4.4. Predators

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Abstract

Predator activity and fox control operations in the Upper Warren region were investigated in relation to their possible association with recent woylie declines. Predator activity surveys, using sandpads, were conducted at the five Upper Warren Population Comparison Study sites during the 12 months commencing August 2006. The surveys were conducted immediately prior to and after the quarterly fox-baiting events performed by DEC as part of the '*Western Shield*' program and Donnelly District conservation management.

Cat activity was least at sites with stable and high woylie abundance and greatest at Balban where woylies were currently declining, however, overall there was no statistically significant difference between sites. The preliminary evidence remains consistent with cats potentially having a role in the decline of woylies, however, it is premature and there is insufficient data to determine the strength or nature of this association.

Fox activity was significantly different between sites and generally increased overtime, particularly from February 2007. Fox activity did not differ significantly between pre and post fox-baiting and whether this is related to baiting effectiveness is uncertain due to limitations in the data and statistical power. Fox control activities have been highly variable in the Upper Warren region since 1996. Although generally within the *Western Shield* baiting framework, intervals in the fox control program have frequently occurred. More strategic spatial and temporal considerations of fox control, particularly in relation to fox biology, would be expected to substantially improve effectiveness with negligible impact on existing resources.

Methodological considerations of sandpad monitoring are also addressed. Sandpads across the full length of forest tracks are preferable to the 1 m^2 plots previously used in the region and passive sandpads were found sufficient for measuring fox and cat activity. The activity indices (AI) derived from the sandpads closely matched the capture rates for other fauna species.

Ongoing monitoring of predator activity and/or abundance would be extremely valuable and highly recommended for the Upper Warren and elsewhere where predator control is conducted and fauna conservation is considered a high priority.

4.4.1. Introduction

One of the multiple competing hypotheses (*sensu* Peery *et al.,* 2004) of the Woylie Conservation Research Project is the possible role of predators in the recent woylie declines. Likely predators include the introduced fox and cat, and native predators, such as the chuditch and the wedge-tailed eagle. The likely role of predation is supported by the evidence that the fox was principally responsible for historical declines of woylies across its former range throughout southern and central Australia (Burbidge and McKenzie, 1989; Start *et al*., 1995) and the spectacular recovery of the species in the presence of fox control (e.g. Start *et al*., 1998).

To assess potential associations between predators and woylies sandpad surveys were conducted at the five Upper Warren Population Comparison Study (PCS) sites.

The primary aims of the PCS predator investigation were to;

1. Measure predator activity at the Upper Warren PCS sites (fox, cat and chuditch)

2. Collate the history of predator control operations in the Upper Warren region
3. Assess the timing of current fox control activities in relation to significant rainfall events (i.e. assessment of potential baiting effectiveness)
4. Relate predator activity to the fox baiting program (i.e. compare predator activity pre and post baiting), and
5. Relate all of this evidence to the patterns of recent woylie declines (spatial and temporal)

This research also provided an opportunity to consider aspects of the sandpad methodology used to examine predators for the purposes of improving its use in possible future applications. Therefore, secondary, (methodological) aims of this research included;

1. Assessment of sandpad design – differences in the detection of predators on passive versus active sandpads (i.e. the use of selected audio and olfactory lures)
2. Development of improved sandpad survey methods (opportunistic)
3. Use of sandpads as an indicator of activity of native fauna (e.g. chuditch, woylie, koomal, and species not readily trapped such as large macropods).

This report predominantly focuses on the introduced fox and cat given their higher likelihood of being involved in recent woylie declines compared with the native predators, which are themselves conservation-listed species. Elements of the predator investigation not addressed in this report include; i) predator scats (predominantly chuditch) collected for dietary analysis, ii) chuditch population data from cage trapping activities, and iii) wedge-tailed eagle records of active nest sites and sightings. This data will be used for possible future investigations. Based on the existing records of opportunistic sightings it is considered unlikely that the wedge-tailed eagle has increased sufficiently in density to be primarily responsible for the substantial and rapid woylie declines within the Upper Warren region and so have not been addressed in detail in this report.

4.4.2. Methods

4.4.2.1. Upper Warren site descriptions and history

The predator component of the project involved all of the Population Comparison Study (PCS) sites – Keninup, Balban, Warrup, Boyicup, Winnejup and Karakamia Wildlife Sanctuary.

Fox baiting history

Historically, predator control within the Upper Warren region was predominantly done for agricultural and stock protection purposes, principally by local farmers and typically in an uncoordinated and sporadic manner using a range of methods. Opportunistic and targeted shooting (and sometimes baiting) of foxes and cats by farmers continues and remains variable spatially, temporally and methodologically. Although this is difficult to quantify, it should be considered as another factor that may relate to observed predator activity levels.

Fox-baiting for the conservation of native fauna and research occurred in two areas of Perup Nature Reserve between 1977 and 1990 (Burrows and Christensen, 2002). Some areas, particularly in the northern part of the Upper Warren, also were occasionally ground-baited to reduce wild dogs (*Canis familiaris*) and foxes and protect nearby livestock between 1986 and 1992. Between 1992 and 1998, a strategy was introduced to ground-bait selected areas for conservation purposes, the selection being based partly on the existing diversity and abundance of native medium-sized mammals (I. Wilson, unpublished data). Extensive aerial fox-baiting (four baitings per year) within most of the publicly-managed forests of the Upper Warren began in 1996 as part of the '*Western Shield*' conservation programme (Department of Conservation and Land Management, 2000; Orell, 2004).

As part of the current *Western Shield* program the area encompassing the PCS sites is aerially baited four times per year. Ground-baiting is conducted in conjunction with the aerial baiting program but concentrates on the interface between private property and DEC-managed estate.

PCS sites in relation to agricultural activities

The potential impact of DEC-managed predator control activities on each of the PCS sites differs based on proximity, interface and extent of private property within the area. The location of each sandpad array and the relevance of each of these variables can be seen in Figure 4.4.1. when overlaid with the aerial and ground baited zones.

Keninup (Figure 4.4.2.) has the greatest extent of forest edge to private property as it is on the northern extent of the aerially baited zone and is adjacent to unbaited land to the north, east and west. In comparison Balban (Figure 4.4.3.) has the least cleared agricultural land to forest ratio but there is a large corridor leading into the southern end of Balban that is not aerially baited. Unlike both Keninup and Balban there are no sandpads greater than 500 m away from the aerially baited zone within Warrup (Figure 4.4.4.), Boyicup (Figure 4.4.5.) or Winnejup (Figure 4.4.6.). The Warrup array is contained the most within the aerial bait zone, and has only a small pocket around private plantations excluded.

