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Reintroduction increased vitamin E and condition in captive-bred yellow-footed rock wallabies *Petrogale xanthopus*

Steven J. Lapidge

Abstract Welfare implications of reintroduction are primarily unknown, although reportedly negative. Few studies have described physiological changes in captive-bred animals post-release and consequently the impact of reintroduction on captive-bred animals is not well understood. Such information is crucial to understanding whether reintroduction constitutes ethical practice. For these reasons two physiological indices associated with animal health, plasma vitamin E concentration (PVEC) or α-Tocopherol, and general condition scores, were monitored in reintroduced captive-bred yellow-footed rock wallabies *Petrogale xanthopus celeris* and *P. x. xanthopus* pre- and post-release. PVEC was chosen because deficiencies are common in captive animals compared to their wild counterparts, and have been linked to stress, myopathy, neuronal degeneration, low reproduction, anaemia and death. Changes in physical condition, within this study indicated principally by mass variation, coat condition, and reproductive status, but also parasite load, visible stress, lethargy and diarrhoea, have also not been reported for captive-bred animals reintroduced to the wild. Captive-bred yellow-footed rock wallabies reintroduced to areas of their former range in Queensland and South Australia showed a rapid and sustained increase in PVEC and physical condition, with post-release values significantly higher than pre-release captive levels. Post-release values for both parameters did not significantly differ from that of wild counterparts. Hence I conclude that there was no welfare implications related to the observed parameters in these reintroductions, rather the opposite.

Keywords α-Tocopherol, captive-bred, condition, *Petrogale xanthopus*, reintroduction, vitamin E, yellow-footed rock wallaby.

Introduction

Reintroducing extirpated species to their former range is a widely and increasingly used conservation technique (Wolf *et al.*, 1996; Fischer & Lindenmayer, 2000), as is the use of captive-bred animals for reintroduction (Wolf *et al.*, 1996), now utilized in 59% of releases (Beck *et al.*, 1994). This occurs despite questions over the humaneness of the practice (Beck, 1995), and the lack of research addressing welfare concerns (UFAW, 1992). Beck (2001) reported 'diminished health and welfare of reintroduced captive-bred animals, compared to their previously sheltered lives', but that reintroductions proceed because 'the risk to an individual may be compensated for by the gain for conservation' (UFAW, 1992; Beck, 1995). Contributing to welfare concerns are reports that captive breeding may diminish the ability of an animal to survive in the wild (Ralls *et al.*, 1988; Kleiman, 1989; Stanley Price, 1989; Frankham, 1994; Kleiman *et al.*, 1994; Snyder *et al.*, 1996; Miller *et al.*, 1999). Consequently, questions have been raised as to the appropriateness of using captive-bred animals for reintroduction (Waples & Stagoll, 1997).

Post-release survival is an essential index of reintroduced animal health and welfare, and monitoring must be undertaken in any ethical reintroduction (IUCN, 1998). However, captive-bred animals can survive post-release, yet suffer diminished health when compared to their captive counterparts (Beck, 1995), thus raising animal welfare concerns. With this in mind, a large-scale investigation was launched into the ecological, physiological and genetic adaptation of captive-bred yellow-footed rock wallabies *Petrogale xanthopus* to the wild upon reintroduction (Lapidge, 2001). This species was selected as the most appropriate rock wallaby for reintroduction based on the recommendations of both the 1993 Reintroduction Biology of Australasian Fauna Conference and the 1994 Rock wallaby Symposium (Serena & Williams, 1994; Eldridge, 1997b). The overall aim was to closely monitor post-release changes in reintroduced captive-bred animals to assess adaptation to the wild and thus welfare. This paper reports on two physiological parameters monitored to assess post-release changes in the health of captive-bred yellow-footed rock wallabies.

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Animal condition indices are widely used to monitor gross changes in animal health because they can provide interim assessments of physical condition and potential well-being, rather than relying solely on survival estimates. Previous investigations into condition of macropods have used body mass coupled with a body measurement, normally tibia, hindfoot length or tail circumference, as indices of animal condition (Bakker & Main, 1980; Catt, 1981; Moss & Croft, 1999; Short & Turner, 2000). Such indices rarely take into account the suite of health variables seen in captured animals. Body mass variations, coat condition, parasite loads, visible stress indicators, lethargy, diarrhoea and reproductive status of sexually mature animals are also indicative of an animal's physical condition. For this reason a condition score index was developed by Royal Zoological Society of South Australia veterinarians to assess individual yellow-footed rock wallaby condition for comparison between conspecifics and over time (D. Schultz, pers. comm.). This index formed the basis for the current study, with additional inclusions and a more defined scoring system.

