



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

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1 Title: Structure of stockmen collaboration networks under two contrasting touristic  
2 regimes in the Spanish Central Pyrenees.

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14

15 Abstract

16 Ecosystem management is a difficult task because it must conciliate the ecological,  
17 economic, and social dimensions of socio-ecological systems. In those systems, the  
18 action of any single component can have an effect on the others, and result in a critical  
19 impact on the organization of the entire system. This study examined the collaboration  
20 networks among stockmen within two traditionally agro-pastoral regions in the Spanish  
21 Central Pyrenees which in the last 30 years included touristic activities: one under the  
22 influence of a National Park and centered on ecotourism, and the other in a region  
23 where there are ski resorts and local stockmen have turned to snow tourism. Our  
24 hypotheses were that economic regime affects the structure of the networks, and the  
25 type of collaboration (*e.g.* for economic reasons) influences the collaborations among  
26 stockmen. We built stockmen collaboration networks by connecting breeders within the  
27 same pastoral partnerships, and calculated the importance of collaborations (links  
28 density), the occurrence of collaborative subgroups (network modularity), and the  
29 existence of collaborations between stockmen in different regions (Krackhardt Ratio).  
30 In addition, we identified the distribution of links among types of pastoral partnerships.  
31 The network under the influence of the National Park presented higher link density and  
32 modularity than did the network influenced by ski resorts, where the presence of non-  
33 local stockmen is higher. Furthermore, economic partnerships played a major role  
34 connecting stockmen. In the study area, differences in the collaboration networks  
35 between the two regions suggest that changes in the economic trend in the last 30 years  
36 has influenced the collaborative structure of the stockmen. We discuss possible reasons  
37 behind these differences and propose some recommendations which could help to  
38 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).

64 Management practices are particularly important in mountainous regions. In mountain  
65 areas, human activities have led to the development of a wide variety of ecosystems that  
66 are nowadays considered biodiversity hotspots (Korner and Spehn, 2002; Lomolino,  
67 2001) and whose environmental value is recognized (mountain ecosystems are included  
68 within the European Habitat Conservation Strategy, Consejo de las Comunidades  
69 Europeas, 1992). Furthermore, those areas have been inhabited for centuries and are  
70 presented as examples of sustainable SES that preserve traditional economic activities,  
71 mainly agro-pastoral practices; together with the ecological value of the ecosystem  
72 (Jodha et al., 1992). For example, in the Spanish Central Pyrenees, the persistence of  
73 traditional pastoral habits such as transhumance (*i.e.* periodic movement of livestock  
74 between summer and winter pastures) led to the development of singular plant  
75 communities that have both high biodiversity and productivity (Caballero et al., 2011;  
76 Ruiz and Ruiz, 1986). Thus, traditional mountain human systems are good examples of  
77 sustainable development, where ecological, economic, and social dimensions of the SES  
78 are balanced.

79 In Europe, however, industrial development near cities at the beginning of the 20th  
80 Century led to massive migration from rural to urban areas (Alados et al., 2014; Mather,  
81 2001; Pinilla et al., 2008). This dramatic reduction in human labor had a profound  
82 impact on mountain SES and, especially, on the conservation of mountain pastures. In  
83 Spanish Central Pyrenees land abandonment and the loss of sustainable pastoral  
84 practices have reduced pasture area due to changes in land use (García-Ruiz et al., 1996;  
85 Gartzia et al., 2016b, 2014) and ‘shrub encroachment’ (*i.e.* increase in the density of  
86 local shrubs in pastures to the detriment of herbs and grasses, Komac et al., 2011; Van  
87 Auken, 2000). For example, the substitution of pastures by shrublands and forests has  
88 been associated to the decrease in livestock numbers in the area (Gartzia et al., 2014). In

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

91 Livestock management is one of the main factors responsible for maintaining the  
92 ecological value of mountain pastures (Kohler et al., 2004; Zervas, 1998). Livestock  
93 grazing influences the growth of the consumed plants, modifies species cover, and  
94 changes the composition and structure of plant communities (Milchunas and Lauenroth,  
95 1993; Van Auken, 2000). Furthermore, pastoral ecosystems have been recognized as  
96 important providers of ecosystem services (Oteros-Rozas et al., 2013). For example,  
97 livestock grazing can increase the productivity of an ecosystem, and transforms a  
98 dispersed, low-energy resource (grass) into a concentrated, high-energy resource  
99 (livestock meat, Frank et al., 1998). In addition, pastoral activities also help to preserve  
100 and transmit traditional local knowledge in mountain SES (*e.g.* location of water points  
101 and grazing paths, regulation of grazing intensities, Hassanein and Kloppenburg, 1995),  
102 which helps to accelerate the reorganization of the system after major disturbances  
103 (Berkes et al., 2008). Therefore, to preserve mountain pastures and their associated  
104 ecosystem services, the conservation of sustainable agro-pastoral activities is essential.

