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Simple fence modification to facilitate huemul *Hippocamelus bisulcus* movement across forestry lands

Modificación simple de cercos para facilitar el desplazamiento del huemul *Hippocamelus bisulcus* a través de terrenos forestales

Marcela PA Espinaze [a,b], Paulo Corti [c,d*]

[a] Universidad Austral de Chile, Campus Patagonia, Coyhaique, Chile.

[b] University of Aberdeen, School of Biological Sciences, Aberdeen, United Kingdom.

* Corresponding author: [c] Universidad Austral de Chile, Facultad de Ciencias Forestales y Recursos Naturales, Instituto de Conservación, Biodiversidad y Territorio, Laboratorio de Manejo y Conservación de Vida Silvestre, Valdivia, Chile, +56 632293108. pcorti@uach.cl

[d] Universidad Austral de Chile, Programa Austral-Patagonia, Valdivia, Chile.

SUMMARY

Fencing to contain livestock movement, demarcate properties, and protect economic assets has been one of the main factors restricting wildlife movement. However, research assessing the impact of fences on large mammals in southern South America is scarce. We modified livestock fences by clipping the bottom wire to enable endangered huemul deer (*Hippocamelus bisulcus*) to cross in and out of forest plantations. Huemul showed a preference for crossing through areas where bottom wire strands had been removed. There was also a greater crossing frequency for fences located at lower elevation. Implementation of this simple management technique increased the availability of crossing areas, thereby facilitating huemul movement. Further fence modifications must seek to improve conditions of intervening habitat where huemul live and move, and thus prevent further population decline of this threatened species.

Keywords: cattle, conservation, forest plantation, wildlife, wire fencing.

RESUMEN

Los cercos para contener el movimiento del ganado, delimitar propiedades y proteger bienes económicos es uno de los principales factores que restringen los movimientos de la fauna silvestre. Sin embargo, son pocas las investigaciones que evalúen el impacto de los cercos en grandes mamíferos en el sur de Sudamérica. En el presente estudio modificamos cercos ganaderos cortando el alambre inferior para permitir que el huemul (*Hippocamelus bisulcus*), un ciervo en peligro de extinción, cruce hacia y desde plantaciones forestales. Los huemules mostraron preferencia por cruzar en zonas en las que se habían retirado las hebras de alambre inferior. Además, existió una mayor frecuencia de cruce en cercos situados a baja elevación. La aplicación de esta sencilla técnica de manejo aumentó la disponibilidad de zonas de cruce, facilitando los movimientos del huemul. Modificaciones de cercos adicionales deben tratar de mejorar las condiciones del hábitat intermedio donde vive y se mueve el huemul, y evitar así un mayor declive de esta especie amenazada.

Palabras claves: ganado, conservación, plantación forestal, vida silvestre, alambrados.

INTRODUCTION

Fences contain livestock, demarcate property boundaries, and protect economic assets. However, fences create a physical barrier for animal movement and disrupt wildlife access to breeding opportunities and to essential resources such as forage, shelter, and water (Hayward and Kerley 2009). Fences can also result in injuries to wildlife, which can range from wounds to deadly entanglements (Pokorny *et al.* 2017).

Forestry is an economic activity that comes into direct conflict with wild ungulates (Graham *et al.* 2010). Fences are used to protect trees from ungulates, which trample, browse, and strip tree bark, thereby negatively affecting quality and growth of trees used for timber (Graham *et al.* 2010). However, herbivores can also positively influence the structure and composition of vegetation and help forest regeneration through grazing, browsing, and seed dispersal (Gill and Beardall 2001). Therefore, well-designed fences in forestry lands can help preserve endangered ungulates, avoiding livestock intrusion, reducing habitat deterioration, competition, and disease transmission (Woodroffe *et al.* 2014), while simultaneously benefitting the forest.

Raising the height of the bottom wire of a fence is an efficient management tool for wildlife conservation (Segar and Keane 2020). Crossing under a fence is facilitated when the lowest strand is higher than adjacent fence sections and ungulates can use these sections as regular crossing sites (Burkholder *et al.* 2018, Jones *et al.* 2018). Moreover, cutting the lower bottom wire of a fence that is made of barbed wire counteracts both the physical barrier effect of the fence that hinders animal movement and the injuries that barbed wire causes on animals (Jones 2014).

