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RED DEER INTRODUCED TO PATAGONIA
1. DISEASES AND IMPLICATIONS FOR NATIVE UNGULATES

Werner T. Flueck[A,B,C] *and Jo Anne M. Smith-Flueck*[B]

[A]National Council of Scientific and Technological Research (CONICET), Buenos Aires, Swiss Tropical Institute, University Basel, DeerLab, C.C. 592, 8400 Bariloche, Argentina.
[B]Institute of Natural Resources Analysis, Universidad Atlantida Argentina, Mar del Plata, DeerLab, C.C. 592, 8400 Bariloche, Argentina.
[C]Corresponding author. Email: wtf@deerlab.org

ABSTRACT
The red deer (*Cervus elaphus*) invasion in Patagonia has been continuing for nearly a century. Red deer are found in all habitats between 34-55°S, occupying >51,000 km², and reaching densities of 100 deer/km² in ecotones and 40-50 deer/km² in steppes. Their distribution, movement patterns and density raise concerns over their potential epidemiological role (e.g. Foot and mouth disease, brucellosis, tuberculosis). Adult females collected by rifle and radiocollared deer that died naturally were necropsied in the field to determine gross pathology, and whole specimens were also examined in a national pathology laboratory. No ectoparasites were found (n = 73). *Fasciola hepatica* was encountered at prevalences of 9-50% (n = 108). *Taenia ovis krabbei* was identified, and *Cysticerus tenuicollis* was found at a prevalence of 8% (n = 12). *Ostertagia* sp., *Bunostomun* sp., and *Dictyocaulus* sp. had a prevalence of 75%, 25% and 13%, respectively. Testing for Foot and mouth disease was negative (n=41). A suspect case of tuberculosis had substantial parietal pleural adhesions, granulomatous mediastinal lymph nodes, nodules covering the costal pleura and liver, lesions in the intestinal tract including lymph nodes covering the rumen. Antler damage was found on 73% of shed antlers, with 36% having major breaks of tines and main beam, possibly indicating mineral imbalances. One male not only had broken tips and tines, but both entire antlers, including pedicles with portions of frontal, parietal and occipital bones, were broken off the skull, causing his death. Regarding native huemul (*Hippocamelus bisulcus*), several gastrointestinal parasites found at low prevalence in Chile are common in livestock and considered commensals in ruminants. Sympatry of huemul with livestock is commonplace, whereas with red deer it occurs in <2% of known populations. In one area of sympatry, per huemul there were 1.2 red deer, but 25.2 livestock, making livestock the determining epidemiological factor. Considering that red deer have been coexisting with livestock for >100 years in Argentina, both red deer and livestock play epidemiological roles for shared diseases. Research, conservation and management efforts should be directed towards livestock herd health programs or restriction of free livestock movements, particularly if diseases are shown to impact on recruitment of threatened natives. Livestock, being routinely researched and inspected at slaughtering time can provide a proxy for diseases afflicting co-existing ungulates.

INTRODUCTION
Argentina has a long tradition of animal introductions, beginning with livestock that reached millions of feral cattle, horses and goats shortly after Spanish settlement (Torrejon 2001). Exotic wildlife were introduced later and included red deer (*Cervus elaphus*), which are considered to be one of the world's 14 worst mammalian invasive species (IUCN 2002, www.issg.org). Red deer expansion into the southern cone of Latin America began less than a century ago, and has yet to reach a state of equilibrium (Flueck and Smith-Flueck 1993; Flueck *et al.* 2003).

