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El Niño Southern Oscillation drives conflict between wild carnivores and livestock farmers in a semiarid area in Chile

G. Acosta-Jamett [a, *], J.R. Gutiérrez [b], D.A. Kelt [c], P.L. Meserve [d, e], M.A. Previtali [f]

[a] Instituto de Medicina Preventiva Veterinaria y Programa de Investigación Aplicada en Fauna Silvestre, Facultad de Ciencias Veterinarias, Universidad Austral de Chile, Valdivia, Chile
[b] Universidad de La Serena, Facultad de Ciencias, CEAZA, Casilla 599, La Serena, Chile and Instituto de Ecología y Biodiversidad, Casilla 653, Santiago, Chile
[c] Department of Wildlife, Fish & Conservation Biology, University of California, Davis, CA, 95615, USA
[d] Department of Biological Sciences, Northern Illinois University, DeKalb, IL, 60115, USA
[e] Department of Biological Sciences, University of Idaho, Moscow, ID, 83843, USA
[f] Departamento de Ciencias Naturales, Facultad de Humanidades y Ciencias, Universidad Nacional del Litoral, Santa Fe, Argentina

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ABSTRACT

The warm phase of El Niño-Southern Oscillation (ENSO) events results in greatly elevated rainfall in north-central Chile, with dramatic effects on small mammals and vertebrate carnivore abundances. In ensuing cool phases of ENSO, plant cover decreases, followed by small mammal densities, in turn affecting the resource availability for their predators. Wild carnivores such as foxes are one of the main predators of small mammals; when the latter decline, foxes could exhibit functional responses, increasing their consumption of domestic livestock. To our knowledge, the influence of native prey abundance on livestock predation has not been assessed. We hypothesize that periods of scarce native prey increases conflicts between carnivores and farmers outside protected areas, especially during drought years. From 1990 to 2005 we used live trapping to determine monthly density of small mammals in a national park (Bosque Fray Jorge National Park, BFJNP) in north-central Chile; rainfall was also monitored. We calculated an index of predation as the number of sheep predated by foxes annually on one farm (encompassing ca. 45,000 ha) located in the vicinity of BFJNP. Path analysis was carried out to assess factors influencing sheep predation by wild foxes. Factors included precipitation and small mammal density. Small mammal density correlated positively with two years moving average of rainfall. Sheep predation by foxes increased after of two years of low rainfall. Our findings suggest that wild carnivores employ functional responses in response to varying prey availability, shifting from wild to domestic prey during periods of drought, which could have important conservation and management implications.

1. Introduction

Carnivores can respond both functionally and numerically to fluctuations in the prey base (Carbone and Gittleman, 2002). The capacity for wild carnivores to adapt to anthropogenic landscapes depends on behavioural plasticity of each species within the modified environment (Cardillo et al., 2004). In such conditions, carnivores may shift from natural to domestic prey (Stoddart et al., 2001). In this scenario, predation upon livestock by carnivores should be perceived as a functional response to the reduction in natural prey, which otherwise may act as a buffer against livestock predation by carnivores; however, in spite of the fact that predation upon livestock has been reported for a number of carnivore species worldwide (Butler, 2000; Holmern et al., 2007; Kolowski and Holekamp, 2006; Ogada et al., 2003; Patterson et al., 2004; Woodroffe et al., 2005), very few empirical studies have analysed this hypothesis (eg. Sacks and Neale, 2007; Stoddart et al., 2001).

In semiarid ecosystems, the density of the most common prey for carnivores (small mammals) usually is driven by factors such as precipitation (Previtali et al., 2009), which impact resource availability for prey populations. Some authors have indicated that extreme variation in weather patterns may induce a reduction in wild prey, resulting in variation in predation success and inducing a shift from wild to domestic prey (Butler, 2000; Kolowski and Holekamp,

* Corresponding author.
E-mail address: gerardo.acosta@uach.cl (G. Acosta-Jamett).

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2006; Patterson et al., 2004; Woodroffe and Frank, 2005). At least some studies have documented that wild carnivores are more likely to attack livestock during the dry season or during years of drought (Butler, 2000; Patterson et al., 2004; Sacks and Neale, 2007).

The north-central region of Chile is semiarid and highly dependent on rainfall. In this area, large rainfall events that occur during the warm phase of the El Niño Southern Oscillation (ENSO) result in increased primary productivity, especially by ephemerals (Gutiérrez et al., 2000; Meserve et al., 2003). Following this vegetative response, small mammal numbers increase in response to the abundance of food resources (Meserve et al., 2003), and predators subsequently increase as well (Farías and Jaksic, 2007; Previtali et al., 2009).