In southern South America, fences for livestock management and rural property delimitation are widely used (Rey *et al*. 2012). However, fences, designed to facilitate wildlife movement, are not common and their potential impact has yet to be assessed. Fences have been shown to negatively affect other South American species like guanaco (*Lama guanicoe* Müller), a large South American camelid that suffers the impact of fences with annual mortality due to entanglement close to 1.6%, where young animals account for most deaths (5.5 %, Rey *et al*. 2012). The objective of the present study is to assess the efficacy of modified livestock fences in a forest plantation, particularly by raising the bottom wire height, to facilitate the passage of huemul deer (*Hippocamelus bisulcus* Molina), while still avoiding cattle encroachment. Huemul, an endemic and endangered deer of southern Chile and Argentina, has a population of < 2,000 individuals (IUCN 2016). Habitat loss is possibly the most important factor affecting this species (Corti *et al.* 2010, Sandvig *et al.* 2016), but our understanding of its real impact is still limited. Currently, there are no records of huemul killed by entanglement in fences (Vila 2005). However, as they can restrain animal movement, fences could indirectly be the cause of death by other means. For example, by preventing their escape from predators or natural disasters, such as forest fires (Hayward and Kerley 2009), and by promoting disease transmission where barbed wire fences can act as fomites (Morales *et al.* 2017). Although it is unknown which fence features ease huemul crossing, we expected that raising the height of bottom wires would facilitate deer movement in and out the forest plantation because huemul have been observed crossing cattle fences by crawling underneath them (Vila 2005, figure 1).

Figure 1. Image captured by a trail camera depicting the crossing behaviour of huemul deer (*Hippocamelus bisulcus*). In this photograph, a male huemul deer is observed traversing a fence beneath the lower wire within the study area, during the summer season. The surrounding habitat primarily consists of southern beech lenga (*Nothofagus pumilio*) forest.

Imagen capturada por una cámara trampa que muestra el comportamiento de cruce del huemul (*Hippocamelus bisulcus*). En esta fotografía, se observa a un huemul macho cruzando un cerco por debajo del alambre inferior en el área de estudio, durante la temporada de verano. El hábitat circundante está compuesto principalmente por bosque de lenga (*Nothofagus pumilio*).

METHODS

Study site. Our study was conducted in Aysén District, Chilean Patagonia, for one year (April 2012-2013) in a forest plantation owned by Forestal Mininco Aysén S.A. (FMA; 45° 21’ 21” S and 71° 52’ 37” W; 700 – 1,089 m a.s.l.), covering 304.72 ha (figure 2). The area comprised a mix of native southern lenga beech (*Nothofagus pumilio* Krasser) forest (159.39 ha) and exotic ponderosa pine (*Pinus ponderosa* Douglas) plantation (145.33 ha) of 17 years old, which still allowed the presence of understory because the slower growth rate of pine at that latitude. The understory consisted of prickly heath (*Gaultheria mucronata* Hook and Arn), Chilean firetree (*Embothrium coccineum* Forst and Forst), redcurrant (*Ribes magellanicum* Poiret), and Magellan barberry (*Berberis microphylla* Forster) (Sandvig *et al.* 2016). The study area exhibits a mean annual temperature of 7.6 ºC, coupled with an annual precipitation of nearly 750 mm, mostly concentrated between the months of May and August. Snowfall primarily occurs from June to August (southern winter season).

Experimental design. In a 4,100 m section of straight wire fence, 164 m (4 %) were modified by clipping the bottom barbed wires to raise its height (41 stations). Likewise, 164 m (4 %) of its length were unmodified but still monitored (41 stations) (Jones *et al.* 2018). The wires at each station were 4 m in length, corresponding to the distance between fence poles (figure 2). The distance between each station was 12 m. The first station was randomly located, then we alternated between modified and unmodified stations (*i.e.* clipped bottom barbed wire, then unclipped bottom wire, and so forth) across 10 stations. After 10 stations, there was a separation of 44 m, after which a section of another 10 stations began. As a result, a 1,565 m section of the total length of the fence was used for this study. At each of the 82 stations, we measured the distance from the bottom wires to the ground, independent of whether wires were removed or not. During fence preparation, each station was georeferenced with GPS (Garmin eTrex Summit, Garmin International Inc., Olathe, KS), and environmental features, such as forest and shrub coverage, and elevation were recorded. The stations were monitored twice a month (n = 24), recording clues indicating huemul crossing events, such as footprints and hair caught in barbed wires (Jones *et al.* 2018). The crossing behaviour of huemul deer reported in this study (*i.e.* crawling underneath fences) was confirmed by the occasional use of trail cameras (figure 1). Using the indirect signs of crossing (footprints and hair caught in the fence) and the images from trail cameras (although not deployed in all stations) we assumed that huemul deer crossed the fences by crawling underneath.

