Journal of Arid Environments xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Human-carnivore interaction in a context of socio-productive crisis: Assessing smallholder strategies for reducing predation in North-west Patagonia, Argentina

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ARTICLE INFO

Keywords:
Adaptive management
Command-and-Control
Husbandry practices
Network analysis
Socio-ecological systems

ABSTRACT

Mitigating carnivore-livestock interaction is essential to ensuring the persistence of carnivores in landscapes dominated by livestock activity. Our aim was to explore, in the context of social and productive crises triggered by environmental events, the values and attitudes adopted by smallholders in relation to wild carnivores. We performed semi-structured interviews on issues related to the management decisions of the productive system. To study the relative importance and associations among different factors, we constructed causal maps and used centrality measures based on network analysis to identify the dominant discourse. Although carnivores were perceived as one of the central problems of the map, retaliatory killing was not a central loss-prevention strategy. Smallholders turned to semi-intensification of livestock practices to increase the efficiency of their production as a response to different perceived problems. Lethal control techniques were weakly associated with a subsidized control system, which the state implements to stimulate the hunting of carnivores. Whereas policies were oriented to control native wild predators as the major source of disturbance, strategies of smallholders were based on adaptive responses to multiple perceived problems. This work provides new insights to improve the monitoring of mitigation measures to promote effective evidence-based policy.

1. Introduction

For decades the relevance of human-wildlife conflict has been recognised as a threat to biodiversity. Nevertheless, conservation biology is dominated by techniques associated with the ecology of the species involved (Dickman, 2010). In particular, human-carnivore conflict is a worldwide issue requiring policies aimed at managing both social and ecological pressures and interactions. Livestock production techniques should ideally adapt their socio-economic role to not only maximize production, but also to mitigate impacts on carnivore populations and their prey base (Treves and Karanth, 2003; Karanth and Chellam, 2009). The livestock sector emerges as one of the top two or three significant contributors to the most serious environmental problems, at every scale from local to global (Steinfeld et al., 2006). However, lethal control to reduce livestock depredation is the main cause of the decrease and extinction of many carnivore populations (Treves and Karanth, 2003; Baker et al., 2008; Inskip and Zimmermann, 2009; Karanth and Chellam, 2009). Scientific literature is mainly dominated by conflict situations within protected areas and along their borders, especially when endangered carnivores are involved (Inskip and Zimmermann, 2009, Fourvel and Mwebi, 2011; Hazzah et al., 2014; Aryal et al., 2014, 2015). Mitigation strategies affecting non-threatened, common or abundant carnivores in agricultural landscapes have been less explored (Carter and Linnell, 2016). On the other hand, analyses focusing on competing factors (i.e. social, economic, environmental) driving perceptions and attitudes of smallholders toward carnivores are rare, in spite of their importance for subsistence economies and policy development programs (Dickman, 2010; Marchini and Macdonald, 2012; Carter and Linnell, 2016; Khanal et al., 2017; Panthi et al., 2017). Different environmental scenarios could modify producers' perceptions of their socio-ecological systems, and even predation mitigation practices can be adapted to specific or local cases (Baker et al., 2008; Carter and Linnell, 2016; Aryal et al., 2017).

Traditional action policies are still based on an oversimplification of

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https://doi.org/10.1016/j.jaridenv.2017.12.005
Received 5 July 2017; Received in revised form 7 December 2017; Accepted 11 December 2017

the complexity of human-carnivore impacts (Aryal et al., 2016). In that way, carnivore management is frequently dominated by the logic of command-and-control management policies (i.e. linear relation between carnivore abundance and predation damage; Holling and Meffe, 1996). Various assumptions around human-carnivore impacts were formulated as shown in Dickman (2010): (a) damage level depends on the abundance of carnivores; (b) there is a linear relationship between the perceived level of damage by predation and the attitude of farmers towards carnivores; and (c) the socio-economic status of farmers is inversely proportional to the level of hostility in response to the damage inflicted by carnivores. Subsistence farmers would be more aggressive than commercial farmers (Romañach et al., 2007; Dar et al., 2009; Hazzah et al., 2009; Aryal et al., 2012a,b, 2014; Bista and Aryal, 2013). As a result of these assumptions, the oldest and most widely applied approach is lethal control of wild and feral carnivores. However, this practice is usually ineffective in reducing the conflict of livestock mortality due to predation (Berger, 2006; Treves et al., 2016). Command-and-control policies frequently promote linear responses to complex problems. They focus on external drivers (e.g. population dynamics, reproductive potential) in an attempt to reduce variability and increase productivity of systems. Nevertheless, many systems have expressed distress in response to the natural resources management: reduction of the natural variability of the system results in a concomitant loss of resilience to external disturbances (Holling and Meffe, 1996).

