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Capture of the vicuña (*Vicugna vicugna*) for sustainable use: Animal welfare implications

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ABSTRACT

The current program of vicuña conservation includes their live-capture for wool harvest in the Andes Region in northern Chile. Here, we describe studies that assess the impacts on the species of different variables relating to the capture process. The immediate physical and physiological effects on vicuña of contrasting capture methods, chase distances and restraint were measured.

Comparisons between two methods of capture showed that cortisol concentrations were higher in animals herded using vehicles alone compared to those herded using a combination of vehicles and local people on foot. Blood glucose levels, heart rate and respiratory rate showed an immediate but ephemeral response to herding into a corral. The range of distances over which animals were herded caused less noticeable changes in blood and physical parameters. The most marked changes were associated with restraint, during which there were significant increases in creatin kinase, packed cell volume and rectal temperature. The implications of changes in these parameters on vicuña welfare and conservation are discussed.

1. Introduction

The vicuña (*Vicugna vicugna*), a South American wild camelid, has been captured, handled and sheared since the 15th century, when the Inca Empire conducted the "chaku" throughout the Andes of South America (Hurtado, 1987; Torres, 1992). The chaku consisted of herding thousands of vicuña into stone corrals for shearing. Local people surrounded large areas and walked behind the animals towards large corrals. Although large numbers of animals were sheared by this method, associated morbidity and mortality probably had little effect on their populations because the process was conducted only once in every 4 years in any given region. When Europeans arrived in South America, the traditional chaku was replaced by indiscriminate hunting (Hoffmann et al., 1983; Cueto et al., 1985; Hurtado, 1987; CONAF, 1991). This, as well as livestock competition and possibly disease brought by domestic European livestock, led to a drastic decline in vicuña numbers over the last hundred years (Koford, 1957). Now, after 30 years of protection, the vicuña has recovered from its previous endangered status and a program of sustainable use is now in place (Bonacic et al., 2003). This sustainable use program is intended to provide economic benefits to local indigenous communities, thereby fostering the species' conservation. The sustainability of this programme is being questioned (Lichtenstein and y Vilá, 2003) although it seems

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that capturing and releasing back to the wild is not detrimental to vicuna in the ways that it is in many other cases in South America (i.e. other ungulates, see Altrichter, 2005). However, several aspects of the effects of capture for shearing on wild vicuña are yet unknown.

There are more than a quarter of a million animals in 5 countries and more than 43 tons of fibre have been sold over the last 10 years. Hence, many small enterprises are starting to capture animals for shearing (Lichtenstein and y Vilá, 2003). Yet there are no animal welfare recommendations available to practitioners, and physiological and ecological findings are not linked in previous studies (Bonacic et al., 2002).

Current policies for vicuña management include practices such as capture and shearing of wild animals, farming, ranching, and translocation and reintroduction (Cueto et al., 1985; Torres, 1987, 1992; Urquieta and Rojas, 1990; Rebuffi, 1993; Urquieta et al., 1994; Wheeler and Hoces, 1997; Galaz, 1998). Despite the importance of handling in the management of vicuña populations, little is known about their response to handling and captivity. However, it is likely that vicuña become stressed by human contact in a similar way to other wild ungulates (Wesson et al., 1979). Poor welfare may add a new mortality factor and increase the risk of less efficient captures in the future, affecting population and economic viability of the utilisation programme. Therefore, this paper addresses the potential animal welfare consequences of capturing and shearing wild vicuñas.

Animal welfare is determined by the degree of adaptation that animals can achieve in human-designed environments, without experiencing any suffering. Since wild vicuñas are driven into human made facilities, restrained, handled and sheared, it is likely that animal welfare problems may occur.

Capture and transportation can cause significant stress in wild ungulates, as well as in carnivores and birds (Bailey et al., 1996; DeNicola and Swihart, 1997; Grigor et al., 1998; Little et al., 1998). In ungulates, such as red deer (*Cervus elaphus*) and white-tailed deer (*Odocoileus virginianus*), capture and immobilisation are known to cause stress, as indicated by changes in haematological and biochemical blood constituents (Wesson et al., 1979; Vassart et al., 1992; Beringer et al., 1996; DeNicola and Swihart, 1997; Marco et al., 1998). Specifically, capture and restraint can cause capture myopathy, also known as exertional myopathy, a syndrome observed in wild and domestic animals (for a review see Wesson et al., 1979; Beringer et al., 1996; Williams and Thomas, 1996; DeNicola and Swihart, 1997). Capture myopathy is caused by complex metabolic changes that may result in per-acute (immediate, within seconds or minutes) fatal acid–base and electrolyte imbalances (Fowler, 1989).

Changes in biological and haematological parameters vary according to the capture method, species and previous capture experience of the animals (Morton et al., 1995). However, some general trends can be described. Several physiological variables are affected by capture stress in a manner similar to stress induced by exercise. The variables likely to respond immediately are core body temperature (as reflected by rectal temperature), cathecholamine levels, heart rate, respiratory rate and packed cell volume, as is the case in other species (Eckert and Randall, 1983; Radostits et al., 1994; Schmidt-Nielsen, 1997; Harris et al., 1999). A less acute response (i.e. from minutes to hours) should be observed in blood glucose, plasmatic cortisol concentrations and creatin kinase (Coles, 1980; Kaneko et al., 1997; Bateson and Wise, 1998; Harris et al., 1999). Finally, some parameters may change within hours to days, such as aspartate aminotransferase, total protein and blood urea nitrogen as well (Kaneko et al., 1997; Harris et al., 1999).