Data analyses. To relate crossing events between stations with and without bottom wires clipped, we used Fish-

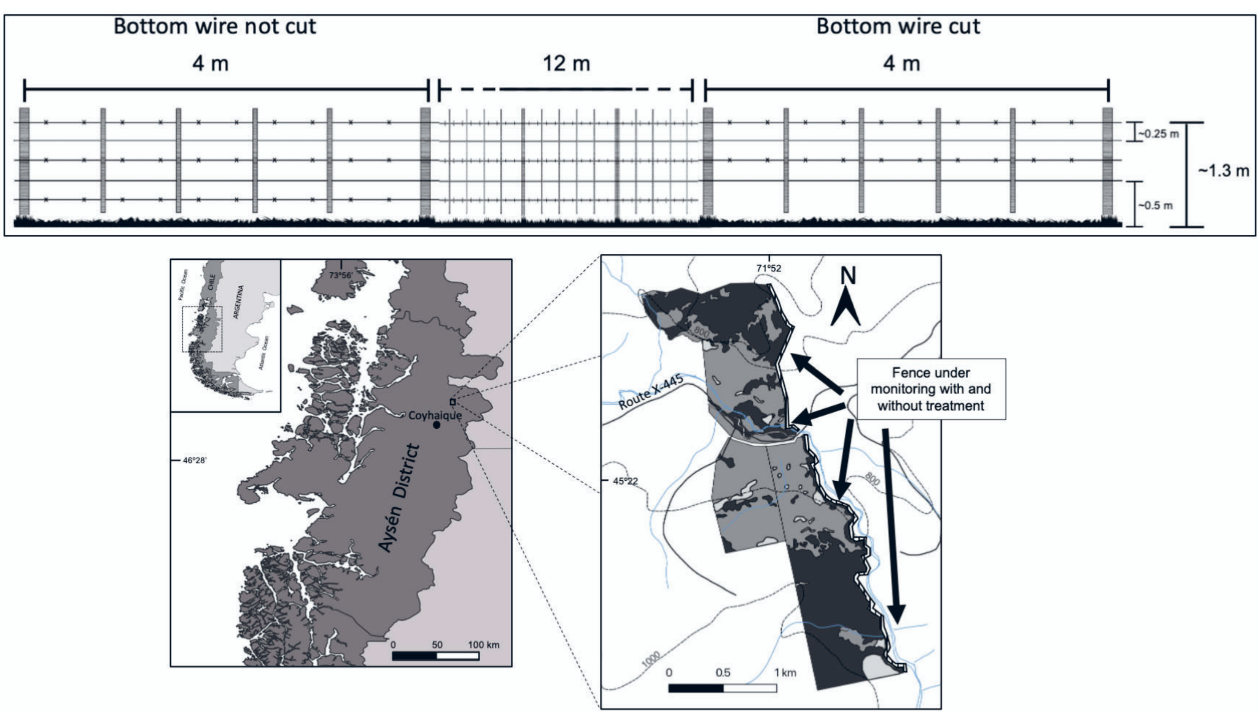

Figure 2. Location of the study site where wire fence treatments (bottom wire clipped) were monitored. Dark grey areas represent native forest and light grey areas correspond to pine plantations. Wire fence details under monitoring and treatment are also shown.

Ubicación del sitio de estudio donde se monitorearon los tratamientos del alambrado (corte de alambre inferior). Las zonas gris oscuro representan bosque nativo y las zonas gris claro corresponden a plantaciones de pinos. También se muestran los detalles de la alambrada, bajo control y tratamiento.

er's exact test and for comparing fence heights between clipped and unclipped sites, we used the Mann-Whitney *U*-test, both in package 'DescTools' for R (Signorell 2021), and $\alpha \leq 0.05$. Then, to control for environmental factors and estimate the effect of fence modification treatments on huemul crossing events, we used generalized linear models with a logit link function and a binomial distribution error (Gude *et al.* 2009) of packages 'ISLR' (James *et al.* 2013) and 'Tidyverse' for R (Wickham 2019). At each monitored site, the type of fence according to clipped and unclipped wires, elevation (m a.s.l.), and proportion of native forest coverage (mean ± standard deviation: 0.24 ± 0.18), pine plantations (0.05 ± 0.11), and native shrub (0.31 ± 0.24) as covariates were included. We measured the understory and forest cover in 200 m^2 plots around sampling stations, visually estimating vegetation cover proportion. Multicollinearity of variables was assessed in a correlation matrix and those with a correlation value > 0.7 were removed (Dormann *et al.* 2013). We included plausible biological combinations among variables in the models. Model fit was assessed with the Akaike Information Criterion adjusted for small sample size (AIC_c). Analyses were conducted in R v.4.0.3 software (R Core Team 2021).

