8.2 Clinical Examinations

In the last three years 14 red squirrels involved in the reintroduction studies at Thetford Forest have been examined clinically at a local veterinary surgery (see Table 15). Examinations were performed under inhalational anaesthesia and samples collected and tests carried out in order to determine their health. All animals were weighed and their condition assessed. Fluids were administered to ensure prompt recovery on return to the Reserve.

8.3 Post-mortem Examinations

Eleven red squirrels from Thetford Forest have required a post-mortem examination and details are shown in Table 16.

8.4 Clinical results

The red squirrels examined clinically had a mean body weight of 273g (range 160-375), a mean shin length of 67mm (range 57-73) and were in good condition.

The blood biochemical findings are shown in Table 17 with some appropriate reference ranges. No abnormalities were detected in the radiographic appearance of the skeleton of each squirrel. Coccidial oocysts (*Eimeria* sp) were identified in the faeces of all those animals from which faeces could be obtained. Fleas were found on all wild-caught animals, ticks were found on several animals, and larval mites on R4. No bacterial isolates were considered to be of significance and the haematological findings were within the expected normal range for a rodent. Parasites of the genus *Hepatozoon* (Protozoa) were identified in the leucocytes of R9.

8.5 Post-mortem results

The results of *post-mortem* examinations are given in Table 16. A significant finding was the electronmicroscopic detection of parapoxvirus particles in skin lesions from two dead squirrels and similar pathological lesions in one of the other animals. No radiographic abnormalities were detected in the skeletons of these animals. No bacteria which were believed to be significant were isolated from the faeces.

No.	Clinical Ref.	Sex	Age	Weight	Date Examined	Origin/notes
R1	0323/93	M	juvenile	160g	19/08/93	Kielder
R2	0324/93	F	adult	260g	19/08/93	David Stapleford
R3	0325/93	M	juvenile	250g	19/08/93	David Stapleford
R4	0326/93	M	adult	270g	19/08/93	David Stapleford
R8	0385/93	M	unknown	220g	22/10/93	Kielder
"			unknown	265g	09/05/94	Kielder
R9	0386/93	M	unknown	270g	22/10/93	Kielder
R13	0055/94	F	adult	360g	29/03/94	Thetford
"			adult	350g	09/05/94	"
"			adult	370g	06/07/94	"
R16	0056/94	F	adult	375g	29/03/94	" pregnant
"			adult	355g	09/05/94	" lactating
"			adult	375g	06/07/94	" pregnant
R17	0057/94	F	adult	330g	29/03/94	"
R20	0090/94	M	juvenile	175g	09/05/94	"
"			juvenile	205g	06/07/94	"
R22	0164/94	F	juvenile	275g	06/07/94	"
R23	0165/94	M	unknown	280g	06/07/94	"
R25	0166/94	M	adult	290g	06/07/94	"
R26	0167/94	M	unknown	285g	06/07/94	"

Table 15 Health examinations

Ref	PM Ref	Sex	Age	Weight	Date Examined	Main post-mortem findings
R7	689/93	M	young adult	235g	2//9/93	Parapoxvirus infection. Confirmed by electronmicroscopy
R10	858/93	F	adult	300g	08/12/93	Cause of death not determined. Mild metabiolic bone disease.
R12	078/94	M	adult	260g	23/02/94	Parapoxvirus infection. Confirmed by electronmicroscopy
R15	127/94	M	adult	225g	22/03/94	Enteritis of uncertain aetiology.
RB0292	197/94	M	adult	230g	10/05/94	Suspected parapoxvirus infection. Mycotic pneumonia.
R21	210/94	M	adult	295g	17/05/94	Road traffic casualty.
R25	B591/94	M	adult	240g	10/09/94	Septicaemia due to Escherichia coli infection.
R13	620/94	F	adult	365g	28/09/94	Septicaemia following bite wound.
R27	028/95	M	unknown	280g	10/01/95	Numerous subcutaneous and thoratic masses. Possible lymphoma.
R6	606/95	F	adult	308g	14/07/95	Severe autolysis. Cause of death undetermined.
R30	840/95	M	unknown	255g	12/10/95	Enteritis, peritonitis and pneumonia.

Table 16 Post-mortem examinations

Table 17 Blood biochemical findings from red squirrels and appropriate reference ranges

			Reference ranges (n)		
	Mean +/- st.dev. (n)	Range	Grey squirrel (1)	Rodentia (2)	*Rattus* spp (3)
Total protein (g/l)	77.6 +/- 14.4 (8)	47-100	37-66 (71)	56.7-80.6 (14)	56-76
Albumin (g/l)	23.1 +/- 4.5 (8)	13-28		24.8-58.8 (13)	38-48
Calcium (mmol/l)	2.0 +/- 0.06 (8)	1.95-2.14	1.8-3.6 (107)	2.08-3.27 (14)	1.3-3.3
Inorganic phosphate (mmol/l)	3.2 +/- 0.86 (8)	2.24-4.84	0.99-7.0 (107)	0.95-2.52 (13)	1.7-2.7
Alkaline phosphatase (IU)	510 +/- 344 (8)	191-1381		1-570 (14)	
Alanin aminotransferase (IU)	10.2 +/- 3.50 (8)	6-18		3-172 (12)	

(1) from Hoff et al (1976), (2) from Bennet et al. (1991), (3) from Harkness and Wagner (1989) (number in sample not given)

9. Discussion

9.1 Grey squirrel removal: benefit to red squirrels

It is now widely accepted that grey squirrels compete with red squirrels, probably by exploiting the same food and space, and are a major factor in the decline in range of the red squirrel (e.g. Gurnell, in press; Gurnell & Pepper, 1988, 1993). Thus, the removal of grey squirrels should benefit red squirrels in places where they co-occur. We believe that the live trapping methods used effectively kept grey squirrel numbers to low levels within the Reserve and that this has benefitted the red squirrel population. However, our evidence is largely circumstantial and based on observations made after the start of the removal period. Despite no red squirrels being seen in the area for two years prior to the start of the study, red squirrels were seen in the Reserve in sector E within seven months of the start of the grey squirrel removal programme, and some were captured in sector C, in the centre of the Reserve, within nine months. Since then the histories of some 31 individuals (i.e. excluding the introduced animals) have been documented. To unequivocally demonstrate the benefits of grey squirrel removal, the control effort must be continued for several more years to enable the red squirrel population to increase in size. However, as will be discussed below, it is possible that the red squirrel population at present is too small (i.e. lower than its minimum viable size) to take advantage of the grey squirrel control, and that translocating squirrels from elsewhere to the Reserve would give a boost to the population.

What is unclear is whether the first red squirrels to be seen and captured in 1993 were residents or had immigrated into the Reserve, and whether the animals simply became more 'visible' after the removal of grey squirrels. Red squirrels were abundant in parts of the Reserve in 1977 but declined quickly thereafter and were replaced by grey squirrels (Reynolds, 1981; Gurnell 1996). It seems likely, although it was not confirmed, that parapoxvirus infection caused heavy mortalities at this time. Red squirrels continued to be sighted very occasionally in the Reserve during the 1980's but numbers generally seemed to be declining (Gurnell & Taylor, 1989; Gurnell, 1996). However, three males were captured in 1986, and a male and a female red squirrel in January 1987, at the boundary between sectors D and E. This coincides with one of the centres of their distribution in the present studies and it seems likely that this has remained a suitable area for red squirrels since 1986. Intensive trapping in this area between March and July 1988 only resulted in large numbers of grey squirrels being captured, but this was a time of good food supplies and it seems likely that the trappability of red squirrels was low (Gurnell & Taylor, 1989, and see below). In addition, the nearest location for red squirrels outside the Reserve is in the Mayday to Brandon Park area to the west of the Brandon Road. Red squirrels have been seen here from time to time, and the last sighting was in early 1996; these animals may constitute another very small, local population. However, the area is 1.8 km from sector C and we consider that it was effectively disconnected from the red squirrels in the Reserve at the beginning of these studies. This does not mean that the populations were isolated because it is theoretically possible that some animals may disperse from one local population to the other; population isolation will be considered in a future report (Gurnell, Clark & Feaver, in prep.). Thus we conclude that the first red squirrels seen and captured were resident in the central and eastern parts of the Reserve.

