Structure of Stockmen Collaboration Networks Under Two Contrasting Touristic Regimes in the Spanish Central Pyrenees

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Abstract

Ecosystem management is a difficult task because it must conciliate the ecological, economic, and social dimensions of socio-ecological systems. In those systems, the action of any single component can have an effect on the others, and result in a critical impact on the organization of the entire system. This study examined the collaboration networks among stockmen within two traditionally agro-pastoral regions in the Spanish Central Pyrenees which in the las 30 years included touristic activities: one under the influence of a National Park and centered on ecotourism, and the other in a region where there are ski resorts and local stockmen have turned to snow tourism. Our hypotheses were that economic regime affects the structure of the networks, and the type of collaboration (*e.g.* for economic reasons) influences the collaborations among stockmen. We built stockmen collaboration networks by connecting breeders within the same pastoral partnerships, and calculated the importance of collaborations (links density), the occurrence of collaborative subgroups (network modularity), and the existence of collaborations between stockmen in different regions (Krackhardt Ratio). In addition, we identified the distribution of links among types of pastoral partnerships. The network under the influence of the National Park presented higher link density and modularity than did the network influenced by ski resorts, where the presence of non-local stockmen is higher. Furthermore, economic partnerships played a major role connecting stockmen. In the study area, differences in the collaboration networks between the two regions suggest that changes in the economic trend in the last 30 years has influenced the collaborative structure of the stockmen. We discuss possible reasons behind these differences and propose some recommendations which could help to strengthen the collaborative bounds between stockmen in the area.

39 Keywords: Agro-pastoral practices, Collaboration networks, Ordesa-Monte Perdido
40 National Park, Socioeconomic systems, Ski resorts.

41

42 1. Introduction

43 Ecosystem conservation is one of the most important challenges of our time. Global
44 change driven by human activities has altered the natural balance and modified Earth
45 processes significantly (Rockström et al., 2009). Those changes have created several
46 threats to the preservation of ecosystems including global warming and biodiversity
47 loss, which are among the most important issues that governments must face to preserve
48 the ecological value of the environment (Sala et al., 2000; Vitousek, 1994; Vitousek et
49 al., 1997). However, finding a balance between the conservation of ecosystems,
50 economic development and the preservation of social values (*i.e.* sustainable
51 development, Hopwood et al., 2005) can be difficult. Ecosystem management covers
52 only one part of social-economical systems (SES), which combine ecological,
53 economic, and social dimensions of human systems (Millenium Ecosystems
54 Assessment, 2005; Ostrom, 2009). In SES, an effect on any single component can
55 spread to the others and have a significant impact on the entire organization of the
56 system (Holling, 2001; Young et al., 2006). Thus, to develop more effective
57 conservation strategies, all different dimensions of SES have to be assessed
58 simultaneously (Fiksel, 2006). Particularly, in recent times the importance of the social
59 dimension to address the resilience of SES has been highlighted (Berkes and Ross,
60 2013; Davidson, 2010). For instance, considering the collaborative structure among the
61 inhabitants in SES is central for the system resilience, as differences in the social
62 organization of the system can have significant effects on the success of management
63 practices (Berkes et al., 2000).

Management practices are particularly important in mountainous regions. In mountain areas, human activities have led to the development of a wide variety of ecosystems that are nowadays considered biodiversity hotspots (Korner and Spehn, 2002; Lomolino, 2001) and whose environmental value is recognized (mountain ecosystems are included within the European Habitat Conservation Strategy, Consejo de las Comunidades Europeas, 1992). Furthermore, those areas have been inhabited for centuries and are presented as examples of sustainable SES that preserve traditional economic activities, mainly agro-pastoral practices; together with the ecological value of the ecosystem (Jodha et al., 1992). For example, in the Spanish Central Pyrenees, the persistence of traditional pastoral habits such as transhumance (*i.e.* periodic movement of livestock between summer and winter pastures) led to the development of singular plant communities that have both high biodiversity and productivity (Caballero et al., 2011; Ruiz and Ruiz, 1986). Thus, traditional mountain human systems are good examples of sustainable development, where ecological, economic, and social dimensions of the SES are balanced.

In Europe, however, industrial development near cities at the beginning of the 20th Century led to massive migration from rural to urban areas (Alados et al., 2014; Mather, 2001; Pinilla et al., 2008). This dramatic reduction in human labor had a profound impact on mountain SES and, especially, on the conservation of mountain pastures. In Spanish Central Pyrenees land abandonment and the loss of sustainable pastoral practices have reduced pasture area due to changes in land use (García-Ruiz et al., 1996; Gartzia et al., 2016b, 2014) and 'shrub encroachment' (*i.e.* increase in the density of local shrubs in pastures to the detriment of herbs and grasses, Komac et al., 2011; Van Auken, 2000). For example, the substitution of pastures by shrublands and forests has been associated to the decrease in livestock numbers in the area (Gartzia et al., 2014). In

addition, the loss of mountain pastures might be accelerated in near future as they are among the most vulnerable habitats to global climate change (Huber et al., 2006).

Livestock management is one of the main factors responsible for maintaining the ecological value of mountain pastures (Kohler et al., 2004; Zervas, 1998). Livestock grazing influences the growth of the consumed plants, modifies species cover, and changes the composition and structure of plant communities (Milchunas and Lauenroth, 1993; Van Auken, 2000). Furthermore, pastoral ecosystems have been recognized as important providers of ecosystem services (Oteros-Rozas et al., 2013). For example, livestock grazing can increase the productivity of an ecosystem, and transforms a dispersed, low-energy resource (grass) into a concentrated, high-energy resource (livestock meat, Frank et al., 1998). In addition, pastoral activities also help to preserve and transmit traditional local knowledge in mountain SES (*e.g.* location of water points and grazing paths, regulation of grazing intensities, Hassanein and Kloppenburg, 1995), which helps to accelerate the reorganization of the system after major disturbances (Berkes et al., 2008). Therefore, to preserve mountain pastures and their associated ecosystem services, the conservation of sustainable agro-pastoral activities is essential.

Traditionally, in the Spanish Pyrenees livestock production has involved a communal grazing system in which stockmen collaborate to expand grazing pastures and to preserve their pastoral value (Caballero et al., 2011). Today, this collaborative structure has led to the creation of different livestock partnerships whose duties include from economic to sanitary tasks (*e.g.* optimize the marketing of products, obtain quality designations for the livestock; or manage veterinary exams, Confederación de Cooperativas Agrarias de España, 2002). Remarkably, the implementation of Common Agricultural Policy (CAP, Consejo Europeo, 2005) has led in recent times to the apparition of several partnerships specialized in maximizing the capture of subsidies

114 (García-Martínez et al., 2009; Veysset et al., 2005). However, changes in mountain SES
115 as depopulation and the reduction in agro-pastoral practices might modify this
116 collaborative system and, ultimately, influence the viability of mountain pastures. Thus,
117 economic and social dimensions of traditional mountain SES have to be reconciled to
118 preserve the ecological value of mountain pastures.

119 In this study, we evaluate the collaborative structure of stockmen in two regions in
120 Spanish Central Pyrenees. This mountainous area has been traditionally driven by agro-
121 pastoral activities, but with the decline of livestock in recent times, inhabitants have
122 supplemented livestock management with other economic activities associated to
123 tourism. One region has supplemented agro-pastoral practices with ecotourism activities
124 under the influence of a National Park. On the other hand, the other region has
125 incorporated snow tourism activities organized around the development of big ski
126 resorts. We studied the collaborative structure in the area through the analysis of their
127 stockmen collaboration networks (SCN). In these networks, stockmen connect among
128 them considering the different economic and cultural partnerships they belonged to. We
129 hypothesize that the analysis of the SCN unveils valuable information about the
130 organization of stockmen in our SES. For example, differences in the current economic
131 trends between regions or the specific type of partnerships considered to represent the
132 collaboration could have a reflection in the stockmen collaborative structure. We expect
133 that the analysis of SCN improves our knowledge about the social dimension in the
134 Spanish Central Pyrenees.

