the duration of the hot coals, spark and smoke emission, and the biomass performance of the species. These attributes are important in the selection of species according to the daily tasks that must be carried out using fire [6,22,25,26]. Various academic studies have shown that certain quantitative characteristics such as calorific value, density, moisture content and ash content are determinant variables in combustibility [6,7,27]. Thus, to estimate the combustibility of a species, a formulas may be used which measure the previously mentioned quantitative variables by means of the Fuel Value Index [27].

According to [28], knowledge of the combustibility and physical properties of the woody species in a region is necessary for the programming of local management plans. In Patagonia (Argentina), the extraction of fuelwood from natural forests is a current practice, due to the permanent demand from the population who still depends on this resource [29]. However, extraction criteria and planning still do not take local valuation criteria into account, or combustibility values that are the scope of the present contribution. Legitimating local knowledge and practices might be a relevant way of increasing awareness and participation of locals in these environmental issues, which might contribute to the mitigation of the biomass loss. In Patagonia there are no studies that have measured the calorific value of native species or its association with local traditional knowledge, so the present investigation would be the first contribution on this matter.

In this work, therefore, we focus on studying the relationship that exists between the fuelwood species used in three rural communities in the northwest of Patagonia and their combustibility, integrating traditional knowledge with the physical properties of woody plants. In accordance with previous studies we expect to find that locals will prefer fuelwood species that will have high hot coal duration, low spark and smoke emission and the biomass performance of the species certain physical characteristics. We also hypothesize that the experience of gathering and using fuelwood of native species, as cognitive know-how, over generations will have enabled local people to know which species have best fuel attributes, and as a result, their preferred species will have the highest combustibility values. Therefore, we expect to find that locals will prefer plants with high Fuel Value Indices.

2. Methodology

2.1. Study area

The study area is located in the northwest of Patagonia, in the province of Rio Negro, Argentina. The work was carried out in three rural communities lying in the last foothills of the Andean Cordillera, west to east. This area includes the communities of Pilquiniyeu del Limay, Laguna Blanca and Comallo. The relief is marked by valleys, wetlands and rocky outcrops. Following the Köppen classification, the climate in these environments is an arid, steppe and cold (BSk) with annual precipitation of between 150 and 300 mm, concentrated in autumn and winter in the form of rain and snow, and the average annual temperature is 8 to 10 °C [30,31]. Additionally, to the west, there are adjacent temperate forests (Csb) and to the east, it borders the desert and cold Patagonian area (BWk) [31].

In Pilquiniyeu del Limay (40° 31′ S and 70° 02′ W; 898 m.a.s.l.) the landscape and vegetation take the forms of plant life predominant of shrubland, with microenvironments of *Larrea nitida*, *Colliguaja integerrima*, *Schinus* spp. and *Lycium* spp. The dwellings within the community are 10 and 20 km apart. The main economic activity is pastoral and agricultural. This community maintains its traditional leaders, the 'lonkos' who coexist with government authorities. The rural community of Laguna Blanca (40° 43′ S and 69° 50′ W; 1251 m.a.s.l.) and the semi-rural community of Comallo (41° 02′ S and 70° 16′ W; 782 m.a.s.l.) are both situated on the same road, at a distance of 70 km each.

The landscape around both communities is similar, the dominant vegetation being native grass species such as Pappostipa spp. and *Festuca pallescens and Festuca argentina*, as well as the growing shrubs *Mulinum spinosum*, *Senecio filaginoides*, *Senecio subulatus* and *Grindelia chiloensis* [32]. The closest urban center to these communities is the touristic city of San Carlos de Bariloche (150.000 inhabitants) at a distance of 220 km. In all cases, the families depend on fuelwood, mainly from their own surroundings, for cooking and heating their homes.

2.2. Methods

2.2.1. Field interviews

Semi-structured interviews, free listing and participant observation were carried out in order to study the use and the preferences of locals regarding domestic fuelwood biomass, and its role in family subsistence [25,26]. Informants named the preferred species which are 'good for firewood' and those which are non-preferred species but used. We inquire about the preference in the collection of woody fuels. The locals prefer the hardest species with longer duration of grilled who do too much sparkle; they do not burn quickly and hold heat. In each community previous consent was obtained for carrying out the work, and the basis for the work was explained to local authorities and all the visited local people.