Facing the impact of predation, decision making by farmers is the result of multidimensional processes (Vanclay et al., 2006; White et al., 2009; Fairweather, 2010; Liu et al., 2011). Social, economic, cultural and environmental aspects interact at different spatial and temporal scales, influencing mental models, perceptions and decisions (Vanclay et al., 2006; Liu et al., 2011; Easdale and Domptail, 2014). Cognitive mapping can make explicit social perceptions and discourses in relation to their farming systems, the interactions among different internal and external factors, and their influence or relationships with management decisions. Understanding these interactions is fundamental to promoting changes in management practices (Özesmi and Özesmi, 2004; Fairweather, 2010; Fairweather and Hunt, 2011) and improving policies on socio-ecological issues (Carter et al., 2012; Domptail et al., 2013). A wildlife management framework should reduce livestock loss and facilitate coexistence with large carnivores. Therefore, mitigation response variables of further studies should directly measure these outcomes. Without such evidence, the capacity for management change is hindered, affecting both human livelihoods and the conservation of large carnivores (Van Eeden et al., 2017). For example, rising expenses in the population control of coyotes (*Canis latrans*) has not resulted in an improvement in the sheep industry, which is more influenced by market prices and production costs (Berger, 2006).

Between 2007 and 2012, the effects of a severe and long-lasting drought coincided with the abrupt deposition of volcanic ash from the eruption of the Puyehue-Cordón Caulle complex in northwestern Patagonia, Argentina. In Río Negro province, the combined effect of the drought and eruption caused a significant reduction in livestock production and, due to the widespread death of livestock, a socially and economically stressful situation (Easdale and Rosso, 2010; Easdale et al., 2014). Since 1972, in Río Negro, law 763 *"fight against wild animal populations circumstantially harmful to livestock"* (Law 763/72, from now on) has been enforced. This law established the creation of a fund for incentive payments, for the lethal control of pumas (*Puma concolor*) and culpeo foxes (*Lycalopex culpaeus*), US$ 170.0 and US$17.0 per hide, respectively. The fund is financed through a tax on the transport and commercialization of livestock products and is administered by the Ministry of Production of Río Negro. This provided a unique scenario within which we could assess whether a policy based on command-and-control logic (subsidized predator control) was effective for standardizing the behaviour of farmers (motivating lethal control) in a situation of disturbance (caused by drought and volcanic ash fall).

The aim of this study was to analyze the perceptions of smallholders in relation to livestock production loss and the strategies they adopted in the context of a severely stressful socio-productive situation in the region of northwestern Patagonia, Argentina. We also aimed to assess whether the predation mitigation strategies adopted by smallholders were aligned with the policies based on command-and-control logics. We seek to find the main perceived problems and the strategies adopted by smallholders to mitigate predation damage, and their relative importance regarding other identified problems and management strategies.

Considering the key assumptions of human-carnivore impacts, we hypothesized that (a) smallholders would perceive predation as one of the most relevant problems affecting their livestock, and (b) their main strategy to reduce predation damage would be associated with some kind of lethal control to reduce losses.

2. Methods

2.1. Study area

The study was carried out in a rural zone of Pilcaniyeu county, Río Negro province (−70.72191,-41.12280), situated in northwestern Patagonia, Argentina. This area is located in the Andes piedmont, which has a strong west-east annual rainfall gradient from 800 mm to 300 mm, respectively, concentrated in the winter. The average annual temperature is 8 °C. The plant community is characterized by grass-shrub steppes, dominated by *Festuca pallescens*, *Pappostipa speciosa, Poa ligularis, Mulinum spinosum* and *Senecio* spp. (Leon et al., 1998). Extensive livestock farming, predominantly sheep raising, is the main economic activity in this region. Culpeo fox predation was reported to be the second most important cause of mortality in lambs in perinatal periods and was described as the main cause of mortality in 7 to 60-days-old lambs (Bellati and Von Thüngen, pers. comm.). The landscape encompasses patches managed by smallholders (< 5000 ha) interspersed with bigger areas owned by large sheep ranchers (> 10000 ha; Easdale pers. obs.). The large ranches are dedicated mainly to raising Merino sheep for the wool market. Although the sale of wool is also the main source of income for the smallholders, their systems tend to be more diversified. Other species, such as Angora goats and cross-bred cows, are also key to their livelihoods (Easdale and Rosso, 2010; Villagra et al., 2015). From 2007 to 2012, precipitation dropped to between 33 and 29% of the annual historic mean (444 mm; Easdale et al., 2014), leading to a prolonged drought. In June 2011, the Puyehue-Cordón Caulle complex (Chile) erupted, affecting the Pilcaniyeu County with the ash fall. As a result, a 1.5–5 cm layer of ash covered the area (Gaitán et al., pers. comm.). The volcanic ash severely reduced foraging availability, also producing multiple sanitary problems such as tooth wear, digestion disorders and even death owing to inaccessibility to water (i.e. water bodies were covered with ash; Robles et al., pers. comm.).