135

136 ## 2. Methods

137 ### 2.1. Study area and data collection

138 The study was conducted in the Central Pyrenees within the province of Huesca in
139 northern Spain. The study area lies within the alpine mountain range (*sensu*, the zone
140 above 1500 m, Fillat et al., 2012) with a maximum elevation of 3340 m. The climate is
141 heterogeneous and strongly influenced by elevation, ranging from alpine in mountain
142 grasslands to sub-Mediterranean at low elevations. Average annual temperature ranges
143 from 5º C (Goriz Refuge at 2200 m, data from 1976 to 2005) to 12.4º C (Salinas de
144 Bielsa at 760 m, data from 1961-1967) and average annual precipitation ranges from
145 1657 mm (Goriz) to 1307 mm (Salinas de Bielsa). Historically, grazing activities, which
146 have involved moving livestock from mountain grasslands in summer to the Middle
147 Ebro valley in winter, have driven the local economy (Caballero et al., 2011; Daumas,
148 1976). However, at the beginning of 20th Century urban development led to a rural
149 depopulation in the area resulting in a reduction of grazing activity and the substitution
150 of pastures and cultivated areas by shrublands and forests (Alados et al., 2014; García-
151 Ruiz et al., 1996; Lasanta and Vicente-Serrano, 2007)

152 We selected two regions in the Spanish Central Pyrenees: Sobrarbe and Alto Gállego
153 counties (Figure 1). Although both regions differ in their population densities (Table 1),
154 their population trends in the 20th Century have been similar (strong decrease until
155 1980s, when population stabilized, Alados et al., 2014). Furthermore, both regions have
156 experienced the same changes in agro-pastoral activities, with a substitution of sheep
157 livestock by cattle (sheep livestock decreased from 1.4 ind/ha in 1940 to 0.2 ind/ha in
158 2000, while cattle increased from 0.05 ind/ha to 0.14. Data from Archivo Histórico de
159 Huesca and Delegación Provincial de Huesca); principally because the cost of managing
160 cattle is smaller (in the study area, livestock can reach the most remote pastures while
161 cattle is concentrated in the most accessible ones, Gartzia et al., 2016a). Together with
162 changes in shepherding, in recent times stockmen in both regions have supplemented

163 pastoral practices with other sources of income mostly linked to services sector (Table
164 1). However, these sources differed between regions.

165 On one hand, Sobrarbe includes six municipalities (Torla, Broto, Fanlo, Puertolas,
166 Tella-Sin and Bielsa) encompassing the area in and around Ordesa-Monte Perdido
167 National Park (OMPNP, Figure 1). Ordesa-Monte Perdido National Park was created in
168 1918 and expanded to its current limits in 1982 (15,608 ha). The presence of OMPNP
169 has induced the rise of ecotourism in recent years, resulting in the development of
170 campsites and rural houses (Table 1). On the other hand, Alto Gállego includes five
171 municipalities (Sallent del Gállego, Panticosa, Hoz de Jaca, Biescas, and Yésero) which
172 comprise two ski resorts (Formigal and Panticosa, Figure 1). In the Central Pyrenees,
173 between 1965 and 1976, five alpine ski resorts and associated tourist infrastructures
174 were built, which led to significant changes in the population and pastoral activities in
175 the area (Marín-Yaseli and Lasanta, 2003). Specifically, in this region the development
176 of snow tourism has led to the increase in the number of apartments and hotels (Table
177 1). It is important to note that, although the touristic development in both regions is
178 different, the number of beds available in touristic accommodations is similar between
179 them (Table 1). However, the number of new building differs, suggesting differences in
180 the presence of secondary residences between regions (Table 1). Thus, we compared
181 two regions which have experienced different economic shifts in the last 30 years:
182 Sobrarbe, which includes ecotourism under the influence of a National Park (NP); and
183 Alto Gállego, which includes snow tourism under the influence of ski resorts (SKI).

184 2.2. Network construction and analysis

185 In both regions, we conducted personal interviews to all stockmen who transport their
186 livestock to pastures within the study area. Interviews included questions about the

187 stockmen (origin, current residence, age, years spent shepherding in the area, education
188 level), and their thoughts about the current environmental situation in the region
189 (changes in the landscape, land use and pastoral practices). We also recorded all the
190 different partnerships which stockmen belonged to. We identified partnerships as
191 groups of individuals which gather sporadically to pursuit a common interest, and used
192 them as a proxy of local associations of stakeholders which collaborate among them
193 (Olsson et al., 2004). All considered partnerships provided a service directly linked to
194 livestock management, and were categorized in four groups according to their
195 objectives: health partnerships, subsidy partnerships, cooperatives, and others (Table 2).
196 It was possible for each stockman to belong to more than one partnership
197 simultaneously, and for stockmen from different regions to belong to the same
198 partnership. Specifically, within the study area, we identified 194 stockmen and 36
199 pastoral partnerships.

200 Using the data from stockmen and their partnerships, we built an X_{SxP} matrix. In the
201 matrix X, stockmen (S) are rows and partnerships (P) columns, and $X_{ij} = 1$ when
202 stockman i belongs to partnership j. Based on X, we built stockmen collaboration
203 networks (SCN), in which a link exists between two stockmen if they belong to the
204 same partnership (*sensu*, affiliation networks, Borgatti and Halgin, 2011). Although
205 sharing a partnership is not an explicit measure of collaboration, as stockmen in the
206 same partnership have common interests and group together to attain benefits related to
207 agro-pastoral practices, we assumed that partnership sharing is a valid proxy of a
208 collaborative link. Therefore, SCN was defined as a square matrix L_{SxS} where l_{ij} is the
209 collaboration between stockmen i and j (l_{ij} = number of partnership shared by stockmen
210 i and j). The number of links of a stockbreeder i (L_i) is the number of collaborative
211 bounds he has with other stockmen, and the total number of collaborations in the system

212 is *L*. We built one SCN for stockmen in each region, and another including both regions
213 combined (TSA, total study area: stockmen in NP + stockmen in SKI). We drew the
214 networks with NETDRAW (Analytic Technologies;
215 http://www.analytictech.com/netdraw/netdraw.htm).

216 For each network we calculated isolation, linkage density, modularity and Krackhardt
217 Ratio (Borgatti and Halgin, 2011; Krackhardt and Stern, 1988; Newman, 2006a),
218 definition and abbreviations of indices are included in Table 3). All of those indices are
219 related to the resilience, adaptive and information-spreading capacity of the network,
220 and have significant effects on the robustness of the system (Janssen et al., 2006;
221 Newman, 2006b). For example, indices related to network cohesion (Isolation, Density)
222 and connection between subgroups (Modularity, Krackhardt Ratio) are related to the
223 communication between subgroups within the system (Barnes-Mauthe et al., 2013),
224 which can pose challenges to manage common resources (*e.g.* low cohesive systems), or
225 can increase the productivity and innovative capacity (*e.g.* high connectivity between
226 different groups) (Bodin and Crona, 2009). To quantify the significance of the indexes
227 observed in each SCN, we simulated 1000 matrixes setting the number of links per row
228 and column to that of X_{SxP}. We built the corresponding L_{SxS} for each simulated matrix
229 and calculated all indices. Real values were significantly different from simulated
230 values if they separated more than 2 standard deviations from the mean of the values
231 from the simulations. We also evaluated differences in the SCN structure of both
232 regions comparing the isolation, number of partnership per stockbreeder (A_i) and the
233 number of links per stockbreeder (L_i). We used a Chi-square test to compare *Iso*, and a
234 Generalized Linear Model (GLM) to compare A_i and L_i between regions. All calculus
235 were performed with R (R Development Core TeamTeam, 2014).

We evaluated the effect of the type of partnership on the collaborations among stockmen in two ways. First, we used a Chi-square test to compare the proportion of collaborative bounds among stockmen between the two regions considering the partnerships categories. Second, we used a Generalized Linear Mixed Model (GLMM) to assess the effects of region and partnership category in A_i and L_i. Model included A_i and L_i as response variables, the interaction between region and type of partnership as an explanatory fixed variable, and stockbreeder identity as an explanatory random variable. In addition, to assess the influence of partnership category on the collaborations within and between regions, we built one individual SCN for each category of partnerships and calculated the Krackhardt Ratio of each network. All comparison tests were performed using R.

