The immediate impacts of timber harvesting and associated activities on the Ngwayir (*Pseudocheirus occidentalis*) in the Jarrah forest of Kingston State Forest Block.

Progress Report
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REPORT SUMMARY

A preliminary investigation into the impacts of timber harvesting on the threatened Ngwayir (western ringtail possum; *Pseudocheirus occidentalis*) began in February 1997 within the Kingston State Forest, 26 km north east of Manjimup Western Australia. The principle aims of this study were to investigate these impacts in terms of the (i) Survivorship, (ii) Habitat Use, and (iii) Home Ranges of the Ngwayir.

A total of 17 treatment animals (from Kingston 4 logging coupe) and 12 control animals (from unharvested control areas east and west of the treatment area) were radio-collared with mortality sensitive radio-transmitters. These animals were studied prior to, during and after the harvesting of the treatment area. Morphological statistics were recorded for each animal when it was first caught and subsequently every five to six months whilst re-collaring. Animals were radio-tracked about three times a week until their death or until loss of contact (e.g. through collar failure, or slippage). Information relating to the daytime refuges utilised by the animals was recorded during these radio-tracking events. Since March 1997 standardised spotlighting surveys of the treatment area were generally conducted fortnightly for the first year and generally monthly thereafter. The results presented here are preliminary and remain incomplete.

Harvesting began within the Kingston 4 coupe in March 1997. Two weeks after harvesting had been completed within the ranges of the experimental animals (August 1997), there were significantly fewer treatment animals (31.2%) alive within the harvest coupe than collared animals within the control areas (80%). All treatment animals and most control animals were dead by October 1998 (ie. prior to the Kingston 4 silvicultural burn in November 1998). Up to 17.6% of the treatment animals died from the falling of their refuge sites during the harvesting process. Predation by introduced predators was the main cause of death in both control and treatment cohorts, however, increased rates of predation are an immediate impact of harvest activities on the Ngwayir. Over the entire study period, there was a marginal significant difference in the survivorship of treatment Ngwayir compared to control animals ($p=0.0559$). Due to the small sample size, however, the statistical power was unable to detect a 40% difference in the survivorship at the 95% confidence level.

A total of 2626 refuge occupancy records involving 413 different refuges were collected from the 29 experimental animals between February 1997 and June 1999. The number of different refuges used by each animal was time and observation dependent. No significant differences were detected with 95% confidence between the control and impact or before and after regression coefficients for these relationships. On the basis of these regression analyses a Ngwayir in Kingston is expected to use 20 different refuges per year (365 days).

Refuges were classified as 'standing trees', Balga (*Xanthorrhoea preissii*), 'above ground nests', 'forest debris', 'burrows', or 'hollow stumps'. Significant differences were observed in the relative proportions of different refuge types used between the western and eastern control areas. 'Above ground nests' (mainly dreys) were the most common refuge type in the western control area which is located within and alongside the dense riparian vegetation of Yerraminnup Creek. 'Standing trees' (with hollows) were used the majority of time within the eastern control area which is jarrah/marri woodland similar to the treatment area. Balga constituted 35% of the refuges within both control areas. Within the treatment area, 'standing trees' were the most common refuge type prior to harvesting and forest debris created by harvesting activity was the most common after disturbance. 'Standing trees', however, remained the most frequently used form of refuge type within the treatment area throughout the study.

Typically most refuges were used rarely (less than 10%) by an individual whilst one to three refuges were used disproportionately more. Many of the most frequently used refuges were 'standing trees' or Balga, however, some 'above ground nests' and 'forest debris' refuges were also used extensively. 'Standing trees' with larger diameters and large Balga with multiple heads are more likely to be used more extensively. The gross characteristics of the refuges used are described in detail. Intra-specific refuge sharing was observed a few times. Non-synchronous multiple users (by other Ngwayir and Koomal, *Trichosurus vulpecula*) of some refuges was also observed.

There will be further development of this preliminary understanding of the general biology and logging impacts on the survivorship and refuge usage of Ngwayir in Kingston prior to publication. The spatial aspects of the study (home-ranges and movement patterns) and spotlight survey data remain to be analysed. Provisional recommendations to management in relation to harvest operations in Ngwayir habitat are briefly presented to stimulate discussion.

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INTRODUCTION

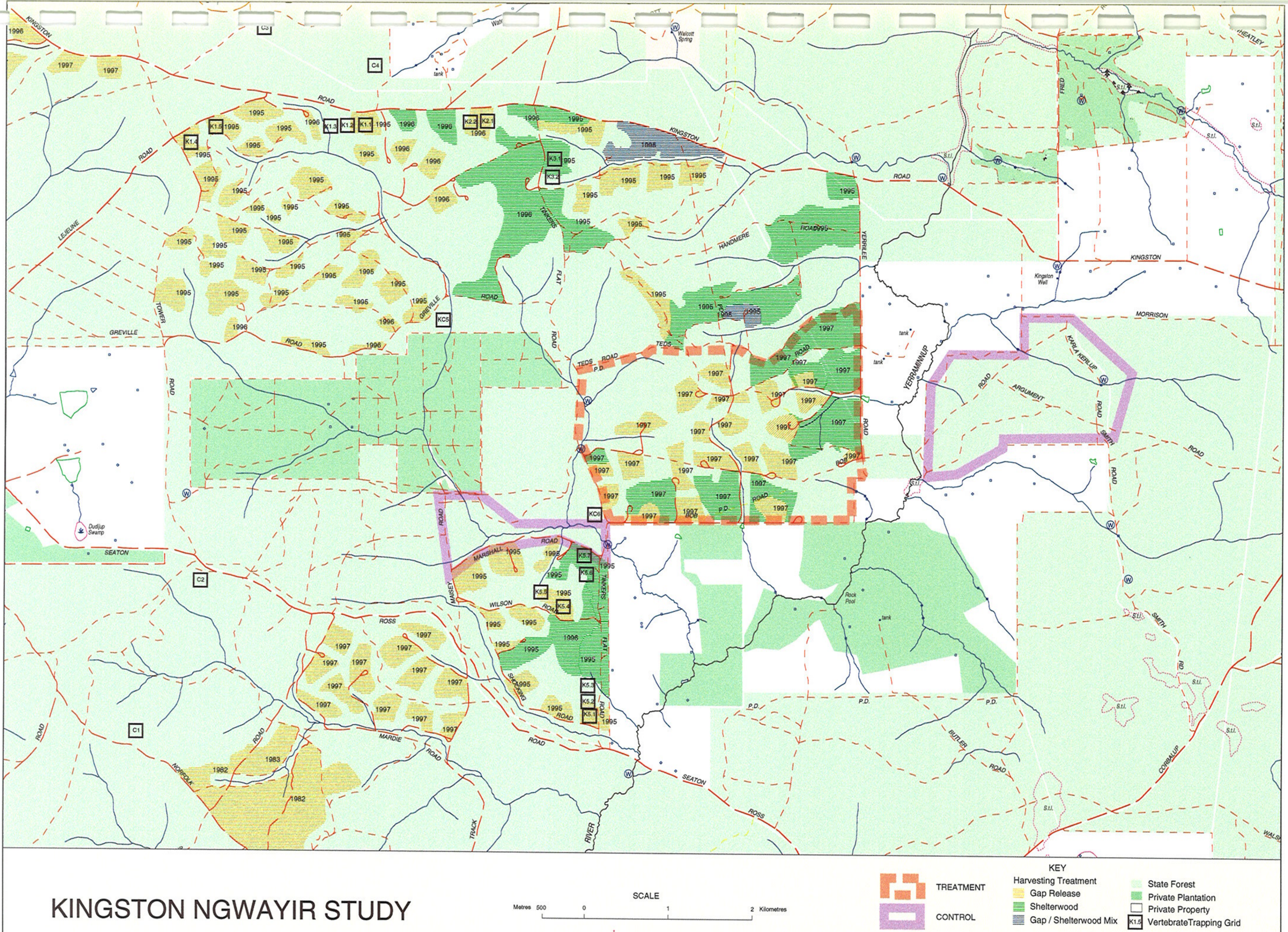
Project Kingston is an integrated series of studies investigating the effects of timber harvesting on selected groups of plants and animals in the jarrah forest ecosystem (Burrows *et al.* 1994). An extensive and intensive trapping program was designed to study the disturbance responses of the medium sized mammals (Morris *et al.* 1996, 2000, Johnson and Morris 1999). This work resulted in extremely low trap capture rates for the Ngwayir (Western Ringtail Possum), *Pseudocheirus occidentalis.* Spotlight surveys of the area, however, suggested the abundance of Ngwayir was comparable to the readily trapped Koomal (Common Brushtail Possum), *Trichosurus vulpecula.* It became apparent that although the trapping methodology is effective in surveying most mammalian species it was clearly ineffective for surveying the Ngwayir. As a consequence a study using different surveying methods began in February 1997 to specifically investigate the impacts of timber harvesting and associated activities on the Ngwayir (CALMScience SPP# 97/0007). The aims of this research were to investigate these impacts in terms of the (i) Survivorship, (ii) Habitat Use, and (iii) Home Ranges of the Ngwayir. This progress report serves to record and report on much of the preliminary analysis results from this study. The spotlighting surveys of the population trends of possums within the greater Kingston areas will be reported on separately. Subsequent to this, the results and findings from these studies will be presented in a series of published journal articles.

METHODS

Study Site
The study was conducted in the Kingston State Forest Block, 26 km north east of Manjimup (Figure 1 & 2). Jarrah, *Eucalyptus marginata*, and Marri, *Corymbia calophylla*, dominate the overstorey of the dry sclerophyll open forest and woodland. Flooded Gum, *Eucalyptus rudis*, is present and occasionally dominant within the larger and wetter drainage profiles, for example Yerraminnup Creek. Wandoo, *Eucaluptus wandoo*, tends to become more common and increasingly patchy within the lower profiles towards the eastern margins of the study areas. The annual rainfall is approximately 900mm and the soils are primarily lateritic with deeper loams in riparian zones. The area had previously experienced high quality jarrah selective harvesting in the 1920's (Heberle 1997) and between 1940 and 1976 (Hardwood Operations Control System records at FMB, Manjimup). Prescribed fuel reduction burns have been implemented in the area since the mid 1960's on a seven to 10 year rotation. Although wildfires have occurred in Kingston, there are no records of wildfires within the study areas since prescribed burning began. A number of privately owned freehold land titles used for agriculture, pine or bluegum eucalypt timber plantations are present throughout the forest-dominated landscape.

Harvesting Associated Activities
Road clearing was conducted during December 1996 and road construction (gravelling) during January 1997. The study began in February 1997. Harvesting occurred within Kingston 4 coupe (K4) and the adjacent remainder of Kingston 3 coupe (K3), from March to August 1997, and November 1997 to January 1998. Harvesting within the ranges of extant experimental animals occurred between May and August 1997. Jarrah Stand Improvement (JSI: the removal of non-merchantable timber to encourage rapid tree regeneration) was conducted November to December 1997 and March to April 1998. The Post-harvest (silvicultural) burn was conducted on 9 November 1998. All harvesting activities conducted within K4 and K3 were compliant with the endorsed prescriptions as set out in the silvicultural guidelines for jarrah forest (CALM 1995, Stoneman *et al.* 1989). The study did not impose any changes to the harvesting prescriptions. Within K4, 146 ha were cut to gap, 136 ha to shelterwood, 50 ha reserved (Riparian and Diverse Ecotype Zones), and 426 ha remained available but unharvested (including TEAS). The associated K3 harvesting involved 8ha of gap and 49ha of shelterwood (Forest Management Branch Area Statement Data 1998).

General Study Design
Consistent with the other studies involved in the Kingston Project, this study conforms to the principles of the BACI (Before, After, Control, Impact) design. Pre-harvesting data was collected from radio-collared animals from February to July 1997. Disturbance data was collected for each individual at the commencement of falling operations immediately adjacent to (within 100m to 200m), or within the known home-ranges of that animal: between 5th May and 24th July 1997. Standardised spotlighting surveys have been regularly conducted since March 1997 to provide Ngwayir and Koomal population response data at the landscape scale of the forest coupe (818ha): to be reported separately.



KINGSTON NGWAYIR STUDY

Figure 1 : Map showing location of the K4 Treatment Area and Western and Eastern Control Areas within Kingston State Forest, Manjimup, Western Australia.

Experimental Animals
Treatment animals were within the K4 logging coupe and control animals were within adjacent and contemporarily unharvested jarrah forest immediately east (part of Kingston 6) and west (part of Kingston 5) of K4 (Figure 1). Both the treatment area and the eastern control area are adjacent to agricultural land. The west control area is adjacent to a long established pine plantation. Ngwayir were located by spotlighting and caught by hand or with the aid of a tranquilliser dart gun (Montech 2 with Zoletil 100 intramuscular anaesthetic). Experimental animals were collared with mortality sensitive radio-transmitters (Biotrack) and then radio-tracked (Biotel RX3 Radio Receiver and Sirtack collapsible hand aerial) to monitor and gather data before, during and after timber harvesting. For the majority of the study, all extant experimental animals were usually radio-tracked about three times a week.

The location of experimental animals within the study areas was largely opportunistic based on successful detection and capture and the aim for roughly equal sex ratios. Animals within the treatment area were incorporated into the study prior to the silvicultural treatments being accurately demarcated. Discrete analyses of the different silvicultural treatment types were not conducted due to the small cohort size and the presence of multiple disturbance treatments within many individual home-ranges. Analyses were therefore conducted by combining all treatment animals into the one impact cohort.

Individuals and their Morphological Statistics
The morphological statistics collected for each individual Ngwayir caught included; ear tag numbers (uniquely numbered small titanium alloy tags), sex, weight, age, head length, short and long pes, scrotum length and width, pouch condition, presence of young, and general comments. Radio-collared individuals were remeasured approximately every five months when they were recaught to replace expiring radio-transmitters.

Survivorship Analyses
The survivorships of control and treatment cohorts were analysed using the Staggered Entry Model (Pollock *et al.* 1989) for the Kaplan-Meier survivorship estimator (Kaplan and Meier 1958). The Log-Rank test was used to test whether the survivorship of treatment animals was less than that observed for the control cohort. The principal assumptions for these tests include; i) animals randomly sampled; ii) independent survival times of different animals; iii) the research does not influence the future survival of individuals; iv) animal censorship is random (ie. is not related to an animal's fate) and v) radio-collared animals have the same survival function irrespective of the timing of their staggered entry.

Refuge Types and their Characteristics
Refuges used by Ngwayir were classified into six types;
Standing Trees (ST)- any arborescent plant in which there is no evidence of nest construction and with an observed hollow; or in the absence of the direct observation, a high likelihood that a hollow of suitable size is present within the tree. Data collected specific to standing trees included; tree species, height, diameter at breast height (dbhob), number of visible hollows greater than 6cm diameter, height to the lowest hollow, senescence scale (Whitford and Williams 2000), whether the tree was dead or alive and whether it was vertical or leaning at the time of first recording.

More detailed data was collected from 'standing trees' which were felled as part of the harvesting process within the treatment area. The number of hollows were recorded and for all hollows greater than 60mm in diameter, 17 parameters of the hollow were measured. A total of 24 'standing trees' were examined in this manner. These data remain to be more extensively analysed.

Balga (BB)- Xanthorrhoea preissii. Also commonly known as one of the 'grass trees' or 'black boy'. Specific details recorded for these refuges included; the number of grass heads, height, diameter at 30cm, length of skirt (formed by the thatch of dead leaves originating immediately below the growing apices of each grass head), senescence, whether it was dead or alive and whether it is vertical or leaning.

Above Ground Nest (AN)- Any nest or drey construction off the ground and within vegetation. Dreys are typically constructed by Ngwayir in middle storey bushes, but may also create nests in epicormic shoots, and stump coppicing. Some above ground nests have no evidence of nest construction, are not hollows, and could alternatively be thought of as roosts (e.g. fork of limbs).

'Above ground nests' were further distinguished by their location/type. These classifications included whether the animal was located within 'crown or foliage', 'epicormic shoots', 'stump coppicing', or within a 'drey' (a well-constructed, spherical and encompassing nest made by Ngwayir). The host species, host height and diameter, vertical or leaning stature of the host and the dead or alive status of the host were recorded. Whether there was evidence of nest construction, nest dimensions, nest materials and the height of the nest/roost were also recorded when relevant.

Forest Debris (FD)- refuge sites within forest floor debris that may or may not have evidence of deliberate nest construction. 'Forest Debris' refuges were classified principally by their origin; either naturally fallen limbs, road construction (roading debris often in piles), harvesting (logging tops) or 'other'. The dimensions of the debris and the nest/roost location were also recorded.

Burrow (BU)- a hollow or tunnel constructed by an animal (e.g. rabbit) or a cavity formed by a now decayed and/or burned and exposed tree root. 'Burrows' were further distinguished by their location and origin (e.g. animal burrow, root cavity, etc). The number of entrances, the dimensions of the entrance(s) and the location of the animal within the burrow were noted.

Hollow Stump (HS)- a hollow within the centre of a tree stump that may be natural or from tree harvesting. The species of stump, its origin (cut or natural fall), stump height and diameter, hollow diameter and the location of the animal in the stump were recorded.

In addition to the collection of data relating to the specific characteristics of the refuge types, location, position in the landscape, associated vegetation (within 20m radius), disturbance notes and general comments were collected for all refuges. This data remains to be incorporated into analyses.

