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Article *in* Regional Environmental Change · January 2016

DOI: 10.1007/s10113-015-0917-8

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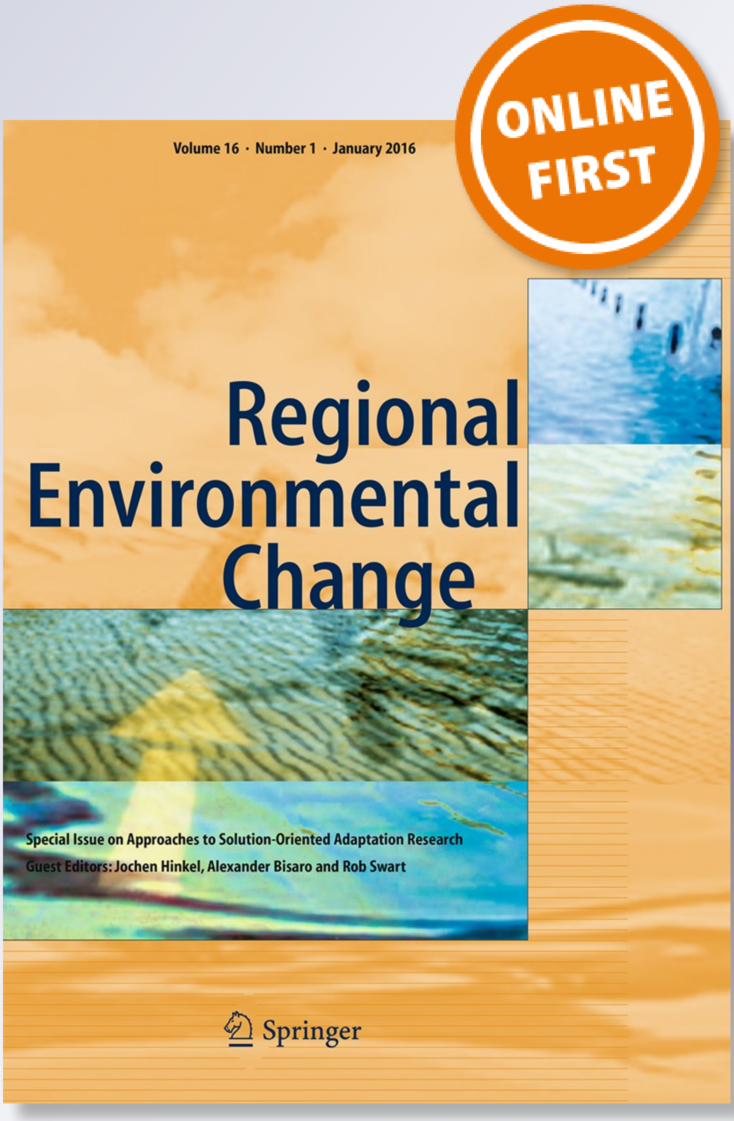
Regional Environmental Change

ISSN 1436-3798

Reg Environ Change
DOI 10.1007/s10113-015-0917-8



Springer

Reg Environ Change
DOI 10.1007/s10113-015-0917-8

ORIGINAL ARTICLE

A social–ecological network analysis of Argentinean Andes transhumant pastoralism

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Received: 31 October 2014 / Accepted: 16 December 2015

Abstract Many mountainous regions worldwide are characterized by harsh environments, scarce infrastructure, and extreme contrasts between mountains and neighboring plateaus and plains. Transhumance is a social adaptation to handle geomorphological heterogeneity such as lowlands and highlands, and to cope with environmental variability (seasonal and regional rainfall and snowfall). We studied the regional transhumant system with a network approach in the Andes of North Patagonia, Argentina. We measured the connectivity promoted by the seasonal movements of herds and people (relationships) among different ecosystems (nodes), defined as winter and summer lands. We identified 238 networks. The highest frequencies corresponded to small network structures (dyads and triads), suggesting that landscape management is highly decentralized. Network complexity was positively related to ecological richness and diversity of connected nodes. However, most networks were dependent upon a central node, suggesting vulnerable situations regarding disturbances affecting such key nodes. The identification of social–ecological traps of this mobile system provided novel insights for policy decision making, which otherwise would not be evidenced with traditional approaches. Management proposals and policy making should consider the spatial and temporal scales of transhumant pastoralism, in order to avoid problems derived from fixation logics, scale mismatches, and disconnection.

Keywords Connectivity · Mobility · Mountain regions · Patagonia · Resilience · Variability

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Introduction

Many mountainous regions worldwide are characterized by harsh environments, scarce infrastructure and services, low human density, and extreme contrasts regarding these attributes between mountains and neighboring plateaus and plains. Many communities from mountainous regions have coevolved in such contexts, by developing strategies to cope with variability and seize opportunities from these highly heterogeneous environments. One of the most frequent adaptive strategies in these mountainous areas is related to mobility.