RESULTS

Huemul crossing success. We checked the 41 modified stations with clipped bottom barbed wire (mean ± SD distance to ground 57.6 ± 7.1 cm) and the 41 unmodified stations (36.2 ± 5.2 cm; $median_{cut} = 57$, $n_{cut} = 41$, $median_{uncut} = 36$, $n_{uncut} = 41$, $U = 1659.5$, $P < 0.001$) on 24 occasions each. We recorded a total of 48 huemul crossing events. Huemul showed preference for crossing where the bottom wire strand had been removed (30 crossing events, 62.5 %), over zones where the bottom wire had not (18 crossing events, 37.5 %; $P = 0.04$). At unmodified sections, the mean (± SD) distance between the ground and the uncut wire was 38.2 ± 8.1 cm where huemul crossed, and 35.0 ± 4.4 cm where huemul did not cross ($median_{crossed} = 36$, $n_{crossed} = 41$, $median_{uncrossed} = 35$, $n_{uncrossed} = 41$, $U = 173.5$, $P = 0.36$).

Considering all stations, whether modified or not, the mean (± SD) distance between the ground and the bottom wire was 51.2 ± 12.8 cm where huemul crossed, and 45.0 ± 11.9 cm where huemul did not cross. Thus, independent of whether the monitored station was modified or not, the median (crossing = 54 cm, non-crossing = 40 cm) bottom-wire height at known crossing sites was different from those sites where huemul did not cross ($n_{crossing} = 25$, $n_{non\text{-}crossing} = 57$, $U = 510$, $P = 0.04$). In the 41 modified stations, 16 (19.5 %) were used to cross with a mean (± SD) of 1.9 ± 1.3 days during the year of monitoring. In the 41 unmodified stations, nine (10.9 %) were used to cross with a mean of 2 ± 1.4 days during the year of monitoring. Cattle crossing the fence were not recorded, despite livestock being present in neighbouring ranches.

Variables affecting huemul crossing success. The best model included the distance to the ground of bottom wire, the elevation above sea level, and the coverage of native forest influencing huemul fence crossing probability (table 1). There was a greater frequency of fence crossing when the bottom wire was at larger distance from the ground ($\beta = 0.47 \pm 0.21$; effect estimate for a 10 cm change in the height of the bottom wire), fences were in lower elevation ($\beta = -0.12 \pm 0.06$), and native forest cover was lower ($\beta = -0.21 \pm 0.14$).

Table 1. Logistic models for huemul wire fence crossing probabilities. Information corresponds to AICc and its differences (ΔAIC_c), AIC_c weight (ω_i), Tjur's R^2 value, and number of variables in the model (*k*).

Modelos logísticos de las probabilidades de cruce de la alambrada por un huemul. La información corresponde a AIC_c y sus diferencias (ΔAIC_c), peso de AIC_c (ω_i), valor R^2 de Tjur y número de variables en el modelo (*k*).

Models	AIC_c	ΔAIC_c	ω_i	Tjur's R^2	*k*
Distance to ground of bottom wire + elevation + native forest cover	**97.77**	**0.00**	**0.39**	**0.13**	**3**
Distance to ground of bottom wire + elevation + shrub cover	**99.75**	**1.98**	**0.15**	**0.11**	**3**
Distance to ground of bottom wire + elevation + native forest cover + shrub cover	99.97	2.20	0.13	0.13	4
Elevation	100.71	2.94	0.09	0.06	1
Distance to ground of bottom wire	100.72	2.95	0.09	0.05	1
Distance to ground of bottom wire + elevation + plantation cover + shrub cover	101.81	4.04	0.05	0.12	4
Native forest cover	102.36	4.59	0.04	0.03	1
Distance to ground of bottom wire + native forest cover + shrub cover	102.55	4.78	0.04	0.09	3
Plantation cover	104.02	6.25	0.02	0.01	1
Shrub cover	104.94	7.17	0.01	0.00	1