We defined the study area by restricting it to a zone with homogenous climatic and floristic conditions. We used GIS to superimpose cadastral layers, vegetation, georeferenced housing units and volcanic ash distribution (Gaitán et al., pers. comm.). Within the zone severely affected by ash deposits (ash layer greater than 3 cm, Fig. 1), we defined a patch dominated by smallholders. We decided to concentrate on smallholders because they are the most vulnerable to extreme environmental events (Morton, 2007). The identified patch had a total surface area of 36,636.0 ha, which contains 50 ranches (average area: 678.0 ha, range: 50–3000 ha).

Fourteen personal interviews were conducted with randomly selected smallholders, with 28% of the total smallholder population surveyed. In each case the study objectives were declared and interviews were carried out once participants provided their consent. All selected individuals agreed to participate. Interviews were performed by one individual (P. Gáspero) in Spanish and employed local terms to

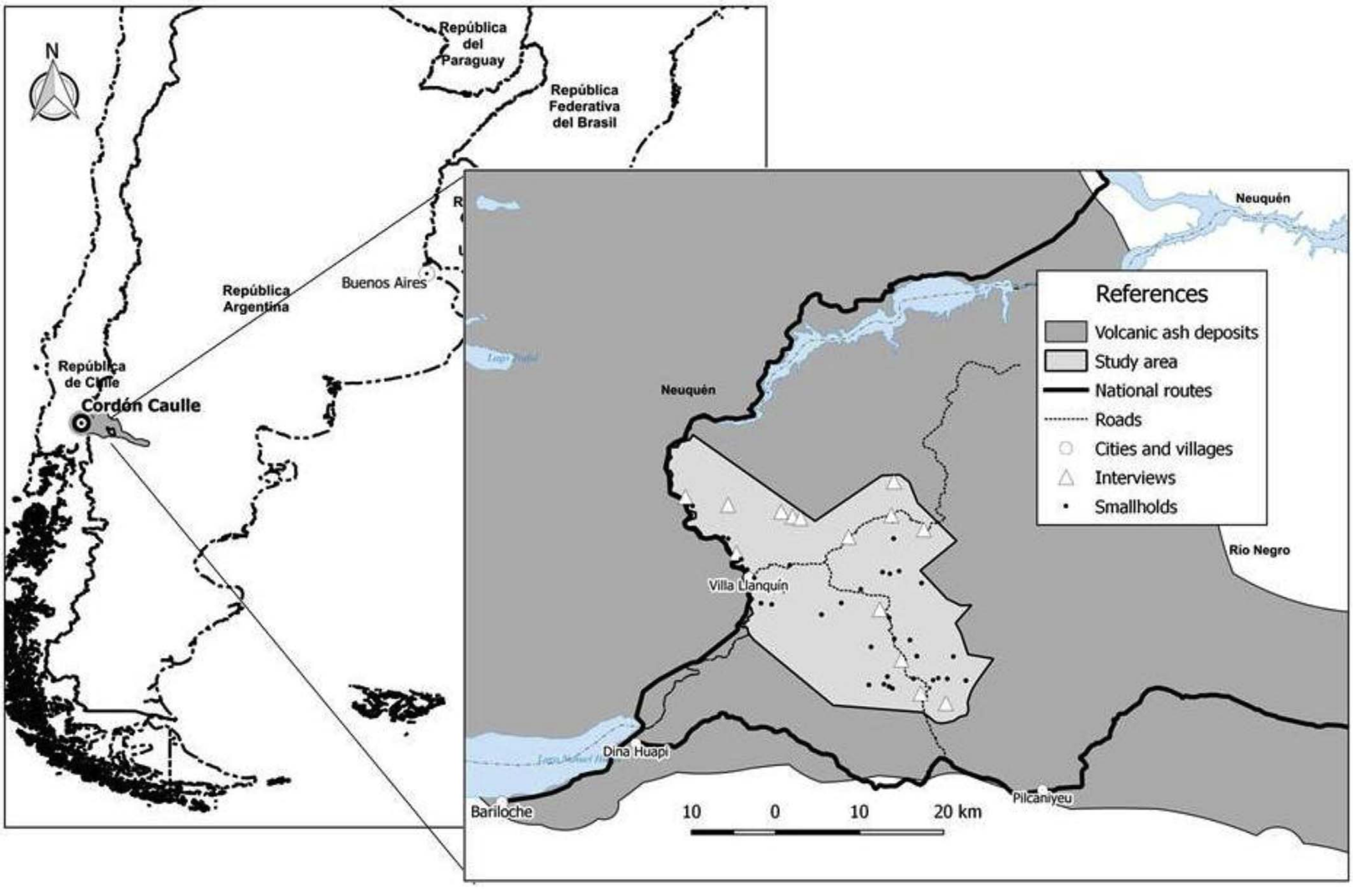

Fig. 1. Location of the study area in reference to the Puyehue-Cordón Caulle volcanic complex and the area severely affected by the volcanic ash (deposits of more than 3 cm thickness).

facilitate comprehension of the questions (e.g. rewards, to allude to the state incentives for lethal carnivore control). Interviews took place in family homes in the presence of all family members found there at the time, but questions were directed at the decision-makers responsible for livestock management. Besides the information associated with livestock management and causes of mortality, we inquired about other complimentary socio-economic aspects (e.g. age, existence of sources of income other than livestock, area and ownership of land).

2.2. Survey and data processing

Collective discourses and mitigation strategies of predation were analyzed by applying graph theory and the construction of a causal map, upon which we performed a network analysis. The collective map was generated from individual perceptions and management strategies (Özesmi and Özesmi, 2004; Fairweather, 2010) that were collected through semi-structured interviews (Fig. 2).