North-central Chile supports a number of terrestrial predators, including one skunk (the chingue, *Conepatus chinga*), a mustelid (the quique, *Galictis cuja*), two wild felids (the colocolo, *Leopardus colocolo*, and the puma, *Puma concolor*), and two wild canids (the culpeo, *Lycalopex culpaeus*, and chilla, *L. griseus*). Most of these species are rare or at best uncommon and very localized; the two foxes are locally or regionally common. The culpeo is the larger of these and weighs between 4 and 14 kg while the chilla fox weighs between 2 and 5 kg (Jiménez and Novaro, 2004). These foxes are opportunistic predators that hunt prey according to their availability in the environment, consuming mainly small mammals (Johnson and Franklin, 1994) and occasionally livestock species in areas near human settlements (González del Solar and Rau, 2004; Pía et al., 2003). Likely reflecting size-dependent hunting abilities, chillas mainly forage on poultry, while culpeos can hunt on larger animals such as lambs and goats (González del Solar and Rau, 2004; Jiménez and Novaro, 2004).

Across four regions of Chile farmers reported that they lost about 10% of their sheep and lambs to predation by wild carnivores (mainly puma and culpeo fox) (Acosta-Jamett et al., 2014). Understanding whether this conflict is increased during different seasons or years, such as during droughts, would be useful to promote measures to avoid the attack of wild carnivores on livestock and thus help farmers to reduce their economic losses. We posit that wild carnivores living in an anthropogenic landscape may be more affected by climate-related nutritional restrictions than animals living in more natural areas, and may be more likely to attack livestock (Pía et al., 2003).

If the above proposition is true then human-wildlife conflict, in the form of predation on livestock, is expected to vary temporally in semiarid regions of north-central Chile, in turn reflecting on the dependence of wildlife in this region on precipitation driven by the ENSO phenomenon. We predict that during periods of prolonged droughts, when small mammal abundance is extremely low, foxes would search for alternative prey, such as exotic mammals (e.g., rabbits, rats), refuse, and livestock. In contrast, in wetter years, predation pressure on livestock would be attenuated as foxes resume foraging on native prey. Given this background, we tested for a link between rainfall and/or prey on reports of livestock predation in a semiarid environment in the Coquimbo Region of Chile. We focus our attention on culpeo foxes as they are one of the most important predators on goats and sheep in Chile (Acosta-Jamett et al., 2014), and they are widespread throughout this region.

2. Methods

2.1. Study area

The study area is the Coquimbo Region in north-central Chile (71° 12′ to 71° 40′ W, 29° 58′ to 30° 39′ S), comprising about 1600 km^2 and including Bosque Fray Jorge National Park (BFJNP) with a surface of 9959 ha and the "El Tangue" ranch, a private land of nearly 45,000 ha situated 25 km north of the park (Fig. 1). Historically, the vegetation of much of the region was a thorn shrub community characterized by spiny drought-deciduous and evergreen shrubs, with a herbaceous understory (Gajardo, 1994); however, except for within BFJNP, most of this has been replaced by badly overgrazed shrubland and plantations of exotic *Atriplex* spp. planted to ameliorate erosion and restore shrub cover.

The climate is arid mediterranean, with a mean annual precipitation of 122.6 ± 91.8 mm (±1SE) in BFJNP, 90% concentrated in the winter months (May–September). Precipitation patterns in the area show a periodicity of approximately 3–4 years which is thought to be associated with the ENSO phenomenon (Dillon and Rundel, 1990).

2.2. Data collection

2.2.1. Precipitation.

Rainfall data for the period 1990–2005 was obtained from a meteorological station existing at FJNP and managed by the University of La Serena (e.g. Gutierrez et al., 2010). Monthly data was only recorded from 1999 onward, therefore we used these data to calculate annual rainfall. Previous studies have reported small mammals density increasing during and after years of high rainfall (Meserve et al., 2003), therefore we calculated a two-year moving average of rainfall for assessing its effect on small mammal density and sheep predation.