Adaptation occurs in systems subjected to a particular type and degree of variability, which may become highly optimized to tolerate and deal with this variability (Carlson and Doyle 2002). Mobility in human societies is an ancient livelihood strategy of adaptation to spatial and temporal environmental variability such as seasonal and regional rainfall and snowfall (Dyson-Hudson and Dyson-Hudson 1980; Niamir-Fuller 1999). Such social adaptation is said to provide resilience to mobile communities in these kinds of environments (Fernández-Giménez and Le Febre 2006;

Published online: 07 January 2016

Janssen et al. 2007). Resilience in social–ecological systems relates to system response to a perturbation or disturbance, its self-regulation or capacity to self-organize, and the capacity to learn and adapt to future changes (Folke et al. 2002; Berkes et al. 2003; Nelson et al. 2007). Hence, adaptive capacity is a central feature of resilience since it is crucial to adjust responses to changing internal dynamics and external drivers (Carpenter and Brock 2008). As an opposite condition, rigidity traps occur in social–ecological systems when institutions become highly connected, self-reinforcing, and inflexible (Gunderson and Holling 2002). Adaptation to a dominant regime of variability is also a trade-off outcome between system performance and sensitivity to other sources of variability (Anderies et al. 2007). In other words, adaptation may include more or less relevant traps to changing conditions. The identification of rigidity traps provides a perspective for vulnerability analysis of social–ecological systems, defined as the degree to which a system is likely to experience harm due to exposure to a hazard (Turner II et al. 2003). Vulnerability is an integrated concept that describes the impact of a hazard as a function of an entity's exposure, sensitivity, and adaptive capacity (Turner II et al. 2003; Smit and Wandel 2006). Then, vulnerability increases when threats or disturbances can affect some critical system components or processes that are locked in a trap with reduced options for further adaptations. We used this perspective to study the adaptations and vulnerabilities of a transhumant social–ecological system.

Transhumance is a mobile strategy that occurs in mountainous regions, in which people and herds move seasonally from lowlands that are pastured during winter, up to the highlands during summer in order to benefit from high-quality pastures (Fryxell and Sinclair 1988). This strategy implies that pastoralists and their herds escape from snowfall and harsh conditions in the mountains during winter, as well as from seasonal droughts and lower forage productivity during summer that occurs in the lowlands. Many studies explored a range of features of transhumant systems, by focusing on the main current problems and future scenarios of global or regional change (e.g., Bendini et al. 1993; Fernández-Giménez 1999; Suttie and Reynolds 2003; Thevenin 2011; Foggin and Torrance-Foggin 2011; Bergmann et al. 2011; Oteros-Rozas et al. 2013a; Krätli et al. 2013), socioeconomic studies (Nautiyal et al. 2003; Pérez Centeno 2004; Bendini and Streimbreger 2011; Lanari et al. 2007; Lkhagvadorj et al. 2013), and traditional ecological knowledge of transhumant communities (e.g., Fernández-Gimánez 2000; Ladio and Lozada 2009; Oteros-Rozas et al. 2013b). However, to the best of our knowledge, network analysis applied to the patterns of regional movements of transhumant pastoralism and the emerging landscape management is lacking. We argue that pastoralists and their herding moving between fragmented environments are involved in regional networks of social, biophysical, and agricultural connectivity (sensu Bodin and Norberg 2007). Such networks promote matter and energy flows among different ecosystems, as well as sociocultural relationships and information exchange (McAllister et al. 2011).

The assessment of social and ecological regional connectivity in mobile systems is a crucial step in order to further understand the adapted institution to the environmental variability that defines the current landscape management. However, such institutional arrangements that are adapted to specific types of biophysical variation may become vulnerable to changing social or ecological conditions (Janssen et al. 2007). Mobile pastoralism is still facing challenges such as climate change, land-use change, and urbanization (Galvin et al. 2008; Luthe et al. 2012; Easdale and Domptail 2014). Hence, the identification of critical sites and most sensible components to disturbance factors is crucial for early warnings of vulnerable social–ecological situations and for effective interventions. We propose that the transhumant movement that determine current landscape management is an institution that can be assessed with a network approach. For this study, the transhumant institution is defined by the combination of different land uses such as lowlands and highlands and human and herd mobility in the landscape. Our study was oriented by two questions: (1) How diverse and complex the networks that describe transhumant systems are? and (2) How diverse ecosystems connected by transhumant networks are? On the one hand, network types may provide evidences of the patterns of landscape management. On the other hand, biophysical diversity that is connected by transhumance may provide insights into the role of mobile pastoralism in the connectivity of fragmented ecosystems and in identifying critical nodes. We explored these issues in the Andes of North Patagonia, Argentina, for which connectivity was defined by the seasonal movements of herds and people (i.e., relationships) among different ecosystems, defined as winter and summer lands (i.e., nodes). We call for a more profound recognition of heterogeneous situations regarding landscape use and management in transhumant pastoralism by tackling regional connectivity, in order to shed light on vulnerabilities to disturbances that otherwise would not be evidenced with traditional approaches.