3. Results

3.1. Characteristics of stockmen

Stockmen groups presented similar characteristics in both regions, with most stockmen presenting similar age (more than 40 years) and education level (secondary level). Furthermore, most stockmen came from a family related to shepherding and have carried their livestock to pastures in the area for more than 30 years. We only found significant differences between regions in the origin of stockmen, with more proportion of foreign stockmen in SKI ($foreign_{NP} = 2/81 = 0.02$; $foreign_{SKI} = 22/113 = 0.19$; $X^2 = 11.06$, $p < 0.001$). All stockmen agreed that in recent times mountain pastures and landscape have changed noticeably (principally, through the substitution of pastures by shrubland and forest). From all stockmen in the study area, nine were not connected to others (*sensu*, they did not present any collaborative links with others). Connected

stockmen organized in SCNs that had a big block composed by most of the stockmen, and few stockmen isolated in smalls blocks (Figure 2). Characteristics of the SCNs are presented in Table 4.

3.2. Network analysis

Network indices showed that the SCN for the whole study area had higher *Iso* and *Q* than expected (Table 5), which suggests that stockmen organized forming close collaborative groups. Focusing on the regions, both networks presented higher densities (*D*) than expected based on the simulations (Table 5). However, the network in SKI had higher *Iso* and lower *Q* than expected, while the network in NP had higher *Q* than expected. This suggests that in NP there were groups of stockmen who collaborated closely with each other, while in SKI there were not tight collaborative groups. Furthermore, in SKI there were also several stockmen who did not present any collaboration links.

Comparing both regions, SKI had significantly more isolated stockmen ($\chi^2 = 4.79$, df = 1, *p*-value = 0.029), and significantly fewer partnerships per stockbreeder and fewer links per stockbreeder than NP (Table 6). This suggests that stockmen established more collaborative associations in the region under the influence of the National Park than in the region with ski resorts. Furthermore, Krackhardt Ratio indicated that most of the collaborative links were between stockmen within the same region (Table 5), which suggests that stockmen preferred to partner with their geographic neighbors.

The effect of type of partnership on the collaborations among stockmen differed between the two regions ($\chi^2 = 1934.38$, df = 3, p-value < 0.001). Specifically, in NP all four types of partnerships were responsible of establishing collaborations, while in SKI, most of the collaborative links were through health and subsidy partnerships (Figure 3).

284 Furthermore, type of partnership and region had a significant interaction on the numbers
285 of partnerships per stockbreeder and links per stockbreeder (Table 6). In NP, stockmen
286 were most likely to belong to cooperatives and local partnerships, and had more
287 collaborative links with other stockmen than stockmen in SKI; especially, through
288 health, cooperative and local partnerships (Figure 4). In both regions, collaborations
289 were significantly more concentrated in subsidy partnerships. Krackhardt Ratio
290 indicated that stockmen associated more with others in the same region; independently
291 of the type of partnership ($E/I_{sanitary}$ = -0.99; $E/I_{subsidy}$ = -0.56; $E/I_{cooperative}$ = -0.97; E/I_{local}
292 = -1; all real *E/I* values were significantly lower than the simulations). Among the types
293 of partnerships, the one which connected most stockmen from different regions was the
294 subsidy partnership (had the highest *E/I Ratio*).

295

296 4. Discussion

297 4.1. Characteristics of Stockmen Collaboration Networks

298 In the Central Pyrenees, the analysis of the stockmen collaboration networks (SCN)
299 helped to disentangle the structure of stockbreeder community. In the whole study area,
300 the SCN presented a modular structure in which stockmen organized themselves into
301 close groups, with this groups mainly formed by stockmen habiting within the same
302 region. These collaborative groups can arise for different reasons. On one hand, study
303 area is characterized by the presence of valleys and mountain ranges. The presence of
304 mountain ranges can act as a geographical barrier to migration and cultural transfer
305 between valleys, resulting in the partial isolation of regions within the area and the
306 development of different cultural landscapes (Axelrod, 1997). Therefore, the historical
307 relationship between human and environment in each region could result in landscapes

and communities highly linked to local identity (Rössler, 2006). On the other hand, in social network analysis, typically, actors preferentially interact with those who are most similar to them (a property called homophily, McPherson et al., 2001) or share common interests (Feld, 1981). In the Spanish Central Pyrenees, stockmen have spent decades organizing the annual use of local pastures (Fernández-Giménez and Fillat, 2012). Because stockmen usually moved their livestock to the pastures closest to their dwelling, they mostly organized the use of pastures with their neighbors and, consequently, more collaborations appeared. This preference for collaborating with neighbors might explain why, in general, stockmen belong to few associations (in the study area, 50% of the stockmen belonged to two or less associations).

Considering the two regions, although stockmen communities were similar in age, education and experience in shepherding, we observed contrasting structures in their SCNs. In the region under the influence of the Ordesa-Monte Perdido National Park (OMPNP) and more focused on ecotourism (NP), the network was organized in close collaborative groups and stockmen established high number of collaborations. In the area near OMPNP, stockmen have been sharing pastures for centuries (Sal and Lorente, 2004), with the creation of historical local organizations such as 'Mancomunidad del Valle de Broto' and 'Casa de Ganaderos de Zaragoza' (founded in the 13th Century) to regulate grazing management. The necessity of sharing pastures in the same place has strengthened the interaction bounds, resulting in a very close collaborative system formed by neighbors and pastures partners. This can be seen in the importance of cooperatives and other partnerships in the region (Figure 3 and 4). The existence of these historical organizations is important in the region and they have been presented as important keepers of traditional knowledge in Pyrenees (Fernández-Giménez and Fillat, 2012). Furthermore, in recent times several partnerships have appeared to maximize the

acquisition of subsidies intended for the maintenance of traditional agro-pastoral practices in the area (related to the presence of a National Park, Gobierno de España, 2007; and Common Agricultural Policy, Consejo Europeo, 2005), which have become the main source of income for stockmen in the area (Fernández-Giménez, 2015; Plieninger, 2006). For example, to defend the interests of livestock owners in the National Park, a specific partnership was formed ('Asociación de Ganaderos del Parque Nacional de Ordesa y Monte Perdido'). This partnership brings together the stockmen who move their herds to the pastures within the Park, and has greatly helped to strengthen the collaborative bounds in the area.

On the other hand, the SCN in the region including snow tourism (SKI) presented several stockmen with no collaborative links and was not organized in groups. In SKI the reduction in sheep and goats has resulted in a significant increase in the amount of ungrazed mountain pastures (García-Ruiz et al., 1996; Lasanta and Vicente-Serrano, 2007). Although the reduction in livestock was widespread in the Pyrenees (including the area within the National Park), the pastures in SKI region have been more attractive because they are easier to manage (*e.g.*, they are accessible by car, have shallow slopes, Gartzia et al., 2016a) and have been highly demanded to develop goods related to snow activities (Marín-Yaseli and Lasanta, 2003). This has resulted in a strong turn from an economy centered in agro-pastoral sector to another more focused on services, which is enhanced in the areas near ski resorts (Marín-Yaseli and Lasanta, 2003). Substitution of agro-pastoral practices by ski tourism is common in mountain areas (Gellrich et al., 2007; Teodoro Lasanta and Vicente-Serrano, 2007) and usually, in farms, different economical activities coexist (Riedel et al., 2007). However, the harmonious coexistence between shepherding and tourism strongly depends in the goals of the local stockmen (Gasson et al., 1993). In general, stockmen in the study area complained

about the hardness of livestock management compared to other jobs and the lack of replacement by new generations (Fernández-Giménez, 2015). This lack of replacement has caused that in recent times, particularly in the SKI region, non-local stockmen have transported their herds to the region. These newcomers belonged to non-local partnerships before they arrived and so, did not require to join the local ones, resulting in a weakest collaborative structure.