Vitamin E (α-Tocopherol) concentration is a widely monitored blood parameter because deficiencies have been associated with numerous degenerative diseases in wild and domestic herbivores (Packer & Fuchs, 1992). Moreover captive animals generally record significantly lower plasma vitamin E concentrations (PVEC) than their wild counterparts (Dierenfeld *et al.*, 1988; Dierenfeld, 1989; Savage *et al.*, 1999). Vitamin E is an essential antioxidant. It is required for embryonic development and to prevent muscle degeneration (Rucker & Morris, 1997). Dietary intake of vitamin E, and physical stress, a vitamin E consumer, are both known to affect plasma concentrations (Kakulas, 1961, 1963; Munday, 1988; Hume, 1999). The principal dietary source of vitamin E is vegetable and seed oils and green leaves (Rucker & Morris, 1997). Increases in PVEC, either through diet or supplementary injections, are known to reverse diseases associated with vitamin E deficiency (Kakulas, 1961; Liu *et al.*, 1984; Dierenfeld *et al.*, 1988). Natural adjustment of vitamin E levels in reintroduced captive-bred animals to levels found in wild counterparts is previously unreported for any species. PVEC was consequently chosen as a physiological index for post-reintroduction monitoring, as changes could potentially alter an animal's susceptibility to PVEC-associated degenerative diseases.

The aim of this study was to monitor changes in physical condition and PVEC of reintroduced yellow-footed rock wallabies to examine the effect that reintroduction has on these two health indices of captive-bred animals. The null hypothesis was that the health of the wallabies would decline post-release, as indicated by Beck (1995, 2001), evident through lower PVEC and condition scores.

Methods

Study species

Two subspecies of the yellow-footed rock wallaby are recognized: *Petrogale xanthopus xanthopus* occurring in South Australia and New South Wales and categorized as Vulnerable on the IUCN Red List (IUCN, 2003), and *P. x. celeris*, categorized as Lower Risk/near threatened, occurring in Queensland (Fig. 1). The two subspecies are reported to have diverged 180,000 years ago (Eldridge, 1997a). Less than 13,500 yellow-footed rock wallabies are reported to exist throughout the species' range (Lim *et al.*, 1987). The species occupies cliffs or rock piles in rocky ranges in semi-arid to arid Australia (Lim *et al.*, 1987), generally in colonies of <20 animals (Copley & Alexander, 1997). Availability of food resources and the number of shelter sites are reported to determine colony size (Sharp, 1994). The main threat to the species is predation by the introduced European red fox *Vulpes vulpes* (Lapidge & Henshall, 2001).

Reintroduction

Twelve *P. x. xanthopus* bred by the Royal Zoological Society of South Australia (Adelaide Zoological Gardens and Monarto Zoological Park) were reintroduced to the

Fig. 1 Yellow-footed rock wallaby reintroduction sites (arrows) in Queensland (*Petrogale xanthopus celeris*) and South Australia (*P. x. xanthopus*), and the current range of the species (shaded; map adapted from Lim *et al.*, 1987).

arid-zone Aroona Sanctuary (30°36′S, 138°21′E; 215 mm mean annual rainfall), Leigh Creek, in the northern Flinders Ranges of South Australia on 26 September 1996 (Fig. 1). The Royal Zoological Society of South Australia, NRG Flinders and the South Australian Department of Environment and Heritage undertook the reintroduction, and I conducted the post-release monitoring discussed herein. Twenty-four *P. x. celeris* bred by the Queensland Environmental Protection Agency (Charleville) were reintroduced to Lambert Pastoral Station in the semi-arid Wallaroo Ranges (25°23′S, 145°51′E; 415 mm mean annual rainfall) on 9 August 1998 (Fig. 1). I conducted this reintroduction with assistance from volunteers, veterinarians and the Queensland Environmental Protection Agency. There were three releases, each of eight animals, on three separate hills (rocky mesas). Founder animal demographic and genetic selection procedures are beyond the scope of this paper but are available in Lapidge (2001). Animal ages were determined using the body measurement logarithms (principally head length) of Poole *et al.* (1985) and Bach (1998), and mass versus age records for *P. x. xanthopus* from SPARKS (Adelaide Zoological Gardens).

