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Comparison of seasonal patterns of growth, voluntary feed intake and plasma hormone concentrations in young sambar deer (*Cervus unicolor*) and red deer (*Cervus elaphus*)

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SUMMARY

During 1991/93, young sambar (5 months old) and red deer (7 months old) were confined indoors in individual pens in New Zealand and fed a pelleted concentrate diet (12 MJ ME/kgDM; 2·9% N) *ad libitum* for 21 months. Seasonal patterns of voluntary feed intake (VFI), liveweight gain (LWG), scrotal circumference and plasma concentrations of prolactin (PRL), luteinizing hormone (LH), testosterone (T) and progesterone (P) were compared using five stags and three hinds of each species.

Red deer showed a strong pattern of seasonality, with high VFI and LWG in summer and low VFI and LWG in winter and with peak plasma T and scrotal circumference in stags in early autumn. Compared with red deer, sambar showed weaker seasonal patterns of VFI and LWG, with maximum values in autumn and minimum values in spring. Over a complete 12-month cycle, sambar deer gained similar amounts of liveweight to red deer but consumed substantially less feed, thus demonstrating a more efficient conversion of feed to bodyweight. Metabolizable energy (ME) requirements for both maintenance and gain were substantially lower for sambar than for red deer. Scrotal circumference and plasma T values in sambar stags attained their highest values during late autumn, winter and spring, but with a lower magnitude than peak values for red stags. Plasma PRL concentrations were seasonal in both species, with highest values in summer and lowest values in winter. Rapid increase of plasma P was first detected in red hinds in autumn and sambar hinds in spring when they weighed 96 and 90 kg respectively, and were aged 17 and 14 months. Rapid increase of plasma T was first detected in red stags in early autumn and sambar stags in mid-autumn when they weighed 117 and 101 kg, and were aged 16 and 15 months respectively.

It was concluded that sambar deer had endogenous cycles of VFI, body growth and hormone secretion, which were of lesser amplitude and with different seasonality from those of red deer. Young sambar deer were more efficient feed converters than red deer, and attained sexual maturity at an earlier age and lower liveweight.

INTRODUCTION

Sambar deer (*Cervus unicolor*) are endemic to tropical regions of India and South East Asia (Whitehead 1972), but have been introduced successfully in some temperate regions of New Zealand and Australia (Wodzicki 1950; Bentley 1978). As with other tropical cervid species in temperate environments, little is known about their patterns of voluntary feed intake (VFI), body growth, reproduction and hormone secretion.

There has been increasing interest in the adoption of tropical cervids into temperate pastoral agricultural systems, in which pasture growth patterns do not correlate precisely with the strongly seasonal patterns of growth and reproduction of temperate cervids such as red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) (Woodford 1991). Pasture growth patterns in the Mediterranean-type climates of coastal Australia may be better suited to species with more malleable patterns of reproduction and growth than those observed in temperate species (Woodford 1991).

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Thus, there has been recent interest in such species as rusa (*Cervus timorensis*), chital (*Axis axis*) and sambar deer. The value of these animals to deer farming may lie in better alignment with local pastoral environments or in their potential to hybridize with farmed temperate species, to generate synthetic breeds better suited to local conditions.

Temperate cervids, such as red and fallow deer, have clearly defined seasonal patterns of VFI, growth and reproduction that are closely related to photoperiod changes, with endogenous cycles cued to photoperiod by the pineal hormone, melatonin (Asher *et al.* 1988; Barry *et al.* 1991). The situation with tropical cervids in temperate environments is not so clear cut. The two most intensively studied tropical cervids are the chital and Brow-antlered Eld's deer (*Cervus eldi thamin*). Interestingly, these two species exhibit contrasting reproductive patterns. Chital deer in Britain and Australia display considerable non-synchrony of births and relatively weak photoperiod–pineal links to the reproductive axis (Loudon & Curlewis 1988; Mylrea 1992). Conversely, Eld's deer exhibit pronounced reproductive seasonality, albeit in a reverse pattern relative to photoperiod than that observed for temperate species (Monfort *et al.* 1990, 1993*a*, *b*).

The objectives of this study were to examine cycles of VFI, body growth and plasma hormone concentrations in sambar deer and to compare these with annual endogenous cycles in red deer.

MATERIALS AND METHODS

Experimental design

Artificially reared male and female sambar and red deer were selected randomly and placed in individual indoor pens under normal photoperiods (38° S). All animals were fed a pelleted diet *ad libitum*, and the two species were compared for rate of body growth, VFI, scrotal circumference in stags and plasma hormone profiles for prolactin (PRL), progesterone (P), testosterone (T) and luteinizing hormone (LH). The study on red deer commenced on 21 July 1991 and concluded on 28 November 1992, whilst the study on sambar deer commenced on 12 October 1991 and concluded on 23 June 1993. These differences were due to late calving and to the wider range in calving in sambar deer than in red deer (Semiadi *et al.* 1994).

Animals

Apart from one red hind, all animals (five stags and three hinds of each species) were artificially reared (Semiadi *et al.* 1993). In January 1992, one sambar stag had to be euthanized because of a neck injury sustained during a concurrent study, and in July and September 1992 one sambar stag and one sambar hind, respectively, died from malignant catarrhal fever (MCF). No replacements were made.

The red deer were placed in individual pens on 7 July 1991. Because of temperamental problems (September and October 1991), one red hind and one red stag were replaced. Because of the wide range of sambar deer calving dates, the sambar were introduced to pens gradually between 23 September 1991 and 2 January 1992. The mean ages and liveweights of sambar and red deer when first penned are shown in Table 1. Data collection commenced after a 2-week period of adjustment to the diet and surroundings.

First year velvet antlers were removed after attaining a length of 15 cm in red stags and 8 cm in sambar stags. The animals were sedated using xylazine hydrochloride (Rompun; Bayer Ltd, NZ) at a dosage rate of 0·50–0·75 mg/kg body weight, intramuscularly. When the animals were mildly sedated, local anaesthetic was then given by administering 15 ml lignocaine hydrochloride (Xylotox; A. H. Robins Co. Ltd, England) per antler, in a ring block. A tourniquet was applied in the coronet area 4 min later, and the velvet was cut. As the blood clotted, the tourniquet was released and xylazine reversed with 1·5–2·0 ml yohimbine hydrochloride (Recervyl; Aspiring Veterinary Services, NZ) to counteract the xylazine effect.

Health

One week before the animals were placed in individual pens, they received oral Ivermectin (Ivomec; Merck, Sharp and Dohme, NZ) to remove intestinal parasites.

Table 1. *Mean age (days, S.E.) and liveweight (kg, S.E.) of young sambar deer and red deer when they were placed in individual indoor pens in New Zealand*

	Stags		Hinds	
	Sambar deer ($n = 3$)	Red deer ($n = 5$)	Sambar deer ($n = 2$)*	Red deer ($n = 3$)
Age (days)	160 (55·4)	219 (18·6)	128 (25·5)*	232 (27·9)
Liveweight (kg)	49·5 (7·70)	51·2 (2·09)	36·6 (2·85)*	44·6 (5·62)

* Where $n = 2$, range (±) is given.

This was repeated 1 week and 3 weeks after the animals were penned. During the rut and when stags were too intractable for blood sampling, mild sedation was induced with an intramuscular injection of xylazine hydrochloride (0·75–1·25 mg/kg liveweight; Rompun; Bayer Ltd, NZ), without any assisted reversal. The use of this drug only applied to red stags and only comprised 5% of total red stag blood samples.

Housing

Sixteen individual indoor pens measuring 4·0 × 2·0 m, with 2·7 m high sides were used. Three-quarters of the pen floor comprised slatted wood and the remainder concrete. Drinking water was available through automatic drinking nipples. The bottom half of the pen walls were made of metal bars, and the upper half of wood. Each animal had visual and limited physical contact with neighbouring animals. Deer were housed under natural ambient temperature and photoperiod, but automatic artificial lights, synchronized with natural daylength, were also provided.

Feeding

All animals were fed a pelleted diet, comprising barley (39·8%), bran/pollard (23·0%), brewers grain (5·0%), soyabean (10·0%), lucerne (15·0%), molasses (4·0%), salt (1·0%), lime (1·5%), dicalcium phosphate (0·5%) and vitamin mix (0·2%). All animals were fed once daily, at 08.00–09.00 h, at 120% of the previous day's consumption. Feed intake and feed refusals were recorded weekly. Samples of feed on offer and feed refusals were collected daily, pooled weekly and dry matter content determined on a weekly basis.