Materials and methods

Study area

Transhumant pastoralism is a prevalent activity and source of livelihood for approximately 1200 households in the northern region of Neuquén province, Argentina (Pérez

Centeno 2007). Transhumant pastoralists are heterogeneous, and socioeconomic differences among households are mainly explained by two factors: (1) resource level (i.e., economic and biophysical), and (2) distance to urban areas (i.e., remoteness), influencing the access to subsidies, off-farm employment, and education. A recent typology has described as *livestock keepers* the most frequent and vulnerable households, which are smallholders with mixed herds dominated by goats, with low resource levels and larger distances from urban areas (Pérez Centeno 2007). Their main livelihoods are based on livestock production and environmental services. On the other hand, *transition farmers* have higher resource levels and are highly linked to urban dynamics while keeping transhumance. A minor proportion is characterized as *ranchers*, who have higher proportions of cattle, economic and biophysical resources, and typically urban residence. At a regional scale, the main livestock is a local goat breed (i.e., *criollo goat*) that is highly adapted to the harsh environmental circumstances (Lanari et al. 2007), generally in mixed herds with cattle and sheep. During almost 8 months (from April to November), herders use the lowlands for grazing, moving in the summer (from December to March) to the pasturelands located in the mountains (Fig. 1). The winter lands are characterized by vast plains, hills, and plateaus dominated by shrub and shrub–grass steppes (i.e., arid and semiarid rangelands). Most cities and towns are located in lowlands. Summer lands are fragmented landscapes due to the orography, dominated by meadows, grass–shrub steppes, and native forest (*Nothofagus* spp.), which are covered by snow in the winter, limiting access. Most summer lands are state-owned, who gives grazing permissions to families every year, without many changes in the assignation due to historical usage of lands. Winter lands have mixed ownerships (i.e., state-owned with permissions, individual properties, and communal properties in indigenous communities). Finally, key components of the transhumance system are the herding roads, which are common lands that connect different landscapes (Bendini et al. 1993).

Transhumant social–ecological network approach

Network approach was proposed as a promising perspective for social–ecological analysis (e.g., Janssen et al. 2006). Some applications include the role of social networks in natural resource management (Bodin et al. 2006), the spatial organization of populations in fragmented landscapes (Bodin and Norberg 2007), and scale mismatches and the value of social networks (Guerrero et al. 2013). In this paper, we propose that the transhumant institution related to landscape management can be assessed by means of a network approach. Network structures are generally represented by nodes and relations. In the case of the transhumant networks, we defined nodes as grazing sites represented by lowlands and highlands (hereafter named as

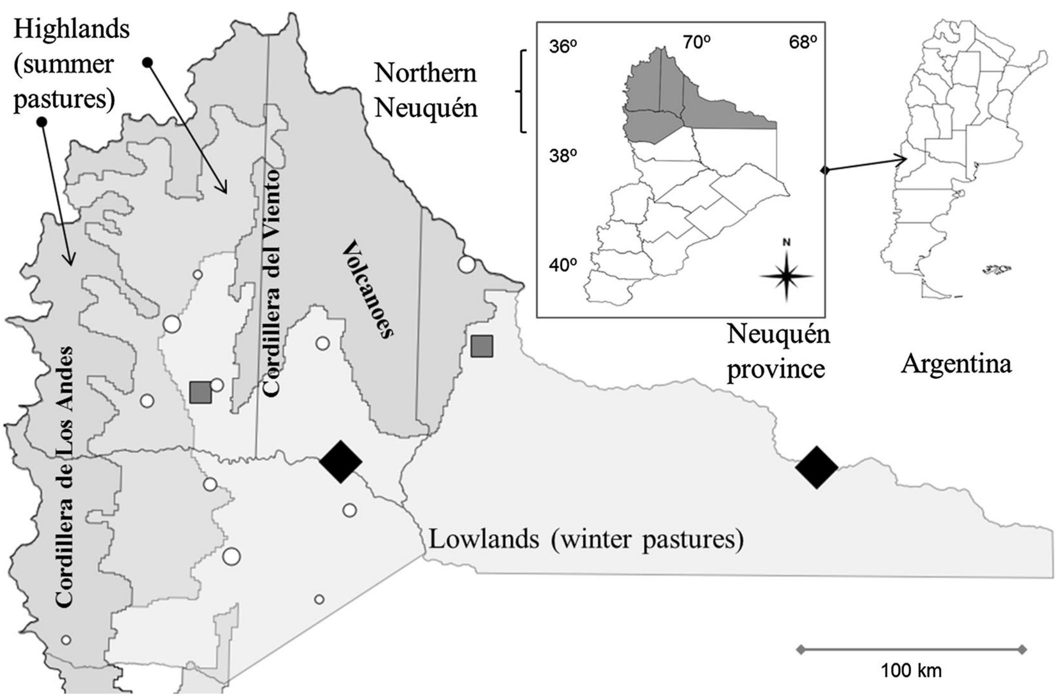

Fig. 1 Study area: Northern Neuquén, Argentina. References: Mountains, highlands, and sub-Andean pastures (*gray* and *dark gray zones*), and lowlands (*light gray zones*). Cities >3000 inhabitants (*black rhombs*), cities with 2000–3000 inhabitants (*dark gray squares*), and towns <2000 inhabitants (*white circles*). Province subdivisions refer to counties

