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A preliminary analysis of death cause, capture-related mortality, and survival of adult red deer in northwestern Patagonia

WERNER T FLUECK[1,✉], JO ANNE M SMITH-FLUECK[2] & NEVER A BONINO[3]

1. *Consejo Nacional de Investigaciones Científicas y Tecnológicas, Bariloche, Argentina*
2. *Universidad del Comahue, Bariloche, Argentina*
3. *INTA Bariloche, CC 277, 8400, Bariloche, Argentina*

ABSTRACT. The red deer (*Cervus elaphus)*, among the world's 14 most invasive exotic mammals, has recently arrived in Patagonia. Forty-seven deer were captured, marked with radio collars, and monitored in order to determine survival rates and identify causes of death. Net gunning from a helicopter allowed captures to be evenly distributed through the study area and in a timely manner. The absence of capture related mortality in our study agrees with previously reported low rates for this method. Animals were monitored for periods ranging from 5 to 2611 days. Ten animals provided censored values due to radio failures or being shot: they survived on average 811 days (*SE* = 221) after capture. Ten animals experienced natural deaths with an average time alive after capture of 413 days (*SE* = 106): eight were killed by puma (*Puma concolor*). The remaining 27 animals were alive for an average of 974 days (*SE* = 52). Twenty-one percent of the animals died naturally during 38.549 deer-days. Using the Kaplan-Meier procedure, the annual survival rates for the years 2001-2003 were 0.89, 0.91 and 0.92 respectively (*n* = 47); the average annual survival rate being 91%. Although predation was the most important cause of adult mortality, all mortality sources combined (puma predation, legal and illegal hunting, disease, emigration) have not maintained deer population density low enough to prevent food limitation from occurring in the recent past.

[Keywords: invasion, *Cervus elaphus*, *Puma concolor*, predation, disease, radio telemetry, population dynamics, capture by net gunning]

RESUMEN. Un análisis preliminar de causas de mortalidad, mortandad relacionada a capturas y supervivencia en adultos de ciervo colorado en el noroeste de la Patagonia: El ciervo colorado (*Cervus elaphus*), uno de los 14 mamíferos exóticos más invasores, llegó a la Patagonia recientemente. Cuarenta y siete ciervos fueron capturados, marcados con radio transmisores y monitoreados para determinar la tasa de supervivencia e identificar causas de muerte. El método de lanzamiento de redes desde un helicóptero permitió que las capturas fueran distribuidas en toda el área de estudio y en corto tiempo. La ausencia de mortalidades relacionadas a este método coincide con las bajas tasas reportadas. El monitoreo de los animales alcanzó periodos de entre 5 y 2611 días. Diez animales proveyeron valores restringidos (censored values) debido a radios fallados o por haber sido cazados: sobrevivieron un promedio de 811 días (*ES* = 221). Diez animales murieron por causas naturales con un promedio de vida de 413 días (*ES* = 106) después de la captura: ocho fueron depredados por puma (*Puma concolor*). Los restantes 27 animales vivieron un promedio de 974 días (*ES* = 52). El 21% de los animales murió por causas naturales dentro de los 38.549 días-ciervo. Aplicando el método Kaplan-Meier, las tasas anuales de supervivencia para el periodo 2001-2003 fueron 0.89, 0.91 y 0.92 respectivamente (*n* = 47); la tasa promedio anual fue del 91%. Aunque la depredación por puma resultó ser la causa principal de muerte de ciervos adultos, todas las fuentes de mortalidad combinadas (depredación, caza ilegal y legal, enfermedades, emigración) no han logrado mantener la densidad lo suficientemente baja en el pasado como para prevenir una limitación poblacional por falta de forraje.

[Palabras clave: invasión, *Cervus elaphus*, *Puma concolor*, depredación, enfermedades, radio telemetría, dinámica poblacional]

✉ Consejo Nacional de Investigaciones Científicas y Tecnológicas, CC 176, 8400, Bariloche, Argentina.
deerlab@baritel.com.ar