Weighing, blood sampling and scrotal measurement

All animals were weighed and blood sampled by jugular venepuncture every 2 weeks. Additional weekly samples were taken from hinds as they approached puberty ($\geq$ 9 months of age). Blood sampling was conducted under hand restraint in a dark room, and samples collected in 10 ml heparinized evacuated tubes (Nippro Medical Industries Ltd, Japan) and placed on ice until processing. All samples were centrifuged at 2000 ***g*** for 15 min, within 50 min of collection. Plasma was transferred to 2 ml plastic tubes and stored at −20 °C until required for analysis. Scrotal circumference of the stags was measured every 2 weeks, using a flexible polypropylene tape around the middle of the scrotum.

Laboratory analyses

Feed samples were freeze-dried and ground to pass a 1 mm sieve (Willey Mill, USA). Dry matter (DM) was measured by drying the samples in an oven at 100 °C for 16 h. Total N was determined by the Kjeldahl procedure and *in vitro* digestibility followed the method described by Roughan & Holland (1977). Gross energy was determined using an adiabatic bomb calorimeter. Samples were pelleted (0·5–0·8 gDM, 12 mm diameter) prior to combustion.

All plasma hormone concentrations were measured by double-antibody competitive binding radioimmunoassay procedures. The prolactin (PRL) assay was based on the method of van Landeghem & van de Wiel (1978) and validated for use with red deer plasma (Ataja 1990). Inter-assay and intra-assay coefficients of variation were 16·6 and 9·7%, respectively. Assay sensitivity (the least amount significantly distinguishable from zero) was 0·84 ng/ml plasma.

The testosterone (T) assay was conducted as described by Barrell & Lapwood (1978). The inter-assay coefficients of variation for the two pools of plasma containing 2·45 and 9·71 ng/ml were 18·4 and 15·5%, and the intra-assay coefficients of variation were 6·9 and 10·5%. Assay sensitivity was 0·10 ng/ml.

The progesterone (P) assay was conducted as described by Asher *et al.* (1988) and Morrow (1992). The inter-assay coefficients of variation for the three pools of plasma containing 1·96, 10·42 and 18·06 ng/ml were 2·5, 16·7, 6·4% and the intra-assay coefficients of variation were 14·3, 8·3, 2·2%, respectively. Assay sensitivity was 0·15 ng/ml plasma.

The luteinizing hormone (LH) assay was conducted as described for sheep by Scaramuzzi *et al.* (1970) and validated for use with fallow deer plasma (Asher *et al.* 1986). All samples were run in a single assay, with the coefficients of variation within the assay for the three pools of plasma containing 0·73, 11·5 and 14·2 ng/ml being 6·3, 6·7 and 3·7%, respectively. Assay sensitivity was 0·10 ng/ml plasma.

Data collection and statistical analysis

Because of the 6-month age difference between sambar and red deer, and the low number of animals of each sex, no statistical comparisons were made at individual time points (i.e. months). Rather, the data were examined for evidence of endogenous (circannual) cycles and the times at which these occurred in the two species. Data from animals that died were excluded. All red deer data recording was concluded on 29 November 1992, while data collected from sambar continued until 23 June 1993, in order to compare the two deer species at the same age. Mean values and standard errors are presented. Metabolizable energy (ME) was calculated as digestible organic matter (kg/kgDM) × 16·3.

To estimate energy requirements, regression equations were calculated of liveweight gain (g) per day per kg metabolic weight ($W^{0.75}$) on calculated ME intake (MJ) per day per kg metabolic weight, as described by Fennessy *et al.* (1981), using data from the same age periods for each deer species. For each

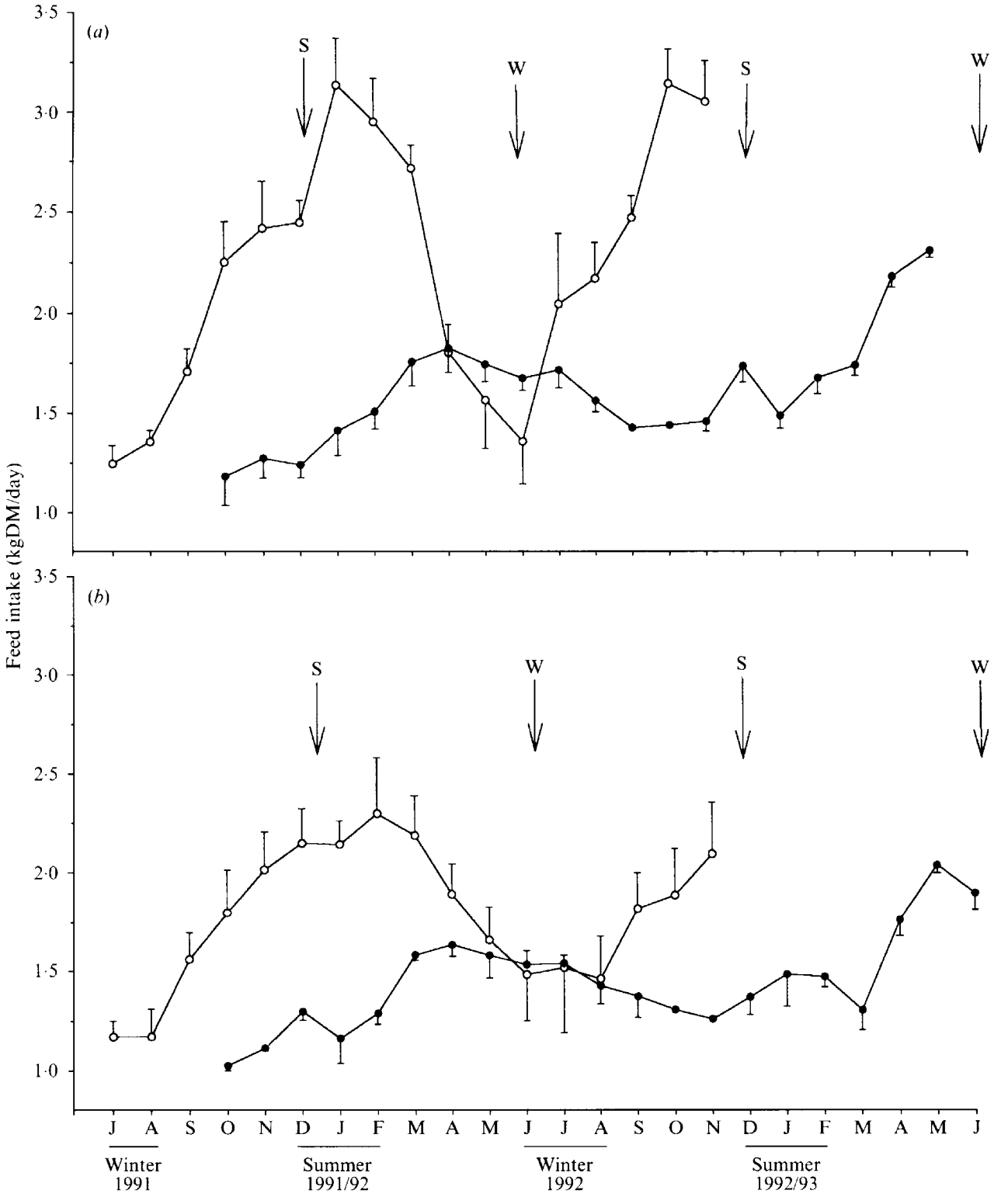

Fig. 1. Voluntary feed intake (kgDM/day) of young sambar (●) and red deer (○) fed indoors on a pelleted diet *ad libitum*. (*a*) stags and (*b*) hinds. Vertical bars represent S.E. S = summer solstice; W = winter solstice.

sex of each species, values for each animal calculated over four consecutive 3-month periods were used in each regression.