4.2. Effect of type of partnership in the collaborative structure

The importance of the type of partnership structuring SCNs showed that, independently of the region considered, most collaborative links were based on economic profit (subsidy partnerships produced the most collaborations, even between stockmen from different regions, Figure 3). Since the implementation of Common Agricultural Policy (CAP) in 1986, subsidies have been the main force shaping the agro-pastoral sector in Spain, particularly replacing sheep farming by cattle (García-Martínez et al., 2009; Plieninger, 2006). Particularly, belonging to partnerships that facilitate the process of receiving funds has been profitable (*e.g.* partnership help its members to request subsidies properly), and consequently, stockmen prioritize most profitable partnerships over other factors as geographical proximity or neighbors preferences. The involvement of public and private services can help to sustain agro-pastoral systems (Bernués et al., 2003), but is central to identify the main drivers behind the organization of SES to apply efficient management practices.

Network structure has strong implications in the resilience of a system (Bodin and Crona, 2009; Olsson et al., 2004; Tompkins and Adger, 2004). In a system with a modular structure, information transfer from one module to another is difficult, but it might also result in the formation of smaller and more efficient working groups (Janssen

et al., 2006). In the Spanish Central Pyrenees, stockmen have collaborated with whom they share pastures and coordinated to move their livestock along the year to optimize pastures forage production. Collaborative groups represented by the modules in the network might facilitate the efficient exploitation of pastures, which might help to maintain their ecological and pastoral value. However, most of those small groups were quite closed, which can obstruct the creation of a large-scale collaborative structure. Studies on adaptive management have suggested that non-modular organizations are more adaptive than modular ones, and they allow the inclusion of external information and the creation and reassembling of links in the system (Aldrich, 1999; Granovetter, 1973). Thus, non-modular organizations respond faster to changes in the external conditions of socio-ecological systems and can evolve to new possible equilibrium states (Holling, 2001). It is possible that the SES in the SKI region is still adapting to the presence of ski resorts, and it will take time before it is known whether this process leads to an equilibrium in which only one between local traditional practices and ski-related sources of incomes dominates, or both activities coexist becoming the main drivers of the economic development in the region.

The collaboration networks used in our study were based on affiliation networks (*sensu* (Borgatti and Halgin, 2011), and it is important to consider that these networks have limitations. For example, in our study we assumed that stockmen who belonged to the same partnership were collaborating, but this is only a proxy of a real collaboration. For example, almost all of the stockmen belonged to partnerships related to mandatory health controls imposed by Government (85% of stockmen belonged to one health association), which was the result of legal issues rather than truly collaborative bounds. Consequently, we did not find a significant effect of health partnerships between the two regions. Thus, is important to consider the actual contribution of a certain type of

407 partnership to the collaborative structure of the system. Another possible limitation
408 involves the transformation from affiliation to stockmen network. An affiliation
409 network indicates which stockman belongs to each of the partnership, but SCN indicates
410 the collaborative links between stockmen (Borgatti and Halgin, 2011). We could have
411 used an affiliation matrix directly to test our hypotheses, but as we were interested in
412 the specific organization among stockmen, we restricted our analyses to SCN. In
413 addition to methodological issues, it is important to consider the effect of other factors
414 on the collaborative structures of both regions. For example, differences in population
415 between regions could influence the collaborative structure (*e.g.* smaller populations
416 have less potential collaboration opportunities); or differences in pastures availability
417 could require alternative management strategies (*e.g.* lower pastures availability needs
418 better collaboration among stockmen). Therefore, although differences in touristic
419 activities between our study regions seem the main reason behind the structure of SCN,
420 we cannot exclude other possible causes.

421 Despite these limitations, our results suggest that differences in current economic trends
422 in the study area might affect the collaborative structure between the inhabitants. In our
423 study area, the collaborative system in the region influenced by the presence of the
424 National Park and ecotourism was characterized by strongly connected groups of
425 stockmen, while in the region turning to ski oriented tourism collaboration was weaker
426 and less organized. Economic factors appeared to be the main reason behind the
427 establishment of collaborations between stockmen, particularly, through partnerships
428 specialized in getting subsidies which gathered most the connections between stockmen
429 from different regions.

430 5. Implications

431 The success of environmental management practices depends on a correct assessment of
432 the ecological, economic and social dimensions of the area under consideration (Fiksel,
433 2006), as the action of any dimension can spread to the others (Holling, 2001; Young et
434 al., 2006). Particularly, in recent times the importance of the social dimension to address
435 the resilience of SES has been highlighted (Berkes and Ross, 2013; Davidson, 2010). A
436 proper understanding of the people living in the communities has been presented as
437 central to include in resilience frameworks (Crane, 2010). For instance, economic
438 changes can alter the social structure of a human community, and hence, modify the
439 environmental management that the community requires (Alados et al., 2014; Isaac et
440 al., 2007); or differences in the social organization of the system can significantly alter
441 the success of management practices (Berkes et al., 2000). Thus, including the social
442 dimension in the study of traditional agro-pastoral SES is essential to improve the
443 management of mountain pastures and avoid unexpected effects on their preservation in
444 the near future.

445 We suggest that the use of Stockmen Collaboration Networks (SCN) could improve the
446 understanding of the social organization of the inhabitants in a region, helping to
447 improve the implementation of management practices. The application of social
448 networks to unveil the structure of stakeholders and help in the management of SES has
449 been shown to be important in recent times (Barnes-Mauthe et al., 2013; Beilin et al.,
450 2013). In our study area, we found that differences in the economic trends associated to
451 tourism between regions affected the collaborative structure among the stockmen.
452 While in the region under the influence of a National Park and ecotourism collaborative
453 structure is characterized by strong bounds and highly connected groups, the
454 development of ski resorts outside that region has caused stockmen near those resorts to
455 turn to snow tourism-related services and the entrance of non-local stockmen, who have

456 not created yet strong cooperative bounds with local stockmen. This separation between
457 local and non-local stockmen can result in the loss of traditional ecological knowledge
458 in the area leading to an inefficient exploitation of pastures, which might reduce their
459 ecological and pastoral value. Thus, preserving the local knowledge would require
460 strengthening the bounds between local and non-local stockmen. In our study area,
461 economic gain appeared as the most important driver of collaborations. Specifically,
462 subsidy-oriented partnerships included the highest number of collaborative links, and
463 were the only partnerships which connected stockmen from both regions. This suggests
464 that economic profit is mandatory to involve local populations. Therefore, including
465 local and non-local stockmen in the same subsidy partnerships seems the most efficient
466 strategy to strengthen the collaboration between them. This way, local knowledge
467 would be more easily transmitted to all stockmen shepherding in the area, helping to
468 preserve traditional ecological knowledge and improving the sustainable use of
469 mountain pastures.

470

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Bibliography

Alados, C.L., Errea, P., Gartzia, M., Saiz, H., Escós, J., 2014. Positive and Negative Feedbacks and Free-Scale Pattern Distribution in Rural-Population Dynamics. PLOS ONE 9, e114561. doi:10.1371/journal.pone.0114561

Aldrich, H., 1999. Organizations evolving. Sage.

Axelrod, R., 1997. The dissemination of culture a model with local convergence and global polarization. J. Confl. Resolut. 41, 203–226.

Barnes-Mauthe, M., Arita, S., Allen, S.D., Gray, S.A., Leung, P., 2013. The Influence of Ethnic Diversity on Social Network Structure in a Common-Pool Resource System: Implications for Collaborative Management. Ecol. Soc. 18. doi:10.5751/ES-05295-180123

Beilin, R., Reichelt, N.T., King, B.J., Long, A., Cam, S., 2013. Transition Landscapes and Social Networks: Examining On-Gound Community Resilience and its Implications for Policy Settings in Multiscalar Systems. Ecol. Soc. 18. doi:10.5751/ES-05360-180230

Berkes, F., Colding, J., Folke, C., 2008. Navigating Social-Ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press.

Berkes, F., Folke, C., Colding, J., 2000. Linking social and ecological systems: management practices and social mechanisms for building resilience. Cambridge University Press.