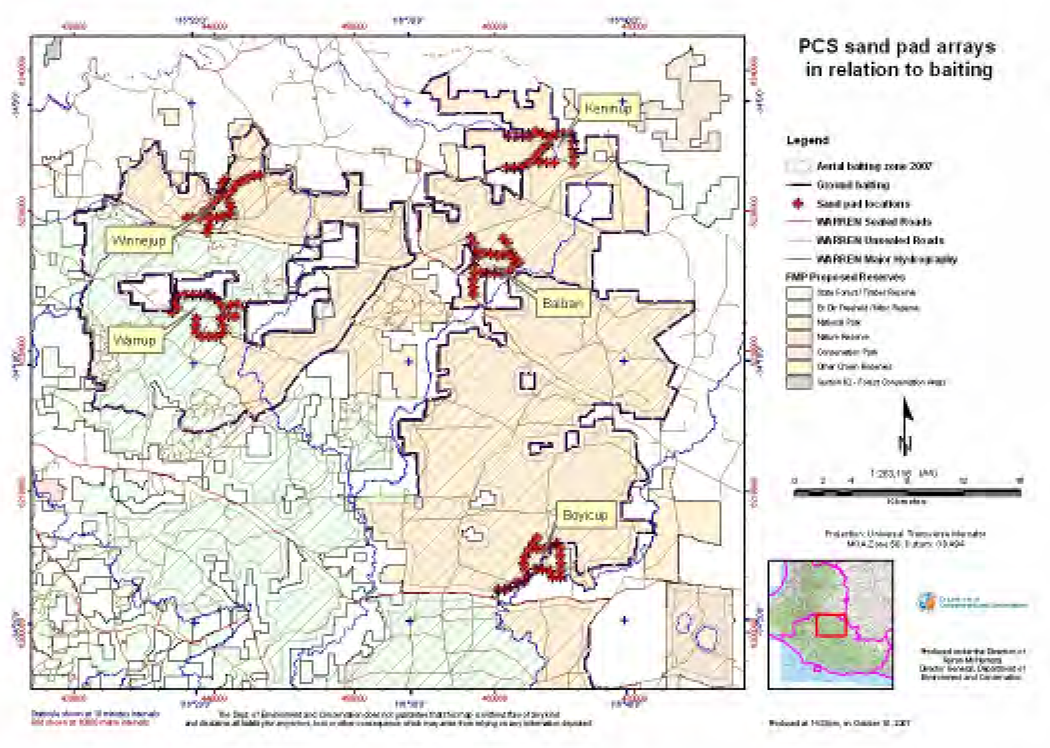


Figure 4.4.1. Overview of the sandpad arrays within the PCS sites in relation to aerial and ground-baited zones.

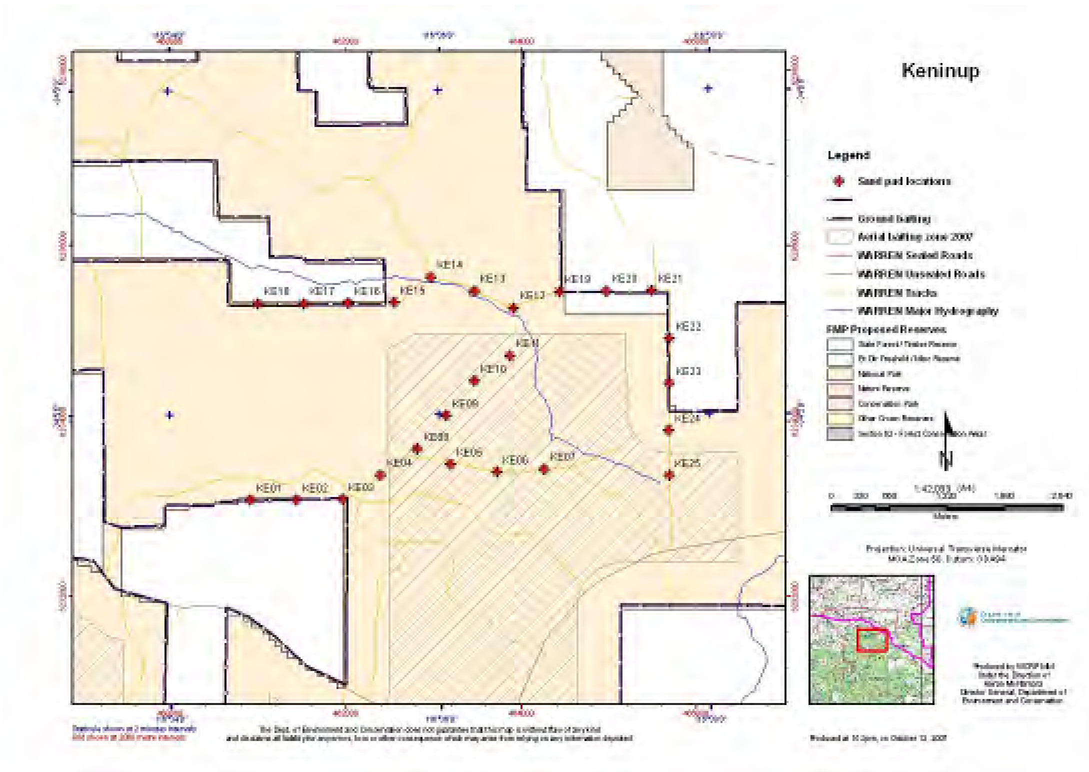


Figure 4.4.2. Keninup sandpad array.