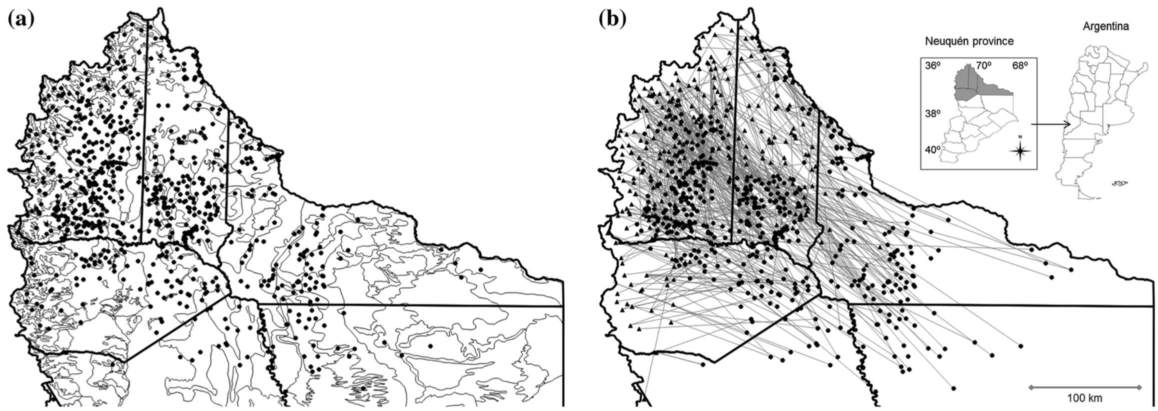

Fig. 2 Study area, **a** Production sites (nodes) and regional ecosystem units (*gray lines*). *Black dots* are nodes that identify different ecosystems associated with production sites. **b** Transhumant networks and political-administrative boundaries (i.e., counties, *black lines*). *Dots* identify winter lands and *triangles* identify summer lands, while *straight gray lines* indicate linkages among nodes. Source of ecosystem units: Movia et al. (1982)

winter and summer lands, respectively, due to the meaning related to land management). The relations among nodes represented the movement of herds and pastoralists that connects winter and summer lands (Fig. 2). Hence, these are social–ecological networks since they integrate ecological sites with different land uses (i.e., different ecosystems identified by nodes) and a socioproductive strategy defined by the mobility of herds and humans (i.e., social process, identified in the relations among nodes). This approach is more suited to address the proposed research questions than a purely social network analysis applied to natural resource management, since the environmental variability is also included in the network definition, throughout the different land management of different nodes. Furthermore, this approach is also more suited than a purely biological network aimed at studying the connectivity among fragmented ecosystems, since the different land uses and the socioproductive mobility are also included in the network definition. Hence, this network configuration provides much more opportunities to explicitly study the linkage between the ecological and social dimensions of transhumant pastoralism across scales.

Winter and summer lands were defined differently, by including attributes related to livestock ownerships and site biophysical features, respectively. Winter lands include production units that are referred to a herder or household, spatially identified by the location of the main house or household. Hence, it is frequent to find different livestock owned by several household members (e.g., partners, brothers). While livestock are generally managed all together, the property is reflected in the different animal identification marks. This means that each winter land site is related to a household, where household members spend almost 8 months a year for living.

Summer lands are defined by biophysical attributes, referring to a watershed or catchment area, a wetland, meadow or even wide areas associated with steppes or hills but with defined grazing boundaries. Hence, each site can be associated with one or more households (i.e., common land use), coming from different areas or winter lands. In general, summer lands are transitory living places (4 months) with very precarious huts or shelters.

Data processing and analysis

We used data from the Servicio Nacional de Sanidad y Calidad Agroalimentaria (SENASA), for the year 2010. This database gathered 1220 sites with relation to agricultural production activities suited in the north region of Neuquén Province, Argentina. Each datum was identified by a code number as winter or summer land, which was based on the type of usage defined by the herders.

Linkages among different sites were not directly recorded in the original database. Relations between winter and summer lands were derived from a unique identification code included in the database which associated each household with different sites, for which annual herding movements were recorded.

In order to assess the regional biophysical attributes of the different connected sites, we mapped and integrated the sites with available cartographic information related to regional ecosystem units (Movia et al. 1982; 1:500,000; Fig. 2a). In Fig. 2a, we located the nodes in order to describe the spatial distribution and general pattern of winter and summer lands. Each ecosystem unit is considered homogeneous in terms of vegetation (i.e., physiognomy, structure, dominant species) and physiography at a regional scale. Hence, these ecosystem units include large areas with a relatively high structural and functional homogeneity. Movia et al. (1982) defined the boundaries among units by aerial photographs, and more precise limits were first determined by differences in patterns of colors and textures. Then, they controlled this information by field work, where legends with descriptions of the most representative vegetation units were developed (Movia et al. 1982). Hence, we associated all sites considered in this study with a regional ecosystem unit.