Against this background, we would expect different methods of capture to have different effects on vicuña, and studying these could reveal ways to substantially reduce stress before shearing. Several capture methods for shearing are currently used for vicuñas in South America (Bonacic and Macdonald, 2003). The simplest capture method, which emulates the ancient chaku and is currently used in Perú (Wheeler and Hoces, 1997), involves people slowly herding groups of 20–500 vicuña into a wire-fenced corral (Bonacic and Gimpel, 2001; Bas and Bonacic, 2003). An alternative method uses vehicles (motorbikes and pick-up trucks) to chase small groups of animals for up to 5 km into fenced corrals (Bonacic, 2000). This is the most common system used in Chile (Bonacic and Gimpel, 2001). These two methods differ in the speed of the chase and the amount of time for which animals are held in captivity (Bonacic and Macdonald, 2001, 2003). An intermediate method, which combines vehicles and people, has also been used in Chile and Argentina. Vehicles herd groups from the perimeter of the capture site and people help to enclose the animals when they approach the corral (Bonacic et al., 2001). Once animals have been enclosed there, they are either restrained (tied up by ropes in sternal recumbency) before shearing begins or, alternatively, held unrestrained in an adjacent corral (Bonacic, 2000).

This study investigated how these last two contrasting capture systems (using vehicles only or a combination of vehicles and people walking on foot), distance over which vicuñas were herded, and whether or not they were restrained affected their physiology. We conducted a clinical examination and measured blood parameters immediately after capture. As a consequence of the capture assessment, a series of animal welfare recommendations are suggested in order to minimise any negative consequences of the capture of this wild species for shearing.

2. Materials and methods

The studies were conducted on sub-sets of free-living animals and involved the observation of capture and handling events for shearing organised by local people and the Chilean Government. Captures were carried out in Las Vicuñas National Reserve (Chile), Parinacota Province in Northern Chile (209,131 ha; South 18°16′–19°00′ and West 68°57′–69°27′). Rainfall there (annual mean 200–331 mm) is concentrated in summer, between December and March. Winter is dry and cold between May and August. July is the coldest month of the year with −0.04 °C and January is the warmest month of the year with a mean of 8 ° C (Bonacic and Macdonald, 2003).

A total of 407 vicuñas were captured between March 1997 and November 1998 in 41 unrelated capture events. The effect of capture on the animals was assessed for all subjects pooled together and compared to reference values from captive vicuña (see Bonacic and Macdonald, 2003 for details of captive in situ stress studies). The studies were conducted on 3 subsets of animals, concerning, respectively, the effects of (1) capture method, (2) herding distance and (3) restraint, on a range of physiological variables. Blood samples were taken by jugular venepuncture and details of each laboratory test are available in studies conducted by the same authors (Bonacic and Macdonald, 2003; Bonacic et al., 2003). Each physical and blood parameter was checked for normality and homocedasticity (Gurevitch and Scheiner, 1993; Underwood, 1997). Blood parameters from captured animals were compared with reference values from habituated captive vicuña held in the same study area, captive-born vicuña taken from private collections and reference values in the published literature for the vicuña and other South American camelids (Bonacic, 2000; Bonacic et al., 2003).

2.1. *The effect of capture method*

Two contrasting capture methods were compared within the same location and season, in October 1997 and 1998, to evaluate how physical and physiological variables were affected by the procedure of capture. The capture methods differed regarding the herding system. One method used vehicles only, while the other employed a combination of vehicles and people. The capture of vicuña with vehicles consisted only of a small team of professional rangers using vehicles to herd animals into a corral where they were held, unrestrained, until shearing. Vehicles were *Chevrolet Luv* pick ups and motorbikes with noise levels below 80 dB each (European Parliament fact sheet: Noise, 2001). The second method, capture with vehicles and people, involved vehicles chasing the animals until they reached the entrance of the funnel formed by the fences leading to the corral, followed by local communities (30–40 people) and rangers herding the animals into the corral by walking behind them (in silence) while holding a rope with coloured plastic strips used as visual barriers. Both methods used a corral that was divided into four sub-corrals: reception, enclosure, shearing area and pre-release corral. Gates connected sub-corrals and plastic covers prevented sight between them.

The capture parameters recorded were herding distance (m), herding time (min) and mean speed (km/h). Herding distances were recorded for each capture event using motorbike speedometers. Herding time was recorded from a vehicle behind the motorbikes from the moment the animals started to run (start time) until the chase ended with the animals enclosed in the capture corral. The mean speed of herding was determined on the basis of distance and time or, where distance could not be measured, by means of repeated records of the vehicle speedometer.

To evaluate the effects of herding distance and herding time, a linear regression model was used, with physical parameters (rectal temperature, heart rate and respiratory rate) and blood parameters (blood glucose, packed cell volume, creatin kinase, cortisol and white blood cell count) as dependent variables, and herding time or herding distance as the independent factor.