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Introduction

The establishment of alien species in natural areas is a major component of global change. Work on introduced alien species has focused on economic losses and detrimental ecological impacts as well as on the positive benefits derived from a novel renewable resource. Of primary concern is how exotic species might influence the persistence of native ones, affect species biodiversity and ecosystem functions (D'Antonio et al. 2001). The red deer, *Cervus elaphus*, effectively adapts to new environments and is considered to be among the world's 14 worst invasive alien mammal species (Lowe et al. 2000). Though the invasion of red deer in Argentine Patagonia began less than a century ago, population growth has yet to stabilize and a state of equilibrium between vegetation and deer has not been reached (Flueck et al. 2003). Negative ecological impacts have been described both for Chile and Argentina however, neither economic losses nor changes to native biodiversity or ecosystem functions have been quantified yet (Ramirez et al. 1981; Veblen et al. 1989). One major potential impact on ecological processes could operate through competition as is thought to occur between red deer and guanaco (*Lama guanicoe)*(Bahamonde et al. 1986; Flueck 1996) or huemul (*Hippocamelus bisulcus)* (Creswell 1972; Lever 1985; Smith-Flueck 2003). Furthermore, the numerical and geographical characteristics of the red deer distribution and their land use behavior raise concerns over their potential epidemiological role for various diseases important in conservation and the livestock industry, including foot and mouth, brucellosis and tuberculosis (Longhurst et al. 1952; Thorne et al. 1979; Rhyan et al. 1995; Fletcher 2001). In contrast, the corollary of these negative impacts arise from the observation that well-established red deer populations, if appropriately managed, can provide an economic asset for certain sectors of the human population (Flueck et al. 1995). Knowledge of the factors driving the population's dynamics is fundamentally necessary for elaborating management strategies (Eberhardt et al. 1996). However, in a recent review of studies on large herbivore vital rates, Gaillard et al. (2000) pointed out that the greatest obstacle to better understanding of the population dynamics of large herbivores is the scarcity of long-term field studies of marked individuals. Telemetry studies present an efficient way to study survival patterns and cause of mortality. Additional reasons for live capturing and tagging wild ungulates, include the surveillance of disease status, translocations, or for procuring founder stock. In this study, we provide an analysis of capture-related mortalities, cause-specific natural mortality rates among adult deer, and causes of death based on radio-telemetered animals.

Methods

Habitat characteristics of capture sites

The capture site was located on a private land within the Nahuel Huapi national reserve, in the province of Neuquén (40º58'S; 71º12'W), Argentina, between 750 and 1600 m.a.s.l. (Fig. 1). During the autumn when deer were caught, they could be found across a range of habitats and slopes of up to 75% incline: patches of forests characterized by ñire (*Nothofagus antarctica*) and ciprés (*Austrocedrus chilensis*) at lower elevations, and by lenga (*Nothofagus pumilio*) at higher elevations; wet grasslands, grass-dominated steppe of coirón amargo (*Stipa speciosa* var. *major*) and coirón dulce (*Festuca pallescens*) with variable occurrence of brush species like neneo (*Mulinum spinosum*), calafate (*Berberis* spp.) and espino negro (*Colletia spinosissima*); riparian areas containing gallery trees like radal (*Lomatia hirsuta*), maitén (*Maytenus boaria*) and laura (*Schinus patagonicus*). In 1994, the population density was estimated at about 100 deer per km^2 (Flueck et al., unpubl. data), though a severe drought in 1998/99 reduced considerably the density; since then, favorable conditions have resulted on a growing population (Flueck et al., unpubl. data).

Captures

For initial captures in 1992, we used five sections of drive net totaling 150 m in length (Van Reenen 1981; Thomas & Novak 1991). A helicopter or men on horseback were used to herd the animals towards the drive nets. As it was necessary subsequently to capture a large number of individuals in a short time period, the paramount goal was to use the best method based on current knowledge in order to reduce the risk of mortality and morbidity of the animals, as well as to minimize impacts related to animal welfare. Thus, net gunning from helicopter was chosen in 2001 as the objective was to capture 20-40 deer dispersed over approximately 130 km² (Flueck et al., unpubl. data). The capture team comprised a local pilot, one assistant to locate animals and help restrain them, and an experienced net gunner. Subsequent captures in 2002/3 were made by darting. In all cases, we caught animals either after the autumn hunting season (March/April, $n = 40$), or in winter (August/September, $n = 7$).

All animals were hobbled and blindfolded immediately after capture. To process animals caught in drive nets, a mixture of ketamine and xylazine was administered intramuscularly at approximately 6 mg and 2 mg per kg body weight, respectively. For the reversal, 0.3 mg/kg body weight of yohimbine was administered intravenously (Jessup et al. 1983; Golightly & Hofstra 1989). Captures by darting used thiafentanil and naltrexone hydrochloride was used for the reversal (Citino et al. 2002). Darting range was < 30 m and darts were placed in the gluteal muscle. Animals captured by net gunning were not subjected to chemical immobilization (Flueck et al., unpubl. data). All animals were ear tagged and fitted with VHF and GPS radio transmitters. All radios contained a motion sensor and a switch to indicate death (no movement for four hours). As cervids rarely are motionless for 4 hours, the changed signal likely indicates the death of the individual.