Red deer have established themselves in all mayor habitats and currently are established in most forested habitat types encountered between about 34-55°S. The area occupied in 2003 was estimated >51,000 km², consisting of 29% forest habitat, 57% Patagonian steppe habitat, and 14% of non-forested habitat such as wet meadows and riparian habitat, brush or grasslands of anthropogenic origin, and high altitude vegetation above the tree line (Flueck *et al.* 2003). In Chile, they were estimated to occupy about 7700 km². The present distribution of red deer has the following environmental characteristics: it covers the latitudes between 37°42'S and 54°55'S (noncontiguous); longitudes between 73°36'W and 69°50'W (noncontiguous); and altitudes from sea level to > 2450 m (Flueck *et al.* 2003). Within the present distribution, red deer may number >100,000 animals at an average density of about 2 deer/km². This appears to be a conservative estimate considering that favorable ecotonal habitats have revealed densities around 100 deer/km² whereas in steppe areas they reached 40-50 deer/km² (J. Amaya pers. comm.; Flueck *et al.* 1995). Initially forming resident populations, red deer now also have migratory segments with individuals traveling 25 km, and cases of dispersal going 40 km (Flueck 2005). In the study area reported here, red deer are commonly sympatric with cattle, horses, sheep, goats and wild species like fallow deer (*Dama dama*), wild boar *(Sus scrofa*), and guanaco (*Lama guanicoe*).

The distribution, movement behavior, and uncontrolled national and transnational shipments of red deer (Flueck and Smith-Flueck 2006; Flueck 2010*a*) raise concerns over their potential epidemiological role for various diseases such as foot and mouth disease (FMD), brucellosis and tuberculosis (Flueck 2005; Flueck and Smith-Flueck 1993; Flueck *et al.* 2003, 2006). Here we report for the first time on various diseases encountered in red deer in Patagonia and evaluate their potential to impact native ungulates.

MATERIALS AND METHODS

The study area is centered in the Patagonian ecotone (40°58'S, 71°12'W), Argentina. The topography is primarily mountainous with most features formed by glacial processes. The dominant climate is temperate with most precipitation occurring between April and September. There is an abrupt precipitation gradient from west to east due to the Andean orography which results in a strongly defined vegetation structure and floristic composition. The study sites are between 900-1200 m elevation and represent grasslands, or ecotones between forests and grasslands. Patches of forests are characterized by false beech (*Nothofagus antarctica*) and cypress (*Austrocedrus chilensis*) at lower elevations and are replaced by deciduous lenga (*Nothofagus pumilio*) at higher elevations. Forest patches at lower elevations alternate with wet grasslands with abundant growth of herbaceous plants whereas at high elevation they are replaced by grass-dominated steppe containing *Stipa speciosa* var. *major* and *Festuca pallescens*, with variable occurrence of brush species like *Mulinum spinosum*, *Berberis* spp. and *Colletia spinosissima*. Riparian areas also contain galleries of *Lomatia hirsuta*, *Maytenus boaria* and *Schinus patagonicus* trees.

Females older than one year were collected randomly by rifle between 1991 and 2009 and radio collared deer that died naturally were evaluated between 2001 and 2009. All individuals were necropsied in the field according to techniques described by Salwasser and Jessup (1978) and Wobeser and Spraker (1980). Time, location and morphometric measurements were recorded (Mitchell *et al.* 1976). The focus of deer collections varied, relating either to issues of reproduction, development, seasonal body condition, population dynamics, genetics or gross pathology. The examination for the presence of diseases was thus not equally intense in every situation, and prevalence is only indicated where an adequate number of individuals had been examined for that purpose (Davis and Anderson 1971; Davis *et al.* 1981; Jones *et al.* 1997; Williams and Barker 2001; Samuel *et al.* 2001). Additionally, in 1994–95 we collected whole female deer, which were examined exhaustively, including the gastrointestinal tract for parasitology, in the pathology laboratory of the National Institute for Agricultural Technology, INTA. The four study areas where animals were collected were: A (41°00'S, 71°17'W), B (40°59'S, 71°11'W), C (40°57'S, 71°11'W), and D (40°29'S, 70°59'W). Considering possible nutritional deficiencies, the damage on antlers and breakage were analyzed. Damage on antlers was classified as broken tips of tines, tines completely broken off, and breakage of the main beam.