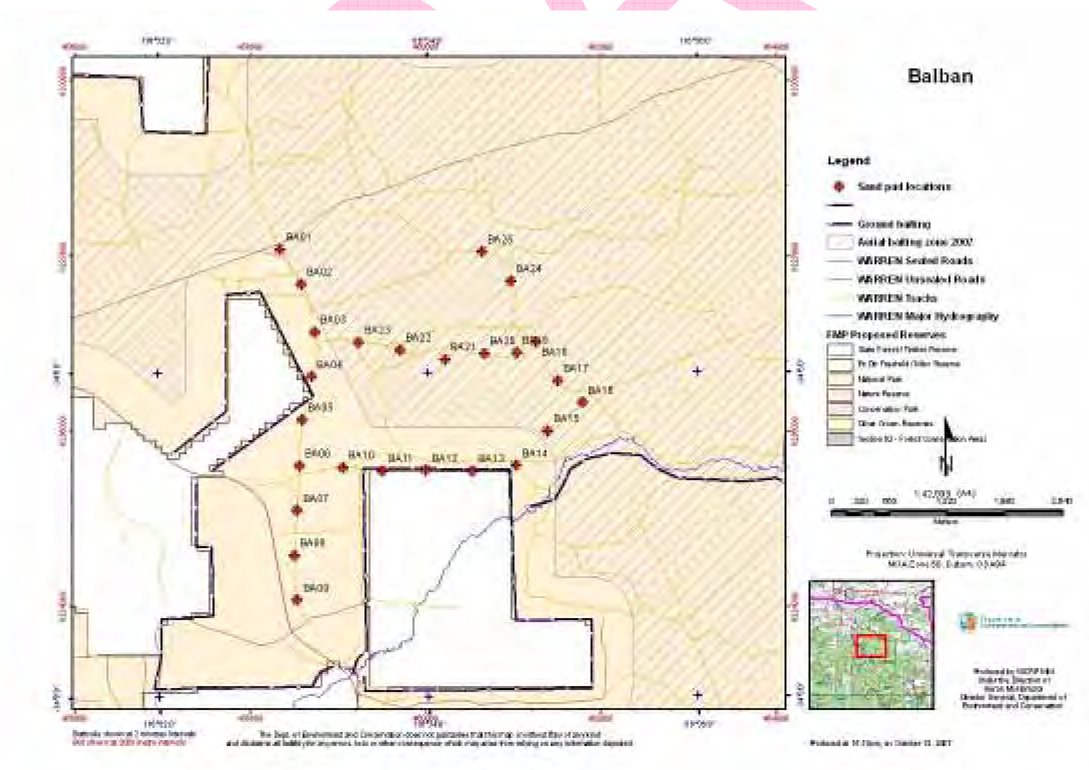


Figure 4.4.3. Balban sandpad array.

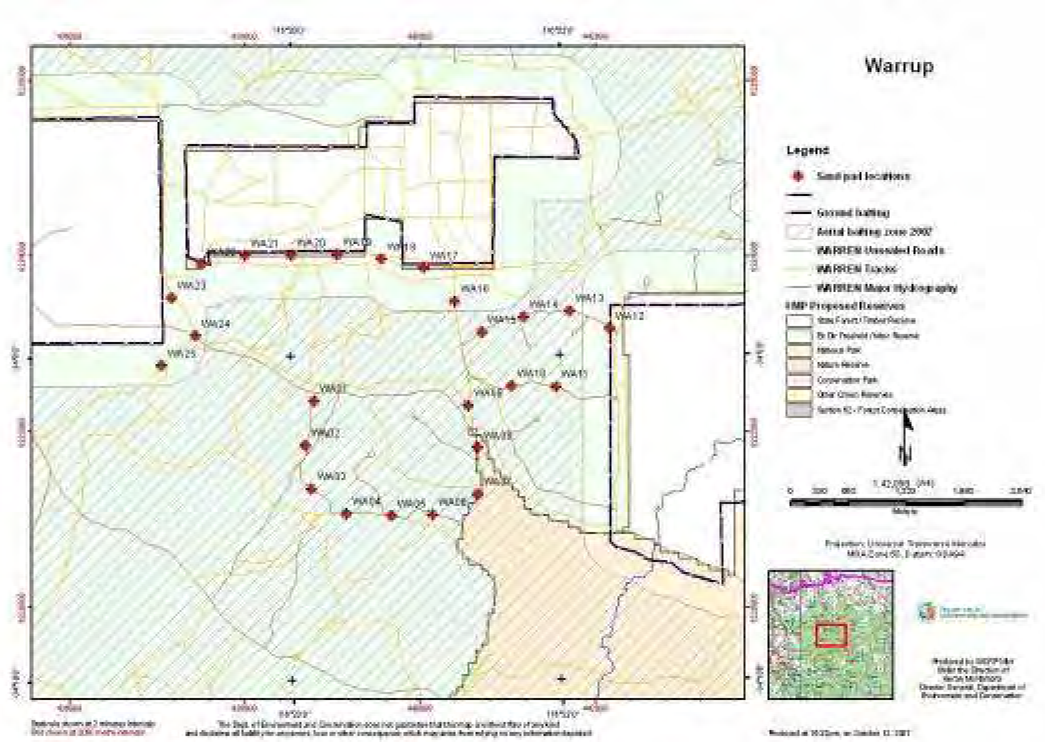


Figure 4.4.4. Warrup sandpad array.

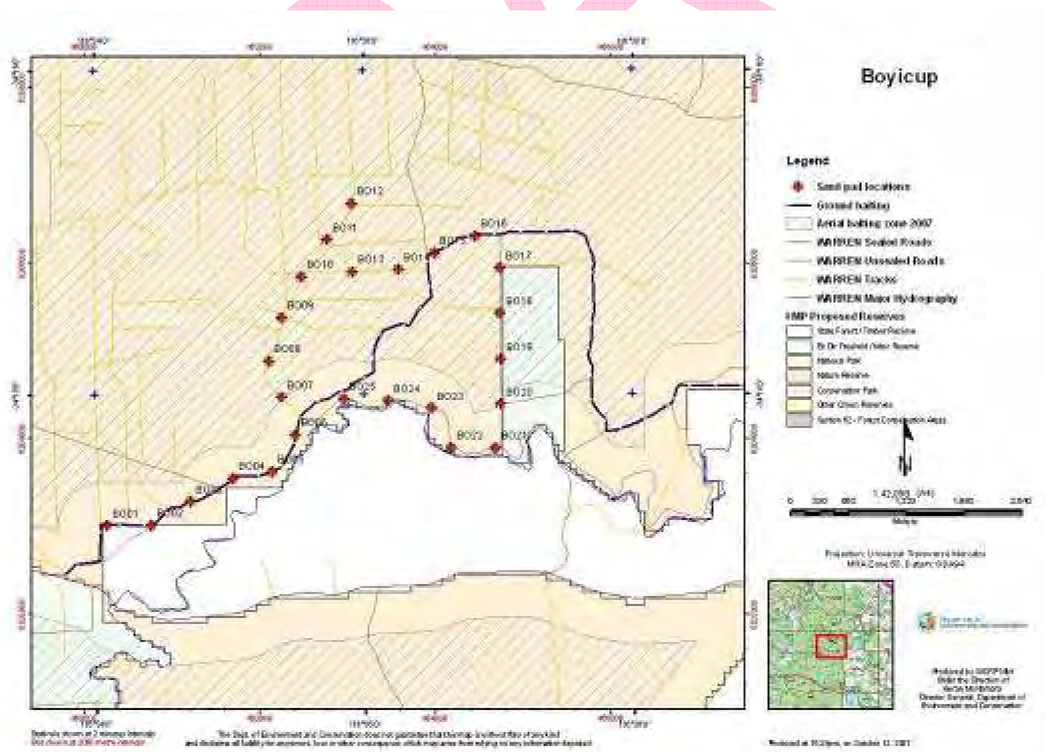


Figure 4.4.5. Boyicup sandpad array.

