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Why the Patagonian huemul deer in Argentina fails to recover: An ecological hypothesis.

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Huemul (*Hippocamelus bisulcus*) had declined drastically by the 20th century. First field studies in Argentina beran in 1988. The 1st Chilean-Argentine meeting (1992) resulted in a preliminary list of hypothetical factors potentially important for huemul recovery. These factors are still claimed dogmatically to cause their declines and failure to recover, though without supportive studies. Efforts still aim to reduce impacts of these factors, but without monitoring, it is not known if these actions are relevant or successful. Huemul are in a precarious state. Only 350-600 animals remain along 1800 km of Andes in Argentina, without known cases of numeric responses or recolonization, yet several populations have vanished in the last few decades, casting doubt on success of earlier actions [1]. Here we evaluate the importance of these factors. We posit that major underlying problems explaining the lack of huemul recovery have not yet been considered: huemul likely are deficient in trace minerals important for recruitment.

Hypotheses from 1992 are reevaluated. a) *Extensive livestock raising*: explanations are needed for populations which coexisted with cattle for >110 years, or which have declined, are declining or went extinct without apparent contact with livestock. b) *Replacement of native forest with exotic trees*: no study shows negative impacts on huemul. Replacement of native forest by exotics is illegal, and earlier plantations do not invade native forest. c) *Irrational management of native forests*: no study shows negative impacts on huemul. On the contrary, huemul respond positively to areas formerly logged and burnt, like growing populations in Chile exhibiting the highest known huemul density. Current successful recolonizations in Chile into treeless areas corroborate that huemul may be pastoreal and only secondarily adapted to sylvan habitat. d) *Introduction of exotic animals*: no study shows negative impacts on huemul, only that exotics eat the same plants and have similar preferences as huemul [2]. This is only relevant if it reduces huemul population growth rates. Considering huemul diet studies, they likely shift diet without necessarily affecting reproduction [3], as is known for other cervid species. Besides, in the absence of exotics, huemul went extinct or have declined. Considering high densities of exotics in former huemul areas, it appears unlikely that such habitat is limiting huemul in terms of energy and major plant nutrients [3]. Huemul also form multi-species guild assemblages, thus presence *per se* of other herbivore species is unlikely to be problematic, as evidenced by documented coexistence with livestock. e) *Illegal hunting*: no information exists about extent or effects on populations. It is likely negligible in remote remaining

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populations, but may prevent migratory behavior. f) *Diseases*: no study shows negative impacts on Argentine huemul. Records from local government research institutions, animal health authorities and veterinarians would indicate the presence of dangerous diseases near huemul, as livestock raising is of major economic importance. Of 376 red deer necropsied, the only unusual observation was a yet unknown exotic *Taenia* [4]. In Chile, no disease problems have been found in huemul. Anecdotal accounts by settlers are cited to claim that foot and mouth disease (FMD) was responsible for decimating huemul over huge areas 60-70 years ago. Based on behavior of 5 wild cervid species in UK, these are considered unlikely to be important in maintaining and transmitting FMD. At normal cervid densities, FMD is self-limiting. Very low huemul densities and reactions of other cervids to FMD makes those early anecdotal accounts doubtful. Also, considering known growth rates, a population of huemul in only 6 years would have increased by 300%. Others claim that *Cysticercus tenuicollis,* when transmitted by livestock is fatal to huemul, citing Texera [5]. However, that author did not consider presence of *C. t.* 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, presence of *C. t.* is considered of little significance. g) *Dogs:* no study shows negative impacts on huemul. Anecdotal accounts indicate that huemul is easily killed by dogs, assumed to be related to absence of native cursorial predators, and that they become paralyzed due to panic, and thus become easy prey. However, the evolutionary history of huemul included cursorial predators in North and South America, including *Canis*. These large canids became extinct in South America only in the Holocene. Other Odocoilines employ a hide-and-freeze strategy, bolt or run off at close encounter, and take to water. Mule deer tend to bound uphill, imposing heavy costs on a predator, whereas white-tailed deer bolt down and along hillsides. Huemul are known to snort, stomp the ground, they run, trot or race away uphill or downhill effortlessly; they also bound like mule deer and take to water. Documented interactions of huemul with dogs are rare, and thus the more instructive (B. Thomas, pers. com.). Case 1: a huemul buck ran down a logging trail, bounding side to side to navigate logs while trying to outrun 3 dogs. Case 2: a female with calf were chased by 2 dogs; they did not run to water but contoured a hill feature for about 1,5 km and then climbed to the higher ground, outrunning the dogs. Case 3: a radio- collared huemul doe and her week-old young were observed. The doe suddenly went in front of several approaching dogs and away from the bedded calf. The barking dogs circled away from the area to about 500 m. After 20 minutes the barking stopped. About 4 hours later, just at dark the doe approach the fawn from the other direction, nursing it and then heading back with it the same way she had come, taking the fawn out of the area some 500 m. Certainly, any loss is important for severely reduced groups, including from puma predation (*Puma concolor*), but this is related to small population size and not to predation *per se* [6]. h) *Small population size, fragmentation and genetic isolation*: although no studies on huemul document population size, degree of fragmentation (metapopulation dynamics) or genetic isolation, comparative studies support the importance of these factors when they exist.