Berkes, F., Ross, H., 2013. Community Resilience: Toward an Integrated Approach. Soc. Nat. Resour. 26, 5–20. doi:10.1080/08941920.2012.736605

Bernués, A., Olaizola, A., Corcoran, K., 2003. Extrinsic attributes of red meat as indicators of quality in Europe: an application for market segmentation. Food Qual. Prefer. 14, 265–276. doi:10.1016/S0950-3293(02)00085-X

Bodin, Ö., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Glob. Environ. Change 19, 366–374. doi:10.1016/j.gloenvcha.2009.05.002

506 Borgatti, S.P., Halgin, D.S., 2011. Analyzing affiliation networks. Sage Handb. Soc. Netw.
507 Anal. 417–433.
508 Caballero, R., Fernandez-Gonzalez, F., Badia, R.P., Molle, G., Roggero, P.P., Bagella, S.,
509 Papanastasis, V.P., Fotiadis, G., Sidiropoulou, A., Ispikoudis, I., others, 2011. Grazing
510 systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. Pastos 39, 9–
511 154.
512 Confederación de Cooperativas Agrarias de España, 2002. Aportación de CCAE sobre
513 cooperativismo. El Libro Blanco Agric. Desarro. Rural.
514 Consejo de las Comunidades Europeas, 1992. Directiva 92/43/CEE del Consejo, de 21 de mayo
515 de 1992, relativa a la conservación de los hábitats naturales y de la fauna y flora
516 silvestres. D. Of. Las Comunidades Eur. 7–50.
517 Consejo Europeo, 2005a. Reglamento (CE) 1290/2005 del Consejo, de 21 de junio de 2005,
518 sobre la financiación de la politica agrícola común.
519 Consejo Europeo, 2005b. Reglamento (CE) 1290/2005 del Consejo, de 21 de junio de 2005,
520 sobre la financiación de la política agrícola común. Doc. Of. Unión Eur.
521 Crane, T.A., 2010. Of models and meanings: cultural resilience in social-ecological systems.
522 Ecol. Soc. 15, 19.
523 Daumas, M., 1976. La vie rurale dans le Haut Aragón Orientale. Institutos de estudios oscenses
524 y de geografia aplicada.
525 Davidson, D.J., 2010. The Applicability of the Concept of Resilience to Social Systems: Some
526 Sources of Optimism and Nagging Doubts. Soc. Nat. Resour. 23, 1135–1149.
527 doi:10.1080/08941921003652940
528 Feld, S.L., 1981. The Focused Organization of Social Ties. Am. J. Sociol. 86, 1015–1035.
529 Fernández-Giménez, M., 2015. “A shepherd has to invent”: Poetic analysis of social-ecological
530 change in the cultural landscape of the central Spanish Pyrenees. Ecol. Soc. 20.
531 Fernández-Giménez, M.E., Fillat, F., 2012. Pyrenean Pastoralists’ Ecological Knowledge:
532 Documentation and Application to Natural Resource Management and Adaptation.
533 Hum. Ecol. 40, 287–300. doi:10.1007/s10745-012-9463-x

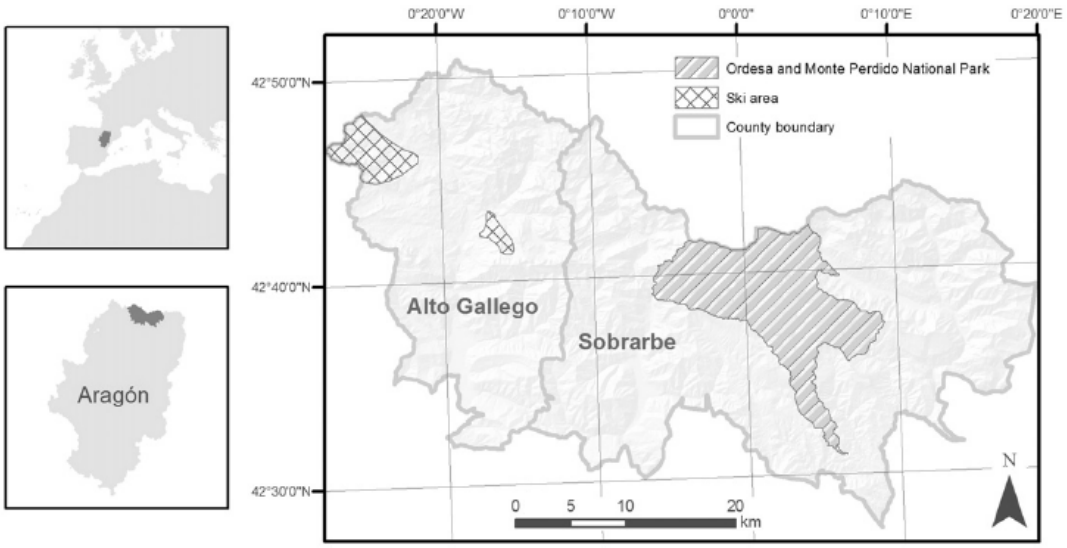
534 Fiksel, J., 2006. Sustainability and resilience: toward a systems approach. Sustain. Sci. Pract.
535 Policy 2, 14–21.
536 Fillat, F., Aguirre, A.J., i Fabré, F.P., Fondevilla, C., 2012. La conservación de la montaña
537 alpina y el bienestar humano. Ambienta Rev. Minist. Medio Ambiente 116–132.
538 Frank, D.A., McNaughton, S.J., Tracy, B.F., 1998. The ecology of the earth's grazing
539 ecosystems. BioScience 513–521.
540 García-Martínez, A., Olaizola, A., Bernués, A., 2009. Trajectories of evolution and drivers of
541 change in European mountain cattle farming systems. animal 3, 152–165.
542 doi:10.1017/S1751731108003297
543 García-Ruiz, J.M., Lasanta, T., Ruiz-Flano, P., Ortigosa, L., White, S., González, C., Martí, C.,
544 1996. Land-use changes and sustainable development in mountain areas: a case study in
545 the Spanish Pyrenees. Landsc. Ecol. 11, 267–277. doi:10.1007/BF02059854
546 Gartzia, M., Alados, C.L., Pérez-Cabello, F., 2014. Assessment of the effects of biophysical and
547 anthropogenic factors on woody plant encroachment in dense and sparse mountain
548 grasslands based on remote sensing data. Prog. Phys. Geogr. 38, 201–217.
549 doi:10.1177/0309133314524429
550 Gartzia, M., Fillat, F., Pérez-Cabello, F., Alados, C.L., 2016a. Influence of Agropastoral System
551 Components on Mountain Grassland Vulnerability Estimated by Connectivity Loss.
552 PLOS ONE 11, e0155193. doi:10.1371/journal.pone.0155193
553 Gartzia, M., Pérez-Cabello, F., Bueno, C.G., Alados, C.L., 2016b. Physiognomic and
554 physiologic changes in mountain grasslands in response to environmental and
555 anthropogenic factors. Appl. Geogr. 66, 1–11. doi:10.1016/j.apgeog.2015.11.007
556 Gasson, R., Errington, A.J., others, 1993. The farm family business. Cab International.
557 Gellrich, M., Baur, P., Koch, B., Zimmermann, N.E., 2007. Agricultural land abandonment and
558 natural forest re-growth in the Swiss mountains: A spatially explicit economic analysis.
559 Agric. Ecosyst. Environ. 118, 93–108. doi:10.1016/j.agee.2006.05.001
560 Gobierno de España, 2007. Ley 5/2007, de 3 de abril, de la Red de Parques Nacionales. Bol. Of.
561 Estado.