Release sites in both states were areas of each subspecies' former range from which they had been extirpated 20–30 years ago, principally due to competition with and predation from introduced mammals. All released animals and their wild-born offspring (>4 kg) were fitted with mortality-sensing radio-collars (Titley Electronics, Australia). Reintroductions were undertaken in accordance with published (Kleiman, 1989; Stanley Price, 1989; Short *et al.*, 1992; Kleiman *et al.*, 1994; IUCN, 1998) and original guidelines (Lapidge, 2001), and subsequent to extensive feral animal control, particularly of red foxes.

Post-release monitoring

Reintroduced *P. x. xanthopus* and their wild-born offspring were trapped at 3-monthly intervals between 18 and 54 months post-release (12 sessions). Reintroduced *P. x. celeris* were trapped at 6-monthly intervals post-release for 30 months (5 sessions). The reduced trapping of *P. x. celeris* was due to the more seasonal rainfall in Queensland. Animals were caught in padded treadle-operated cage-traps (38H * 38W * 76L cm; Crestware Industries, Australia) containing bait (peanut butter and rolled oats) and water. Reintroduced *P. x. celeris* were accustomed to entering traps in captivity to facilitate a high post-release recapture rate of reintroduced animals per trapping session. Rainfall was monitored daily at each release site. The vegetation at each release site was sampled in conjunction with trapping to determine the ground coverage of flora, and hence relative vegetation abundance, using the line-intercept method of Brower *et al.* (1990). Survey procedures are detailed in Lapidge (2001).

Vitamin E analysis

PVEC was determined in eight captive *P. x. celeris* and 69 captive *P. x. xanthopus* prior to reintroduction. Mean and standard deviation of PVEC for captive *P. x. xanthopus* were obtained from Conaghty & Schultz (1998). Although individual records for released *P. x. xanthopus* would have been preferable, results were included in the overall population mean and not available separately. Seasonal post-release PVEC samples were obtained from 21 individual reintroduced *P. x. celeris* (including wild-born progeny), and 20 individual reintroduced *P. x. xanthopus* (including wild-born progeny) in total during all sampling sessions, with 7–14 (*P. x. celeris*) and 2–9 (*P. x. xanthopus*) individuals sampled during each post-release trapping session. Samples were not consistently obtained from individual animals across each sampling period due to variations in the trapability of each animal, and therefore population subset trends were monitored rather than individual values.

Blood samples (4 ml) were obtained from a lateral tail vein using a 21g * 1″ needle (Terumo) for adults and 23g * 1¼″ needle for juveniles (Terumo) and a 5 ml Luer syringe (Terumo). Whole blood samples were partitioned in two, with 0.5 ml being transferred to an EDTA vial (Sarstedt) and refrigerated for later haematological analysis, and 3.5 ml being transferred to a Lithium Heparin vial (Sarstedt) and centrifuged at high speed for 10 min, with plasma extracted by pipette. Resulting plasma was divided into two Eppindorf tubes, with 0.5 ml frozen for biochemical analysis, and the remaining 1 ml (on average) frozen for PVEC analysis. Complete results from haematological and biochemical analyses are presented and discussed in Lapidge (2001). As haemolysis influences PVEC (D. Schultz, pers. comm.), plasma was not used if animal blood samples were haemolysed. PVEC was analysed using reverse-phase High Performance Liquid Chromatography (Shimadzu, Japan) at Royal Prince Alfred Hospital, Sydney.