105 Traditionally, in the Spanish Pyrenees livestock production has involved a communal  
106 grazing system in which stockmen collaborate to expand grazing pastures and to  
107 preserve their pastoral value (Caballero et al., 2011). Today, this collaborative structure  
108 has led to the creation of different livestock partnerships whose duties include from  
109 economic to sanitary tasks (*e.g.* optimize the marketing of products, obtain quality  
110 designations for the livestock; or manage veterinary exams, Confederación de  
111 Cooperativas Agrarias de España, 2002). Remarkably, the implementation of Common  
112 Agricultural Policy (CAP, Consejo Europeo, 2005) has led in recent times to the  
113 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 5° C (Goriz Refuge at 2200 m, data from 1976 to 2005) to 12.4° 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  $X_{S \times P}$  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  $L_{S \times S}$  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).

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

247

### 248 3. Results

#### 249 3.1. Characteristics of stockmen

250 Stockmen groups presented similar characteristics in both regions, with most stockmen  
251 presenting similar age (more than 40 years) and education level (secondary level).  
252 Furthermore, most stockmen came from a family related to shepherding and have  
253 carried their livestock to pastures in the area for more than 30 years. We only found  
254 significant differences between regions in the origin of stockmen, with more proportion  
255 of foreign stockmen in SKI ( $\text{foreign}_{\text{NP}} = 2/81 = 0.02$ ;  $\text{foreign}_{\text{SKI}} = 22/113 = 0.19$ ;  $\chi^2 =$   
256  $11.06$ ,  $p < 0.001$ ). All stockmen agreed that in recent times mountain pastures and  
257 landscape have changed noticeably (principally, through the substitution of pastures by  
258 shrubland and forest). From all stockmen in the study area, nine were not connected to  
259 others (*sensu*, they did not present any collaborative links with others). Connected

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

### 263 3.2. Network analysis

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

273 Comparing both regions, SKI had significantly more isolated stockmen ( $\chi^2 = 4.79$ , *df* =  
274 1, *p*-value = 0.029), and significantly fewer partnerships per stockbreeder and fewer  
275 links per stockbreeder than NP (Table 6). This suggests that stockmen established more  
276 collaborative associations in the region under the influence of the National Park than in  
277 the region with ski resorts. Furthermore, Krackhardt Ratio indicated that most of the  
278 collaborative links were between stockmen within the same region (Table 5), which  
279 suggests that stockmen preferred to partner with their geographic neighbors.

280 The effect of type of partnership on the collaborations among stockmen differed  
281 between the two regions ( $\chi^2 = 1934.38$ , *df* = 3, *p*-value < 0.001). Specifically, in NP all  
282 four types of partnerships were responsible of establishing collaborations, while in SKI,  
283 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

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

318 Considering the two regions, although stockmen communities were similar in age,  
319 education and experience in shepherding, we observed contrasting structures in their  
320 SCNs. In the region under the influence of the Ordesa-Monte Perdido National Park  
321 (OMPNP) and more focused on ecotourism (NP), the network was organized in close  
322 collaborative groups and stockmen established high number of collaborations. In the  
323 area near OMPNP, stockmen have been sharing pastures for centuries (Sal and Lorente,  
324 2004), with the creation of historical local organizations such as ‘Mancomunidad del  
325 Valle de Broto’ and ‘Casa de Ganaderos de Zaragoza’ (founded in the 13th Century) to  
326 regulate grazing management. The necessity of sharing pastures in the same place has  
327 strengthened the interaction bounds, resulting in a very close collaborative system  
328 formed by neighbors and pastures partners. This can be seen in the importance of  
329 cooperatives and other partnerships in the region (Figure 3 and 4). The existence of  
330 these historical organizations is important in the region and they have been presented as  
331 important keepers of traditional knowledge in Pyrenees (Fernández-Giménez and Fillat,  
332 2012). Furthermore, in recent times several partnerships have appeared to maximize the