We constructed a binary symmetric matrix that identified the absence or presence [0, 1] of relation among all sites, respectively. Hence, the connections among nodes or sites were undirected, which means that edges or relations have no orientation (Fig. 2b). This matrix represented the transhumant network and was used to perform the analyses.

We identified the transhumant network structures by performing the n-clique analysis. An n-clique of an undirected graph is a maximal subgraph or subgroup in which every pair of nodes is connected by a path of length n or less. This method is usually used to identify different levels of complexity of network structures, based on the basic components of a network: nodes and relations (Luce and Perry 1949). The analysis was performed step by step, by selecting first the smallest structure defined by a dyad (i.e., two nodes and one relation), without considering those who were included in greater structures. Progressively, we continued with more complex structures by including additional nodes and relations to identify triads and subsequent greater network structures (i.e., >4 nodes and three relations). With this method, we obtained a census of the different transhumant network structures in the study area (Fig. 3). We performed the analysis and n-clique graph with Pajek 2.0 software (Batagelj and Mrvar 1998).

From a biophysical perspective, biological diversity is a key driver of ecosystem processes, and richness could be defined in different hierarchical levels, from genes to landscapes or regions (Noss 1990). We used the regional ecosystem units (Movia et al. 1982) as a proxy to characterize ecosystem flows of energy, matter, and water. These ecological units were used to characterize the ecological richness and diversity of the connected nodes of transhumant networks. Richness was defined as the total number of different regional ecosystem units involved in each network. On the other hand, the ecological diversity is a concept that integrates two components: richness (i.e., quantification of different elements) and equity (i.e., relative abundance of each element). We constructed an ecological diversity index for transhumant networks, adapted from the diversity index proposed by Simpson (1949). The network ecological diversity index (ED) was defined by the following equation (Eq. 1):

$$\mathrm{ED} = 1 - \frac{\sum_{i=1}^{S} n(n-1)}{N(N-1)} \quad (1)$$

where N is the total number of nodes (i.e., sites) that comprise the network, S is the number of different regional ecosystem units in which sites are located, and n is the number of nodes included in each regional ecosystem unit. The values that the index could take can range from 0 to 1, and for this equation, ecological diversity of networks increases with higher values.

Results

From the 1220 nodes of the original database, we found linkages among 793 nodes (65 %), from which 535 were winter lands and 258 summer lands (Fig. 2b). Every summer land had a linkage with at least one winter land. Households that were associated only with one site (all of them located in winter lands) represent those who do not perform movements and therefore were not considered as transhumant (35 % of nodes). In general, these were crop and pasture farmers, or livestock sedentary farmers in irrigated valleys.

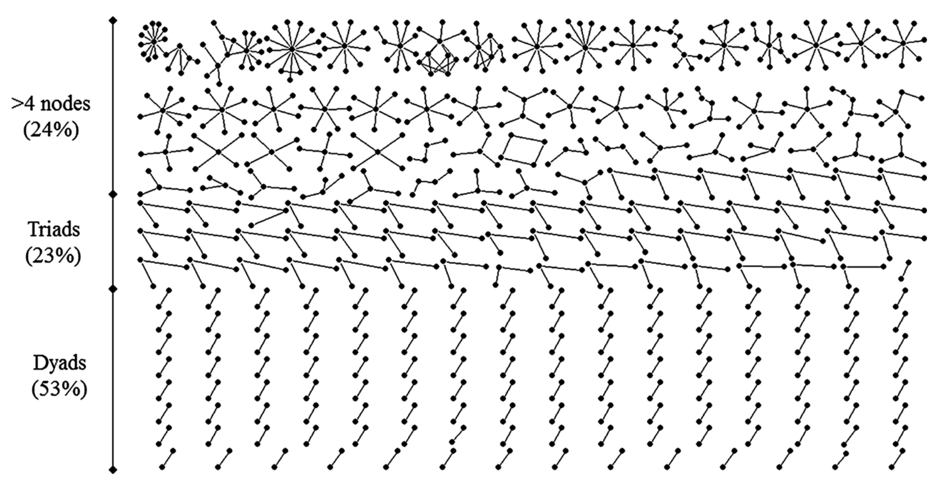

Fig. 3 Frequency of different network structures identified in the study area (see Fig. 1; n-clique method), organized from the *bottom* to the *top* in: dyads, triads, and more complex networks, respectively

We identified 238 transhumant networks, and the highest frequencies corresponded to small-size network structures (i.e., 53 % dyads, 23 % triads; Fig. 3). There were more complex network structures (>4 nodes) with different configurations. The main identified network topologies were linear and star networks. There were minor proportions of partially connected mesh networks, distributed star networks, and only one circular or ring network. The 68 % of the more complex networks had 100 % in betweenness, meaning that each structure relied on a central node associated with a star network topology (Fig. 3). This type of networks, and considering also dyads and triads, involved 82 % of the total nodes, from which 428 nodes (54 % of the total) were dependent upon 220 central or key nodes (28 % of the total). These central nodes were summer lands.