The two capture methods were compared within age categories using a mixed random nested model (SPSS, 1997). The model was nested because individuals belonged to social groups, and were herded from the total population into the capture facilities. This approach also took account of the fact that individuals were sampled at different times within each group. A mean for each group was compared with the mean of other groups and reflected the effect of capture method.

Twenty-three groups of vicuña were sampled to study the effect of capture with vehicles alone ($n = 167$ vicuña) in October 1997and October 1998 and compared with six groups that were captured by vehicles and people in October 1997 ($n = 56$ vicuña).

2.2. *The effect of herding distance*

The effect of the herding distance was studied by comparing blood samples from the first animal captured from independent groups that were herded for different distances.

2.3. *The effect of restraint*

The effect of restraint on vicuña was studied in March 1997. A sample of vicuñas, captured by herding with vehicles into a semi-circular corral, was restrained with ropes for different lengths of time and the effects on physical and blood parameters were measured. The first animal captured in each group was sampled immediately, therefore it was considered to have no effect of restraint and was used to compare against the other subjects. A second group of animals that was restrained for less than 15 min were considered the short restraint time group and a third group that was restrained for more than one hour constituted the long restraint time group. The animals remained restrained throughout the period of handling and sampling and were released back to the wild on the same day. A second group of animals, held in a corral prior to blood collection without the use of ropes (unrestrained) for a variable period of time, was also studied and the same parameters were measured. These animals were also released back to the wild on the same day of capture.

Restrained animals were compared with unrestrained animals correcting by restraint time (covariance). This allowed the comparison of the effect of restraint for both groups and eliminating the confounding effect of different sampling times since captivity and restraint began.

3. Results

Overall, capture events were characterised by a mean herding time of 10 min: 52 s ± 45 s ($n = 29$ groups) with a mean herding distance of 3999 m ± 270 m ($n = 28$ groups) and a mean speed of 25.7 km/h ± 1.7 km/h ($n = 29$ groups). The mean time that each animal was held in the corral before sampling and shearing was 16 min ± 2 s. In total, 33 independent groups of vicuña were rounded up, captured and sampled. The mean group time in captivity was 1:38 h ± 8 min ($n = 33$). Capture with vehicles alone was the fastest method, with a mean speed of 34.4 km/h ± 3.1(s.e.) compared to capture by vehicles and people on foot (4.9 km/h ± 6.6 s.e.). Captures with vehicles ($n = 23$ groups) also covered greater distances (range 4000–4175 m) than vehicles and people on foot (range 720–860 m; $n = 6$ groups). Overall, there was no significant difference in herding time between the two herding methods used

($F_{1,3} = 0.6$, $p = 0.5$). This can be explained by the significant difference in herding distance between methods ($F_{3,32} = 3.3$, $p = 0.03$). Vehicles had a larger range allowing more rapid herding and capture than could be achieved by people on foot. Total time that the animals were maintained in captivity was positively related to group size captured (R^2: 0.71, $F_{1,41} = 103$, $p < 0.001$). Larger groups remained for longer periods of time in captivity because they were not released until the last animal of their group had been sampled. Individual mean waiting time (total group time/group size) to be sampled and sheared was similar between capture methods (16 ± 2 min; $F_{1,38} = 1.2$, $p = 0.2$; range: 1–6 h). That is, larger groups did not cause an efficiency loss in each individual handling time, considering the range of group sizes captured in this study (range 1–19 animals).

Less than 1% of all captured animals presented trauma and nose bleeding as a consequence of crushing against posts of the corral. No mortality was recorded during the capture and handling. Crias (less than 1 year old animals) were immediately removed from the group and kept separately to avoid physical damage by crushing between adults.

3.1. *The effects of capture*

Five variables were affected by capture when compared with baseline values from captive animals (Bonacic and Macdonald, 2003; Bonacic et al., 2003). Rectal temperature, heart rate, respiratory rate, creatin kinase, and plasmatic cortisol concentration all increased as a result of capture, beyond the normal range described for vicuña and other South American camelids (Bonacic and Macdonald, 2003). For example, plasmatic cortisol was 41% higher than baseline values, suggesting an active response to capture. In contrast, blood glucose, packed cell volume, aspartate amino transferase, plasma protein, blood urea nitrogen, blood cell count, differential white blood cell counts and N:L ratio were within normal ranges suggested for the species.

3.2. *The effects of herding distance*

There was no significant effect of herding distance on any of the physical and blood variables measured. The effect of herding was studied in 37 vicuña with a mean herding distance of 3917 ± 281 m (range 695–6800 m) and a mean herding time of 10 min: 39 s ± 43 s (range 2–22 min). Only rectal temperature, heart rate and respiratory rate reached values outside the normal range for the species, indicating a short agitation response to exercise (Table 2).