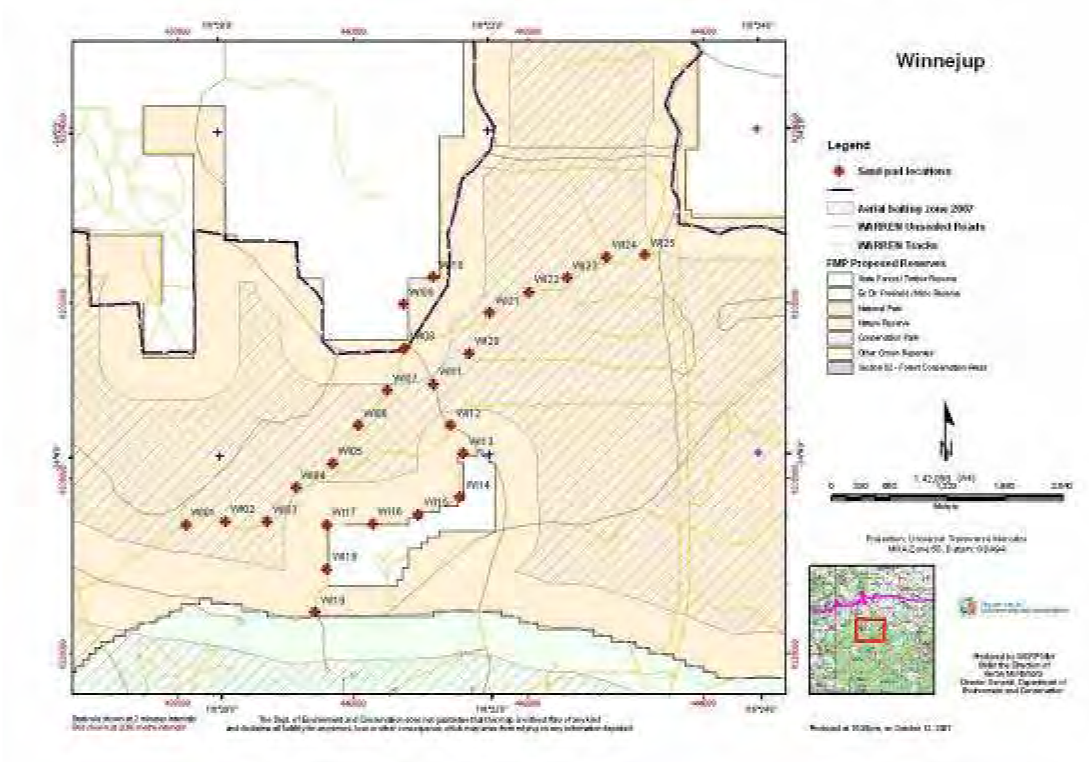


Figure 4.4.6. Winnejup sandpad array.

4.4.2.2. Karakamia

Karakamia Wildlife Sanctuary (managed by AWC) is surrounded by a 'predator-proof' fence and considered free of introduced predators. Predator surveillance is continual and control methods are only used when there is an incursion (Schmitz and Copley, 1997). Monitoring involves checking fence condition by quad bike once a week and then a close check by walking the fence once every 1-2 months. The functionality of the electric fence and gate are checked daily. A series of 14 sandpads on the inside of the fence line and one in the core are also checked opportunistically. General signs of predator incursion are continually monitored, including predator scats particularly along the boundary fences, and visual surveillance (Trish Gardner, pers. comm.).

In the last 15 years there have been at least three fox incursions. One of these was as a result of fence damage caused by a bushfire in 1996. Another was due to gate malfunction. These foxes were removed by 1080 baiting, utilising the sandpads. One cat was enclosed within the fence during the addition of a parcel of land to Karakamia and was target-trapped for removal (Trish Gardner, pers. comm.).

Natural predators do exist within Karakamia. These include a pair of breeding wedge-tailed eagles (Cherriman, 2007). Carpet pythons have been opportunistically observed with fresh woylie carcasses and have consumed radio-collared animals (Trish Gardner, pers. comm.). Chuditch have been caught during trapping surveys (Jacqui Richards, pers. comm.), although chuditch have not been released into the reserve (Trish Gardner, pers. comm.).

Given that Karakamia is effectively predator free, the Karakamia woylie population is not going to be addressed any further in this report in relation to predators.

4.4.2.3. Survey (Sandpad) design

Sandpad array

For each Upper Warren PCS site an array of 25 sandpads, spaced no closer than 500 m apart, were distributed along existing tracks and roads. Attempts were made to use tracks infrequently used by vehicle traffic (i.e. minimise pad disturbance) and arranged as compactly as practical to provide site-specific data. Consideration was also given to achieving a representative balance between forest edge and forest away from agricultural land.

Survey timing

The timing of surveys were directly associated with the quarterly fox-baiting events, although the exact timing of these events were not precisely known in advance (i.e. dependent on weather, availability of contractors, baits, etc). The objective was to conduct the pre baiting surveys as close to the anticipated baiting event as possible, and within a maximum of four weeks. Post-bait survey sessions were aimed to start at least 10 days and less than four weeks after the completion of a baiting operation. The surveys were conducted concurrently at each site, with pre-bait sessions in August and December 2006, February and June 2007 and post-bait surveys in October 2006, January, April, and July 2007.

Sandpad dimensions and characteristics

The sandpads were at least one metre wide x 50-100 mm deep across the entire track from ‘batter to batter’. Depending on the width of the track this varied from three to five metres.

The minimisation of the risk of introducing and/or spreading plant dieback from *Phytophthora* infection was a particularly high priority for the construction and operation of the sandpads (i.e. best-practice observed). The sand used on the pads was sourced locally from a sand pit near Manjimup that was managed under strict hygiene conditions, and was considered *Phytophthora* free (confirmed by soil analysis - 10 samples tested negative by Vegetation Health Service, DEC Science Division, 17 Dick Perry Ave, Kensington, WA 6152).

The sandpads were constructed using either a kanga or backhoe to dig a shallow trench, which when filled with sand was approximately flush to the surrounding ground surface. Gypsum was added to all sandpads during the December survey and mixed through with a mechanical cultivator, to improve sandpad quality.

Sandpad preparation

Refer to the WCRP Operations Handbook (Volume 3) for a detailed description of the operational protocols and a materials list. In summary, the preparation of the sandpad involved clearing debris, ‘harrowing’, and sweeping to achieve a flat, consistently light and friable substrate suitable for reading sign from vertebrates. Adding moisture to very dry sandpads was not routinely done given that superficial application resulted in an undesirable surface crust and more complete sandpad moisturising was logistically impractical.

Alternate sandpads were consistently passive (no lure) and active (lure) along each sandpad array (12 and 13 pads respectively). The active sandpads had both a scent and auditory lure. A capful of fish oil (Bait Mate Tuna Oil©, 6/61 Buckingham Drive, Wangara WA 6065) was placed in the centre of the sandpad between the wheel ruts and replenished every day of the survey. A FAP (Felid Attracting Phonic) was tethered at one end of the sandpad in the same place each survey session.

Data protocols and collection

- Refer to the WCRP Operations Handbook (Volume 3) for a detailed description of the data recording protocols and ‘data sheet’.
- The key species recorded from the sandpads included the cat, fox, chuditch, woylie, koomal and macropod. All other fauna including quenda, birds, reptiles, etc were also recorded in an “other” field.