9.2 Grey squirrel removal: cost and efficiency

The trapping programme adopted was a balance between the intensity of trapping in any one trap period and the time interval between successive periods. Grey squirrels were trapped in permanently baited, multi-capture (MC) live traps on the ground, or in single capture (SC) live traps attached to trees at a height of 3 m to 4 m. SC traps were specifically aimed at trapping red squirrels (Gurnell & Pepper, 1994) but at Thetford we have found that they are equally effective at catching grey squirrels, particularly in conifer plantations with a dense field layer. Normally only MC traps or SC traps on the ground would be used to control grey squirrels for red squirrel conservation (Gurnell & Pepper, 1996), in which case we would recommend using 8 clusters of 5 MC traps. In this study, 8 to 10 MC and 30 to 40 SC traps were used in the Reserve every six weeks, the latter in clusters of 5 traps, within each half of the Reserve (one half consisted of sectors A, B and C, and the other of sectors D and E). Effectively, there were 8 trapping periods in each half of the Reserve each year, each period consisting of 4½ man-days of work (1 day - put traps out and prebait; ½ day - second prebait; ½ day - third prebait; ½ day - set traps; 6 x ¼ days - check traps; ½ days - check and pick up traps). Thus during a year there were 4½ x 16 = 72 man-days of work involved in the control programme. At current FE Ranger rates this approximates to £4000 a year. Allowing £440 for bait, bin liners and trap depreciation, the total cost of controlling grey squirrels in the Reserve annually can be taken as £4440 or £2.61 ha^{-1}. For comparison, in broadleaf woods, control would not be effective during the autumn (September to November) because grey squirrels would not be attracted to the bait at the traps at this time of tree seed abundance. In this case the annual cost of control would be slightly less at £1.96 ha^{-1} (Gurnell & Pepper 1996). Gurnell & Pepper (1996) have also estimated the cost of controlling grey squirrels using live traps in small, fragmented woodlands, with a total area of <250 ha, to be £6.93 ha^{-1}. In contrast, control using warfarin poison, if it was legal, would approximate to £1.35 ha^{-1} in either extensive forests or fragmented woods. None of these estimates include an amount for the cost of transport or equipment maintenance.

It could be argued that the control of grey squirrels using live trapping methods should be based on traps being set continuously. However, this not only would be very labour intensive, but also would lose the benefits of prebaiting, i.e. allowing squirrels to become used to entering traps before they were set. Consequently trapping should be carried out at discrete time intervals and most studies on squirrels (i.e. using live traps but not removing animals) employ an interval of between 4 and 12 weeks (e.g. Dubock, 1976, Gurnell, 1996). Live trapping as a form of control is effectively a 'pulsed' removal technique with grey squirrels entering the removal area between each trap period, and then being trapped and removed. In this study, trapping was carried out alternately in each half of the Reserve every three weeks and thus each half of the Reserve was trapped every six weeks. Considerable numbers of grey squirrels moved into the Reserve between successive trap periods, especially during the spring and summer each year (e.g. 110 grey squirrels were captured in June 1994). If we assume that the presence of grey squirrels has a negative competitive effect on red squirrels, then grey squirrels should be removed as quickly as possible. During this study, it might have been possible to shorten the trapping interval to, say every four weeks in each half of the Reserve, if time had been available. As from April 1996, live trapping control within the Reserve is being carried out FE staff. It is based on an eight week cycle of trapping in each half of the Reserve, except during the main periods of dispersal in late spring and autumn, when the trapping interval will be four weeks. This amounts to the same number of man-days per year as trapping every six weeks, i.e. 72 man-days. We believe that this is the optimum control strategy for the Thetford Reserve.

Normally, clusters of removal traps are targeted to the sites most likely to catch grey squirrels (e.g. patches or belts of broadleaf trees). Indeed, an argument can be made to maintain small patches of broadleaf trees around designated red squirrel conservation areas to provide a focus for the control effort. MC traps were sited in such places in our study, but the SC traps were sited in pure conifer to try to capture red squirrels. Nevertheless, we believe that it is not possible to reduce the overall density of traps used, i.e. one cluster of five traps (at a density of 1 trap per 1-2 ha) for every 100 ha of forest, and effectively trap out grey squirrels in each trapping period.

On the basis of the above arguments, we do not consider that it is possible to reduce the amount or cost of grey squirrel control using live traps for the benefit of red squirrels within the Reserve at Thetford. If it becomes legal to do so in the future, the use of warfarin poison in special 'grey-only' hoppers would offer considerable savings, and would have the advantage in that it would result in the continuous removal of grey squirrels rather than the present pulsed removal.

9.3 Patterns in grey squirrel demography in pine forest

After the first few months of the study, we consider that the majority, if not all, of the grey squirrels captured were immigrants to the Reserve, rather than residents. Nevertheless, the distinct annual cycles in numbers, with an increase in spring, peak numbers in summer and a decline in the autumn, and changes in population structure show remarkable similarities to the normal annual cycle for squirrels (Gurnell, 1987), including cycles for grey squirrels in broadleaf woodland (Don, 1981). We believe, therefore, that the numbers captured are a good reflection of numbers within Thetford forest as a whole. Evidence to support this comes from a comparison of the structure of the population during the first few months of removal and during the rest of the study, and from captures outside the Reserve to the west of the Brandon Road; more work will be carried out on this point in 1996 and 1997. Further support comes from the fact that similar demographic patterns were found in the studies carried out in the 1980's when the grey squirrels were not removed (Gurnell & Taylor, 1989, Gurnell, 1991, 1996).

Low numbers in the autumn may partly result from poor trappability because grey squirrels concentrate on feeding on broadleaf seeds at this time (Gurnell 1996). This was clearly seen in Thetford in 1995, even though Thetford is a predominantly conifer forest. In 1995, the broadleaf seed crops were abundant at Thetford, as they were over much of the country, and grey squirrels were very difficult to catch from September 1995 through to spring 1996. This demonstrates that even small belts or patches of broadleaf trees can have an important influence on grey squirrel trappability and demography. This is supported by the review of Lurz *et al.* (1995). Gurnell (1996) proposed that patches of broadleaf trees within conifer plantations provide survival foci for grey squirrels. They expand from these foci into the conifer stands when food conditions are good, and retreat back when they are not. Strips of broadleaf trees also act as movement corridors for grey squirrels into conifer forests.

Tree seed availability and winter weather have been shown to be important determinants of squirrel numbers (Gurnell, 1989, 1996), and, in addition to the annual cycles, there was a distinct difference in the numbers captured in 1995 compared with the preceding two years. This is attributed to a smaller cone crop in 1995 affecting numbers throughout the forest, although the size of cone crops on the trees was not satisfactorily quantified. Cone crops within the Reserve would not give a true reflection of food availability since the removal of grey squirrels would have resulted in less cone feeding than outside the Reserve and the cone food supplies would have lasted longer. This would have favoured red squirrels, but it also provided the ideal conditions of plentiful space and food to attract grey squirrels into the area. Results from the feeding transects support the annual cycles in numbers of grey squirrels, and provide evidence that particular areas of forest were used in a patchy manner (see Lurz & Garson, in press; Wauters & Dhondt, 1992). However, feeding in some areas of sectors C, D and E in 1995 have been attributed mainly to red rather than grey squirrels.

Adult body weights fell within the typical range of grey squirrels in Britain (Gurnell, 1991, 1996). The amount of body fat was lowest in late summer/early autumn despite the presence of new cone crops over the summer. Thereafter body weight, standardised body weight and body fat increased from autumn to winter as is typical for grey squirrels in broadleaf woodland in years when autumn seed crops are good (Gurnell, 1987, 1996).

More adult males than females were captured except in the autumn, in keeping with the fact that males are the more mobile of the two sexes, especially during the breeding season (Gurnell, 1987). Reproductive cycles in males and females appeared normal with males showing a regression in testis size during the autumn and females showing peaks in the production of young in spring and summer and little breeding activity in November and December (Gurnell, 1987). The amount of scrotal staining in males correlated well with testis size but may be a better indicator of reproductive behaviour. There was no obvious pattern to litter size between or within years. The mean number of embryos per female was 3.2, and the mean number of placental scars in lactating females was 2.8 suggesting some loss of young before parturition. The total number of offspring produced declined in each of the three years of the study reinforcing the idea that the cone crops were poor in 1994/5.

From the results of the studies carried out in the 1980's, Gurnell (1996) reported that grey squirrels did not produce spring litters in Thetford Forest in 1986 and 1987, although they did in 1988. Red squirrels in contrast, probably did in all three years. This was attributed to differences in the size of the annual cone crop, but it may also be coupled with the size of the broadleaf seed crop. The combination of a poor broadleaf seed crop and a poor cone availability during the winter may result in a delay in the start of the breeding season until the spring; this occurs in broadleaf woods (Gurnell, 1996).

The most fundamental difference between grey squirrel numbers in Thetford Forest and those in mixed or broadleaf woods was that densities were very low, less than 1 ha^{-1} compared with 2 to 8 squirrels ha^{-1}. This was demonstrated by the studies carried out in the 1980's (Gurnell, 1996), and they can be substantiated by the numbers of squirrels captured during the first few months of removal in this study. Assuming that it took four months to remove most resident squirrels, a reasonable generous period, an estimate of grey squirrel density in the Reserve at that time would be 0.05 squirrels ha^{-1} (using the area of forest with the Reserve that was >20 years old). Assuming it took six months to remove red squirrels, the estimate of red squirrel density is 0.17 squirrels ha^{-1}.