Voluntary feed intake, liveweight gain (LWG) and feed conversion efficiency (FCE; kgDMI/kgLWG) for the two species were statistically compared over corresponding complete 12-month periods (sambar, Nov 1991–Nov 1992; red deer, Jul 1991–Jul 1992),

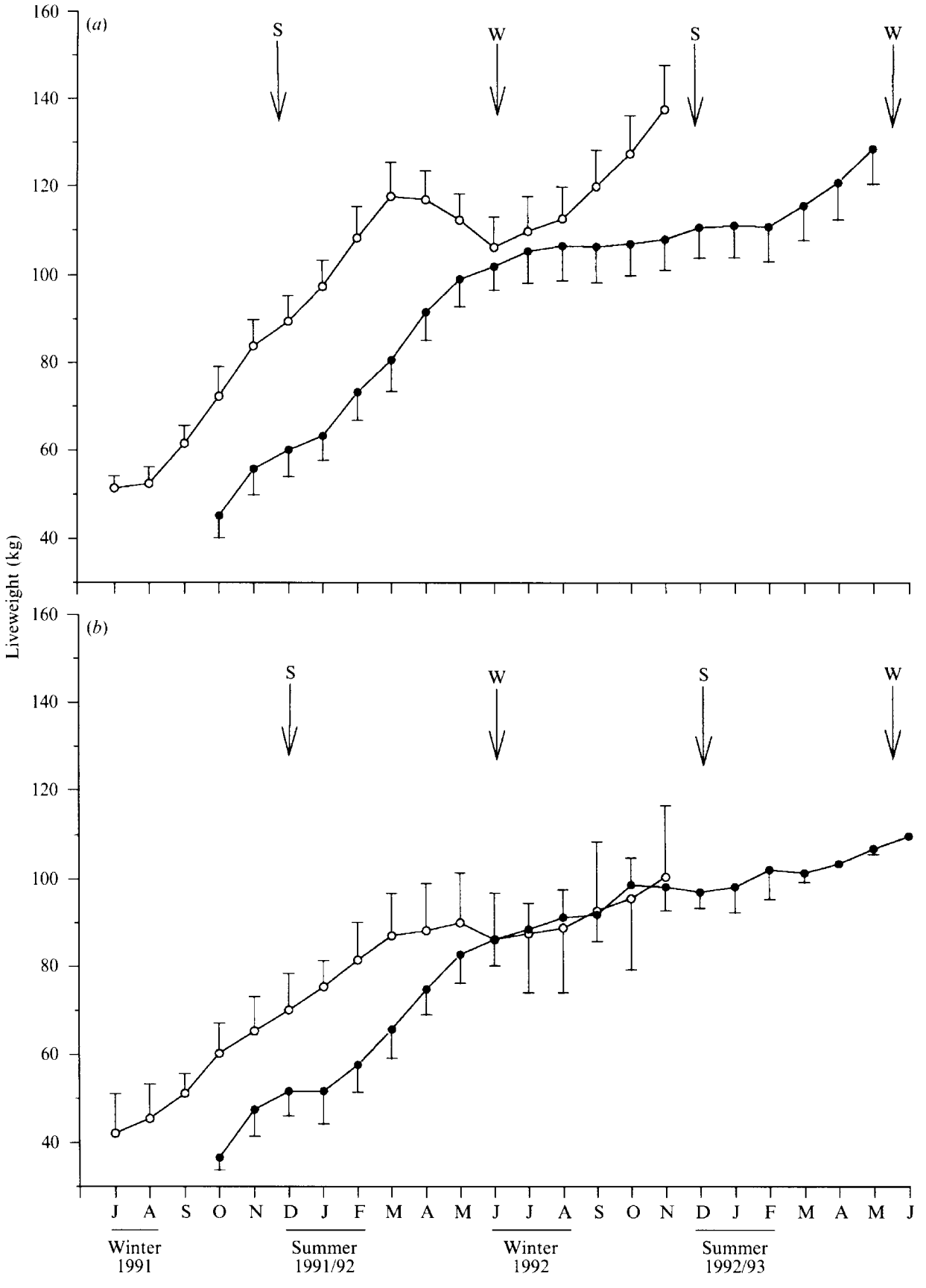

Fig. 2. Liveweight changes (kg) of young sambar (●) and red deer (○) fed indoors on a pelleted diet *ad libitum*. (*a*) stags and (*b*) hinds. Vertical bars represent S.E. S = summer solstice, W = winter solstice.

Table 2. *Seasonal patterns of voluntary feed intake (VFI), liveweight gain (LWG; g/day) (mean, S.E.) and feed conversion efficiency (FCE; kgDMI/kgLWG) (mean) in young sambar and red deer, fed indoors on a pelleted diet* ad libitum. *At the start of summer 1992, sambar deer were 6 months and red deer were 12 months of age*

	Sambar stag ($n = 3$)	Red stag ($n = 5$)	Sambar hind ($n = 2$)*	Red hind ($n = 3$)
		Spring 1991		
VFI				
(kgDM/day)		2·13 (0·164)		1·79 (0·168)
(gDM/BW$^{0·75}$/day)		85·7 (3·41)		84·1 (1·77)
LWG		348 (23·9)		219 (35·1)
FCE		6·1		8·2
		Summer 1992		
VFI				
(kgDM/day)	1·31 (0·06)	2·75 (0·176)	1·31 (0·044)	2·19 (0·191)
(gDM/BW$^{0·75}$/day)	59·2 (2·27)	87·8 (1·44)	63·4 (1·66)	85·5 (1·75)
LWG	199 (44·8)	291 (17·7)	192 (35·5)	191 (13·0)
FCE	7·0	9·3	6·8	11·5
		Autumn 1992		
VFI				
(kgDM/day)	1·79 (0·185)	2·02 (0·109)	1·64 (0·093)	1·91 (0·171)
(gDM/BW$^{0·75}$/day)	62·1 (3·24)	57·3 (1·28)	61·3 (12·5)	66·6 (2·64)
LWG	260 (31·8)	40 (17·5)	254 (12·5)	90 (23·9)
FCE	6·9	50	6·3	31·7
		Winter 1992		
VFI				
(kgDM/day)	1·62 (0·047)	1·93 (0·258)	1·52 (0·078)	1·48 (0·259)
(gDM/BW$^{0·75}$/day)	51·0 (1·28)	56·0 (5·67)	50·6 (0·28)	51·4 (4·07)
LWG	71 (22·0)	4 (16·3)	78 (26·0)	23 (7·5)
FCE	22·5	475	19·2	65·2
		Spring 1992		
VFI				
(kgDM/day)	1·43 (0·019)	2·88 (0·122)	1·31 (0·044)	1·93 (0·219)
(gDM/BW$^{0·75}$/day)	43·5 (2·54)	76·3 (2·11)	42·3 (0·11)	63·3 (1·74)
LWG	25 (5·8)	268 (28·1)	25 (13·5)	131 (0·02)
FCE	56·0	10·8	52·0	14·5
		Summer 1993		
VFI				
(kgDM/day)	1·64 (0·096)		1·43 (0·104)	
(gDM/BW$^{0·75}$/day)	47·7 (1·44)		45·7 (1·43)	
LWG	31 (6·1)		33 (12·5)	
FCE	52·0		39·3	
		Autumn 1993		
VFI				
(kgDM/day)	2·07 (0·045)		1·69 (0·001)	
(gDM/BW$^{0·75}$/day)	56·3 (3·93)		52 (0·52)	
LWG	194 (0·035)		53 (0·06)	
FCE	10·7		31·9	

* Where $n = 2$, range (±) is given. Summer = Dec–Feb; Autumn = Mar–May; Winter = Jun–Aug; Spring = Sep–Nov.

when the two deer species were of similar age. A 2 × 2 factorial model was used, to examine effects of species, sex and any species × sex interaction. An additional analysis was also performed with FCE, calculated from the start of the experiment to the attainment of an arbitrary liveweight (stags 100 kg; hinds 80 kg).

Table 3. *Voluntary feed intake (VFI), liveweight gain (LWG) and feed conversion efficiency (FCE) (mean, S.E.) in young sambar and red deer, fed indoors on a pelleted diet* ad libitum, *over corresponding 12 month periods (sambar: Nov 1991–Nov 1992; red deer: Jul 1991–Jul 1992)*

	Sambar stag ($n = 3$)	Red stag ($n = 4$)	Sambar hind ($n = 2$)*	Red hind ($n = 2$)*
Initial age (days)	198 (64·0)	201 (2·5)	169 (39·0)	204 (2·5)
VFI (kgDM/day)	1·63 (0·072)	2·21 (0·131)	1·42 (0·081)	1·82 (0·293)
LWG (g/day)	138 (24·5)	159 (17·8)	139 (1·3)	126 (33·2)
FCE (kgDMI/kgLWG)	12·2 (2·21)	13·9 (1·09)	10·3 (0·70)	15·0 (1·66)

* Where $n = 2$, range (±) is given.

