The impacts of timber harvesting and associated activities on the small terrestrial vertebrates of the Jarrah forest.

Kingston Project Progress Report
May 2001

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REPORT SUMMARY

A total of 23, 568 pit trap nights, 28,884 Elliott trap nights and 17,334 wire cage trap nights were conducted between April 1994 and February 2000 on 22 trapping grids within Kingston. As a result there were 2831 captures of small vertebrates including five species of small mammals, 17 species of reptiles and 11 frog species. The responses of small vertebrate species to current timber harvesting and silvicultural treatments could not be examined thoroughly because the sample sizes for each species were too small. Consequently, the trends and relationships to harvesting have remained largely descriptive. For all small vertebrates with greater than 40 captures and that were present before logging disturbance, all remained present within each treatment after disturbance. The species richness of small mammals was variable between treatments and declined over time. Frog and reptile species richness declined during harvesting and recovered afterwards to pre disturbance levels. Since the external controls also followed these trends, timber harvesting cannot directly account for these changes. For the house mouse (*Mus domesticus*), there was a strong positive relationship between the number of captures and the intensity of logging disturbance. The black rat (*Rattus rattus*) was rarely captured during the study and did not show a corresponding increase during or after harvesting within treatment areas. The brushtailed phascogale (*Phascogale tapoatafa*), having been in abundance in 1994, declined dramatically in early 1995 and has not been captured since June 1995. The decline was observed predominantly before harvesting disturbance, and similar declines were observed elsewhere in the absence of logging. Reduction in invertebrate prey and the species, ecology best explain these declines. Trends for other small vertebrates are also presented. Implications to management and considerations for future research are discussed.

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INTRODUCTION

The impacts of disturbance associated with jarrah forest timber harvesting and silvicultural treatments on small terrestrial vertebrates were investigated as part of the integrated Kingston Project research program (Burrows *et al.* 1994; CALMScience SPP 93/0115). The small terrestrial vertebrates studied comprised the frogs, reptiles and small mammals.

The results of the preliminary analyses on the small vertebrate data collected from April 1994 to February 2000 are reported here.

METHODS

Study Site

This study was conducted within the Kingston, Warrup and Winnejup State Forest Blocks, 26 km north east of Manjimup, Western Australia (Figure 1). Its design is integrated and consistent with that of the other studies associated with the Kingston Project (Burrows *et al.* 1994). In particular, the small vertebrates study design was closely associated with the trapping grids used to study the disturbance impacts upon the medium sized mammals (Morris *et al.* 1996, 2000). A total of 22 grids were used to provide replicated study sites within five principal treatments (External Controls, EC; Shelterwood Creation, SW; Gap Release with prescribed habitat trees, G+H; and Gap Release with prescribed habitat trees removed ,G-H; and Temporary Exclusion Area System/unlogged Buffers, TEAS) and the ecotonal zones between impacted treatment sites and adjacent unharvested buffers, (Eco.S/W, Eco.G+H, Eco.G-H; Table 1).

Table 1. Treatments and sampling grids used in the terrestrial vertebrate studies of the Kingston Project.

TREATMENT	GRID	FOREST BLOCK	LOCATION (AMG)		ELEVATION (metres)
			Easting	Northing	
External Control (EC)	C1	Warrup	436585	6220888	339
	C2	Warrup	437344	6222685	339
	C3	Winnejup	438076	6229257	355
	C4	Winnejup	439398	6228809	340
Internal Reference (IR)	KC5	Kingston	440220	6225787	296
	KC6	Kingston	442036	6223495	277
Shelterwood Creation (S/W)	K3.1	Kingston	441542	6227698	333
	K5.7	Kingston	441914	6223006	257
Gaps with Prescribed Habitat Trees Retained (G+H)	K1.5	Kingston	437503	6228067	354
	K2.1	Kingston	440742	6228145	349
	K5.4	Kingston	441669	6222399	293
Gaps with Prescribed Habitat Trees Removed (G-H)	K1.1	Kingston	439287	6228095	348
	K5.1	Kingston	441989	6221103	253
Temporary Exclusion Area System and Unlogged Buffers (TEAS)	K1.3	Kingston	438872	6228080	339
	K5.3	Kingston	441965	6221465	279
Ecotonal Shelterwood (Eco.S/W)	K3.2	Kingston	441517	6227486	326
	K5.6	Kingston	441943	6222783	271
Ecotonal Gaps +H (Eco.G+H)	K1.4	Kingston	437208	6227884	356
	K2.2	Kingston	440536	6228134	344
	K5.5	Kingston	441401	6222570	294
Ecotonal Gaps –H (Eco.G-H)	K1.2	Kingston	439071	6228088	341
	K5.2	Kingston	441969	6221281	272

Grid and Sampling Design

Each trapping grid was a composite of pitfall traps, medium-sized Elliott traps and wire cages (Figure 2). The central 80 x 80 metre grid of 15 pitfall traps was arranged in three lines spaced 40 metres apart, with five pitfall traps (spaced 20 metres apart) per line. Each pitfall trap was constructed from a 20 litre plastic Rheem bucket (25cm wide, 40cm deep) with a 7m long by 30cm wide (buried approximately 10cm deep) flywire fence. A medium-sized polystyrene food tray with a corner cut out, was placed inverted in the bottom of each pit. Its purpose was to provide shelter from the weather and potential opportunistic predators and to function as a raft during unanticipated high rainfall events. To avoid potential drowning of trapped animals, all pits were closed when significant rainfall was forecast or thought likely to occur.

Individual pits were also closed when it was judged that ants posed a potential threat to the welfare of captured small vertebrates. Superimposed over the pitfall trap grid 15 medium-sized Elliott traps (Elliott Scientific Co., Upwey Victoria) were spaced 40 metres apart along three lines (spaced 80 metres apart) of five. Nine wire cages (Sheffield Wire Co., Welshpool WA) were spaced along three lines of three traps, with 80 metre spacings between adjacent traps. The total grid area was 2.56 ha.

All grids were sampled for three consecutive nights over a two week trapping session. To minimise weather exposure and avoid welfare compromise of trapped animals, the grids were split into a northern and southern sector so that all traps set at any one time could be cleared by midday. The southern sector was sampled in the first week of a trapping session and the northern grids in the second week. The two "internal reference" grids (KC5 and KC6) were sampled in both weeks so that any extraordinary variation in animal captures between weeks could be measured and accounted for.

This study examined the frogs, reptiles and small mammals (mammal species with adult weight ranges less than 400 grams) caught on these grids during a total of 27 trapping sessions conducted between April 1994 and February 2000. During the first two years of the study there were five trapping sessions conducted per annum. Since 1996 the trapping sessions have been quarterly (February, May, August and December).

Fauna Processing

Captured small mammals were individually marked by ear notching. Only some species and individuals of frogs and reptiles were toe clipped for individual identification purposes. Data was collected on the sex (where possible), weight and size of animals before release at the site of capture. Some individuals were held over night or vouchered to assist with accurate species identification and/or contribute to a small reference collection registered with the Western Australian Museum . All trapping, sampling and animal handling techniques were approved by the CALM Animal Ethics Committee (CAEEC #19/93/2000).

Timber Harvesting and Associated Disturbance

Timber harvesting operations within Kingston were conducted according to standard Departmental operational procedures and silvicultural guidelines (Bradshaw 1986, CALM 1995). The only exception to this was the removal of the marked habitat trees from two gap release cells within which grids K1.1, K1.2 (partial/ecotonal), K5.1 and K5.2 (partial/ecotonal) were established to examine the effects of habitat tree retention on fauna, particularly the arboreal mammals.

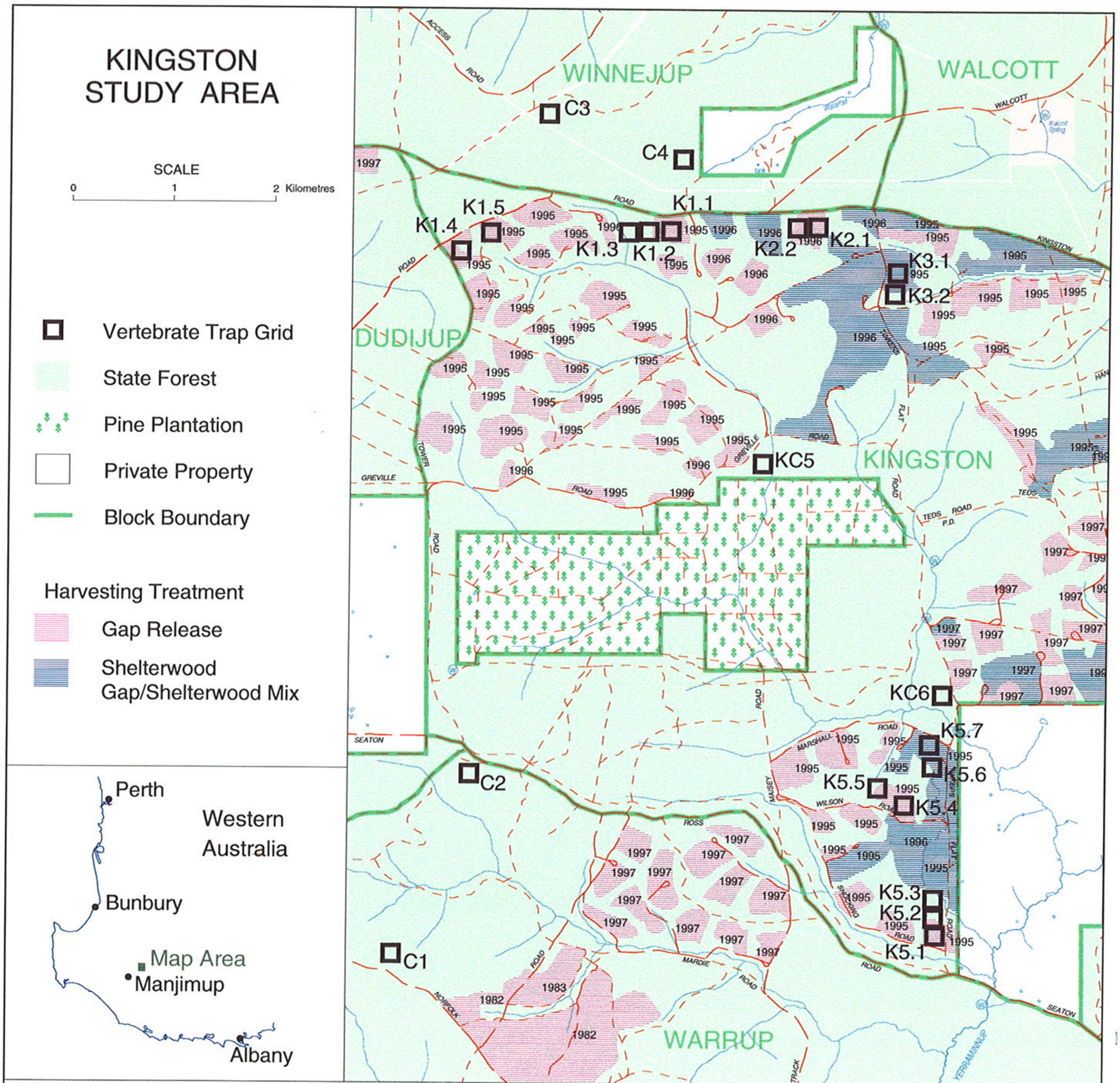


Figure 1 . Kingston Study Area including the terrestrial vertebrate trapping grids

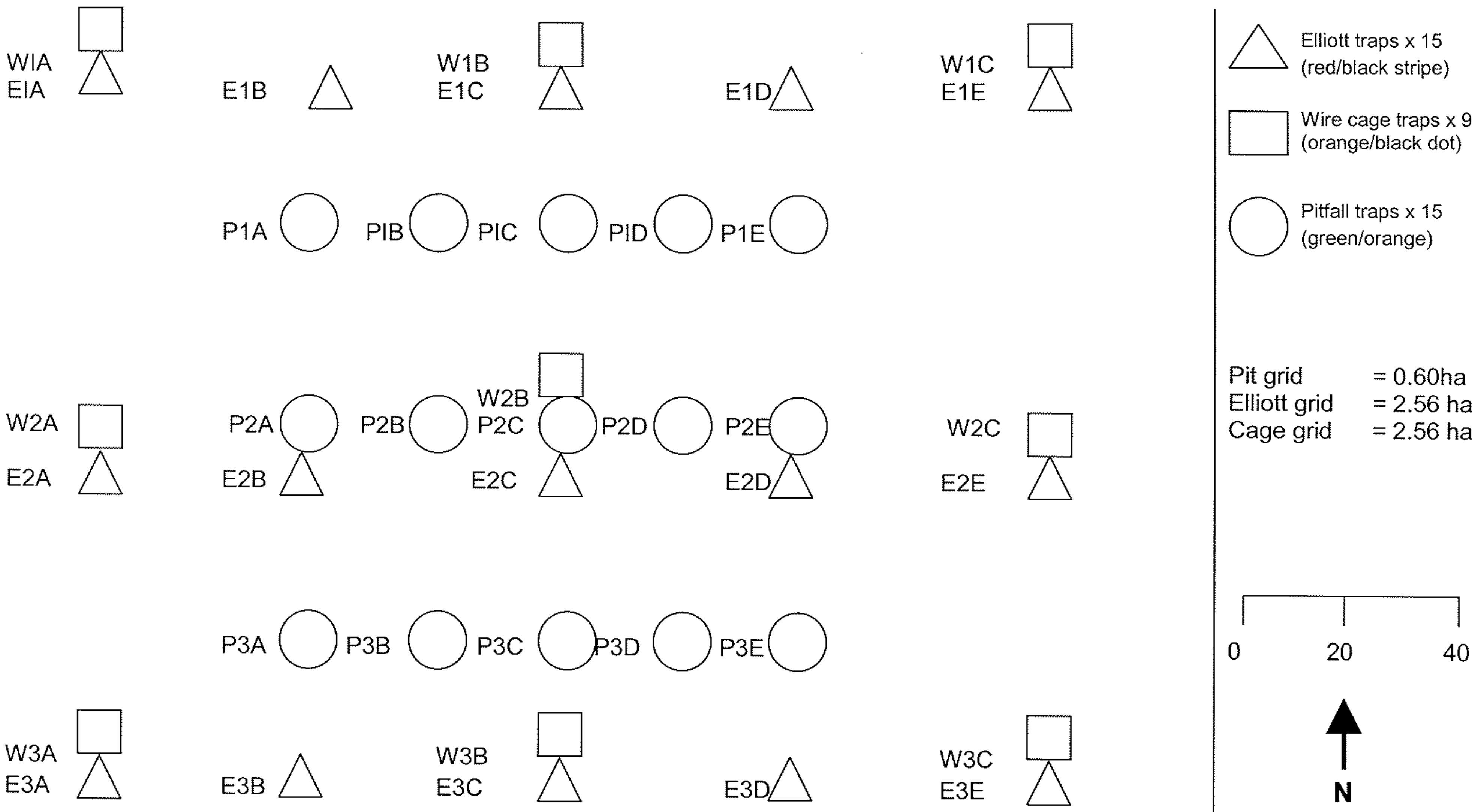


Figure 2. The grid design used in the Kingston Study to trap terrestrial vertebrates (Frogs, Reptiles, small and medium-sized Mammals).