In Pilquiniyeu del Limay a total of 28 families (total = 55) were interviewed; in Laguna Blanca 28 families (total = 45) and in Comallo 35 (only those who use firewood, total = 150). Questions were related to the use of plant species as domestic firewood and the characteristics which led to certain species being preferred. Walks were also carried out and inquiries made as to local people perception of the availability of fuelwood biomass in the area. Informants were interviewed between 2009 and 2011. A total of 91 families were visited, each one counting as a sample unit. Previous studies indicated that the three communities used a total richness of 26 species as firewood [25,26], 21 of them (17 species native to the region and 4 exotic trees) were included in this study. The 5 remaining species were not included in this study. These species are used little by locals as they are found a long distance away.

2.2.2. Sampling vegetation

The species selected for the physical analysis of the wood and the comparison of results with locals' preferences were most of the native shrubs and exotic trees used as firewood in each of the three communities [25,26]. The samples were all collected during the summer of 2012 in order to minimize variation of the variables to be measured. The samples were collected walking in a circle around the homes of Pilquiniyeu del Limay which are established in the town (40° 31′16″ S; 70° 02′ 36″ W) and the remaining homes which are distributed throughout different valleys on the reservation (e.g., 40° 26′ 59″ S, 70° 05′ 44″ W; 40° 29′ 58″ S, 70°01′ 23″ W; 40° 30′ 08″ S, 69° 53′ 28″ W; 40° 31′ 29″ S, 70° 05′ 59″ W; 40° 33′ 09″ S, 69° 57′ 03″ W and 40° 23′ 65″ S, 69° 56′ 23″ W). In Laguna Blanca and Comallo the collection was performed around the homes of the town with the geocoordinates described previously. For all samples the same collection methodology was used.

For the 21 species studied 17 shrubs and 4 trees. The height of the shrubs was between 0.5 (e.g. *S. filaginoides* or *G. chiloensis*) and 2 m (*Ochetophila trinervis*); all were adult plants. For each species, nine branches with bark (were obtained from 3 different specimens of green vegetation of similar sizes). The diameter of the samples collected varied between 0.5 and 2 cm, because they were adults with medium size. The branches collected were those located at the top of the bushes (at the approximate height which local people collect them). In these communities, residents usually do not leave harvested wood to dry in their homes, but they collect and use all fuelwood during two to four days, both in winter and summer. Hereby, the green weight of each sample was measured in the field with Pesola precision scales of 100 g. Each subsample was stored and labeled in the field, in an airtight polythene bag. The density and the moisture content was measured with the fresh samples and the calorific value and ash fraction was measured with the dried samples. Medium-sized shrubs of this arid zone have little foliage compared with trees. Therefore, the samples collected contained only timber parts without foliage. The bark of these shrubs was very thin. So, the bark was considered as part of the total sample. The collection can be found in the Herbarium at the Laboratory Ecotone (INIBIOMA). The taxonomic affiliation follows [33] and [32].

2.2.3. Wood analysis

For each species, calorific value, density, water mass fraction and ash mass fraction were recorded. The calorific value of each sample was measured using differential scanning calorimetry (DSC), with a power compensation differential scanning calorimeter TA 2910 MDSC, by means of which the heat flow between the sample and the reference was measured as a function of temperature (MJ/k). A heating ramp of 5 °C min^{-1} in air was used, from room temperature to 570 °C [34]. These analyses were carried out in Instituto Balseiro, Comisión Nacional de Energía Atómica.