Table 4. *Age, liveweight gain, voluntary feed intake (VFI) and feed conversion efficiency (FCE) in young sambar and red deer growing to arbitrary target liveweights (stags 100 kg; hinds 80 kg), fed indoors on a pelleted diet* ad libitum (*mean, S.E.*)

	Stags		Hinds	
	Sambar deer ($n = 2$)*	Red deer ($n = 5$)	Sambar deer ($n = 2$)*	Red deer ($n = 2$)*
Initial liveweight (kg)	52·7 (12·10)	51·2 (2·09)	36·6 (2·85)	50·2 (0·80)
Initial age (days)	186 (85·5)	219 (18·6)	128 (25·50)	248 (40·50)
Target liveweight (kg)	100·3 (0·25)	100·7 (0·44)	80 (0)	80·8 (0·40)
Age at target liveweight (days)	371 (67·5)	413 (24·05)	310 (25·0)	401 (46·50)
Total LWG (kg)	47·6 (11·85)	49·5 (2·31)	43·4 (2·85)	30·6 (1·20)
Days on experiment	185	194	182	153
Total VFI (kgDM)	264 (38·3)	342 (20·0)	235 (20·5)	306 (43·5)
FCE (kgDMI/kgLWG)	5·7 (0·62)	6·9 (0·26)	5·4 (0·12)	9·9 (1·03)

* Where $n = 2$, range (±) is given.

Table 5. *Regression equations of liveweight gain (g) per day per kg$W^{0.75}$ on MEI (MJ) per day per kg$W^{0.75}$ for young sambar and red deer between similar ages (sambar: 8–20 months, autumn 1992 to summer 1993; red deer: 9–21 months, spring 1991 to winter 1992)*

Sex	Sambar deer	Red deer
Stags	LWG = 37·71 MEI − 20·14 S.E. 5·09 3·20 $R^2 = 0·85$ $n = 12$ $P < 0·001$ MER* = 0·53 MJME/kg$^{0·75}$/day	LWG = 26·45 MEI − 16·75 S.E. 3·43 3·08 $R^2 = 0·78$ $n = 20$ $P < 0·001$ MER = 0·63 MJME/kg$^{0·75}$/day
Hinds	LWG = 40·09 MEI − 20·80 S.E. 4·70 2·90 $R^2 = 0·92$ $n = 8$ $P < 0·001$ MER = 0·52 MJME/kg$^{0·75}$/day	LWG = 21·63 MEI − 13·56 S.E. 3·76 3·37 $R^2 = 0·78$ $n = 12$ $P < 0·001$ MER = 0·63 MJME/kg$^{0·75}$/day

* MER = metabolizable energy requirements for maintenance.

RESULTS

Diet quality and voluntary feed intake

The pelleted diet contained 2·9% total N, with an organic matter digestibility of 83·2% and gross energy of 18·3 KJ/gDM. Calculated metabolizable energy was 12·2 MJ/kgDM.

Sambar tended to consume less feed than red deer, with the latter showing a more pronounced seasonal fluctuation (Fig. 1). Sambar deer of both sexes had peak VFI in April (autumn), remaining relatively constant until June (winter), declining thereafter until October/November (spring) and then slowly increasing. In contrast to sambar, red deer showed a peak VFI in January (summer), which declined sharply thereafter, reaching its lowest level in June (winter), before increasing again in spring. A drop in VFI in both sexes of red deer coincided with the breeding season. Collectively, the data show maximum and minimum VFI in red deer in summer and winter, whereas in sambar, maximum and minimum VFI occurred in autumn and spring respectively.

Liveweight change, efficiency of feed conversion and energy requirements

Both sambar deer sexes showed a reduction in growth rate in their first spring, followed by rapid growth over summer/autumn (Fig. 2). Sambar hinds exhibited a continuous but slow body growth throughout winter and their second spring, but sambar stags demonstrated slow growth over winter and no growth during their second spring. In contrast, red deer underwent a slowing of growth in their first winter, and increasing liveweight gain over their second spring and summer. However, red deer decreased in liveweight during their second autumn, this being more pronounced in stags than in hinds (6·8 and 4·4% of liveweight, respectively). On the other hand sambar deer showed increased growth during their second summer and autumn, with the increase being especially large for stags.

Seasonal patterns of VFI and LWG in sambar and red deer indicated that both sexes of sambar deer showed highest VFI (1·6–2·1 kgDM/day) and LWG (194–260 g/day) in autumn and minimum values in spring (1·3–1·4 kgDM/day; 25 g/day) (Table 2). On the other hand, red deer showed maximum VFI (1·8–2·8 kgDM/day) and LWG (191–348 g/day) in spring/summer and minimum VFI in winter (1·5–1·9 kgDM/day; 4–23 g/day). As might be expected, feed conversion was most efficient at the times when both deer species showed high VFI and LWG.

When calculated over a 12-month period (from similar initial ages) no interaction between species × sex or effects of sex on VFI, FCE and LWG were found ($P > 0·05$; Table 3). However, between species, sambar had a significantly lower VFI ($P < 0·01$) and better FCE ($P < 0·05$) than red deer, in spite of a similar growth rate to red deer.

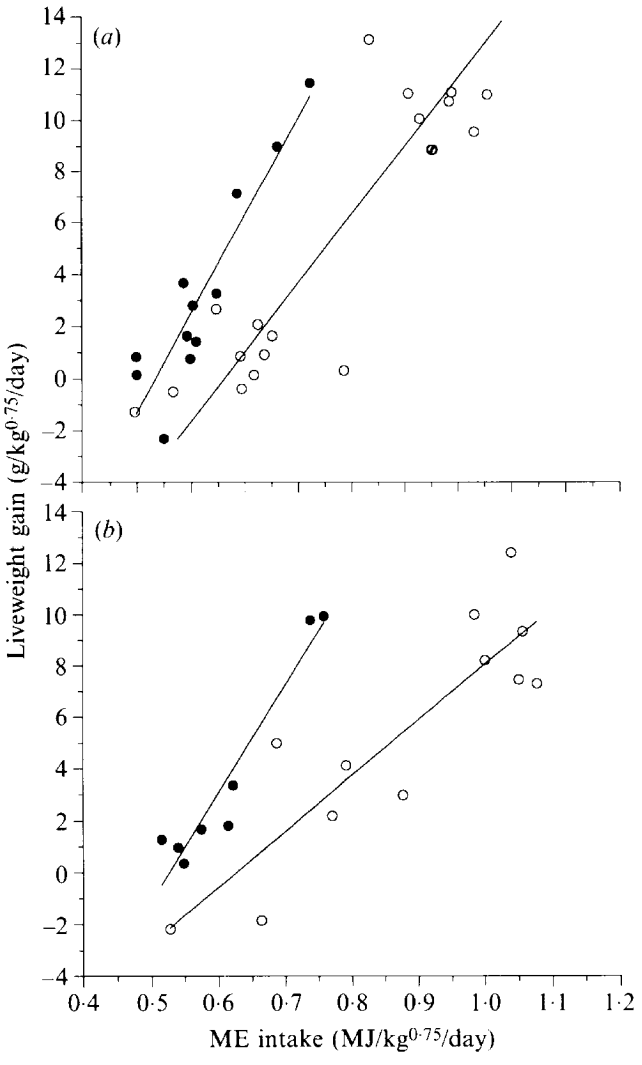

Fig. 3. Relationships between metabolizable energy intake and liveweight gain for young sambar (●) and red deer (○). Three data points for red stags are concentrated closely together and appear as one point in Fig. 3*a* ⊖ (see Table 5 for equations). (*a*) stags and (*b*) hinds. Measurements were taken for sambar deer from autumn 1992 to summer 1993 (8–20 months of age) and for red deer from spring 1991 to winter 1992 (9–21 months of age).

The two species were also compared from the start of the experiment to the attainment of specified liveweights (stags 100 kg; hinds 80 kg; Table 4). Sambar deer tended to attain this objective earlier than red deer, and with improved FCE ($P < 0·01$). The interaction between species and sex was significant ($P < 0·05$) for FCE, indicating that efficiency of the sambar hinds was greater than for stags.

For both sexes of both species, liveweight gain (g) per day per kgW$^{0·75}$ was strongly related to ME intake (MJ; MEI) per day per kgW$^{0·75}$ (Table 5 and Fig. 3).