333 acquisition of subsidies intended for the maintenance of traditional agro-pastoral  
334 practices in the area (related to the presence of a National Park, Gobierno de España,  
335 2007; and Common Agricultural Policy, Consejo Europeo, 2005), which have become  
336 the main source of income for stockmen in the area (Fernández-Giménez, 2015;  
337 Plieninger, 2006). For example, to defend the interests of livestock owners in the  
338 National Park, a specific partnership was formed (‘Asociación de Ganaderos del Parque  
339 Nacional de Ordesa y Monte Perdido’). This partnership brings together the stockmen  
340 who move their herds to the pastures within the Park, and has greatly helped to  
341 strengthen the collaborative bounds in the area.

342 On the other hand, the SCN in the region including snow tourism (SKI) presented  
343 several stockmen with no collaborative links and was not organized in groups. In SKI  
344 the reduction in sheep and goats has resulted in a significant increase in the amount of  
345 ungrazed mountain pastures (García-Ruiz et al., 1996; Lasanta and Vicente-Serrano,  
346 2007). Although the reduction in livestock was widespread in the Pyrenees (including  
347 the area within the National Park), the pastures in SKI region have been more attractive  
348 because they are easier to manage (*e.g.*, they are accessible by car, have shallow slopes,  
349 Gartzia et al., 2016a) and have been highly demanded to develop goods related to snow  
350 activities (Marín-Yaseli and Lasanta, 2003). This has resulted in a strong turn from an  
351 economy centered in agro-pastoral sector to another more focused on services, which is  
352 enhanced in the areas near ski resorts (Marín-Yaseli and Lasanta, 2003). Substitution of  
353 agro-pastoral practices by ski tourism is common in mountain areas (Gellrich et al.,  
354 2007; Teodoro Lasanta and Vicente-Serrano, 2007) and usually, in farms, different  
355 economical activities coexist (Riedel et al., 2007). However, the harmonious  
356 coexistence between shepherding and tourism strongly depends in the goals of the local  
357 stockmen (Gasson et al., 1993). In general, stockmen in the study area complained

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

#### 364 4.2. Effect of type of partnership in the collaborative structure

365 The importance of the type of partnership structuring SCNs showed that, independently  
366 of the region considered, most collaborative links were based on economic profit  
367 (subsidy partnerships produced the most collaborations, even between stockmen from  
368 different regions, Figure 3). Since the implementation of Common Agricultural Policy  
369 (CAP) in 1986, subsidies have been the main force shaping the agro-pastoral sector in  
370 Spain, particularly replacing sheep farming by cattle (García-Martínez et al., 2009;  
371 Plieninger, 2006). Particularly, belonging to partnerships that facilitate the process of  
372 receiving funds has been profitable (*e.g.* partnership help its members to request  
373 subsidies properly), and consequently, stockmen prioritize most profitable partnerships  
374 over other factors as geographical proximity or neighbors preferences. The involvement  
375 of public and private services can help to sustain agro-pastoral systems (Bernués et al.,  
376 2003), but is central to identify the main drivers behind the organization of SES to apply  
377 efficient management practices.

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

382 et al., 2006). In the Spanish Central Pyrenees, stockmen have collaborated with whom  
383 they share pastures and coordinated to move their livestock along the year to optimize  
384 pastures forage production. Collaborative groups represented by the modules in the  
385 network might facilitate the efficient exploitation of pastures, which might help to  
386 maintain their ecological and pastoral value. However, most of those small groups were  
387 quite closed, which can obstruct the creation of a large-scale collaborative structure.  
388 Studies on adaptive management have suggested that non-modular organizations are  
389 more adaptive than modular ones, and they allow the inclusion of external information  
390 and the creation and reassembling of links in the system (Aldrich, 1999; Granovetter,  
391 1973). Thus, non-modular organizations respond faster to changes in the external  
392 conditions of socio-ecological systems and can evolve to new possible equilibrium  
393 states (Holling, 2001). It is possible that the SES in the SKI region is still adapting to  
394 the presence of ski resorts, and it will take time before it is known whether this process  
395 leads to an equilibrium in which only one between local traditional practices and ski-  
396 related sources of incomes dominates, or both activities coexist becoming the main  
397 drivers of the economic development in the region.