To design the interviews, literature related to Patagonian farm systems and regional human-carnivore conflicts was reviewed. A total of 28 relevant factors were defined and grouped into six a priori categories: i) livestock management, ii) causes of livestock losses, iii) non-lethal predation mitigation, iv) lethal predator control, v) rewards and vi) type of production system. Participants were consulted concerning the presence/absence ("yes/no") of each factor and for each category were asked about the presence of other factors that were not found within the options. Regarding livestock management, a distinction was made between the varied mobility regimes and the level of grazing system intensification. One of these regimes is transhumance, where part or all of the family engaging in predictable seasonal movements of livestock between grazing areas. This is in contrast to sedentary systems (i.e. families are established in the same housing unit during the entire

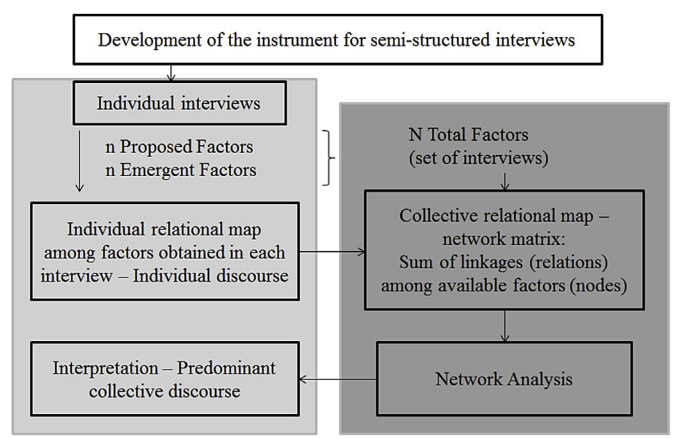

Fig. 2. A scheme with the sequence of the performed methodological steps. White box identifies early steps of the study, light grey box identifies steps based on qualitative procedures and dark grey box identifies steps based on quantitative procedures.

year and the grazing flocks are limited to one productive unit), where we differentiate between extensive systems (i.e. flocks graze without any human intervention or external inputs of fodder), paddock rotation (i.e. seasonal or periodical movement of flocks to allow for pasture recovery), night-time enclosures (i.e. confining flocks during the night in a pen near the family home) and forage supplementation (i.e. external inputs of fodder, commonly hay, to counter the low availability of fodder from natural grasslands) (Fernandez-Gimenez and Le Febre, 2006; Easdale and Domptail, 2014). Regarding the non-lethal methods of predation prevention, participants were asked about the use of livestock-guarding dogs (LGDs from now on; González et al., 2012) and

Table 1
Complimentary information regarding livestock stock before and after the ash deposition and perceived damage from predation. References. n*: Quantity of systems with herds of sheep, goats or cows. Mean[1]: Average perceived damage per carnivore and livestock species, considering only participants who perceived losses from predation.