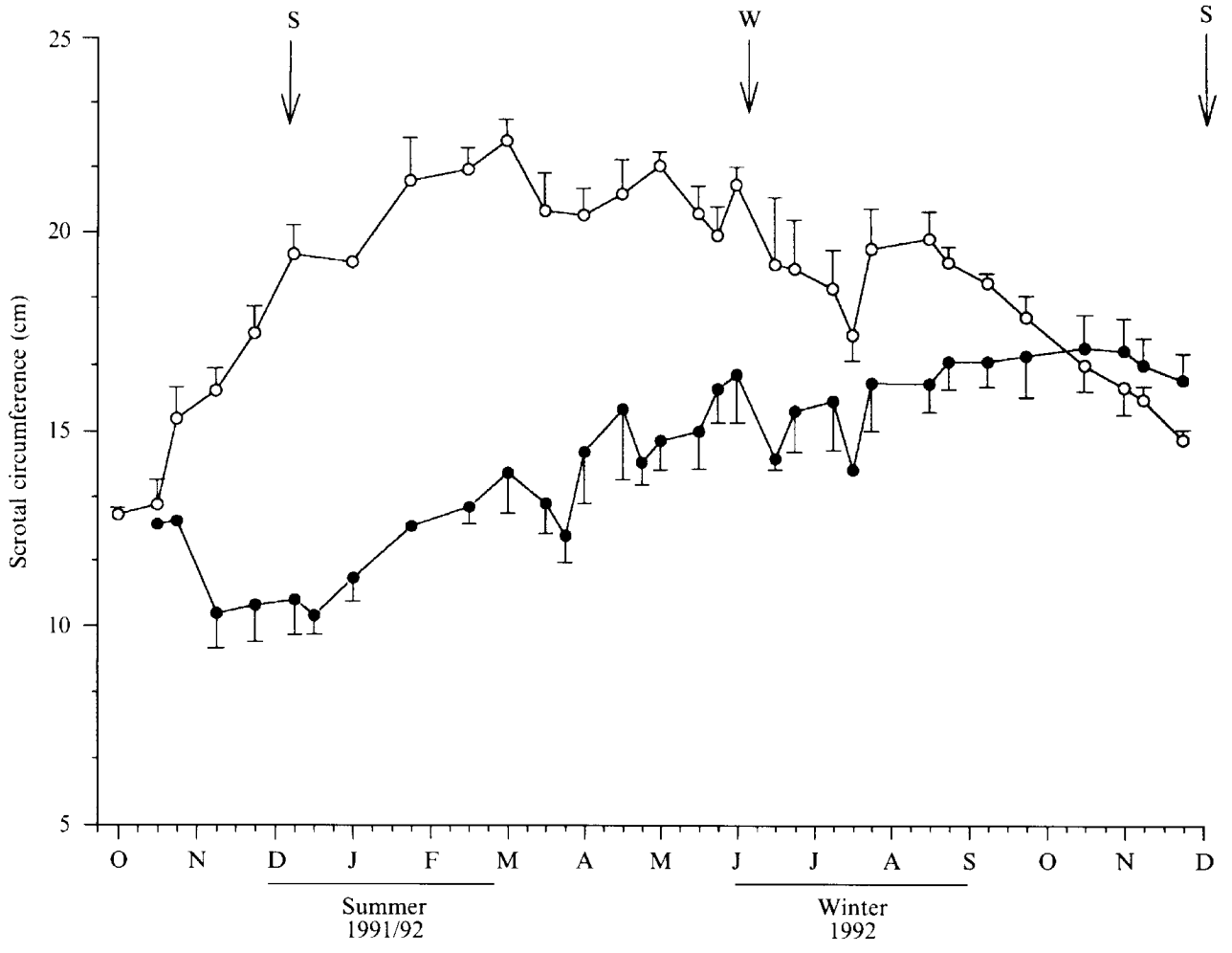

Fig. 4. Changes in scrotal circumference (cm) of young sambar (●) and red stags (○) fed indoors on a pelleted diet *ad libitum*. Vertical bars represent S.E. S = summer solstice, W = winter solstice.

The regression coefficients were higher for sambar deer than for red deer ($P < 0{\cdot}05$) in both sexes. Maintenance energy requirement (MER), calculated as MEI corresponding to zero LWG, was consistently lower for sambar deer than for red deer, whilst LWG per MJ MEI was higher for sambar deer than for red deer.

Scrotal circumference and hard antlers

Scrotal size in sambar stags increased progressively over summer, autumn and winter, reaching a maximum size in October (spring), before declining (Fig. 4). In contrast, scrotal circumference in red stags increased rapidly over summer, with maximum average size being recorded in March (autumn), and decreasing thereafter.

Timing of attainment of hard antler in sambar stags was noted as quite variable compared to that of red stags. For example, one sambar stag underwent antler calcification in May, whilst the remaining two stags calcified in June and July. In contrast, all red stags developed hard antlers in March.

Hormonal patterns

Plasma PRL concentrations in red stags and hinds were highest from spring to mid-summer, and lowest in autumn and winter (Fig. 5). A similar trend was also shown by sambar stags and hinds, except that sambar deer tended to have higher plasma PRL concentrations than red deer in autumn. In general, sambar stags had slightly higher plasma PRL concentrations than red stags during autumn and winter, but lower peak concentrations in summer.

Sambar stags tended to have highest plasma LH concentrations during autumn, winter and early spring, but these were of lower magnitude than the peak values for red stags, and were maintained over a longer time period (Fig. 6). Sambar hinds showed low plasma LH concentrations during summer and autumn, and increasing plasma LH concentrations towards the end of winter.

In contrast, high concentrations of plasma LH in red stags were noted from mid-spring to the end of

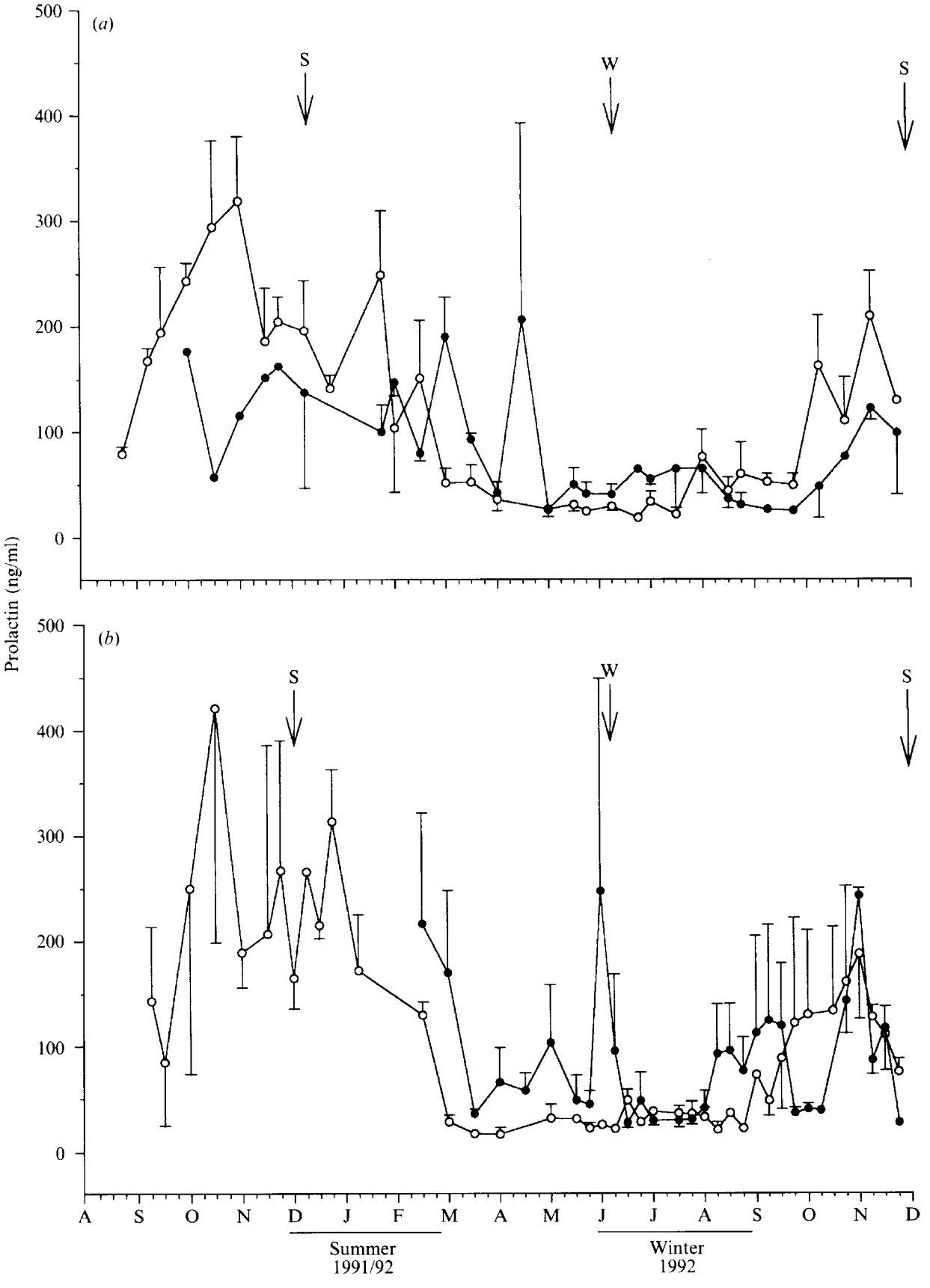

Fig. 5. Plasma prolactin concentration in young sambar (●) and red deer (○) fed indoors on a pelleted diet *ad libitum*. (*a*) stags and (*b*) hinds. Vertical bars represent S.E. S = summer solstice, W = winter solstice.