Condition scores

All independent yellow-footed rock wallabies were scored for general condition when captured prior to release (*P. x. celeris* only; *P. x. xanthopus* were reintroduced prior to the current scoring system being defined) and during each trapping session for both subspecies. Scores ranged from 1 for an animal in extremely poor condition to 5 for an animal in faultless condition. Each animal was initially designated a score of 5, with points being deducted as follows: ½ point for minor loss in mass (< 5% initial body mass) or gain less than expected for the animal's age (prior mass is required); 1 point for major loss in mass (> 5% initial body mass) or gain far less than expected for the animal's age; ½ point for presence of alopecia or hair loss (although alopecia from fighting does not indicate poor health, it can indicate heightened social stress and/or be associated with wounds that could turn septic, thus its inclusion in the overall condition score.); ½ point for presence of a heavy parasite load, such as a tick infestation (the presence of some louse is normal in captive and wild *P. x. xanthopus*); ½ point for visible indicators of stress (e.g. profuse forearm and/or groin licking, as this often indicates underlying physiological problems such as heat stress, dehydration or under-nutrition); ½ point for subdued response to handling, lethargy, or a slow departure upon release; ½ point for evidence (in trap or during handling) of diarrhoea; ½ point for non-reproducing sexually mature females (yellow-footed rock wallabies are continuous breeders). For example, a wallaby suffering minor mass loss, heavy tick load, diarrhoea and lethargy would score 3 out of 5.

Wild animal data

PVEC has not been reported for wild *P. x. xanthopus*, and PVEC and condition scores from five wild *P. x. celeris* were obtained from males that emigrated to one of the reintroduced colonies from a natural colony 17 km distant from 12 months post-release. This dispersal distance is six times further than that previously reported for the species (Sharp, 1997), and was thus unforeseeable. All wild captured males were healthy adults or subadults likely to be subordinates dispersing from their original colony. Some of these males had successfully reproduced with reintroduced females by the cessation of monitoring, as indicated by mitochondrial DNA analysis (S. Lapidge, unpubl. data).

Data analysis

Differences between captive and reintroduced (first post-release sample for both subspecies) and reintroduced and wild *P. x. celeris* (paired samples from 1 year post-release) PVEC values and condition scores were tested for significance using one-factor ANOVA for unequal replication (Zar, 1984) using SYSTAT 10 (SPSS Inc., 2000). Examination of residuals indicated no transformation was necessary. Although preferable, repeated measures ANOVA was not possible due to the inconsistency of the individual animals recaptured during each trapping session. Differences between captive and reintroduced *P. x. xanthopus* PVEC values were tested for significance using a two-sample *t* test for means as the raw data for captive *P. x. xanthopus* at Adelaide Zoo were not available. Differences in post-release sex and season PVEC values and condition scores were tested for significance using non-orthogonal two-way ANOVA using GenStat 7 (VSN International Ltd., 2003). Dependence of condition scores on independent measures of age, mass, rainfall, vegetation abundance, and PVEC were analysed using simple linear regression (Zar, 1984). The purpose of this was to test the condition scoring index against independent physiological and environmental factors that generally dictate animal health. Minimum significance was defined as $P < 0.05$.

Results

Lambert Pastoral Station received above average rainfall of 520, 511 and 677 mm during the project, in 1998, 1999 and 2000, respectively. However, little rain fell in the winters of 1999 and 2000. Annual rainfall for Aroona Sanctuary in the years since release has been slightly above average (224 ± 52 mm), with 1997 and 2000 above (242 and 298 mm respectively) and 1998 and 1999 below average (196 and 159 mm respectively). Vegetation surveys undertaken at both release sites indicated that Lambert Station had higher vegetation abundance than Aroona Sanctuary. Ground cover at Lambert Station averaged 42.3 ± SD 11.2% throughout monitoring compared to 27.2 ± SD 7.0% at Aroona Sanctuary. The higher vegetation abundance on Lambert Station was predominantly in the form of *Acacia* woodland on hill slopes. This should provide greater protection from the sun and aerial predators, and greater food reserves in times of drought (Lim *et al.*, 1987). Monthly rainfall totals and detailed results of vegetation surveys are available in Lapidge (2001).