The dates used to define 'Before', 'During' and 'After' harvesting disturbance are specific for each trapping grid (Table 2). The disturbance dates used for the Internal Reference (IR) and TEAS grids are derived from the dates of disturbance experienced in forest adjacent to these grids. For the purposes of comparing treatments with controls, disturbance dates were artificially imposed on the External Controls despite these grids being remote from contemporary logging disturbance (C1~2000m; C2~1600m; C3 ~800m; C4~500m). The dates used for the external controls coincide with the first records of contemporary logging in Kingston State Forest. The end of harvesting disturbance is defined as the completion of the silvicultural burn, which for most of Kingston was during November 1996 and 9 November 1998 for Kingston 4 which is east and adjacent to KC6 grid.

Data Analysis
To test the statistical significance of any changes in abundance, species richness or community structure of the three small vertebrates groups studied, two methods were applied. Analysis of variance (ANOVA) estimated changes in species richness for different silviculture treatments. Non-metric multi-dimensional scaling (NMDS) assessed changes in community structure. Each method is explained in detail below. For both methods, samples were grouped into three treatment periods: before, during and after harvest. Sites were grouped into nine silviculture treatments: External Control (EC), Internal Reference (IR), Shelterwood Creation (S/W), Gaps with Prescribed Habitat Trees Retained (G+H), Gaps with Prescribed Habitat Trees Removed (G-H), Temporary Exclusion Area System and Unlogged Buffers (TEAS), Ecotonal Shelterwood (Eco.S/W), Ecotonal Gaps with Prescribed Habitat Trees Retained (Eco.G+H) and Ecotonal Gaps with Habitat Trees Removed (Eco.G-H).

In the ANOVA, the species richness per site per trap effort was calculated for each small vertebrate animal Class (amphibia, reptilia and mammalia) and then analysed, with the effect of treatment period and silviculture estimated. Three single degree of freedom contrasts tested the effects: (i) during harvest, relative to the period before harvest; (ii) after harvest, relative to the period before harvest; and (iii) after harvest, relative to the period during harvest. Contrasts were also used to assess any differences between silviculture treatments. Standard diagnostic tests (SAS, 1985; 1989) were used to ensure that the underlying assumptions of the ANOVA were met.

NMDS is a multi-variate ordination technique that is widely applied in examining the relationship between patterns of species abundance and environmental changes (Cox and Cox, 1994). NMDS uses the between-site dissimilarities to determine a measure of "distance" between sites and presents this dissimilarity in an ordination. NMDS of the Bray-Curtis dissimilarity measure has consistently performed well in a variety of tests and simulations on different types of data (Faith *et al.*, 1987). For this ordination, samples were the same as in the ANOVA above; thus silviculture treatments for before, during, and after harvest by the species abundance matrix were used. Data were analysed using PATN (Belbin, 1985 a, b).

Table 2. The definition dates used for each trapping grid to investigate the impacts of harvesting disturbance on the small terrestrial vertebrates within the Jarrah forest of Kingston State Forest, Manjimup, Western Australia.

Grid		Before Disturbance (less than)	During Disturbance		After Disturbance (> or = to)
			Start	End	
External Controls (EC)					
	C1	1/2/95	1/2/95	1/12/96	1/12/96
	C2	1/2/95	1/2/95	1/12/96	1/12/96
	C3	1/2/95	1/2/95	1/12/96	1/12/96
	C4	1/2/95	1/2/95	1/12/96	1/12/96
Internal Reference (IR)					
	KC5	1/2/95	1/2/95	1/12/96	1/12/96
	KC6	24/11/97	24/11/97	10/11/98	10/11/98
Shelterwood Creation (S/W)					
	K3.1	11/5/95	11/5/95	1/12/96	1/12/96
	K5.7	20/5/95	20/5/95	1/12/96	1/12/96
Gaps with Prescribed Habitat Trees Retained (G+H)					
	K1.5	1/2/95	1/2/95	1/12/96	1/12/96
	K2.1	15/4/96	15/4/96	1/12/96	1/12/96
	K5.4	16/3/95	16/3/95	1/12/96	1/12/96
Gaps with Prescribed Habitat Trees Removed (G-H)					
	K1.1	1/2/95	1/2/95	1/12/96	1/12/96
	K5.1	22/5/95	22/5/95	1/12/96	1/12/96
Temporary Exclusion Area System and Unlogged Buffers (TEAS)					
	K1.3	1/2/95	1/2/95	1/12/96	1/12/96
	K5.3	22/5/95	22/5/95	1/12/96	1/12/96
Ecotonal Shelterwood (Eco.S/W)					
	K3.2	11/5/95	11/5/95	1/12/96	1/12/96
	K5.6	20/5/95	20/5/95	1/12/96	1/12/96
Ecotonal Gaps with Prescribed Habitat Trees Retained (Eco.G+H)					
	K1.4	1/2/95	1/2/95	1/12/96	1/12/96
	K2.2	15/4/96	15/4/96	1/12/96	1/12/96
	K5.5	16/3/95	16/3/95	1/12/96	1/12/96
Ecotonal Gaps with Prescribed Habitat Trees Removed (Eco. G-H)					
	K1.2	1/2/95	1/2/95	1/12/96	1/12/96
	K5.2	22/5/95	22/5/95	1/12/96	1/12/96

RESULTS

A total of 23, 568 pit trap nights, 28,884 Elliott trap nights and 17,334 wire cage trap nights were conducted over the duration of the study (Table 3). As a result there were 2831 captures of small vertebrates (overall trap success rate of 4.1% or an average of 0.12% per species/taxa). Five species/taxa of small mammals, 17 species/taxa of reptiles and 11 frog species were consequently recorded (Table 4). Almost all species were less than 0.5%, and no one species exceeded 2%, trap success per trap type. The trap success rates of all frogs, all reptiles and all small mammals from pits were 2.2%, 2.8% and 2.4% respectively. Similarly the trap success rates for all reptiles and all small vertebrates in Elliotts were 0.7% and 3.15% and in wire cages 0.6% and 1.03% respectively. Table 5 summarises the presence/absence of captures of taxa before, during and after harvesting disturbance for the logging treatments. Taxa with less than 40 total records were not regarded in this respect since their sample sizes were too small to provide useful results. For those taxa with greater than 40 records and present within each treatment before harvesting, they are also all present after harvesting disturbance. The only exception to this is the brush-tailed phascogale (*Phascogale tapoatafa*), which was not trapped after harvesting on any grid, including the external control and internal reference sites.

Table 3. Trap effort (trap nights) for pits, Elliotts and wire cages for each grid within the Kingston project study area for small vertebrates (frogs, reptiles and small mammals), before, during and after harvesting disturbance.

	PITS			ELLIOTTS			WIRE CAGES		
Treatment Grid	Before	During	After	Before	During	After	Before	During	After
External Control (EC)									
C1	180	315	495	180	360	675	108	216	405
C2	180	315	493	180	360	675	108	216	405
C3	180	315	488	180	360	675	108	216	405
C4	180	315	466	180	360	675	108	216	405
Internal Reference (IR)									
KC5	360	630	981	360	720	1305	216	432	783
KC6	1170	360	444	1440	360	585	864	216	351
Shelterwood Creation S/W									
K3.1	225	270	492	225	315	630	135	189	378
K5.7	225	270	492	225	315	630	135	189	378
Gaps with Prescribed Habitat Trees Retained (G+H)									
K1.5	180	315	492	180	360	630	108	216	378
K2.1	360	45	484	360	90	630	216	54	378
K5.4	225	270	477	225	315	630	135	189	378
Gaps with Prescribed Habitat Trees Removed (G-H)									
K1.1	180	315	472	180	360	630	108	216	378
K5.1	225	270	494	495	315	630	297	189	378
Temporary Exclusion Area System and Unlogged Buffers(TEAS)									
K5.3	225	270	495	225	315	630	135	189	378
Ecotonal Shelterwood (Eco.S/W)									
K3.2	225	270	489	225	315	630	135	189	378
K5.6	225	270	492	225	315	630	135	189	378
Ecotonal Gaps +H (Eco.G+H)									
K1.4	180	315	425	180	360	630	108	216	378
K2.2	360	45	486	360	90	630	216	54	378
K5.5	225	495	491	225	540	630	135	324	378
Ecotonal Gaps –H (Eco.G-H)									
K1.2	180	315	477	180	360	630	108	216	378
K5.2	225	270	494	225	540	629	135	324	378
Total	5895	6570	11103	6435	7785	14664	3861	4671	8802

Table 4. A summary of the number and species of small vertebrate captures during the Kingston project study into the impacts of timber harvesting within the jarrah forest of the greater Kingston area, Manjimup, Western Australia.

	Trap Type			
Mammals	**Pit Traps**	**Elliotts**	**Wire Cages**	**Total**
Mus domesticus	94	556	20	670
Sminthopsis spp.	470	94	2	566
Phascogale tapoatafa		41	45	86
Rattus fuscipes	1	11	5	17
Rattus rattus	1		3	4
Reptiles				
Egernia napoleonis	124	182	6	312
Hemiergis peronii	192			192
Lerista spp.	133			133
Morethia obscura	126			126
Egernia kingii	3	19	43	65
Tiliqua rugosa	3	4	30	37
Varanus rosenbergi		1	23	24
Ctenotus labillardieri	21			21
Cryptoblepharous plagiocephalus	14			14
Bassiana trilineatum	13			13
Christinus marmoratus	9			9
Menetia greyii	7			7
Ramphotyphlops australis	2			2
Apraisia repens	1			1
Diplodactylus polyophthalmus	1			1
Notechus scutatus		1		1
Pseudonaja affinis			1	1
Frogs				
Crinia georgiana	187	1		188
Metacrinia nichollsi	102			102
Limnodynastes dorsalis	75			75
Heleioporus inornatus	46	1		47
Heleioporus psammophilus	36			36
Crinia glauerti	23			23
Heleioporus eyrei	18			18
Pseudophryne guentheri	17			17
Crinia pseudinsignifera	16			16
Crinia insignifera	5			5
Littoria moorei	2			2

Table 5. The Presence (✓) / Absence (X) of small terrestrial vertebrates captured (Pits, Elliotts and Wire Cages) within the jarrah forest on the Kingston study trapping grids within differing logging treatments, before during and after timber harvesting disturbance. Note only taxa with greater than 40 total captures have been included.

Species	N	Logging	External Control	Internal Reference	TEAS	Shelterwood	Gaps + Habitat	Gaps – Habitat	Ecotonal S/W	Ecotonal Gaps +H	Ecotonal Gaps -H
MAMMALS											
Mus domesticus	670	Before	✓	✓	✓	✓	✓	✓	X	✓	✓
		During	✓	✓	✓	✓	✓	✓	X	✓	X
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Dunnarts (*Sminthopsis*)	566	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	✓	✓	✓	✓	✓	✓	✓	✓
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Phascogale tapoatafa	86	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	X	✓	X	✓	X	✓	X	X
		After	X	X	X	X	X	X	X	X	X
REPTILES											
Egernia napoleonis	312	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	✓	✓	✓	✓	✓	✓	✓	✓
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hemiergis peronii	192	Before	✓	✓	✓	X	✓	✓	✓	✓	✓
		During	✓	✓	✓	X	X	✓	✓	X	✓
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Lerista species	133	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	✓	✓	X	✓	✓	✓	X	X
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Morethia obscura	126	Before	✓	✓	X	✓	✓	✓	✓	✓	X
		During	✓	✓	X	✓	X	✓	✓	✓	✓
		After	✓	✓	X	✓	✓	✓	✓	✓	✓
Egernia kingii	65	Before	X	✓	✓	X	X	✓	X	✓	✓
		During	X	✓	X	✓	X	✓	X	X	X
		After	✓	✓	✓	X	✓	✓	✓	✓	✓
FROGS											
Crinia georgiana	188	Before	✓	✓	✓	✓	✓	X	✓	✓	✓
		During	X	✓	X	X	✓	X	X	✓	X
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Metacrinia nichollsi	102	Before	✓	✓	✓	X	X	✓	X	✓	✓
		During	✓	✓	X	X	✓	✓	X	✓	X
		After	✓	✓	✓	X	X	✓	✓	✓	✓
Limnodynastes dorsalis	75	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	X	X	X	X	X	X	X	X
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Heleioporus species combined (*H. eyrei*, *H. inornatus*, and *H. psammophilus*)	101	Before	✓	✓	✓	✓	✓	✓	✓	✓	✓
		During	✓	X	X	X	✓	✓	✓	✓	✓
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓
Crinea species combined (*C. glauerti*, *C. pseudinsignifera*, and *C. insignifera*)	44	Before	✓	X	✓	X	X	X	✓	✓	X
		During	✓	✓	X	X	✓	X	✓	X	X
		After	✓	✓	✓	✓	✓	✓	✓	✓	✓

Trap Success Rates:
Mammals
The ordination (Non-metric multi-dimensional scaling, NMDS) of the trap capture rates per grid per trap effort for mammals found that there was a change before, during and after harvesting disturbance (Figure 3). In particular, mammal abundances before harvesting were distinct to those during and after harvesting. Since the internal reference sites and external controls behaved in a similar manner to the treatment grids, timber harvesting cannot directly account for these changes.