3.3. *The effects of restraint*

Animals that were restrained in the enclosures had significantly higher creatin kinase levels, increased neutrophil: lymphocyte (N:L) ratio, packed cell volume and blood glucose (Table 1) compared to unrestrained animals. Longer restraint times also caused significant changes in the blood parameters, indicating excessive exertion. Longer restraint time was significantly correlated with an increase in blood enzyme values (creatin kinase and aspartate aminotransferase) and blood parameters (packed cell volume, N:L ratio). Animals with higher creatin kinase also showed higher levels of blood glucose and higher rectal temperature. The N:L ratio tripled in animals restrained for longer periods (Fig. 1) and creatin kinase rose ten times above values recorded from unrestrained animals (Fig. 2).

Comparison with the mean of the first animals sampled in each group, considered to be the reference control value because they were handled and sampled immediately following capture, showed little difference in physical variables with animals sampled within 15 min post-enclosure. The main differences observed were with the mean values for the animals

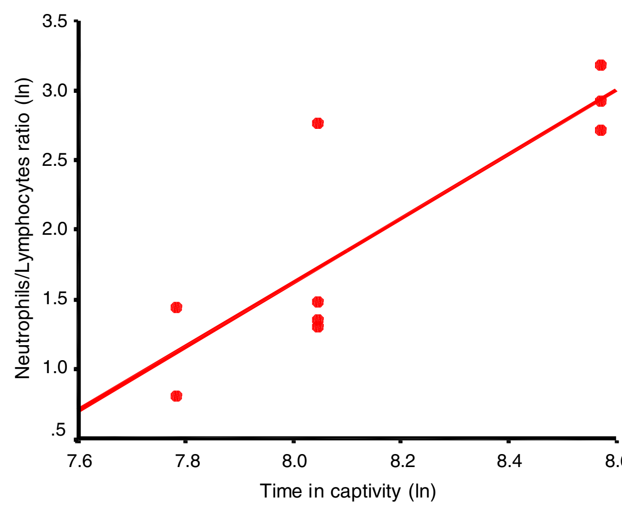

Fig. 1 – Neutrophils:lymphocyte ratio increase in juvenile vicuña by time. N:L ratio (ln) increased linearly with increased restraining time in corral ($F_{1,7} = 15.5$, $p = 0.006$).

Table 1 – Comparison of physical parameters between restrained and unrestrained vicuña

Parameter	Parameter Reference values	Treatment: Restrained (*n*) Mean ± SE	Treatment: Unrestrained (*n*) Mean ± SE	ANOVA Significance test: F	df	Sig.
Creatin kinase (IU/l) (ln)	1–4.9	4.8 ± 0.1	6.1 ± 0.2	40.6	1,133	0.001
Neutrophils:lymphocyte ratio (ln)	0.58	1.5 ± 0.5	3.4 ± 0.5	5.8	1,28	0.002
Packed cell volume (%)(arcsine)	15.6–26.7	36.6 ± 0.2	37.7 ± 0.4	7.6	1,184	0.006
Blood glucose (mg/dl)	102 ± 6.5	117.7 ± 3.2	223.5 ± 6.8	195.3	1,165	0.001

Note: ANOVA model included time of sampling as covariate. Reference values (Bonacic et al., 2003).

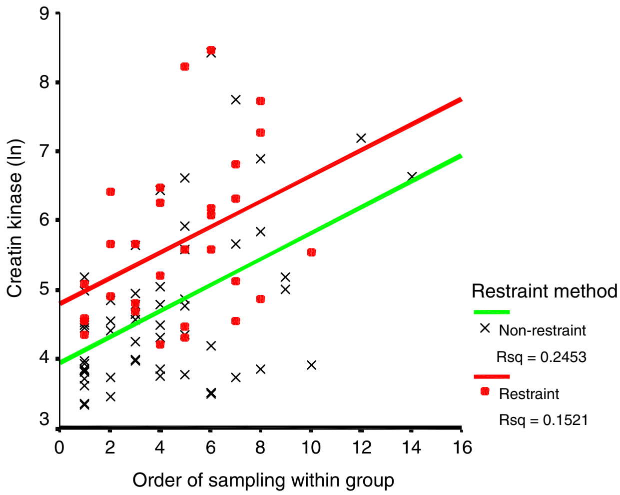

Fig. 2 – The effect of restraining time on creatin kinase (restraint effect: $F_{1,83} = 22.3$, $p = 0.000$; covariance sampling time: $F_{1,83} = 13.0$, $p = 0.000$).

restrained beyond 1 h. They had higher rectal temperatures, packed cell volume, blood glucose, aspartate aminotransferase and creatin kinase (Table 1).

3.4. *Comparison between capture methods*

The two capture methods were similar in terms of mean herding time, herding distance, speed, waiting time and group size captured (Table 2). The total of animals captured in 28 independent groups had a mean body weight (kg) of 31.3 ± 0.7 ($n = 164$). Animals captured by vehicles only showed higher rectal temperature, glucose, aspartate aminotransferase and cortisol than animals captured by vehicles and people (Table 2). Calves had the highest absolute values for cortisol after capture by vehicles (see Table 3).