	Herd size					Perceived wild carnivores predation damage			
	n*	Before eruption		At the survey		Puma		Culpeo fox	
		Mean	Range	Mean	Range	Mean[1] (%)	Range (%)	Mean[1] (%)	Range (%)
Sheep	10	260.0	40–400	92.0	10–270	3.2	0–14.0	9.0	0–43.3
Goats	6	110.0	10–300	75.0	10–160	–	–	7.2	0–28.9
Cows	7	42.9	10–110	25.4	3–70	–	–	–	–

daily patrols (i.e. a shepherd that supervises the flock while they graze during the day).

To obtain additional information on the relative impact of ash deposits and drought, participants were asked about the quantity of livestock before the eruption and at the time of the interview. In addition, participants were asked about their perceptions of losses to predation during the last 12 months, as well as how they described the attacks and how they identify the predators. All of the participants correctly described the attack pattern of the predators. In two cases, the participants described suffering losses to wild carnivores, but could not specify how many livestock they had lost. All participants responded to the presence/absence questions for each listed factor. Of the initial predefined 28 factors, five of them were absent in the discourses and three factors that were not initially considered emerged from the interviews. Thus, 26 factors were used for the construction of the collective mapping and further analysis (Table 2). The connections among factors were defined by a 26 × 26 matrix, with binary relationships among them (1 = related; 0 = unrelated) that represented an individual discourse obtained from the individual interviews. The collective discourse was summarized in a general matrix that represented the collective mapping (i.e. the sum of all individual interviews). This general matrix was used to perform a network analysis, in which the factors represented the nodes and the connections among factors the relations or linkages. Topological centrality indicators that described the relative importance of each factor in the network were selected: node degree, betweenness and closeness (Freeman, 1979). Degree is the number of direct links from each node. The nodes of higher degree are more active since they have the highest number of relationships with other network nodes. Betweenness is the number of times that a node acts as a bridge along the geodesic paths between two nodes. Closeness is the geodesic distance from one node to the remaining ones, which can be estimated by direct links or mediated by other nodes (Wasserman and Faust, 1994). A core-periphery analysis was performed based on geodesic distances among all nodes in order to determine the dominant factors from which all nodes were interconnected (Borgatti and Everett, 1999).

3. Results

In 93% of cases, management decisions were made by the most experienced men in the family. With the exception of one elderly couple subsist on their pensions and farm production (poultry and orchard). The average age of participants was 59.3 ± 14.3 years (range: 23–83 years), all native and permanent residents of the zone. Of the producers, 50.0% were located on public land. The average area of each property was 1005.0 ± 986.5 ha (range: 50–3000 ha), three participants did not know the dimensions of their productive land. With respect to the sampled families, 85.7% complimented their income through external sources: pensions (64.3%) and occasional off-farm work (21.4%). Only 14.3% of families sustained themselves exclusively with income and products generated by livestock. The reduction of stock, following the eruption and drought, principally affected sheep (57.9%; range: 0–98.0%; Table 1), cattle (38.8%; range: 0–46.7%; Table 1) and, to a lesser extent, goats (18.9%; range: 0–46.7%; Table 1).

Table 2
Frequency of each factor (quantity as recognised by participants, responding "Yes" to the presence of *i* factor in their productive systems) and results from network analysis, showing centrality indicators and core factors.