- A print identification confidence rating was applied to each record (1-certain, 2-probable, 3-possible).
- Pad condition was described, e.g. ok, washed out by rain, etc.
- Weather conditions were recorded particularly in reference to local rain events given the variability between sites and during the day.
- Description of predator activity included the size, direction and location of foot prints on the sandpad, and number of sets of prints. Also whether the predator visited the FAP and / or olfactory lure.
- Predator scats found on the sandpads were collected, labelled and dried (3-4 days at 35 degrees centigrade) and stored at room temperature. These remain available for DNA confirmation and diet analysis.
- Photographic records were taken for reference purposes and for unusual or difficult to identify prints.

4.4.2.4. Measures of predator activity

Predator activity index is a relative measure of encounter rate that can be used as a simple estimation of the probability (or risk) of a woylie encountering a predator, notwithstanding the assumptions required to do so (i.e. activity, behaviour, and interactions between and within prey and predator species). This is likely to be more useful than estimates of predator density/numbers derived from sandpad encounter data given the additional assumptions and limitations associated with converting activity-based data into population estimates.

Allen's activity index

Originally developed for dingoes, the Allen's index (Allen *et al.,* 1996) is applicable for other species. In summary, the Activity Index (AI) for a species (per site/session) is the average of the daily calculation of the total number of sandpads with confidently-identified prints divided by the total number of available (readable) sandpads. Only records with a confidence rating of one were included in analysis. A variant (EPA / QLD PWS, 2007) of the Allen Activity Index was used in this study. The basis of the variation to Allen's AI is the decision set for determining the available pads as the denominator and the number of sets of prints for a species to be used as the numerator.

A more robust AI can be calculated if all sandpads that don't have the potential to leave clear prints are removed from the AI calculation. In this study, field comments on sandpad condition were classified as an estimate of decipherability (1 = good - ok; 2 = moderate, 3 = poor). However, consistency and subjectivity issues associated with this approach were problematic, and so, was not used in the final analysis. Instead, survey days where sites were affected by heavy overnight rain were removed from the analysis, and individual sandpads were only removed if disturbed by vehicles and stock, irrespective of the extent of disturbance.

The presence/absence of confidently-identified prints on a sandpad was used in this study, as opposed to Allen *et al.,* (1996), by which the number of sets of prints was used. In so doing, this study avoids the need to consider assumptions of independence between sets of prints.

Changes in activity indices for each species were estimated using a generalized linear model. Any temporal trend in activity was accounted for by using a quartic polynomial (i.e. effects were fitted for the first four powers of time) as a covariate, before testing for site differences and changes pre- and post-baiting (treatment effects), and their interaction. Models were fitted using SAS statistical software (SAS, 2006).

4.4.3. Results

4.4.3.1. Fox baiting history

Aerial baiting

Table 4.4.1 summarises the timing of all aerial baiting sessions in relation to the amount of rain for the Upper Warren region, since the commencement of *Western Shield*. The timing of baiting has not been consistent over time. The number of baiting sessions per year has ranged from 3 - 6 (average=4).

The interval between successive aerial baiting sessions ranged from 40 to 189 days (average=90.9, SE=4.22). Winter baiting events have been more frequently associated with substantial rain than not – 54% of baiting events in June/July were associated with >40 mm rain within two weeks after baiting. A total of 20.9% of all aerial baiting events were associated with >40 mm rain within two weeks after baiting. If these high rainfall events were considered likely to be ineffective at fox control, the interval between successive effective baiting events has been up to nine months (2003).

Ground baiting

The Upper Warren region is divided into two cells for ground baiting, Kingston and Perup. Hand baiting duration for the Kingston cell ranged from 1 - 13 days (average=2.2, SE=0.28) and for the Perup cell, 2 - 13 days (average=4.9, SE=0.50). Aerial and ground baiting have not been conducted simultaneously. The lag between aerial and hand baiting for the Kingston cell ranged from -15 - 64 days (average=6.9, SE=2.44). The lag for the Perup cell ranged from -10 - 42 days (average=13.7, SE=2.11) (Table 4.4.2.). On nine occasions either the Perup or Kingston cell was not ground baited at all following aerial baiting. The period between successive Kingston ground baiting sessions ranged from 25 - 279 days (average=98.2, SE=6.48) and for Perup the range was from 52 - 294 days (average=100.4, SE=6.87). The largest intervals in the baiting program generally occurred over the summer months from December to April, coinciding with the dispersal period of young foxes (Saunders *et al.,* 1995; de Tores, 1999; Thomson *et al*., 2000).

Table 4.4.1. Aerial fox baiting history in the Upper Warren in relation to rain.

Year / month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996											X	
1997			X			X				X		
1998				X		X				X		
1999	X		X		X		X			X		X
2000				X			X				X	X
2001				X		X				X		X
2002			X				X		X			X
2003			X			X			X			X
2004			X			X			X			X
2005				X			X		X			X
2006			X				X		X			X
2007			X			X						

X < 30 mm rainfall in 14 days post baiting = assumed effective

X = 30 mm - 40 mm rainfall in 14 days post baiting = possibly effective

X > 40 mm rainfall in 14 days post baiting = potentially ineffective

Table 4.4.2. Ground baiting history for the Kingston and Perup cells of the Upper Warren region including number of lag days between aerial and ground baiting sessions.

		Month											
Year	**Site**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1997	K	-12		*	16		*	19			*-8		
	P	7		*	30		*	22			*-3		
1998	K				*	34	-7	*			*3		-12
	P				*	19		*5			*17		
1999	K	*		*	11	*		*-6			*	20	*
	P	*	36	*	22	*		*2			*	32	*
2000	K				*-7			*-15				*17	*
	P				*	8		*-8				*	*
2001	K				*	11	*		64		*4		*
	P				*	17	*			-10	*		*
2002	K			*				*-2		*7			*0
	P			*	11			*5		*	14		*-8
2003	K			*	24		*-1			*8			*6
	P			*	27		*8			*	23		*14
2004	K			*	20		*14			*9			*
	P			*	28		*21			*16			*
2005	K	21			*15			*-9		*9			*5
	P	23			*24			*-1		*	42		*
2006	K			*6			-15	*		*7			*0
	P	11		*	25			*-5		*	13		*2
2007	K			*9			*-1						
	P			*13			*4						

K=Kingston cell, P=Perup cell

*aerial baiting event

No. of days = difference between last day of aerial baiting and last day of ground baiting.

4.4.3.2. Species detected from sandpads – raw data

The incidences of cat and fox records were low relative to chuditch (except Boyicup) and native 'prey' (Figure 4.4.7.). The koomal was the most commonly recorded species (total of 1495 records) and had the highest representation at all sites except Keninup, where the woylie was the most common. Quenda records were not common but were particularly low at Balban and Boyicup (n=1).