Network complexity, as measured by nodes per network, was positively related to ecological richness ($r^2 = 0.84$) and ecological diversity ($r^2 = 0.51$) of connected nodes (Fig. 4). From a biophysical perspective, most transhumant networks (92 %) promoted connections of at least two different regional ecosystem units, while 45 % of networks had an ecological diversity >0.5 (Fig. 5). Only 8 % of networks (i.e., dyads and triads) were composed by nodes located within the same regional ecosystem unit (Figs. 4, 5).

Discussion

The network analysis of the Andean transhumant system of Argentina provides a quantitative description and an explicit representation of how this mobile pastoralism manages the landscape. The transhumant system was based on a variety of small-size networks (Fig. 3). Hence, regional management is highly decentralized and based on a positive relationship between network complexity and diversity in ecological connections (Fig. 4). However, almost half of the networks were dependent upon a central node, suggesting that households are vulnerable to disturbances affecting such key sites such as natural capital degradation, due to cascade effects toward other connected nodes (Motter and Lai 2002). Such key nodes highlight zones where conservation and policy decisions should be oriented to the face of future hazards with regard to environmental (e.g., climate, ecosystem degradation) or social (e.g., land tenure, land use) change.

Various vulnerability assessments in the Andes emphasize that most vulnerable situations are related to resource-constrained households, in particular those with a higher education deprivation, lack of alternative income and the absence of partnership (e.g., Pérez Centeno 2007; Easdale and Rosso 2010; Sietz et al. 2012; López-i-Gelats et al. 2015). In these contexts, livestock is the most important source of income for pastoral livelihoods, and mobility strategies allow a higher tolerance to climate change (i.e., decreased mean annual precipitation and increased variability) than sedentary production (Martin et al. 2014; Easdale and Domptail 2014). The positive relationship between network complexity and ecological diversity found in this study supports the argument that most networks effectively seize opportunities from the highly heterogeneous environment. High ecological diversity enhances the adaptive capacity because redundancy increases the ability to respond to disturbing factors and gives rise to higher resilience (Gunderson and Holling 2002). For instance, pastoralists decide when to start moving from one site to another depending not only on seasonal cycles, but also on weather conditions, rangeland status, and forage productivity both in the winter land and the summer land (Easdale 2015). If the impact of climate change differs among ecosystems, networks with higher ecological diversity have higher probabilities to experience more diverse situations of impact. Hence, a more diverse portfolio of adaptation strategies can be used or developed by pastoralists. These interactions should be tackled by future research. However, our results highlight some weaknesses in the transhumant pastoral strategy at a regional scale that may need further attention.

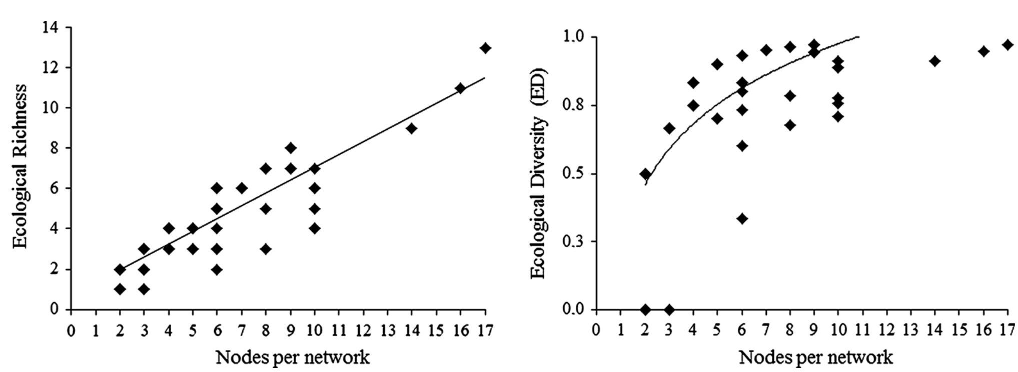

Fig. 4 Relationship between nodes per network and **a** ecological richness (number of regional ecosystem units linked by networks; $y = 0.64x + 0.68$, $r^2 = 0.84$). **b** Ecological diversity ($y = 0.32\ln(x) + 0.24$, $r^2 = 0.51$; see Eq. 1)