9.4 Red squirrels: numbers, distribution and health

9.4.1 Numbers and distribution

Red squirrels have proved to be very difficult to catch in Thetford Forest. A minimum estimate of the probability of capturing a red squirrel in a trap has been calculated as 0.016. As a comparison, Peter Lurz (pers. com.) estimates that the probability of catching a red squirrel in his studies in Kielder Forest was 0.124. Red squirrels were also difficult to capture in Thetford during the studies carried out in the 1970's (Reynolds, 1981) and the 1980's (Gurnell, 1996; Gurnell & Taylor, 1989; also see Lurz *et al.*, 1995). The most plausible explanation for poor capture rates is that the squirrels have adequate supplies of food in the canopy and are not attracted down to the bait at the traps. One interesting point to emerge from the research was that the pre-release pen proved attractive to both red and grey squirrels and operated as a large live-capture trap when the bridges were not in place. As a result of poor capture success, it has not been possible to put a firm figure of the number of red squirrels present in the Reserve. However, based on all the information available, we judge that there were only 10 to 20, and no more than 40, red squirrels in the Reserve in 1995.

The analysis of the distribution of all known locations of red squirrels indicated a clear preference for conifer habitats, especially Corsican Pine, Scots Pine, or Mixed Conifer (MC) 21-35 years old, or MC >55 years old. Small patches of Mixed Broadleaves and Lodgepole Pine were also used. Together these habitats comprised 32% of the Reserve, but much of it occurred in isolated patches and extensive areas were only found in sectors C and D and D's boundary with E. The radiotracking results suggest that the minimum area of pine forest required by male and female red squirrels at Thetford was at least 6 ha (the 70% core range area). This is similar to the 7 ha core areas of male red squirrels in conifers in northern England, but larger than the 3.5 ha core area of females (Lurz & Garson, in press), and almost three times the size of core areas recorded in Belgian forests (Wauters & Dhondt, (1992). The minimum area of a woodland that will hold red squirrels depends on many factors such as tree species and age in a woodland (e.g. Andren and Delin, 1994), by the distance between woodlands and their connectivity (e.g. Verboom & Apeldoorn, 1990; Wauters et al., 1994; also see Fitzgibbon, 1993), and by the landscape context of the woodlands (e,g, Celada et al. 1994). Bright (1993) assumed that a wood of 20 ha or more would hold squirrels permanently, and act as a source of colonizers, from his studies in NE England, Verboom & Apeldoorn (1990) found that an equivalent woodland size in The Netherlands was 30 ha, and Celada et al. (1994) for oak woods in Italy was >10 ha. From this, we believe that small, isolated patches of, between 6 and 10 ha, would be unlikely to contain resident red squirrels and there was no evidence of red squirrels in such patches from our studies. Our findings suggest that there may be some, unmarked red squirrels in the eastern or southern parts of the Reserve but not elsewhere. Habitat suitability and potential squirrel numbers within the Reserve will be examined in detail elsewhere (Gurnell, Clark & Feaver, in prep.), but here we suggest that there were approximately 450 ha of suitable habitat in blocks of sufficient size to hold red squirrels. Recorded red squirrel densities in pine vary between 0.3 and 1.4 squirrels ha^{-1}. Reynolds (1981) estimated the density of red squirrels in Highlodge as 1.1 ha^{-1} from his studies in Thetford in the 1970's (see the recent review by Lurz *et al.*, 1995, and Gurnell 1983, 1987, 1991, 1996). Densities of >1 ha^{-1} are likely to occur when cone crops are good, and longterm average densities will be lower than this (Gurnell, 1987). Thus, here we have used a figure of 0.55 ha^{-1}, half of Reynolds estimate (range 0.11 to 1.1), to calculated how many squirrels the Reserve should hold, and this gives a figure of 250 animals (range 50 to 500).

An unexpected result from the habitat study is that red squirrels appeared to completely ignore Scots pine >55 years old that had undergone late or final thinning. This we have attributed to large distances between the trees and open canopies. We consider that the most suitable or preferred habitats of red squirrels (and other species) are revealed when populations are at a low density, as we believe is the case here. If the red squirrel population within the Reserve was larger, then red squirrels would probably move into the less favoured areas. However, these areas may not be able to sustain squirrels on a permanent basis.

Encouragingly, at least some red squirrels bred each year, although precise figures on recruitment were not forthcoming. However, of concern is that 14 adult red squirrels were known to have died over the three years through predation (35% raptors and cars) or disease (57%). This figure of about 5 animals a year is a minimum estimate since some animals must have died without our knowledge. If we assume that double this number died per year, and that average juvenile mortality rates between birth and adulthood are 75% (Gurnell, 1987), then 40 offspring would be needed to be born each year to compensate for mortality in adults. Using an average litter size of 3 (Gurnell 1991a), then 13 breeding females would be needed to produce this number of offspring, assuming each female produces only one litter per year. Although these figures are largely conjecture, they illustrate the point that the small population is unlikely to be holding its own and is probably declining in size, albeit slowly.

9.4.2 Health

The finding of two confirmed cases of parapoxvirus infection and one suspected case since 1993 from a population of red squirrels which is estimated to number less than 40 animals is of concern and suggests that parapoxvirus infection could be a significant problem for the conservation of red squirrels in Thetford Forest. Recently close monitoring of an outbreak of parapoxvirus infection in red squirrels in the UK suggested that the disease can cause mortality at a rate which could lead to local extinction (Sainsbury and Ward 1996). Moreover, and although unconfirmed, parapoxvirus is believed to have caused extensive mortalities in red squirrels in Thetford during the 1970's, a period coincident with the colonisation of the forest by grey squirrels (Reynolds, 1981; Gurnell 1996). The origin of parapoxvirus in red squirrels is unknown. Keymer (1983) noted that pox viruses associated with fibromata of the skin have been reported in grey squirrels in North America and epidemic disease resembling "distemper" has been reported on at least one occasion in grey squirrels in the UK (Middleton 1930). Recently parapoxvirus-like virus particles have been detected by electronmicroscopy in a grey squirrel from Hampshire, UK which showed skin lesions including raised erythematous areas with scabs and alopecia (Duff, Scott and Keymer 1996). The grey squirrel virus has not been isolated and so its identity remains unclear. There is a clear need to investigate the epidemiology of parapoxvirus infection in red and grey squirrels. It is particularly important to study the infection in captive and wild red squirrel populations between which animals will be moved as part of the conservation programme. Cases of parapoxvirus infection have been reported from northern England including several from Lancashire (Sainsbury and Ward 1996) and one each from Cumbria and Northumberland. No cases have been confirmed from Scotland or Ireland where both red and grey squirrels co-exist; squirrels from these and possibly other areas may not have been exposed to infection and consequently have no immunity. Studies have commenced on determining which populations of red squirrels in the

UK have antibodies to the virus and have been exposed to infection (Sainsbury, Nettleton and Gurnell, unpubl., funded by the Peoples Trust for Endangered Species). The introduction of immunologically naive animals to a population in which the infection is endemic could place them at risk.

There is a pressing need to investigate the epidemiology of parapoxvirus infection in red and grey squirrels in the UK, with particular emphasis on determining the threat that this disease represents to translocations and introductions.

Blood biochemical reference ranges for red squirrels were not available but based on values for rats and other Rodentia, red squirrels were at the lower end of the reference ranges for albumin. Inorganic phosphate was elevated compared with the cited reference ranges for Rodentia including rats but Hoff and others (1976) found that values in grey squirrels are more variable, although their calculated mean and standard error (2.3 and 0.06 respectively) suggested that most grey squirrels had values in the lower part of the range. The relatively low calcium values measured may be due to a decrease in the protein-bound fraction and related to the low albumin levels. Simesen (1980) reported that hyperphosphataemia with hypocalcaemia is indicative of nutritional secondary hyperparathyroidism but no further evidence of this disease was apparent. Some animals showed moderately elevated levels of plasma alkaline phosphatase compared with a reference for Rodentia but the only value above 700IU was from a juvenile and young animals may have higher levels associated with higher osteoblastic activity (Kerr 1989). Other biochemical values were apparently normal. None of the captive or wild squirrels radiographed in this study showed any significant bony abnormalities. However, bony defects of a certain size may not be visualized (Ardran 1951) and over 30% of bone mineral density must be lost before becoming radiographically detectable (Finsen and Anda 1988). It appears that the diet in captivity and in the enclosure is sufficient to prevent metabolic bone disease.

In a review, Keymer (1983) found that coccidiosis was a common cause of death in red squirrels and *Eimeria* spp oocysts were a common finding in the faeces of animals in this study. Two species, *Eimeria sciurorum* and *E silvana* were identified. *E sciurorum* was thought to be pathogenic in wild red squirrels by Keymer (1983) and this species pathogenicity has been confirmed experimentally (Pellerdy 1974). However, no evidence of disease due to *E sciurorum* was found in this study.

Parasites of the genus *Hepatozoon* have been previously identified in the white blood cells of red squirrels (Watkins & Nowell, 1991) but there is doubt over the identity and life-cycle of the species which parasitise red and grey squirrels in the UK. They are apparently non-pathogenic.