2.2.2. Small mammal density

Small mammals were monitored monthly from 1990 until 2005 in the park, using four 5 × 5 trapping grids with 15 m intervals (hence, 0.56 ha) and two live traps/station (For further details see Meserve et al., 1996, 2003; 1999). Small mammals were surveyed for four days and nights per month on each grid, and all captured animals were marked with ear tags or leg bands with a unique numbered and released at the point of capture. The average minimum number known alive (MNKA) of small mammals per year was calculated by adding the MNKAs calculated for each sampling period (all species combined) in a year and diving the result by 12. MNKA was justified in this system as mean monthly trappability for most species exceeds 90%.

2.2.3. Predation on livestock

We obtained data on the numbers of sheep raised annually and the numbers of animals reported to be killed by carnivores in the El Tangue ranch (Fig. 1). These data spanned the period 1990–2005. The causes of loss were assigned to either predation by "dogs", "fox" or "puma" when signs of predation of these carnivores were found. In such cases, the species of predator was identified via analysis of footprints around the kill (see Acosta and Simonetti, 1999) and the wounds on the carcass.

Because Chile has no program for financial compensation to farmers losing livestock to wild carnivores there was no apparent incentive for exaggerating or fabricating claims; the only purpose of the records on causes of mortality was to register the disappearance/death of sheep and thus reduce the animal losses from the ranch inventory. We calculated a livestock predation index (LPI) using the data on sheep reported to be killed by wild carnivores using the formula:

$$LPI = \frac{a}{(b+c)/2} \times 100$$

where, a is the number of sheep killed by foxes each year, b is the number of sheep at the beginning of the year and c the number of sheep at the end of the year.

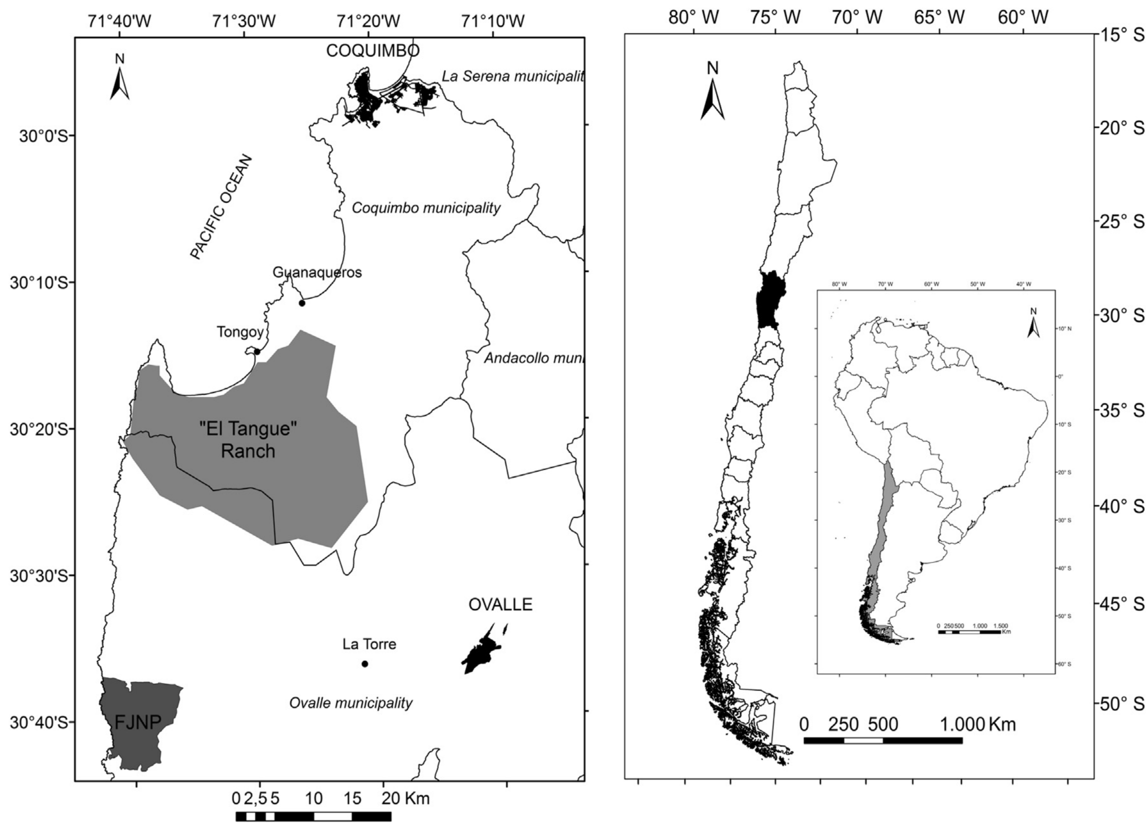

Fig. 1. Map of the study area showing Coquimbo region of Chile in gray (right), and in pale gray "El Tangue" ranch and in dark gray Bosque Fray Jorge National Park. Small dots show towns in the area. Two large cities, Coquimbo and Ovalle, are also shown (left).