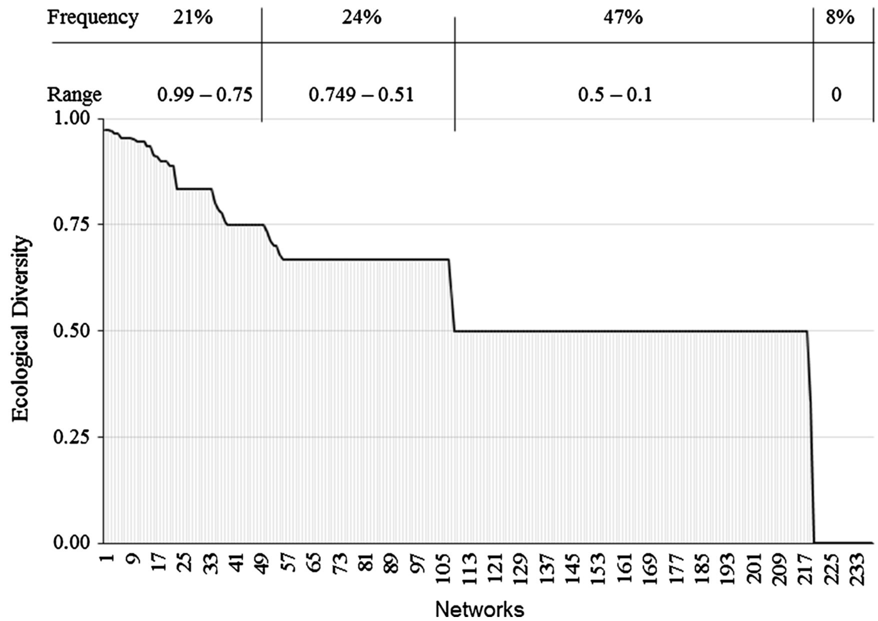

Fig. 5 Networks ordered by decreasing ecological diversity of connected nodes (see Eq. 1)

There is a regional structural rigidity trap in relation to landscape use that may reduce adaptation options (Carpenter and Brock 2008). One of the main features of transhumance is that both winter and summer lands are already established or occupied by each herder, meaning that grazing sites are generally the same for each household. The reasons for the current network topological simplicity may be complex and need a historical approach (Fig. 2). However, and given the traditional land use, network simplicity was driven at a regional scale by the impossibility for a given network to use or include another node within their structure, since all landscape units were occupied by a node from another simple network. This suggests that adaptations at a finer scale, as measured by household mobile pastoralism involving winter and summer lands, may promote vulnerabilities at a coarser scale, such as a structural rigidity due to limited land resources. For example, a desertification process affecting a summer land with a central position on a star network may impact on all the winter lands that are connected by the network. The low carrying capacity in the summer land due to degradation may increase stocking pressure on rangelands of the winter lands and promote further degradation in these sites. This transfer process in networks was described as a cascade effect (Motter 2004). The regional rigidity trap means that other summer lands are not available for grazing because they are already occupied. Hence, these types of networks are vulnerable to such processes, and policy making should consider this regional trap in the design of intervention programs.

Reconfiguration of networks was proposed as a potential solution to abort cascade effects (e.g., Motter 2004; Sahasrabudhe and Motter 2011). However, in the study region assessed here, it is not trivial and seems not to be an easy-to-implement alternative to reduce vulnerability to disturbances in social–ecological systems. This is due to limited land resources, but most importantly, the network reconfiguration implies land redistribution among social actors, which is a political and social challenge. Hence, intervention schemes should prioritized key nodes (e.g., nodes with high betweenness) in order to enhance overall network resilience. Such central nodes are reflecting not only key ecological and pastoral processes for overall network functioning, but also common land, in which local rules and agreements among herders may be defining and supporting management (Ostrom 1990). For example, some key nodes are common meadows or native forests, which are areas of high biodiversity (Alfonso and Prina 2009) that provide critical ecological services such as safe water and hydrological regulation. Some areas of these key nodes are dominated by fragmented populations of *Nothofagus* spp. with a high genetic diversity among the populations located in Argentina such as *Nothofagus obliqua* (Azpilicueta et al. 2013) and *N. antarctica* (Soliani et al. 2012). In addition, these key nodes are meeting areas where pastoralists exchange breeding (i.e., *criollo* goats), livestock products such as cheese or meat, textile, and leather handicrafts. Other social relations include collaboration among households in many productive activities (e.g., marking, shearing), logistics (e.g., travel to town), and social activities (e.g., *veranador* festival). Further research is needed to explore the roles of social relations in connecting and articulating the diversity of transhumant networks identified in this paper (Fig. 3). These interconnected networks may provide other social dimensions for adaptive capacity and resilience, which were not tackled by this study.

In relation to land use, the relative low connectivity among networks, as measured by the higher proportion of dyads than more complex networks, hinders contagion effects among them, but challenges governance systems at a regional scale. Policies that promote increasing individual land use (i.e., private land tenure) instead of fostering the current common lands (i.e., specially for summer lands) are hazard for this type of mountainous regions and mobile pastoralism (Rohde et al. 2006; Easdale and Domptail 2014). The main implications of increasing individualism are related to the loss of local institutions associated with common lands (i.e., weakness of social capital), increased biophysical and social disconnection, and hence more decentralization of landscape management. There are three potential consequences (or a combination of them) as a result of network fragmentation and a concurrent weakening of local social capital: (1) to be substituted by other regional institutions based on herders' participation, (2) a greater participation of the State in the regional pastoral management decisions and regulations, or (3) a complete regional decentralized management based on individual land-use herding (e.g., sensu Hardin 1968). The paradox of pasture land tenure proposes that pastoralists need both secure resource tenure and socially and spatially flexible patterns of resource use, since mobile pastoralism often requires diversity of habitats. From the lens of this perspective, the development of institutions to coordinate pastoral movements is recommended over formal tenure for different pasturelands (Fernández-Giménez 2002).