RESULTS

Ectoparasites were not present upon gross examination in study area A (*n* = 21) (Flueck *et al.* 1993), nor in the 1995 study area C (*n* = 9, Flueck *et al.* unpublished data), nor in the study site D (*n* = 43) (Smith-Flueck and Flueck 1998). *Fasciola hepatica* were encountered regularly among deer: at site A, the prevalence in the population was 50% (n = 20) (Flueck *et al.* 1993, 1995 unpublished data), whereas at site D it was 9% (*n* = 43) (Smith-Flueck and Flueck 1998). Additional deer examined between 1998-2009 in area A exhibited a prevalence of 13% (*n* = 45). *Taenia ovis krabbei* was identified based on hook characters, size, appearance, and anatomical location of a cysticercus. A sylvatic cycle involving red deer appears to exist (Flueck and Jones 2006). On several occasions we found taenid larval stages attached to liver, omentum and peritoneum, with the typical gross appearance of *Cysticercus tenuicollis*, which were deposited and identified by the state agency INTA. In the study area A their prevalence was 8% (*n* = 12) (Flueck *et al.* 1993). *Ostertagia* sp. were found at a prevalence of 75%, with two individuals carrying 800 and 900 adult parasites, respectively; *Bunostomun* sp. were found at a prevalence of 25%; and *Dictyocaulus* sp. occurred at 13% prevalence (Flueck *et al.* 1995 unpublished data). FMD was tested for by the Federal agency SENASA in deer from site B (*n* = 41) in 1994–95 to allow export of the tissue as part of a genetic study (Flueck and

Smith-Flueck 2011): all samples were negative (there had been an outbreak in livestock in 1991). Among an additional 393 specimens collected for reproductive and physical condition studies, the only notable finding was a suspected case of tuberculosis from 1996 in area D. We submitted fresh tissue from this specimen to INTA but no cultivation was done and histological sections were negative. There were substantial parietal pleural adhesions, granulomatous mediastinal lymph nodes, nodules covering the costal pleura, and additional lesions in the intestinal tract, including lymph nodes covering the rumen and nodules in liver (Fig. 1).

Broken antlers
Damage was found on 73% of shed antlers collected between 2006–2009 (Table 1, *n* = 132). Antlers with broken tips had on average 2 broken tips, and 36% of antlers had major breaks of tines and main beam (Fig. 2). An extreme case was a male that died during the rut from breakage of the skull and antlers remaining solely attached to skin. Not only were 2 tines and 7 tips broken off, but both pedicles with portions of frontal, much of the parietal and anterio-dorsal portion of occipital bones were broken out such that the animal lost most of the upper brain case (Fig. 3). Incidentally, deer and cattle have been observed eating bone or antlers. One ranch reported in 2009 on 3 free-ranging domestic cows that continued to deteriorate, and when eventually captured for checking, all had bones stuck sideways in the mouth preventing them from foraging.

Table 1. Breakages on shed red deer antlers found between 2006-2009

Type of damage	*n*
Main beam only	2
Tines only	10
Main beam and tips	3
Main beam, tines and tips	1
Tines and tips	31
Tips only	50
No damage	35

DISCUSSION
The general absence of ectoparasites upon gross examination refers foremost to groups like ticks, fleas and lice. Similarly, it is common for wild ruminants like guanaco living in cold Patagonia to be devoid of ectoparasites (Karesh *et al.* 1998), although contact with sheep may lead to cross contaminations. Infections with *F. hepatica* and *C. tenuicollis*, both cosmopolitan parasites, as well as the exotic *T. o. krabbei,* are considered trivial for otherwise healthy cervid hosts. For the same reason, *Ostertagia* sp., *Bunostomun* sp. and *Dictyocaulus* sp. are also trivial, but the latter two can be a concern when deer are weak for other reasons. These parasites have been noted in Argentine Patagonia in livestock and wildlife including red deer (Flueck and Jones 2006; Suarez *et al.* 2007; this study).

Although it is not possible to differentiate between *T. o. ovis* and *T. o. krabbei* on morphological grounds with absolute certainty, red deer have been reported to be refractory to *T. o. ovis* infection whereas other potential intermediate hosts like cattle, goats, pigs and sheep have been shown to be refractory to *T. o. krabbei*. Possible or known definitive hosts in the study area include native felids like *Puma concolor*, *Felis colocolo*, *F. guigna* and canids like *Dusicyon griseus*, *D. culpaeus*, and domestic dogs. The adult stage of *C. tenuicollis*, the tapeworm *Taenia hydatigena,* is also found commonly in domestic and wild canids and felids in the region.