Density was measured using the water displacement method [35] for the green samples. The volume was calculated using the formula:

$$\text{Volume} = \text{volume of displaced water in test tube} = \P{*}r^2{*}h$$

where

r = the test tube radius
h = the height of the displaced water column

In addition, the density of each sample was calculated by means of the expression:

$$\text{Density} = \text{green weight/volume of sample.}$$

To calculate moisture content the samples were weighed in their fresh state, then dried at 70–80 °C for 72 h until a constant weight was obtained, expressed as follows,

$$\text{Water mass fraction} = (\text{green weight} - \text{dry weight}) \times /\text{green weight})$$

The ash mass fraction was measured for all dry samples of each species (9) using the loss on ignition method [27]. We subjected 2 g of the ground material to 600 °C in a muffle furnace [27], with a particle size in the unit of mm. This analysis was carried out by the Soil Laboratory of Centro Regional Universitario Bariloche, Universidad Nacional of Comahue.

With the values obtained for the measured variables, the Fuel Value Index [6,27] was calculated in accordance with the following equation:

$$\text{Fuel Value Index(FVI)} = \frac{\text{Calorific value*Density}}{\text{\% Water mass fraction*\% Ash mass fraction}}$$

For the calculation of Fuel Value Index we utilized the percentage of ash and water fractions in order to obtain a number of FVI with no more than four digits.

2.3. Data analysis

The preference frequency of the 21 species used was calculated for each of the three communities, taking the number of people to cite a species as preferred over the total number of informants in the community [36,37], considering that this index can be interpreted as an estimation of the consensus or cultural preference for the species [38] (Table 1). In addition, total preference frequency was calculated by taking the data from all three communities together (Table 1). Spearman correlations were calculated to evaluate the association between the preferred species (taking the sum of values from all three communities) and their combustibility values (FVI) [39].

3. Results and discussion

3.1. Preferred species

In all three communities studied, firewood is a vital resource for dwellers, who possess a wide knowledge of local resources. According to their perception and cultural interpretation, the way locals conceptualize preferred plants differs to the way they view the others. The species have different preference rankings, the most valued belonging to species of the genus *Schinus*, while the least valued are species with little wood, such as *Nassauvia axillaris* and *G. chiloensis* (Table 1). Of these 21 species, 15 were named in all three communities and only 8 were named as preferred in general. Cultural preference not only implies valuing the physical characteristics which imply good combustion, but also represents elements which identify the local landscape. Various informants mentioned that the decrease in abundance over time of certain preferred fuel species, such as the genus *Schinus*, has been a result of evident changes in the landscape, and therefore, changes in gathering practices, which means that the distances which have to be traveled in search of fuel are increasing [25,26].A tendency towards the disuse of species growing at a large distance can also be seen amongst informants, as well as the incorporation of species which are not preferred because of their energy qualities, but for their local availability. This is the case of *Neosparton aphyllum* (matasebo), *Satureja darwinii* (tomillo), *Atriplex lampa* (zampa), *M. spinosum* (neneo) and *Corynabutilon bicolor* (montemoro), which are taken advantage of when firewoods are extremely scarce, or in the absence of alternative fuels [25,26].

In this steppe environment, the richness of native species used is similar to other arid and semi-arid regions [15,40–42]. Locals' extensive knowledge and preference for native species rather than exotic ones (Table 1) coincides with other studies in rural communities with subsistence economies [2–4]. This phenomenon reflects the importance of contact time with the species and experimentation with the woods and their potential combustion properties.

Without doubt, the use of the 4 exotic species is related to the scarcity of native resources [25,43]. These trees, from the genus

Table 1
Preference frequency, Fuel Value Index estimated with the following variables: Calorific value, Density, Water Mass Fraction, and Ash Mass Fraction, of 21 woody combustible species used and preferred in the communities of Pilquiniyeu del Limay, Laguna Blanca and Comallo (Patagonia, Argentina). The species marked (–) are used but not preferred as good firewood. In all cases average values and standard errors are shown. The species are grouped according to their botanical families.