Mus domesticus
The majority (83%) of the 670 house mice were caught within medium sized Elliott traps, whilst 14% were caught within pit traps. Both on control and internal reference treatments there tended to be more mice caught after logging than compared with before or during disturbance. The greater the level of disturbance between treatments the greater the increase in mice captures during and after disturbance (Figure 4i).

Sminthopsis species
Although there are believed to be at least two, possibly three species of *Sminthopsis* present within the Kingston area, distinguishing between them within the field is unreliable. Therefore the dunnarts were analysed at the genus level. The majority of dunnarts (83%) were caught within the pit traps, whilst 17% were caught within Elliotts. Similar trends in dunnart captures were observed throughout Kingston, irrespective of treatment. Dunnart captures were greatest before disturbance and generally remained low thereafter (Figure 4ii).

Phascogale tapoatafa
The trap success rate of phascogales were greater in wire cages compared with medium sized Elliotts. Captures of phascogales dropped off sharply during 1995 and have not been caught on the grids since June 1995. This trend was observed throughout Greater Kingston, irrespective of treatment (Figure 4iii, Table 5). Captures along the road trap transects followed a similar trend to the grids, however there were three records from 1997.

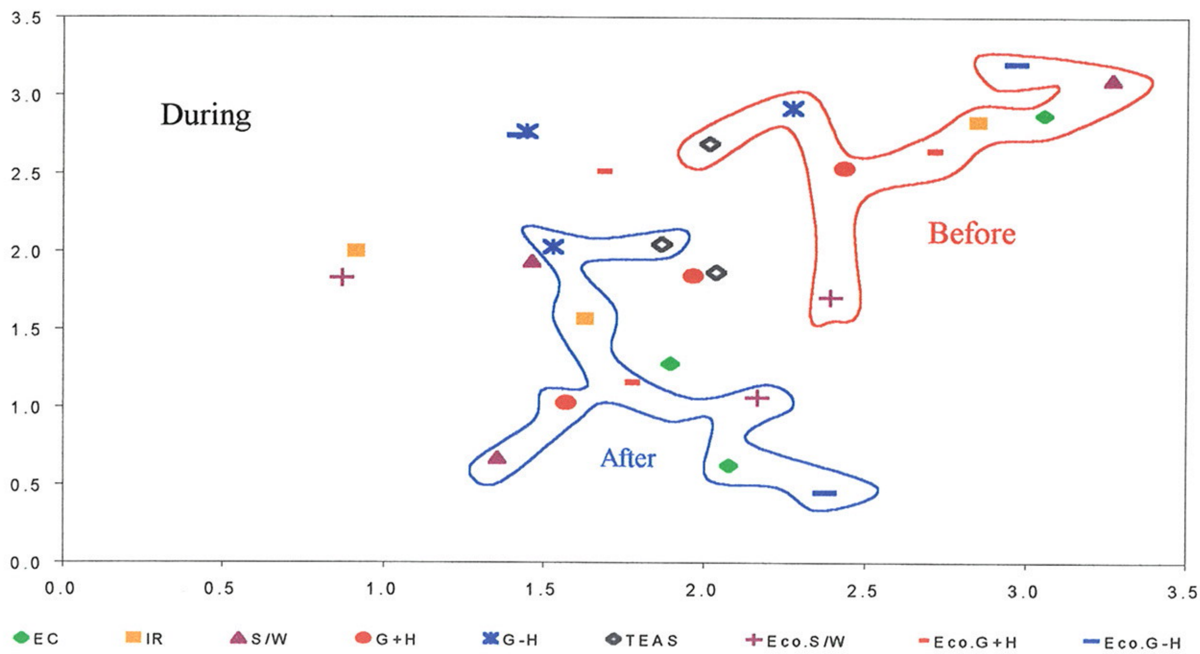


Figure 3. Non-metric multi-dimensional scaling (NMDS) examining the relationship between mammal abundance and time in relation to logging (before, during, after).

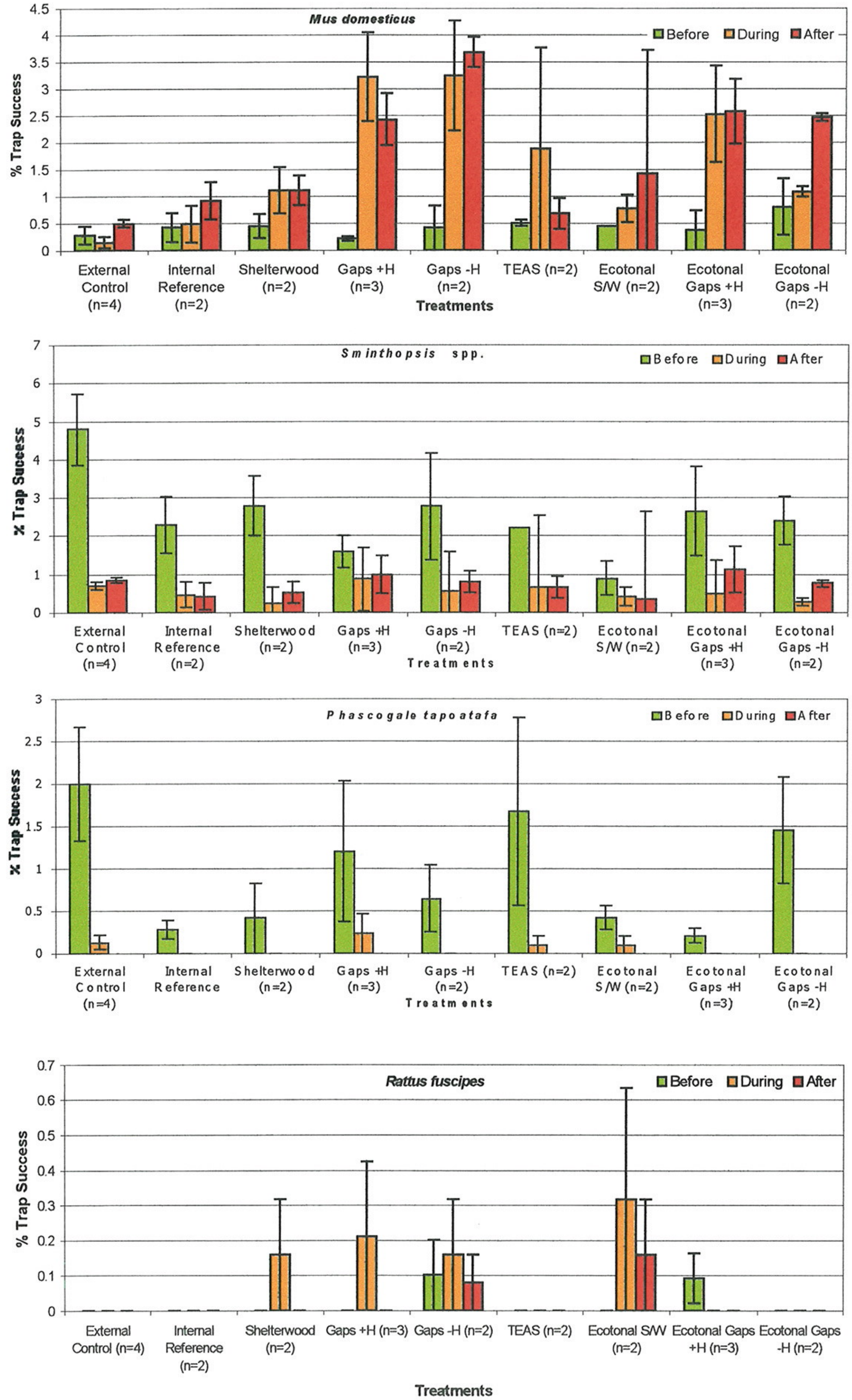


Figure 4. Mean trap success rate (%) of *Mus domesticus* (Pits and Elliotts; n=650), *Sminthopsis spp*. (Pits, Elliotts; n=564), *Phascogale tapoatafa* (Elliotts and Wire cages; n=86) and *Rattus fuscipes* (Elliotts and Wire Cages; n=16) caught from the Kingston grids, before, during and after timber harvesting associated disturbance.

Rattus fuscipes
The native bush rat was rarely trapped but when done so, they were predominantly captured in Elliotts during the harvesting disturbance phase (Figure 4iv). Records of this species were largely confined to two grids (K3.2 and K5.1) but one or two captures were also recorded on four other grids (K1.1, K2.2, K3.1, and K5.4).

Rattus rattus
The introduced black rat was only recorded on four occasions throughout the Kingston grid trapping.

Reptiles:

The pattern of trap success rates for all reptiles combined and caught within the pit traps was generally similar for all treatments including the undisturbed controls (Figure 5i). Generally trap success rates were lower during harvesting but after disturbance these recovered to approximately preharvest levels. Compared with before and during data, there were substantially greater trap success rates observed after harvesting within the Gaps without habitat trees and within ecotonal shelterwood areas. The trap success rates within the TEAS were substantially less after harvesting compared with pre-disturbance results. The trap success rates of all reptiles within Elliotts and wire cages were relatively less than the pits, however, similar trends were generally observed (Figure 5ii and 5iii). The results from the ordination (MDS) generally concur with these trends (Figure 6). Although there were substantial shifts in the trap capture rates of reptile species during harvesting, the ordination indicates that trap capture rates after harvesting disturbance were similar to those before.

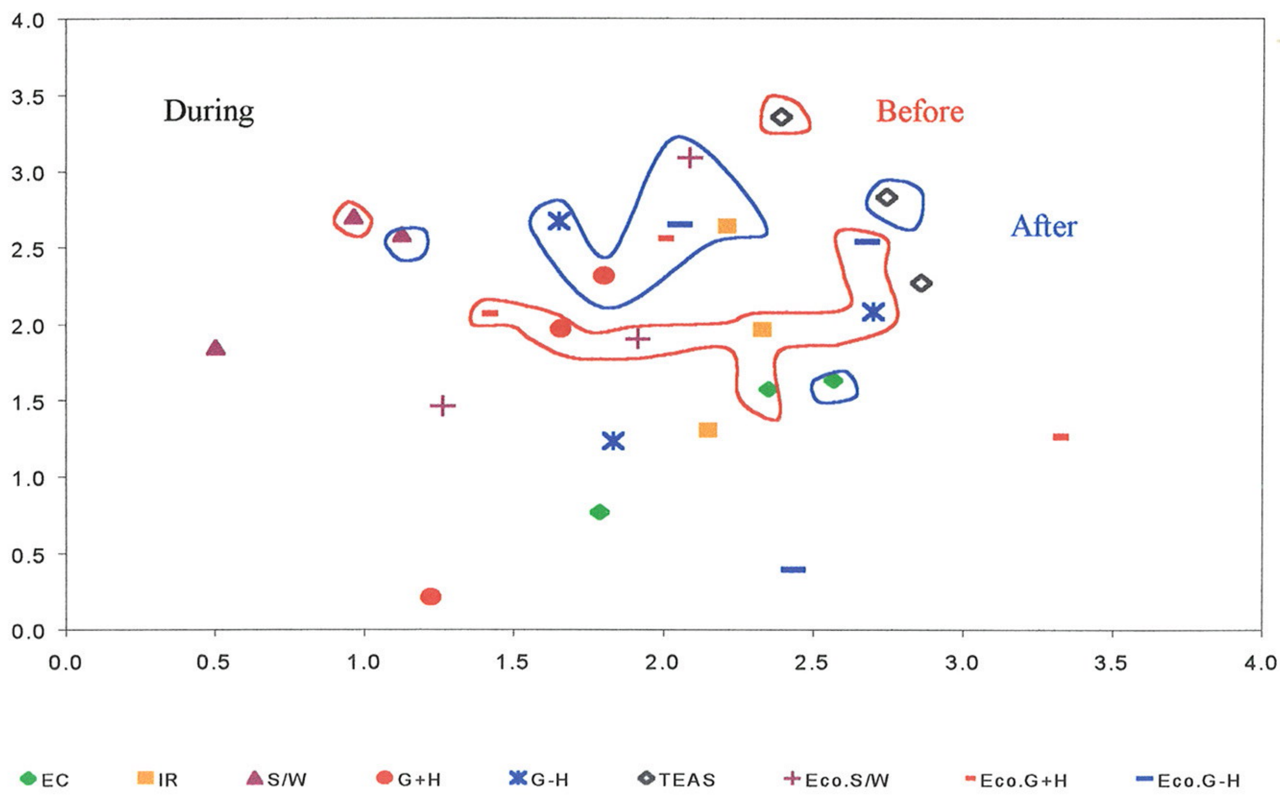
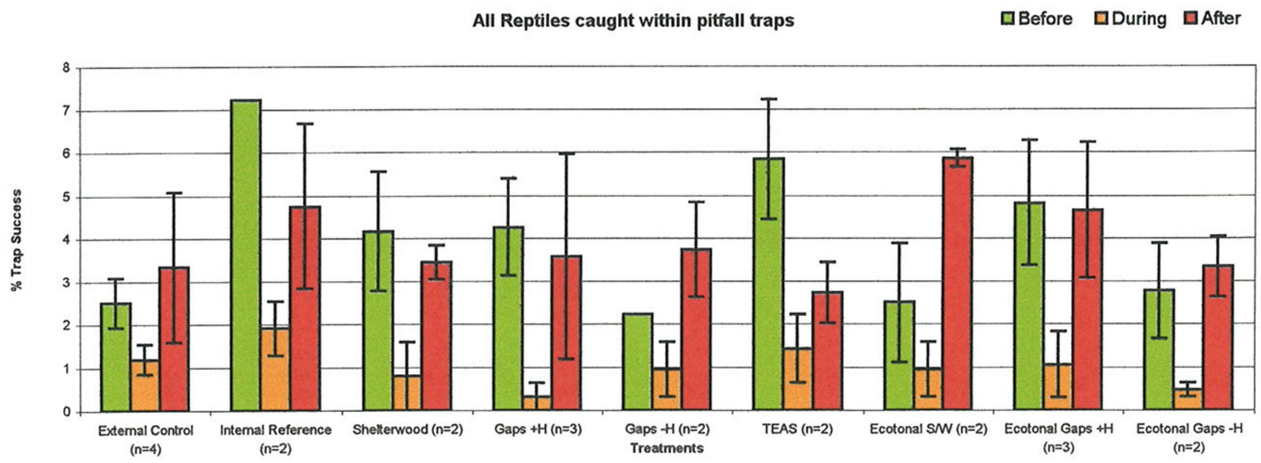
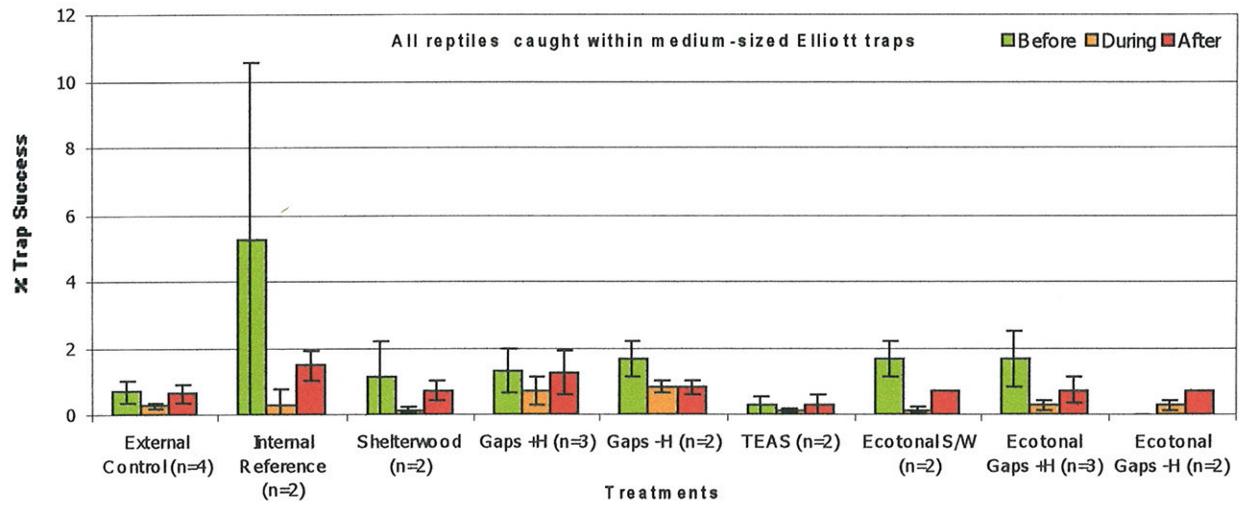