RESULTS

Experimental Animals

A total of 17 treatment animals and 12 control animals were radio-collared. All except two of the 17 treatment animals were collared prior to timber-harvesting commencing within its local area. One of these exceptions (#17) was opportunistically collared with no prior known history and subsequently has not been included in the survivorship analyses. The second Ngwayir (#18) had been ear-tagged prior to harvesting commencing and whilst it was the 'at heal' (predominantly out of the pouch but still dependant) offspring of another collared individual (#12;). It was first collared (five months after being ear tagged) after its mother had been dead for just over four months, and about a week after harvesting had first disturbed its territory. Given its known history prior to harvesting, this individual was included in the survivorship analysis. Seven of the control animals (C01-C07) were caught within the western control area. One of these ('C04') was thought to slip its radio-collar (found in tact in a drey) two weeks after it was first collared and has subsequently not been included in the survivorship analyses. The remaining five control animals (C08 – C12) were from the eastern control area (Figure 2). All collared individuals were adults and thought to be fully independent at the time of collaring except treatment individual #9 which was the well advanced 'at heal' offspring of #10.

Individuals and their Morphological Statistics
Within the eastern and western control areas eight male and four female Ngwayir were collared. Nine male and eight females were collared within the K4 treatment area. Six other adult Ngwayir within the treatment area were caught but not collared and four sub-adult offspring of experimental animals were also ear-tagged but not radio-collared. The weights of adult females ranged from 810g to 1200g and males were 910g to 1400g. Sub-adults ranged from 415g to 780g.

Analyses of the morphological statistics remain to be done. There are plans to determine whether animal condition was affected by the seasons or harvesting activities. Similarly reproductive patterns and pouch young development are yet to be examined.

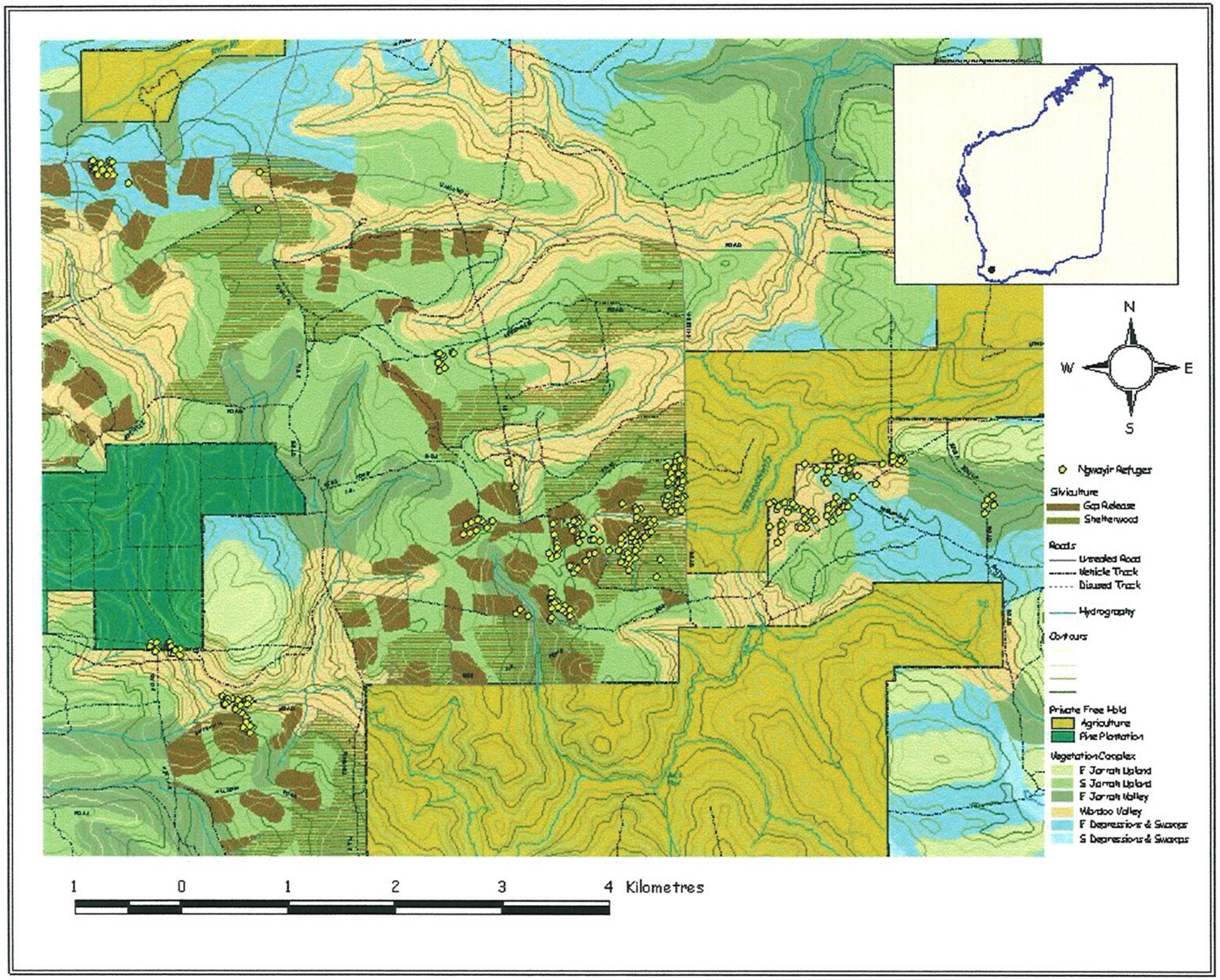


Figure 2. Distribution of the refuges (yellow dots) used by the 17 Treatment and 12 Control Ngwayir within Kingston State Forest, Manjimup, Western Australia.

Survivorship

Figure 3 summarises the survivorship history of the 29 Ngwayir radio-collared during this study. Two weeks after harvesting had been completed within the ranges of the experimental animals (1 September 1997), only 31.2% of the treatment animals remained alive within the harvest coupe. One treatment individual (#5) had relocated outside of the harvest area and 1.5 kilometres NNE from its original territory and the remaining treatment animals had perished. Of the control animals, 80% remained alive. The results at this stage demonstrate that there was significantly higher mortality of Ngwayir as a result of timber harvesting (Fisher Exact Test, two tail, p=0.041). All treatment animals were dead or contact had been lost (censored) prior to the silvicultural burn of K4 and K3 in November 1998. The majority of deaths of experimental animals were observed in June-August 1997, and April 1998 to July 1998.

The log-rank test (Table 1) indicated that the difference in overall survivorship of control and treatment animals (Appendix 1) was marginally significant ($p = 0.0559$, 1-tailed test, $X^2 = 2.5297$, DF = 1). However, the sensitivity of the data to detect survivorship differences is constrained by the sample sizes. There would need to be greater than approximately 40% difference in survivorship before there would be an 80% probability of detecting a significant difference with 95% confidence (Cochran and Cox 1957).

Fate of Experimental Animals

All recovered bodies and live animals during recollaring exercises were examined to determine whether the radio-collar appeared in anyway to be reducing the fitness of individuals. Some hair loss around the neck (under the collar) was common. Initially there were a few cases where some individuals sustained small lesions on the ventrolateral areas of the neck. Improvements to the radio-collar, its placement and the application of Betadine antiseptic overcame these problems, allowed free movement of the head and the collar, and in no way appeared to constrain breathing or the ability to feed. None of the recovered bodies provided any evidence that the radio-collars had in any way significantly reduced the fitness of the experimental animals or contributed to their deaths.

Predation

Table 2 summarises the fate of all radio-collared Ngwayir, and Appendix 2 lists the cause of death of each individual. Predation was the main cause of death for both cohorts: 12 cases plus predator involvement in other deaths classified as complicated or uncertain. In almost all cases fox or cat appear to be the predator involved in the deaths of the experimental animals. Evidence collected at the body sites (markings on collars and bones, hair, scats, etc) are yet to be fully studied in detail to provide additional predator specific information.

Complicated Death

The fate of one treatment and one control animal were classified as 'Complicated' on the basis that multiple factors may have contributed to their death. Several weeks leading up to its predation (thoracic crush and lung collapse, tail and testicles missing), observations of possum #01 (weak and behaving abnormally, e.g. frequently on the ground day and night) were symptomatic of an animal subject to stress or illness (possibly from old age). The weak disposition of this animal is likely to have made it vulnerable to predation. Although predation was the ultimate cause, other factors were possibly the primary reason for its death. In the case of the control animal (#C10), a fatal diaphragmatic hernia (caused by intense pressure) may have resulted solely from the swelling of a full stomach of dry feed pellets (possibly marron pellets associated with the adjacent farmland dam). However thoracic and head bruising indicative of crushes from the mouth of a fox or dog, sustained whilst the possum was still alive, may have caused the hernia. If this was the circumstance, then prior to the predation event, the animal would have had at the very least, limited mobility as a result of the dry feed pellets swelling from the absorption of body fluids within the gastro-intestinal tract. Consequently, irrespective of whether the hernia was sustained by an engorged stomach or predator, death resulted from a complicated misadventure by the over-consumption of feed pellets.

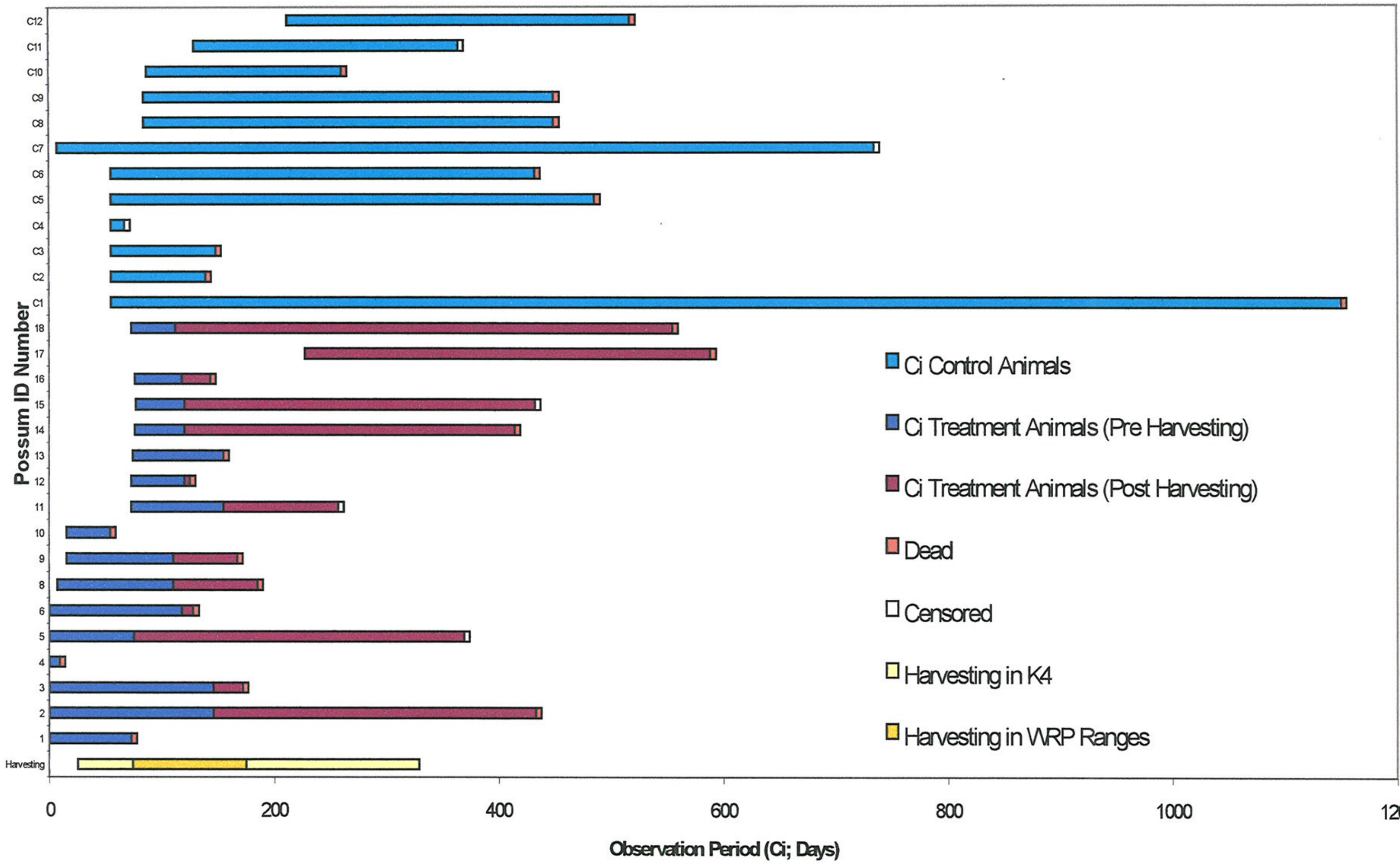


Figure 3. The observed survivorship history (C_i) of radio-collared ngwayir (*Pseudocheirus occidentalis*) within the K4 harvest coupe (treatment animals) and adjacent unharvested forest (control animals) within Kingston State Forest, Manjimup, Western Australia. Note #17 and C04 were not included in the survivorship analyses.

Table 1. Log-rank test calculations comparing survivorship of radio-collared ngwayir (*Pseudocheirus occidentalis*) within the K4 harvest coupe (treatment animals) and adjacent unharvested forest (control animals) within Kingston State Forest, Manjimup, Western Australia.

	Control Animals		Treatment Animals		Total Animals					
Period (t)	No. at Risk (r_{0i})	No. Deaths (d_{0i})	No. at Risk ($r1_i$)	No. Deaths ($d1_i$)	No. at Risk (r_i)	No. Deaths (d_i)	$E(d_{1i})$	$E(d_{0i})$	$var(d_{1i})^a$	$var(d_{1i})^b$
1	1	0	9	1	10	1	0.9000	0.1000	0.0900	0.0900
2	6	0	8	1	14	1	0.5714	0.4286	0.2449	0.2449
3	9	0	14	1	23	1	0.6087	0.3913	0.2382	0.2382
4	9	0	13	0	22	0	0	0	0	0
5	10	2	13	3	23	5	2.8261	2.1739	1.2287	1.0053
6	8	0	10	3	18	3	1.6667	1.3333	0.7407	0.6536
7	8	0	7	1	15	1	0.4667	0.5333	0.2489	0.2489
8	9	0	6	0	15	0	0	0	0	0
9	9	1	6	0	15	1	0.4	0.6	0.24	0.24
10	8	0	5	0	13	0	0	0	0	0
11	8	0	5	0	13	0	0	0	0	0
12	8	0	5	0	13	0	0	0	0	0
13	8	0	5	0	13	0	0	0	0	0
14	7	0	4	1	11	1	0.3636	0.6364	0.2314	0.2314
15	7	3	3	1	10	4	1.2000	2.8000	0.8400	0.5600
16	4	0	1	0	5	0	0	0	0	0
17	4	1	1	0	5	1	0.2000	0.8000	0.1600	0.1600
18	3	1	1	0	4	1	0.2500	0.7500	0.1875	0.1875
19	2	0	1	1	3	1	0.3333	0.6667	0.2222	0.2222
20	2	0	0	0	2	0	0	0	0	0
21	2	0	0	0	2	0	0	0	0	0
22	2	0	0	0	2	0	0	0	0	0
23	2	0	0	0	2	0	0	0	0	0
24	2	0	0	0	2	0	0	0	0	0
25	2	0	0	0	2	0	0	0	0	0
26	1	0	0	0	1	0	0	0	0	0
TOTAL		8		13		21	9.786	11.213	4.673	4.082

Period t = 30days

$E(d_{1i}) = d_i . r_{1i} / r_i$

$E(d_{0i}) = d_i . r_{0i} / r_i$

$var(d_{1i})^a = d_i . r_{1i} . r_{0i} / r_i^2$

$var(d_{1i})^b = d_i . r_{1i} . r_{0i} (r_i - d_i) / r_i^2 (r_i - 1)$

Table 2. An overall summary of the Fates of radio-collared ngwayir (*Pseudocheirus occidentalis*) within the K4 harvest coupe (treatment animals) and adjacent unharvested forest (control animals) within Kingston State Forest, Manjimup, Western Australia. (Treatment: n = 17, Control: n = 12; Note #17 and C04 included here but not included in survivorship analyses).

	Predation	Uncertain	Harvesting	Complicated	Fate Unknown
Treatment	41.2	17.6	11.8	5.9	23.5
Control	41.7	25.0	0.0	8.3	25.0

Fate Unknown
There were seven incidences where the fate of the individual remains unknown. Two cases (#05 and #C11) were due to radio-collar failure prior to the animal being successfully caught before the collar batteries expired. Another two possums (#15 and #C04), removed their radio-collars and also successfully evaded extensive attempts to be re-captured and re-collared. In the month prior to contact loss with possum #11, it had abandoned its territory during harvesting disturbance and had relocated within another harvest cell 750 metres from its original territory. Although its fate is unknown, it is possible that it may have died or been predated given that its health appeared substantially compromised in the month leading up to its disappearance. The remaining two individuals (#17 and #C07) for which their fate remains unknown involve circumstances where it is inconclusive as to whether the possums were predated or simply slipped their collar. No conclusive evidence of predation could be observed at the sites where the radio-collars were recovered. Similarly subsequent attempts to relocate the individuals by nocturnal spotlight surveys failed to locate them alive.