What might account for a generalized absence of recolonization or numeric responses? A growing huemul population in Chile had a lambda of 1,21 and life spans of at least 14 years [2]. This numeric response occurred in presence of some dog

predation and natural predators (puma, foxes). As several Chilean populations have been recovering, but no such cases are known from Argentina, we evaluated the potential of nutritional factors which likely could affect reproduction and survival more so on the Argentine than Chilean side of the Andes.

Geology and Pedology: The central Andes occupied by huemul are characterized by acidic rocks, landscapes strongly modified by past glaciations, and acidic soils strongly influenced by volcanic depositions, all of which favor low selenium (Se) and iodine levels. The influence of volcanic ash diminishes to the east due to drier climates. Westerly Pacific winds result in minimal aerial Se input which is highest by the coast and decreases further inland. The gradient of iodine depositions also decreases from west to east, and with increasing altitude in the Andes. Cattle near the Peruvian coast had levels 6 times higher than found inland at higher altitude. Hence, Se and iodine provision in Argentina is expected to be lower than in Chile. Topography modulates soil concentrations as leaching occurs on ridge land and results in a decrease of soil Se and iodine, while adjacent valleys maintain or increase Se and iodine levels [7]. Past and current land use further diminish bioavailable Se and iodine [8].

Biochemical Functions: Only recently discovered, the genetic code had to be expanded and Se forms part of the 21st amino acid, essential in all mammals. Se, an active part of several enzymes, is involved in oxygen metabolism and thus functions at very basic biochemical levels, and deficiency is thus expressed in many ways. In all animal species studied, deficiency impairs reproductive performance of females and males. In ruminant neonates, white muscle disease is typical of deficiency. It also is fundamental for proper immune function, disease resistance and myocardial disease. It is essential in iodine metabolism and causes iodine deficiency secondarily in the thyroid gland which is present in all vertebrates, with its hormones playing an indispensable role in control of the basal metabolic activity. Iodine is essential for gestational development, particularly of the central nervous system, and deficiency during pregnancy has negative and irreversible effects on the developing fetus; postnatal deficiency is associated with cognitive deficits. In ruminants common problems include abortions, young born dead, weak neonates, increased neonatal mortality, prolonged gestation and infertility.

Selenium and Iodine Status in Patagonia: concentrations of Se and iodine in most forages of agricultural systems in southern Chile are deficient, indicating marginal levels in natural habitat. Levels on the east of the Andes are expected to be even lower. There are a still focal areas with endemic goiter in Argentinean Patagonia.

Huemul Migrations as a clue to the current predicament?

In autumn, cattle were commonly herded together with huemul to lower elevations for the winter. Huemul also moved from high Andes down to Pacific coastal areas. Based on telemetry they were shown to spend the evening and night in valley bottoms and to move to higher elevations in the morning in valleys not settled or used by humans. Many huemul lived in bottoms of valleys in Argentina during winters about 60 years ago, though people now residing there have never seen a huemul [2]. In Santa Cruz, huemul groups of 50 used to migrate annually some 50 kilometers from the high Andes into the treeless steppe. Others reported huemul at 200 km from the Andes in treeless grasslands, or wintering groups of 100 huemul 80-100 km from forests,

resembling migratory behavior of other Odocoilines.