In Chile, *Ostertagia* sp., *Capillaria* sp., *Bunostomum* sp., *C. tenuicollis* and *Dictyocaulus* sp. have all been found at low levels in free-ranging exotic fallow and red deer, whereas fecal exams from 9 native huemul deer (*Hippocamelus bisulcus*) showed only very low levels; and in only 3 animals *Moniezia* sp. was confirmed and also considered to be non-significant to the hosts (Rioseco *et al.* 1979). Most all of these parasites, considered in general to be nonthreatening, are common in livestock and thus occur in most areas with livestock (Love and Hutchinson 2003). The suspected case of tuberculosis is a concern more for animal production systems with high densities of animals. The present case stemmed from a high density population of red deer at site D (about 50 deer/km^2, Flueck and Smith-Flueck unpublished data). As a zoonosis it requires caution by people involved with wild deer. Similar lesions (costal pleural, pulmonary, rumenal) have been described for white-tailed deer (*Odocoileus virginianus*) and red deer infected with *Mycobacterium bovis* (O'Brien *et al.* 2001; Glawischnig *et al.* 2006; Martin-Hernando *et al.* 2010).

There are frequent claims in the literature of huemul being highly susceptible to cattle diseases such as *C. tenuicollis*, FMD, coccidiosis, 'parasites', or actinomycosis (Povilitis 1978; Thornback and Jenkins 1982; Schuerholz 1985; Redford and Eisenberg 1992; Simonetti 1995; Wemmer 1998; Lord 2007). According to Simonetti (1995), "*Cysticercus tenuicollis,* when transmitted by livestock is fatal to huemul", citing Texera (1974). However, Texera stated that he did not consider the presence of *C. tenuicollis* to be the cause of death, rather that the condition of the female deteriorated after a premature parturition, aggravated by very little space and little variety of food provided. Furthermore, in other cervids and ungulates the presence of *C. tenuicollis* is considered of little significance (Leiby and Dyer 1971). Then, high susceptibility of huemul to coccidiosis is frequently mentioned and based on the only report on coccidiosis by Texera. However, Texera (1974) questioned whether it was the cause of death, because there existed many *other* problems, besides again referring to limited space and poor nutrition. A sick sheep was brought to the same pen later on, and huemul which subsequently died also had, among many other problems, coccidia. Anecdotal accounts by settlers are cited to claim that FMD via livestock was responsible for decimating huemul over huge areas 60-70 years ago. In contrast, recent FMD outbreaks in the UK resulted in experimental studies of 5 cervid species that were all susceptible to FMD to some degree. Based on natural behavior of these free-living deer in the UK, they are considered unlikely to be an important factor in the maintenance and transmission of virus during an epidemic of FMD in domestic livestock (Thrusfield and Fletcher 2002; Fletcher 2004). Earlier concerns about FMD in deer during an outbreak in 2001 in the UK proved to be unfounded (Davies 2002): numerous samples from deer showing lesions suggestive of FMD were sent in to the Pirbright laboratory but all proved to be negative. There has been no evidence of wild deer being implicated in this epidemic despite the fact that the deer population in Great Britain was 10 times greater than it was in 1967 (Davies 2002). At normal densities of cervids, FMD is considered a self-limiting disease (Morgan *et al.* 2003). The very low densities of huemul and reactions of other cervids to FMD renders those early anecdotal accounts by settlers doubtful. Additionally, even if FMD would reduce the population, after the outbreak is over and at the rate of increase of 1.21 documented in Chile for huemul, a population would have recovered by 300% in only 6 years. Thus, claims that FMD decimated huemul populations in the last century are unfounded. Lastly, a recent review on FMD found no reports of any previous disease nor outbreaks in wildlife populations under field conditions among several South American wild animal species susceptible to FMD (Pinto 2004).