Uncertain Cause of Death
The post-mortems of three animals could not conclusively identify a cause of death and were therefore classified as 'Uncertain'. These individuals showed no signs of trauma that may have been sustained from predatory attack or harvesting activity. High parasite loads and occasional possible ulcerations in the stomach of some of these animals may be a contributing factor to their death and/or an indicator that these individuals were stressed. A fourth animal (#C12) was classified as 'Uncertain' given that although death was caused by trauma (subcutaneous bruising, particularly ventrally, thoracic haemorrhage and, collapsed and ruptured lungs), the reason for the trauma remains uncertain. The bruising was possibly caused by an impact (maybe a fall or vehicle), and there was no apparent evidence to provide further clues at the body site (a known Balga refuge).

Observed for two days short of three years, the cause of death of control possum C01 remains uncertain since only a few skeletal remains and the radio-collar were located a month after it had last been radio-tracked. The male was observed for the first 163 days within the western control area. It subsequently established itself a second territory (C01b), 4700m north and within a harvest cell that was logged and burned in 1996, where it remained until its death in April 2000. From February 1999, this possum was the last remaining study animal.

Harvesting
The cause of death for possum #16 remains uncertain although harvesting remains at least indirectly implicated. The individual was found dead eight days after the falling of the tree in which it was suspected to be refuged and whilst timber extraction within its territory was being completed. It can not be confirmed that the possum was in the refuge when it was fallen however the animal was found 22 metres from the tree within logging tops a couple of hours later when project staff arrived. The possum had been frequently using this refuge in the days leading to its falling, including the previous day. The post-mortem, however, could not detect any conclusive evidence of trauma or injury. The death of two of the 16 treatment animals known prior to disturbance, were witnessed by research staff as a direct result of harvesting when their refuge trees were fallen.

Opportunistic Possum Observations during Hollow Assessments of Felled 'Standing Tree' Refuges
An unmarked male Ngwayir survived apparently uninjured from the falling of one of the 'standing trees' (R41), and a total of four Koomal were found within other 'standing trees' fallen (R087, R088, R098, R123). Three of these escaped apparently uninjured another animal was killed directly.

Refuge Usage

Number of Refuges Used

During the main study period, February 1997 to June 1999, a total of 2626 refuge occupancy records were collected from the 12 control animals (1322 refuge observations) and 17 treatment animals (1304 refuge observations; Table 3). The occupancy records from the sole remaining radio-collared animal (C1) from June 1999 to April 2000 are not included here. Within the main study period, the observation periods for each individual ranged from 9 days to 727 days (mean 254 days, SD = 200.9) depending on their survivorship or our ability to remain in contact (ie.until lost contact). Given the regularity and standardised frequency by which refuge occupancy data was collected, the number of records for each individual is highly dependent on the observation period (r^2= 0.96, p= $4.1x10^{-20}$, n= 29). For each individual, the number of refuge occupancy records ranged from 2 to 227 (mean 90, SD = 60.8). On average, each individual was successfully radio-tracked to a refuge site 35% of the days within its observation period.

A total of 413 different refuges were observed being used by the experimental Ngwayir during the main study period. The number of different refuges used by each possum within its territory ranged from 2 to 35 (Table 3). For each individual the number of different refuges recorded is time and effort dependent (Figure 4, Table 4). No significant differences were detected with 95% confidence, between the Control and Impact or Before and After regression coefficients. The subsequent common regression equation for the treatment data has $\alpha = 2.666$ and β=0.04673. On the basis of these regression analyses a Ngwayir in the control and treatment study areas is predicted to use 20.0 and 19.7 different refuges per year (365 days) respectively. The 95% Confidence Intervals for the predicted number of refuges used by an individual annually using these regression coefficients are yet to be determined.

Refuge Types

Control Areas:

Significant differences existed between the two control areas with respect to the relative proportions of the different refuge types used by Ngwayir (Figure 5). There were significantly fewer 'standing trees' and significantly more 'above ground nests' and 'forest debris' in the western control area than in the eastern control area. 'Standing trees' were the most numerous type of refuge within the eastern control area (56%) and 'above ground nests' were the most common refuge type within the western control area (49%). Balga refuges were equally as common within both areas (35%). 'Burrow' refuge types were negligible and no 'hollow stumps' were recorded.

Treatment Area (K4 and K3):

No refuge information was collected prior to the road construction activities within K3 and K4. Standing trees constituted 65% of the refuges pre-harvesting; 'forest debris' (mainly from road construction) 19%, Balga 8% and 'above ground nests' 6% (Figure 6). Post-harvesting there was a significant decrease in the 'standing trees' (to 35%) and a significant increase in the number of forest debris refuges (44%). Slight but insignificant increases in Balga and above 'ground nest' refuge types were observed post-harvesting. Burrow and Hollow Stump refuge types were negligible. No refuge information was collected from any treatment animals post silvicultural burn since all animals had either died or contact had been lost prior to the burn.

Table 3. The number of refuge occupancy records collected for each of the 12 control and 17 treatment (pre- and post- harvesting) ngwayir at Kingston between Feb 1997 to June 1999.

Control Animals				
Animal No.	Sex	Observation Period (days)	No. Refuge Occupancy Records	Number of Different Refuges
C01a	Male	163	66	9
*C01b		637	148	34
C02	Male	84	35	10
C03	Female	93	40	8
C04	Male	13	4	2
C05	Male	430	158	25
C06	Female	377	138	24
C07	Male	727	227	30
C08	Male	365	133	22
C09	Female	365	128	7
C10	Male	173	59	20
C11	Male	235	77	18
C12	Female	305	109	14
Total		**3967**	**1322**	**223**
Average		**305.15**	**101.69**	**17.15**
SD		211.71	61.62	9.72

Treatment Animals							
		Pre-Harvesting			Post-Harvesting		
Animal No.	Sex	Observation Period Pre-Harvest (d)	No. Refuge Occupancy Records	Number of Different Refuges	Observation Period Post-Harvest (d)	No. Refuge Occupancy Records	Number of Different Refuges
1	Male	73	30	9	-	-	-
2	Female	146	68	7	287	102	7
3	Male	146	71	9	26	11	3
4	Female	9	2	2	-	-	-
**5	Female	43	7	5	-	-	-
6	Male	118	54	13	10	6	3
8	Male	103	49	10	75	39	11
9	Male	95	47	4	57	30	4
10	Female	39	17	2	-	-	-
11	Male	82	42	9	102	29	6
12	Female	47	23	4	5	2	1
13	Female	81	42	6	-	-	-
14	Female	44	21	5	294	111	28
15	Female	43	21	5	312	92	9
16	Male	-	-	-	25	8	5
17	Male	-	-	-	361	130	35
18	Male	39	1	1	442	123	14
Total		**1108**	**495**	**91**	**1996**	**683**	**126**
Average		**73.87**	**33.00**	**6.07**	**166.33**	**56.92**	**10.50**
SD		41.34	22.42	3.39	159.70	50.30	10.57

* C01b is the 2nd territory established by C01. This territory is outside the control area and within a gap release harvest cell (last disturbed Nov 1996).

** Animal #5 moved out of its original territory within 2 days of tree felling beginning in K4, about 200m away. It established a 2nd territory outside the treatment area where over a 326 day period, a further 126 refuge occupancy records involving 14 different refuges were collected (includes transitory refuges).

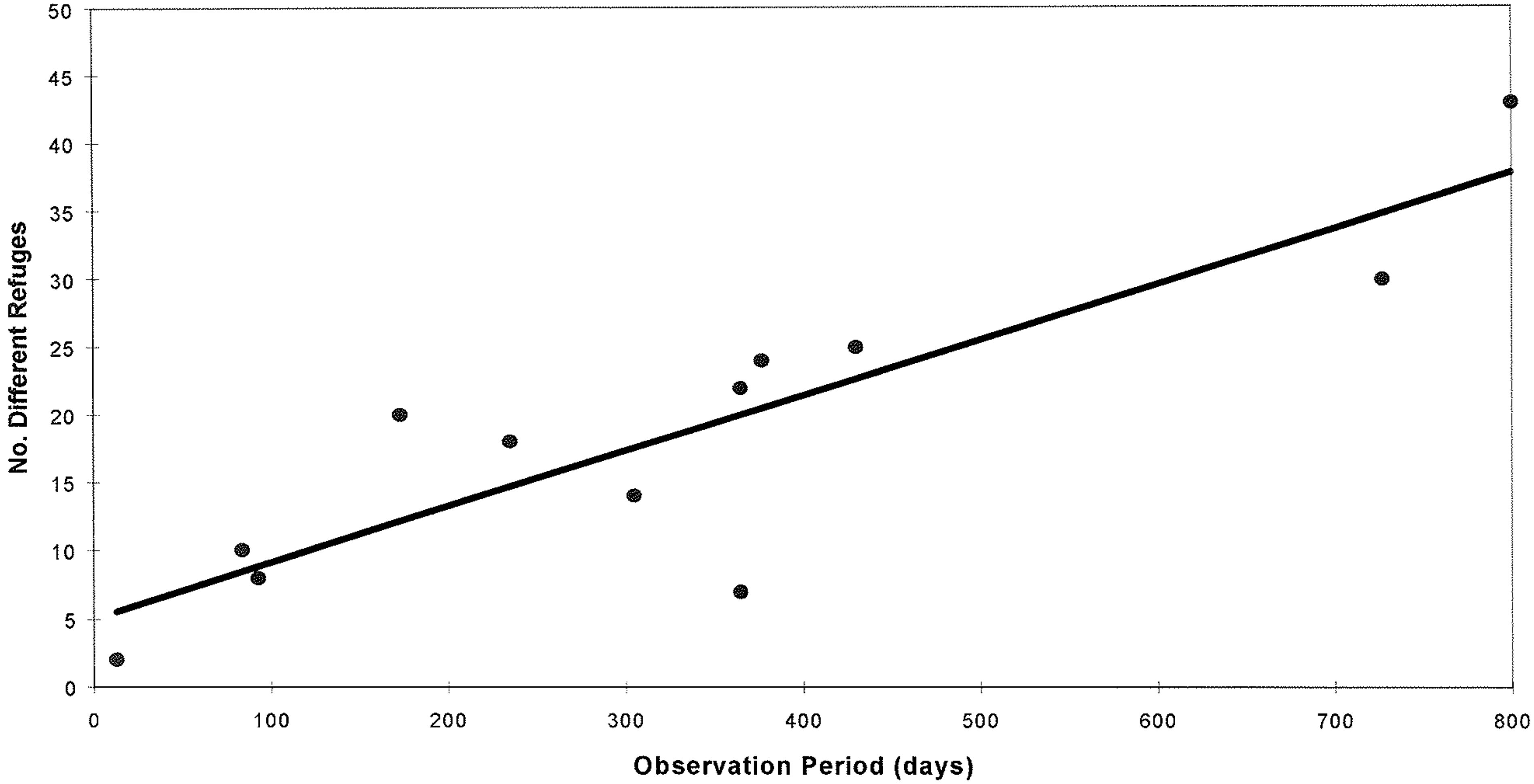


Figure 4. The number of different refuges used by each radio-collared ngwayir within the Kingston control areas, over time (y=5.023 + 0.041.x; r2=0.76, p=0.0002).

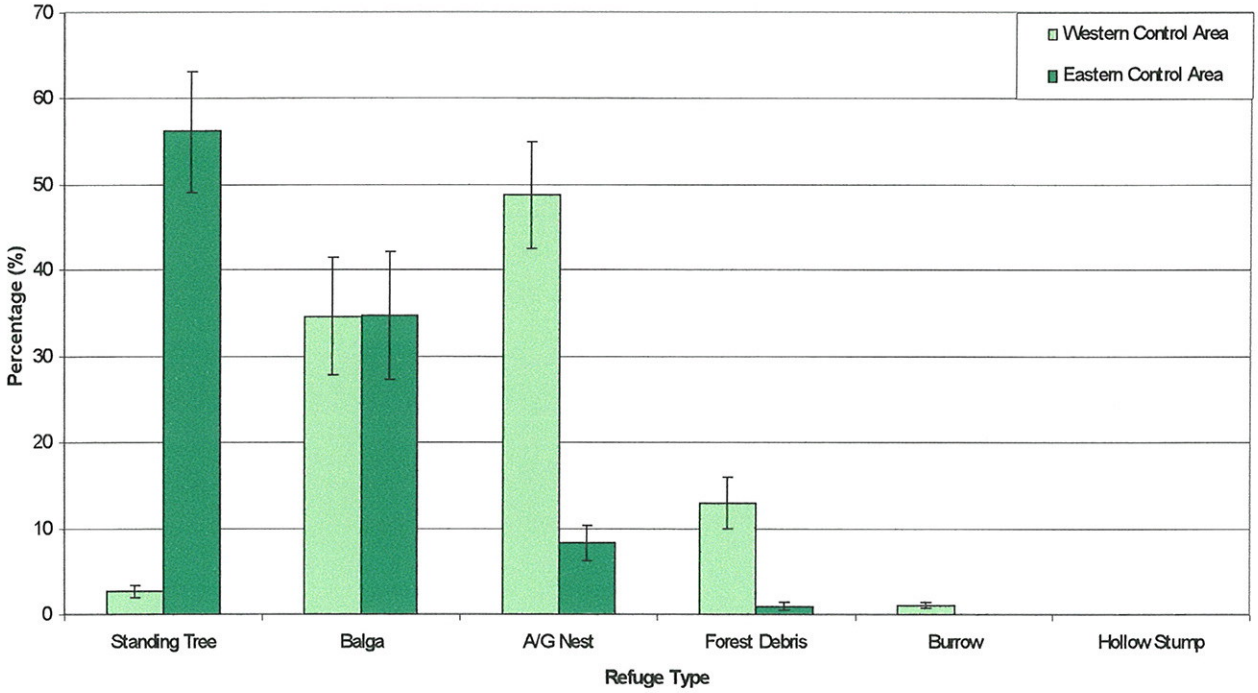


Figure 5. Ngwayir refuge types within the Kingston Western (7 individuals; n=108) and Eastern (5 individuals; n=81) Control Areas.

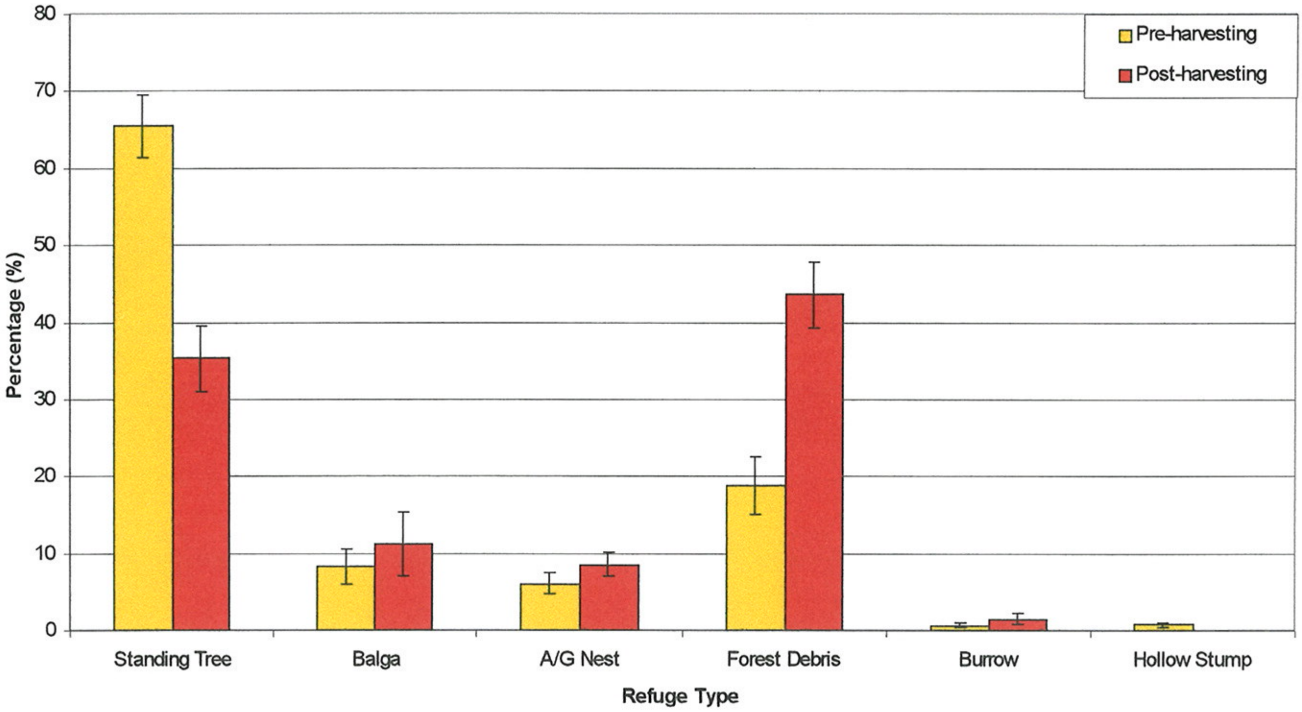


Figure 6. Ngwayir refuge types in Kingston 4, Pre- and Post- Harvesting (15 individuals; n=91 & 12 individuals; n=126 respectively).

Occupancy of Refuge Types

Control Areas:
Within the western control area, Balga and 'above ground nests' were the two most commonly occupied refuges (43% and 41% of the time respectively), whilst 'forest debris' and 'standing trees' were less frequently occupied (9% and 6% respectively; Figure 7). In contrast the 'standing tree' refuges were most commonly occupied (73%) in the eastern control area. Balga, 'above ground nests', and 'forest debris' were occupied significantly less than in the western control area (22%, 5% and 0.2% respectively). Except for Balga these results follow a similar trend to those observed for the 'Refuge Type' data.