398 The collaboration networks used in our study were based on affiliation networks (*sensu*  
399 (Borgatti and Halgin, 2011), and it is important to consider that these networks have  
400 limitations. For example, in our study we assumed that stockmen who belonged to the  
401 same partnership were collaborating, but this is only a proxy of a real collaboration. For  
402 example, almost all of the stockmen belonged to partnerships related to mandatory  
403 health controls imposed by Government (85% of stockmen belonged to one health  
404 association), which was the result of legal issues rather than truly collaborative bounds.  
405 Consequently, we did not find a significant effect of health partnerships between the  
406 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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479

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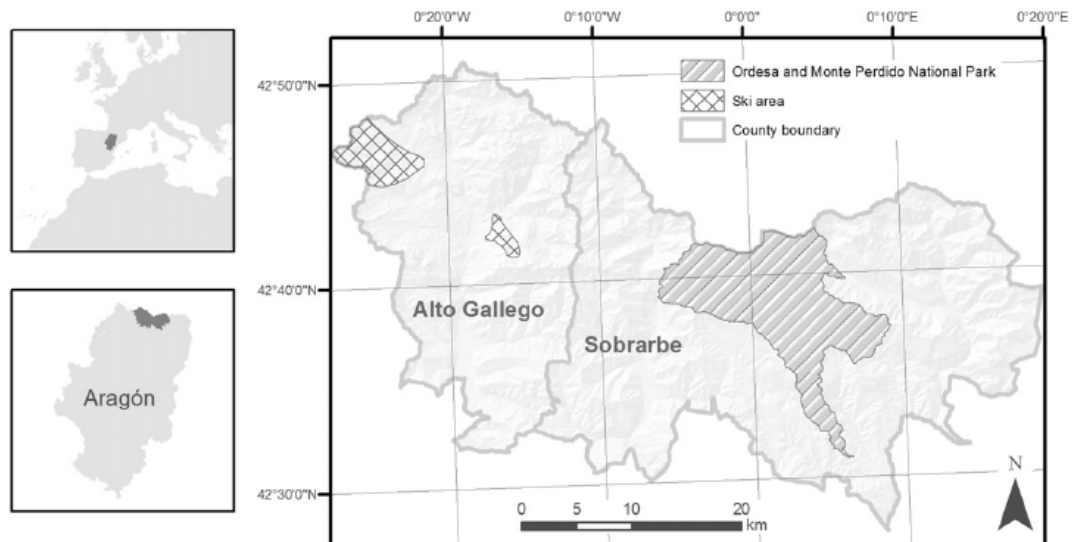
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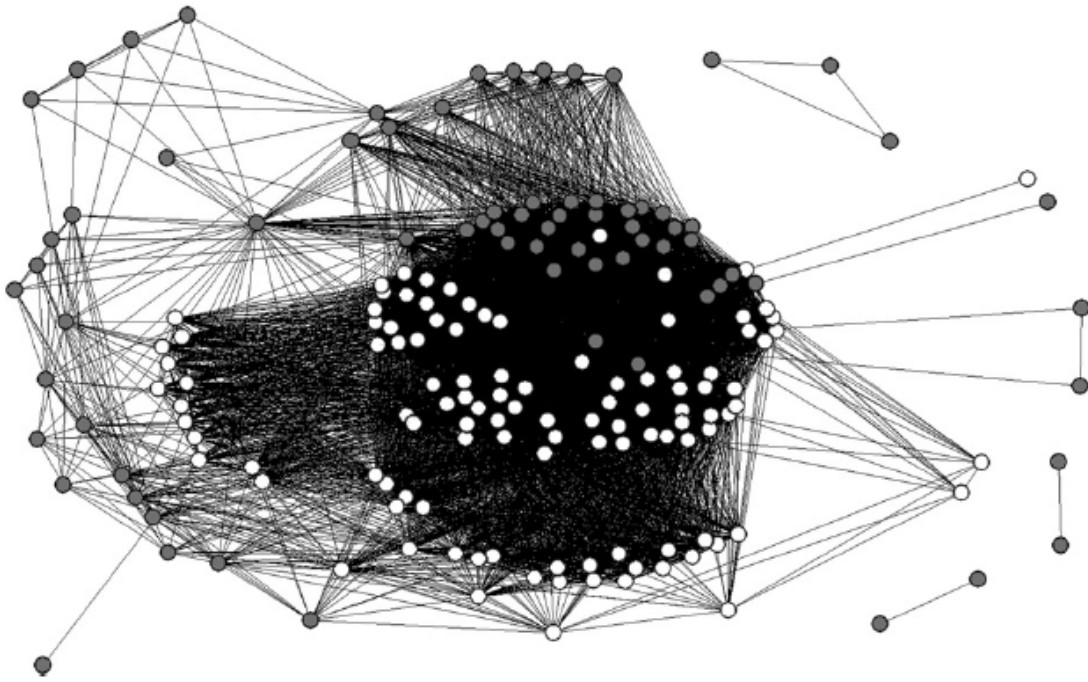
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657