Plasma vitamin E concentration (PVEC) was significantly lower in captive than wild *P. x. celeris* ($F_{1,20} = 126$; $P < 0.001$), as reported for other herbivores (Dierenfeld *et al.*, 1988; Savage *et al.*, 1999) (Table 1). PVEC in captive *P. x. celeris* and *P. x. xanthopus* was however greater than that reported for other captive herbivores (Schweigert *et al.*, 1991), potentially (although unlikely due to the short half-life of α-tocopherol) due to periodic intramuscular Vitamin-E-Selenium injections during handling in captivity (0.2 ml Vitamin-E-Selen: 150 IU vitamin E and 0.5 mg selenium/ml: Hoechst Roussel Vet). PVEC increased in reintroduced *P. x. celeris* ($F_{1,16} = 35.2$; $P < 0.001$) and *P. x. xanthopus* ($t = 2.83$; $P < 0.01$) by the first recapture session (6 and 18 months respectively), and remained at the elevated level for the duration of subsequent monitoring (Tables 1 & 2). Concurrent values

Table 1 Mean plasma vitamin E concentration and condition score (± SD), with sample size in parentheses, of captive, reintroduced and wild *Petrogale xanthopus celeris* and captive and reintroduced *P. x. xanthopus.* There was a significant difference between captive and reintroduced values (P < 0.0001) but not reintroduced and wild values (P > 0.05) for *P. x. celeris*, and a significant difference (P < 0.05) between captive and pooled reintroduced values for *P. x. xanthopus.*

Species & group	Date	Vitamin E ± SD (N)	Condition score ± SD (N)
P. x. celeris			
Captive	Various	9 ± 3 (8)	3.1 ± 0.5 (24)
Reintroduced	Jan. 1999	21 ± 5 (10)	4.2 ± 0.3 (11)
	July 1999	25 ± 6 (13)	4.2 ± 0.3 (13)
	Jan. 2000	24 ± 6 (13)	4.2 ± 0.3 (14)
	July 2000	34 ± 10 (14)	4.3 ± 0.6 (14)
	Jan. 2001	28 ± 8 (7)	4.6 ± 0.4 (7)
Wild	July 1999	27 ± 7 (3)	4.2 ± 1.4 (3)
	Jan. 2000	25 ± 1 (2)	4.5 ± 0.7 (2)
	July 2000	29 ± 6 (4)	4.6 ± 0.6 (4)
	Jan. 2001	29 ± 1 (5)	4.6 ± 0.4 (5)
P. x. xanthopus			
Captive	Various	4.8 ± 5.8 (69)	–
Reintroduced	Apr. 1998	22 ± 7 (6)	–
	July 1998	–	3.3 ± 0.4 (5)
	Oct. 1998	21 ± 7 (4)	3.9 ± 0.3 (4)
	Jan. 1999	18 ± 4 (3)	3.3 ± 0.9 (4)
	Apr. 1999	23 ± 5 (8)	4.0 ± 0.4 (8)
	July 1999	19 ± 6 (9)	3.4 ± 0.4 (9)
	Oct. 1999	21 ± 5 (6)	3.8 ± 0.3 (6)
	Jan. 2000	19 ± 4 (6)	4.1 ± 0.3 (6)
	Apr. 2000	22 ± 3 (7)	4.2 ± 0.6 (7)
	July 2000	20 ± 7 (7)	4.6 ± 0.3 (7)
	Oct. 2000	31 ± 9 (2)	4.9 ± 0.2 (3)
	Jan. 2001	24 ± 3 (4)	4.7 ± 0.3 (5)

obtained from wild *P. x. celeris* were not significantly different from that of reintroduced *P. x. celeris* ($F_{1,69} = 0.21$, P = 0.65).

PVEC did not increase with age in *P. x. celeris* ($F_{1,78} = 0.89$; P > 0.05), yet did in *P. x. xanthopus* ($F_{1,61} = 4.19$; P < 0.05). PVEC was also significantly higher in reintroduced *P. x. celeris* than *P. x. xanthopus* ($F_{1,112}$=16.0; P<0.001), and significantly higher in winter than summer in *P. x. celeris* ($F_{1,56} = 7.49$; P < 0.01) with no season effect detected in *P. x. xanthopus* ($F_{3,61} = 0.87$; P < 0.05). No significant relationship was detected between PVEC and sex (*P. x. celeris*: $F_{1,56} = 0.84$; *P. x. xanthopus*: $F_{1,61} = 2.87$) or mass (*P. x. celeris*: $F_{1,56} = 0.09$; *P. x. xanthopus*: $F_{1,61} = 3.06$). Mean trapping sample PVEC was independent of accumulated rainfall between trapping sessions (*P. x. celeris*: $F_{1,3} = 00.03$; *P. x. xanthopus*: $F_{1,9} = 1.24$) and vegetation abundance (*P. x. celeris*: $F_{1,3} = 0.26$; *P. x. xanthopus*: $F_{1,9} = 1.57$).