DISCUSSION

This study explores for the first time some fence structures that assist huemul movement across productive lands. We have implemented a simple fence modification that facilitates huemul crossing (the assumption is by crawling underneath) in and out of forest plantations. Huemul show preference for crossing where the bottom barbed wire strand is removed, over zones where the bottom wire is not modified. This is consistent with the greater frequency of fence crossing when the bottom wire is at a greater distance from the ground, which is the case in the modified areas. This intervention allows huemul to pass between plantations more easily, while still restricting cattle movement, and therefore is an effective management action (Jones *et al.* 2018).

Crossing under a fence is facilitated when the lowest strand of the fence wire is higher than adjacent fence sections and ungulates can use these sections as regular crossing sites (Burkholder *et al.* 2018, Jones *et al.* 2018). Raising the bottom wire of the fence can be beneficial for ungulate crossing during winter snowfall. This adjustment in the fence could counteract the effect of snow accumulation under the fence, which makes crossing under a fence more difficult (Yoakum 2004). In our study, huemul only show preference for crossing in places where the bottom wire is not clipped (*i.e.* keeping the bottom barbed wire) when the distance between the bottom wire and the ground is large enough to allow huemul crossing (mean distance 38.2 ± 8.1 cm). Nevertheless, clipping the bottom barbed wire must also have prevented the negative impacts of barbs when huemul deer crawl under the fence, such as hair loss and skin damage (Jones 2014). In fact, both fence modifications (*i.e.* raising the bottom wire height and removing barbs) are important to allow wildlife movement (Paige 2012, Jones *et al.* 2018).

Previous studies have suggested that the bottom wire of a fence must be at least 40 cm above ground and be of smooth wire strands to allow adult and young wild ungulates to safely cross underneath (Bleich *et al.* 2012). Studies in North America found that increasing the height of the bottom fence wire to 46 cm is an important factor for successful crossing by pronghorn (*Antilocapra americana* Ord), mule deer (*Odocoileus hemionus* Rafinesque), and white-tailed deer (*Odocoileus virginianus* Zimmermann) (Jones *et al.* 2018, 2020); increasing crossing success by 33 % (Burkholder *et al.* 2018, Segar and Keane 2020). Our results also show higher fence crossing probability in areas of lower coverage of native forest and lower elevation. At higher elevations of this forest plantation, the fence is in more mountainous zones and the terrain is steeper. By contrast, at lower elevations, the fence is in less steep terrain and may be easier for huemul to pass under. Likewise, there was lower native forest cover at low elevations. Sandvig *et al.* (2016) showed that huemul roam in pine plantations and native forest as long as there was enough understory cover. It is therefore expected to find huemul deer roaming in areas of pine plantations and crossing sections of fence located in terrain with a lower slope gradient because this may require less energy expenditure to cross (Gaudry *et al.* 2015).

This study shows that a simple fence modification to facilitate huemul movement in and out of forest plantations could be easily implemented by landowners, thus making their economic activities more compatible with wildlife conservation. Raising the height of the bottom wire of a fence to at least 50 cm above the ground is a valuable tool for protecting wild ungulate species, such as huemul, allowing them to safely cross fences to access critical resources, while still preventing livestock encroachment (Bleich *et al.* 2012, Jones *et al.* 2018). Similarly, this fence modification can restrict vehicle access of people from outside of the forestry, thus preventing further human disturbance in areas where huemul deer roams. The implementation of this simple fence modification may also mitigate the many costs associated with fence construction and maintenance when making fencing an effective wildlife conservation measure (Ringma *et al.* 2017).

Despite these promising results, we strongly encourage further research on fence management for huemul deer by using trail cameras in all stations. This would allow for a more accurate assessment of crossing behaviour (over and under the fence) and crossing activity by sex and age-class, across different seasons and geographic areas inhabited by huemul (*i.e.* private lands and public protected areas). This would inform decisions by conservationists and landowners on how to make appropriate local modifications to fence structures. Fence modifications must seek to improve the conditions of the intervening habitat where the huemul lives and moves, and thereby prevent further population decline of this threatened species.

AUTHORS CONTRIBUTION

MPAE and PC designed the study. MPAE collected data in the field. PC performed statistical analyses and modelling. MPAE and PC wrote the manuscript.

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