4. Discussion

The data presented in this paper relate to the responses of specific stress markers in blood serum responding to two different capture systems (for shearing effect see Bonacic and Macdonald, 2003). From these data, it is possible to suggest explicit animal welfare recommendations, even though it is not possible to set exact limits to each activity, because animal welfare consequences of human interventions affect individuals rather than populations as a whole. We therefore give clear and simple animal welfare recommendations based not only on the physiological data obtained, but also on our experience and judgement of the whole capture practice (but also see Mendl, 1991, who criticises the use of cut-off points in animal welfare recommendations). This is not particularly different from any other discipline within conservation science. Conservation recommendations are based on robust data, past experience and sensible judgement. The physiological, behavioural and capture data reported in this paper and our other cited papers provide enough information to support our specific recommendations.

4.1. *Animal welfare recommendations*

The capture and shearing of vicuñas is logistically complex and many factors are involved. We found that capturing for shearing triggered an acute stress response directly related to the capture method, which was reflected in the physiological parameters described above. Captures, regardless of the method, should also consider that acute stress may trigger long term consequences in animals after they are released back to the wild. Undesirable consequences of poor animal welfare standards are:

1. Injuries and death.
2. Separation of crias from females because of human disturbance (see Birtles et al., 1988).
3. Muscle damage and body trauma that may impede escape from predators or proper movement in the wild.
4. Crushing and stress of pregnant females predisposing to abortion.

Captures should always round up groups of males if possible and, if family groups are captured, crias and young animals should be handled first and separated immediately into an adjacent corral to avoid crushing during handling. Crias should be released back to the wild with the whole group. Clearly, rounding up hundreds of animals from different groups may be commercially ideal but likely to cause stress, injuries and death, particularly in young animals. Blindfolding animals for handling proved to be significantly positive in terms of reducing stress and should be a regular practice (see Bonacic and Macdonald, 2003).

In the past, only one study, in the Peruvian Altiplano, has described selected blood parameters in captive vicuña (Copaira, 1949). However, the effects of restraint on physiological parameters are still poorly understood in South American wild camelids (Fowler, 1994; DeNicola and Swi-

Table 2 – Mean values for both capture variables pooled for vehicles, and vehicles and people

Parameters	Summary statistics for capture variables			Statistical comparison between methods		
	Mean ± SE	Minimum	Maximum	*F*	d.f.	Sig.
Herding time (min:s)	11:28 ± 55 (29)	00:02:00	00:24:00	0.4	1,27	0.5
Herding distance (m)	4138.2 ± 271.4 (28)	800	6800	0.1	1,26	0.8
Mean speed (km/h)	24.5 ± 1.4 (29)	12	39.7	0	1,27	1
Mean waiting (min:s)	17:47 ± 02:34 (33)	00:07:40	01:25:00	1.1	1,31	0.3
Group size (*n*)	6.7 ± 0.6 (33)	1	19	1.1	1,31	0.3

Table 3 – Comparisons of two capture methods on physical and blood parameters for adults, juveniles and calves

Age categories	Capture methods		Mixed nested model		
	Mean ± SE parameter		With body weight and sampling time as covariate		
	Vehicles	Vehicles–people	Statistical significance		
	Mean ± SE	Mean ± SE	F	d.f.	Sig.
Rectal temperature (°C)					
Adults	39.8 ± 0.1	39.8 ± 0.1	0.25	1,22	0.6
Juveniles	40.0 ± 0.2	39.8 ± 0.1	0.7	1,19	0.38
Calves	40.3 ± 0.2	39.8 ± 0.1	3.3	1,28	0.07
Blood glucose (mg/dl)					
Adults	119.1 ± 4.9	100.6 ± 4.7	5	1,23	0.03
Juveniles	114.5 ± 6.3	100.3 ± 4.4	1.7	1,16	0.2
Calves	121.2 ± 8.3	101.3 ± 4.8	3.2	1,39	0.07
Packed cell volume arcsine (%)					
Adults	36.2 ± 0.3	37.5 ± 0.3	6.8	1,23	0.01
Juveniles	37.4 ± 0.5	37.4 ± 0.3	0.001	1,22	0.97
Calves	35.8 ± 0.5	37.4 ± 0.3	3.3	1,29	0.07
Creatin kinase (ln IU/l)					
Adults	4.6 ± 0.2	4.8 ± 0.2	0.8	1,21	0.37
Juveniles	5.1 ± 0.3	5.0 ± 0.2	0.1	1,17	0.6
Calves	4.8 ± 0.3	5.0 ± 0.2	0.24	1,33	0.6
Aspartate aminotransferase (ln IU/l)					
Adults	5.0 ± 0.1	4.8 ± 0.1	4.5	1,33	0.04
Juveniles	5.2 ± 0.1	4.8 ± 0.1	6.6	1,28	0.015
Calves	5.2 ± 0.2	4.8 ± 0.1	3	1,45	0.08
Cortisol concentration (ln mmol/l)					
Adults	4.9 ± 0.1	4.5 ± 0.1	3.2	1,28	0.08
Juveniles	4.8 ± 0.1	4.5 ± 0.1	7.7	1,25	0.01
Calves	5.1 ± 0.2	4.4 ± 0.1	10.8	1,33	0.002

Note: reference values for vicuñas are rectal temperature 37.5–38.9 °C; glucose 95–150 mg/dl; packed cell volume 27–45%; aspartate aminotransferase 128–150 UI; creatin kinase 0–137 IU; cortisol 18–24 nmol/l (Bonacic et al., 2003; Bonacic and Macdonald, 2003; Fowler, 1989).