Questions and Factors	Frequency	Degree	Betweeness	Closeness
Which livestock management practices do you implement? (Yes/No)				
Extensive	2	10	0.4	55
Night-time enclosure [a]	7	19	14.3	46
Plot rotation	4	14	5.6	51
Supplementation [a]	6	18	11.8	47
Transhumance	1	4	0.0	61
Which factors generated livestock losses in the last 12 months? (Yes/No)				
Starvation due to drought [a]	7	21	23.9	44
Starvation due to volcanic ash [a]	14	25	40.7	40
Hypothermia	1	6	0.0	50
Wild carnivores [a]	9	23	30.3	42
Feral dogs	1	7	0.0	58
Theft [a]	6	15	4.0	50
Have you applied a non-lethal technique to avoid predation during the last 12 months? (Yes/No)				
Daily patrol [a]	8	21	19.2	44
Guard llamas	1	7	0.0	58
Cowbell	1	7	0.0	58
Early weaning	1	7	0.0	58
Have you employed a form of lethal control of predators during the last 12 months? (Yes/No)				
Trapping	3	14	2.1	51
Direct persecution	2	11	0.9	54
Opportunistic hunt	1	8	0.0	57
Poison	4	15	6.1	50
Have you claimed "rewards"? (Yes/No)	1	8	0.0	57
What species of livestock raised? (Yes/No)				
Sheep	2	7	0.2	58
Goat	1	8	0.0	57
Cattle	1	6	0.0	59
Sheep-Goat	3	13	1.7	52
Sheep-Cattle	4	14	5.5	51
Sheep-Goat-Cattle	2	8	0.5	57

[a] Central factors obtained from the core-periphery network analysis.

Starvation due to volcanic ash, predation by wild carnivores, daily herd patrol and drought were the nodes with the highest degree (Table 2). Predation from wild carnivores, theft and starvation due to drought and volcanic ash were the main perceived causes of livestock losses. The strong relationships between starvation due to ash deposits and wild carnivores, and between mortality due to drought and starvation due to ash deposits suggest an interaction among these different drivers (Fig. 3). The most representative livestock management strategies were night-time enclosure, daily patrol and forage supplementation, which constituted the core-nodes of the network (Fig. 3). Daily patrols were related to animal theft, and together with night-time enclosures, both strategies were mostly related to preventing starvation

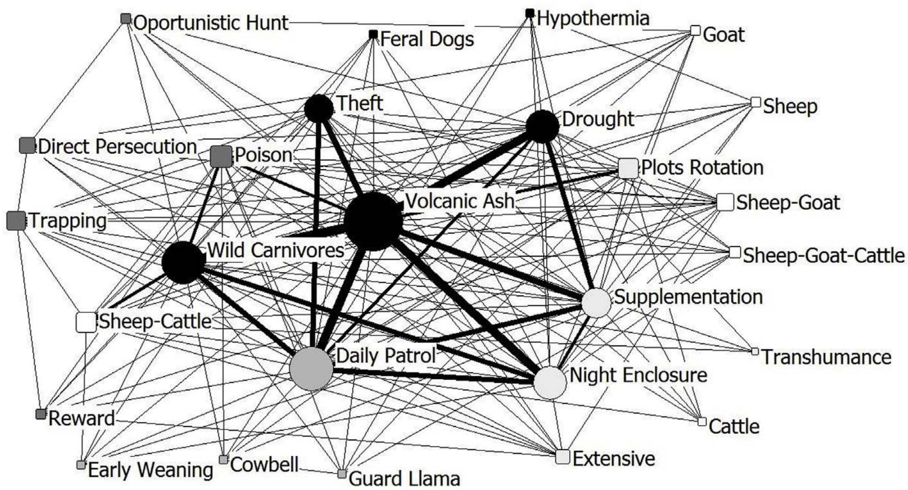

Fig. 3. Cognitive mapping representing the collective discourse of the interviewed smallholders. References: circular nodes: core factors; square nodes: periphery factors; links' thickness: relative intenseness of association between factors; white nodes: type of livestock system; light grey nodes: livestock management; black nodes: causes of livestock mortality; grey nodes: non-lethal predation mitigation; dark grey nodes: lethal predator control and rewards.

(due to ash deposits) and wild carnivore attacks. Forage supplementation was strongly associated with drought and ash deposits, indicating a management response to animal nutritional deficiencies. The most relevant lethal strategy was the use of poison, whereas lethal control of carnivores and rewards were not significant factors (Table 2; Fig. 3).

The five candidate factors that were not mentioned by interviewees were: infectious and parasitic diseases, and metabolic disorders like intoxication (as other causes of livestock losses), use of livestock guard dogs (as non-lethal predation mitigation) and goat-cattle production systems. The emerging factors were guard llamas, use of cowbells and early lamb weaning (non-lethal mitigation of predation).