The prevalence of antler breakage reported here was similar to that found in *C. elaphus* in California by Johnson et al. (2005), who suggested that it related to Cu and/or P deficiencies (Johnson *et al.* 2007). There are no reports of Cu deficiency in this Andean region, however, P is low in part due to volcanic soils (Wittwer *et al.* 1997; Thomas *et al.* 1999). Given that the area has been exploited for >100 years without fertilizer replacement, P levels might have continued to diminish. The harvest of red deer alone represents an export of P of about 1.8 kg P/female, whereas removing from the system the antlers shed by a male that is harvested later at age of 8 years exports about 7.2 kg of P (Flueck 2009). Removing livestock from the systems exports additional substantial P, and the estimated overall export rate for P compares to rates measured in other extensive production systems which, in contrast, receive 10-50 kg/ha.year of P as fertilizer to compensate the losses from biomass exports.

In conclusion, red deer were found to harbor a few diseases commonly associated with livestock and wildlife, with the only exception of *T. o. krabbei,* which though is a trivial parasite. Having been in Argentina for >100 years and in coexistence with livestock, both red deer and livestock play roles in the epidemiology of the various diseases they share. Regarding huemul, whereas livestock are commonly sympatric with them (probably 100% of huemul populations), spatial overlap with red deer is exceptionally rare, occurring in <2% of known populations, and is of recent time (Flueck 2010*b*). Even in this latter case, livestock presence is the determining epidemiological factor, since in the one (of two) population, for each huemul there were 1.2 red deer, but 25.2 livestock (Pastore and Vila 2003). Thus, for most if not all huemul populations the primary factor regarding infectious and parasitic diseases are feral and free-ranging livestock. Research, conservation and management efforts should thus be directed towards finding appropriate solutions, including livestock herd health programs or restriction of free livestock movements, particularly where huemul still occur in protected areas. Livestock, being regularly researched and inspected at slaughter provide a good proxy for the parasite community and other diseases afflicting sympatric red deer. Although sympatry between red deer and guanaco is common and substantial, including the formation of mixed groups, and has been suggested to affect the epidemiology of shared diseases (Flueck 1996; Flueck *et al.* 2003), we found no other reports expressing sanitary concerns. Lastly, uncontrolled importations of wild ungulates is of special concern if it involves cervids, due to transmissible spongiform encephalopathy of cervids. The appearance of this disease could be disastrous for South America due to the large variety of endemics cervids.

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Figure 1. Female red deer: (*a*) Lesions in rumenal lymph tissue, (*b*) Pulmonary adhesions and costal pleural and pulmonary lesions, (*c*) nodules in liver.