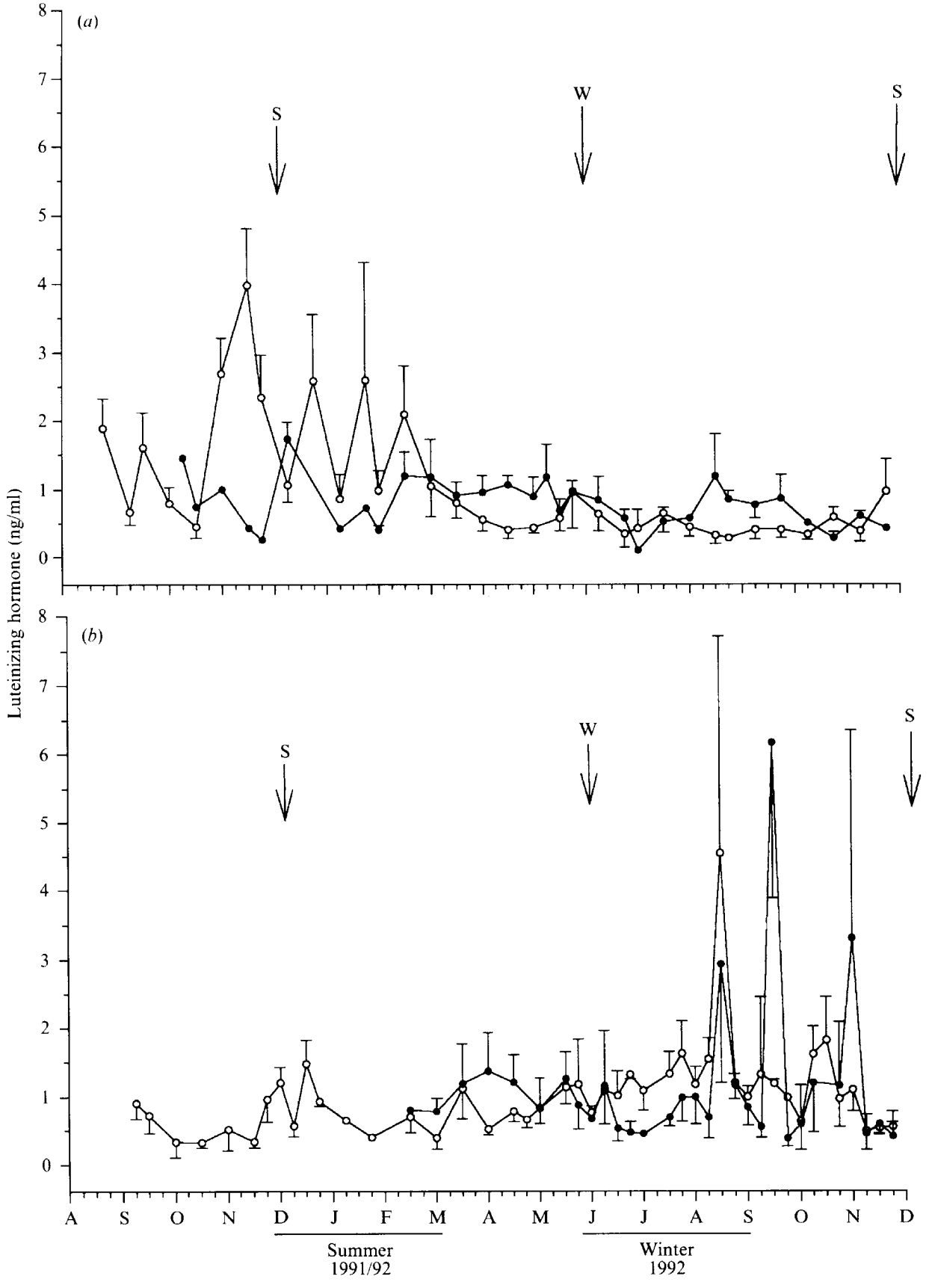

Fig. 6. Plasma luteinizing hormone concentration in young sambar (●) and red deer (○) fed indoors on a pelleted diet *ad libitum*. (*a*) stags and (*b*) hinds. Vertical bars represent S.E. S = summer solstice, W = winter solstice.

summer, before declining and remaining low throughout late autumn, winter and early spring. In red hinds, plasma LH concentrations fluctuated less than in red stags, while rapid increase in plasma LH concentrations did not commence until the end of their second winter.

Plasma T concentrations in sambar stags were low from mid-October until April, with higher values from April to September (Fig. 7*a*). The pattern was actually an average of three stags at three different ages and individual sambar stags were quite different in timing of the onset of rapid increase of plasma T concentrations. Whilst in hard antler, the oldest stag experienced up to four rapid increases in plasma T concentration, and the other two stags experienced one and two rapid increases of plasma T concentration, respectively.

By comparison, red stags all had their highest plasma T concentrations during March/early April, before declining through winter. Peak plasma T concentrations in red stags occurred in their second autumn with lowest values in spring. In contrast, sambar stags had peak plasma T concentrations for a longer period, from autumn to spring but at a lower magnitude than red stags.

Increases in plasma P in sambar hinds were not detected until winter and their second spring (Fig. 7*b*). By contrast, the P profile in red hinds showed three peaks, the first occurring in summer and the second and third peaks during autumn and winter.

DISCUSSION

The present study showed seasonal cycles in sambar deer, which were evident in VFI and body growth in both sexes and in plasma T concentrations in stags. In general, the cycles were of much lower amplitude than observed for red deer, with maximum and minimum VFI and LWG occurring in autumn and spring, respectively. The breeding season for sambar in NZ is not precisely known, as sambar stags do not vocalize during the rut (Semiadi *et al.* 1994). However, plasma T concentrations and scrotal circumference values suggest that the peak breeding condition occurs during late autumn, winter and early spring in this species. This is similar to the observed breeding season of tropical rusa deer (van Mourik 1985) and Eld's deer (Monfort *et al.* 1990) in temperate environments.

The present study demonstrated changes in seasonal VFI in red deer with maximum VFI in both sexes during summer, gradually declining as the breeding season commenced, and reaching its lowest levels in winter. The red stags in the present study experienced a sharp decline in their VFI of up to 57% during the breeding season, and the red hinds up to 32%. Suttie *et al.* (1978) also found that although red hinds declined in their VFI during the breeding season, the drop was not as rapid and/or as great as in red stags. The overall pattern was similar to other studies (Suttie *et al.* 1989), although a greater decline in VFI occurred in the red hinds in the present study. Sambar deer of both sexes also showed a decline in VFI during the breeding season, but the magnitude of the reduction was not as large as for red deer.

Peak liveweight in red stags occurred in March, or at *c.* 15 months of age, similar to the findings of Suttie *et al.* (1987). From March, liveweight declined as a result of a drop in VFI, then increased during spring. The young red stags in the present study decreased in liveweight during the rut by as much as 7% and red hinds by 3%. In contrast, sambar deer of both sexes had no liveweight loss during this study, but rather a slower/static growth during winter and their second spring. Similar patterns of growth were shown by rusa deer aged 3–15 months, in a sub-tropical environment (Suttie *et al.* 1992).