Monitoring, evaluation of mortality cases and analysis

Animals were daily checked for 2 weeks after initial capture, and once per week thereafter until death. As soon as a radio transmitted in mortality mode, a search was initiated to evaluate the cause of death. A field necropsy was performed (Salwasser & Jessup 1978; Wobeser & Spraker 1980) and pathological changes were evaluated according to Davis & Anderson (1971), Davis et al. (1981) and Jones & Hunt (1983), with signs of predation according to Wade and Bowns (1982) recorded. Mortalities occurring > 10 days post-capture were considered to be unrelated to capture (Flueck et al., unpubl. data). Radio failure was defined as absence of radio signal for more than a year, and the date of the last signal was used as the

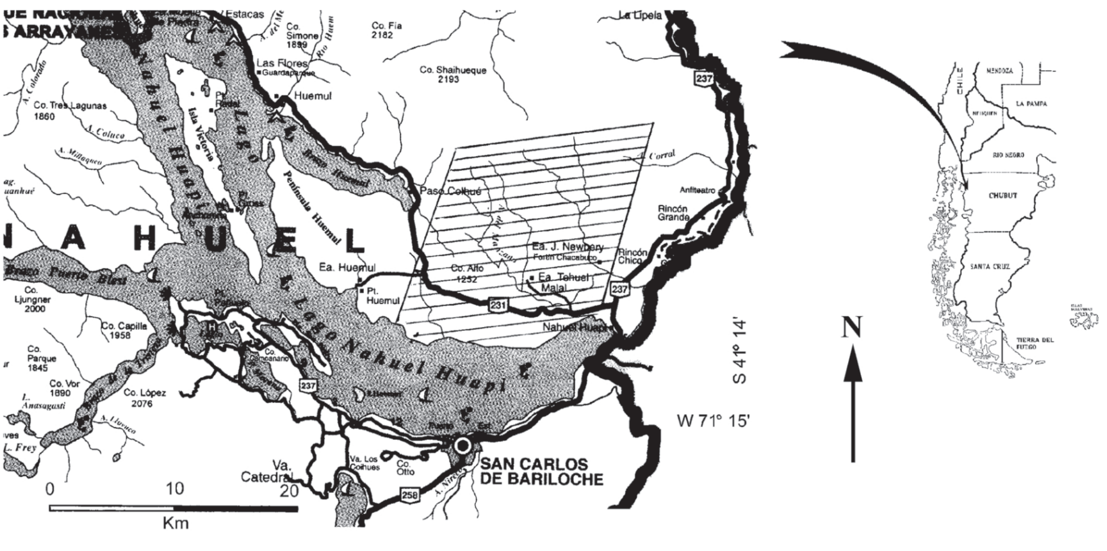

Figure 1. Study area in the Nahuel Huapi national reserve

Figura 1. Área de estudio en la reserva nacional Nahuel Huapi end point for these censored values (Pollock et al. 1989). Animals shot by hunters, accidentally or illegally, were also used as censored values. The survival function was evaluated using the Kaplan-Meier procedure for a staggered entry design (Pollock et al. 1989) using 3 months time intervals. The animal marked in 1992 was added to the next group marked in 2001 for the analysis (Pollock, pers. com.).

Results

The monitoring of marked animals was based on a total of 3.044 VHF telemetry readings and span periods of 5 to 2.611 days. There appeared to be no capture-related mortalities, irrespective of the method used (Table 1). Capturing by means of net-gunning, darting and drive nets, using helicopters or men on horseback, resulted in a capture of 41, 5 and 1 deer respectively.

A total of 10 cases were considered censored: 4 radios apparently failed after fitting, 2 animals were shot accidentally (i.e. they were not illegal takes), and 3 animals were collected. An additional animal migrated into the Nahuel Huapi National Park where it was clearly illegally shot. The area was closed off to hunting, and although the animal remained completely intact, we found 2 more fresh un-collared deer killed and butchered nearby. The average time these 10 animals survived after capture was 811 days (*SE* = 221). The death of 10 animals was detected by telemetry, with an average time alive after capture of 413 days (*SE* = 106). Of these, 9 animals survived > 35 days after capture, and one case was killed by a puma (*Puma concolor*) 5 days after capture. A thorough examination of the nearly intact carcass did not reveal any trauma or secondary complications resulting from the capture. The remaining 27 animals were alive since capture for an average of 974 days (*SE* = 52).

Due to advanced scavenging, the cause of death was undetermined for 1 animal found 50 m from a major highway. The head and neck area clearly had no signs of puma predation, the animal was only 3 years old and was possibly illegally shot, which is common along that highway. Another animal was found dead in a bedded position without signs of predation. Although the cause of death could not be determined, the area is frequented by poachers and a possible scenario is abdominal injuries from small caliber rifles. The remaining 8 animals died from puma predation (Fig. 2).