Figure 5. Non-metric multi-dimensional scaling (NMDS) examining the relationship between reptile abundance and time in relation to logging (before, during, after).





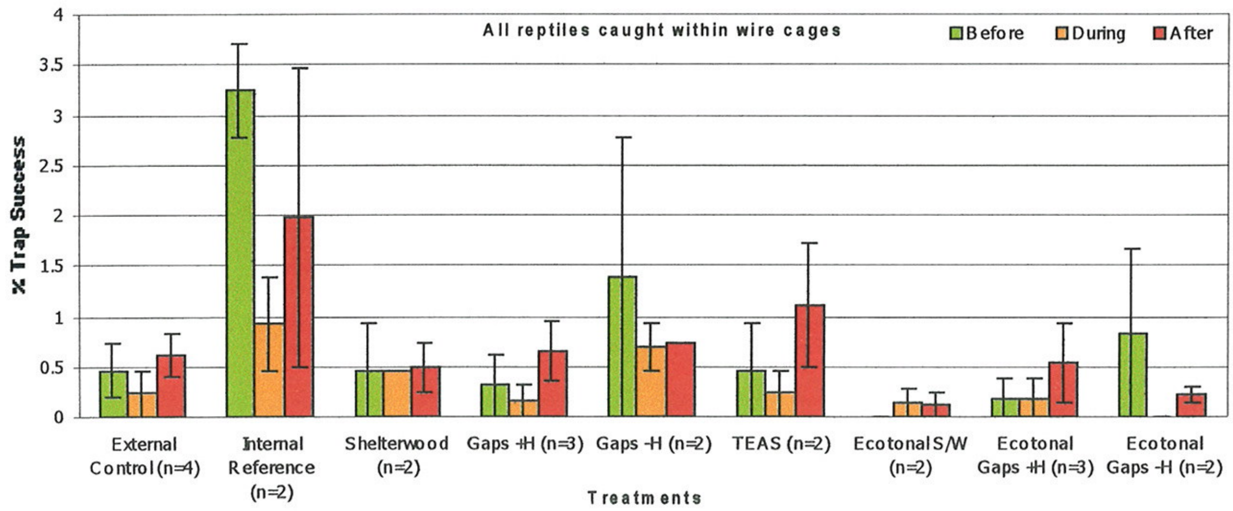


Figure 6. Mean trap success rate (%) all reptiles caught from the Kingston grids, before, during and after timber harvesting associated disturbance.

Reptiles: Moderate to Large Lizards

Egernia napoleonis
With 312 recorded captures from the Kingston grids, *E. napoleonis* was the most frequently captured reptile species. The overall trap success rate of Napoleon Skink captures was slightly greater within medium sized Elliotts (0.63%) when compared with pit traps (0.53%). Generally the trends observed on the controls was similar to the treatments before, during and after harvesting disturbance. In particular, lower during success rates were followed by a post disturbance recovery to roughly predisturbance levels (Figure 7i).

Egernia kingii
With only 65 captures during the study it was not possible to determine any trends over time or between treatments for the King Skink (Figure 7ii).

Tiliqua rugosa
Bobtail lizard captures were highly variable both within and between treatments. With only 37 captures it was not possible to elicit any reliable relationships between *T. rugosa* abundance measures and timber harvesting (Figure 7iii).

Varanus rosenbergi
With only 24 captures, there was insufficient data to discern any patterns or relationships to logging disturbance (Figure 7iv).

Reptiles: Small Skinks

Amongst the small skinks (Figure 8i), there was only sufficient data to potentially identify major patterns in the association with timber harvesting and trap success rates, for three taxa; *Hemiergis peronii, Lerista,* and *Morethia obscura.* The capture histories for these species were variable between grids and over time, however, trends generally observed for treatments did not differ greatly from controls. Interestingly *Hemiergis peronii was* rarely caught on the two shelterwood grids and was particularly abundant within the TEAS (Figure 8ii). *Lerista* species from the elegans complex included *L. distinguenda,* and *L. microtis*. Due to difficulties of reliable identification in the field, these species were considered as one taxon (Figure 8iii). *Morethia obscura* captures were relatively variable and approximately the converse to *Hemiergis peronii*. In particular, there were no records of *M. obscura* caught within the TEAS, whilst there were greater than average captures in the shelterwood areas over time (Figure 9i, Table 4). For the remaining small skink species (*Ctenotus labillardieri, Cryptoblepharous plagiocephalus, Bassiana trilineatum* and *Menetia greyii*), the rates of capture were too low to discern any useful trends or patterns (Figures 9 and 10).

Reptiles: Geckoes, Pygopods and Snakes

None of the other reptiles caught within Kingston were in sufficient numbers to ascertain any responses to timber harvesting disturbance. Of the two gecko species, there were nine records of *Christinus marmoratus* (Figure 10iii) and one of *Diplodactylus polyophthalmus*. The only pygopod record was one *Apraisia repens* from K5.5 in February 1996. *Ramphotyphlops australis* was the only blind snake recorded and the Dugite (*Pseudonaja affinis*) and Tiger snake (*Notechus scutatus*) were the only elapids caught during the grid trapping sessions. It is interesting to note however, that a *Rhinoplocephalus gouldii* was recovered from a pit trap on K2.2 grid on 3 November 2000 when four grids (K2.1, K2.2, K3.1, K3.2) were opened on four consecutive nights for demonstration purposes.

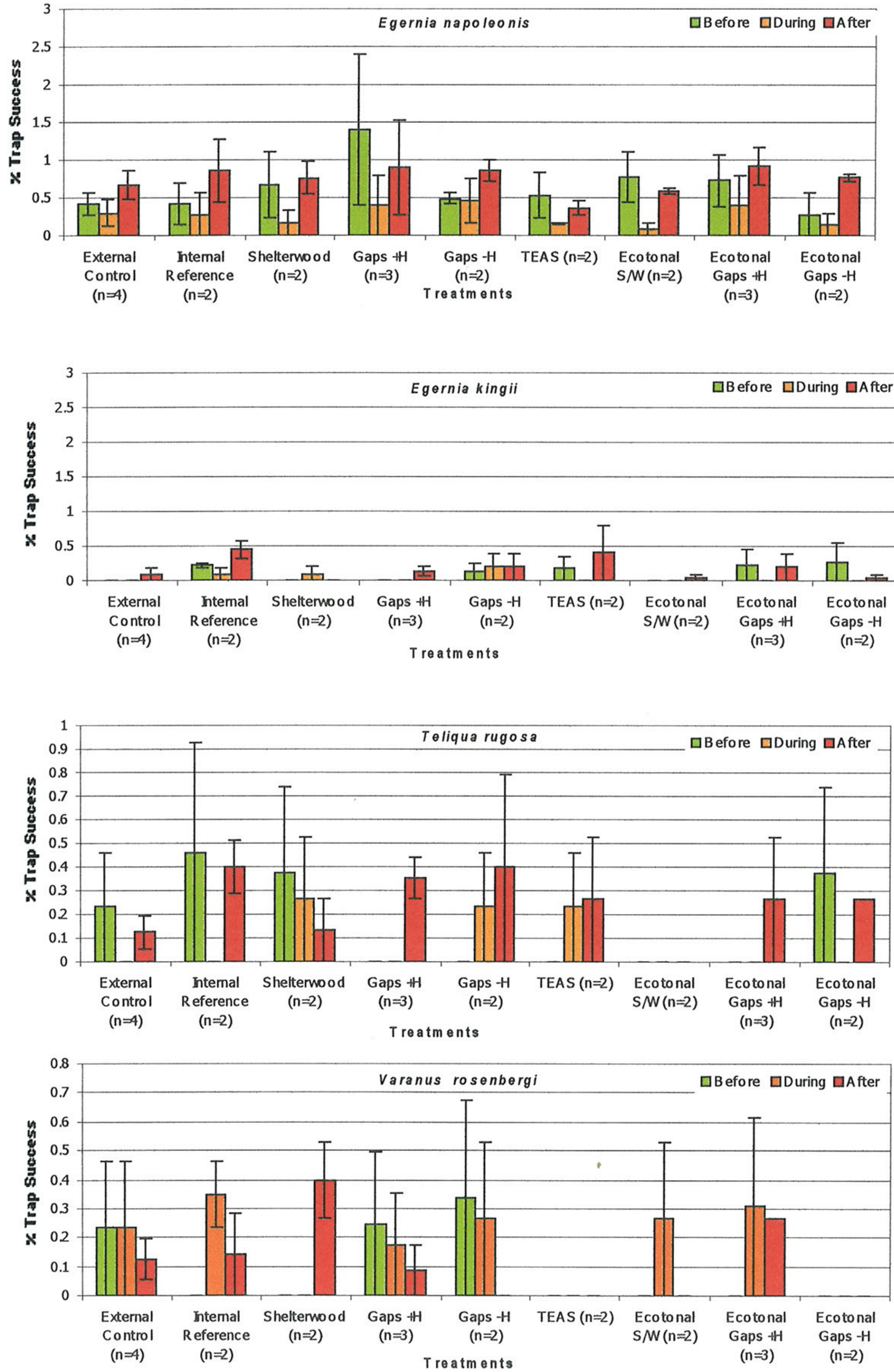


Figure7. Mean trap success rate (%) of *Egernia napoleonis* (Pits and Elliotts; n=306), *Egernia kingii* (Elliotts and Wire cages ; n=62), *Tiliqua rugosa* (Wire cages; n=30) and *Varanus rosenbergi* (Wire cages; n=23) caught from the Kingston grids, before, during and after timber harvesting associated disturbance.