Treatment Area:
'Standing trees' were occupied significantly less (from 69% to 51%) and 'forest debris' and 'above ground nests' were occupied significantly more (from 16% to 29%, and 4% to 10% respectively) after harvesting (Figure 8). Balga were occupied about 10% of the time pre- and post-harvesting. These results are similar to the 'Refuge Type' results.

The Frequency of Use of Different Refuges

The Frequency of Use of Each Refuge by Each Possum
In general, each Ngwayir used the majority of refuges less than 10% of the time. In most cases usually one, but occasionally two or three, refuges were used disproportionately more by a particular Ngwayir than others (Figures 9 & 10a, b, c). Possum 'C12' is an example of how typically within the control animals one refuge is used preferentially, constituting on average 32% of the occupations, whilst a few other refuges are used occasionally and most are used rarely (less than 5 times each). The most extreme example of this pattern is animal #9 pre-harvesting where out of four refuges and 47 occupancy records, it used one 'standing tree' (R020) 91% of the time. As the refuge occupancy sample sizes decrease this pattern of usage becomes less evident.

The Ratio between the Number of Different Refuges and Occupations for each Refuge Type.
The general relative value of different refuge types to Ngwayir was measured by dividing the average number of occupancy records by the average number different refuges for each refuge type for each possum cohort (Table 5a). Within the western and eastern control cohorts, 'standing trees' were the most frequently revisited refuge type; each 'standing tree' being used on average 10.7 and 9.0 times respectively. Balga were also extensively revisited within the western control area (8.5 times each) and to a lesser extent within the eastern control area (3.6 times each). Balga were the most revisited refuge type within the treatment area, both pre- and post- harvesting (8.8 and 11.1 times each respectively). The 'standing tree' refuges used by treatment Ngwayir were of secondary value in terms of their extent of their use (5.8 and 8.3 times each for pre- and post harvesting respectively).

It is worthy noting that this measure of relative importance is derived from cohorts with wide ranging differences in sample size. For example, for each Eastern Control Ngwayir an average of 101 occupancy records were recorded from an average of 16 different refuges. In comparison, treatment Ngwayir pre-harvesting had an analogous ratio of 33:6, approximately a third the sample size of the eastern control data set.

As a consequence, an alternative measure of the relative value of different refuge types can be derived from the ratio between occupancy and number of different refuges for each refuge type using the averages of *proportional* occupancy and type data, instead of absolute values (Table 5b). The results of this measure are relatively similar in expressing the general relative importance of 'standing trees' and Balga as a form of refuge when compared with the alternatives ('above ground nests', 'forest debris', 'burrows', and 'hollow stumps'). The rankings of importance do however differ between the two different measures for the treatment data. The most notable of these differences is within the post-harvesting data where 'standing trees' and 'above ground nests' are ranked higher than Balga.

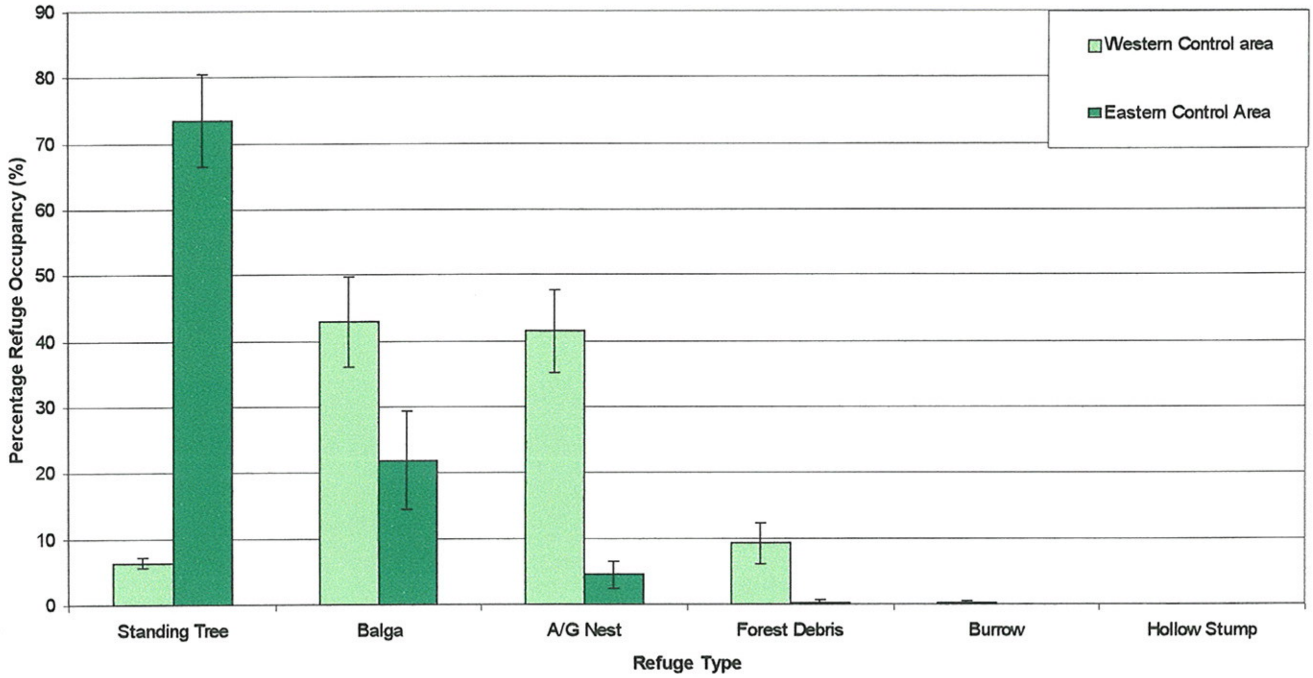


Figure 7. Ngwayir refuge occupancy within the Kingston Western (7 individuals; n=668), and Eastern (5 individuals; n=506) Control Areas.

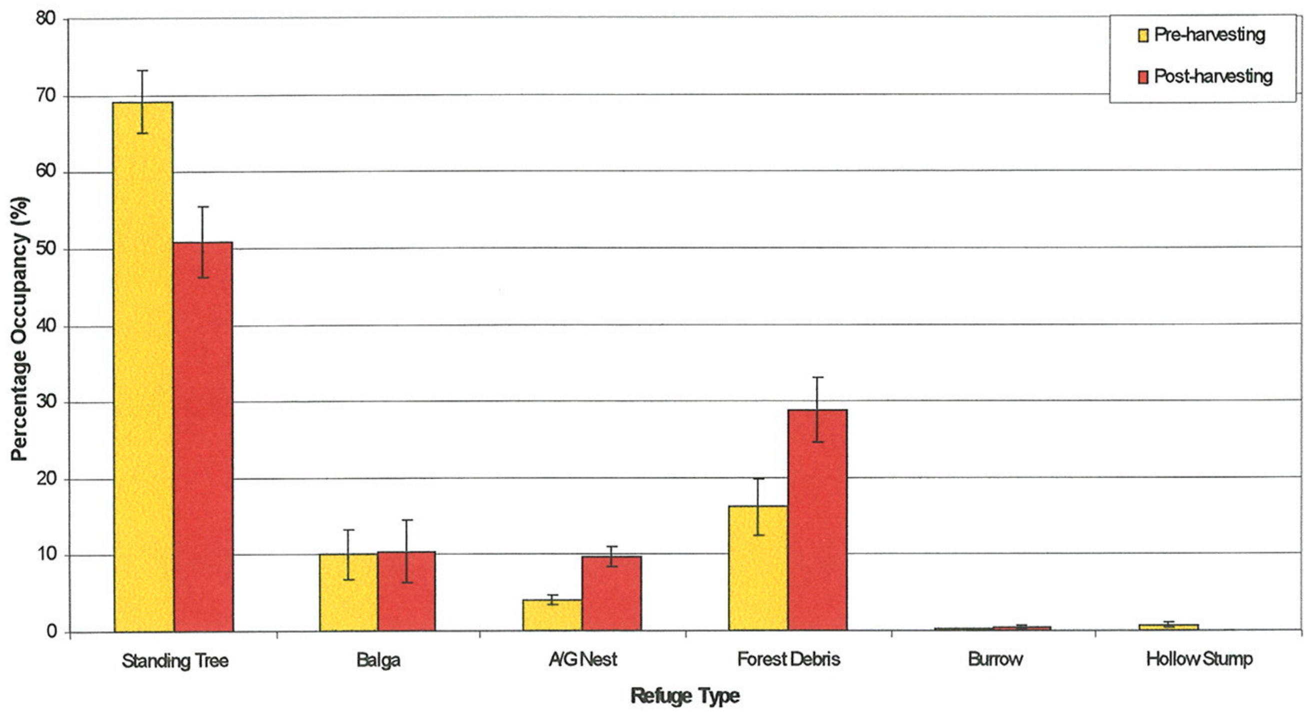


Figure 8. Ngwayir refuge occupancy in Kingston 4 Pre- and Post- Harvesting (15 individuals; n=495 & 12 individuals; n=683 respectively)

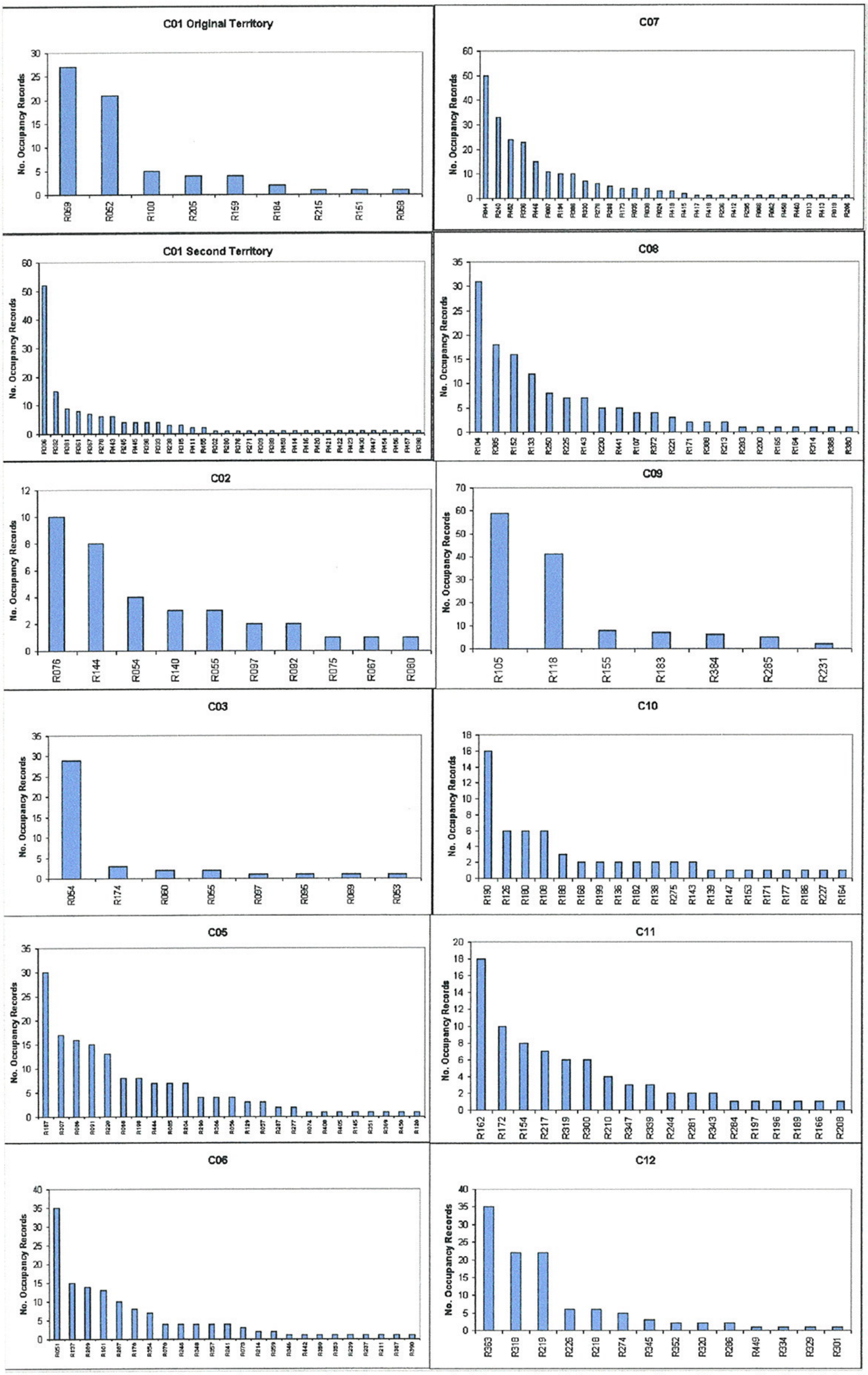


Figure 9. The prevalence of use of each refuge occupied by each of the ngwayir radio-tracked within the Kingston Western Control area (C01 - C07) and Kingston Eastern Control area (C8-C12). Note; Individuals with less than 6 occupancy records are not shown here.

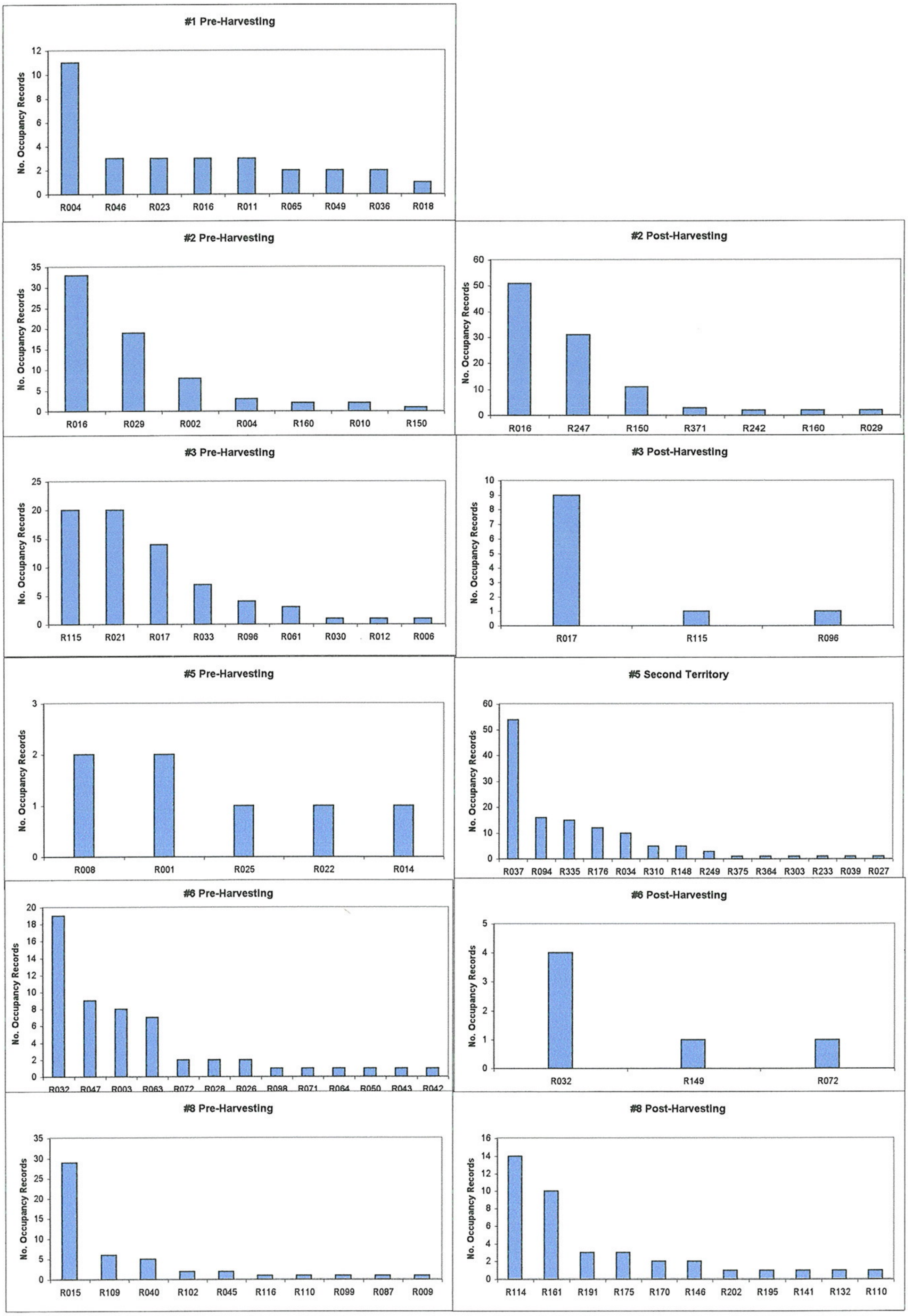


Figure 10a. The prevalence of use of each refuge occupied by each ngwayir radio-tracked within the Kingston 4 Harvest Coupe. Preharvest data is on the left and post-harvest data on the right. Note; Individuals with less than 6 occupancy records are not shown here.