Wild *P. x. celeris* were found to be in significantly better condition that captive *P. x. celeris* prior to release ($F_{1,36} = 42.6$, P < 0.001; Table 1). Condition scores for reintroduced *P. x. celeris* significantly increased post-release ($F_{1,81} = 111$, P < 0.001; Table 1) with the greatest change occurring in the 6-months post-release. Condition scores of reintroduced and wild *P. x. celeris* did not significantly differ ($F_{1,72} = 2.2$, P > 0.05; Table 1) when first assessed post-release (6 months), or during any subsequent trapping session. Although not statistically testable within the subspecies (without pre-release and wild scores), a similar pattern was observed for reintroduced *P. x. xanthopus.*

Condition scores were found to be independent of age (*P. x. celeris*: $F_{1,58} = 0.24$; *P. x. xanthopus*: $F_{1,62} = 0.53$), mass (*P. x. celeris*: $F_{1,58} = 3.38$; *P. x. xanthopus*: $F_{1,62} = 2.53$), sex (*P. x. celeris*: $F_{1,58} = 1.58$; *P. x. xanthopus*: $F_{1,62} = 0.189$) and season (*P. x. celeris*: $F_{1,58} = 0.31$; *P. x. xanthopus*: $F_{3,62} = 2.22$) in reintroduced animals. Mean trapping sample condition scores of *P. x. celeris* were found to be independent of prior rainfall ($F_{1,3} = 0.03$) and vegetation abundance ($F_{1,3} = 0.03$). Mean trapping sample condition scores of *P. x. xanthopus* were found to be dependent on prior rainfall ($F_{1,9} = 7.0$; P < 0.05) and even more so on vegetation abundance ($F_{1,9} = 15.2$; P < 0.005). Overall condition scores were significantly related to independently-measured PVEC ($F_{1,113} = 16.7$; *P. x. xanthopus*: $F_{1,9} = 1.57$) (Fig. 2).

Discussion

Plasma vitamin E concentration underwent the most significant change post-release of all measured biochemical parameters (Lapidge, 2001), doubling in 6 months in *P. x. celeris* (Table 1) and increasing four-fold in *P. x. xanthopus* in 22 months (Table 1). Post-release PVEC in *P. x. celeris* did not significantly differ from that of sympatric wild counterparts (Table 1). The control of PVEC is reported to be multifactorial, with nutrition and physical stress implicated (Kakulas 1961, 1963; Munday, 1988; Speare *et al*., 1989; Rucker & Morris, 1997; Hume, 1999). Results from the current study indicate that browse, including woody shrubs and trees, is the most likely dietary source of the vitamin for free-living yellow-footed rock wallabies. Although analysis of vitamin E content of the myriad of plant species at both study sites would have confirmed this, such a large-scale analysis was beyond the means of this study. The diet of reintroduced *P. x. xanthopus* contained minimal browse (4%) at Monarto Zoological Park prior to release (Lapidge, 2000), potentially causing the low PVEC recorded in the captive population. One month post-release browse intake had risen to 12% of the diet, and remained similarly high at the end of the study (Lapidge, 2000). A reduction in physical stress may also be involved, a suggestion supported by the highly significant decrease in plasma creatinine concentration in yellow-footed rock wallabies