Other non-mammalian natives and other introduced mammals were also occasionally detected on the sandpads (Table 4.4.3.). Varanids were the most commonly recorded reptiles, which also included some bobtail and skink-sized prints. Raven and magpie sized birds were the most common birds detected, as well as some cockatoos and smaller perching birds. Rabbit presence was generally localised to private property boundaries.

The dog prints detected at Winnejup and Keninup were immediately adjacent to agricultural land and were usually associated with human activity (i.e. neighbouring landholder dogs). There was no evidence of associated human activity for the dog prints detected at Balban or Boyicup. Dog prints were evident at Boyicup during the August 2006 and April, June, July 2007 survey sessions. Overall, dog activity and potential threat to the woylie was minimal and as a result is not discussed further in this report.

Other rare and interesting prints identified on the sandpads included one record each of wambenger and numbat, at Keninup and Balban, echidna at Balban (n=1), and dunnart at Boyicup (n=1).

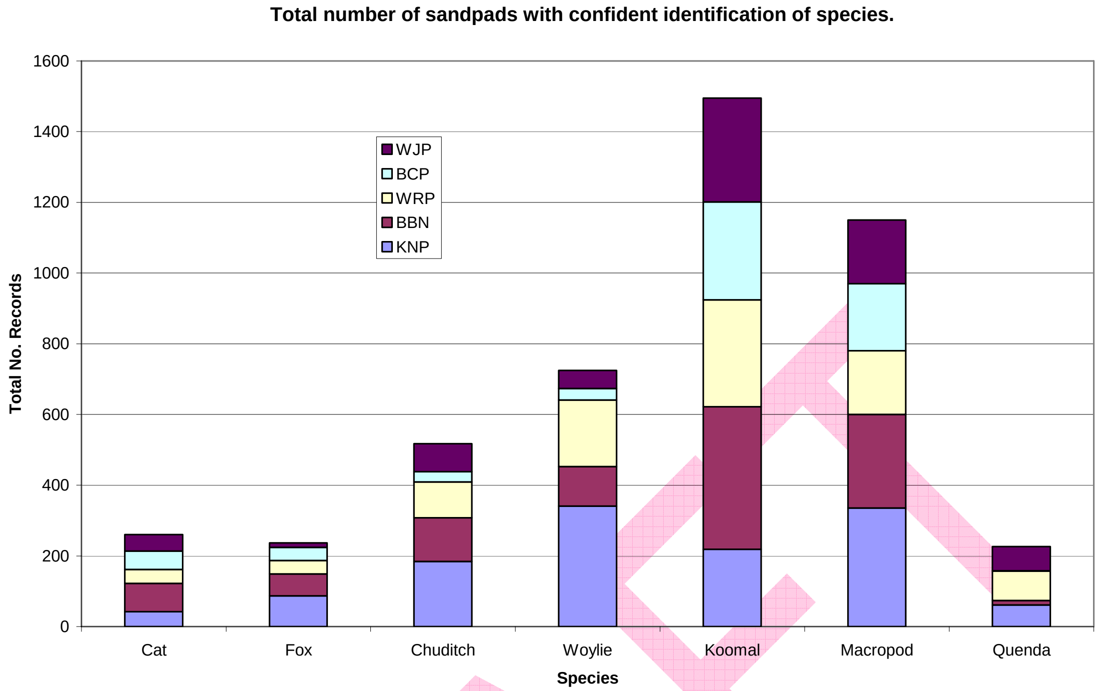


Figure 4.4.7. Representation of the key species recorded on the sandpads.

Table 4.4.3. Total number of records of other species identified on the sandpads.

Site	Emu	Native Bird (not emu)	Reptile	Rabbit	Introduced Dog	Sheep
Keninup	32	174	39	33	3	1
Balban	4	86	33	5	3	4
Warrup	10	52	22	13	0	0
Boyicup	18	72	41	5	8	0
Winnejup	15	80	52	19	5	6
Total	**79**	**464**	**187**	**75**	**19**	**11**

4.4.3.3. Predator activity from sandpads

Suitable sandpads – AI denominator development

Exclusion of days at sites where heavy rain affected sandpads resulted in the removal of 20% of the sandpad data (Table 4.4.5.). Heavy rain impacts on sandpads during the October ‘06 and Feb ‘07 were especially disruptive. As a consequence, the October ‘06 AI results for all sites and the February ’07 results for Boyicup and Warrup were based on limited data. Additional surveys at Balban and Keninup were conducted in the week following the Feb ’07 session to partially compensate for the impacts of the heavy rain. As a result, the four survey days at Balban and Keninup in the February ’07 survey were not consecutive. Additional compensatory surveys at other sites in Feb ’07 were not conducted due to human resource limitations.

A total of 189 sandpads were disturbed by vehicles (motorbikes, passenger vehicles, tractors, etc) and removed from the analysis (approximately 5% of the sandpads otherwise available for the AI calculations; Table 4.4.5.). Keninup had the greatest disturbance from vehicles, followed by Warrup and Winnejup. Most (61%) of the vehicle incursions at Keninup occurred on the eastern boundary sandpads (#20 to #25).

Of the 3579 sandpad records used in the analysis, 154 were from sandpads rated as either moderate or poor condition (i.e. little influence on the AI calculations). The condition of sandpads on any one day varied considerably between sites as a result of substantial site differences in weather (especially rainfall and evaporation), road condition, aspect, etc. For example, Winnejup sandpads were the most affected by rain and hence an extra three days were removed from AI calculations compared to the other sites (Table 4.4.4.).

Footprints – AI numerator development

More cats had a lower print confidence (i.e. less than 1=confident) rating than foxes (10.8% and 4.6% respectively) - these instances were filtered out prior to analysis. Reasons for these differences include, cat prints were more difficult to decipher than fox on sand not of perfect quality, and differences in the weight and the behaviour of the species on the sandpad.

Using the presence/ absence of prints on the pads as the numerator in the AI calculation was considered robust and more reliable than an estimate of number of individuals per sandpad. Nonetheless, the alternative approach would not have ultimately affected the data significantly: there were only six cat and 18 fox cases where sandpads were found to have had probable two or more individuals present on any one pad (i.e. two or more sets of prints in the same direction).

Table 4.4.4. Sandpad survey session details for the Upper Warren PCS sites.

Session	Fox bait treatment	Aerial baiting date	Ground-baiting date	Session start date	Site	No. survey nights	No. nights heavy rain	Total survey nights per session
Aug06	Pre			22/8/2006	ALL	9	2	35
Oct06	Post	20/09/2006	29/09/2007	10/10/2006	ALL	4	2	10
Dec06	Pre			5/12/2006	ALL	4	0	20
Jan07	Post	19/12/2006	20/12/2006	16/1/2007	ALL	4	0	20
Feb07	Pre			27/2/2007	KNP	6	2	
					BBN	6	2	
					WRP	4	2	
					BCP	4	2	
					WJP	4	4	12
Apr07	Post	13/03/2007	20/03/2007	3/4/2007	ALL	4	0	20
Jun07	Pre			12/6/2007	ALL	4	1	15
Jul07	Post	29/06/2006	29/06/2007	10/7/2007	ALL	4	0	20
Total						189	37	152

Table 4.4.5. Total number of sandpads available for calculation of the activity index (AI).