562 Granovetter, M.S., 1973. The strength of weak ties. Am. J. Sociol. 1360–1380.
563 Hassanein, N., Kloppenburg, J.R., 1995. Where the Grass Grows Again: Knowledge Exchange
564 in the Sustainable Agriculture Movement1. Rural Sociol. 60, 721–740.
565 Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems.
566 Ecosystems 4, 390–405.
567 Hopwood, B., Mellor, M., O'Brien, G., 2005. Sustainable development: mapping different
568 approaches. Sustain. Dev. 13, 38–52.
569 Huber, U.M., Bugmann, H.K., Reasoner, M.A., 2006. Global change and mountain regions: an
570 overview of current knowledge. Springer.
571 Isaac, M.E., Erickson, B.H., Quashie-Sam, S.J., Timmer, V.R., 2007. Transfer of knowledge on
572 agroforestry management practices: the structure of farmer advice networks. Ecol. Soc.
573 12, 32.
574 Janssen, M.A., Bodin, Ö., Anderies, J.M., Elmqvist, T., Ernstson, H., McAllister, R.R., Olsson,
575 P., Ryan, P., 2006. Toward a network perspective of the study of resilience in social-
576 ecological systems. Ecol. Soc. 11, 15.
577 Jodha, N.S., Banskota, M., Partap, T., others, 1992. Sustainable mountain agriculture. Volume
578 1: perspectives and issues. Volume 2: farmer's strategies and innovative approaches.
579 Intermediate Technology Publications.
580 Kohler, F., Gillet, F., Gobat, J.-M., Buttler, A., 2004. Seasonal vegetation changes in mountain
581 pastures due to simulated effects of cattle grazing. J. Veg. Sci. 15, 143–150.
582 Komac, B., Alados, C.L., Camarero, J.J., 2011. Influence of topography on the colonization of
583 subalpine grasslands by the thorny cushion dwarf Echinospartum horridum. Arct.
584 Antarct. Alp. Res. 43, 601–611.
585 Korner, C., Spehn, E., 2002. Mountain biodiversity: a global assessment. CRC.
586 Krackhardt, D., Stern, R.N., 1988. Informal networks and organizational crises: An
587 experimental simulation. Soc. Psychol. Q. 123–140.
588 Lasanta, T., Vicente-Serrano, S.M., 2007. Cambios en la cubierta vegetal en el Pirineo aragonés
589 en los últimos 50 años. Pirineos 162, 125–154.

590 Lasanta, T., Vicente-Serrano, S.M., 2007. Cambios en la cubierta vegetal en el Pirineo aragonés
591 en los últimos 50 años. Pirineos 162, 125–154.
592 Lomolino, M., 2001. Elevation gradients of species-density: historical and prospective views.
593 Glob. Ecol. Biogeogr. 10, 3–13.
594 Marín-Yaseli, M., Lasanta, T.L., 2003. Competing for meadows: A case study on tourism and
595 livestock farming in the Spanish Pyrenees. Mt. Res. Dev. 23, 169–176.
596 Mather, A., 2001. The transition from deforestation to reforestation in Europe. Agric. Technol.
597 Trop. Deforestation 35–52.
598 McPherson, M., Smith-Lovin, L., Cook, J.M., 2001. Birds of a feather: Homophily in social
599 networks. Annu. Rev. Sociol. 415–444.
600 Milchunas, D.G., Lauenroth, W.K., 1993. Quantitative effects of grazing on vegetation and soils
601 over a global range of environments. Ecol. Monogr. 63, 327–366.
602 Millenium Ecosystems Assessment, 2005. Ecosystems and human well-being. Island Press
603 Washington, DC.
604 Newman, M.E., 2006a. Modularity and community structure in networks. Proc. Natl. Acad. Sci.
605 103, 8577–8582. doi:10.1073/pnas.0601602103
606 Newman, M.E., 2006b. Modularity and community structure in networks. Proc. Natl. Acad. Sci.
607 103, 8577–8582.
608 Olsson, P., Folke, C., Berkes, F., 2004. Adaptive Comanagement for Building Resilience in
609 Social–Ecological Systems. Environ. Manage. 34, 75–90. doi:10.1007/s00267-003-
610 0101-7.
611 Ostrom, E., 2009. A General Framework for Analyzing Sustainability of Social-Ecological
612 Systems. Science 325, 419–422. doi:10.1126/science.1172133
613 Oteros-Rozas, E., Martín-López, B., González, J.A., Plieninger, T., López, C.A., Montes, C.,
614 2013. Socio-cultural valuation of ecosystem services in a transhumance social-
615 ecological network. Reg. Environ. Change 1–21.

616 Pinilla, V., Ayuda, M.-I., Sáez, L.-A., 2008. Rural depopulation and the migration turnaround in
617 Mediterranean Western Europe: a case study of Aragon. J. Rural Community Dev. 3,
618 2008.
619 Plieninger, T., 2006. Habitat loss, Fragmentation, and Alteration – Quantifying the Impactof
620 Land-use Changes on a Spanish Dehesa Landscape by Use of Aerial Photography and
621 GIS. Landsc. Ecol. 21, 91–105. doi:10.1007/s10980-005-8294-1
622 R Development Core TeamTeam, 2014. R: A language and environment for statistical
623 computing. R Foundation for Statistical Computing, Vienna, Austria, 2012. ISBN 3-
624 900051-07-0.
625 Riedel, J.L., Casasús, I., Bernués, A., 2007. Sheep farming intensification and utilization of
626 natural resources in a Mediterranean pastoral agro-ecosystem. Livest. Sci. 111, 153–
627 163. doi:10.1016/j.livsci.2006.12.013
628 Rockström, J., Steffen, W., Noone, K., Persson, \AAsa, Chapin, F.S., Lambin, E.F., Lenton,
629 T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., others, 2009. A safe operating space
630 for humanity. Nature 461, 472–475.
631 Rössler, M., 2006. World Heritage cultural landscapes: A UNESCO flagship programme 1992 –
632 2006. Landsc. Res. 31, 333–353. doi:10.1080/01426390601004210
633 Ruiz, M., Ruiz, J., 1986. Ecological history of transhumance in Spain. Biol. Conserv. 37, 73–86.
634 Sal, A.G., Lorente, I., 2004. The present status and ecological consequences of transhumance in
635 Spain, in: Transhumance and Biodiversity in European Mountains. pp. 233–248.
636 Sala, O.E., Chapin, F.S., Armesto, J.J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald,
637 E., Huenneke, L.F., Jackson, R.B., Kinzig, A., others, 2000. Global biodiversity
638 scenarios for the year 2100. science 287, 1770–1774.
639 Tompkins, E.L., Adger, Wn., 2004. Does adaptive management of natural resources enhance
640 resilience to climate change? Ecol. Soc. 9, 10.
641 Van Auken, O., 2000. Shrub invasions of North American semiarid grasslands. Annu. Rev.
642 Ecol. Syst. 197–215.