Of all marked animals, a 21% died of natural death during 38.549 deer-days, equivalent to an approximate annual adult mortality rate of 8.6%. Using the Kaplan-Meier procedure, the annual survival rates (*SE*) for the years 2001-2003 were 0.89 (0.05), 0.91 (0.05) and 0.92 (0.05), respectively ($n = 47$); the average annual survival rate being 90.8%.

Discussion

Capturing red deer in drive nets through herding by helicopter failed due to the inexperience of the pilot. As an alternative, herding

Table 1. Capture method, survival and cause of mortality of red deer adults in northwestern Patagonia.

Tabla 1. Método de captura, supervivencia y causa de muerte de individuos adultos de ciervo colorado en el noroeste de la Patagonia.

Capture Method	Predated or undetermined *n*	Died < 10 days *n*	Alive *n*	Censored* *n*
Net gun	10	1**	24	7
Darting			3	2
Drive net				1
Days survived (SE)	413 (106)		974 (52)	811 (221)

* radio failure, accidental and illegal hunting, collection

** fresh puma kill without indications of capture-related injuries by men on horseback was tried, and although one animal was captured, it was considered an inefficient method. Net-gunning from a helicopter has become the deer catching method of choice as it is more efficient, causes less trauma and stress, and reduced morbidity and mortality, compared to alternative methods (Andryk et al. 1983; Krausman et al. 1985; Jessup et al. 1988; Carpenter, pers. com.). Benefits include zero drug use, animals are only pursued for a very short distance, and there is no need for much personnel and logistics, thus making it more economical. This method permits captures during any daytime hour in areas that are hard to access due to topography, vegetation or snow and it allows large areas to be covered in any one attempt.

The absence of capture related mortality in our study agrees with previously reported low rates using net guns with helicopters. Carpenter (pers. com.), for example, reported < 2% capture-related mortalities based on 2598 telemetered animals (also see Kock et al. 1987; Jessup et al. 1988; DelGiudice et al. 2001). In Argentina, an ongoing project focusing on the endangered Pampas deer (*Ozotoceros bezoarticus*) also determined that helicopter net-gunning would be the most efficient and humane capture method, discarding the use of dart gunning which had resulted in a 6% mortality in an earlier operation (Beade 2003). In Brazil, threatened marsh deer (*Blastocerus dichotomus*) were successfully captured by helicopter (Nunes et al. 1997; Mourao et al. 2000). Similarly, in 1989 helicopter capture of the endangered huemul in Chile was the recommended method of capture to provide stock for a breeding center to produce stock for future re-introductions (CONAF, unpubl. data).

The radios that were not relocated may have broken, though it is also possible that animals wearing them might have dispersed. Topographic features of the study area may have masked a signal even when the animal had not moved a great distance. Although several aerial censuses had been conducted in attempts

Figure 2. Remains of deer killed by puma

Figura 2. Restos de ciervo depredado por puma to locate animals, the areas surveyed might have been too restricted to find animals that had emigrated long distances. For red deer of both sexes, dispersal distances of 30-60 km are common, but even females are known to disperse as much as 115 km in mountain habitat similar to our study area (Ruhle & Looser 1991; Haller 2002).

Impact of legal hunting could not be evaluated as hunters were instructed not to harvest marked animals. The causes of death we detected confirm that illegal hunting does occur and generates a continuous supply of venison to local markets in various nearby towns. However, its impact on the population dynamics is likely to be minimal and may simply slow the rate of population growth as it is not thought to depress deer densities (Flueck 2001). Puma predation also appears to be a frequent cause of death for adult red deer. Ballard et al. (2001) found that puma predation is more important among adults than neonates, and therefore it has a greater impact on the population dynamics (Gaillard et al. 2000). However, it is clear that all mortality sources combined (puma predation, legal and illegal hunting, disease, emigration) have not maintained deer population density low enough to prevent food limitation from occurring in the past as evidenced by poor body condition and its impact on reproduction (Flueck 2001). Mortality rates for adult female red deer in non-growing populations reportedly range from 11-67% (Lowe 1969) and 1-67% (Caughley 1971) depending on age class. Pollock et al. (1989) estimated that, using their modifications of the Kaplan-Meier survival estimator, precision was poor with < 20 animals and good with 40-50 animals. Our annual survival estimates for adult red deer thus are precise ($SE = 0.05$ based on 47 animals). The average annual survival rate of 0.91 for adults across all age classes in this study is similar to the 0.89 reported for harvested *C. elaphus* by Stussy et al. (1994), the 0.97 for prime-aged and 0.79 for senescent females in an unharvested population by Garrott et al. (2003). These high survival rates, as an important factor promoting population growth (Nelson and Peek 1982; Gaillard et al. 2000), suggest that growth in this population occurs unchecked until limitation by food shortage sets in.

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