Site	No. sandpads disturbed by heavy rain	No. sandpads disturbed by vehicles*	No. sandpads disturbed by stock*	Total no. available sandpads	% of the raw total
Keninup	175	75	0	725	74.4
Balban	175	6	4	790	81.0
Warrup	175	47	0	703	76.0
Boyicup	175	5	0	745	80.5
Winnejup	250	56	3	616	66.6
Total	**950**	**189**	**7**	**3579**	**75.7**

*Mutually exclusive of number sandpads disturbed by heavy rain.

Cat activity indices

Cats were detected at all sites during all sessions except two, one at Boyicup April 2006 and Winnejup January 2007 (Figure 4.4.8.). Proportionally more cat records were removed from Keninup than other sites due to disturbance, one case due to vehicle and 12 due to heavy rain (Table 4.4.6.). Balban then had the greatest number removed due to rain.

The overall average cat AI was highest at Balban, followed by Boyicup, Winnejup, Warrup and Keninup. However, there was no significant difference in activity between sites (p=0.3927, df=4). Cat activity differed significantly over time (p=0.0311, df=4) with a trend for increasing cat activity over time (Figure 4.4.9.). Very little cat activity was observed at Winnejup until April 2007 after which it increased markedly for the remainder of the study (Figure 4.4.8.).

There was no significant difference in the activity index between pre and post baiting (p=0.1534, df=1) (Table 4.4.12.) as would be expected.

Table 4.4.6. Summary of cat print records and activity indices from the sandpad surveys at the Upper Warren PCS sites.

Site	No. of +ve records	% of the raw total	Activity Index	SE
Keninup	29	69.0	0.041	0.009
Balban	61	76.3	0.075	0.013
Warrup	34	85.0	0.044	0.009
Boyicup	44	84.6	0.060	0.015
Winnejup	39	84.8	0.069	0.028
Total	**207**	**79.6**		

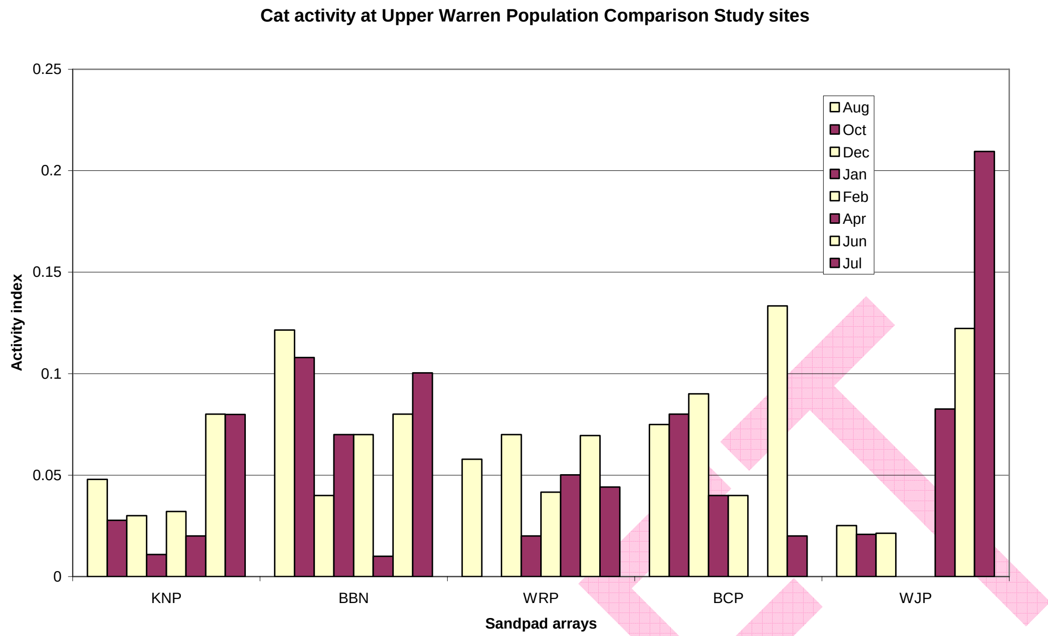


Figure 4.4.8. Cat activity index for each session at all Upper Warren PCS sites.

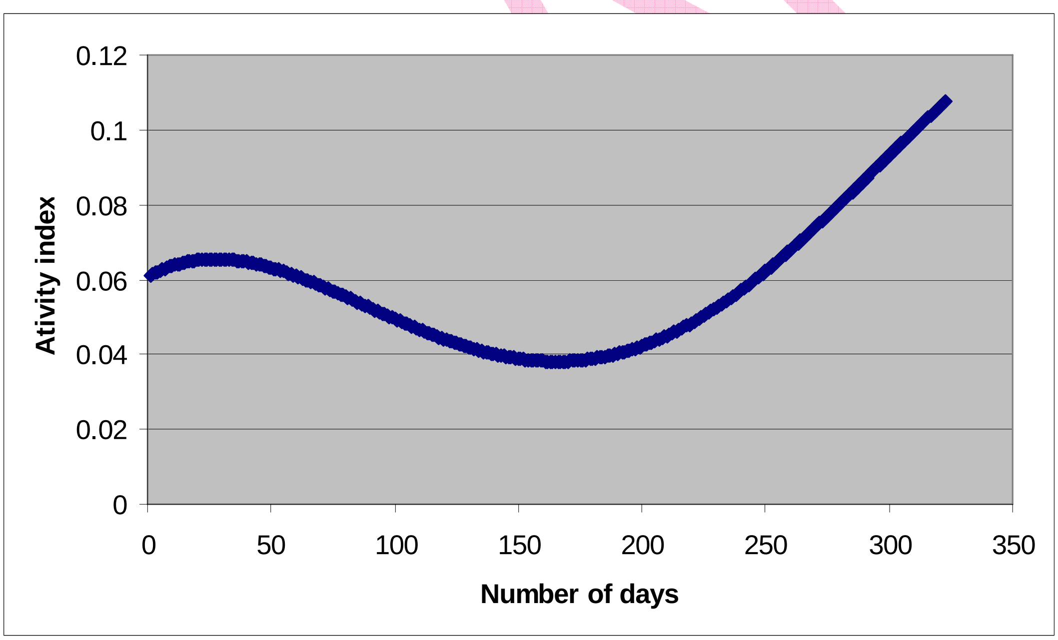


Figure 4.4.9. Temporal differences in the cat activity index for Upper Warren PCS sites.