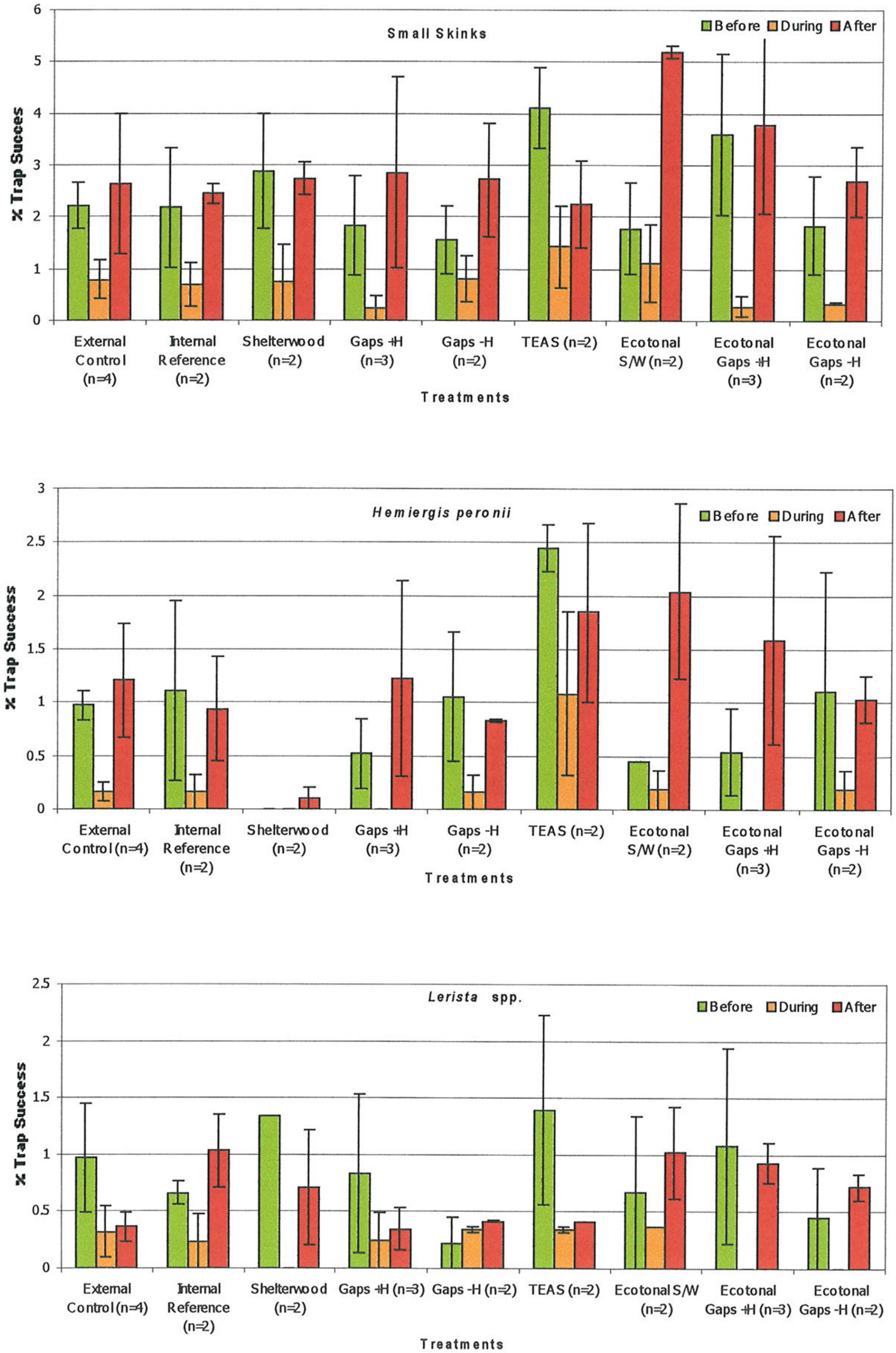


Figure 8. Mean trap success rate (%) of small skinks (n=516), *Hemiergis peronii* (n=192) and *Lerista spp.* (n=133) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

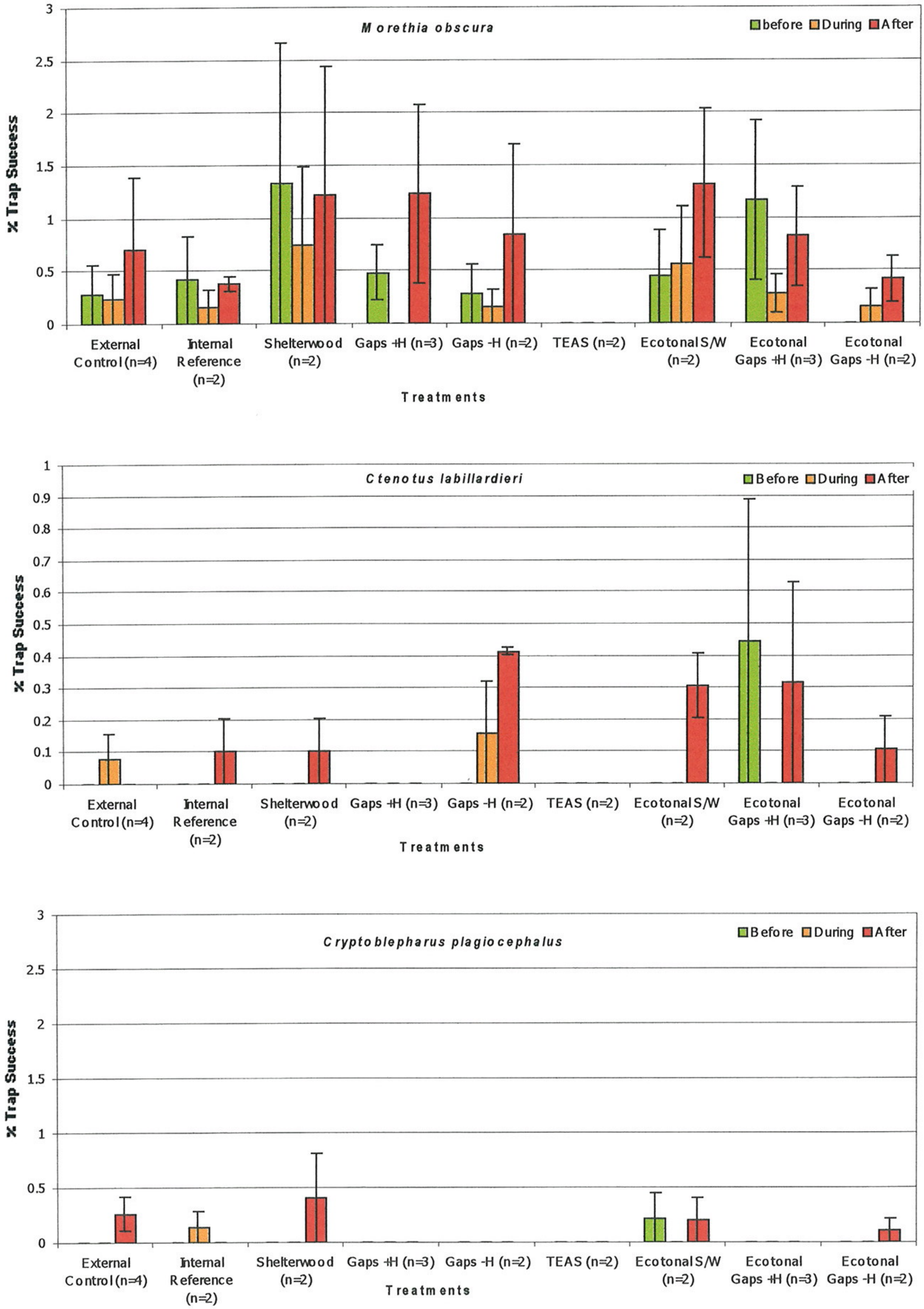


Figure 9. Mean trap success rate (%) of *Morethia obscura* (n=128), *Ctenotus labillardieri* (n=21) and *Cryptoblepharous plagiocephalus* (n=14) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

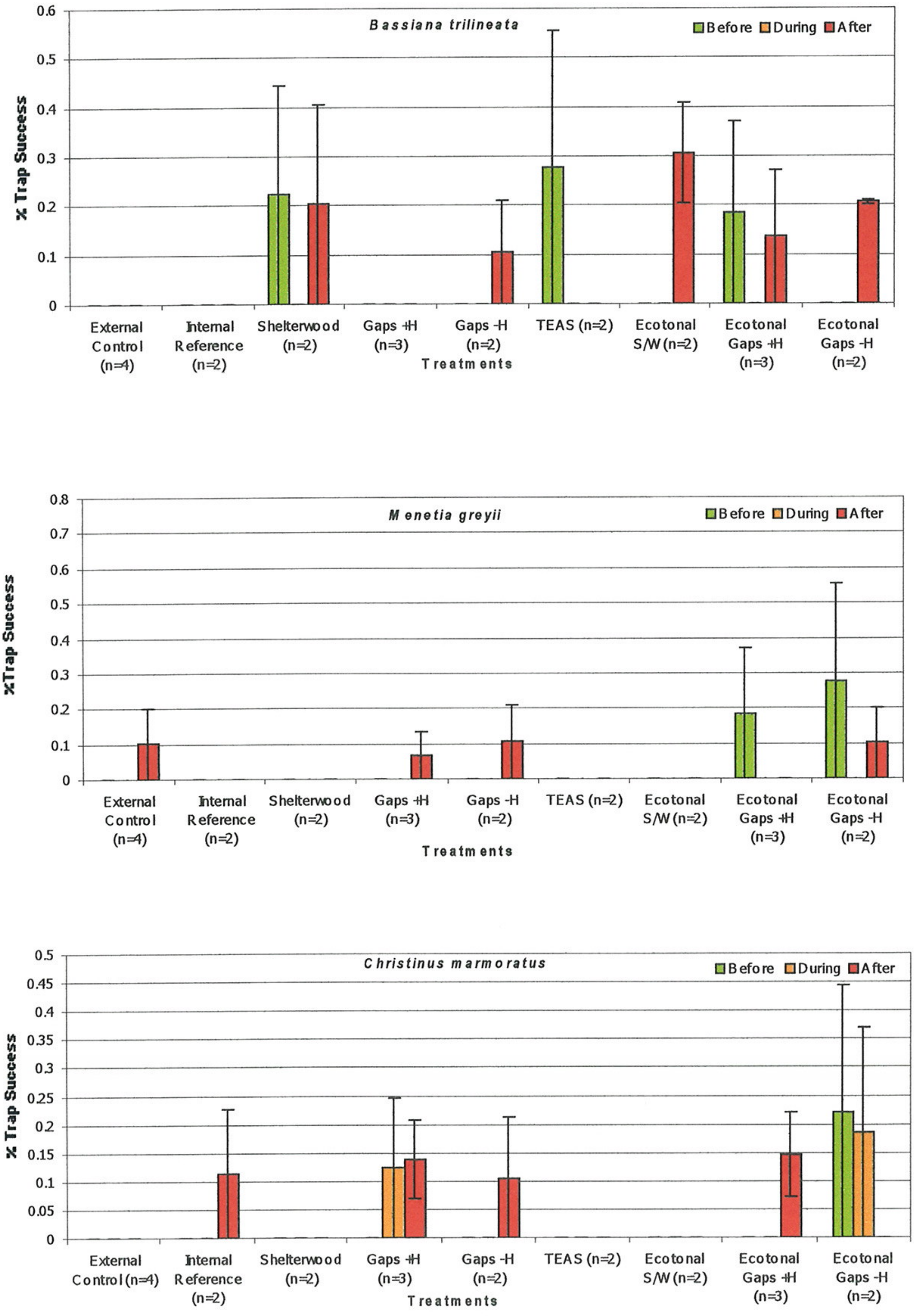


Figure 10. Mean trap success rate (%) of *Bassiana trilineata* (n=13), *Menetia greyii* (n=7) and *Cristinus marmmoratus* (n=9) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

Frogs
The ordination (MDS) results for the characteristics of the trap capture rates of frog species per grid were generally similar, particularly before and after harvesting disturbance (Figure 11). The grids of three treatments (Shelterwood, TEAS and Ecotonal Gaps without habitat trees), were notably different from all others during harvesting disturbance, since no frog captures were recorded within these treatments during this period.

The trap success trends for frogs on the treatment grids were similar to the trends observed on the control grids before, during and after logging disturbance (Figure 12i). Similar to the reptiles, frog captures were substantially less during harvesting, but recovered after disturbance to levels similar to those observed prior to harvesting disturbance. The variation between replicate grids within the same treatments were generally less than observed for the reptiles. The exception to this is between the ecotonal shelterwood grids after timber harvesting disturbance, in which case K5.6 caught only five frogs compared to K3.2 which recorded 63 frog captures since December 1996.

The rate of capture of *Heleioporus* frogs was greater before harvesting disturbance on the control grids than during or after disturbance (Figure 12ii). A similar trend was observed within most treatments. Conversely, there was a slight tendency across most treatments, including controls, for the trap success of *Crinia* to be greater after timber harvesting disturbance (Figures 12iii and 13i). *Metacrinia nichollsi* appeared quite patchy amongst the grids with most captures being records from C3, the internal reference grids (KC5, KC6), the TEAS grids (K1.3 & K5.3), and K1.2 (ecotonal gap without habitat trees; Figure 13ii). There were no records of *Limnodynastes dorsalis* during harvesting disturbance except for on grid C2 (3 captures). Besides a general tendency across treatments for similar *L. dorsalis* capture rates both before and after harvesting disturbance, there were no recognisable patterns to their captures (Figure 13iii). For the remaining frog species there were insufficient data to recognise patterns or relationships with timber harvesting activity (Figures 14 and 15).