The increased individual land use may still keep transhumance as a main strategy (i.e., defined by the winter and summer lands), but might promote future increases in the relative proportion of dyads as a result of the fragmentation of more complex networks, which needs further attention (Fig. 3). Our results show that more complex networks are associated with higher ecological diversity (Fig. 4), with implications in adapted options as discussed above. Sedentarism is also said to be one of the main disruptive threats with biophysical and social consequences (Galvin et al. 2008). For instance, compulsory primary education is an encouraging State program in Argentina but based on fixation logics. Children and women stay near the towns or in the winter lands (where schools are located), in times when men move to the summer land (Pérez Centeno 2004; Easdale 2015). This process fragments the households and avoids knowledgeable transfer to the new generations. For these kinds of regions, policies should consider more flexible educational schemes such as mobile schools.

Management proposals and policy decision making should consider the spatial and temporal scales of transhumant pastoralism, in order to avoid scale mismatches (Guerrero et al. 2013). Scale mismatches have been defined as occurring when the scale of environmental variation and the scale of social organization with regard to management are misaligned in such a way that one or more functions of the social–ecological system are disrupted and/or important components of the system are lost (Cumming et al. 2006). Based on inferences from our analysis, we emphasize that regional development proposals should consider novel institutional designs (Fernández-Giménez 2002) that acknowledge the spatial and temporal connectedness promoted by transhumant networks, and consider that landscape management is highly decentralized. However, past and present institutional landscapes may constraint the development of new co-management initiatives (Sandström et al. 2014). We call for recognition of social and biophysical heterogeneous situations at local scales in order to identify weaknesses of the mobile strategy that otherwise would not be evidenced with approaches based on the comparison of productive, socioeconomic, or ecological attributes, without considering their interconnection.

Conclusions

The institution related to landscape management defined by transhumant pastoralism in the Andes was assessed with a network approach. We highlight that transhumant social–ecological networks integrate ecosystems, as measured by ecological sites represented by nodes (i.e., geographic dimension) and a social process determined by a mobile strategy as represented by linkages among nodes (i.e., network dimension). This analytical procedure can be applied to other similar regions worldwide. The main strength of this approach is the identification of different patterns of landscape management and their relations with the ecological heterogeneity. The results support the conclusion that most networks effectively seize opportunities from the highly heterogeneous environment. This approach provided evidences to identify critical nodes for the functioning of transhumant networks and to orient intervention programs. We emphasize that policy making should consider the spatial and temporal scales of these types of regions with mobile pastoralism. Policy design should avoid scale mismatches, fixation logics, and network fragmentation with a concomitant ecological diversity loss due to disconnection, which may reduce future adaptive capacity. Furthermore, intervention schemes should prioritize the ecological and social functions of key nodes in order to avoid cascade effects, acknowledging the regional rigidity trap identified in this study.

From an operative perspective, the main requirements of this network approach are the need for novel methodological definitions aimed at developing statistics of mobile pastoralism and the concomitant gathering of data related to movements (Krätli et al. 2015). First, data of pastoralism need a step toward a relational approach, which means that farming and households are also defined by their social relations rather than only by inherent socioproductive or biophysical features. Second, data collection needs time investment, and the fieldwork is not trivial in these kinds of regions because of the difficult access in many areas due to the lack of infrastructure in roads and communication, and harsh environmental conditions, which implies higher costs than sedentary livestock regions. Finally, this approach is more suited to address the proposed research questions than a purely social or ecological network analysis. However, it lacks deeper information in these both dimensions. Future research should integrate other ecological processes that may be influenced by connectivity and biological fluxes among fragmented ecosystems, such as energy and matter, or seed transportation between winter and summer lands. As well, social networks such as commercial, collaborative, or livestock exchange networks may help to better understand the role of other buffering strategies when pastoralists face threats that may affect mobility networks.

Acknowledgments We acknowledge the financial support provided by Instituto Nacional de Tecnología Agropecuaria (INTA-PATNOR 810262) and PIA 10059. We are very grateful to Luciano Mammoni and SENASA for their support with data and confidence on this study. We thank F. Umaña and F. Raffo for their help in an early stage of data processing. We strongly thank editors, with a special acknowledge to Dr. Diana Sietz and Dr. Giuseppe Feola, and two anonymous reviewers for their helpful suggestions that substantially improved this paper. Finally, we are very grateful to Helen Easdale for her careful proofreading and improving the readability of the paper.

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