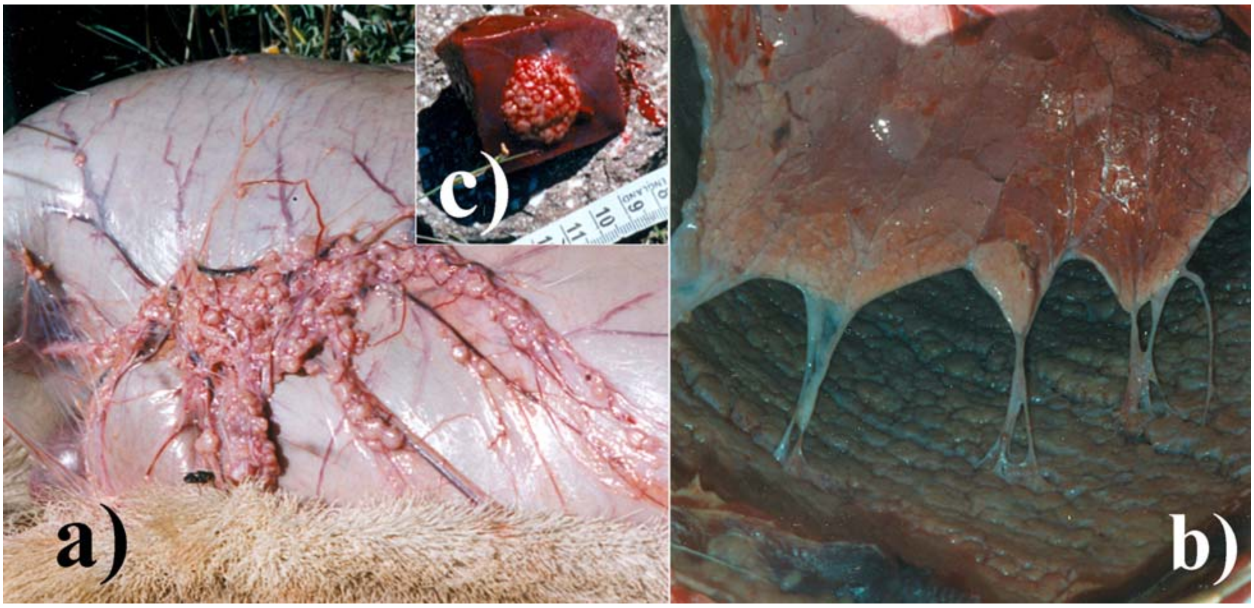

Figure 2. Antler damage in red deer: (*a*) broken tines, (*b*) broken crowns, (*c*) broken main beams.

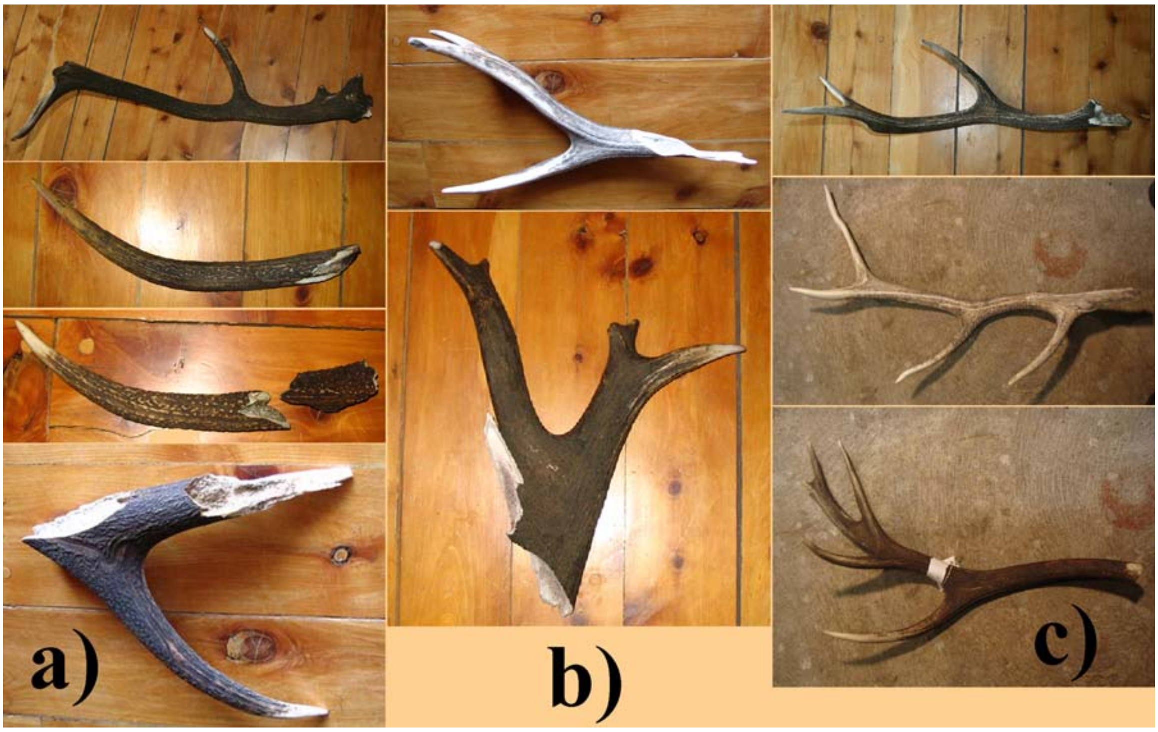

Figure 3. Breakage of antler and skull: (*a*) bases of antlers as found, (*b*) dorsal view of cranium with posterior part of frontals and most of parietal broken out. Note that the occipital is cracked and has the anterio-dorsal portion broken out (arrow).