These interesting findings indicate the value of monitoring the health of both the released animals and the resident population. Although the albumin and inorganic phosphate levels obtained from the red squirrels were not in the expected range, metabolic bone disease does not appear to be a significant threat to red squirrels in the reintroduction programme.

9.5 Future trends in Thetford

Although grey squirrel removal has benefitted the red squirrel population in the Reserve, the population is small, vulnerable, and restricted to specific habitats. The area of suitable red squirrel habitats will increase over time as the areas of young Corsican pine mature. Other management options to increase the overall suitability of the Reserve include encouraging natural regeneration under the >55 year old Scots pine. Such management options will be examined in a future report based on GIS and habitat modelling of the Thetford Reserve (see Gurnell, Clark and Feaver, 1995, 1996 and in prep.). Thus, there is optimism that the Reserve will have the potential to hold a much larger, and consequently more sustainable, population of red squirrels in the future. Nevertheless, it would seem appropriate at this time to maintain the level of grey squirrel control and to boost the small, and possibly dwindling number of red squirrels in the Reserve by introducing new stock from elsewhere in the country (see Barratt *et al.*, 1996). This will form the focus of the red squirrel conservation studies at Thetford Forest in 1997 to 1999.

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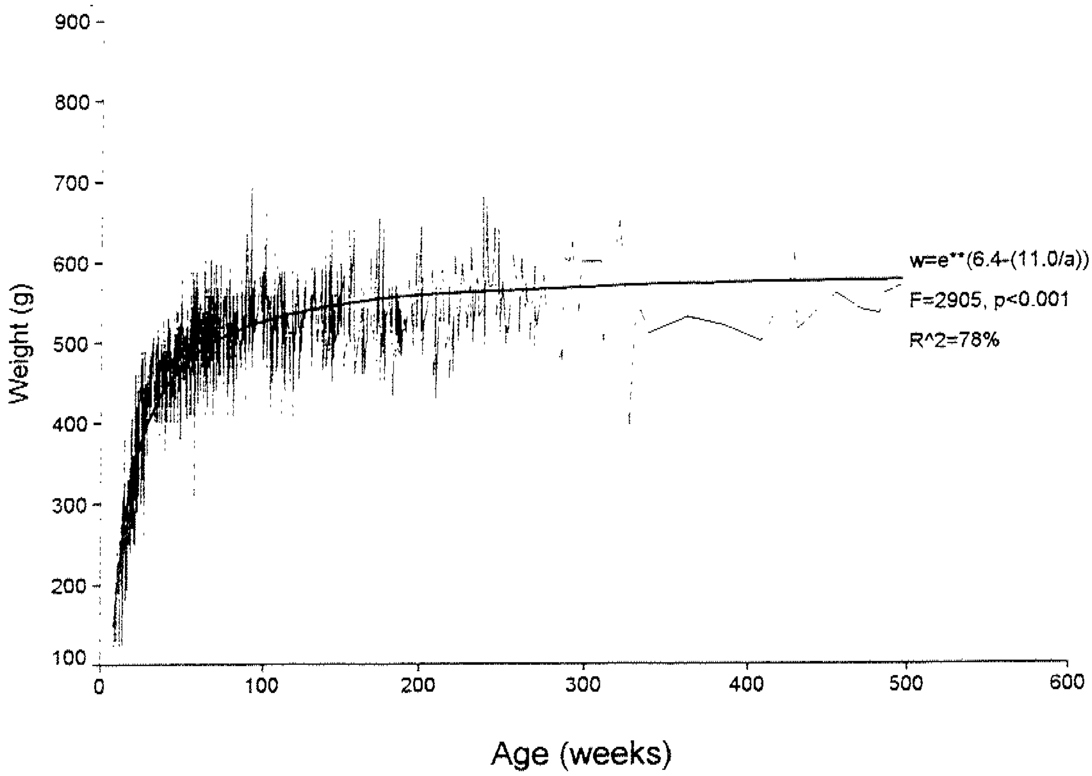
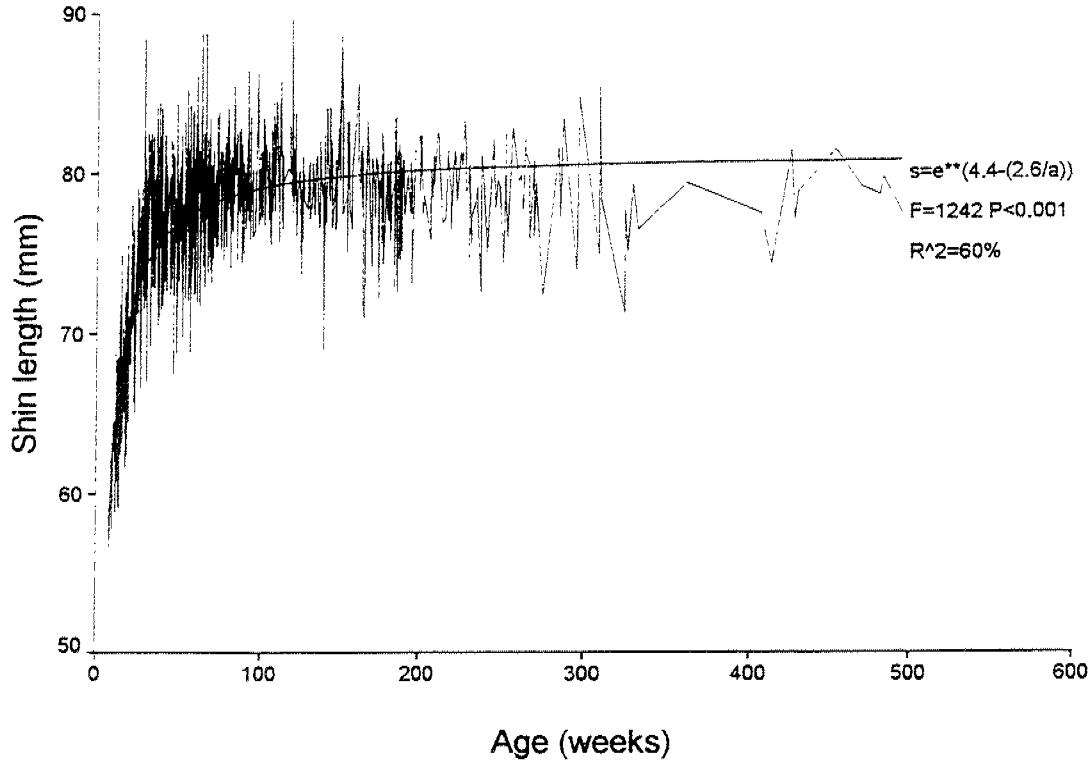
Appendix 1