Botanical family	Scientific name, Vernacular name	Origin	Forms of life	Preference frequency (%)	Calorific value [MJ k^{-1}]	Density [km$^{3-1}$]	Water mass fraction	Ash mass fraction	FVI equation
Anacardiaceae	*Schinus johnstonii*, Molle colorado	N	Shrub	158	9.13	926.49 ± 158.33	0.366 ± 0.052	0.022 ± 0.005	122.81 ± 99.59
	Schinus marchandii, Molle blanco	N	Shrub	46	9.35	345.62 ± 46.31	0.226 ± 0.057	0.025 ± 0.006	64.41 ± 25.39
Scrophulariaceae	*Monttea aphylla*, Yaque	N	Shrub	7	8.69	508.26 ± 150.56	0.312 ± 0.033	0.039 ± 0.012	47.91 ± 43.71
Zygophyllaceae	*Larrea nitida*, Jarilla	N	Shrub	–	7.41	592.93 ± 157.02	0.340 ± 0.038	0.030 ± 0.012	47.16 ± 46.06
Solanaceae	*Fabiana peckii*, Siete camisas	N	Shrub	–	9.72	522.35 ± 103.68	0.413 ± 0.149	0.017 ± 0.001	115.21 ± 58.61
	Lycium spp., Monte negro	N	Shrub	9	9.34	533.71 ± 124.34	0.252 ± 0.039	0.015 ± 0.003	117.79 ± 82.69
Asteraceae	*Grindelia chiloensis*, Santa María	N	Shrub	–	8.60	826.06 ± 87.29	0.438 ± 0.0 81	0.078 ± 0.022	22.39 ± 9.67
	Chuquiraga erinaceae, Montetachuela	N	Shrub	–	8.21	850.84 ± 34.70	0.232 ± 0.069	0.020 ± 0.009	179.99 ± 56.53
	Nassauvia axillaris, Uña de gato	N	Shrub	–	7.14	287.16 ± 52.34	0.199 ± 0.155	0.136 ± 0.039	10.82 ± 9.60
	Senecio subulatus, Romerillo	N	Shrub	–	8.95	862.72 ± 114.76	0.364 ± 0.055	0.021 ± 0.002	107.07 ± 55.36
	Senecio filaginoides, Charcao	N	Shrub	–	7.96	266.88 ± 43.55	0.294 ± 0.060	0.040 ± 0.005	20.04 ± 12.09
Fabaceae	*Adesmia volckmanni*, Mamuel choique	N	Shrub	–	10.55	383.03 ± 63.49	0.403 ± 0.090	0.022 ± 0.015	44.46 ± 18.13
	Prosopis denudans, Alpataco	N	Shrub	35	9	734.22 ± 172.94	0.289 ± 0.031	0.021 ± 0.004	141.09 ± 117.97
Euphorbiaceae	*Colliguaja integerrima*, Coliguay	N	Shrub	3	8.66	474.87 ± 77.17	0.382 ± 0.049	0.034 ± 0.005	32.17 ± 16.73
	Stillingia patagonica, Mata de perro	N	Shrub	–	7.89	689.41 ± 81.20	0.393 ± 0.046	0.021 ± 0.002	68.50 ± 31.24
Rhamnaceae	*Ochetophila trinervis*, Chacay	N	Shrub o Tree	–	7.59	374.95 ± 117.77	0.359 ± 0.055	0.032 ± 0.003	30.52 ± 28.47
Salicaceae	*Populus alba*, Álamo plateado	E	Tree	–	7.70	230.67 ± 14.17	0.499 ± 0.078	0.034 ± 0.006	11.11 ± 3.79
	Populus nigra, Álamo verde	E	Tree	–	7.20	340.91 ± 80.68	0.418 ± 0.069	0.036 ± 0.007	16.26 ± 15.57
	Salix fragilis, Sauce mimbre	E	Tree	4	8.05	640.61 ± 91.99	0.525 ± 0.037	0.026 ± 0.006	37.61 ± 18.48
Berberidaceae	*Berberis microphylla*, Michay	N	Shrub	10	9.60	1031.07 ± 128.09	31.07 ± 11.94	0.025 ± 0.004	152.69 ± 99.05
Ulmaceae	*Ulmus minor*, Olmo	E	Tree	–	8.39	798.01 ± 114.00	0.462 ± 0.078	0.034 ± 0.006	43.33 ± 21 ± 51