2.2.4. Statistical analyses

We applied a path analysis for accounting for direct and indirect effects of rainfall and small mammals density on sheep predation index in the period 1990–2005. This analysis was carried out in Stata 11.0.

3. Results

Rainfall varied markedly over the duration of our study, exceeding 300 mm during El Niño years and falling below 50 mm during many dry or La Niña years (Fig. 2a). Seven species of small mammals have been captured in our long-term sampling in Fray Jorge. This includes six species of rodents (*Abrocoma bennettii*, *Abrothrix longipilis*, *Abrothrix olivacea*, *Octodon degus*, *Oligoryzomys longicaudatus* and *Phyllotis darwini*) and one marsupial (*Thylamys elegans*). The three most abundant species at Fray Jorge are *A. olivacea*, *O. degus*, and *P. darwini* (Meserve et al., 2011). Small mammal populations fluctuated markedly, with high densities recorded following periods of high precipitation (Fig. 2).

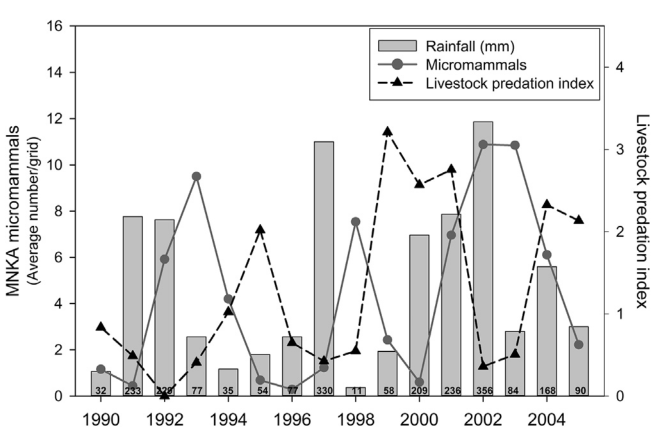

Fig. 2. Variation on the average annual rainfall (in numbers) recorded at the Bosque Fray Jorge National Park (gray bars), temporal variation of average number of small mammals known alive per trapping grid in the FJNP (circle) and temporal dynamic of fox predation on sheep (triangle) are shown.

At the El Tangue ranch, numbers of sheep fluctuated between 7307–11,429 during the period 1990–2005. Livestock predation also varied markedly (Fig. 2), but a total of 7416 sheep were reported as "lost". Whereas just over half of these animals (50.5 ± 0.8%) were recorded as "presumably stolen," the remainder (49.5 ± 0.8%) was attributed to predation. Most losses due to predation were reported to be due to predation by culpeo foxes (*Pseudalopex culpaeus*) (57.4 ± 1.2%), followed by dogs (32.2 ± 1.1%) and pumas (*P. concolor*) (10.4 ± 0.9%).

The density of small mammals was strongly associated with a moving average of current and previous year precipitation ($\beta = 0.897$, $p < 0.001$). Sheep predation by foxes at El Tangue exhibited no direct correlation with rodent density ($\beta = -0.218$, $p > 0.05$) and the two-years moving average of rainfall showed a nearly significant direct negative correlation with sheep predation ($\beta = -0.399$, $p = 0.07$). The total effect ($\beta = -0.595$) in this causal path explaining sheep predation through direct and indirect effects of rainfall and rodents indicate an increase of predation influenced by reduction in rainfall (Table 1).

4. Discussion

The ecosystem within the FJNP is strongly dependent upon

Table 1
Path model of the effect of two-years moving average rainfall and rodent density on sheep predation indicating direct and indirect coefficients.

Outcome	Determinant	Causal effects		
		Direct	Indirect	Total
Rodent $R^2 = 0.805$	Rainfall	0.897[a]	–	0.897
Sheep predation $R^2 = 0.260$	Rainfall	−0.399	−0.196	−0.595
	Rodents	−0.218	–	−0.218

[a] Direct effect significant at the 0.05 level.

precipitation, which produces an increase in primary productivity. Here and elsewhere, small mammal populations presented a positive delayed numerical response to rainfall (Previtali et al., 2009), indicating that small mammal populations increase after high rainfall event, which, in this area typically occur during El Niño events (Díaz and Markgraf, 2000; Meserve et al., 2011).