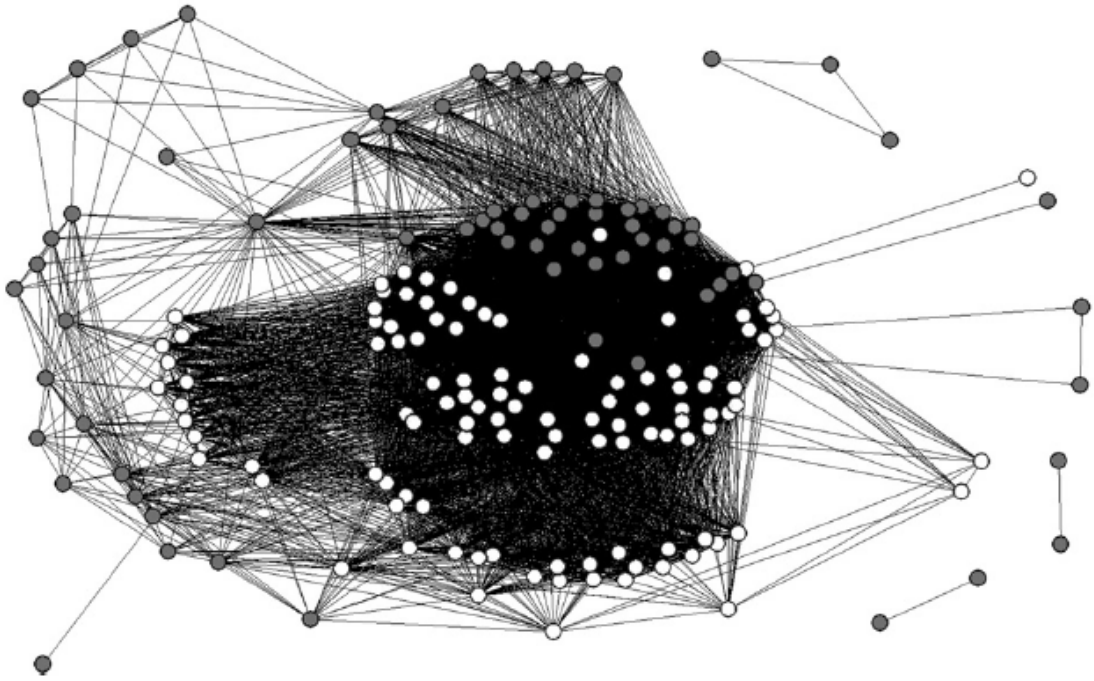
643 Veysset, P., Bebin, D., Lherm, M., 2005. Adaptation to Agenda 2000 (CAP reform) and
644 optimisation of the farming system of French suckler cattle farms in the Charolais area:
645 a model-based study. Agric. Syst. 83, 179–202. doi:10.1016/j.agsy.2004.03.006
646 Vitousek, P.M., 1994. Beyond global warming: ecology and global change. Ecology 75, 1861–
647 1876.
648 Vitousek, P.M., D'Antonio, C.M., Loope, L.L., Rejmanek, M., Westbrooks, R., 1997.
649 Introduced species: a significant component of human-caused global change. N. Z. J.
650 Ecol. 21, 1–16.
651 Young, O.R., Berkhout, F., Gallopin, G.C., Janssen, M.A., Ostrom, E., van der Leeuw, S., 2006.
652 The globalization of socio-ecological systems: An agenda for scientific research. Glob.
653 Environ. Change 16, 304–316.
654 Zervas, G., 1998. Quantifying and optimizing grazing regimes in Greek mountain systems. J.
655 Appl. Ecol. 35, 983–986.
656



657

658 **Figure 1.** Study area in the Spanish Central Pyrenees. Study was conducted in the north
659 side of the regional county of Aragón, Spain. Two study regions are adjacent, but one is
660 strongly influenced by Ordesa-Monte Perdido National Park (NP, Sobrarbe, right), and
661 the other is influenced by the presence of ski resorts (SKI, Alto Gallego, left).
662 Highlighted parts in the map represent the area covered by the Ordesa-Monte Perdido
663 National Park in Sobrarbe, and the area covered by ski resorts in Alto-Gállego.

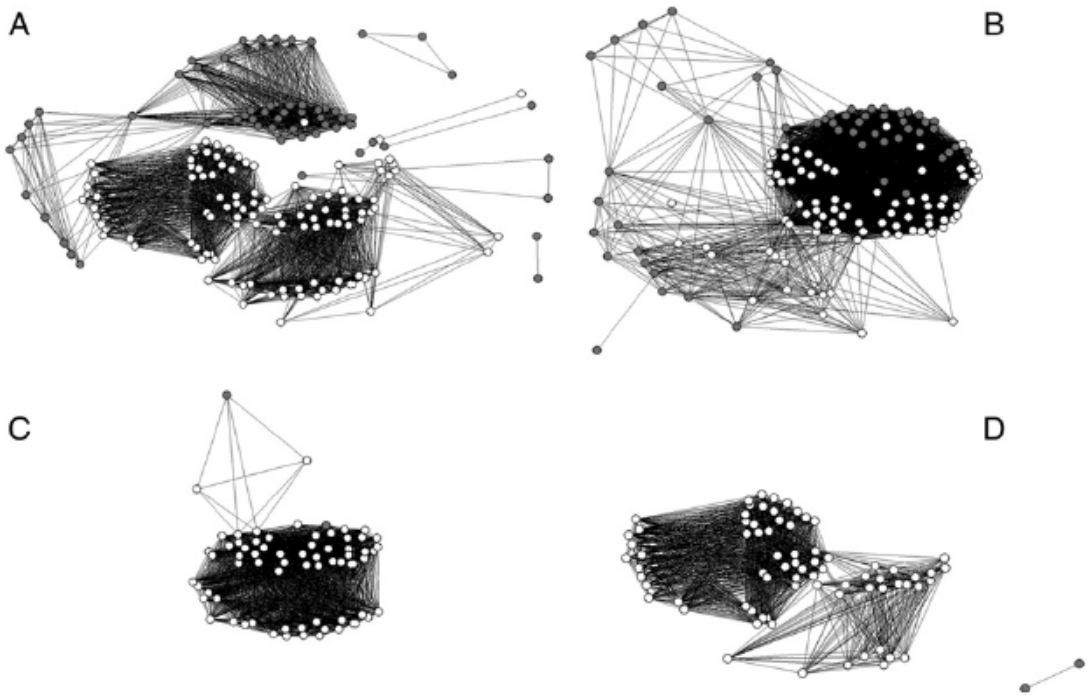
664



665

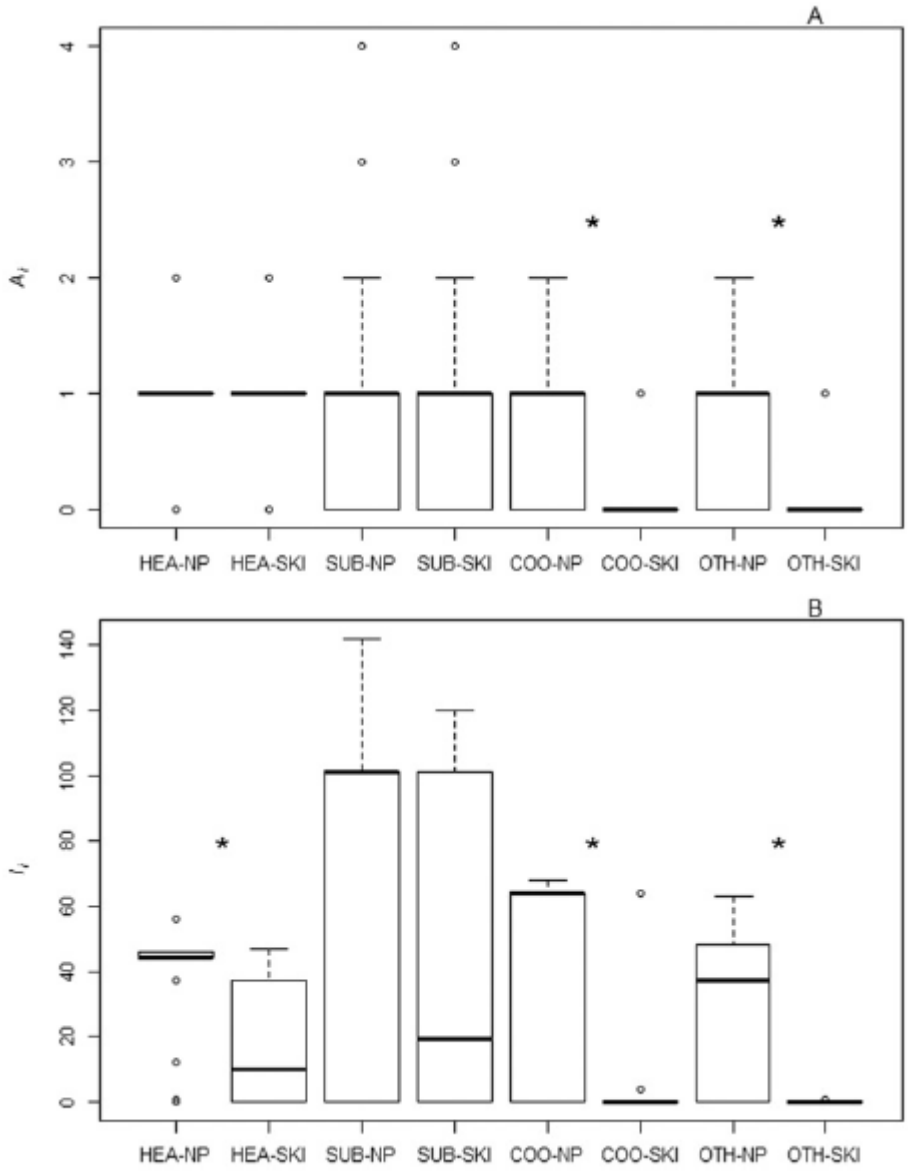
666 **Figure 2.** Stockmen Collaborative Network in Spanish Central Pyrenees. White nodes
667 are stockmen in NP and grey nodes stockmen in SKI. Links are drawn under the
668 assumption that all have the same strength ($l_{ij} = 1$ if $l_{ij} \geq 1$). Isolated stockmen
669 (stockmen which did not connect to any other) are not included (9 nodes).