An arbitrary target liveweight (100 kg in stags and 80 kg in hinds) was achieved earlier (−42 days in stags, −91 days in hinds) in sambar deer than red deer (Table 4). Collectively, the VFI, LWG and FCE data indicate that whilst the total amount of weight gained over a complete 12-month period is similar for young sambar deer and young red deer, less total feed is eaten by sambar deer and hence sambar have an improved FCE. When ME requirements for maintenance and gain (above maintenance) were calculated (Fennessy *et al.* 1981), it appears that young sambar deer require less ME for both maintenance and gain than do young red deer (Table 6). For red stags, maintenance requirements for ME estimated in this study were slightly higher than those calculated by Fennessy *et al.* (1981), perhaps because of a slight overestimation of organic matter digestibility (OMD) values from laboratory analyses. Frisch & Vercoe (1970) found similar trends in feed conversion efficiency studies with temperate (Shorthorn × Hereford; SH) and tropical (Brahman) cattle as reported here for temperate and tropical deer. They reported better feed conversion efficiency (10·3 *v.* 11·5 kg DMI/kg LWG) and a lower fasting metabolic rate (87 *v.* 101 kJ/kg LW) in the tropical than in the temperate cattle, implying lower maintenance heat production. This gives further emphasis to the need for calorimetric studies comparing the efficiency of energy utilization in tropical sambar and temperate red deer. To combat hot tropical conditions effectively, it may be that cattle and deer that evolved in the tropics have developed lower levels of heat production, and this hypothesis needs to be tested for deer.

The length of time that sambar stags exhibited maximum scrotal circumference (5 months) was similar to that of chital stags (Mylrea 1992). In contrast, maximum scrotal circumference in red stags lasted for only 3 months. Thus, in sambar and chital

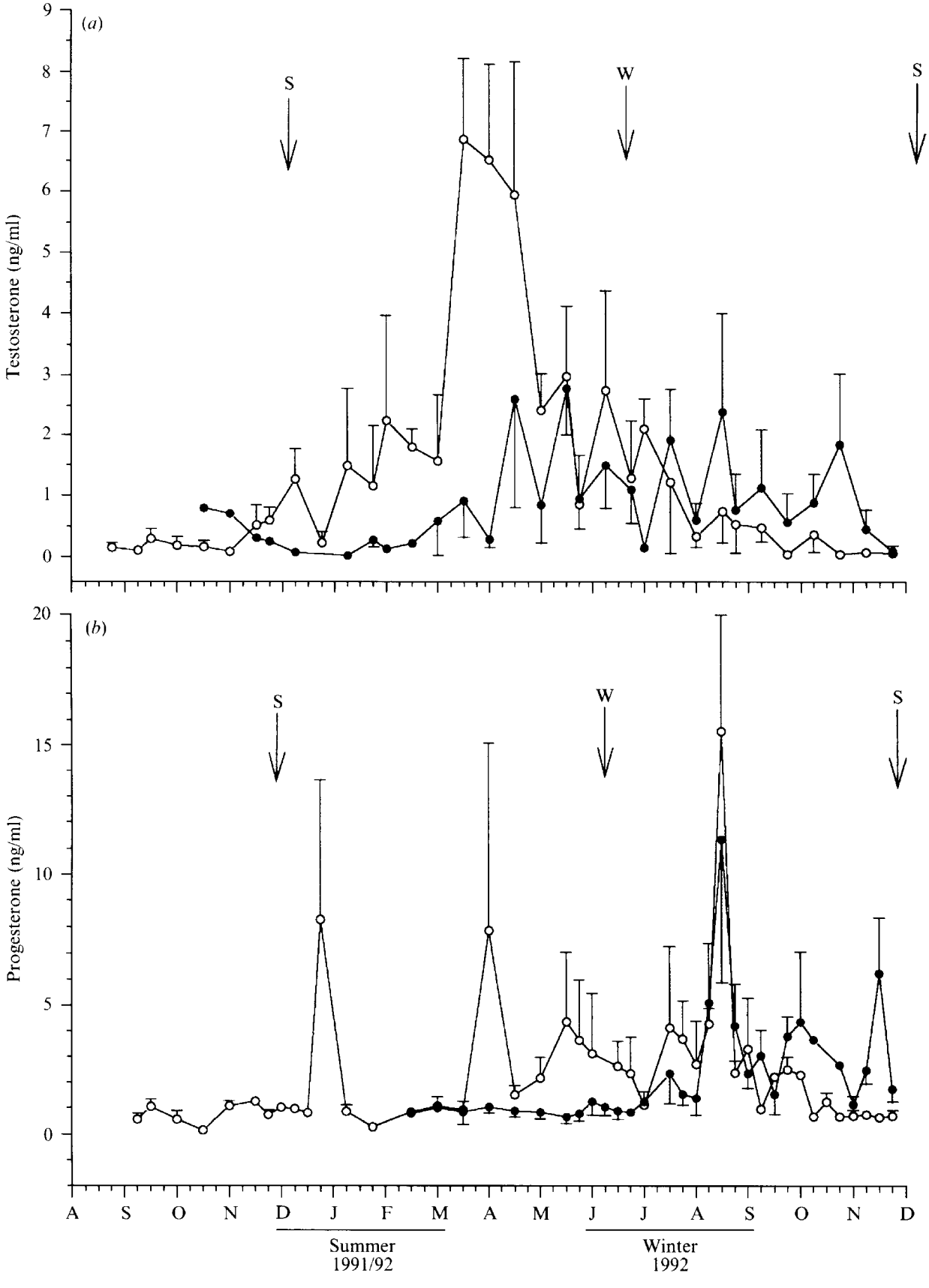

Fig. 7. (*a*) Plasma testosterone concentration in young sambar (●) and red stags (○), and (*b*) plasma progesterone concentration in young sambar (●) and red hinds (○) fed indoors on a pelleted diet *ad libitum*. Vertical bars represent S.E. S = summer solstice, W = winter solstice.

Table 6. *A comparison of estimated metabolizable energy requirements for maintenance (MER) and gain in young sambar and red deer in New Zealand*

Sex	Sambar deer	Red deer	Authors
	MER(MJME/kgW$^{0.75}$/day)		
Stags		0·57, 0·57	Fennessy *et al.* (1981)
Stags	0·53	0·63	Present study*
Hinds		0·52	Suttie *et al.* (1987)
Hinds	0·52	0·63	Present study*
	ME for gain (MJ/kgLWG)		
Stags		33·8, 39·2	Fennessy *et al.* (1981)
Stags	26·5	37·8	Present study*
Hinds		55·0	Suttie *et al.* (1987)
Hinds	24·9	46·2	Present study*

* Calculated from the equations in Table 5.

stags the breeding season is likely to be longer than in red stags. Moreover, in recent studies motile spermatozoa have been detected in ejaculates from chital stags (Loudon & Curlewis 1988; Mylrea 1992) and brow-antlered Eld's deer (Monfort *et al.* 1993*a*) at all stages of the annual reproductive cycle, indicating a longer potential breeding season in tropical cervids.

Assuming that the maximum plasma T concentrations in both young sambar and red stags and that the first rapid increase of plasma P in young hinds of both species can be used as an indication of the onset of puberty, then sambar of both sexes reached sexual maturity earlier and at lighter liveweights than red deer (Table 7).

Table 7. *Mean age and liveweight when young sambar and red deer first showed peak values in plasma testosterone and progesterone concentrations and the age when stags had their first hard antler (mean, S.E.; n = number of animals)*

	Sambar deer	Red deer
Stags		
Peak of testosterone		
Age (days)	445 (108·1)	469 (3·9)
Weight (kg)	100·8 (8·87)	116·7 (7·65)
n	3	5
Hard antler commencement		
Age (days)	376 (28·3)	443 (1·9)
Weight (kg)	97·3 (4·48)	112·7 (7·94)
n	3	5
Hinds		
Peak of progesterone		
Age (days)	407 (32·6)*	506 (25·0)*
Weight (kg)	90·0 (5·87)*	95·5 (13·05)*
n	2	2

* Where $n = 2$, range ($\pm$) is given.

The first peak of P in red hinds occurring in summer may have been due to the release of adrenal progesterone, experienced when the animals were stressed (Jopson *et al.* 1990). Sambar hinds showed a rapid release of plasma P in mid-August, 100 days earlier and 4·5 kg lighter than red deer (Table 7). However, as the blood sampling regime was conducted at weekly intervals, the study may not have accurately identified the first rapid increase of plasma P in either of the two deer species. Woodford & Dunning (1992) indicated that farmed rusa hinds reached puberty at 8 months, while chital hinds attained puberty from 9 to 17 months of age (Acharjyo & Mishra 1980; Chapple 1989). In order to define the age of puberty and length of the reproductive season more precisely, a more intensive blood sampling regime should be undertaken in sambar deer.