hart, 1997). Studies conducted on white-tailed deer have shown that packed cell volume and glucose are higher in animals manually restrained when compared to those anaesthetised or killed by shooting (Wesson et al., 1979). In our study, capture by herding over long distances (more than 4 km), or keeping the animals restrained for long periods (more than 15 min), caused more profound changes in physical and blood parameters than did shorter chases and brief restraint. The duration of restraint seemed to be the main factor causing stress and increasing the subsequent risk of exertion myopathy (Harris et al., 1999). Longer restraint times were associated with significantly greater creatin kinase, packed cell volume and glucose levels as has been found in other species after prolonged chases (Bradshaw and Bateson, 2000). In addition, animals subjected to longer and faster periods of herding had significantly higher levels of cortisol concentration. In a sustainable harvest programme of vicuña wool, both factors should be minimised. We conclude that the method of combining vehicles and people led to fewer changes in our measured physiological parameters than the chase using vehicles alone. The latter significantly increased the levels of cortisol, aspartate aminotranferase and glucose to the extent that it could have long-term effects on some animals.

This study was conducted under the challenging conditions of real round-ups in the field, thus we inevitably faced many potentially uncontrolled variables. However, by sampling more than 400 animals, by repeating the work over two years in the same area, and by contrasting results on wild and captive animals, we believe we have exposed the factors of greatest biological significance. Well-known markers of stress were evaluated and can now be used in future studies (Broom and Johnson, 1993; Wolfensohn and Lloyd, 1994; Webster, 1995).

4.2. *Conservation and sustainable use of the vicuña*

The role of conservation science in the protection of endangered species is well known (Sapolsky, 1994; Møller et al., 1998). Less well known is the importance of linking behavioural observations to physiological changes so as to understand welfare problems in exploited wild species. Only recently has the concept of sustainable use become widespread as a basic pillar of conservation (Eltringham, 1988; Robinson and Redford, 1991). The main aim of sustainable use is to reconcile the needs of local people and the conservation of the species that they use (Altrichter, 2005). Advocates of this approach often focus on benefits to whole communities (Robinson and Bolen, 1989; Bothma, 1990), and traditionally the products have been hunting quotas or controlled extraction of a natural resource (Eltringham, 1988; Robinson and Redford, 1991). More recently, alternative uses, seemingly less consumptive (such as eco-tourism), have been promoted (Bonacic, 1996). The use of vicuña wool lies somewhere on this continuum. However, the fact that vicuñas are released after shearing does not mean that the process is entirely non-consumptive, nor that the process impacts only the shorn individuals (Bonacic et al., 2001). European and other western societies are increasingly concerned about biodiversity and animal welfare. An inadequate management system could result in animal welfare, population and marketing problems since the products are offered as coming from 'sustainable sheared-and-released-back-to-the-wild vicuña'. The textile industry trades products from vicuñas in Europe and targets the ethical products market (J Sudgen, pers. com. 2005).

Physiological markers cannot alone evaluate welfare status. For example, higher cortisol values recorded following a race, or during mating, indicate little about the welfare status of an individual (Moberg, 1985; Møller et al., 1998). Likewise, increased heart rate and temperature cannot always be correlated with fear or stress, since animals can significantly increase their heart rate and body temperature during normal behavioural display without a direct indication that this is detrimental in any way. In the case of the vicuña, welfare problems were more apparent during long restraint periods. In general terms vicuna management means capture, chasing, rounding and restraining for shearing. We recommend that the techniques should, and can, be adapted in the light of our findings to limit the speed (40 km/h or less) and distance of motor vehicle chases (less than 3 km) and to minimise the use of restraint (no more than 15 min per animal). Also capturing young animals (less than 1 year) for shearing should be avoided. In the event that crias or less than 1 year old animals are captured in family groups they should remain non-sheared. Further research is needed to evaluate longer-term consequences of capture and shearing after the animals are returned to the wild. There are not enough data available at the moment to assess the long-term sustainability of this programme of vicuña use. However, we have clearly opened a new research area that needs addressing in this unique case of sustainable use that intervenes in populations but does not kill the animals during the process of use.

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REFERENCES

Altrichter, M., 2005. The sustainability of subsistence hunting of peccaries in the Argentine Chaco. Biological Conservation 126, 351–362.

Bailey, T.A., Samour, J.H., Naldo, J., Howlett, J.C., Tarik, T., 1996. Causes of morbidity in bustards in the United Arab Emirates. Avian Diseases 40, 121–129.

Bas, F., Bonacic, C., 2003. Adaptive strategies of South American Camelids. In: Mannetje, L.T., Ramirez-Aviles, L., Sandoval-Castro, C., Ku-vera, J. (Eds.), VI International Symposium on the nutrition of herbivores. Universidad Autonoma de Yucatan, Merida, pp. 21–33.

Bateson, P., Wise, D., 1998. Welfare of hunted red deer. Veterinary Record 142, 95.

Beringer, J., Hansen, L.P., Wilding, W., Fischer, J., Sheriff, S.L., 1996. Factors affecting capture myopathy in white-tailed deer. Journal of Wildlife Management 60, 373–380.

Birtles, T., Goldspink, C., Gibson, S., Holland, R.K., 1988. Calf site selection by red deer (*Cervus elaphus*) from three contrasting habitats in North-West England: Implications for welfare and management. Animal Welfare 7, 427–443.

Bonacic, C., 1996. Sustainable use of the vicuña in Chile. School of Animal and Microbial Sciences. University of Reading, Reading. p. 100.

Bonacic, C., 2000. Manejo sostenible de la vicuña: ¿'es posible conciliar la explotación de la especie y el bienestar animal? In: González, B., Bas, F., Tala, C., Iriarte, A. (Eds.), Manejo Sustentable de la Vicuña y el Guanaco. Servicio Agrícola y Ganadero. Pontificia Universidad Católica de Chile, Fundación para la Innovación Agraria, Santiago, Chile, pp. 193–205.

Bonacic, C., Bas, F., Macdonald, D.W., Villalba, L., Galaz, J., Villouta, G., 2001. Sustainable use of the vicuña (*Vicugna vicugna*): a critical analysis. In: Wildlife, land and people: priorities for the 21st century. In: Field, R., Warren, R.J., Okarma, H., Sievert, P.R. (Eds.), Proceedings of the Second International Wildlife Management Congress. The Wildlife Society, Bethesda, Maryland, USA, pp. 26–30.

Bonacic, C., Gimpel, J., 2001. The response to productive management in the wild vicuña and its animal welfare consequences. In: Garcia, F., Cretton, P., (Eds.), International Symposium in Animal production and the environment and XXVI Meeting of the Society for Animal Production, pp. 67–76.

Bonacic, C., Macdonald, D.W., 2001. Preliminary physiological assessment of the effects of capture for shearing on vicuña (*Vicugna vicugna*). In: Gerken, M., Rainieri, C. (Eds.), Progress in South American Camelids Research. Wageningen Press, Gottingen, pp. 34–39.

Bonacic, C., Macdonald, D.W., 2003. The physiological impact of wool-harvesting procedures in vicuñas (*Vicugna vicugna*). Animal Welfare 12, 387–402.

Bonacic, C., Macdonald, D.W., Villouta, G., 2003. Adenocorticotrophin-induced stress response in captive vicuñas (*Vicugna vicugna*) in the Andes of Chile. Animal Welfare 12, 369–385.

Bonacic, C., Macdonald, D.W., Galaz, J., Sibly, R.M., 2002. Density dependence in the camelid Vicugna vicugna: the recovery of a protected population in Chile. Oryx 36, 118–125.

Bothma, J.D.P., 1990. Game Ranch Management. J.L. van Schaik, Pretoria.

Bradshaw, E.L., Bateson, P., 2000. Welfare implications of culling red deer (*Cervus elaphus*). Animal Welfare 9, 3–24.

Broom, D.M., Johnson, K.G., 1993. Stress and Animal WelfareAnimal Behaviour Series. Chapman and Hall, London.

Coles, E.H., 1980. Veterinary Clinical Pathology. Saunders, Philadelphia.

CONAF, 1991. Estudio de factibilidad Técnico-Económica para el Manejo y Aprovechamiento de la Vicuña en Chile. Corporacion Nacional Forestal, Ministerio de Agricultura, Santiago.
Copaira, M., 1949. Estudios hematologicos en Auquenidos. Revista Facultad de Medicina Veterinaria 5, 73–85.
Cueto, L., Ponce, C., Cardich, E., Rios, M., 1985. Management of Vicuña: Its Contribution to Rural Development in the High Andes of Peru. Food and Agriculture Organization of the United Nations, Rome. p. 38.
DeNicola, A., Swihart, R., 1997. Capture-induced stress in white-tailed deer. Wildlife Society Bulletin 25, 500–503.
Eckert, R., Randall, D.J., 1983. Animal Physiology: Mechanisms and Adaptations. W.H. Freeman, San Francisco.
Eltringham, S.K., 1988. Wildlife Resources and Economic Development. International Book Distributors, Dehra Dun, India.
Fowler, M.E., 1994. Physical Examination and Restraint and Handling. Update on Llama Medicine. Food Animal Practice, The Veterinary Clinics of North America.
Fowler, M.E., 1989. Medicine and Surgery of South American Camelids. Iowa State University Press, Ames.
Galaz, J., 1998. El manejo de la vicuña en Chile. In: Valverde, V. (Ed.), La Conservacion de la Fauna Nativa Chilena: Logros y perspectivas. Corporacion Nacional Forestal, Santiago, p. 178.
Grigor, P.N., Goddard, P.J., Littlewood, C.A., 1998. The behavioural and physiological reactions of farmed red deer to transport: effects of sex, group size, space allowance and vehicular motion. Applied Animal Behaviour Science 56, 281–295.
Gurevitch, J., Scheiner, S.M., 1993. Design and Analysis of Ecological Experiments. Chapman and Hall, New York, London.
Harris, R., Halliwell, T., Shingleton, W., Stickland, N., Naylor, J., 1999. The Physiological Response of Red Deer *Cervus elaphus* to Prolonged Exercise Undertaken During Hunting. Royal Veterinary College, Newmarket. Page 182.
Hoffmann, R.K., Otte, K.C., d.Prado, C.F.P., Rios, M.A., 1983. El manejo de la vicuña silvestre. GTZ, Eschborn.
Hurtado, L., 1987. Notas Arqueologicas y Etnohistoricas acerca de la vicuña en el antiguo Peru. In: Torres, H. (Ed.), Tecnicas para el manejo de la vicuña. IUCN-PNUMA, Santiago, pp. 13–32.
Kaneko, J.J., Harvey, J.W., Bruss, M., 1997. Clinical Biochemistry of Domestic Animals. Academic Press, London.
Koford, C., 1957. The Vicuña and The Puna. Ecological Monographs 27, 152–219.
Lichtenstein, G., y Vilá, B.L., 2003. Vicuña use by Andean communities: an overview. Mountain Research and Development 23 (2), 198–202.
Little, S.E., Davidson, W.R., Howerth, E.W., Rakich, P.M., Nettles, V.F., 1998. Diseases diagnosed in red foxes from the southeastern United States. Journal of Wildlife Diseases 34, 620–624.
Marco, I., Vinas, L., Velarde, R., Pastor, J., Lavin, S., 1998. The stress response to repeated capture in mouflon (*Ovis ammon*): Physiological, hematological and biochemical parameters. Journal of Veterinary Medicine Series a Physiology Pathology Clinical Medicine 45, 243–253.
Mendl, M., 1991. Some problems with the concept of a cut-off point for determining when an animal's welfare is at risk. Applied Animal Behaviour Science 31, 139–146.
Moberg, G.P., 1985. Biological response to stress: key to assessment of animal well-being. In: Moberg, G.P. (Ed.), Animal Stress. American Physiological Society, Bethesda, Maryland, pp. 27–49.
Møller, A.P., Milinski, M., Slater, P.J.B., 1998. Stress and Behaviour. Academic Press, London.
Morton, D.J., Anderson, E., Foggin, C.M., Kock, M.D., Tiran, E.P., 1995. Plasma cortisol as an indicator of stress due to capture and translocation in wildlife species. Veterinary Record 136, 60–63.
Radostits, O.M., Blood, D.C., Gay, C.C., 1994. Veterinary Medicine: A Textbook of the Diseases of Cattle, Sheep, Pigs, Goats and Horses. Baillière Tindall, London.
Rebuffi, G., 1993. Captura de vicuñas en semicautiverio. In: Eaton, S. (Ed.), Simposio Internacional Camelidos Sudamericanos. Organizacion de Estados Americanos, La Paz, pp. 23–27.
Robinson, W.L., Bolen, E.G., 1989. Wildlife Ecology and Management. Macmillan, London, UK.
Robinson, J., Redford, K., 1991. Neotropical Wildlife Use and Conservation. University of Chicago Press, Chicago.
Sapolsky, R.M., 1994. Why Zebras Don't Get Ulcers: A Guide To Stress, Stress-related Diseases, and Coping. W.H. Freeman, New York.
Schmidt-Nielsen, K., 1997. Animal Physiology Adaptation and Environment. Cambridge University Press, Cambridge.
SPSS, 1997. SPSS Advanced Statistics 7.5. SPSS, Chicago.
Torres, H., 1987. Tecnicas para el manejo de la vicuña. UICN-PNUMA, Santiago.
Torres, H., 1992. South American Wild Camelids: An Action Plan for their Conservation. IUCN, Glandz.
Underwood, A.J., 1997. Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press, Cambridge.
Urquieta, B., Cepeda, R., Caceres, J.E., Raggi, L.A., Rojas, J.R., 1994. Seasonal-Variation in Some Reproductive Parameters of Male Vicuña in the High Andes of Northern Chile. Journal of Arid Environments 26, 79–87.
Urquieta, B., Rojas, R., 1990. Studies on the Reproductive Physiology of the Vicuña (*Vicugna vicugna*). Livestock Reproduction in Latin America. International Atomic Energy Agency, Vienna. Page 407-428.
Vassart, M., Greth, A., Anagariyah, S., Mollet, F., 1992. Biochemical parameters following capture myopathy in one Arabian Oryx (*Oryx Leucoryx*). Journal of Veterinary Medical Science 54, 1233–1235.
Webster, A.J.F., 1995. Animal Welfare: A Cool Eye Towards Eden. Blackwell Science.
Wesson, J., Scanlon, P., Kirkpatrick, R., Mosby, H., 1979. Influence of chemical immobilization and physical restraint on packed cell volume, total protein, glucose, and blood urea nitrogen in blood of white-tailed deer. Canadian Journal of Zoology 57, 756–767.
Wheeler, J., Hoces, D., 1997. Community participation, sustainable use, and vicuña conservation in Peru. Mountain Research and Development 17, 283–287.
Williams, E., Thomas, E., 1996. Exertional myopathy capture myopathy. In: Fairbrother, A., Locke, L.N., Hoff, G.L. (Eds.), Non-infectious Diseases of Wildlife. Manson, London, pp. 181–193.
Wolfensohn, S., Lloyd, M., 1994. Handbook of Laboratory Animal Management and Welfare. Oxford Press.