4. Discussion

In concordance with our first hypothesis, predation by wild carnivores was perceived as an important factor in the loss of livestock. Factors at the center of collective causal models from smallholders around their production systems in Patagonia were starvation arising from the volcanic ash and drought events of 2011, daily herd patrol, predation by wild carnivores, livestock theft, sheep and goat night-time enclosures, and forage supplementation. The interaction among environmental drivers, such as volcanic ash deposits, predation and drought concurred with the expected causes of socio-productive crisis. In this context, we expected to find strong hostility toward predators. However, contrary to our second hypothesis, smallholders did not use hunting modes as their main strategy to reduce predation damage. Instead they sought to increase management response options aimed at preventing starvation and predation losses, by means of forage supplementation, night-time enclosures and daily patrols.

Volcanic ash deposits clearly dominated smallholders' perceptions as the main disturbance. Even though the event occurred at the same time as a drought process that began in 2007, the shock produced by the mass mortality of livestock may have homogenised the perceptions of participants. The responses of producers to volcanic events have been poorly documented and their variation in terms of intensity, duration, extent and the physiochemical composition of pyroclastic material make comparisons difficult (Easdale et al., 2014). For example, the eruption of the Hudson volcano (Chile) in 1991 produced a layer of ash 1–8 cm deep across approximately 100,000 km^2 of steppe in the province of Santa Cruz, in the extreme south of Argentinian Patagonia (Oliva et al., pers. comm.; Wilson et al., 2012) This region was dominated by large holdings of extensive sheep breeding. The inability to concentrate the livestock and provide forage supplements to avoid starvation, dehydration and a lack of State financial assistance to mitigate losses led to permanent abandonment of 80% of the livestock farms (Wilson et al., 2012).

Although no lethal control methods were part of the center of the network, poisoning was the most commonly used method in our study area, which also occurs in other sites of Patagonia and other regions of the world (Greentree et al., 2000; Travaini et al., 2000; Lambertucci, 2010; Mateo-Tomás et al., 2012; Cano et al., 2016). In the four cases where poison use was admitted we tried to investigate the subject in greater depth. When asked about which product was used, participants responded uncertainly, as since it's an illegal practice poisons are sold informally, distributed in small containers and without labels. One interviewee mentioned "Strychnine", another "Carbofuran" and the remaining two didn't know the name of the product. Strychnine has been illegal in Argentina since 1990 and the use of Carbofuran is restricted to agricultural crops. The majority, 3 out of 4 cases, applied the poison by injecting it into eggs or small pieces of meat that are placed in areas frequented by culpeos. In the remaining case it was applied by scattering the poison directly over the carcasses of lambs that were hunted by culpeos. This method is particularly risky for birds and other scavengers species (Koenig, 2006). All stated that it was used for the lethal control of culpeos, although two cases recognised that this affected non-target species, mentioning the southern caracara (*Caracara plancus*), chimango caracara (*Milvago chimango*) and black-chested buzzard eagle (*Geranoaetus melanoleucus*). The indiscriminate use of poison particularly affects scavengers birds (Koenig, 2006), and is considered one of the principal threats to such emblematic species as the Andean condor (*Vultur gryphus*) (Lambertucci, 2010). Thus the use of poisons is frequently associated with exacerbated and unjustified levels of hostility (Travaini et al., 2000). However, it is possible that in the context of decapitalization producers who used poison perceive that predation threatens family support (Hazzah et al., 2009). It is also likely that the use of poison is independent of the impact of predation and is a practice rooted within part of the rural population (Gáspero, pers. obs.). This may be due to those that use poison generally considering it the most effective means of controlling predators (Buys, 1975; Travaini et al., 2000; Glen et al., 2007; Mateo-Tomás et al., 2012).

Aggression towards carnivores should not be associated linearly with the level of dependence on livestock. Smallholders often use traditional practices that reduce the vulnerability of livestock from predation, e.g. night-time enclosures and people supervising the pasture during the day, LGDs, audio or visual deterrents (Ogada et al., 2003; Woodroffe et al., 2007; González et al., 2012; Carter and Linnell, 2016; Amit and Jacobson, 2017). Furthermore, the role of external income sources as a means of favouring adaptation to situations of disturbance shouldn't be disregarded (Easdale and Rosso, 2010; Wilson et al., 2012). The availability of these incomes would allow for a reduction in pressure on natural resources (grassland) and invest in supplies that diminish the vulnerability of livestock (i.e. hay, materials for pens, sheds and electric fences; Easdale and Rosso, 2010; Sapkota et al., 2014; Aryal et al., 2017).