670



671

672 **Figure 3.** Stockmen Collaborative Networks in the Spanish Central Pyrenees depending
673 on the type of association. A) SCN for health associations; B) SCN for subsidy
674 associations; C) SCN for cooperative associations; D) SCN for local associations.
675 White nodes are stockmen in NP and grey nodes stockmen in SKI. Links are drawn
676 under the assumption that all have the same strength ($l_{ij} = 1$ if $l_{ij} \geq 1$). Isolated stockmen
677 (stockmen who did not connect to any other) are not represented (9 nodes).



678

679 **Figure 4**. Effect of type of associations and region in the number of associations per
680 stockbreeder and links per stockbreeder in the Spanish Central Pyrenees. A) A_i, number
681 of associations per stockbreeder; B) l_i, number of links per stockbreeder. HEA, health-
682 based associations; SUB, subsidy-based associations; COO, cooperative-based
683 associations; OTH, others associations; NP, region that included a National Park; SKI,
684 region that included ski resorts. * indicates significant differences between regions for a
685 given type of associations (based on a post-hoc Tukey test).

686

687

688 **Table 1.** Current characteristics of the two study regions in the Spanish Central
689 Pyrenees.

Variable	*Sobrarbe (NP)*	*Alto Gállego (SKI)*
Area	893.62 km^2	490.02 km^2
Population	2.27 hab/km^2	8.44 hab/km^2
Agro-pastoral activity	14% (*-35%*)	3% (*-29%*)
Touristic activity	74% (*+38%*)	87% (*+49%*)
Campsites and rural houses	5138 places	1377 places
Hotels and apartments	2196 places	4126 places
New buildings	1041 houses	11317 houses

690 *Area*, surface of the region ; *Population*, density of inhabitants; *Agro-pastoral activity*,
691 proportion of the population mainly identified as working in agro-pastoral activities;
692 *Services activity*, proportion of the population mainly identified as working in services
693 activities (values in parentheses represent the change in proportion of the population
694 identified as working in each activity since 1981); *Campsites and rural houses*, number
695 of touristic places available in campsites and rural houses; *Hotels and apartments*,
696 number of touristic places available in hotels and apartments; *New buildings*, number of
697 new houses constructed since 1980. Sobrarbe region is under the influence of a National
698 Park (NP); while Alto Gállego region is under the influence of Ski resorts (SKI). All the
699 data were obtained from Instituto Aragonés de Estadística and Instituto Nacional de
700 Estadística and represent year 2010.

701

702 **Table 2.** Partnerships of stockmen in the study area in the Spanish Central Pyrenees.

Partnership	*Number*	*Objective*	*Example of activity*
Health (HEA)	15	Maintain health standards of the animals	Periodically perform mandatory sanitary tests to animals (health protection associations)
Subsidy (SUB)	12	Obtain funds for pastoral activities	Help stockmen to obtain quality labels (protected breed associations)
Cooperatives (COO)	4	Improve marketing of livestock products	Coordinate and advises stockmen business (agro-pastoral cooperatives)
Others (OTH)	5	All other stockmen associations	Organize country markets (groups of stockmen from the same town)

703 *Partnership*, type of partnership according to the interest pursued by its members;
704 *Number*, number of associations of each type in the whole study area; *Objective*, duty of
705 the partnership; *Example of activity*, actions taken by partnerships which directly
706 involve stockmen members.

707 **Table 3. Definitions of indices used in stockmen collaboration networks.**

Index	*Definition*	*Interpretation*
Isolation (*Iso*)	Number of nodes with no links.	High values indicate that many stockmen do not collaborate with others.
Density (*D*)	Mean number of links per node.	High values indicate that stockmen highly collaborate with others.
Modularity (*Q*)	Presence in the network of subgroups composed by highly connected nodes.	High values indicate that stockmen form groups inside which collaboration is strong.
Krackhardt Ratio (*E/I*)	Ratio between links from nodes in different and links from nodes in the same network.	Positive values indicate that stockmen principally collaborate with stockmen from other region, while negative values indicate that interact with stockmen from the same.

708 **Table 4.** Characteristics of the stockmen collaboration networks in study area in the
709 Spanish Central Pyrenees.

Region	*S*	*P*	*P/breed*	*Iso/S*	*D*	*Q*	*E/I*
Total study area (TSA)	194	36	2.63	0.05	124.7	0.27	-0.79
Sobrarbe (NP)	81	21	1.88	0.02	145.2	0.25	
Alto Gállego (SKI)	113	26	3.69	0.1	32.97	0.12	

710 *S*, number of stockmen; *P*, number of partnerships that stockmen in the network
711 belonged to; *P/breed*, mean number of partnerships which a stockbreeder belonged to;
712 *Iso*/*S*, proportion of stockmen without links; *D*, density; *Q*, modularity; *E/I*, Krackhardt
713 Ratio. Sobrarbe region is under the influence of a National Park (NP); while Alto
714 Gállego region is under the influence of Ski resorts (SKI).

715

716 **Table 5.** Indices for Stockmen Collaboration Networks in the study areas of the Spanish
717 Central Pyrenees.

Region	*Network*	*Iso*	*D*	*Q*	*E/I*
Total study	real	**9**	-	**0.27**	**-0.79**
area (TSA)	sim	6.39 (0.61)	-	0.11 (0.02)	-0.18 (0.02)
Sobrarbe (NP)	real	2	**145.2**	**0.25**	-
	sim	2.08 (0.28)	107.62 (0.29)	0.08 (0.02)	-
Alto Gállego	real	**8**	**32.97**	**0.12**	**-**
(SKI)	sim	5.57 (1.2)	25.23 (0.13)	0.22 (0.05)	**-**

718 *Iso*, stockmen without links; *D*, density; *Q*, modularity; *E/I*, E/I Ratio. Sobrarbe region
719 is under the influence of a National Park (NP); while Alto Gállego region is under the
720 influence of Ski resorts (SKI). Sim is the mean (standard deviation) of the index based
721 on 1000 simulations. Indices were significantly different from simulated ones (indicated
722 in bold) if they were more than 2 standard deviations above or below the mean values
723 from the simulations. *D* was calculated for the two regions, individually, because the
724 null model fixed *L* in the network, and *E/I* was only calculated for the two regions
725 combined because it included the links with and between regions.

Table 6. GLM and GLMM for the number of partnerships per stockbreeder and links per stockbreeder in the Spanish Central Pyrenees.

Level	*Response variable*	*Explanatory variable*	*Df*	*SSE*	*MSE*	*F-value*	*p-value*
All data	A_i	**Region**	1	123.6	123.6	88.06	<0.001***
		Residuals	192	269.4	1.4		
	L_i	**Region**	1	503569	503569	107.5	<0.001***
		Residuals	192	899054	4683		
Type of partnership	A_i	**Region**	1	30.89	30.89	88.06	<0.001***
		Partnership	3	44.21	14.737	51.93	<0.001***
		Region x Partnership	3	14.57	4.857	17.11	<0.001***
		Residuals	576	163.47	0.28		
	L_i	**Region**	1	125892	125892	107.5	<0.001***
		Partnership	3	192.96	64321	82.77	<0.001***
		Region x Partnership	3	75.98	2533	3.26	0.021*
		Residuals	576	447638	777		

Ai, number of partnerships per stockman; *Li*, number of links per stockman. Statistically significant variables are indicated in bold. * p<0.05; ** p<0.01; *** p<0.001.