Populus, *Salix* and *Ulmus* (Table 1), are fast growing species planted for various reasons, such as shelter, shade, fodder, fence posts, ornamental, etc, as well as for firewood [43].Knowledge of native and exotic species, therefore, constitutes a body of essential know how which enables inhabitants to overcome environmental scarcity and has a high adaptive value [44]. In particular, this knowledge is not limited to the recognition of certain species, but to a set of physical and symbolic characteristics related to the plants' combustion efficiency, which is perceived by inhabitants. In addition, some species which are simply components of the general repertoire, but are not preferred, in certain environmental circumstances are taken advantage of and become species of interest.

Maintaining the transmission of this knowledge amongst isolated populations becomes indispensable, even at the present time, given that a large number of inhabitants depend on this resource for their subsistence. In addition to this, in the context of possible intercultural dialogue, this knowledge can make a significant contribution to scientific work, offering an insight into solutions to the search for high quality local of bioenergetic resources.

3.2. Physical properties of the woods and local knowledge

3.2.1. Calorific value

The calorific value of the species examined ranged from 7.14 MJ k^{-1} (*N. axillaris*) to 10.55 MJ k^{-1} (*Adesmia volckmanni*) (Table 1). These values are similar to average values for other species [45]. Although these values depend on the type of development, growth or age of the different species, as well as seasonal variations, among other factors [46], we can say that these values coincide with the standard average values of species which possess the relevant combustion qualities.

Local people's most preferred species, such as *Schinus jhonstonii*, *Schinus marchandii*, *Prosopis denudans*, *Monttea aphylla*, *Lycium* spp. and *Berberis microphylla* are those which present relatively high calorific values (Table 1). Although the preferred species presented the highest calorific values, high values were also observed in non-preferred species, as in the case of *Chuquiraga erinaceae* (Table 1). This could indicate that the selection of firewood, based on the capacity of the wood to release heat, also takes into account the use of resources according to local availability, since this species is not abundant [25].

Exotic tree species such as *Populus nigra*, *Populus alba* and *Salix fragilis* presented lower values for calorific power in comparison with the preferred and non-preferred native species (Table 1). In another study it was observed that the highest calorific value was measured in two-year young poplars and willows [46], and it would therefore be interesting to carry out analysis of the physical properties of the woods in the north Patagonian region, both in native and exotic species, taking into account the age of the plants and comparing the calorific value of different cohorts. These results could be considered in the design of energy crop plantations.

3.2.2. Density

According to [47] (1999) the density of wood is the property that can maintain hot coals for a significant period of time. In our work, the woods with higher density are found among the native species such as *C. erinaceae* and *B. microphylla*, whose values range from 850 to 1034 km$^{3-1}$ (Table 1). The densities found in this study, particularly for local species, present very high values compared with the preferred species of other arid communities [6,47,48] or of a tropical climate [45]. The importance of these denser species is verified because many are the most preferred or commonly used for energy purposes, as in the case of *S. jhonstonii*, *S. subulatus* or *B. microphylla*.

The density of woods is an important attribute not only in the use of the wood for burning, but it also gives the wood additional use value [1,49]. The dense species in this work, moreover, stand out as being multipurpose, providing inhabitants with other important benefits for local subsistence, such as the making of handcrafts, fence construction, etc., as well as other uses such as medicinal and dyes, which are, for example, attributed to Schinus and Berberis [18,50].

3.2.3. Water mass fraction

The woody resources in this community are used mainly in the form of dry firewood, but are complemented substantially with green wood [25,26]. Both states of the wood are used at the same time, in order to maintain heat for longer. As a result, the water fraction in the samples of the species used varies greatly, ranging from 0.199 (*N. axillaris*) to 0.525 (*S. fragilis*). It has been recorded that the moisture in wood varies with the season and state of the wood, amongst other factors [22,47]. However, the water fraction registered here, also represents this traditional method of mixed use. *S. fragilis*, *Ulmus minor* and the species of the genus *Populus* presented values between 0.418 and 0.525, and the native shrubs *A. volckmanni*, *G. chiloensis* and *Stillingia patagonica* had between 39% and 41% moisture in their woody structure.