Weight as a function of age

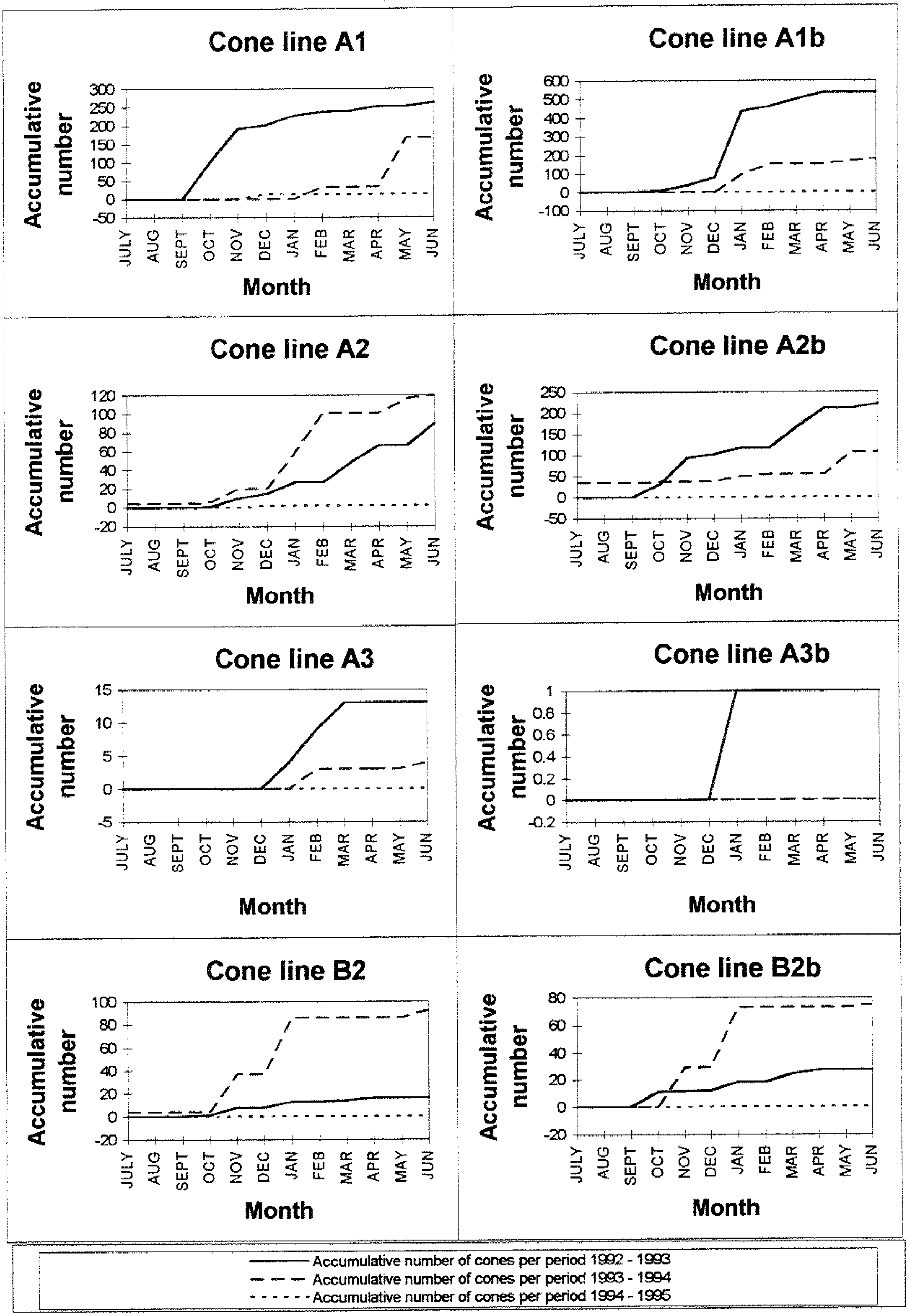


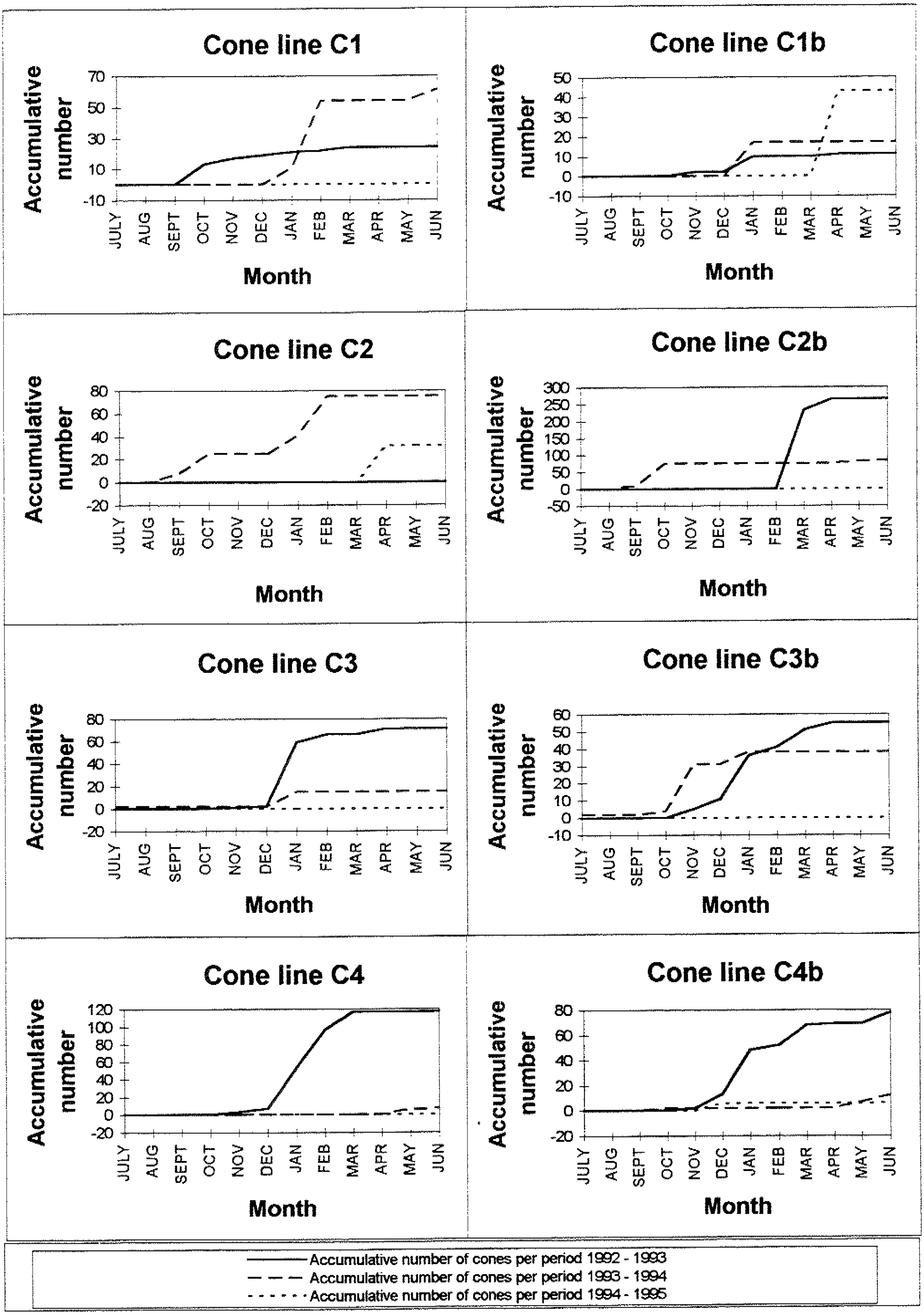
Appendix 2

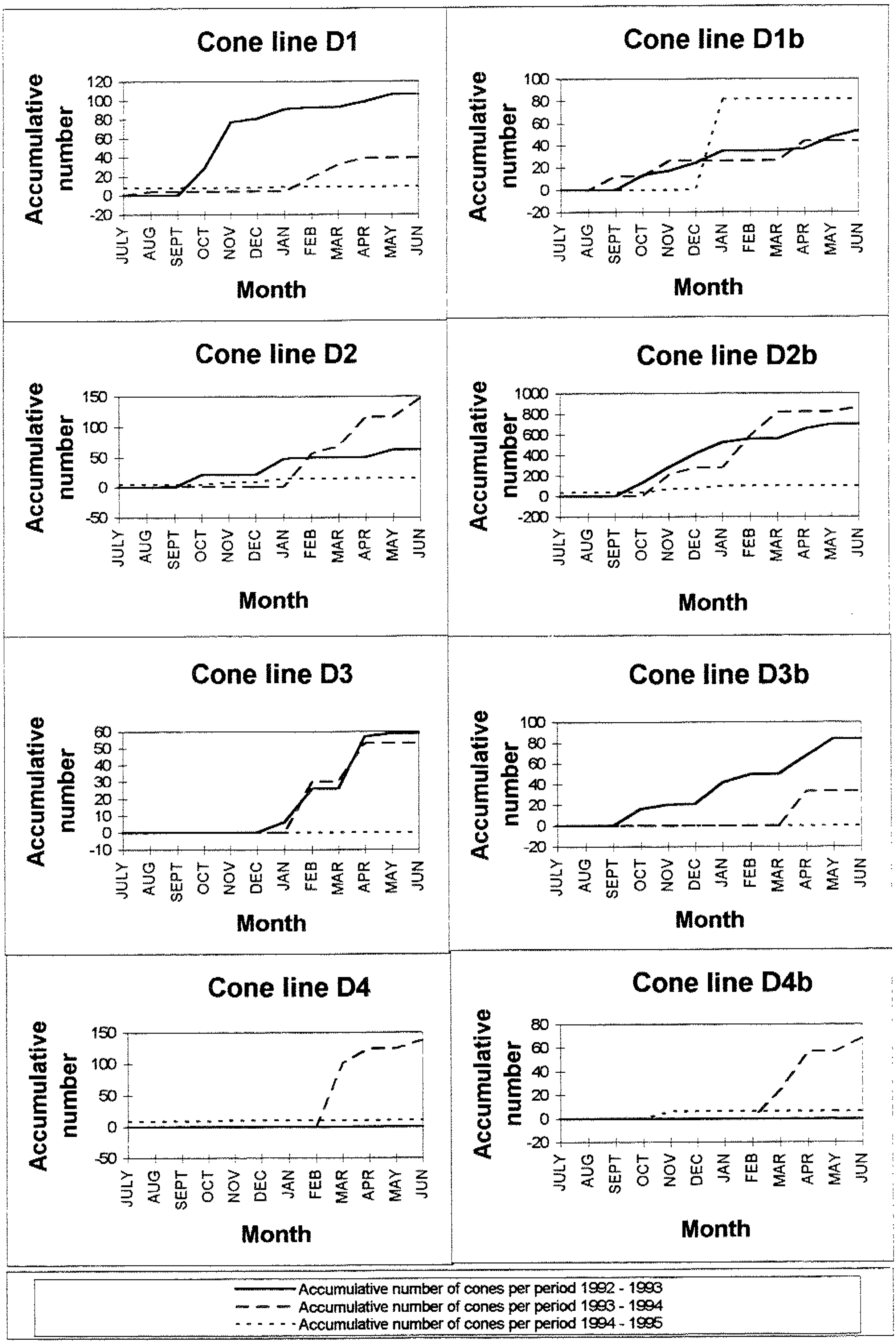
Shin length as a function of age

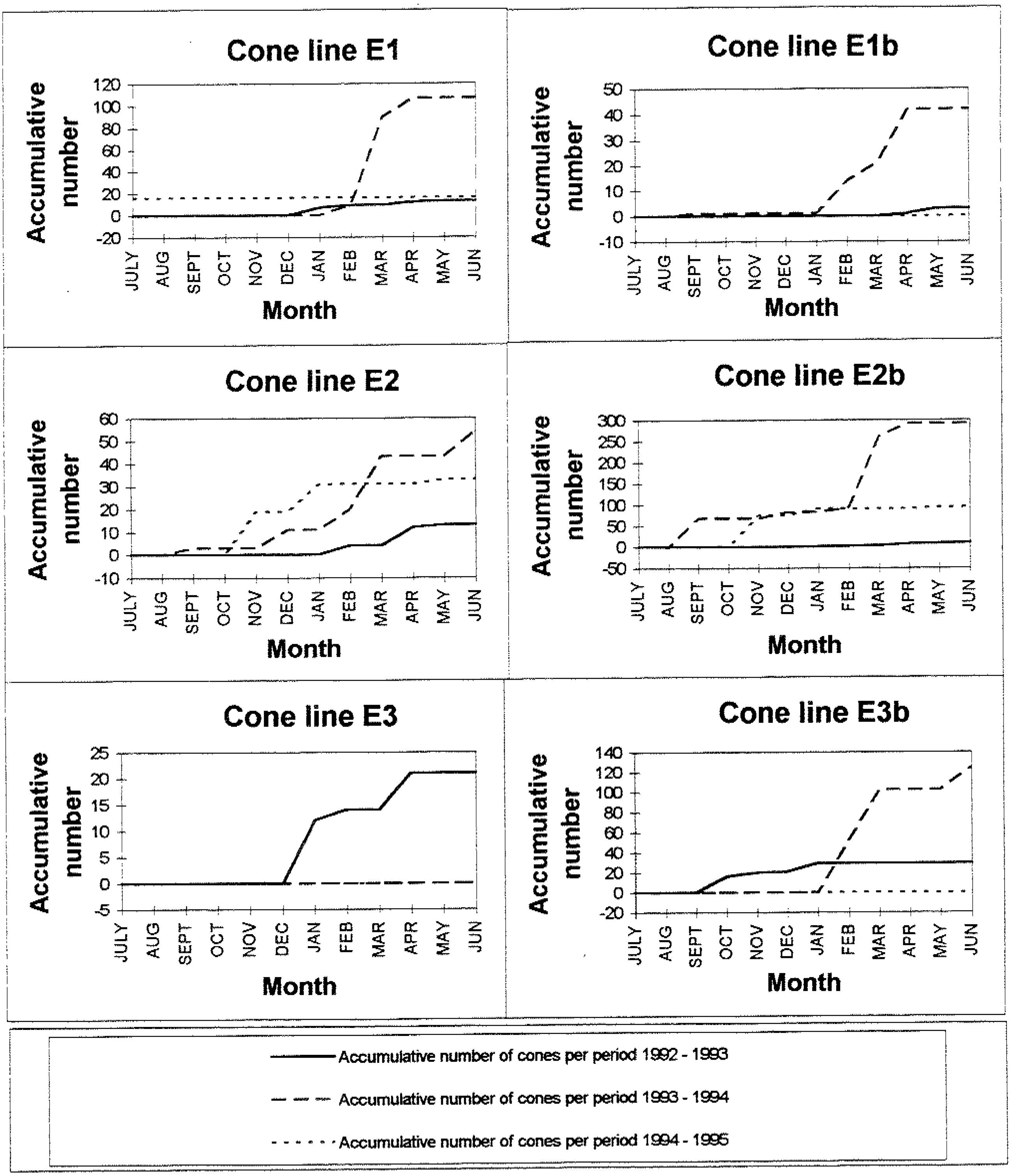


Appendix 3 Cumulative numbers of cone cores for each feeding line for each year.

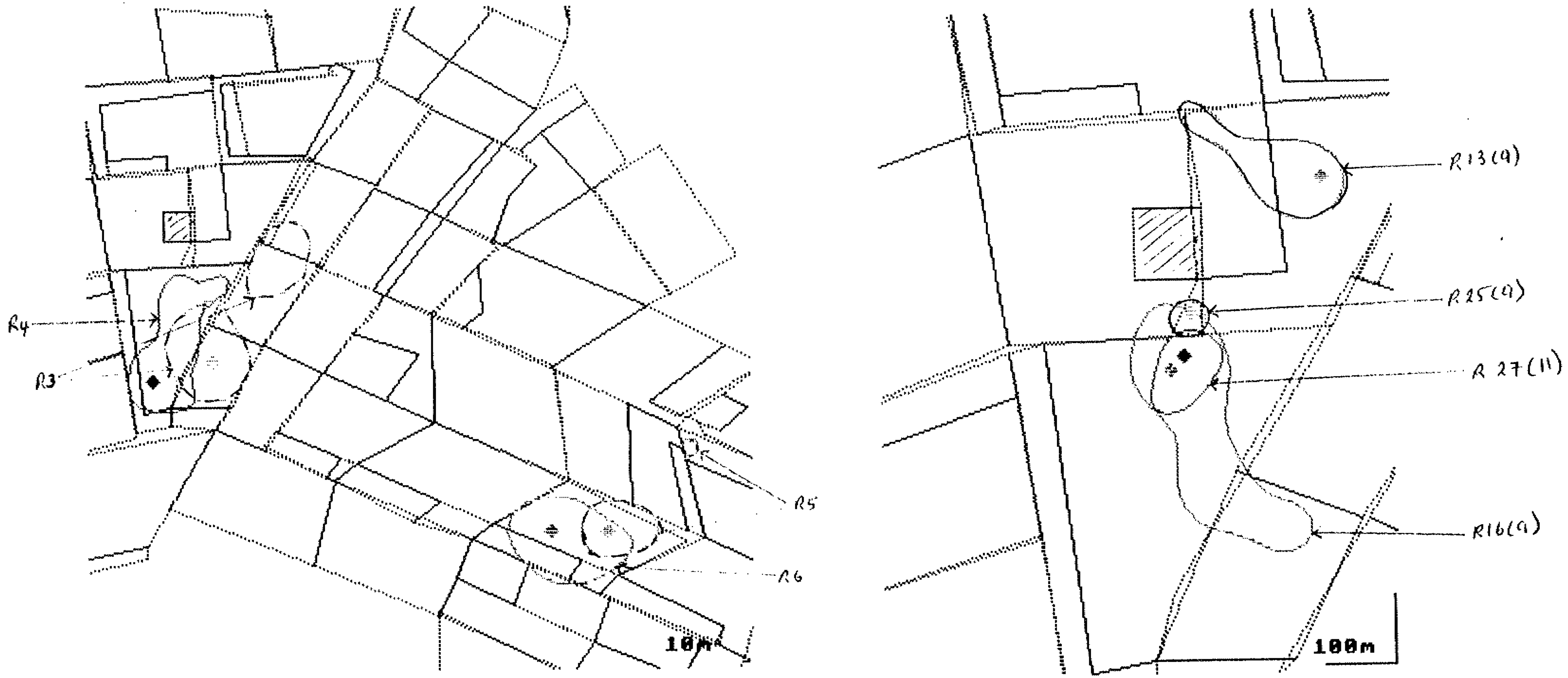



Cone line C1
Cone line C1b
Cone line C2
Cone line C2b
Cone line C3
Cone line C3b
Cone line C4
Cone line C4b
Accumulative number
Month
JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN
Accumulative number of cones per period 1992 - 1993
Accumulative number of cones per period 1993 - 1994
Accumulative number of cones per period 1994 - 1995