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.

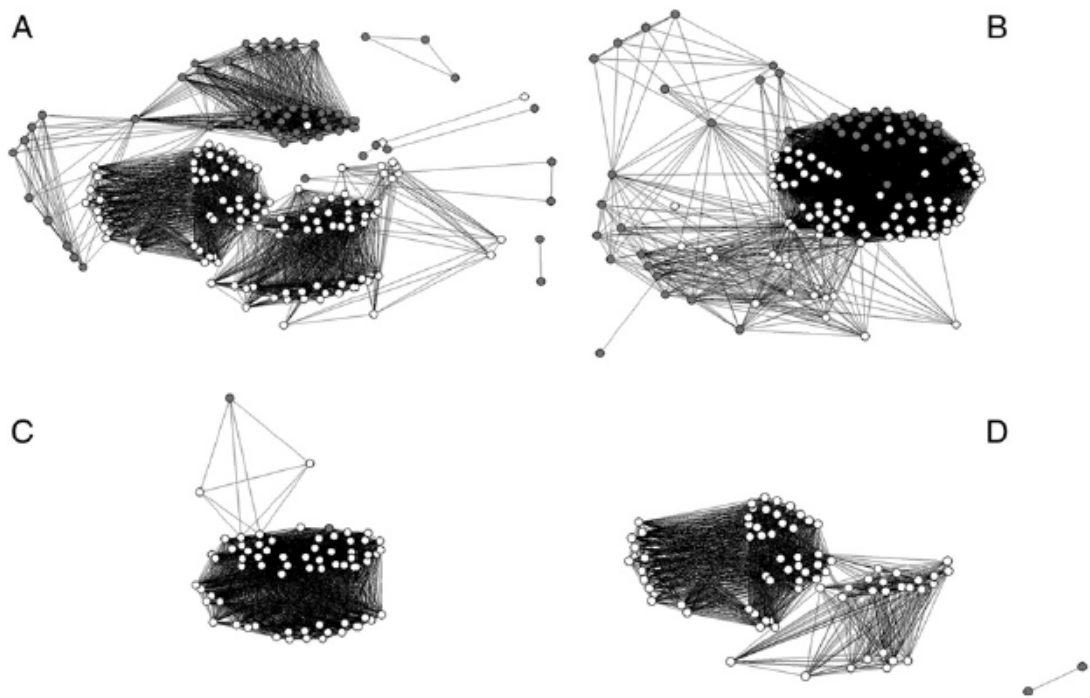
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665

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).