Social systems with higher levels of organization (state or communities) frequently implement controlling actions to a much greater degree than at individual decision levels (smallholder or household; Domptail et al., 2013). Smallholders perceived a complex interaction of different factors affecting their livestock systems simultaneously. Hence their actions tended to prioritize management adaptations as responses to a variety of disturbance factors, which may improve resilience at a socio-ecological level (Olsson et al., 2004; Leach et al., 2010). Abundant evidence on this subject (adapting people to the presence of wildlife) has deepened the debate over the term human-wildlife conflict or, in this case, livestock-carnivore conflict (Ogada et al., 2003; Woodroffe et al., 2007; Redpath et al., 2015; Carter and Linnell, 2016). Management policies that promote the control of predators focus on the individual problems of cause and effect logic (i.e. lethal control to reduce predation). Consequently, since policy design is decoupled from individual actions, the synergistic impact of different levels of action is reduced and there is no direct effect on the activity that sustains small producers, i.e. their livelihoods (Easdale and López, 2016).

The management policies for carnivores should be coupled with livestock promotion policies and a consideration of the needs of producers in socio-environmentally vulnerable situations (Easdale and Rosso, 2010). In a pastoralist economy, production does not play a financial role, but functions rather as a livelihood to support domestic needs (Shanin, 1973). In such cases, a reward probably does not constitute a contribution to fulfilling this role, generating disinterest or even rejection of the rewards scheme. For example, one of the interviewees referred to the Río Negro argentinean province Law 763/72 as a "fox tax", alluding to their dissatisfaction with not receiving significant damages for predation, despite that when selling their products the State retains a percentage from wool sales (US$ 0.01/kg wool), destined for the reward payment fund which is then not used. We consider that it would be more appropriate to implement adaptive co-management policies that accompany the processes of livestock farmers (Carter and Linnell, 2016) and facilitate their participation in the decision-making structures at higher organizational levels (Olsson et al., 2004; Armitage et al., 2009; Sapkota et al., 2014; Aryal et al., 2017).

To increase the resilience of socio-ecological systems it is necessary to approach with a consideration of all of their dimensions (Holling and Meffe, 1996). We propose using state resources, as established in Law 763/72, to strengthen social capital (i.e. producer cooperatives and associations) through participatory work and institutions for technical assistance (Armitage et al., 2009; Easdale and Rosso, 2010). In socio-environmentally vulnerable and remote systems, co-management can prove a mechanism that permits indirect intervention in other subsystems (Easdale and Domptail, 2014; Easdale and López, 2016): environmental capital (adjust livestock loads to available fodder; Aryal et al., 2014), cultural capital (promote changes in practices rooted in the rural population such as poison use), productive capital (incorporate low-cost practices, for instance improving pens by building sheds -Villagra, 2002; Aryal et al., 2014-, and introducing visual and audio deterrents -Ogada et al., 2003; Woodroffe et al., 2007-, incorporating mixed-breed LGDs in the smallholdings -González et al., 2012; Novaro et al., 2017-, or pure-breed LGDs for producers with more capital -Van Bommel, 2010), economic/financial capital (generate improvements in the prices of supply purchases and sale of products, through joint marketing -Easdale and Rosso, 2010-, or adhering to quality certifications -Easdale and Domptail, 2014) and human capital (reduce socio-environmental vulnerability sustaining the pensions system or promoting other sources of income diversification -Easdale and Rosso, 2010; Aryal et al., 2014).

5. Conclusion

Although predation by wild carnivores was perceived as a relevant problem, the payment of lethal control incentives has failed to homogenise smallholders behaviour towards wild predators. We expected that the crisis caused by ash deposition and drought would have created a hostile situation, resulting in a linear reaction towards predation. However, in the context of environmental and productive stressors, smallholders' actions tended to prioritize management adaptations as responses to a variety of problems. This situation calls for the redesign and promotion of flexible integrated co-management policies to better tackle human-carnivore interactions in these kinds of regions. We propose that state interventions aim to strengthen social capital (i.e. cooperatives) as a means of increasing the resilience of socio-ecological systems to variability and environmental disturbances.

Acknowledgements

We thank Bidau, C., Scognamillo, D. and Serrano, S. for discussing our work at different developmental stages. We thank Taylor, J. for your contributions and corrections. To the anonymous reviewers and to Dr. Liora Horwitz. This work was financed by grants PATNOR-1281102, PATNOR-1281103 and PNNAT 1128053.

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