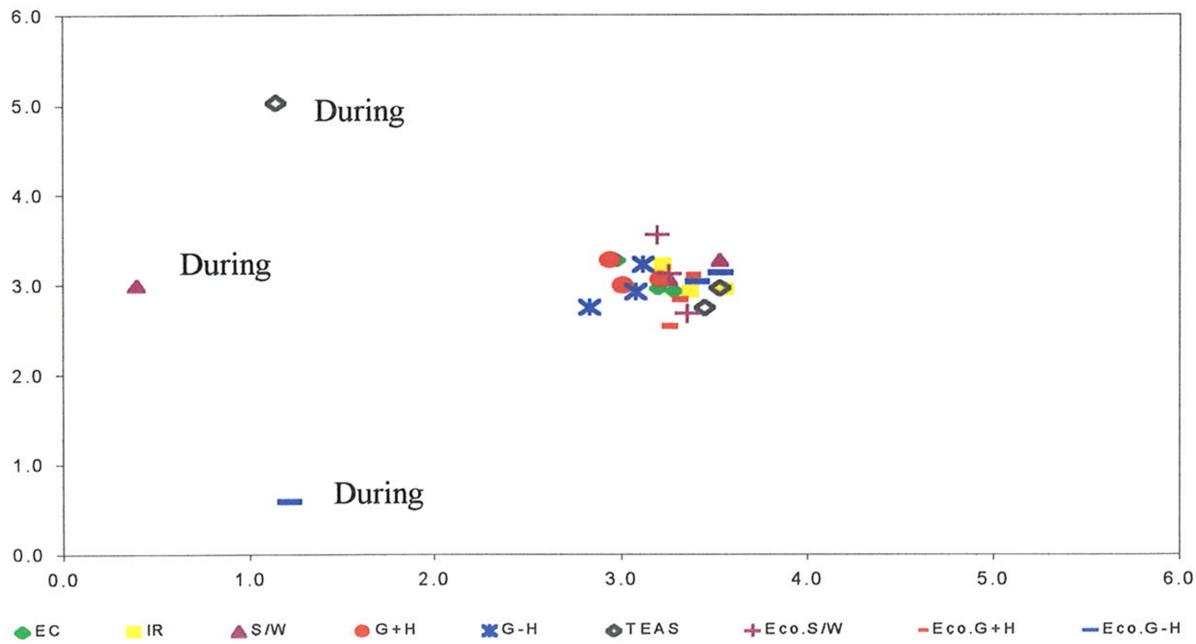


Figure 11. Non-metric multi-dimensional scaling (NMDS) examining the relationship between frog abundance and time in relation to logging (before, during, after).

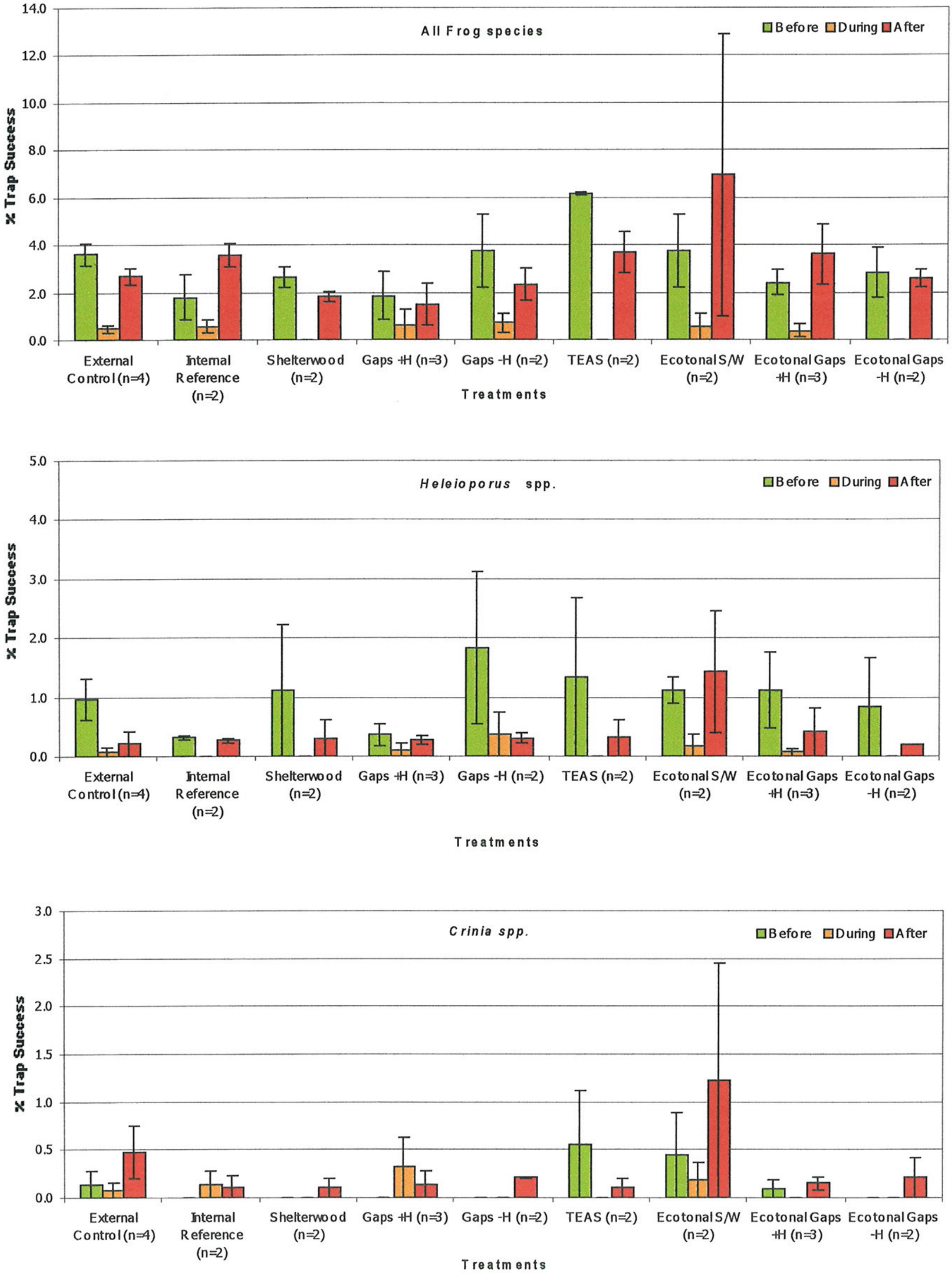


Figure 12. Mean trap success rate (%) of All frogs (n=527), *Heleioporus spp.* (n=100), *Crinia spp* (n=44) (not including) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

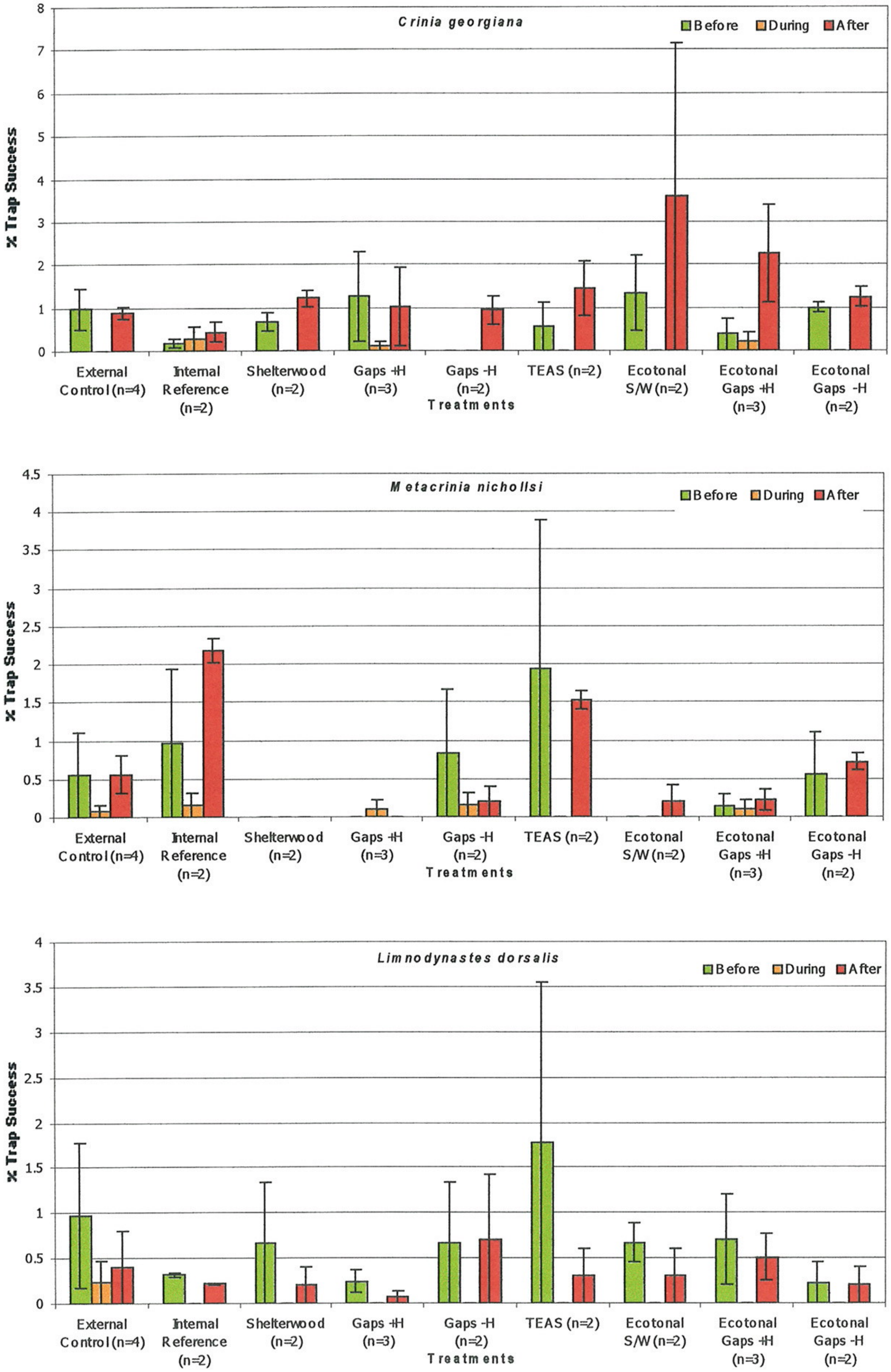


Figure 13. Mean trap success rate (%) of *Crinia georgiana* (n=187), *Metacrinia nichollsi* (n=102) And *Limnodynastes dorsalis* (n=75) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

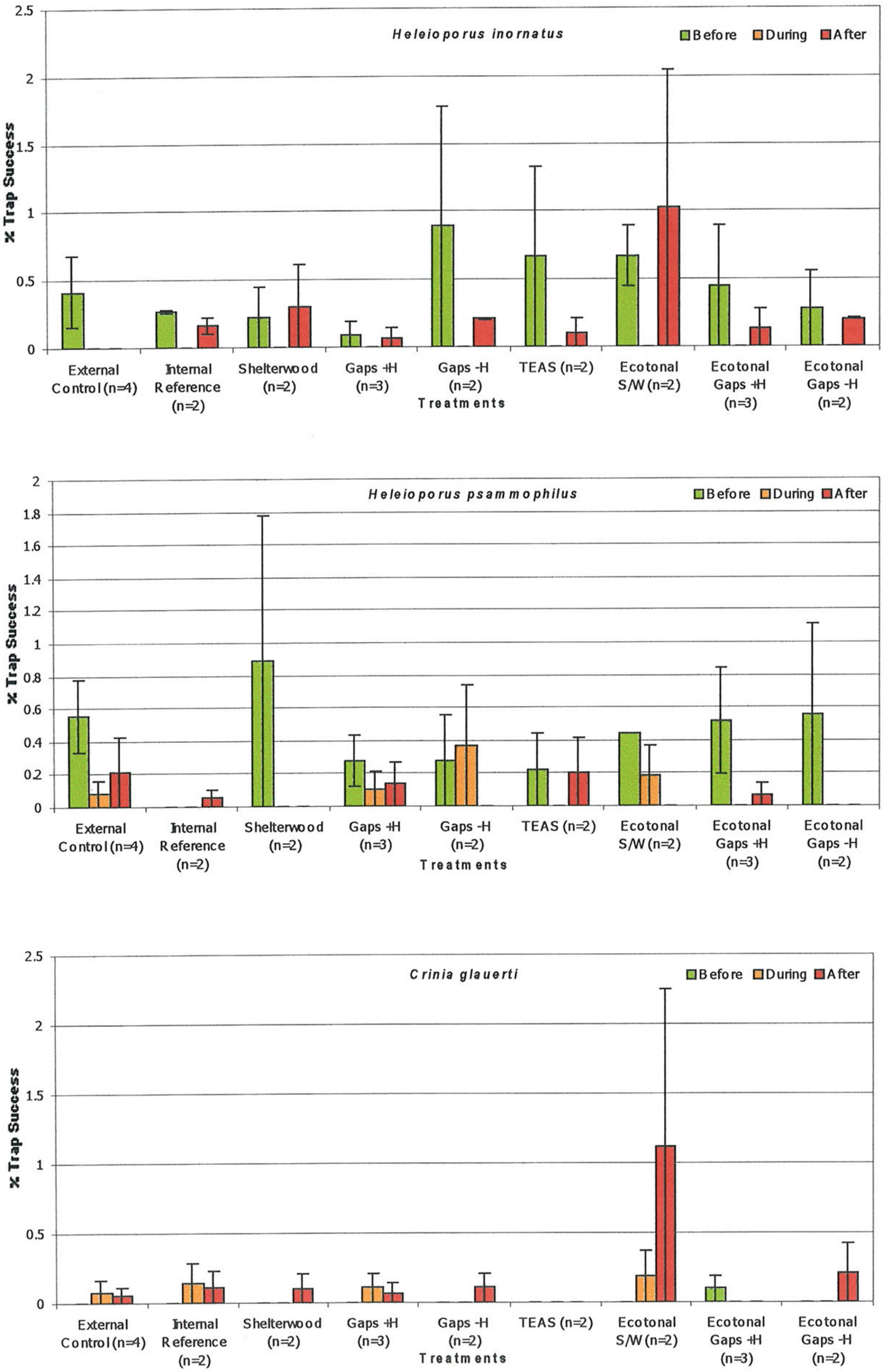


Figure 14. Mean trap success rate (%) of *Heleioporus inornatus* (n=46), *Heleioporus Psammophilus (n=36)* and *Crinia glauerti* (n=23) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