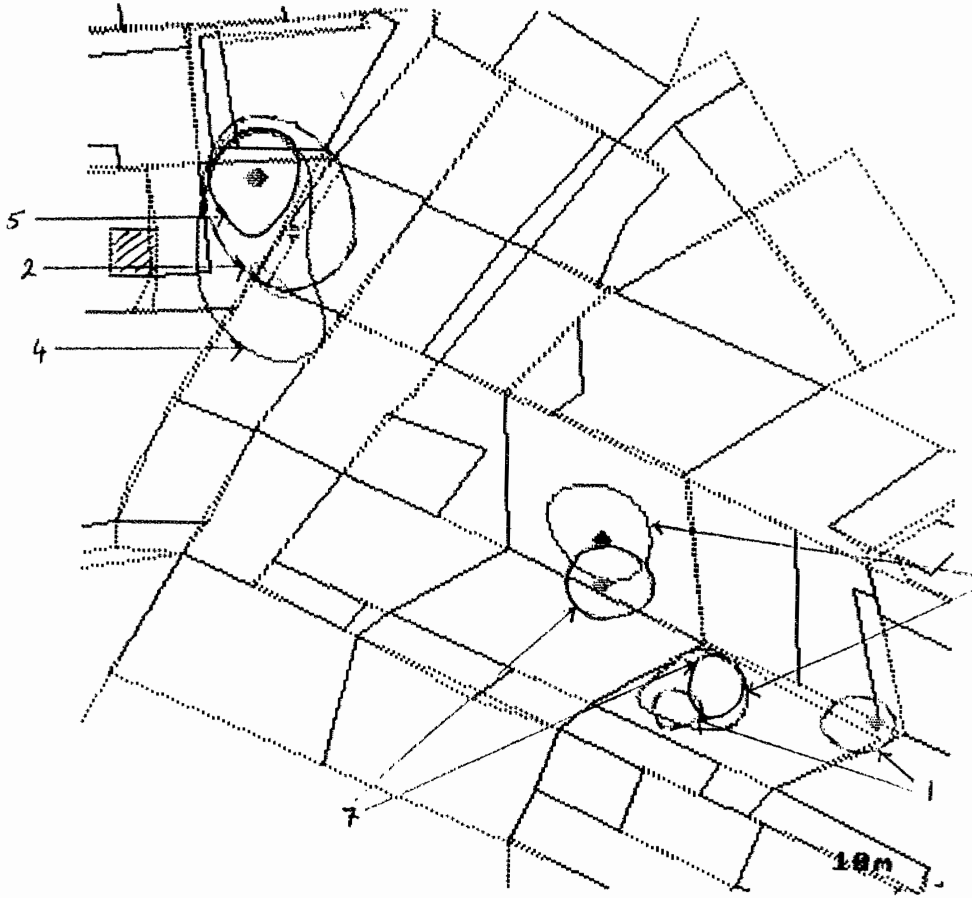

Cone line D1
Cone line D1b
Cone line D2
Cone line D2b
Cone line D3
Cone line D3b
Cone line D4
Cone line D4b
Accumulative number
Month
JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN
Accumulative number of cones per period 1992 - 1993
Accumulative number of cones per period 1993 - 1994
Accumulative number of cones per period 1994 - 1995

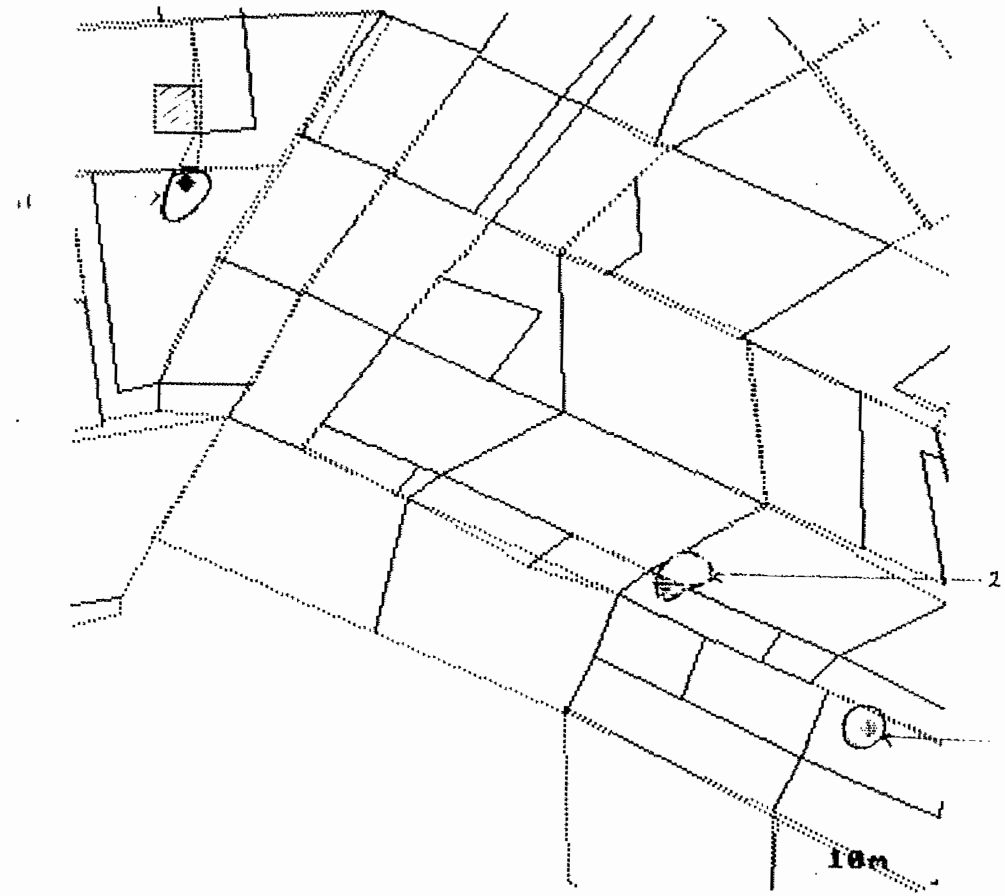


Cone line E1
Accumulative number
120
100
80
60
40
20
0
-20
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Cone line E1b
Accumulative number
50
40
30
20
10
0
-10
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Cone line E2
Accumulative number
60
50
40
30
20
10
0
-10
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Cone line E2b
Accumulative number
300
250
200
150
100
50
0
-50
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Cone line E3
Accumulative number
25
20
15
10
5
0
-5
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Cone line E3b
Accumulative number
140
120
100
80
60
40
20
0
-20
JULY
AUG
SEPT
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Month
Accumulative number of cones per period 1992 - 1993
Accumulative number of cones per period 1993 - 1994
Accumulative number of cones per period 1994 - 1995