3.2.4. Ash mass fraction

In general terms, the inhabitants of all three communities reported that the greater amount of ash produced, are less preferred the species. The ash fraction of the plants used was also found to vary greatly, from 0.015 (*Lycium* spp.) to 0.136 (*N. axillaris*). The native shrub species such as *C. erinacea*, *B. microphylla*, *S. marchandii*, *S. jhonstonii*, *P. denudans* and *S. subulatus*, plus the species of the genera *Lycium* and *S. patagonica* are found within the group of species presenting the lowest percentage of ash, between 0.015 and 0.021, and are mostly preferred species (Table 1). In contrast, the species producing most ash were the exotic trees such as *U. minor*, *S. fragilis*, *P. alba* and *P. nigra* (Table 1). The wood of the native *M. aphylla* is also found in this group with high ash content, and although it is a preferred species, it does not have a significantly high frequency of preference (Table 1).

Within the native species, *G. chiloensis* with 0.078 and *N. axillaris* with 0.136 (Table 1) presented the highest values for ash mass fraction. These values were considered outliers since they were too different from the values observed for the other species in this and other studies, where in general the ash fraction did not exceed 0.06 [46,47,51]. The traditional use practice of these two species is that the whole plant is used for burning, including leaves, flowers and fruit, since they lack a significant woody structure as in the case of species like *P. denudans* or the species of the genus *Schinus*, of which the woody trunk is generally used. The high levels of ash content suggest that this material possesses different, special combustion properties (Table 1). Their value lies in that they act as fire starters, or kindlers; these species are the first elements used to light the fires in the homes, and so are responsible for generating good combustion with the other, thicker pieces of wood.

3.2.5. Fuel Value Index

The preferred species presented higher combustibility values than the non-preferred species (Fig. 1). The species which presented the highest values for FVI were *C. erinaceae*, *B. microphylla*, *P. denudans*, *S. subulatus*, *Fabiana peckii* and the species of the genera *Lycium* and *Schinus* (Fig. 1). Species of the genus *Schinus*, principally *Schinus johnstonii*, is the most preferred and used in all three communities, and presented one of the highest combustibility values, along with the other species with high preference consensus. *S. marchandii* is not found in the group of species with highest combustibility, but is one of the preferred species and is very commonly used especially in the Pilquiniyeu del Limay community, where its availability is higher than in the other communities.

Analyzing the data by means of equation we observe that they reflect the proposed hypothesis, with agreement between

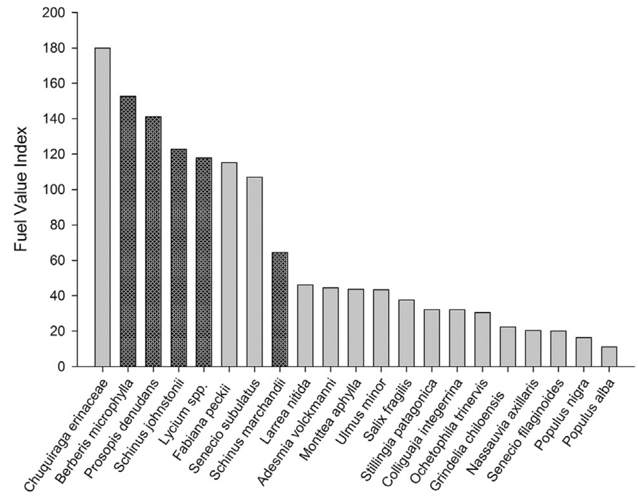

Fig. 1. Combustibility of the woody species estimated using Fuel Value Index equation. The colored bars represent species with high preference frequency. *Colliguaja integerrima* and *Salix fragilis* were not colored, because they present irrelevant preference frequency.

combustibility values and inhabitants' preferences (Fig. 1). The species that stood out due to their high preference consensus presented a positive correlation with the FVI values calculated ($\rho = 0.750$; $p = 0.050$), as is the case for the shrubs of the *Lycium* and *Schinus* genera and the species *B. micrhopylla* and *P. denudans*. *B. microphylla*, a species which is commonly used and preferred in the Laguna Blanca community, has a high combustibility value and due to this and the scarcity of other woody plants, its presence in this community is of great importance. The Laguna Blanca landscape is the most arid and steppe-like and therefore woody species are less available, so *B. microphylla* plays an essential role there as a woody fuel resource.