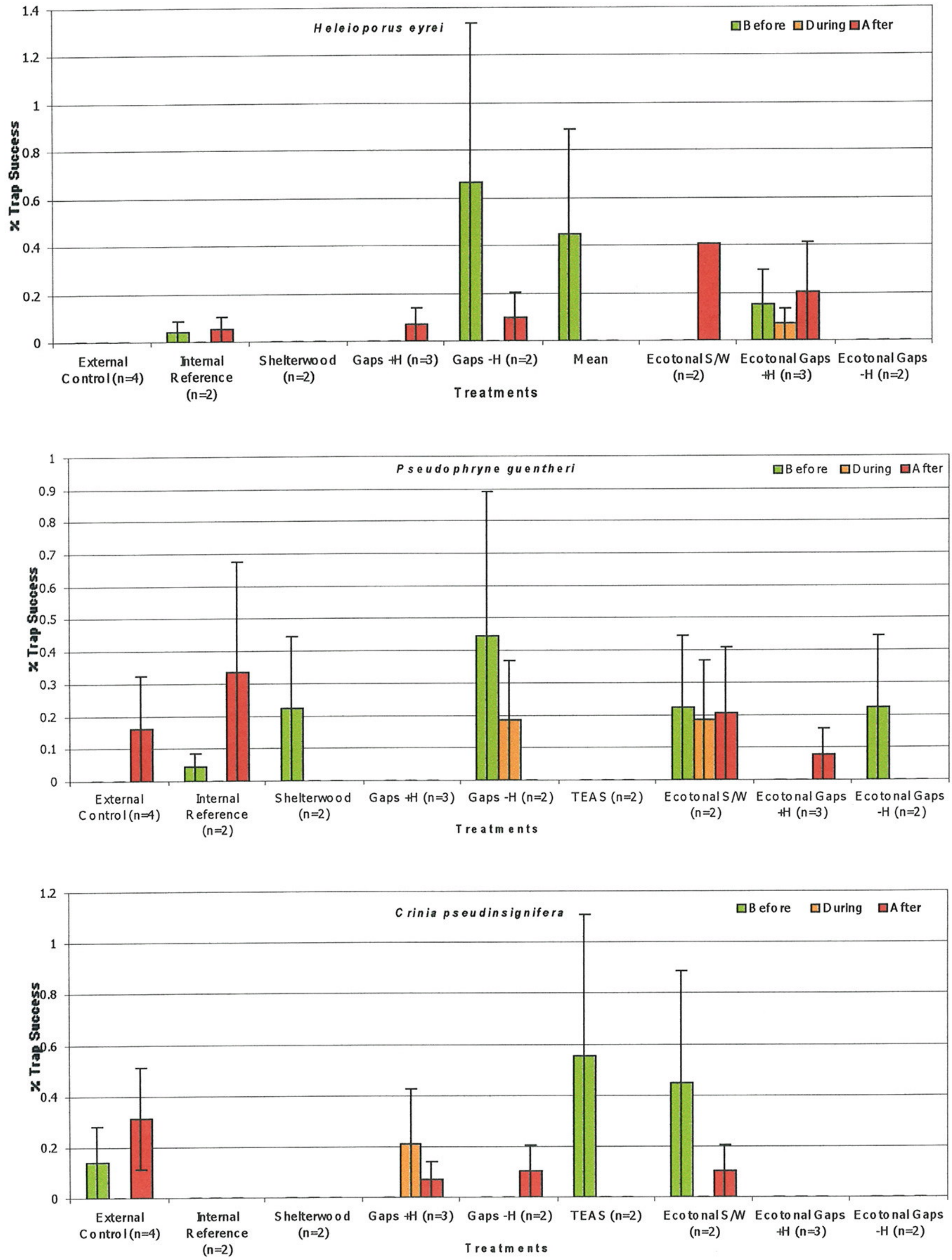


Figure 15. Mean trap success rate (%) of *Heleioporus eyrei* (n=18), *Pseudophryne guentheri* n=17) and *Crinia pseudinsignifera* (n=16) caught from pit traps on the Kingston grids, before, during and after timber harvesting associated disturbance.

Species Richness

The results of the two way ANOVA assessing the species richness per grids per trap efforts for each of the small vertebrate classes examined time in relation to logging (before, during and after) and treatments (nine treatments including the external controls). There were significant differences in the species richness over time (before, during and after logging) for mammals, reptiles and frogs (2 DF, P-values, 0.0093, 0.0001 and 0.0005 respectively). Species richness of mammals declined over time, whilst reptiles and frogs declined during harvesting and recovered afterwards to levels similar to those observed before logging (Table 6). Since the external controls behaved in a similar manner to the treatments, the direct cause of these differences is not likely to be logging (Figure 16).

Table 6. Species Richness Estimates of Mammals, Reptiles and Frogs, in relation to Logging (Before, During and After Harvesting Disturbance) at Kingston, Western Australia.

	Mammals		Reptiles		Frogs	
Logging	Estimates	Std err	Estimates	Std err	Estimates	Std err
Before	0.00141340	0.00011633	0.01232359	0.00137109	0.01388294	0.00194109
During	0.00121694	0.00011633	0.00445473	0.00137109	0.00162737	0.00194109
After	0.00083674	0.00011633	0.01606415	0.00137109	0.01313867	0.00194109

There was a significant difference between treatments in the species richness of mammals (8 DF, P-value 0.0004), however, this was not so for reptiles and frogs (P-values 0.1951 and 0.2002 respectively; Figure 17). The significance levels (P-values) of the comparisons between logging periods and between treatments are summarised in Appendix 1.

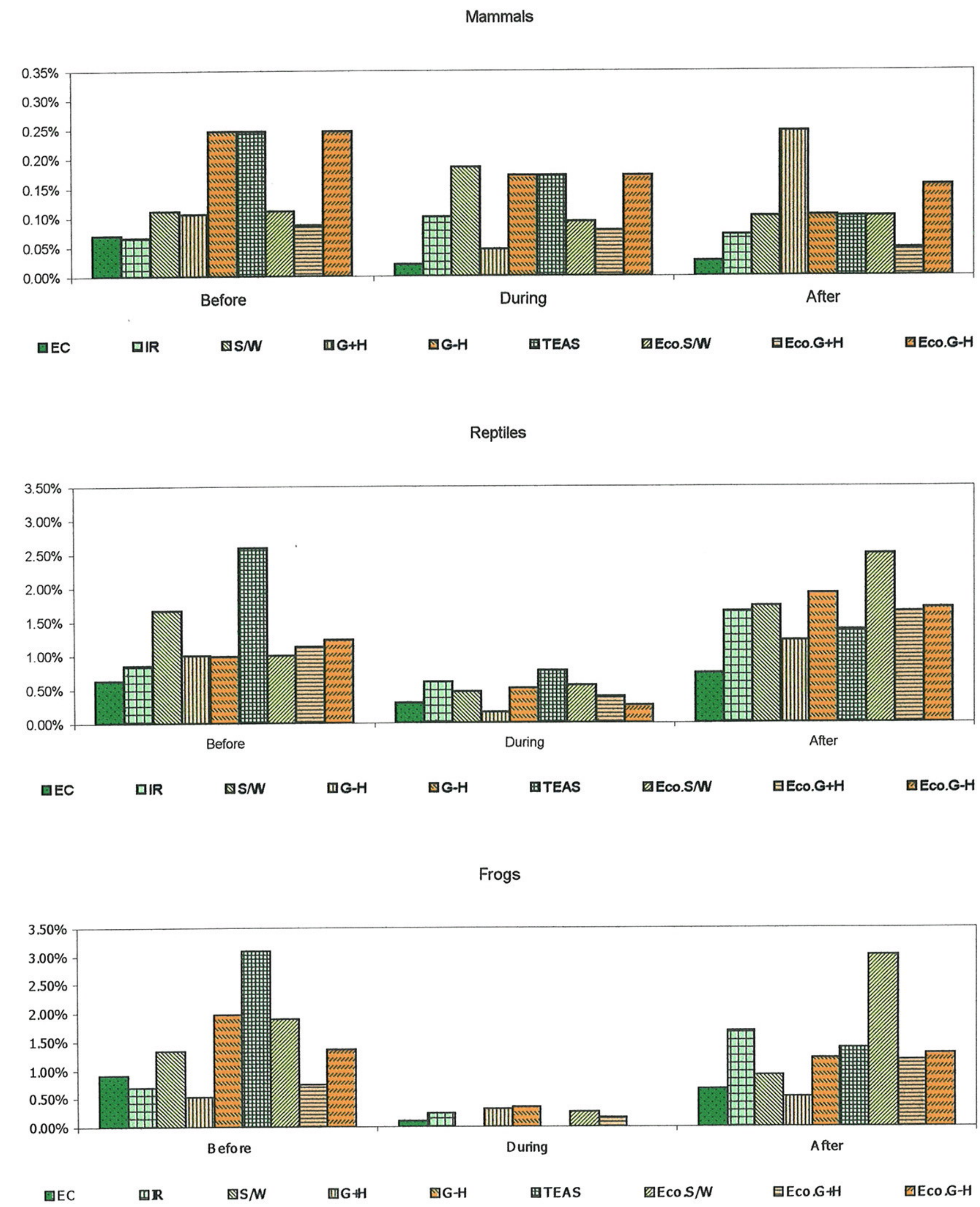


Figure 16. Relative species richness (per grid, per trap effort) of mammals, reptiles, and frogs in relation to disturbance (before, during and after timber harvesting) within the treatments of the Kingston Study.

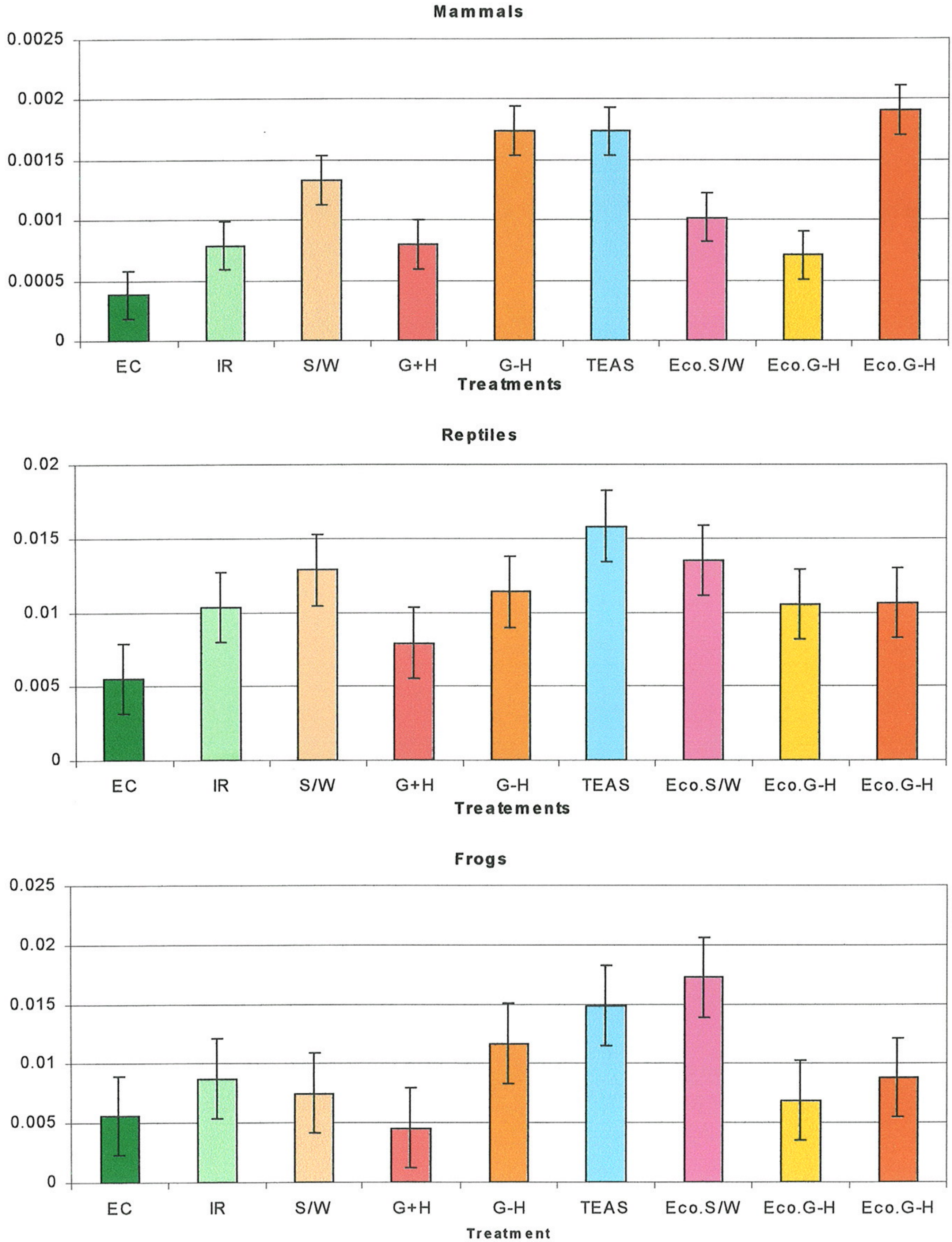


Figure 17. The relative species richness (per grid, per trap effort) of mammals, reptiles and frogs within the different logging treatments of the Kingston study.

DISCUSSION

From nearly 70,000 trap nights at Kingston over six years, the overall trap success rate for all small vertebrates was 4.1% (average 0.12% per species). Overall, there were five mammals (two dasyurids, an endemic rodent and two introduced rodents), 17 reptile species and 11 frog species captured during the study. Even for the more abundant species, the overall capture rates per trap type did not exceed 2% and the overall average species capture rates per trap type did not exceed 0.2% for frogs and reptiles and 0.6% for mammals. The small sample sizes for each species meant that relative population abundance estimates were not considered worthwhile. As a result, the trends of capture rates observed for species remained largely descriptive. A species richness analysis was used to provide a more generalised but more powerful means of analysing the impacts of timber harvesting.