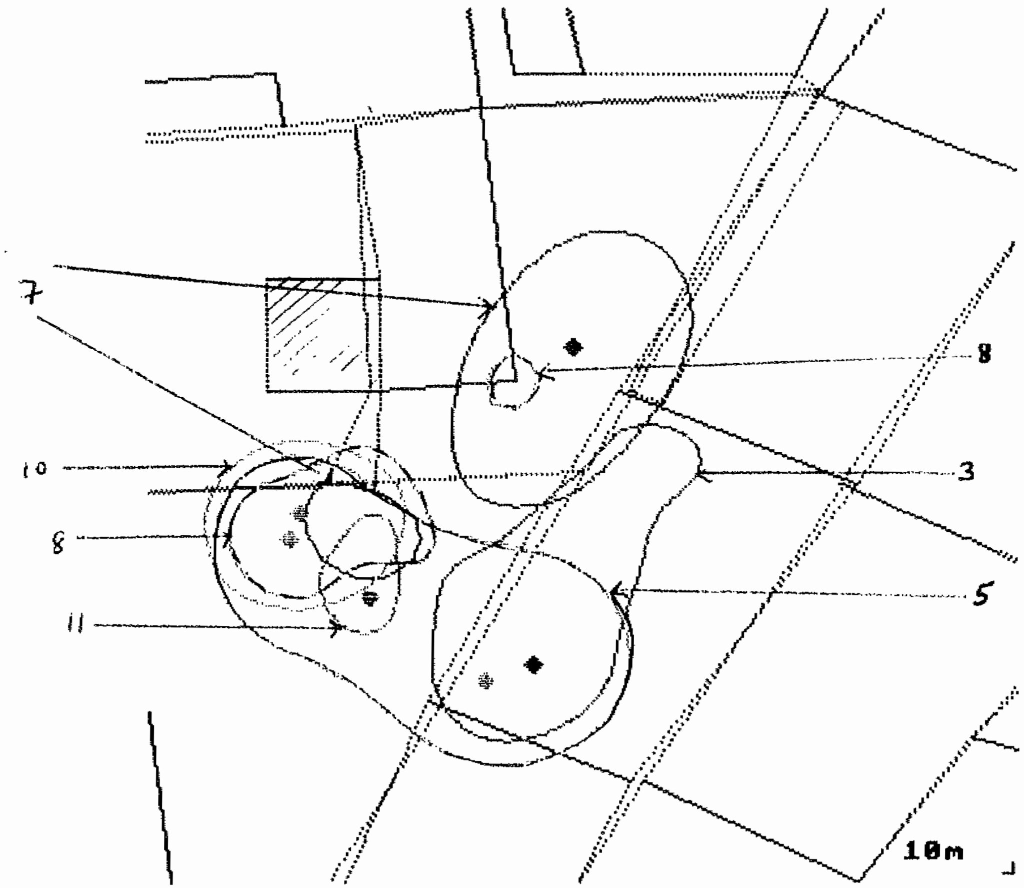


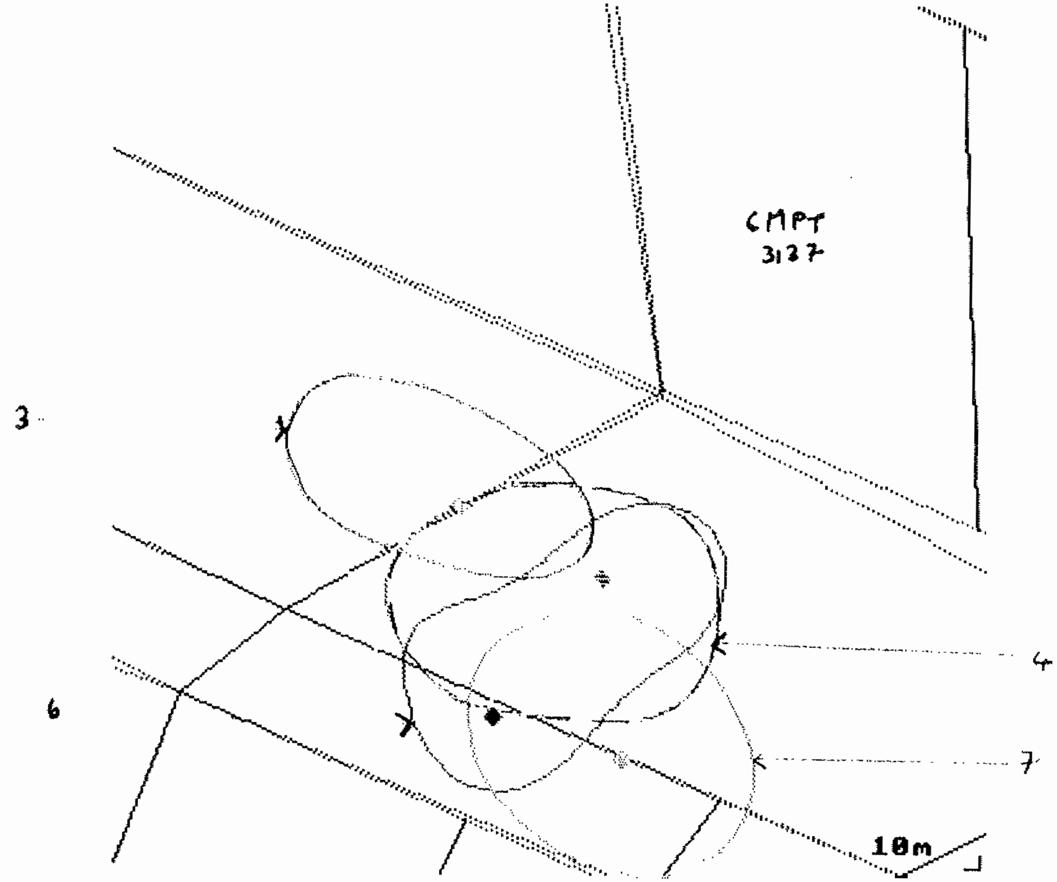
Appendix 4 70% kernal ranges. Left - September 1993: R3 and R4 were released from the pen, R5 and R6 were resident squirrels. Right - September (9) and November 1994. Cross hatched area = pre-release pen.



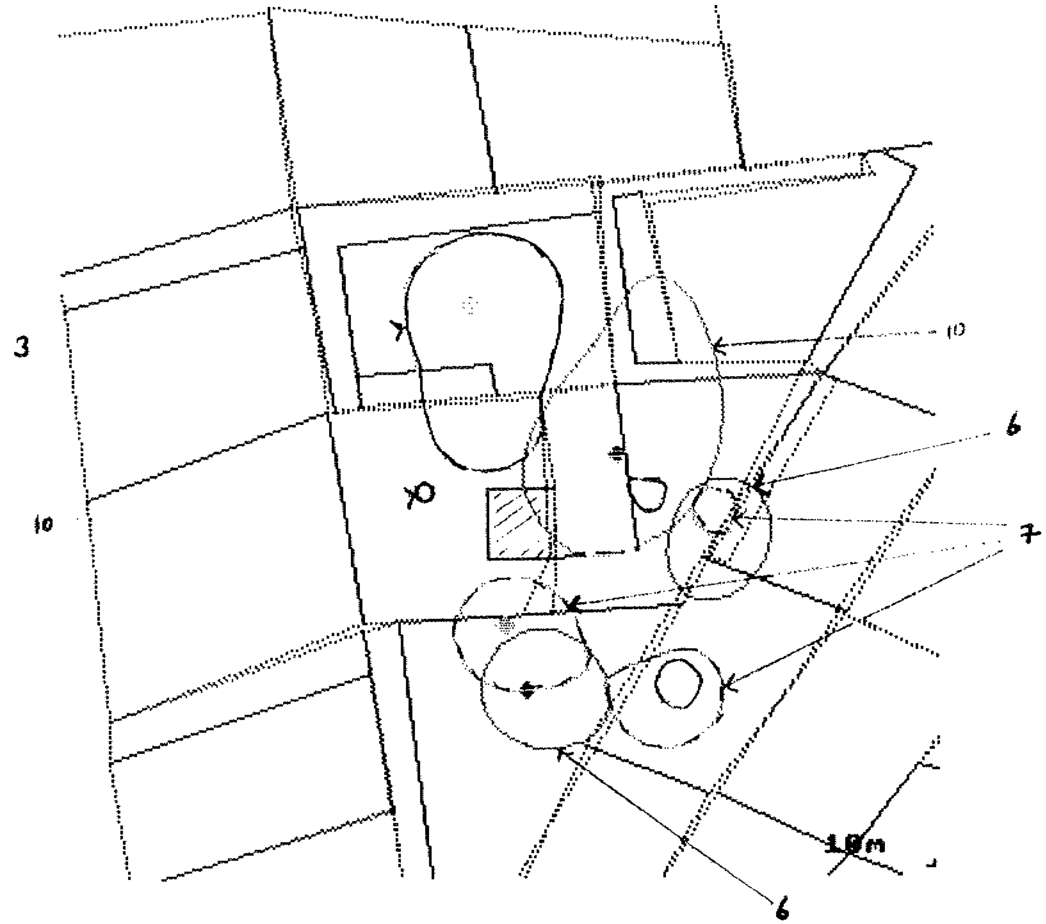


Appendix 4 cotd. 70% kernal ranges. Left - R6, numbers refer to months in 1995
Right - R27, 11 refers to November 1994, other numbers refer to months in 1995





Appendix 4 cotd. 70% kernal ranges. Left - R16, numbers refer to months in 1995
Right - R17, numbers refer to months in 1995



Appendix 4 cotd. 70% kernal ranges. R30, 10 refers to October 1994, other numbers refer to months in 1995

Appendix 5a Tree species-age matrix for relative proportions of habitats within the Reserve

	Age (yrs)					
Species	0-10	11-20	21-35	36-54	>54	All
CP	23.69	5.89	10.72	1.73	2.23	44.26
SP	0.01	0.89	0.31	1.57	22.40	25.18
MC	1.53	0.70	5.55	1.44	14.17	23.39
CD	0.95	0.00	0.44	0.00	2.50	3.89
MB	0.04	0.00	0.09	0.12	0.81	1.06
BD	0.00	0.16	0.00	0.00	0.59	0.75
LP	0.00	0.00	0.18	0.00	0.00	0.18
OK	0.10	0.00	0.00	0.00	0.05	0.15
BE	0.00	0.00	0.00	0.00	0.05	0.05
CB	0.08	0.00	0.00	0.00	0.30	0.38
HL	0.14	0.00	0.00	0.00	0.00	0.14
RAN	0.00	0.19	0.00	0.00	0.00	0.19
NF	0.00	0.00	0.08	0.00	0.00	0.08
DF	0.22	0.00	0.00	0.05	0.02	0.29
All	26.76	7.83	17.37	4.91	43.12	99.99

Appendix 5b Tree species-age matrix for habitats within the Reserve

CP	372.41	92.59	168.52	27.20	35.06	695.77
SP	0.16	13.99	4.87	24.68	352.13	395.83
MC	24.05	11.00	87.25	22.64	222.75	367.69
CD	14.93	0.00	6.92	0.00	39.30	61.15
MB	0.63	0.00	1.41	1.89	12.73	16.66
BD	0.00	2.52	0.00	0.00	9.27	11.79
LP	0.00	0.00	2.83	0.00	0.00	2.83
OK	1.57	0.00	0.00	0.00	0.79	2.36
BE	0.00	0.00	0.00	0.00	0.79	0.79
CB	1.26	0.00	0.00	0.00	4.72	5.97
HL	2.20	0.00	0.00	0.00	0.00	2.20
RAN	0.00	2.99	0.00	0.00	0.00	2.99
NF	0.00	0.00	1.26	0.00	0.00	1.26
DF	3.46	0.00	0.00	0.79	0.31	4.56
All	420.67	123.09	273.06	77.19	677.85	1571.84