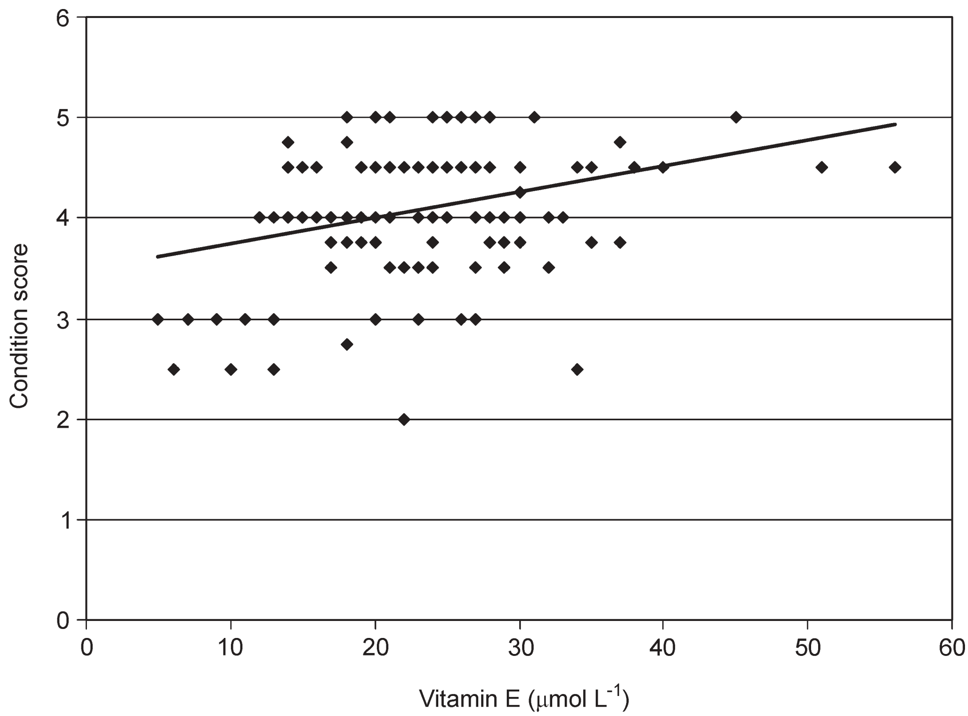

Fig. 2 The positive relationship between independently-measured plasma vitamin E concentrations and condition scores for yellow-footed rock wallabies (both subspecies combined) is significant ($F_{1,133} = 16.7$, $P = 0.01$).

post-release (Lapidge, 2001), and the opposite effect (increased cortisol levels) occurring in brushtail possums transferred from the wild to captivity (Baker *et al*., 1998). Thus, the results lead to a rejection of the null hypothesis: PVEC increases in reintroduced animals due to less physical exertion in the wild and increased dietary intake of browse species and hence vitamin E.

PVEC was independent of age for reintroduced *P. x. celeris* but dependent on age in reintroduced *P. x. xanthopus*. This difference may be due to the disparity in vegetation structure between the two release sites. Limited green leaf vegetation was often browsed by adults to a height above which juvenile wallabies could reach at Aroona Sanctuary. This did not occur on Lambert Station due to an abundance of trees. This potentially resulted in juvenile *P. x. xanthopus* having a lower browse intake and consequential PVEC. Although this is unproven, PVEC was also significantly higher in *P. x. celeris* than *P. x. xanthopus*, consistent with the higher availability of browse at Lambert Station than Aroona Sanctuary (Lapidge, 2001).

Significantly higher PVEC in winter in *P. x. celeris*, but no season affect in *P. x. xanthopus*, is probably related to higher consumption of browse species in winter as more herbaceous species succumb to lower rainfall (Lapidge & Allen, *in press*). Furthermore, the independence of PVEC on vegetation abundance and rainfall in both subspecies is probably due to browse species (trees and woody shrubs) being the most consistent plant group available, and the least affected by rainfall patterns when compared to forbs and grasses (Lapidge, 2001).

Condition scores for captive *P. x. celeris* increased significantly post-release (Table 1). Animals generally gained mass faster than in captivity, males suffered less alopecia, females were more fecund and both sexes showed less visible evidence of capture stress. By 6 months post-release, reintroduced *P. x. celeris* were found to be in similar condition to their wild counterparts. Although Short & Turner (2000) found that reintroduced burrowing bettongs *Bettongia lesueur* maintained similar body condition to the source population post-release, both populations were free-living. Despite seasonal variation in rainfall and vegetation abundance at Lambert Station, there was no difference in condition scores of *P. x. celeris* between summer and winter, indicating that captive-bred animals were highly resilient to seasonal change. Moreover, significantly higher PVEC and overall condition indicated that both indices improved upon reintroduction to the wild for both captive-bred yellow-footed rock wallaby subspecies.