The species belonging to the *Schinus* genus are more freely available than the other preferred species, and perhaps this is why they present the highest preference consensus (Table 1) even though they don't have the highest combustibility values. Both *P. denudans* and the species belonging to the genus *Lycium* presented relatively higher combustibility values. This is due to the high calorific value and low ash fraction in these genera (Table 1). Some studies have concluded that it is not necessary to add water mass fraction to the formula for FVI to take its seasonal variation into account, as has been previously mentioned [22,47], or that the ash mass fraction does not vary significantly [6]. The species which are used but have a very low preference consensus such as *C. integerrima* and *M. aphylla*, present the lowest FVI values. This may be related to the fact that although they are important as fuel, they are present only in one of the three communities, and are found growing as single specimens. *S. fragilis* is a species which is commonly used in Comallo due to the plantations and annual pruning in the peridomestic area [43], and also because of the scarcity of native wild species; knowledge of the use of this species and species of the *Populus* genus has been transmitted for some time now, even though they are exotic trees.

C. erinaceae is the species that presents the highest combustibility value (Table 1), but even so, very few inhabitants use it and nobody prefers it, since this species is scarce in the area studied, and is only found in Pilquiniyeu del Limay. *Fabiana peckii* is a low growing shrub which produces logs of a small diameter and is also scarce in the area, so is not preferred. Its branches, however, are used as kindling, since the wood is thin and easy to carry. *S. subulatus* is used a lot and available in the Comallo area. It has good combustibility but a poor woody structure and perhaps this is why it is not preferred. For these reasons, it could be possible that *C. erinaceae*, *F. peckii* and *S. subulatus* had important combustibility values, but were not preferred.

It is interesting to observe that the exotic tree species that grow in the peridomestic area are found within the group of species with the lowest FVI values [43] (Table 1, Fig. 1). These are fast growing species but their water mass is higher than the native species (Table 1), thus reducing their combustibility. Nevertheless, inhabitants who do not have an opportunity to obtain a better variety of native firewood prefer these willows and poplars, taking advantage of the products of the annual pruning.

The pattern found reveals the importance of combustibility in the selection process of fuel species carried out by Patagonian inhabitants, but also reveals the marked influence of other factors, such as the availability of the required resources. In general, the shrubs used and preferred are mainly those with a greater trunk diameter, i.e., adult specimens whose time of development and growth have led to an increase in density and hardness, as in the case of the *Schinus* spp. or *P. denudans*. However, the scarcity of woody species in these environments makes the search for all available woods necessary, even when their trunk diameters are not so high, as in the case of *B. microphylla*, and the species of the genus *Lycium* or *S. subulatus*, a species much used in Comallo [25,26].

4. Conclusions

The results show that the woody plants used as fuel in the three communities were chosen according to a complex biophysical and sociocultural rationale which is the result of longstanding cognitive processes transmitted and enriched over generations. Firewood gathering is a traditional practice, essential to the survival of the rural communities in northwest Patagonia; up to now, however, the relationship between use, preference and the combustibility of species present in this arid region had not been previously evaluated, therefore, the present research contributes to the understanding of this relevant issue.

In this work, the congruence observed between the empirical data and traditional ecological knowledge seems to revalue local's know how related to the use of these fundamental resources that could be beneficial for sustainable management.

Given that the fact the spatial and temporal of availability of fuelwood influences the use frequency and also their preference of species used by the local people, in the future, we will evaluate these variables in order to complement the present findings. Interdisciplinary work would be highly substantial, in order to apply sustainability policies which include local management, focusing on preferred bioenergetic resources found in this study.

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