The species richness of mammals trapped as part of this study was highly variable between treatments (P-value = 0.0004). Much of this variability is best explained by the overall low species richness for small mammals trapped within the Kingston area, the patchy occurrence of *Rattus fuscipes,* and the rarity of *Rattus rattus*. Although the variability of frog and reptile species richness between treatment areas was moderate (ie significantly different between only a few treatments), there was no overall treatment effect (P-values = 0.2002 and 0.1951 for frogs and reptiles respectively).

The species richness of mammals significantly declined over time (P-value = 0.0093). The declines in the species richness of frogs and reptiles were significant during harvesting disturbance but recovered to at least their former levels immediately after disturbance (P-values = 00005 and 0.0001 respectively). The capture rates for almost all small vertebrate species (*Mus* being the most notable exception) followed similar trends to those of species richness. Since the external control sites behaved in a similar manner to the treatment grids, timber harvesting cannot directly account for these changes. As a consequence, the decline of frogs and reptiles species richness and species capture rates during harvesting disturbance is most likely a sampling affect. This, however, remains to be fully examined and further tested. The decline of the mammal species richness over time was driven by the declines of the Brushtailed Phascogale (*Phascogale tapoatafa*) and Dunnarts (*Sminthopsis spp.*). These declines are discussed in detail in the subsequent section.

For all small vertebrates with greater than 40 captures and that were present before logging disturbance, all remained present within each treatment after disturbance. The trends for the more commonly caught species suggested that the abundances within treatment areas were similar to those of the undisturbed controls. However, sample sizes for most species were not sufficiently large enough to examine whether there were any significant declines in abundance as a result of logging.

Notable Species Specific Responses to Jarrah Forest Timber Harvesting

Mus domesticus is clearly a disturbance opportunist. The results from this study suggest that there is a strong positive relationship between the intensity of disturbance and *Mus* population response.

Phascogale tapoatafa was not detected on the Kingston grids after June 1995, having previously been captured in abundance. However, it is known that phascogales have not entirely disappeared from the Kingston area since there have been occasional records from road trap transects and spotlight surveys. The grid results clearly indicate that this decline is not as a direct result of logging. This is because most of the decline occurred before harvesting disturbance began within Kingston. Furthermore, the decline occurred throughout Greater Kingston, irrespective of treatment, including throughout the unharvested control areas. Similar trends were also observed elsewhere and in the absence of logging (Scarff *et al.* 1998). Although it is not fully understood, it is thought that this is part of a natural cyclical fluctuation in population abundance related to invertebrate food availability. Supporting evidence for this includes the observations made about the same time by Scarff *et al.* (1998) of animals loosing weight and reduced reproductive success. Coincident invertebrate light trap surveys conducted near Manjimup also indicate that there was a dramatic decline in invertebrate captures and biomass (Farr and Wheeler pers. comm). Therefore it is likely that the brushtailed phascogale is a 'boom-bust' species that is highly responsive to fluctuating invertebrate food abundance. The period of these population cycles, the ecology of this species and its relationships with other factors such as climate (eg. El Nino Southern Oscillation) and invertebrates, remains to be better understood.

Because of the phascogale decline in Greater Kingston before logging, this study cannot determine the impacts of timber harvesting disturbance on this species. The direct impacts of timber harvesting have, however, been studied to some extent by Rhind (1996 and 1998). An improvement on this understanding is not easily done until such time as brush-tailed phascogale numbers recover sufficiently to make any disturbance ecology research viable.

Similar, but not as dramatic trends for the Brush-tailed Phascogale were observed for *Sminthopsis*. Given that this taxon is also a consumer of invertebrates, it is not surprising that there is some commonalities in capture trends between these taxa. The relatively lower biomass demands of *Sminthopsis* individuals for invertebrate foods may explain why their abundances are sustained at greater numbers than Phascogales since 1995. In addition or alternatively, niche differences in invertebrate prey between the dasyurids may also account for the differences in the magnitude of dasyurid declines. Smaller and litter dwelling invertebrates are possibly afforded greater buffering to extreme weather and drought conditions than other invertebrates that occur in more exposed habitat, such as some arboreal species. It would follow that if there were differential declines amongst the invertebrates, that there would possibly be corresponding declines of the species that preyed upon them.

The patchiness of *Rattus fuscipes* captures is most likely related to habitat. Although it remains to be tested using the Kingston vegetation data, there was a tendency for native bush rats to be caught within the moister and/or denser habitats surveyed within Kingston. Interestingly, there were no indications of an increase in *Rattus rattus* during or after disturbance as was observed for *Mus domesticus*. This is despite the proximity of much of the forest to agricultural land. Instead captures of the black rat remained extremely rare throughout the study (only four captures in total).

The capture rates for the mammals, and particularly for the reptiles and frogs remains to be examined in relation to the vegetation, topography and soils of these sites. Although the sample sizes for each species is generally small, it is possible that such an investigation would provide some interesting ecological information about some of these species. For instance, the tendency for possible differences in micro-habitat preferences of *Hemiergis peronii* and *Morethia obscura* may well be demonstrated, such as *H. peronii* preferences for deeper litter layers and *M. obscura* for more open sandy habitats.

Records of *Metacrinea nichollsi* in jarrah forest at Kingston are an expansion of its known range and habitat use. Previous records suggested that the species was confined to the karri in the extreme southwest and Stirling Ranges (Tyler *et al.* 1994, Cogger 1994). The patchiness of *M. nichollsi* captures in Kingston is probably associated with generally deeper litter layers and/or those areas low in the profile of moderately steep valleys. The data remains to be rigorously compared with the vegetation, topography and soil information for the Kingston grids.

General Discussion Points

The species list of small vertebrates in Kingston is incomplete. Nor do the captures for each species necessarily reflect their relative abundance. This is due to the inherent biases associated with the various trapping techniques. The differences in the capture rates between pits, Elliott traps and wire cages for each species demonstrate this. There also remains the possibility that some species of small vertebrates present in the area were not recorded either because of their rarity (abundance or activity) relative to the trap effort, or incompatibility between the species ecology and the trapping methods. For example, the difficulty of capturing snakes with the trap types used and the inefficiency of surveying those reptiles with subterranean habits resulted in very few or possibly no captures for these ecotypes. The Kingston species list is therefore probably an underestimate of the species richness for the area. The capture of *Rhinoplocephalus gouldii* on one of the trap grids only a few months after the formal completion of the Kingston small vertebrate fieldwork provides evidence for this.

It is important to gauge the magnitude of the trap effort required to provide a large enough dataset to allow reliable and robust analysis for jarrah forest small vertebrates. As well as the magnitude of the trap effort, the timing of the surveys also has important implications on the results. Particularly for the small vertebrates, there can be substantial seasonal differences in the species captures. For instance, the post-breeding male die-off characteristic of many of the small dasyurids has implications for abundance estimates. More challenging is the effort required to adequately survey frogs and reptiles. For much of the herpetofauna, periods of high activity, and therefore potential trapability, can be acute, and closely related to season and weather. As a consequence, trap captures can be highly variable over time and between species. For example, some but not all frog species seem more likely to be trapped when the first few days of substantial autumn rain break the summer drought. For other frog species, their peak capture rates are during other times of the year. Similarly and more generally, the conditions more conducive for high frog captures are often entirely different for those of many reptiles. Therefore, if small vertebrate surveys are going to be comprehensive and useful, in addition to requiring substantial effort, the surveys need to be frequent to improve the chances of surveying during the peak periods for each of the species. These surveys also need to be sustained over a number of years in order to account for annual differences.

The need for a long-term survey regime for ecological studies such as this is no better emphasised than by the brushtailed phascogale (*Phascogale tapoatafa*) which appears to be subject to natural cyclical fluctuations that may occur over decades at least. Long term surveys of species such as the brush tailed phascogale would need to be at least 10 to 20 years in duration to better understand their ecology in a manner that would be helpful to relate how disturbances such as timber harvesting may affect this species. The use of a range of survey and trapping techniques also minimises the influence of the inherent biases of any one technique and therefore strengthens the comprehensiveness of such a study. For frogs as an example, in addition to the use of various trap types, it would be useful to survey frog calls throughout the seasons. In so doing, some species would be better surveyed than others using different methods.

Implications for Management

The introduced house mouse is clearly a disturbance opportunist that exploits at least the early years post harvesting. Furthermore, the greater the level of disturbance the tendency for a greater population response. This has potential implications for any native fauna with which the house mouse may compete with for resources as well as direct implications for the species that are preyed upon by mice. Interestingly the introduced black rat did not behave in a similar manner at Kingston, however, the potential does remain that under different conditions, the black rat increases in numbers in response to disturbance.

Although the results from Kingston do not indicate that there are any species of small vertebrates that are significantly and detrimentally affected by current jarrah forest harvesting activities, the small sample sizes for most species does not negate the potential that some of these species are negatively impacted. Further research is clearly required to resolve the potential impacts of timber harvesting on the small vertebrates of the jarrah forest.

Future Research

A more intensive and more frequent sampling program would be required to collect sufficient data to minimise the chances of a Type II error (ie. when the null hypothesis is not rejected when in fact there is a difference). Furthermore, those species that are potentially at greater risk from disturbance tend to be those that are rare and/or more specialised – the very species for which it may generally be more difficult to collect adequate field data. As a consequence, it may be logistically extremely difficult if not impossible to get sufficient data to confidently determine any potential impacts via this approach. This considered, alternative approaches would need to be explored, such as a retrospective study, and/or the use of Bayesian approaches to hypothesis testing (eg. Johnson 1999 and Crome *et al.* 1996), with emphasis on biological significance. Another potentially useful approach would be indirectly through an improved understanding of the ecology of these species. By understanding their ecology, more accurate predictions could be made on how these species may respond to various disturbances.

The intensive trap effort, frequency and duration of surveys required to collect sufficient data for useful and interpretable results has implications for any future research or monitoring of small vertebrates within the southwest forest, such as FORESTCHECK (CALMScience).

The dependence on trees for habitat makes the brushtail phascogale one of the species potentially at greatest risk from disturbance such as timber harvesting. In addition, the brushtail phascogale is currently listed as a priority 3 species. Clearly if there is a negative impact on a species whilst it is in a cyclical low, and the potential for recruitment through immigration is limited, the potential for recovery may be compromised. It is therefore important that both research and management recognise this species as a priority for future work. For example, it would be useful to undertake long-term research into the brushtail phascogale ecology in conjunction with other anticipated important factors such as climate, weather and invertebrate abundances (also fox control, logging history, habitat, and dieback).

ACKNOWLEDGMENTS

Gordon Friend and Brent Johnson designed and initiated this study, which was subsequently supervised by Keith Morris in 1996 before custody of the program was based from Manjimup in 1997. Graeme Liddelow has assisted with much of the grid trapping since 1997. Manjimup District staff have assisted with field support and operational information. Throughout the study, the field data collection has been assisted by a great number of volunteers. Matthew Williams has provided statistical advice and support, and provided useful comments on an earlier draft of this manuscript. Verna Tunsell has assisted with some of the formatting of the manuscript. Paul Davies provided mapping support. To all of these people, the authors are deeply grateful.

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Appendix 1. Results of single degrees of freedom accessing changes in species richness per grids per trap efforts for selected periods.

		Mammals P-value	Reptiles P-value	Frogs P-value
Logging	Before vs During	0.2498	0.0009	0.0004
	Before vs After	0.0029	0.0716	0.7898
	During vs After	0.0345	0.0001	0.0007
Treatments	External Control vs Internal Reference	0.1744	0.1698	0.5229
	External Control vs Shelterwood Creation	0.0044	0.0442	0.7015
	External Control vs Gaps +H	0.1668	0.4849	0.8236
	External Control vs G-H	0.0002	0.1000	0.2211
	External Control vs TEAS	0.0002	0.0075	0.0696
	External Control vs Eco.SW	0.0404	0.0302	0.0266
	External Control vs Eco.G+H	0.2702	0.1542	0.7984
	External Control vs EcoG-H	0.0001	0.1474	0.5131
	Internal Reference vs S/W	0.0773	0.4660	0.7960
	Internal Reference vs G+H	0.9788	0.4803	0.3920
	Internal Reference vs G-H	0.0042	0.7618	0.5439
	Internal Reference vs TEAS	0.0044	0.1240	0.2148
	Internal Reference vs Eco.S/W	0.4308	0.3607	0.0927
	Internal Reference vs Eco.G+H	0.7836	0.9545	0.6991
	Internal Reference vs Eco.G-H	0.0012	0.9335	0.9877
	S/W vs G+H	0.0812	0.1611	0.5460
	S/W vs G-H	0.1680	0.6670	0.3902
	S/W vs TEAS	0.1725	0.3935	0.1396
	S/W vs Eco.S/W	0.2964	0.8484	0.0570
	S/W vs Eco.G+H	0.0457	0.5008	0.8977
	S/W vs Eco.G-H	0.0582	0.5174	0.7841
	G+H vs G-H	0.0045	0.3179	0.1531
	G+H vs TEAS	0.0046	0.0322	0.0453
	G+H vs Eco.S/W	0.4460	0.1156	0.0168
	G+H vs Eco.G+H	0.7634	0.4464	0.6333
	G+H vs Eco.G-H	0.0013	0.4313	0.3838
	G-H vs TEAS	0.9874	0.2070	0.5115
	G-H vs Eco.S/W	0.0226	0.5359	0.2599
	G-H vs Eco.G+H	0.0023	0.8054	0.3258
	G-H vs Eco.G-H	0.5594	0.8259	0.5540
	TEAS vs Eco.S/W	0.0233	0.5046	0.6262
	TEAS vs Eco.G+H	0.0024	0.1370	0.1114
	TEAS vs Eco.G-H	0.5490	0.1434	0.2202
	ECO.S/W vs Eco.G+H	0.2929	0.3903	0.0444
	ECO.S/W vs Eco.G-H	0.0066	0.4045	0.0953
	ECO.G+H vs Eco.G-H	0.0007	0.9790	0.6878