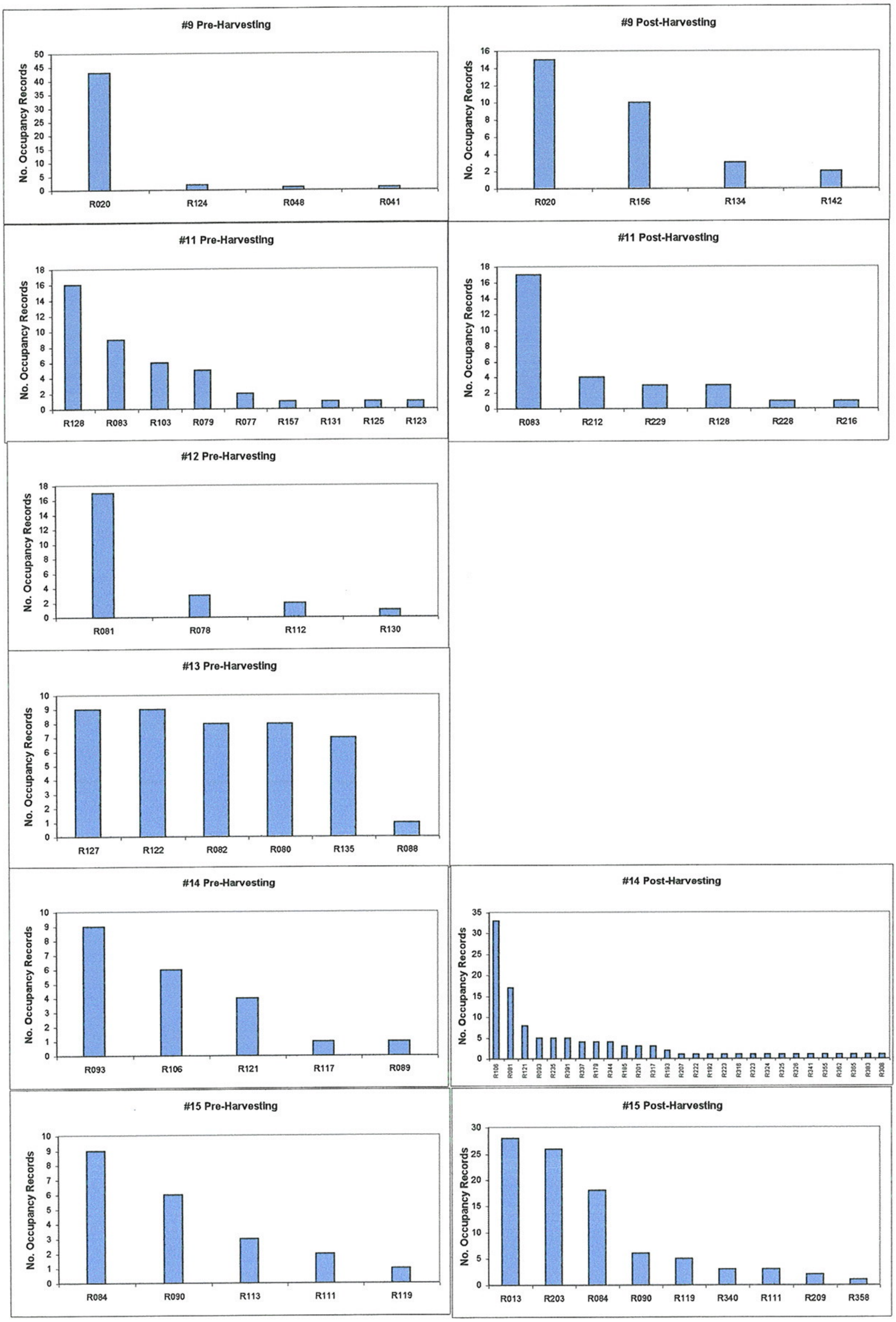


Figure 10b. The prevalence of use of each refuge occupied by each ngwayir radio-tracked within the Kingston 4 Harvest Coupe. Preharvest data is on the left and post-harvest data on the right. Note; Individuals with less than 6 occupancy records are not shown here.

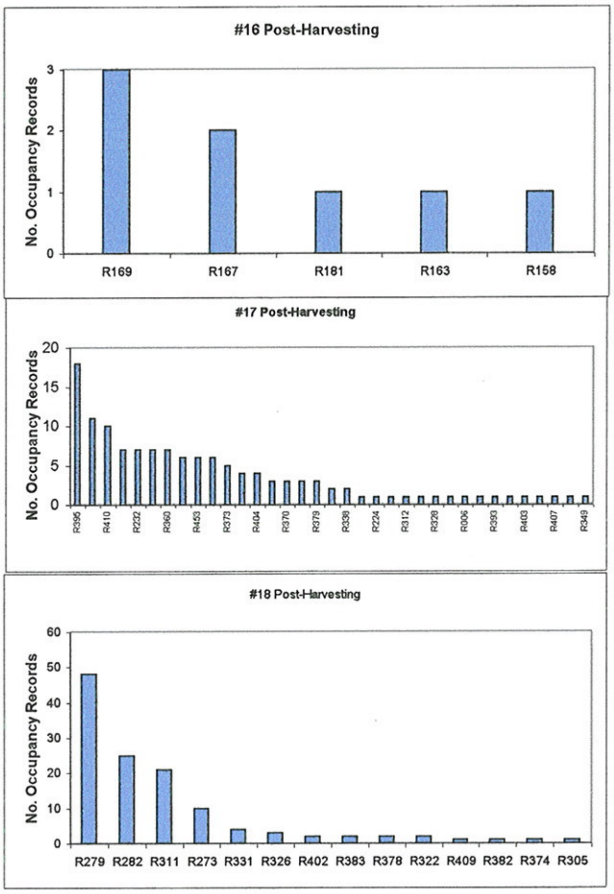


Figure 10c. The prevalence of use of each refuge occupied by each ngwayir radio-tracked within the Kingston 4 Harvest Coupe. Preharvest data is on the left and post-harvest data on the right. Note; Individuals with less than 6 occupancy records are not shown here.

Table 4. Statistics for the regression coefficients for the relationship between the number of different refuges used by ngwayir in Kingston and the observation period over which these records were made. Note: Control includes C01b; Post-harvest excludes #5b

Treatment	Sample (*n*)	R^2	*F*	Significance *F*	α, Y intercept	β, Slope
Control	12	0.760	31.694	0.00022	5.0228	0.04102
Pre-harvest	15	0.518	13.965	0.00249	1.7069	0.05902
Post-harvest	12	0.476	9.1009	0.01297	2.9007	0.04569

Table 5a. The average number of occupancy observations per refuge for the different treatment cohorts of ngwayir within Kingston (ie. average number of occupations divided by the average number of different refuges, for each refuge type for each treatment cohort).

	Standing Tree	**Balga**	**A/G Nest**	**Forest Debris**	**Burrow**	**Hollow Stump**
Western Control	10.67	8.54	3.22	3.11	1.00	-
Eastern Control	9.02	3.57	2.38	1.00	-	-
Pre-Harvesting	5.81	8.80	3.25	2.83	1.00	3.00
Post- Harvesting	8.26	11.10	4.36	3.86	1.00	3.00

Table 5b. A measure (refuge occupancy divided by the average proportional number of refuges) of the relative value of the different refuge types used by ngwayir for the different treatment cohorts within Kingston.

	Standing Tree	**Balga**	**A/G Nest**	**Forest Debris**	**Burrow**	**Hollow Stump**
Western Control	2.38	1.24	0.85	0.71	0.16	-
Eastern Control	1.31	0.63	0.55	0.17	-	-
Pre-Harvesting	1.06	1.21	0.66	0.86	0.20	0.90
Post- Harvesting	1.44	0.93	1.13	0.66	0.28	-

Table 6. The relative proportions (%) of each species of 'Standing Tree' used as daytime refuges by ngwayir for each of the treatment cohorts within Kingston. 'All Kingston' includes all 'standing tree' records during the study. The sum of the number of 'standing trees' does not equal 141 since several refuges are recorded within the Pre- and Post- Harvesting treatments. [Note C01b and #5b are the second territories for two individuals which moved out of their experimental areas]

	C. calophylla	**E. marginata**	**E. rudis**	**E. wandoo**	**No. Standing Trees**
Control	29.55%	47.73%	2.27%	20.45%	44
Pre-Harvesting	66.07%	30.36%		3.57%	56
Post-Harvesting	57.14%	34.29%		8.57%	35
C01b		100.00%			7
#5b	58.33%	41.67%			12
All Kingston	48.23%	41.84%	0.71%	9.22%	141

Gross Characteristics of Refuge Types

Standing Trees
Of the 141 'standing trees' used by Ngwayir within Kingston, 48% were *Corymbia calophylla*, 42% *Eucalyptus marginata*, 9% *Eucalyptus wandoo*, and 1% *Eucalyptus rudis* (Table 6). *E. marginata* was more commonly used in the control areas than *C. calophylla*, whereas the opposite was true for the treatment area (Kingston 4). The relative proportion of standing trees by species did not change substantially pre- and post-harvesting other than a relative increase in *E. wandoo*.

Figure 11 shows the height, DBH and senescence distributions of 'standing trees' for the control, pre-harvest and post-harvest treatments. Within the control areas the majority of *C. calophylla* and *E. marginata* were greater than 15 metres in height (85% and 76%% respectively), greater than 70cm DBH (61.5% and 52.4% respectively) and had a senescence score between six and nine (77% and 67% respectively). Similar trends were observed within the treatment area pre- and post- harvesting.

Balga
A total of 101 Balga were used by Ngwayir during the study at Kingston, 84 of which were from the control areas. Notably, 82% of Balga were greater than 2 metres in height, 94% had two or more heads and 72% had skirts greater than 1 metre long (Figure 12).

Above Ground Nests
Of the 87 'above ground nests' catalogued, 40 of them were from animals within the control areas (principally the western control area). A further 27 were used by control animal 'C01' within its second territory that was established outside the control area and within a 1996 gap release harvest cell. Two thirds of this refuge type had clear evidence of nest construction. The remaining third were typically roost sites amongst dense foliage (dead or alive), and occasionally were little more than the forks of limbs or other highly exposed sites. 'Above Ground Nests' were observed in eight species; *E. marginata* (45%%), *C. calophylla* (31%), *Melaleuca incana* (17%), *Sollya heterophylla* (2%), *E. rudis* (1%), *Hardenbergia comptoniana* (1%), *Leucopogon propinquus* (1%), and *Persoonia longifolia* (1%). Dreys were the most common form of 'above ground nest' (74%), and similar to the other forms of this refuge type, their number increased slightly within the treatment area post-harvesting (Figure 13 i and ii).

Forest Debris
The majority of the 79 forest debris refuges were observed post disturbance within the treatment area (78%). Most forest debris refuges originated from the harvesting process (72%). Refuges in debris piled up after road construction were used to some extent (18%) in the treatment area both pre- and post- harvesting. Refuges within naturally created debris were rare (6%). The three 'forest debris' refuges classified as 'other' were refuges within a small space between the ground and leaf or trash obstructed by either a dense bush or small log. The use of 'forest debris' as a form of refuge by Ngwayir within the control areas was uncommon (11%; Figure 13 iii). Logging tops used by control animals occurred when the private pine plantation adjacent to the western control area was thinned.

Burrows
Only four burrows were observed to be used by Ngwayir. Of these, the same treatment animal (#08) used two. The only repeated use of a burrow was recorded from this individual and from a burrow (R110) created by a root cavity within an old natural stump that had been largely destroyed by fire. The other burrow (R132) used by this individual was also created by fire alongside a log, creating a one-metre cavity between the remaining log and adjacent soil. Two eastern control animals (C07 and C06) used the other two burrow refuges (R295, R350). Their respective occupier recorded the uses of both only once and both were created by root cavities within burnt out stumps.

Hollow Stumps
Only one hollow stump (R046) was recorded being used by Ngwayir as a form of daytime refuge. It was the stump (127cm diameter, 70cm high) of a jarrah tree felled during a previous harvest operation more than two decades ago. The centre of the stump had been hollowed by decay (internal diameter 62cm) and the treatment animal (#01) refuged within a 30cm deep root cavity within the stump on at least three occasions during the same pre-harvesting month (April 1997).

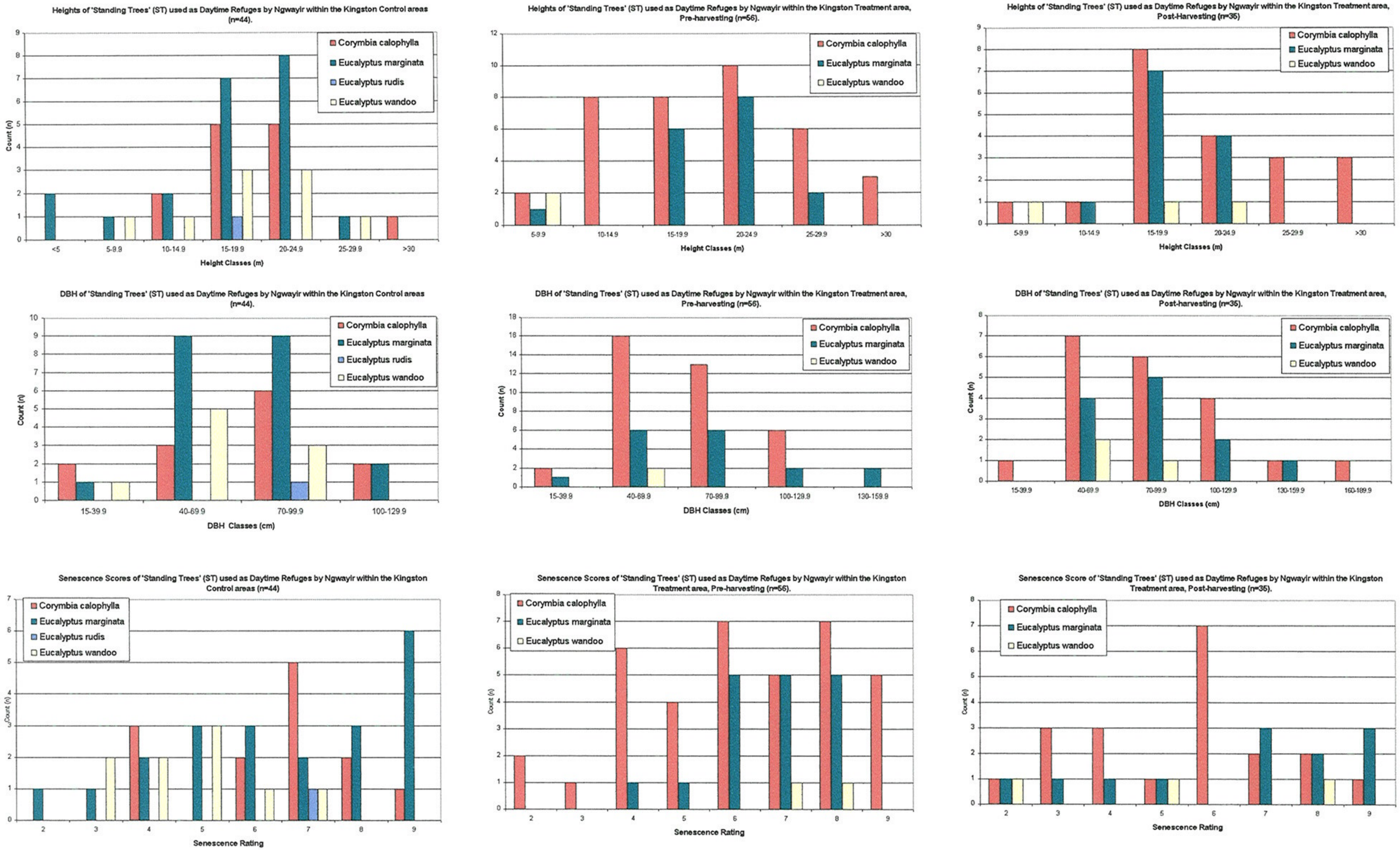


Figure 11. The characteristics of the 'Standing Tress' (ST) used by Ngwayir within the Control and Treatment (Pre- & Post- Harvesting) areas of Kingston: i. Tree Height, ii. DBH, iii. Senescence rating.