Traditional winter ranges and valley bottoms likely were source areas for huemul populations and for migratory behavior. Krieg [9] mentioned the existence of all-year resident huemul in quiet valley bottoms. Migratory huemul in Argentina were likely eliminated by overhunting, easily being killed as they show no fear. Thousands per year were killed at rates of 1-2 deer per km^2, coincidently the average density where they still occur now [2]. Huemul were used to feed people, dogs, chicken and pigs; their skins were used for shelters for people and domestic animals. With loggers also killing huemul indiscriminately during the colonization, only the most inaccessible areas provided refuges for remaining huemul. In 1897, reports based on many Andean expeditions already mentioned few huemul left due to constant and heavy hunting pressure. All areas useful as winter ranges for livestock were occupied by settlers early on or became private, and often were cleared of forests. Migratory behavior is an acquired trait. Thus, by eliminating the migratory segment of a huemul population, the remaining animals became tied to a refuge. The few dispersers potentially leaving such populations would tend to follow prime habitat like valley bottoms and be at high risk to be eliminated by hunting or dogs.

Discussion

Currently favored reasons for failing huemul recovery in Argentina do not explain several observations. In healthy populations, losses due to predation by puma, foxes and feral dogs, and accidents would not present a problem. Domestic and exotic wild herbivores do not generally affect healthy native cervids elsewhere as most plant-herbivore systems are multi-species guilds. Domestic and exotic wild herbivores as disease agents also do not generally affect healthy populations of native cervids, but undoubtedly increase the risk of introducing epidemiologically important new diseases. These factors might affect individual huemul, thus current conservation efforts aim at reducing or eliminating these, but it is not known if such actions have resulted in improvements. Regardless, populations do not recover even in the absence of one or several supposedly detrimental factors.

Recruitment in Argentina is too low for recolonizations or numeric increases of populations. Remaining refuges occur at high elevations near the continental divide, with high precipitation, far from the Pacific, and in plant communities growing on soils strongly influenced by igneous rocks, glaciation and volcanism. We posit that these areas likely provide suboptimal trace mineral levels to huemul. This affects their reproduction and survival because they lack the opportunity to compensate these nutritional imbalance by migrating to more favorable sites like valley bottoms and historical winter ranges.

Deficient dietary iodine and Se levels result in a plethora of problems. Although ultimate relationships are biochemical, these are expressed in reduced immune functions, reduced systemic growth and reproductive potential, and behavioral changes. Thus, the initial diagnosis might be death due to diseases, whereas the proximate factor might actually be lack of iodine and Se [10]; resistance to diseases is tied to adequate dietary iodine and Se. Similarly, predation rates might be mistaken as the problem, whereas the proximate factor might be behavioral changes due to nutritional deficiency of iodine and/or Se, causing animals to be weak, uncoordinated and behaviorally affected [10].

Increasing Se levels in otherwise deficient wild deer increased the recruitment rate by 260% [11]. *Ovis canadensis* responded drastically to Se mineral licks [10]. Adults shed summer coats much earlier, young were weaned much later, and predation losses diminished. Movement behavior changed once animals had access to Se salt blocks placed on summer ranges: animals no longer made temporary movements to winter grounds and valley bottoms to search for natural mineral licks. In contrast, control sheep without salt blocks continued to make such movements and had lower neonatal survival. In an additional population, salt blocks on summer ranges were also provided, but lacking Se; sheep also stopped movements to lower areas, but recruitment rates were 67% lower than the population receiving Se salt. In comparison, huemul in Chile also was observed to make summer movements to valley bottoms (Saucedo, pers. com.), but they would only survive if those areas were free from people and dog disturbances. The absence of such movement behavior in Argentine populations likely stems from the continuous elimination of huemul reaching lower areas populated with people.

Future efforts must be directed beyond the current belief system. The current lack of science-based monitoring prevents drawing any conclusions about cause and effect. In the worst case, decisions will be made on unreliable data, thereby compromising the future of the species. First and foremost is the need to study huemul populations directly with telemetry as indirect methods will be cost-prohibitive [1]. Specifically, studies should test our hypothesis.

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