Although the effect of rainfall variables has been previously reported for ephemeral vegetation (Gutiérrez and Meserve, 2003), rodent species (Meserve et al., 2011; Previtali et al., 2009) and predators (Jaksic, 1997), in the Coquimbo Region, to our knowledge, no previous studies have linked an increase in livestock predation in the surroundings of a protected area following reduction in prey during dry years. As rains in this region are largely driven by the ENSO phenomenon, and this is a principal environmental force worldwide (Kovats et al., 2003), these data suggest a previously unappreciated consequence that may have implications well beyond Fray Jorge or even Chile.

Interestingly, we did not find the predicted increase in sheep predation following reduction in native prey availability. We suspect that the lack of direct correspondence with small mammal abundance is readily explained. Data for small mammals comes from inside a protected area whereas data on livestock predation are obtained from an area where natural vegetation has been greatly modified. Moreover, data on small mammal abundance at El Tangue is limited, precluding a direct connection between prey density and livestock predation. However, unpublished data documented that El Tangue has dramatically lower small mammal abundances and diversity than our study site in Fray Jorge, at least over a 1-year period. Nevertheless, data from Fray Jorge documents a clear relationship between rainfall and small mammal abundance, and our data at El Tangue suggest that sheep predation is inversely related to the two-year moving-average of rainfall as recorded at Fray Jorge; more predation occurred after periods of drought, which strongly implicates a connection with native prey abundance when indirect effects are included in our path model. The results presented here are consistent with previous studies in arid and semiarid environments in which trophic webs are regulated by bottom-up processes (or shifting bottom-up and top-down; Meserve et al., 2003), reflecting limits in food resources that are driven by precipitation (Holmgren et al., 2001, 2006; Marshal et al., 2002; Meserve et al., 2003; Pace et al., 1999).

Relatively little work has been conducted on culpeo fox behaviour in this region. However, Salvatori et al. (1999) documented a decline in relative abundance of foxes during a drought in the early 1990s; presumably these foxes emigrated from the park. Whether these animals searched for alternative prey is unknown, but if natural prey is scarce predation on livestock could be a result of this. Research elsewhere has suggested that low density of wild prey can induce wild carnivores to shift alternate (domestic) prey (Meriggi and Lovari, 1996; Stoddart et al., 2001; Vos, 2000; Woodroffe et al., 2005) in areas where livestock is present (Pía et al., 2003). Furthermore, predation on livestock may be negatively correlated with the consumption of wild prey (Sacks and Neale, 2002, 2007). Further research on the spatio-temporal dynamics of fox populations at Fray Jorge would be helpful to better understand this dynamic.

What makes the current study interesting is the apparent indirect linkage between livestock predation and climate. Whereas changes in intensity of livestock predation by carnivores has been reported from many regions (eg. Butler, 2000; Patterson et al., 2004) few studies have related this dynamic to changes in climate. In east-central Africa high predation occurs during the dry season, presumably because resident carnivores depredate more upon resident livestock when native ungulates migrate following the vegetation rise (Butler, 2000). Moreover, during drought, carnivores have higher opportunities to predate upon livestock because both predators and prey spend most of their time near the few remaining water resources where opportunities for predation are more prevalent (Kays and Patterson, 2002; Patterson et al., 2004). The same pattern of increasing predation upon livestock after rainfall reduction was found in fragmented forests in northern Mato Grosso (Brazil) by jaguars (*Panthera onca*) and pumas (*Puma concolor*) (Michalski et al., 2006) and also by pumas in Venezuela (Polisar et al., 2003). However, wild carnivores generally do not predate selectively on livestock, since they tend to predate in proportion to their availability (Sacks and Neale, 2002, 2007), which could be the case in this study, where a high predation by wild foxes could be occurring during dry years in areas with high abundance of livestock such as within El Tangue. Our results support.

suggestion that native prey serve to buffer livestock from predation, and suggest that management strategies to reduce the human-wild carnivores conflict should be directed to maintaining viable populations of native prey, while allocating efforts towards livestock protection during periods of droughts, which could help to minimize the economic impact of wild carnivores on farmers (Acosta-Jamett et al., 2014).

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