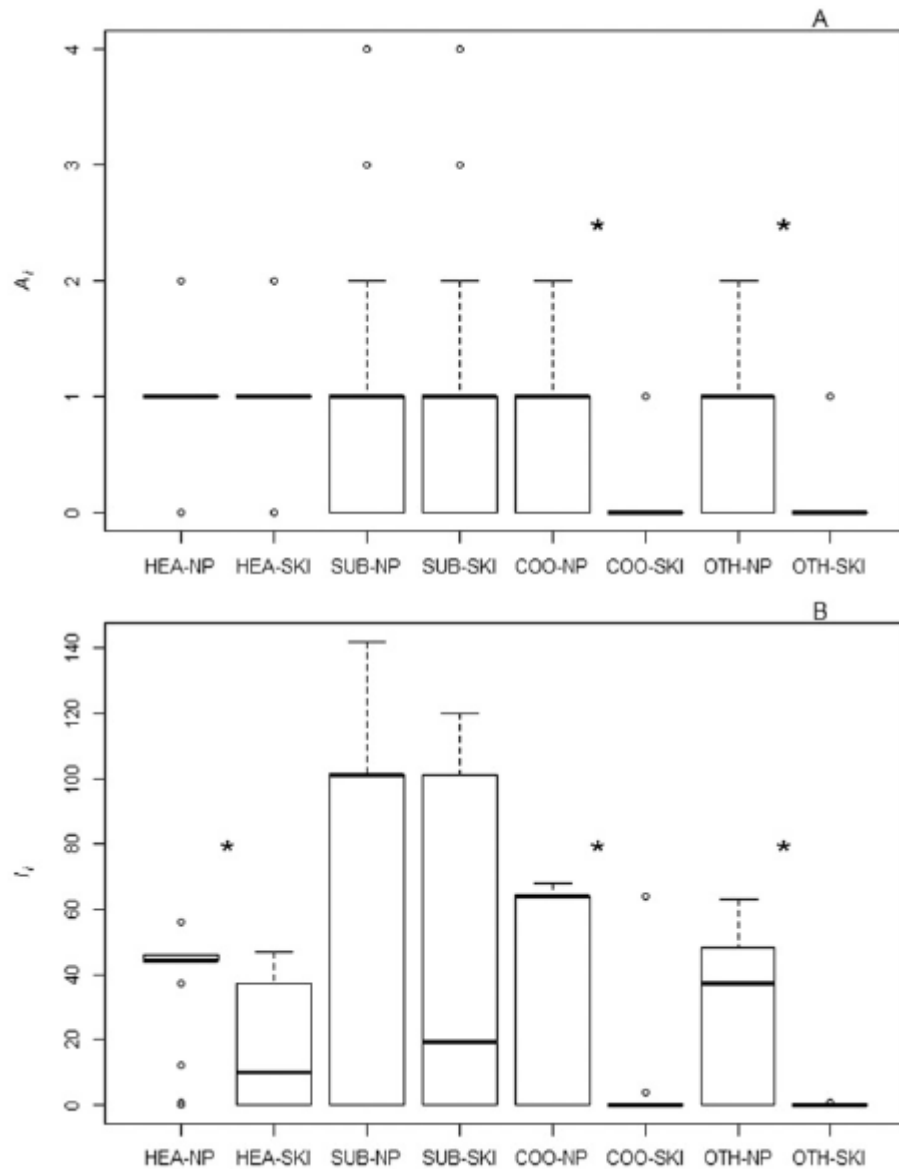
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671

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.

<i>Variable</i>	<i>Sobrarbe (NP)</i>	<i>Alto Gállego (SKI)</i>
Area	893.62 km <sup>2</sup>	490.02 km <sup>2</sup>
Population	2.27 hab/km <sup>2</sup>	8.44 hab/km <sup>2</sup>
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.

<i>Partnership</i>	<i>Number</i>	<i>Objective</i>	<i>Example of activity</i>
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.**

<i>Index</i>	<i>Definition</i>	<i>Interpretation</i>
Isolation ( <i>Iso</i> )	Number of nodes with no links.	High values indicate that many stockmen do not collaborate with others.
Density ( <i>D</i> )	Mean number of links per node.	High values indicate that stockmen highly collaborate with others.
Modularity ( <i>Q</i> )	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 ( <i>E/I</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.

<i>Region</i>	<i>S</i>	<i>P</i>	<i>P/breed</i>	<i>Iso/S</i>	<i>D</i>	<i>Q</i>	<i>E/I</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.

<i>Region</i>	<i>Network</i>	<i>Iso</i>	<i>D</i>	<i>Q</i>	<i>E/I</i>
Total study	real	<b>9</b>	-	<b>0.27</b>	<b>-0.79</b>
area (TSA)	sim	6.39 (0.61)	-	0.11 (0.02)	-0.18 (0.02)
Sobrarbe (NP)	real	2	<b>145.2</b>	<b>0.25</b>	-
	sim	2.08 (0.28)	107.62 (0.29)	0.08 (0.02)	-
Alto Gállego (SKI)	real	<b>8</b>	<b>32.97</b>	<b>0.12</b>	-
	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.

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

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

729  $A_i$ , number of partnerships per stockman;  $L_i$ , number of links per stockman. Statistically  
 730 significant variables are indicated in bold. \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ .