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THE PHYSIOLOGICAL IMPACT OF WOOL-HARVESTING PROCEDURES IN VICUNAS (*VICUGNA VICUGNA*)

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Abstract *Animal Welfare 2003, **12***: 387-402

A current programme of wildlife utilisation in the Andean region involves the capture of wild vicunas, their shearing, transport and, in some cases, captive farming. The effects of these interventions on the physiology, and thus welfare, of wild vicunas are unknown. As a first step to quantifying and thus mitigating any adverse welfare consequences of this harvest, we measured the immediate and longer-term physical and physiological effects of capture, shearing and transport. A sample of juvenile male vicunas was captured. Six were shorn at the capture site, six after two weeks in captivity, and the remaining seven animals were kept as controls for 39 days. In general, vicunas showed changes in blood glucose, packed cell volume, cortisol, and neutrophil:lymphocyte ratios within 4–6 h following capture. Creatine kinase was also affected by capture and transport, showing a peak plasma level 24 h after capture, which was followed by a peak plasma level of aspartate aminotransferase four days after capture and transport. After 12 days in captivity, all of the vicunas showed physiological parameters close to expected baseline values for the species. We could detect no differences in physiological parameters between animals that were captured, sheared and transported and those that were only captured and transported. Similarly, we could detect no differences in most responses of vicunas between those sheared after 12 days in captivity and a control group held under similar conditions but from which blood was sampled without shearing. A further comparison between animals sheared immediately after capture and animals sheared after 12 days in captivity revealed that creatine kinase levels were higher in the former group. During transport prior to release back into the wild, only minor injuries (lip bleeding and limb contusions) and a significant increase in rectal temperature were observed. Our results provide a basis for recommendations to improve the welfare of vicunas during the wool harvest, and provide baseline and stress-response data to serve as reference points for further studies of vicuna welfare.

Keywords: *animal welfare, capture effects, ecophysiology, shearing effects, stress response, sustainable use*

Introduction

The vicuna (or vicuña, *Vicugna vicugna*), a wild South American Camelid, is regularly captured, handled and sheared, and this practice has occurred since the 15th century, when the Inca Empire conducted a round-up, known as the *chaku*, throughout the Andes of South America (Hurtado 1987; Torres 1992). The *chaku* involved herding thousands of animals into stone corrals for shearing. Large numbers of animals were shorn using this method;

probably whatever morbidity and mortality resulted (and there are no records of this) had little effect on the population because the *chaku* took place in a given locality only once every four years. Furthermore, prior to the arrival of Europeans, vicunas were abundant in the Andes (Koford 1957; Hurtado 1987).

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). The number of vicunas rapidly declined, probably through the combined impact of hunting, livestock competition and, possibly, diseases introduced by European domestic livestock (Koford 1957). By the 1950s the species faced extinction, but their decline was successfully reversed by the introduction of a 30-year moratorium (Bonacic *et al* 2002). Local communities observed this moratorium — enduring the loss of vicuna wool and meat, and tolerating perceived competition with livestock — in the expectation that they would see long-term benefits from the sustainable use of vicuna wool, a luxury product that attracts a high premium on international markets. Attempts to realise this potential market rest, under the dictates of CITES, on *in vivo* harvest of the vicuna's wool. Clearly, this might be achieved by various means and, in evaluating the alternatives, one consideration is the welfare of the animals. Here, we report on our assessment of the welfare consequences of various aspects of the harvest.

Current policies for vicuna management include capture and shearing of wild animals, farming, ranching, translocation and reintroduction (Cueto *et al* 1985; Torres 1987; Urquieta & Rojas 1990; Torres 1992; Rebuffi 1993; Urquieta *et al* 1994; Wheeler & Hoces 1997; Galaz 1998). For example, during the early 1990s, wild vicunas were translocated, by road and air, from Peru, Argentina and Chile to a Natural Reserve in Ecuador to begin a reintroduction programme (CITES 1997).

The welfare implications of the handling and transportation of domestic stock are a long-standing topic of research (Goddard *et al* 1996; Grigor *et al* 1997a; Grigor *et al* 1997b). Although less scientific attention has been given to welfare as an element of wildlife conservation and management, it is already clear that capture and transportation can cause stress in wild ungulates as well as in carnivores and birds (Bailey *et al* 1996; DeNicola & 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 & Swihart 1997; Marco *et al* 1998). Specifically, capture and restraint can cause capture myopathy, also named exertional myopathy (for a review, see Wesson *et al* 1979; Beringer *et al* 1996; Williams & Thomas 1996; DeNicola & Swihart 1997). Capture myopathy is caused by complex metabolic changes that may result in hyper-acute fatal acid–base and electrolyte imbalances (Fowler 1998). Various biological and haematological parameters are known to vary according to the capture method, species and previous capture experience (Morton *et al* 1995). Capture myopathy is a syndrome resulting from excessive exercise and multiple traumas during capture and handling that produces dramatic changes in the activity of creatine kinase, aspartate aminotransferase, packed cell volume and cortisol (Radostits *et al* 1994).

Interpretation of the physiological response to capture requires caution because of variation with age, season and, notably, species (see Bonacic *et al*, pp 369–385, this issue). However, it is generally true that capture induces, within seconds, changes in core body temperature (reflected by rectal temperature), catecholamine concentrations, heart rate,

respiratory rate and packed cell volume (Eckert & Randall 1983; Schmidt-Nielsen 1997; Radostits *et al* 1994; Harris *et al* 1999). A less acute response (ie from minutes to hours) is observed in blood glucose, plasma cortisol and creatine kinase concentrations (Coles 1980; Kaneko *et al* 1997; Bateson & Wise 1998; Harris *et al* 1999). Finally, some parameters change only on a time-scale of hours to days, such as aspartate aminotransferase, total protein, and blood urea nitrogen (Kaneko *et al* 1997; Harris *et al* 1999).

In the case of vicunas, our concern was that capture and shearing — activities essential to the planned sustainable harvest of wool — could result in morbidity and potential mortality; indeed, shearing is known to cause a risk of fatal hypothermia in other South American Camelids (Fowler 1998). Adverse signs of shearing in llamas (as in sheep) include decreased heart and respiratory rates, hypothermia and an increase in packed cell volume, accompanied by hypotension and a state of physical depression or lack of activity (Radostits *et al* 1994; Fowler 1998).

Various capture, transport and shearing methods are currently used for vicunas throughout South America. The simplest capture method, in Peru, emulates the ancient *chaku* and involves people slowly herding groups of between 20 and 500 vicunas into a wire-fenced corral (Wheeler & Hoces 1997). Elsewhere, and commonly in Chile, motorbikes and pick-ups are used to drive small groups of animals for up to five kilometres into fenced corrals (Bonacic 2000). Some people use combinations of these approaches. Once in the corral, the vicunas are either restrained with ropes until they are shorn or wait unrestrained in an adjacent corral.

The purpose of this study was to investigate the effects of different capture and handling strategies on selected physiological parameters. Here, we report on an experiment designed to disentangle the characteristics and relative magnitudes of physiological indicators of stress associated with each of a) capture, b) shearing, and c) transportation, and the effects of habituation on the vicuna's response to stress. We provide capture and handling recommendations that optimise animal welfare and thus also maximise harvest sustainability.

Methods

Study area

The study took place in Las Vicunas National Reserve (209 131 ha; South 18°16'–19°00' and West 68°57'–69°27') in Chile, which lies within the Surire basin in the Parinacota Province (490 401 ha) and has been used as a centre for research on the sustainable use of the vicuna (CONAF 1991). Rainfall (annual mean 200–321 mm) is concentrated in summer (December–March); July is the coldest month with a mean temperature of –0.04°C, and January the warmest with a mean of 8°C. The study was conducted in November 1998.

Experimental design

Vicunas were captured at Site Number 32 within The Las Vicunas National Reserve in the northern region of Chile at 4400 m above sea level, in an open grassland plain with steppe vegetation surrounded by mountains and bisected by a main road. Capture facilities were built at the middle of the site, 100–200 m east of a road. In the course of local shearing operations, 19 juvenile male vicunas were herded by vehicles into a corral (15 m × 25 m). Some were shorn immediately with mechanical clippers (Lister®) used for sheep. However, because vicunas are less tractable than sheep, shearing involved two people holding the animal prostrate on the ground (one at its head holding the forelegs, the other to the rear and holding the hindlegs), while a third person sheared the animal's back and flanks. All of the vicunas, whether shorn or not, were then transported carefully in a Toyota double-cabin

four-wheel-drive pick-up truck for 20 km at 40–50 km h^{-1} on a dirt road within the Reserve to the holding facility, where they were kept for 39 days (until 30 November 1998). The animals were transported in the same way after the study was completed, and clinical examination and any injuries during transport were recorded.

Physical examination and blood sampling were carried out after capture, after transport to the capture facilities, and after shearing. The vicunas were allocated at random to one of three treatments:

a) C-T: controls animals which were maintained in captivity but were not shorn during the entire captive period (n = 7);

b) C-S-T: sheared immediately at capture and prior to transportation to the holding facility; thus the effects of capture and shearing were acting together (n = 6);

c) C-T-S12: sheared after 12 days in captivity with the aim of allowing the animals to recover from the initial stress of capture and transport (n = 6).

The shearing experiment conducted on day 12 compares animals that were not shorn with shorn animals; both groups were handled in the same way during the same period in captivity. This design seeks to minimise the confounding effects of capture and transport on the effect of shearing (see Appendix). Because our approach involves *in vivo* sampling from unanaesthetised animals, stress associated with handling is a component of each treatment.

At capture, and on days 1, 2, 4 and 12, blood samples were taken from each animal. In addition, rectal temperature, heart rate and respiratory rate were recorded daily. The haematological parameters were: packed cell volume (PCV), total white blood cell count (WBC), neutrophil count, lymphocyte count, eosinophil count, monocyte count, and neutrophil:lymphocyte ratio (N:L ratio). The biochemical assays on blood plasma were: blood glucose concentration (GLU), cortisol concentration (CORT), and activity levels of the serum enzymes creatine kinase (CK) and aspartate aminotransferase (AST).

Blood sampling and analysis

Blood samples were obtained by jugular venepuncture from the upper section of the neck (Urquieta & Rojas 1990; Fowler 1994), following Fowler's guidelines for llamas, except that an upper neck patch was shaved and disinfected with an alcohol–iodine solution (Fowler 1998). The minimum amount of blood necessary was drawn, using 21 GX1 1/2" UTW needles (Venoject®) and 5 ml blood tubes (Vacutainer®; Becton Dickinson, Franklin Lakes, NJ, USA) which contained ethylene diamine tetra-acetic acid (EDTA) and heparin, for haemogram and cortisol measurements, respectively (Schalm & Jain 1986; Kaneko *et al* 1997).

Blood smears were prepared following standard procedures for sampling wild ungulates in the field, by placing a drop of fresh blood, using a glass capillary (of 75 mm/75 µl), onto a Marienfeld® slide and smearing with another slide (76 × 26 × 1 mm approximately; Fowler 1986; Rhiney 1982). The smear was fixed with methanol and the slide labelled with a graphite pencil, in preparation for Giemsa staining and differential white blood cell counts (Coles 1980; Schalm & Jain 1986). These counts were carried out using standard procedures in the Veterinary School of the University of Chile (Coles 1980; Schalm & Jain 1986). Total white cell counts were undertaken for each sample in the field using a Neubauer® improved bright line camera (Precicolor of 0.100 mm by 0.0025 mm^2) (Coles 1980; Schalm & Jain 1986). Under the extreme and remote field conditions of the study area, no automatic blood counter was available. Plasma was extracted by centrifugation and stored in a nitrogen tank within 2 h of collection for further enzyme and cortisol analysis. The same researcher performed all measurements in the field and the laboratory.

Plasma cortisol concentration was measured using radioimmunoassay following WHO guidelines (Hall 1978) in the Endocrinology Laboratory of the Faculty of Biological Sciences (Pontificia Universidad Católica de Chile — a registered laboratory in the WHO programme of matched reagents and laboratory techniques for reproductive studies [Zekan & Ezcurra 1998]). The cortisol level was measured directly in aliquots of 50 µl of plasma diluted with 0.1M phosphate-buffered saline with pH 7.4, and heated to 60°C. The standard antibody, tracer and methodology were provided by the WHO matched reagent programme (Hall 1978; Zekan & Ezcurra 1998). The antibody is raised in rabbits and has a sensitivity of 10.5 nmol l^{-1}. It cross-reacts with cortisol (100%), cortisone (25%), corticosterone (2.2%), 11-deoxycortisol (40%), 17-hydroxyprogesterone (10%), progesterone (0.5%), and 11-hydroxyprogesterone (<1.0%), measured at 50% displacement. The assay range was 187–6000 fmol per tube and was validated for the measurement of vicuna plasma samples as for other South American Camelids (Parraguez *et al* 1989). The mean inter- and intra-assay coefficients of variation were 10.8% and 7.5%, respectively.

Blood glucose was measured using a portable glucometer, 'Glucometer Elite' (Elite®, Bayer, Germany). The method delivers the results in 30 s with a range of 20–600 mg dl^{-1} (1.2–33.3 mmol l^{-1}) and an optimal haematocrit range of 20–60%. Under field conditions, the speed and ease of sampling blood glucose in fresh blood using a portable glucometer offered an excellent alternative to laboratory measurements, which were not available under the remote conditions of this study area. Because blood samples with heparin were centrifuged and frozen within 2 h of sampling, blood glucose was also estimated by Gluco-quant in the laboratory (Glucose/HK, Boehringer–Mannheim).

The activity of aspartate aminotransferase was measured at 30ºC with the UV ASAT/GOT test. The activity of creatine kinase was measured with the CK NAC-activated test.

Statistical analysis

Each physical and blood parameter was checked for normality and homoscedasticity (Gurevitch & Scheiner 1993; Underwood 1997). The mean values for physical and blood parameters obtained from captured animals were compared with reference values from captive vicunas (see Bonacic *et al*, pp 369–385, this issue).

Results

The effect of capture, transport and shearing

The mean blood parameters from the captive vicunas considered as baselines, compared to zoo-housed vicunas and South American Camelids, are presented in Table 1. There were no significant differences in mean blood values (GLU, PCV, CORT, CK, AST and N:L ratio) between C-T and C-S-T groups during the first 12 days after capture. Thus, both groups were pooled for the analysis of changes in these parameters (see Figure 1), which revealed that over consecutive days GLU and CORT were significantly affected by transport after capture (Figure 1a,b). After transport, GLU and N:L ratio increased and PCV significantly decreased. All three parameters returned to their pre-transport values after one day in captivity. CORT also increased significantly after transport and thereafter declined until day 12. CORT concentrations were one third lower than the original values at capture and by the last day of sampling (day 12) had dropped to one-fifth of the level measured immediately after transportation. CK and AST showed different release kinetics (Figure 1c,d) when compared to haematological parameters and CORT. CK increased and reached a peak value 24 h after capture and AST reached a peak value 120 h after capture (5 days).

Table 1 Baseline physical and haematological parameters for captive vicunas.

Reference values	Vicunas in captivity (n = 10)[1]		Zoo-housed vicunas (n = 13)		South American domestic Camelids[2–5]
Parameter	**Mean (Median)**	**SE (IQ range)**	**Mean (Median)**	**SE (IQ range)**	**Normal Range**
Baseline heart rate[6]	65.3	4.6	—	—	60–90[2]
Respiratory rate (mov/min)	20.2	2.4	—	—	10–30[2]
Rectal temperature (°C)	38.1	0.1	—	—	37.5–38.9[2]
Blood glucose (mg/dl)	100.3	3.83	111.8	6.7	95–150[2]
Packed cell volume (%)	39.5	0.94	40.7	1.8	27–45[2]
Creatine-kinase (IU/l)	103	101	34.0	12.8	0–137[3]
Aspartate aminotransferase (IU/l)	246.5	184.3	—	—	128–450[3]
White blood cell count (cells/µl)	(7370)	(2736)	10.166	1348	8,000–22,000[2,3]
Neutrophils	61	14.25	58.2	4.8	41–67[4]
Lymphocytes	33.5	14.5	32.7	4.8	17.5–42.5[4]
N:L ratio	1.8	2.4	2.8	1.1	1.34–1.96[4]
Plasma cortisol (nmol/l)	29.9	4.7	108.6	25.3	20.6 ± 2.48[5]

Records from undisturbed animals during 15 min (n = 7). There was no significant difference between physical examination and heart rate monitors ($t = -0.5$, $df = 10$, $P = 0.6$).
Reference values: [1]the present study; [2]llama and alpaca in South America and USA; [3]llama and alpaca in USA; [4]captive vicunas in Peru; [5]alpaca in USA; [6]heart-rate baseline values obtained from automatic non-invasive recorder (Polar®).
IQ range, interquartile range; —, data not recorded.

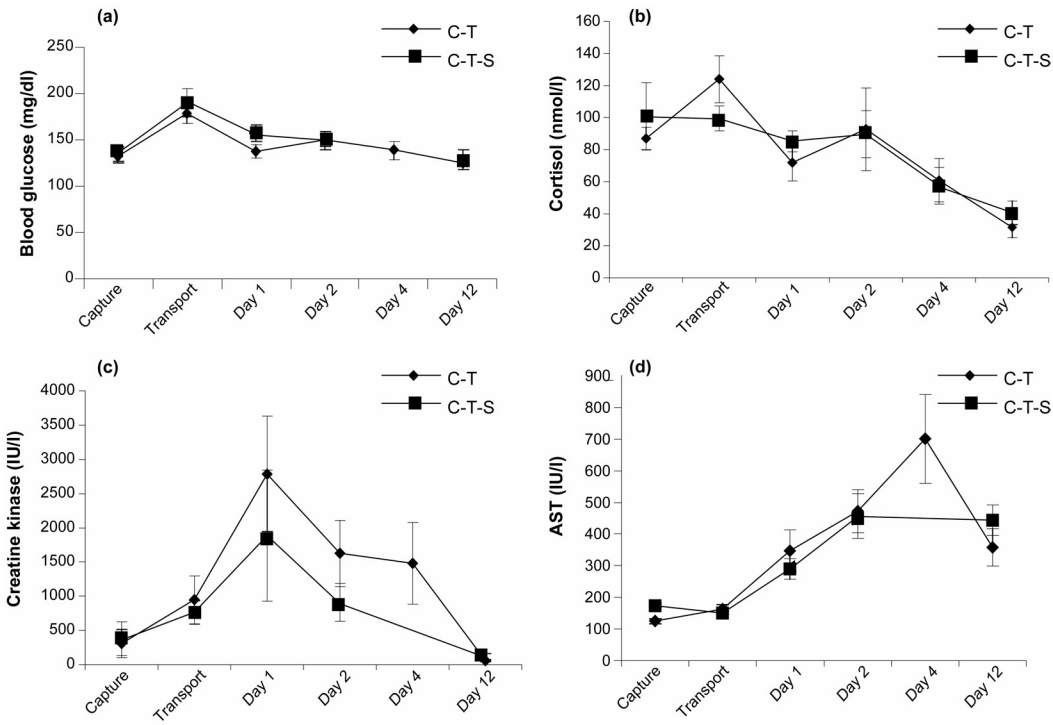

Figure 1 Effect of capture, transport and captivity on (a) blood glucose, (b) cortisol, (c) creatine kinase, and (d) aspartate aminotransferase.

CK, AST, CORT and GLU measured at capture correlated highly with the peak values sampled after transport (Figure 2). Mean CK (IU l^{-1}) at capture was 754.5 ± 1404 (n = 10) and reached a peak of 3956.7 ± 6121 in the blood sample taken 24 h after capture ($r^2 = 0.67$, $P = 0.031$; Figure 1c). AST also showed a correlation on the borderline of statistical significance between the first sample at capture and the peak value reached four days later in captivity ($r^2 = 0.76$, $P = 0.06$). The mean cortisol concentration immediately following capture also correlated with the peak cortisol values immediately after transport ($r^2 = 0.80$, $P = 0.003$; Figure 2), as did glucose values ($r^2 = 0.54$, $P = 0.000$; Figure 2). In contrast, neither PCV nor N: L ratio showed such correlations.

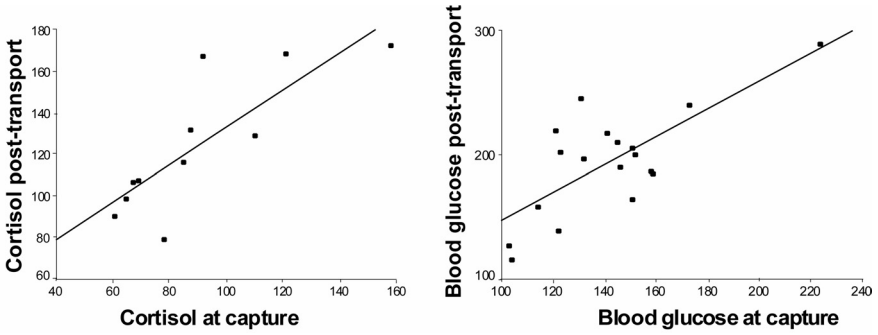

Figure 2 **Cortisol (nmol l^{-1}) and blood glucose concentration (mg dl^{-1}) after transport predicted by concentration at capture.**

The effect of shearing

Vicunas in group C-T-S12 were shorn 12 days after capture and transportation. A comparison of the C-T-S12 responses to shearing with those of the control group (C-T, which was handled for sampling, but not shorn) enabled us to isolate the effect of shearing from the initial effect of capture. Only CORT and AST showed a significant difference between the C-T-S12 and C-T groups. CORT concentrations were higher in sheared animals (C-T-S12) than in controls (C-T) 48 h after shearing ($F_{1,7} = 5.9$, $P = 0.044$; Figure 3). Sheared animals' (C-T-S12) cortisol concentrations (nmol l^{-1}) increased from 38.5 ± 7.4 to 59.5 ± 15.6, while control animals' (C-T) CORT concentrations decreased from 35.3 ± 5.2 to 30.7 ± 4.8. GLU, PCV and CK showed no differences between the C-T-S12 and C-T treatments, and their rectal temperatures were similar, with a mean of 38.1 ± 0.09ºC.

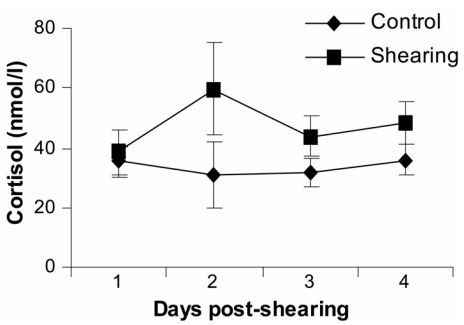

Figure 3 **Cortisol response to shearing in captive vicunas.**

An additional comparison was made between the animals sheared immediately after capture (C-S-T) and the animals sheared 12 days later (C-T-S12). There were no significant differences between these groups in most of the physiological parameters. The exception was CK, which was significantly higher in C-S-T than in C-T-S12 animals (Figure 4). The magnitude of the difference between CK values one day after shearing in the C-S-T compared to the C-T-S12 animals was 36:1, and this difference increased to 126:1 during day two ($Z = –2.88$, $P = 0.001$), declining during days three ($Z = –2.24$, $P = 0.003$) and four ($Z = –2.56$, $P = 0.01$). Five days after shearing, the ratio was similar between the groups.

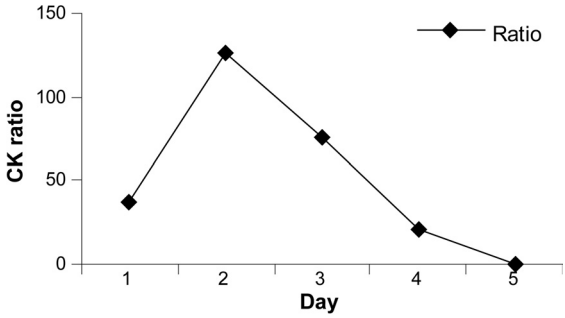

Figure 4 **The difference in creatine kinase values between vicunas that were sheared immediately after capture and vicunas sheared 12 days post-capture. This graph represents the ratio between both groups, which increases to a peak value of CK nearly 120 times higher in the vicunas shorn immediately after capture than in the animals shorn after 12 days of adaptation in captivity.**

The effect of transport back to the wild

The effect of transport was assessed in the animals when they were released back into the wild after 40 days in captivity. The incidence of injuries/trauma associated with transport was recorded. Logistical difficulties prevented a quantitative assessment of the effect of transport to the release site on blood biochemistry, but we were able to measure rectal temperature and signs of injuries during transportation. There was a significant increase in rectal temperature, from 38.5 ± 0.12ºC (pre-transport) to 39.09 ± 0.10ºC (post-transport) ($t = –5.6$, $df = 18$, $P < 0.001$). Transport time was 10–15 min for 5 km in a pick-up truck on a dirt road with groups of six to eight vicunas, which were restrained and blindfolded. The main injuries recorded were small lip cuts (31.6%) and regurgitation of rumen content (31.6%). A total of 10.5% of the animals showed more serious, but nonetheless relatively minor, leg lacerations and contusions. No detectable injuries were sustained by 26% of animals.

Discussion

The cortisol, CK, AST and haematological changes observed after capture were assessed through comparison with reference values taken from vicunas habituated to captivity (see Bonacic *et al*, pp 369–385, this issue). We rejected alternative methods, such as collecting samples from specimens that were shot, chemically restrained or anaesthetised, for combinations of scientific, logistical and ethical reasons (Bonacic *et al* 2002). AST, CK, blood glucose and cortisol all appeared to be useful indicators of a stress response and should be considered as potential indices of stress in future capture procedures.

Capture and transport in combination caused changes in blood glucose, packed cell volume, cortisol and neutrophil:lymphocyte ratios within 4–6 h following capture. CK was also affected by capture and transport, showing a peak plasma level 24 h after capture, followed by a peak plasma level in AST four days after capture and transport. After 12 days in captivity, all of the vicunas showed physiological parameters close to expected baseline values for the species.

We could detect no difference between the responses of captured, sheared and transported (C-S-T) vicunas and those that were captured and transported only (C-T). From this, we deduce that shearing does not add to the burden of the other two stressors. The extremely high CK values from captured and sheared animals compared to C-T-S12 animals suggests that capture, unsurprisingly, is an acute stress stimulus. The group of animals sheared after 12 days in captivity (C-T-S12) showed no significant differences in the majority of the physiological values compared to unsheared animals (C-T), except that cortisol and AST concentrations were higher in sheared animals (48 h and 72 h after shearing, respectively). We deduce, then, that shearing adds to the burden of handling only in so far as the cortisol and AST values indicate additional stress. A comparison between C-S-T and C-T-S12 animals showed that those shorn immediately after capture had significantly higher CK levels than those shorn after they had become accustomed to captivity and handing. From this we suggest that the impact of capture under the two circumstances was similar with and without habituation, except in so far as the elevated CK levels indicated additional stress. During transport to release the animals back into the wild (day 40), minor injuries (ie small lip cuts and limb contusions) and a significant increase in rectal temperature were observed. Although these injuries were slight, the journey in this case was short compared with translocation practices used in the altiplano, where animals are transported for more than 50 km, which raises concern that longer journeys might pose more significant welfare problems. Irrespective of the impact of variable journey length, which remains to be explored, other studies have identified loading/unloading as the main cause of injuries in domestic species (S Wolfensohn, personal communication 2002).

Capture and transport of vicunas are increasingly widespread practices associated with the trend to establish vicuna farms in South America; within these farms vicunas will be sheared. In addition, the traditional practice of rounding up and shearing free-living vicunas continues. Our intention has been to evaluate the effects of capture, transport and shearing on physiological and physical parameters in captive wild vicunas following similar procedures that are currently in place for vicuna use. We have sought to provide the first reference values with which to evaluate the impact of management on this wild species. This information is important for judging the acceptability of the wool harvest, and for evaluating the merits of alternative management and handling protocols. Handling and repeated sampling are important stressors in domestic and wild animals (Goddard 1998). Using animals that were part of a local shearing programme, it was opportune to monitor a small sample of individuals held in captivity to secure physiological measures as reference values for future vicuna farming operations. These captured animals, maintained under three regimes (C-T, C-S-T and C-T-S12) served as their own reference points and controls.

Capture stress has been described for other ungulate species (Seal *et al* 1972; Conner *et al* 1987; Beringer *et al* 1996; Coulson 1996; Vassart *et al* 1992; Antognini *et al* 1996; Williams & Thomas 1996; Marco & Lavin 1999). The effects of different capture methods on cortisol are summarised in Table 2. The response to capture varies between species and capture method, ranging from 1.5 to 80 times baseline values in ungulates. The increases in cortisol

Table 2 The effects of capture on cortisol ratios in other ungulate species.

Sampling method	Mean cortisol level	Standard error	Ratio of increase	n
***Species* [Reference]**				
***White-tailed deer (wild)* [DeNicola & Swihart 1997]**				
Basal	4.1 ng ml^{-1}		—	19
Darted	8 ng ml^{-1}		1.9	8
Darted	13.6 ng ml^{-1}	2.9	3.3	15
Drop-net	60.5 ng ml^{-1}	3.6	14.7	69
***White-tailed deer (captive)* [Wesson *et al* 1979]**				
Basal	45.1 ng ml^{-1}	12.46	—	20
Darted	125.2 ng ml^{-1}	17.65	2.7	20
***White-tailed deer (wild)* [Wesson *et al* 1979]**				
Basal	53.27 ng ml^{-1}	8.68		30
Darted	95 ng ml^{-1}	20.88	1.8	30
***White-tailed deer (wild)* [Seal *et al* 1972]**				
Darted	0.54 µg dl^{-1}	0.07	—	9
Clover trap	4.37 µg dl^{-1}	0.69	8.09	6
Cannon net	3.88 µg dl^{-1}	0.82	7.2	5
***Mule deer (wild)* [Seal *et al* 1972]**				
Net-gun	10.6 µg dl^{-1}	0.2		10
***Pronghorn (wild)* [Seal *et al* 1972]**				
Chase 9.7 km	6.1 µg dl^{-1}	0.3		
Chase 4.9 km	5.8 µg dl^{-1}	0.4		
Chase 9.1 km	4.3 µg dl^{-1}	0.3		
***Guanaco (wild–captive)* [LeRoy 1999]**				
Basal	16.3 nmol l^{-1}			4
ACTH	92 nmol l^{-1}		5.6	4
***Guanaco (wild–captive)* [Bustos 1998]**				
Wild captured chased with horses and dogs	102.2 nmol l^{-1}		6.3	30
***Guanaco (wild)* [Gustafson *et al* 1998]**				
Hand-captured	55.18 nmol l^{-1}		3.4	100
***Red deer (wild–farmed)* [Bateson & Bradshaw 1997]**				
Culled (domestic)	2.7 nmol l^{-1}	—	—	20
Chased (domestic)	225 nmol l^{-1}	—	83.3	33

concentration displayed by vicunas were at the low end of the range of inter-specific values (2–5 times baseline).

This finding may suggest that the response of Camelids to stress is driven by different selection pressures than those affecting the better-known Cervids. Perhaps the relatively 'slow and small' cortisol-release reaction revealed to be characteristic of the Camelids is related to their very open habitat in which predation risk may be less than that faced by many Cervids that live in close bush or forest. Tests of this hypothesis await further comparative studies of different species.

We found a strong positive correlation between cortisol concentration immediately after capture (in all three groups) and later values based on samples taken during the 39 days in captivity. We interpret this as indicating that some individuals were consistently more 'nervous' than others — a conclusion compatible with our findings during a trial of individual responses to ACTH injection (see Bonacic *et al*, pp 369–385, this issue).

The comparison between animals shorn under C-S-T and C-T-S12 treatments revealed significant differences only in cortisol and AST. From this we deduce that the stress associated with capture, handling and shearing of unhabituated animals differs from that of habituated animals handled and shorn only in so far as higher cortisol and AST in the C-S-T group indicate that they were more stressed. The fact that the stress levels associated with shearing in both treatments were not high is, importantly, in contrast with earlier findings by Bonacic (2000). An explanation may lie in the fact that the current experiments were conducted in austral spring, whereas the earlier publication, which reported severe stress and associated mortality, was conducted in the austral autumn.

The vicuna's fine fleece is an adaptation to its highly variable environment, characterised by large daily temperature fluctuations and intense solar radiation (Wilson 1989; Koford 1957; INIA 1989; CONAF 1991). Obviously, shearing takes from the animal an attribute that natural selection has demonstrated to be of survival value, and thus is likely to be disadvantageous. It is not obvious, however, just how disadvantageous shearing is and how its negative impacts can best be mitigated by alternative protocols. Motivated by similar questions, Lobel (1992) studied the effects of winter shearing in alpacas (*Lama pacos*), in a trial conducted in Mediterranean conditions and below 1000 m in Central Chile. She concluded that shearing alpaca in winter caused stress, on the grounds that fleece removal caused an increase in plasma cortisol and lower rectal temperature. The most important changes in the haematological parameters were neutrophilia, lymphopenia and eosinopenia (Lobel 1992). In addition to the stress induced by shearing itself and by the associated procedures of capture, handling and transport, which has been the topic of this paper, we cannot discard subtle longer-term consequences of shearing on the health and welfare of shorn vicunas exposed to wind and low temperatures overnight in the extreme climate of the *puna* ecosystem. That is the topic of our sister paper in this series (see Bonacic *et al*, pp 369–385, this issue).

A potential drawback of our approach is that wild-caught animals in captivity might yield results confounded by the stress of handling and, in the long-term, by chronic stress. Indeed, although our animals appeared to habituate to handling, as evidenced by the absence of visible agitation and by the decline of their N:L ratio and CK concentrations, we were able to discount the possibility that they were chronically stressed only because we conducted (see Bonacic *et al*, pp 369–385, this issue) a separate ACTH challenge to test this (stress-responsiveness to ACTH provides a useful distinction between habituation and chronic stress; Beerda *et al* 1998).

Animal welfare implications

Conservation is an inescapably inter-disciplinary, and highly practical, activity. It draws upon the social sciences — economics and community development — and upon the biological sciences. Of the latter, behaviour and ecology are crucial elements of conservation biology; in addition, however, our study stems from the conviction that another biological discipline — welfare science — has an important contribution to make (see also Clemmons

& Buchholz 1997). Welfare science should approach any problem from a physiological and behavioural standpoint in a wise combination of markers that makes an evaluation an objective assessment. This paper emphasises the value of physiological data; behavioural analyses are underway.

It is a great hope of wildlife conservationists, although one yet rarely seen to be realised, that some wildlife can be used sustainably to the greater common good of the exploited species, its ecosystem, and the communities of the people using it (Eltringham 1988; Robinson & Redford 1991). Sustainable use is often characterised as being either consumptive, such as hunting quotas, or non-consumptive, such as eco-tourism. On closer inspection, however, this dichotomy can be somewhat blurred and, indeed, the case of the vicuna wool-harvest is somewhat intermediate. True, the captured, shorn vicunas are released alive back into the wild, but their use may have consequences both for the individual animals and for the population from which they were drawn. These consequences, both in terms of individual welfare and population demography, are among the diverse and often incommensurable factors by which the desirability of this harvest will be judged.

Our experiment has provided profiles of cortisol levels in vicunas following habituation, adrenocortical response to ACTH challenge (see Bonacic *et al*, pp 369–385, this issue), the response of cortisol, CK and AST enzymes to capture and shearing, and WBC changes after capture, transport and shearing. In total, 16 physical and physiological parameters have been quantified under different management conditions. The results therefore provide well-known markers of stress that can be used to interpret future studies of vicuna welfare (Broom & Johnson 1993; Wolfensohn & Lloyd 1994; Webster 1995). Our results suggest that capture, transport and shearing cause acute stress, but at levels with which the animals can cope.

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Appendix

Nineteen animals were captured and penned for 40 days in Surire (Chilean altiplano) between 20 October and 30 November 1998. Physical examination and blood sampling followed capture, transport to the capture facilities and shearing. Animals were separated into three treatments. Controls (C) were maintained in captivity and sampled regularly (n = 7). Animals in the two treatments were either sheared immediately at capture (C-S-T; n = 6), or sheared after 12 days of adaptation to captivity (C-T-S12; n = 6).

ID/Time	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Control group (C) 109, 112, 43, 53, 63, 64, 65.	Capture–transport	Habituation study (n = 7) and control group. Repeated sampling until the end of captivity				Release
C-S-T group AM-10, 55, 56, 58, 59, 60	Capture–transport–shearing (n=6)	Post-capture, transport and shearing sampling				Release
Captured and transported group (C-T-S12)* 44, 61, 62, 66, AM-24, 127	Capture–transport		Shearing (n=6)	Post-shearing sampling		Release

*C-T-S12 animals were sheared after 12 days in captivity.