PVEC and its association with myopathy, or physical stress, is reported to be affected by enclosure size in quokkas *Setonix brachyurus*, with animals housed in smaller enclosures more prone to myopathy (Kakulas, 1963). Results from the current study suggest that other factors such as nutrition were involved; *P. x. xanthopus* housed in large natural enclosures at Monarto Zoological Park had a lower PVEC than *P. x. celeris* housed in small crowded enclosures at the Charleville Environmental

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Protection Agency compound (pers. obs.). Furthermore, a number of *P. x. xanthopus* at Monarto Zoological Park reportedly died from myopathy (S. Conaghty, pers. comm.), whereas there are no reported cases for *P. x. celeris*. The difference is possibly because the diet of captive *P. x. celeris* was supplemented with mulga *Acacia aneura* leaves. This feature of captive *P. x. celeris* animal husbandry may be one that has prevented animal deaths from myopathy in the overcrowded enclosures (Kakulas, 1963). The technique is recommended for other captive herbivores that are prone to myopathy.

Tocopherol (vitamin E) comes from the Greek word 'tokos' meaning reproduction or childbirth, as it is known to aid embryonic development (Rucker & Morris, 1997). The effect of vitamin E on macropod reproduction has not been reported. Higher fecundity of *P. x. celeris* was recorded post-release (100% of females pregnant at any one time) than pre-release (86%), with associated higher PVEC (Lapidge, 2001). Similarly, higher fecundity was recorded in reintroduced *P. x. celeris* (100%) than *P. x. xanthopus* (53%), along with significantly higher PVEC in the former. These limited data indicate that vitamin E may assist reproduction in yellow-footed rock wallabies.

The condition score index adopted and refined in the current study provides a simple but indicative parameter with which to compare the condition of animals across the population and over time. Although less objective than body measurements previously used to assess condition in macropods (Bakker & Main 1980; Catt 1981; Moss & Croft, 1999; Short & Turner 2000), the technique takes into account more factors that indicate animal health. Condition scores were significantly related to PVEC, which was independently determined, and to vegetation abundance and rainfall for *P. x. xanthopus*, which occupies the more extreme and variable environment. Furthermore, condition scores were independent of age, mass and sex, and were therefore not biased towards any particular group of animals. These findings attest to its usefulness.

In addition, the technique was found particularly useful in conveying information on animal health throughout the study to project supporters, particularly the Royal Zoological Society of South Australia. Although PVEC provides a more objective index of independently monitoring individual changes in animal condition, the cost of at least AUS $15.00 per sample analysis (> AUS $3,000 for sample analysis in this study) may be prohibitive for other reintroduction projects. Thus, the condition scoring system used in the current study provides a reasonable index for monitoring visible changes in animal condition. The applicability of findings from the current study to other species, particularly within the genus *Petrogale*, is unknown. However, as the biology of the genus is predominantly similar among species, findings should be useful in providing a basis on which to monitor the health of other reintroduced *Petrogale* species. Furthermore, as low PVEC is common to numerous captive herbivores, wider applications of these findings to include eutherian herbivores can therefore be anticipated.

These findings show a change in plasma vitamin E concentration in reintroduced captive-bred yellow-footed rock wallabies to levels found concurrently in wild counterparts at the same site. Improved nutrition through access to fresh pasture, particularly browse species, and a reduction in captivity-associated physical exertion probably produced the increase (Kakulas, 1961, 1963; Dierenfeld *et al*., 1988; Baker *et al*., 1998). Reintroduction has thus reduced the susceptibility of released animals to vitamin E deficiency-related diseases through increasing their ability to counter antioxidant stress (Kakulas, 1961; Liu *et al.*, 1984; Dierenfeld *et al.*, 1988). With the proper endpoint of captive breeding being reintroduction (Tudge, 1991), the current finding provides original evidence that some captive animals, principally herbivores, may benefit from reintroduction to the wild. Furthermore, to maintain animal condition and possibly increase fecundity of threatened herbivore species, these findings support *in situ* rather than *ex situ* conservation where possible (Balmford *et al*., 1995). However, reintroduction and *in situ* conservation introduces a suite of other technical problems, including ongoing habitat preservation and predator control.

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Biographical sketch

Steven Lapidge has studied the dietary adaptation of reintroduced captive-bred wallabies, and other factors involved in adaptations of captive-bred animals to the wild. He has also carried out research on invasive red fox and feral pigs in Queensland. His current research involves developing additional tools, including toxins, baits, lures, molecular detection methods and education programs, for the humane, target specific and integrated control of vertebrate pest animals in Australia.