The present studies have shown that sambar do have endogenous (circannual) cycles of VFI, body growth and hormone secretion, but with a different seasonality from those of red deer. However, the major finding was improved feed conversion in sambar compared with red deer. This, together with the earlier calving of sambar deer (Semiadi *et al.* 1994), are compelling reasons for initiating studies into hybridization between sambar and red deer, with the objective of producing earlier calving deer that are more efficient food converters.

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REFERENCES

ACHARJYO, L. N. & MISHRA, CH. G. (1980). Some notes on age of sexual maturity of seven species of Indian wild mammals in captivity. *Journal of the Bombay Natural History Society* **77**, 504–507.

ASHER, G. W., BARRELL, G. K. & PETERSON, A. J. (1986). Hormonal changes around oestrus of farmed fallow deer, *Dama dama*. *Journal of Reproduction and Fertility* **78**, 487–496.

ASHER, G. W., BARRELL, G. K., ADAM, J. L. & STAPLES, L. D. (1988). Effects of subcutaneous melatonin implants on reproductive seasonality of farmed fallow deer (*Dama dama*). *Journal of Reproduction and Fertility* **84**, 679–691.

ATAJA, A. M. (1990). *Venison production from weaner red deer stags grazing annual ryegrass or perennial ryegrass pastures*. PhD thesis, Massey University, New Zealand.

BARRELL, G. K. & LAPWOOD, K. R. (1978). Effects of pinealectomy of rams on secretory profiles of luteinizing hormone, testosterone, prolactin and cortisol. *Neuroendocrinology* **27**, 216–227.

BARRY, T. N., SUTTIE, J. M., MILNE, J. A. & KAY, R. N. B. (1991). Control of food intake in domesticated deer. In *Physiological Aspects of Digestion and Metabolism in Ruminants* (Eds T. Tsuda, Y. Sasaki & R. Kawashima), pp. 385–401. Proceedings of the 7th International Symposium on Ruminant Physiology. San Diego: Academic Press.

BENTLEY, A. (1978). *An Introduction to the Deer of Australia: with Special Reference to Victoria*. Melbourne: The Koetoeng Trust.

CHAPPLE, R. S. (1989). *The biology and behaviour of chital deer* (Axis axis) *in captivity*. PhD thesis, University of Sydney, Australia.

FENNESSY, P. F., MOORE, G. H. & CORSON, I. D. (1981). Energy requirements of red deer. *Proceedings of the New Zealand Society of Animal Production* **41**, 167–173.

FRISCH, J. E. & VERCOE, J. E. (1969). Liveweight gain, food intake, and eating rate in Brahman, Africander and Shorthorn × Hereford cattle. *Australian Journal of Agricultural Research* **20**, 1189–1195.

JOPSON, N. B., FISHER, M. W. & SUTTIE, J. M. (1990). Plasma progesterone concentrations in cycling and in ovariectomised red deer hinds: the effect of progesterone supplementation and adrenal stimulation. *Animal Reproduction Science* **23**, 61–73.

LOUDON, A. S. I. & BRINKLOW, B. R. (1992). Reproduction in deer: adaptations for life in seasonal environments. In *The Biology of Deer* (Ed. R. D. Brown), pp. 261–278. New York: Springer-Verlag.

LOUDON, A. S. I. & CURLEWIS, J. D. (1988). Cycles of antler and testicular growth in an aseasonal tropical deer (*Axis axis*). *Journal of Reproduction and Fertility* **83**, 729–738.

MONFORT, S. L., WEMMER, C., KEPLER, T. H., BUSH, M., BROWN, J. L. & WILDT, D. E. (1990). Monitoring ovarian function and pregnancy in Eld's deer (*Cervus eldi thamin*) by evaluating urinary steroid metabolite excretion. *Journal of Reproduction and Fertility* **88**, 271–281.

MONFORT, S. L., BROWN, J. L., BUSH, M., WOOD, T. C., WEMMER, C., VARGAS, A., WILLIAMSON, L. R., MONTALI, R. J. & WILDT, D. E. (1993*a*). Circannual inter-relationships among reproductive hormones, gross morphometry, behaviour, ejaculate characteristics and testicular histology in Eld's deer stags (*Cervus eldi thamin*). *Journal of Reproduction and Fertility* **98**, 471–480.

MONFORT, S. L., BROWN, J. L., WOOD, T. C., WEMMER, C., VARGAS, A., WILLIAMSON, L. R. & WILDT, D. E. (1993*b*). Seasonal patterns of basal and GnRH-induced LH, FSH and testosterone secretion in Eld's deer stags (*Cervus eldi thamin*). *Journal of Reproduction and Fertility* **98**, 481–488.

MORROW, C. J. (1992). *Studies on oestrus synchronisation of farmed fallow deer* (Dama dama). MSc thesis, University of Waikato, New Zealand.

MYLREA, G. E. (1992). *Natural and artificial breeding of farmed chital deer* (Axis axis) *in Australia*. PhD thesis, University of Sydney, Australia.

ROUGHAN, P. G. & HOLLAND, R. (1977). Predicting in-vivo digestibilities of herbages by exhaustive enzymic hydrolysis of cell walls. *Journal of the Science of Food and Agriculture* **28**, 1057–1064.

SCARAMUZZI, R. J., CALDWELL, B. V. & MOORE, R. M. (1970). Radioimmunoassay of LH and estrogen during the estrus cycle of the ewe. *Biology of Reproduction* **3**, 110–119.

SEMIADI, G., BARRY, T. N. & MUIR, P. D. (1993). Growth, milk intake and behaviour of artificially reared sambar deer (*Cervus unicolor*) and red deer (*Cervus elaphus*) fawns. *Journal of Agricultural Science, Cambridge* **121**, 273–281.

SEMIADI, G., MUIR, P. D. & BARRY, T. N. (1994). General biology of sambar deer (*Cervus unicolor*) in captivity. *New Zealand Journal of Agricultural Research* **37**, 79–85.

SUTTIE, J. M., FENNESSY, P. F., VEENVLIET, B. A., LITTLEJOHN, R. P., FISHER, M. W., CORSON, I. D. & LABES, R. E. (1987). Energy nutrition of young red deer (*Cervus elaphus*) hinds and a comparison with young stags. *Proceedings of the New Zealand Society of Animal Production* **47**, 111–113.

SUTTIE, J. M., FENNESSY, P. F., CORSON, I. D., LAAS, F. J., CROSBIE, S. F., BUTLER, J. H. & GLUCKMAN, P. D. (1989). Pulsatile growth hormone, insulin-like growth factors and antler development in red deer (*Cervus elaphus scoticus*) stags. *Journal of Endocrinology* **121**, 351–360.

SUTTIE, J. M., CORSON, I. D., WEBSTER, J. R. & WOODFORD, K. B. (1992). Photoperiodism and growth. In *Proceedings of a Deer Course for Veterinarians No. 9* (Ed. P. R. Wilson), pp. 136–142. Palmerston North, New Zealand: New Zealand Veterinary Association.

VAN LANDEGHEM, A. A. J. & VAN DE WIEL, D. F. M. (1978). Radioimmunoassay for porcine prolactin: plasma levels during lactation, suckling and weaning and after TRH administration. *Acta Endocrinologica* **88**, 653–667.

VAN MOURIK, S. (1985). *Behaviour and physiology of farmed rusa deer* (Cervus rusa timorensis). PhD thesis, University of Melbourne, Australia.

VERCOE, J. E. (1970). The fasting metabolism of Brahman, Africander and Hereford × Shorthorn cattle. *British Journal of Nutrition* **24**, 599–606.

WHITEHEAD, G. K. (1972). *Deer of the World*. London: Constable Publications.

WODZICKI, K. A. (1950). *Introduced Mammals of New Zealand*. DSIR Bulletin 98.

WOODFORD, K. B. (1991). Reproductive cycles and performance of rusa deer in the tropics and sub-tropics. In *Proceedings of a Deer Course for Veterinarians No. 8* (Ed. P. R. Wilson), pp. 262–267. Palmerston North, New Zealand: New Zealand Veterinary Association.

WOODFORD, K. B. & DUNNING, A. (1992). Production cycles and characteristics of rusa deer in Queensland, Australia. In *The Biology of Deer* (Ed. R. D. Brown), pp. 197–202. New York: Springer-Verlag.