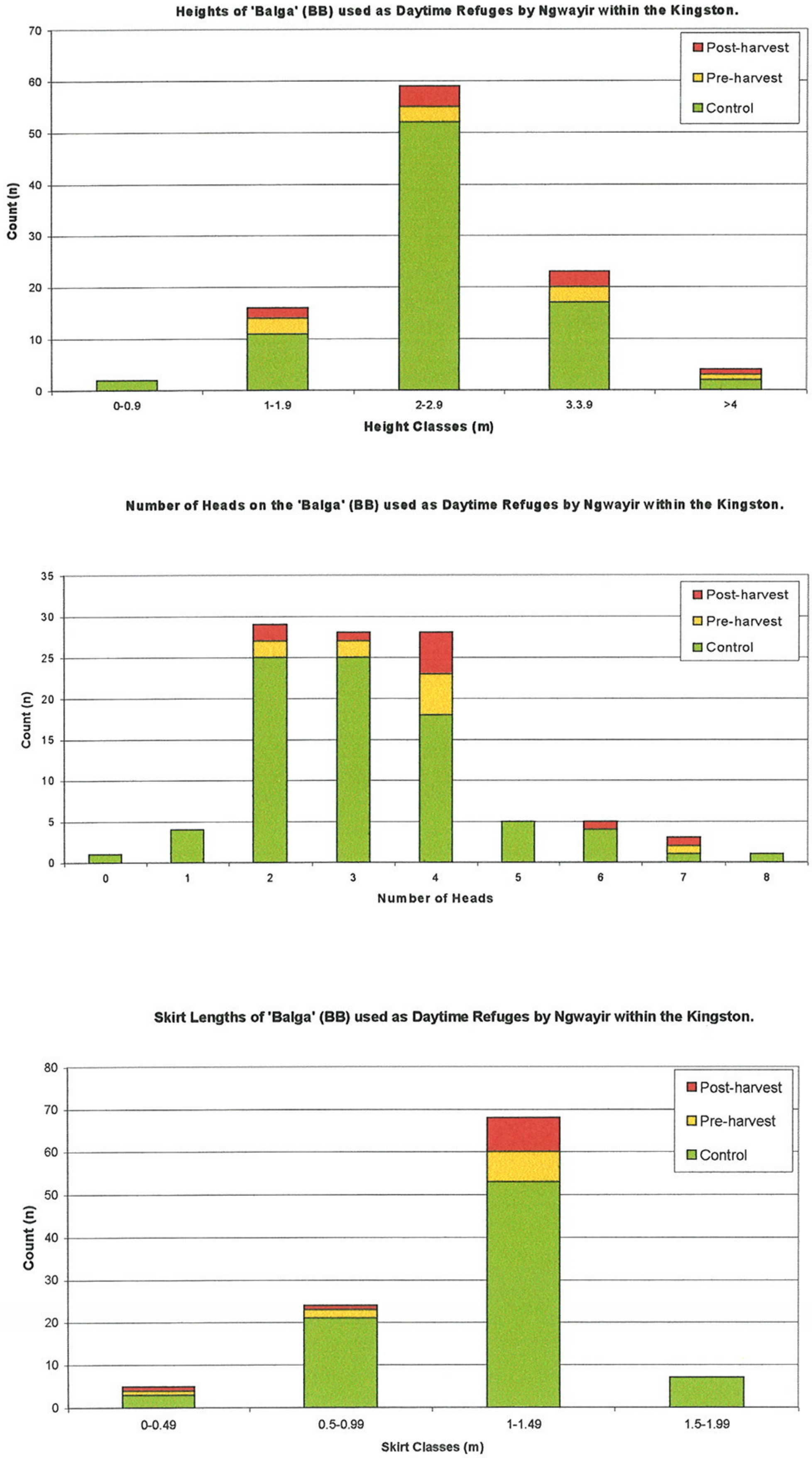
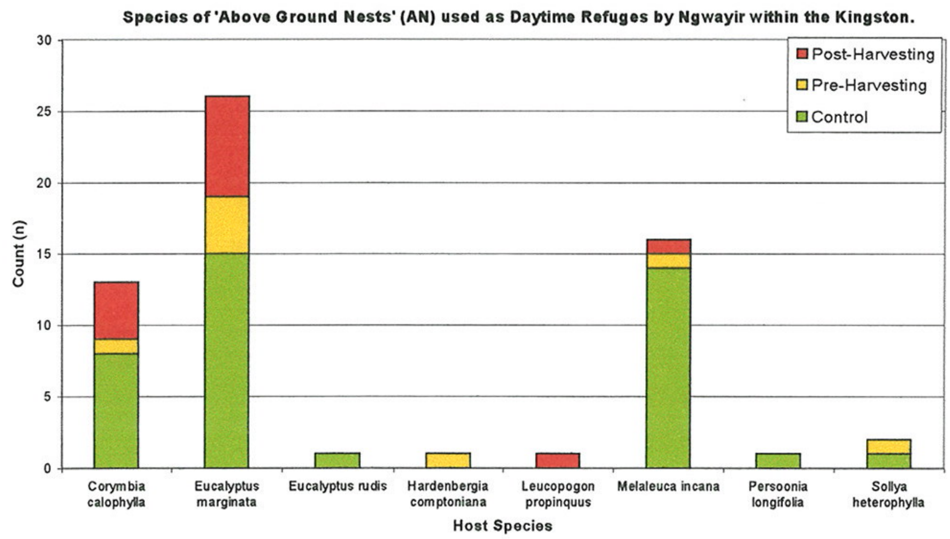
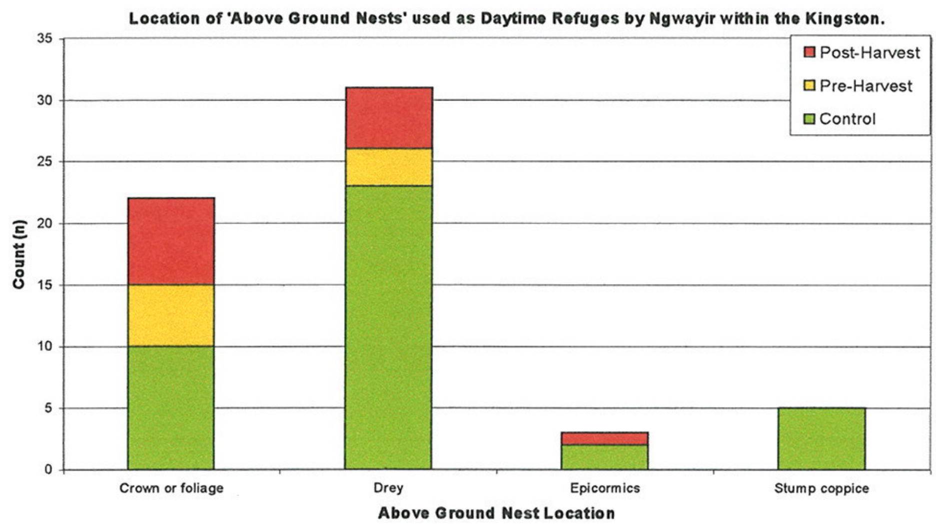


Figure 12. Characteristics of the Balga (BB) used by Ngwayir within the Control and Treatment (Pre- & Post- Harvesting) areas of Kingston: i. Balga Height, ii. Number of Heads, iii. Dead Leaf Skirt Length.





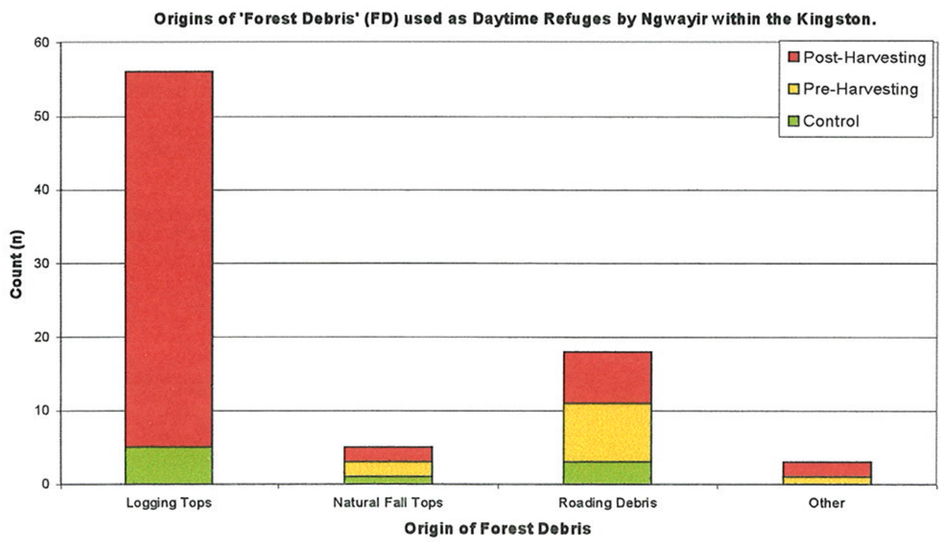


Figure 13. (i.) Species and (ii.)Type of 'Above Ground Nests' (AN) and (iii.) 'Forest Debris' (FD) Origins Used by Ngawyir within the Control and Treatment (Pre- and Post- Harvesting) areas of Kingston.

Characteristics of Refuges in Relation to their Extent of Use

Of particular interest are the traits of preferred refuges used disproportionately more than others. Linear regression analyses were used to examine whether there were any relationships between the frequency by which a refuge was used by an individual (using proportional occupation data) and the characteristics of that refuge. Many of the most frequently used refuges are 'standing trees' and Balga, however, some 'above ground nests' and 'forest debris' refuges were also used extensively.

Standing Trees
Overall, known refuges with larger diameters at breast height were more likely to be used more frequently (Figure 14 i.). Tree diameter, however, could only explain 13% of the variance observed in standing tree frequency of use. The variance explained by diameter was marginally better within the pre- and post-harvest treatments (16% and 24% respectively). No significant corresponding relationship could be found within the two control cohorts. No other significant linear regression relationships were found with the other 'standing tree' specific characteristics measured, when analysed within each treatment or with all 'standing tree' data combined.

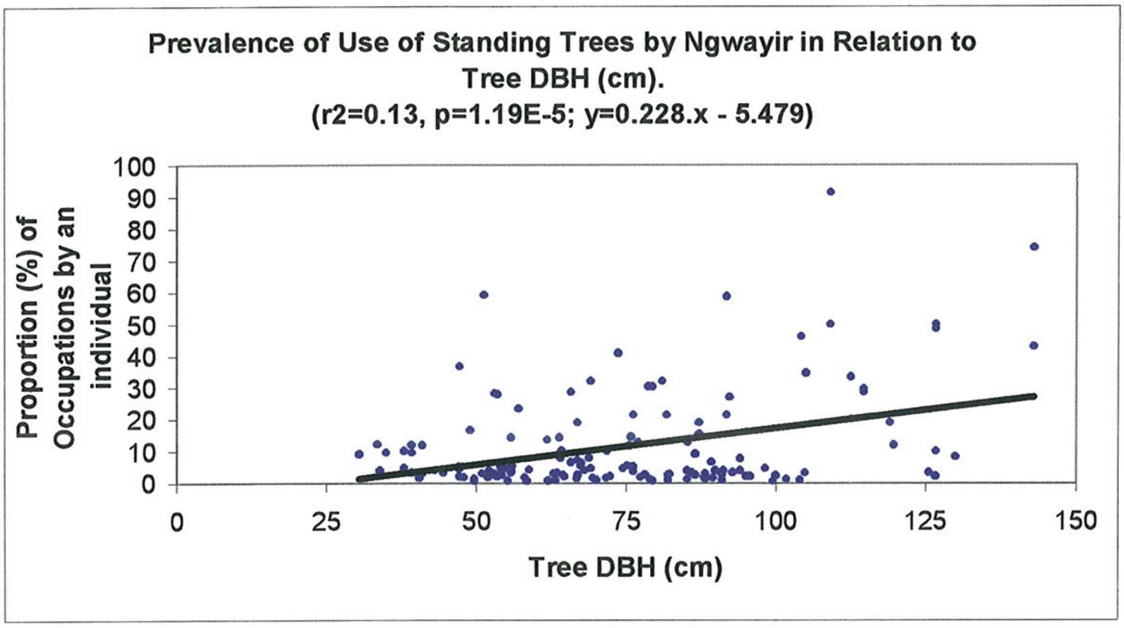
Balga
Balga with more heads were used significantly more within Kingston (Figure 14 ii.), however the extent of usage variance explained was extremely low ($p= 0.0059$, $r^2 =0.07$). Within the eastern control area, Balga with larger diameters at 30cm above ground were used significantly more ($r^2=0.19$, $p=0.0130$; $y=.450.x - 9.649$). No other significant linear regression relationships were found between the Balga traits measured and the relative extent of occupancy.

Analyses yet to be conducted include testing whether there are relationships between the relative extent of use and i) refuge type and species, ii) above ground nest characteristics, iii) forest debris characteristics, iv) associated vegetation, v) position in landscape, and vi) spatial distribution. Multivariate analyses using an array of refuge variables may also be useful here.

Extent of Refuge Sharing

There were 15 refuges that were observed being used by two different radio-collared animals, and one refuge that was used by three study animals (Table 7). Many of these refuges were 'standing trees' (seven), although 'above ground nests', Balga, and 'forest debris' were also used by more than one individual. Four refuges (three ST and one BB) were shared simultaneously by a pair of individuals of opposite sex. In the case of refuge R020, mother (#10) and sub-adult son (#09) were observed sharing on seven different occasions before the mother was predated. The remaining three refuges shared simultaneously had only one observation of co-occupancy each and were all between adults. Female #02 was observed sharing with two different males (#01 and #17), nine months apart and after the first male had died.

Multiple users were observed using four different refuges within the same time period. In the remaining eight circumstances observed usage was discrete and successive (ie. all occupations by one individual of a particular refuge were observed before the occupation observations of the second animal). These refuge-sharing observations are expected to considerably under estimate the extent of refuge sharing (both simultaneous and successive) conducted by Ngwayir. This is as a result of not all individuals within the territories of the experimental animals being radio-collared. This is evident from night time observations of radio-collared animals in close association with non-experimental animals (pers obs) and the detection of an unmarked male Ngwayir within a known 'standing tree' refuge during the harvesting activities and hollow assessment surveys. The extent of refuge sharing between Ngwayir and Koomal is also evident from the hollow assessment surveys but its extent is unknown.



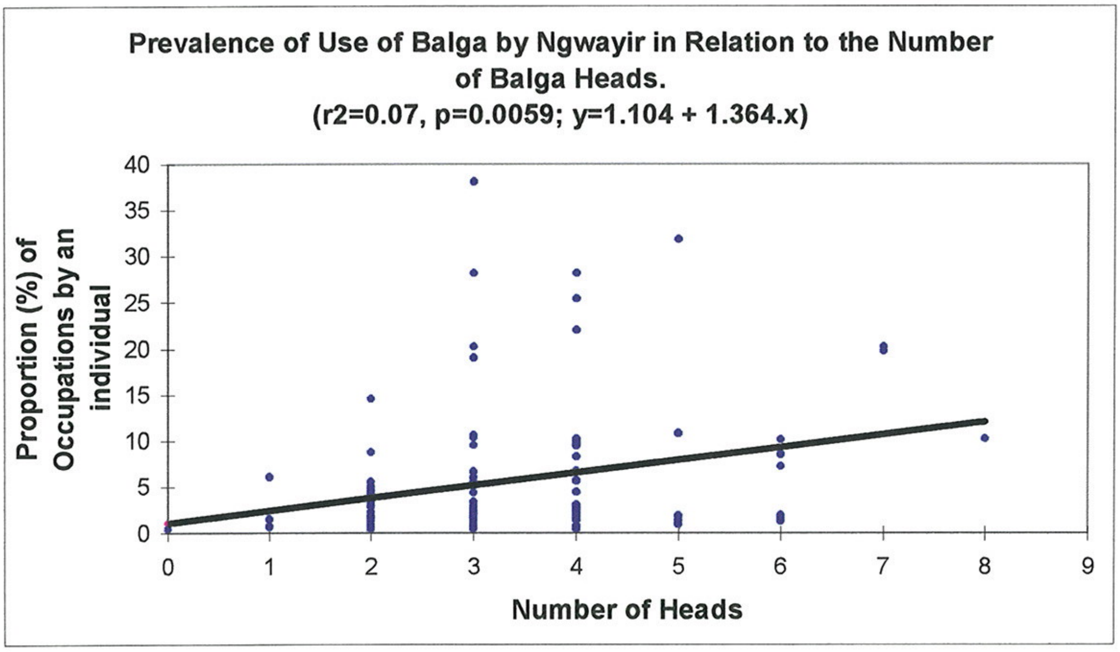


Figure 14. Plots of the proportional occupation by individual Ngwayir of refuges in relation to significant explanatory refuge characteristic variables;
i. Diameter at Breast Height (DBH) for 'Standing Tree' (ST) refuges and,
ii. Number of heads on Balga (BB).

Table 7. Refuges recorded with multiple users and observation of simultaneous refuge sharing. Note that circumstances which are associated with '*' are occasions when there was no simultaneous sharing but usage was not temporally exclusive by each possum (ie there was alternate use within the same time period).

Refuge Number	Refuge Type	Possum Number	Sex	Number of Occupations	No. of Simultaneously Shared Occupations
R006	ST	#3	Male	1	
		#17	Male	1	
R013	ST	#4	Female	1	
		#15	Female	28	
R016	ST	#1	Male	3	1
		#2	Female	84	
R020	ST	#9	Male	58	7
		#10	Female	8	
R053	AN	C3	Female	1	*
		C4	Male	3	
R054	AN	C2	Male	4	*
		C3	Female	27	
		C4	Male	1	
R055	AN	C2	Male	3	
		C3	Female	2	
R060	AN	C2	Male	1	
		C3	Female	2	
R081	ST	#12	Female	19	
		#14	Female	17	
R097	FD	C2	Male	2	*
		C3	Female	1	
R143	ST	C8	Male	7	
		C10	Male	2	
R164	BB	C8	Male	1	
		C10	Male	1	
R171	BB	C8	Male	1	
		C10	Male	2	
R247	ST	#2	Female	31	1
		#17	Male	1	
R287	BB	C5	Male	2	1
		C6	Female	10	
R383	FD	#14	Female	2	*
		#18	Male	1	

Home-Ranges and Movement Patterns

Homeranges
A preliminary examination of the home ranges of the experimental Ngwayir has been undertaken using minimum convex polygon algorithms on the refuge location data (Table 8). These estimates use incomplete and partially validated data. For individuals with more than 20 occupancy records, refuge ranges vary from 0.2 to 11.1 hectares each. The average refuge range estimates for the treatment, western control and eastern control cohorts were 2.6, 1.1 and 6.1 hectares respectively. For individuals with more than 100 refuge occupancy records, the refuges to range ratio (Σ No. Refuges / Σ Home Range) is 7.7 refuges per hectare, the average refuge range size is 2.7 hectares and an average of 11.4 refuges per hectare are used by an individual (median = 10.3 refuges/ha). These estimates will be refined in the near future and with the assistance of the Arcview 3.1 based software Program that Jane Lawley (MSc Student, Curtin) has recently completed.

Additional analyses that will be conducted include;

i) exploring alternative home range algorithms and identifying the most appropriate for this data,
ii) a determination of the relationship between the refuge range estimate and the sample effort,
iii) identify what is the minimum sample size required to obtain a reliable refuge range estimate,
iv) to distinguish core refuge ranges from total refuge ranges,
v) investigate whether there are differences in home range between experimental areas, habitat and treatment pre- and post- disturbance.
vi) to examine any gender differences in range size, and
vii) quantifying to what extent refuge ranges overlap between individuals in close proximity.

Movement Patterns
Currently no detailed investigation of the movement patterns of the experimental Ngwayir has been conducted.

Table 8. Preliminary refuge range (hectares) estimates (minimum convex polygon) for the 17 treatment (1-6, 8-18) and 12 control (C01 – C12) Ngwayir at Kingston. Note that the numbers of refuges per hectare are omitted for individuals with less than 20 occupancy records. Data for C01b does not include data after June 1999. All data remains to be thoroughly validated.

Animal No.	Sex	No. Refuge Occupancy Records	Number of Different Refuges	Home Range (ha)	Number of Refuges per Hectare	Home Range Overlap (ha)
1	M	30	9	1.983	4.54	P01 - P02 **0.480**
2	F	170	10	0.733	13.64	P02 - P01 **0.480**
3	M	82	9	3.759	2.39	P03 - P17 **0.801**
4	F	2	2	N/A	-	
5a	F	7	4	0.489	-	
5b		126	15	1.481	9.45	
6	M	60	14	5.372	2.61	P06 - P16 **0.032**
8	M	88	20	2.702	7.40	
9	M	77	8	1.367	5.12	
10	F	17	2	N/A	-	
11	M	71	13	2.588	1.61	
12	F	25	4	0.745	5.37	P12 - P14 **0.218**; P12 - P18 **0.707**; P12 - P14 - P18 **0.216**
13	F	42	6	1.185	5.06	
14	F	132	30	4.097	7.32	P14 - P12 **0.218**; P14 - P18 **1.293**; P14 - P12 - P18 **0.216**
15	F	113	10	0.446	22.42	
16	M	8	5	0.178	-	P16 - P06 **0.032**
17	M	130	35	7.509	4.66	P17 - P03 **0.801**
18	M	124	14	2.779	5.04	P18 - P12 **0.707**; P18 - P14 **1.293**; P18 - P14 - P12 **0.216**
C01a	M	66	9	0.302	29.80	
C01b		148	34	2.42	14.05	
C02	M	35	10	0.901	11.10	C02 - C03 **0.181**
C03	F	40	8	0.182	43.96	C03 - C02 **0.181**
C04	M	4	2	N/A	-	
C05	M	158	24	1.177	21.24	C05 - C06 **0.046**
C06	F	138	24	2.338	10.27	C06 - C05 **0.046**
C07	M	227	30	1.486	20.19	
C08	M	133	22	7.371	2.98	C08 - C10 **0.466**; C08 - C11 **0.248**; C08 - C10 - C11 **N/A**
C09	F	128	7	0.584	11.99	
C10	M	59	20	8.758	2.28	C10 - C08 **0.466**; C10 - C11 **0.242**; C10 - C08 - C11 **N/A**
C11	M	77	18	11.077	0.77	C11 - C08 **0.248**; C11 - C10 **0.242**; C11 - C10 - C08 **N/A**
C12	F	109	14	2.521	5.55	

DISCUSSION POINTS

Experimental Animals

- Analyses of the morphological statistics remain to be done. There are plans to determine whether animal condition was affected by the seasons or harvesting activities. Similarly reproductive patterns and pouch young development are yet to be examined.

Survivorship

- This study has only examined the impacts of the harvesting and extraction process and to a small and incomplete extent the JSI (jarrah stand improvement) treatment. This study did not examine the impacts of road construction and the silvicultural burn treatments, both of which have the potential to have significant impacts on Ngwayir populations and their viability.
- There is a significant increase in mortality during and immediately after harvesting disturbance within the territories of Ngwayir. Those individuals that survive this period probably have an improved survivorship expectation, something closer to that expected for the controls.
- The small sample sizes for the treatment and control cohorts are not sufficiently large enough to detect any survivorship differences less than about 40%. Larger sample sizes would be required to increase the sensitivity of the survivorship analyses (Cochran and Cox 1957).
- There was no evidence to suggest that the radio-collars substantially reduced the fitness or the survivorship of experimental animals. Therefore satisfying one of the principal assumptions of Kaplan-Meier survivorship estimator (Kaplan and Meier 1958).
- The majority of deaths of experimental animals were observed in June-August 1997, and April 1998 to July 1998. Although these have not been analysed, factors responsible for these Autumn-Winter trends are expected to include; seasonal fox activity (ie. sub-adult dispersal), time since last aerial fox bait, and the impacts of timber harvesting within the ranges of most treatment animals (June-August 1997).

Fate of Experimental Animals

- Evidence collected at the body sites (markings on collars and bones, hair, scats, etc) are yet to be fully studied in detail to provide additional predator specific information.
- Although #16 was classified as Fate 'Uncertain' it is highly likely that the death can be attributed to harvesting. Harvesting was therefore directly responsible for 11.8 to 17.6% of the treatment animals.
- Increased rates of predation, during and immediately after disturbance, were an impact of logging. Although a similar proportion of animals ultimately died from predation, the survivorship expectation of animals within the treatment area may be about 40% less than the survivorship expectation of control animals. The significantly shorter life expectancy will have negative implications on the reproduction of individuals and future recruitment potential of populations. The generally short life span of this species and their innately conservative fecundity further exacerbate this problem.
- The number of cases of Fate 'Unknown' was high despite considerable effort to monitor and recapture animals and radio-collars. Improving techniques of capture need to be explored in order to improve the chances of recapturing experimental animals for recollaring and thus reduce the long and inefficient efforts currently used. This is difficult given the evasive 'nature of the beast'. More intensive radio-tracking efforts may also detect early signs of collar failure or enable more immediate responsive action when required (e.g. collar slipped and animal may still be nearby).

The Number of Refuges Used

- The number of different refuges used by each Ngwayir did not differ between treatment and control areas and the number of different refuges used before and after harvesting did not differ. In other words, the number of refuges doesn't change as a result of logging but the types of refuges do. Therefore there is the potential for the quality or suitability of the refuges to change also.
- Ngwayir at Kingston use about 20 different refuges each annually. This will be an underestimate of the actual number since observations were made on average only 35% of days within the observation periods. The underestimate is expected to bias against the more rarely used refuges that have a higher probability of remaining undetected.
- The number of refuges used per year overestimates the number of refuges needed as a minimum to support an individual. The minimum requirements would be expected to vary between areas and in accordance with habitat quality, climate, competition and other biological and physical factors. A specific and detailed study would be required to determine this relationship.

- The number of refuges used per year underestimates the number of refuges used by an individual in a lifetime. It is not appropriate to extrapolate the existing data beyond the period of observation since it might be expected that the relationship between time and number of refuges used is nonlinear.
- If refuge resources are limiting, the relationship between the number of different refuges used and time is expected to be non-linear over the lifetime of an individual. If an individual remains within the same territory then Ngwayir ecology and behaviour, the distribution of refuges, the life span and recruitment of suitable refuges (such as post fire balga skirts and hollow formation), and the ability to construct dreys are factors that will affect this relationship.
- It is important to understand how Ngwayir respond to the loss of refuges, such as 'forest debris', 'above ground nests', and Balga as a result of the silvicultural burn.
- Sexual difference in the number of refuges used, the types used and the occupancy patterns are yet to be investigated. Similarly seasonal differences need to be examined to explain and understand observed variability.

Types and Occupancy of Refuges Used
- Significant differences exist in the relative proportions of different refuge types used and extent of occupancy by individuals and cohorts within and between treatment areas.
- This study did not measure how refuge usage related to available habitat resources and/or refuge competition with other species such as Common Brushtail Possums (Koomal). By studying these factors it would be possible to determine the Ngwayir refuge preferences and habitat selection and thus provide valuable information for the conservation management of this species.
- It is still possible to get some measure of the physical (but not the biological; e.g. competition) abundance of refuge resources available to the experimental Ngwayir within the control areas given that there has been little physical disturbance to these areas. This could be used to measure the relative importance of different refuge types and explore the differences in refuge usage between individuals.
- The relative proportions of the number of refuges that were used both pre- and post-harvesting are yet to be determined. The number and condition of pre-harvesting refuges that survived harvesting and the silvicultural burn was not quantified.
- The extensive use of Balga by Ngwayir has not to our knowledge been previously reported. There have, however, been observations of Ngwayir refuging on the ground under the skirts of small Balga in Yalgorup and Lane Poole Reserve (de Tores pers com) and Gilbert noted (1843? Manuscript, Natural History Museum Library, London) that it "does not confine itself to the hollows of growing or standing trees, but is often found in holes in the ground or hollow stumps".
- In future, refinement in the definition of 'above ground nests' in relation to the distinctions between dreys and 'crown or foliage' should avoid confusion and ensure discrete classifications.

The Frequency of use of Each Refuge by Each Possum
- Generally most refuges were used rarely and one or two refuges were used disproportionately more than the others.
- On the basis of observations of the one subadult radio-collared (#09), this pattern may moderate with age. The vast majority of time (91%) by this individual was spent within one refuge. It is possible that this was the maternity hollow in which it spent most of its developmental life. An examination of other experimental animals with dependent young needs to be conducted to explore whether there are specific maternity refuges (as proposed by the 1996 correspondence of Barbara Jones).

The Ratio between the Number of Different Refuges and Occupations for each Refuge Type
- Quantifying the relative value of different refuge types can be helpful to management in prioritising habitat that needs to be protected for Ngwayir refuges.
- Preliminary analyses demonstrate that 'standing trees' Balga and 'above ground nests' are generally relatively more important refuge types than 'forest debris', 'burrows', and 'hollow stumps'.
- Careful consideration needs to be exercised when determining what is the most appropriate measure to examine the relative importance of different refuge types. That refuge type ranking differs between the two similar approaches used in Table 5a and b emphasises this point.

Gross Characteristics of Refuge Types

- The majority of 'standing trees' were jarrah or marri and tended to be larger than 15 metres in height, have a DBH greater than 70cm, and a senescence scale between six and nine. Balga refuges tended to be greater than two metres in height, multi headed and with leaf skirts greater than one metre in length (ie old and long unburnt). Most 'above ground nests' were located within jarrah, marri, or *Melaleuca incana*, and were typically dreys or within the crown or foliage of the host. The majority of 'forest debris' refuges were observed being used by treatment animals post- harvesting. Debris created by the harvesting activity was the most common form of debris used and available. The four 'burrows' used were most commonly root cavities formed by fire and decay. The only hollow stump observed being used by a Ngwayir was created in a previously cut stump subject to 'heart rot'.
- Much of the data relating to the specific characteristics of the refuge types remains to be examined in detail. All of the general refuge association data (e.g. location, vegetation associations, position within landscape, etc.) remains to be incorporated into the understanding of the refuges used by Ngwayir.
- Data from the hollow assessments of standing trees remains to be analysed. The more detailed characteristics of the 'standing trees' and the hollows used by Ngwayir will be valuable to refining habitat tree prescriptions and a useful contribution to the published literature.

Characteristics of Refuges in Relation to their Extent of Use

- Determining the characteristics of those refuges that are used most frequently will help management in prescribing suitable habitat retention in an attempt to sustain Ngwayir populations.
- Initial analyses indicate that DBH of 'standing trees' and the number of heads on Balga positively correlate with frequency of use. There is however, considerably more to these relationships that remains to be explained. There are more analyses that are yet to be done to refine and add to this preliminary understanding.

Extent of Refuge Sharing

- Multiple users of the same refuge were observed. Simultaneous sharing was observed between a mother and sub-adult offspring and on three other occasions it was between adults of the opposite sex. Discrete and successive occupations of the same refuge by different experimental animals over time were also observed. The extent of refuge sharing is under estimated by these observations due to the diffuse distribution of most radio-collared animals and observations being made on only 35% of days within the observation periods of the experimental animals.
- Refuges used by Ngwayir were also observed being used by Koomal, however, simultaneous intraspecific sharing of refuges was not observed. It remains to be determined whether there is competitive exclusion between the possum species for refuge use.

Home-Ranges and Movement Patterns

- The home/refuge-range and movement data remains to be thoroughly analysed.
- In conjunction with the refuge number and type data, the refuge range estimates will be used to estimate the density of refuges used per individual. Although the extent of refuge range overlap between individuals will be a gross underestimate, it can provide additional information to suggest what density of refuges need to be maintained within a harvested jarrah forest to potentially sustain Ngwayir populations.
- It is expected that there would be a correlation between home range size and habitat quality. The main factors determining habitat quality would be availability of suitable refuges and access to sufficient food and water. The extent of intra and inter specific competition and their relative densities will also affect home range size

PROVISIONAL RECOMMENDATIONS FOR JARRAH FOREST SILVICULTURAL PRACTICES, FOREST MANAGEMENT AND CONSERVATION.

This information is presented in a manner to encourage discussion and generate creative solutions in a cooperative and multi-disciplinary workshop context. In no way are these points intended to be prescriptive in their current form.

ISSUE 1: THE NEED FOR CLEAR GOALS AND OBJECTIVES

Clear and concise conservation and management objectives are instrumental to the success of adaptive management. Appropriate objectives provide direction to research and operational guidelines and activities that improve the efficiency and likelihood of achieving agreed goals. Furthermore, useful and relevant recommendations to management for conservation necessitate the need for goals and objectives by which the recommendations can work toward and attempt to satisfy.

Therefore clearly understood goals and objectives are an imperative to effective conservation and management.

Recommendation:

Formulate and communicate clear and useful goals and objectives in relation to forest management, silviculture and conservation that can effectively provide a direction and framework for research and operational activities. The SMART (Specific, Measurable, Achievable and Aligned, Resourced, and Timed) model to objectives provides a useful framework by which to formulate appropriate objectives.

In the absence of existing specific, relevant and appropriate silvicultural objectives the following recommendations have been aligned to proposed objectives. In no respect are these presented as complete and definitive but aim to stimulate the process of objective formulation and provide a framework by which recommendations can be presented here.

A Proposed Silvicultural Main Objective:

Manage the CALM forest estate in an ecologically sustainable manner so that the viability of present and potential future populations of all species of vertebrate fauna are not compromised by timber harvesting and associated activities.

Note :

- The Spatial scale needs to be agreed upon but will differ for each species on the basis of its ecology and its habitat context (e.g. home ranges and dispersal/recruitment ranges for each species, proximity and communication with other suitable habitat and populations, other potential threatening processes, etc). Perhaps for Ngwayir it could be at the forest block level (~3000-5000 ha).
- The Time scale also needs to be agreed upon both from a scientific perspective and according to what is publicly acceptable (this also applies to the spatial scale considerations). For example, viable populations within 120 years (ie rotation cycle), 20 years post disturbance or always?
- The non-vascular plants, invertebrates and microbiota ar ebeyond the scope of this report and its recommendations. They should probably be addressed in a separate objective given the current paucity of knowledge of these groups and given the aim to develop SMART objectives.
- Population dynamics need to be considered when developing objectives and management guidelines. For example, the ecology and population dynamics will change as species recovery programs such as 'Western Shield' and 'Western Everlasting' succeed in re-establishing populations within their former distributions. Therefore forest management activities should ensure that they do not compromise the medium to long term potential for species recoveries within their former ranges.

The Generalised Disturbance Ecology Principle: An ecological context can provide structure to generating solutions

Population and community responses to disturbance depends on the disturbance type and its characteristics:
Disturbance can be considered in terms of its,
- -Extent
- -Frequency
- -Intensity
- -Timing

Where these characteristics can be controlled to some extent, they can be used to moderate the impacts of disturbance to species/communities in a manner that achieves Conservation and Management Objectives. These characteristics of disturbance can therefore provide a structure that can be used to explore and generate strategies and tactics to meet objectives.

ISSUE 2: REDUCED SURVIVORSHIP DURING HARVESTING ACTIVITIES.

Two weeks after harvesting had been completed within the ranges of the experimental animals, there were significantly fewer treatment animals (31.2%) alive within the harvest coupe than collared animals within the control areas (80%). Over the entire duration of the study, the survivorship of treatment Ngwayir was marginally significantly different at the 95% confidence level ($p=0.0559$) compared to control animals. However, the statistical power of the analysis is not sensitive enough to confidently detect survivorship differences as large as about 40% at the 95% confidence level. Predation by introduced predators was the main cause of death in both control and treatment cohorts. Increased rates of predation are at least a short-term impact of harvest activities on Ngwayir. During the harvesting process, up to 17.6% of the treatment animals died from the falling of their refuge sites. All treatment animals were dead by October 1998, prior to the silvicultural burn (November 1998).

Objective:

Minimise the impact of timber harvesting activities on the survivorship/population abundance of the Ngwayir above a level that does not compromise the immediate and long-term viability of populations at the forest block scale.

Extent of Application: Within areas of planned extensive disturbance (logging, burning or other) where Ngwayir are known to occur or thought highly likely to occur.

Recommendations

a) **Strategy:** Reduce predation of Ngwayir by introduced predators (feral cats and red fox) during and after the silvicultural activities (ie. road construction, harvesting, JSI and burning disturbance).

   Tactic 1: Increase fox baiting (bait density and frequency), immediately prior to, during and after disturbance and until such time as the increased threat to predation has reduced (e.g. habitat structural complexity increased, predator attraction to disturbed areas subsided – yet to be resolved by research and/or monitorring). Apply an analogous cat bait program when the technology is available and operational.

b) **Strategy:** Conduct major disturbance activities when it is less likely that Ngwayir and other fauna are going to be most at risk.

   Tactic 1: Burn road and logging debris at night when these are least likely to be occupied by nocturnal fauna

Other Strategies and Tactics that are perhaps less practical:

1. Strategy: Reduce predation of Ngwayir by feral cats and red fox during and after harvesting and burning disturbance.
   Tactic: Retain more areas of continuous canopy around habitat trees and within harvested forest cells so that Ngwayir do not need to spend as much time on the ground to travel between feed trees and refuges. For example, suitable secondary habitat trees could be preferentially selected adjacent to primary habitat trees, and/or have intact patches maintained around marked habitat trees that are not subject to JSI treatments.

2. Strategy: Conduct major disturbance activities when it is less likely that Ngwayir are going to be directly at risk.
   Tactic: Create barriers that exclude access to merchantable habitat trees (but allow exit) at least 24 hours prior to harvesting (e.g. 50cm wide non-grip brace around trunk 2m above ground).

ISSUE 3a: CONSERVING AND MAINTAINING THE DIVERSITY OF REFUGES USED BY NGWAYIR

- Significant differences were observed in the relative proportions of different refuge types being used in different forest areas. It is expected (but not yet tested) that most of the variation can be explained by habitat variation (e.g. refuge availability and quality).
- 'Above ground nests' (mainly dreys) were the most common refuge type used in riparian vegetation and associated areas with dense mid-storeys.
- 'Standing trees' (with hollows) were used the majority of time within more open mid-slope and up-slope jarrah/marri forest.
- Balga constituted 35% of the refuges within both control areas. It is expected, however, that the extent of use of balga is largely dependent on their availability and suitability.
- Within the K4 treatment area, 'Standing trees' were the most common refuge type prior to harvesting and forest debris created by harvesting activity was the most common after disturbance, however, 'standing trees' remained the most frequently used form of refuge within the treatment area throughout the study.
- Depending on alternative refuge availability and suitability, balga in some habitats may constitute the most important form of refuge for Ngwayir (e.g. 97% of 227 occupancy records for C07 were within Balga).
- In the presence of Koomal, Balga may be particularly important Ngwayir refuges due to the potential competitive exclusion by Koomal from hollows and with no known records of Koomal refuging within Balga.

Objective 1:
Maintain the diversity of suitable refuge types used by the Ngwayir and protect current and future potential refuge abundances at a level to sufficiently sustain viable Ngwayir populations.

Extent of Application: Within CALM Estate and State Forest harvest coupes where Ngwayir are known to occur, should occur and used to occur between of European Settlement (1829) and red fox invasion (1930's) – ie. in habitat suitable for potential re-introduction

Objective 2:
Minimise the extent and magnitude of disturbance to the forest ecosystems (ie. in keeping with the general principle of minimising the extent and intensity of the disturbance in order to minimise the overall impact to the forest ecosystem).

Extent of Application: Within areas of planned extensive disturbance (logging, burning or other).

Recommendations:

a) **Strategy:** Ensure that at the landscape level the diversity and abundance of suitable refuges and future recruits are maintained and protected within reserved areas not available for harvesting

b) Strategy: Within harvest cells, protect from destruction as many as is possible mature balga and sufficient immature balga for future refuge habitat recruitment.

Tactic 1: Prescribe and regulate the retention of balga as habitat within harvest cells in a similar manner that habitat trees are currently managed and protected.

c) Strategy: Protect riparian vegetation, other unharvested forest and clumps of balga (ie. existing and potential drey and balga habitat) from moderate to intense fire during the silvicultural burn (ie minimise the extent of disturbance).

Tactic 1: Conduct silvicultural burns when moisture differentials are suitable to achieve silvicultural objectives but are also able to minimise or exclude fire from protected habitat and unharvested areas.
Tactic 2: Minimise disturbance to retained and protected habitats within harvest cells. For example, regulate a minimum distance requirement of forest fuel from protected areas containing habitat trees, balga, logs and stumps.
Tactic 3: If fuel loads in protected areas adjacent to harvest cells pose too large a risk to forest regeneration conduct advanced burns. These can be done in a manner that at the time of the silvicultural burn will minimise or exclude fire from protected areas and have allowed time for balga skirts and thickets to re-establish.

d) Strategy: Forego or minimise the application of the JSI treatment to unharvested trees and understorey species.

ISSUE 3b: HABITAT REFUGE RETENTION RATES FOR MAXIMUM CONSERVATION VALUE

- Ngwayir in Kingston use 20 different refuges per year (365 days).
- For Ngwayir observed on over 100 occasions, the average refuge-range is 2.7ha with an average of 7.7 refuges per hectare.
- Within the treatment area 'Standing trees' constituted 65% of the refuges pre-harvesting; 'forest debris' (mainly from road construction) 19%, Balga 8% and 'above ground nests' 6% (No refuge information was collected prior to the road construction activities within K3 and K4).
- Within the control areas balga constituted 35% of all refuges. The other main refuge types varied greatly in their relative use between areas (standing trees averaged 56% in the eastern control area and above ground nests averaged 49% in the western control area).
- Typically most refuges were used rarely (less than 10%) by an individual whilst one to three refuges were used disproportionately more. Many of the most frequently used refuges were 'standing trees' or Balga, however, some 'above ground nests' and 'forest debris' refuges were also used extensively.
- The number and extent of refuges used and the relative use of different refuge types will be highly variable between areas and is expected to be correlated with their availability within the landscape and other biological and physical factors (remains to be tested).
- It is expected that there would be a correlation between home range size and habitat quality. The main factors determining habitat quality would be availability of suitable refuges and access to sufficient food and water. The extent of intra and inter specific competition and their relative densities will also affect home range size.
- The average number of refuges used per hectare overestimates the absolute minimum number of refuges needed to support an individual.
- The number of refuges used per year, the average refuge range and the average number of refuges per hectare underestimate actual refuge usage. Reasons include;

- Sampling artefact (ie refuge records for 35% of observation period will not detect all refuges used, less common ones in particular).
- An individual is expected to use more refuges in its lifetime than it uses in just one year of adulthood.
- The refuge density estimates do not consider refuge range over laps with other individuals. The extent of refuge sharing within these range overlaps will moderate to some extent the refuge density underestimate but not completely. Data collected during this study is insufficient to reliably quantify refuge range overlap and the extents of refuge sharing.

Objective:
Protect and maintain sufficient refuge habitat within forest coupes to be able sustain viable Ngwayir populations throughout the silvicultural cycle.

Extent of Application: Within CALM Estate and State Forest harvest coupes where Ngwayir are known to occur, should occur and used to occur between of European Settlement (1829) and red fox invasion (1930's) – ie. in habitat suitable for potential re-introduction

Recommendations:

a) **Strategy:** Maintain the number of refuges per hectare at a level expected to be used by a viable population of Ngwayir prior to harvesting.

   Tactic 1: Protect at least 5 habitat trees per hectare (ie 65% of 7.7 refuges per ha) that are suitable for Ngwayir within harvest areas.
   Tactic 2: Protect and retain all possible existing and future balga habitat.
   Tactic 3: Protect healthy thickets and riparian vegetation (including balga, existing and potential dreys and drey habitat) from logging and the silvicultural burn.
   Tactic 4: Forego or minimise the application of the JSI treatment to unharvested trees and understorey species.
   Tactic 5: Retain understorey trees and canopy continuity by leaving patches or corridors undisturbed within the harvest cells.

Note: The recommended rates of habitat tree retention are an underestimate of what is expected to be actually used in Kingston by Ngwayir because of the reasons stated above and because the extent of inter and intra specific competition for refuge resources have not been factored.

ISSUE 4: REFUGE CHARACTERISTICS AND SELECTION CRITERIA FOR MAXIMUM CONSERVATION VALUE

- *Standing Trees* (n=141)
  - Ngwayir within Kingston used: 48% *Corymbia calophylla*, 42% *Eucalyptus marginata*, 9% *Eucalyptus wandoo*, and 1% *Eucalyptus rudis*.
  - Within the control areas, the majority of *C. calophylla* and *E. marginata* were greater than 15 metres in height (85% and 76%% respectively), greater than 70cm DBH (61.5% and 52.4% respectively) and had a senescence score between six and nine (77% and 67% respectively). Similar trends were observed within the treatment area pre- and post- harvesting.
  - Standing trees with larger diameters at breast height were likely to be used more frequently ($p=1.19x10^{-5}$, $r^2 = 0.13$).

- *Balga* (*n*=101)
  - 82% of Balga were greater than 2 metres in height, 94% had two or more heads and 72% had skirts greater than 1 metre long (Figure 12).
  - Balga with more heads were used significantly more within Kingston, however the extent of usage variance explained was extremely low ($p= 0.0059$, $r^2 =0.07$).

- *'Above Ground Nests'* (*n*=87)
  - observed in eight species; *E. marginata* (45%%), *C. calophylla* (31%), *Melaleuca incana* (17%), *Sollya heterophylla* (2%), *E. rudis* (1%), *Hardenbergia comptoniana* (1%), *Leucopogon propinquus* (1%), and *Persoonia longifolia* (1%).
  -Dreys were the most common form of 'above ground nest' (74%), and similar to the other forms of this refuge type, their number increased slightly within the treatment area post-harvesting.

- Intra-specific refuge sharing and non-synchronous multiple users (by other Ngwayir and Koomal, *Trichosurus vulpecula*) of some refuges was also observed.

Objective:
Protect and maintain refuges with characteristics preferred by fauna thought to be potentially impacted from harvesting activities.

Extent of Application: Within CALM Estate and State Forest harvest coupes where Ngwayir are known to occur, should occur and used to occur between of European Settlement (1829) and red fox invasion (1930's) – ie. in habitat suitable for potential re-introduction

Further Research Required:
Further research is required to identify selection and preferences of refuges used by comparing what was used with what was available. Other factors which may influence selection, such as competition also need to be studied to improve understanding of habitat use and therefore be able to refine prescriptions for refuge habitat retention rates and characteristics. In the interim, the existing data can be compared with current prescriptions to explore whether improvements can be made.

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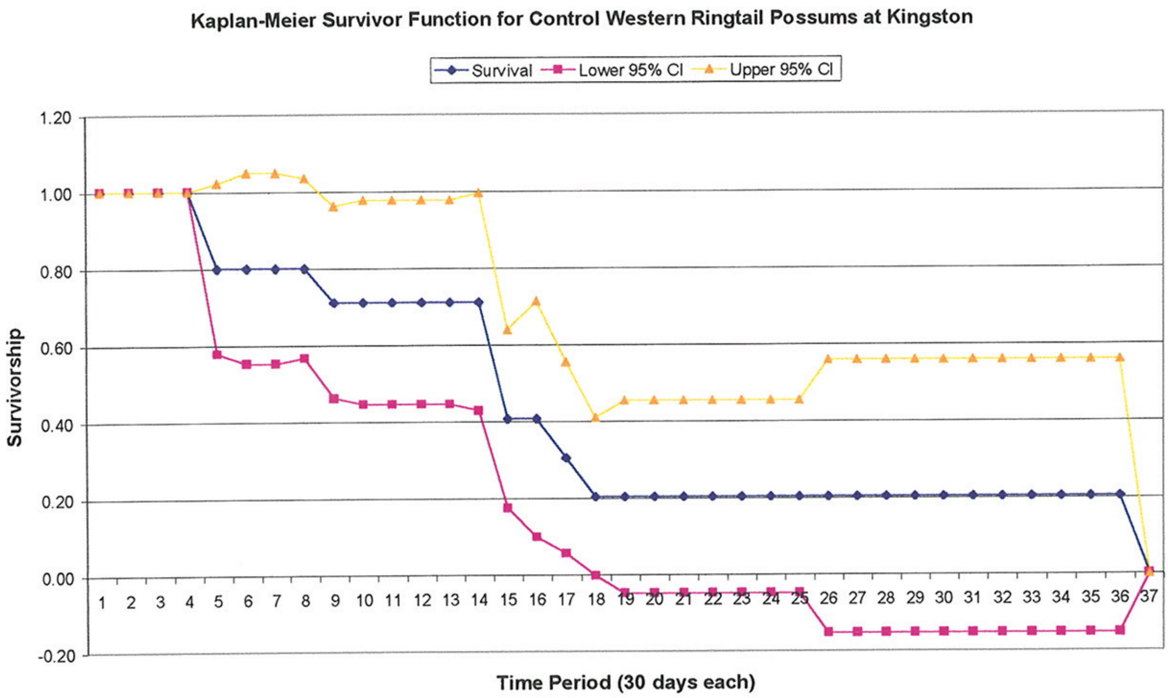

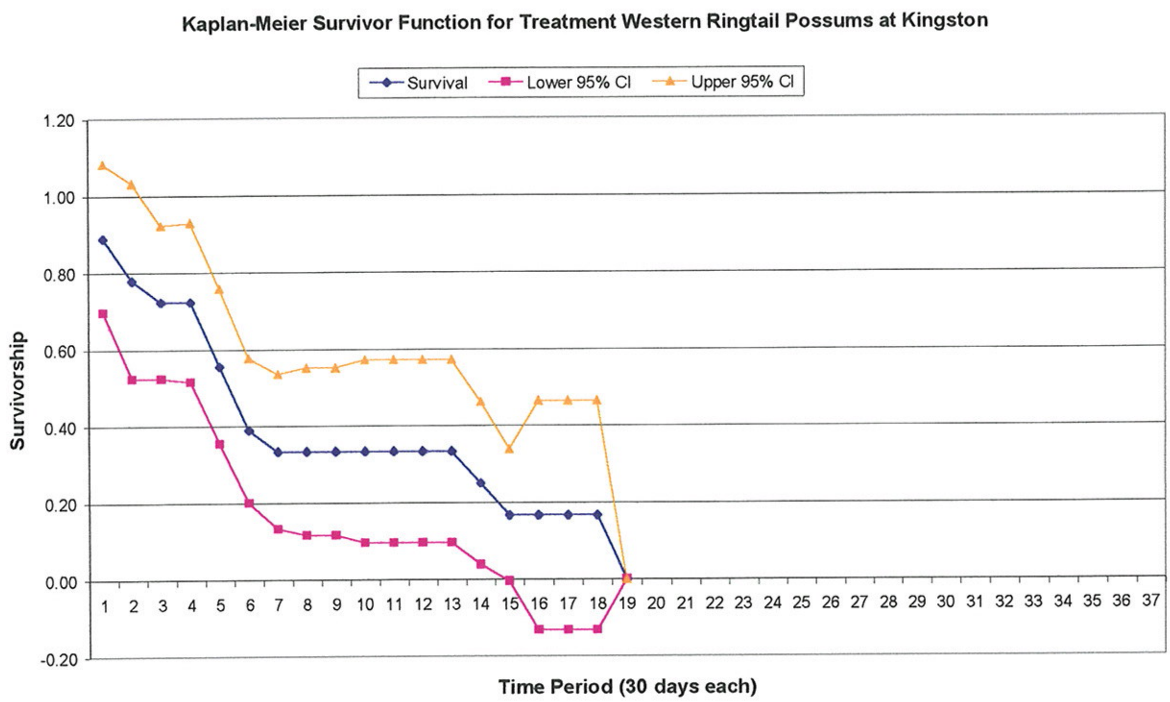

Appendix 1. The Kaplan-Meier survival function for Ngwayir (*Pseudocheirus occidentalis*) within (i) the Control areas and (ii) the K4 Treatment area of Kingston State Forest, near Manjimup, Western Australia.

Appendix 2. A brief description of the Fates of individual radio-collared ngwayir (*Pseudocheirus occidentalis*) within the K4 harvest coupe (treatment animals) and adjacent unharvested forest (control animals) within Kingston State Forest, Manjimup, Western Australia. (Treatment: n = 17, Control: n = 12; note #17 and C04 not included in survivorship analyses).

WRP#	Cause of Death
01	Complicated death – ultimately predation but complicated by illness
02	Predation
03	Predation
04	Predation
05	Fate Unknown (Censored) – collar failure (battery expiry), eluded recapture efforts
06	Harvesting
08	Predation
09	Uncertain - Illness? Stress?
10	Predation
11	Fate Unknown (Censored) – collar failure (faulty signal)
12	Predation
13	Harvesting
14	Predation
15	Fate Unknown (Censored) - collar slipped (later observed alive but eluded capture)
16	Uncertain. Harvesting-Stress? Illness?
17	Fate Unknown (Censored) –collar found, no predation evidence or possum (omitted from survivorship analyses since it was caught after harvest disturbance)
18	Uncertain - Illness? Stress?
C01	Uncertain –only a few skeletal remains found 1 month after last recorded alive.
C02	Uncertain - Illness? Stress?
C03	Predation
C04	Fate unknown (Censored) – collar slipped and left in nest two weeks after collaring. Not included in any analyses.
C05	Predation
C06	Predation
C07	Fate Unknown (Censored) – collar recovered, no evidence of animal or predation
C08	Predation
C09	Predation
C10	Complicated death - Diaphragmatic Hernia - engorged stomach, predator visited
C11	Fate Unknown (Censored) – collar failure (battery expiry), eluded recapture efforts
C12	Trauma- cause uncertain