Fox activity indices

Presence of fox activity was less consistent than cat activity, with a total of eight incidences where foxes were not recorded at a site during a session (Figure 4.4.10.). Of these incidences, four were during the October 2006 session. Fox activity at Keninup increased markedly in February 2007 and remained high through to the end of the study in July 2007. There was a similar trend at Balban. A large increase was also observed at Boyicup in July 2007 (Figure 4.4.10.). Fox activity was consistently low at Winnejup throughout the survey sessions.

There were only three cases of subadult size fox prints being recorded: Keninup 18/01/07 and 3/4/07; Balban 19/01/07.

There was a marginally significant difference in the fox AI between sites (p=0.0593, df=4), with activity being the highest at Keninup and least at Winnejup. The variance of session AI's were higher than for cat. Similarly, there was a greater fluctuation in the AI within sites between sessions (Table 4.4.7.). There was a significant difference in activity over time (p<0.05, df=4) with a general increase in fox activity (Figure 4.4.11.). There was however, no significant difference in the overall activity index between pre and post baiting (p=0.3581, df=1) (Table 4.4.12.).

Table 4.4.7. Summary of fox activity.

Site	No. +ve records	% of the raw total	Activity Index	SE
Keninup	68	78.2	0.095	0.027
Balban	58	93.5	0.075	0.025
Warrup	35	92.1	0.050	0.015
Boyicup	34	91.9	0.041	0.025
Winnejup	6	46.2	0.011	0.004
Total	**201**	**84.8**		

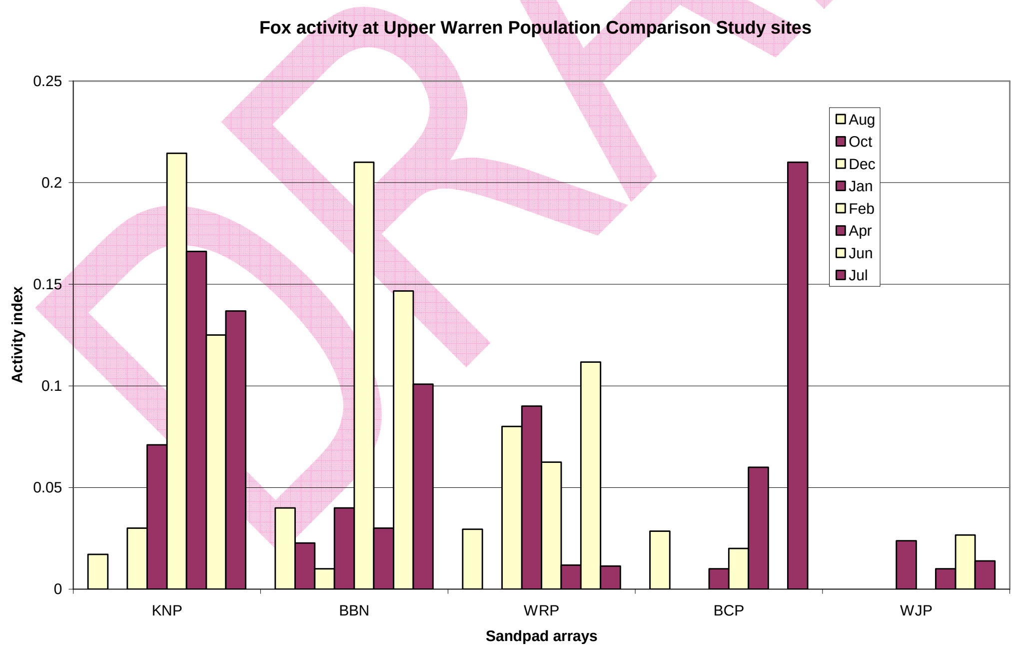


Figure 4.4.10. Fox activity index for each session at all Upper Warren PCS sites.

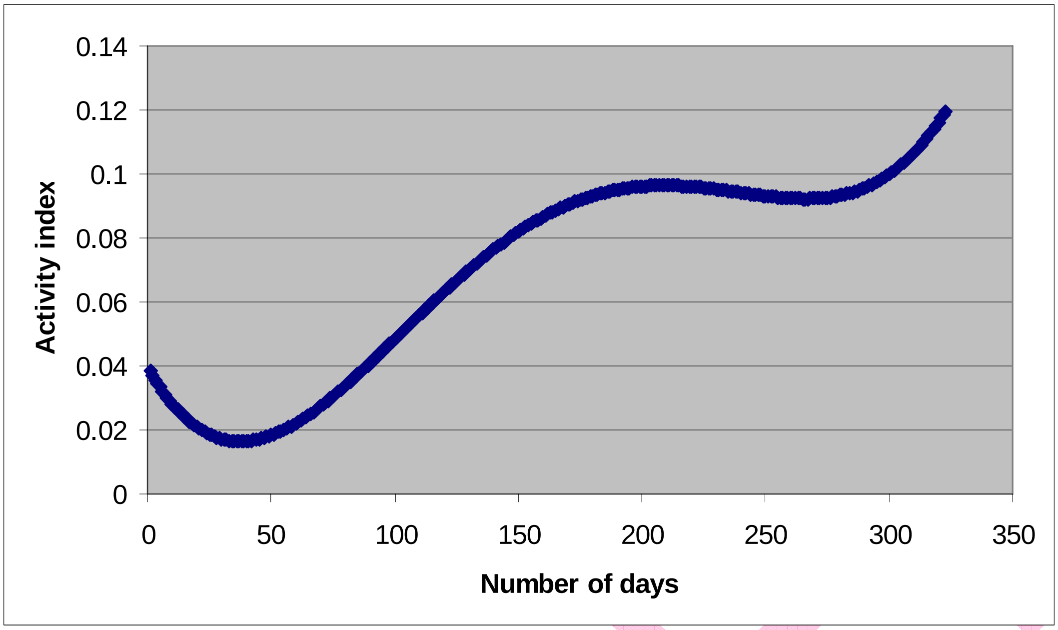


Figure 4.4.11. Temporal differences in the fox activity index for Upper Warren PCS sites.

Chuditch activity indices

Keninup overall had the greatest chuditch activity, followed by Balban, there was then a drop to Warrup and Winnejup and Boyicup had the lowest index of activity. This spatial difference was highly significant (p=<0.0001, df=4) with Keninup being higher and Boyicup lower than all other sites (Figure 4.4.12. and Table 4.4.8.).

There was an overall significant difference in chuditch activity for PCS sites over time (p<0.05, df=4). The activity fluctuated over time with a peak around May using a Type I covariate model (Figure 4.4.13.). There was no overall significant difference in activity between pre and post baiting (p=0.2786, df=1) (Table 4.4.12.).

Table 4.4.8. Summary of chuditch activity.

Site	No. +ve records	% of the raw total	Activity Index	SE
Keninup	151	82.1	0.218	0.034
Balban	114	91.9	0.146	0.022
Warrup	79	78.2	0.111	0.035
Boyicup	23	79.3	0.035	0.010
Winnejup	62	78.5	0.108	0.028
Total	**429**	**83.0**		

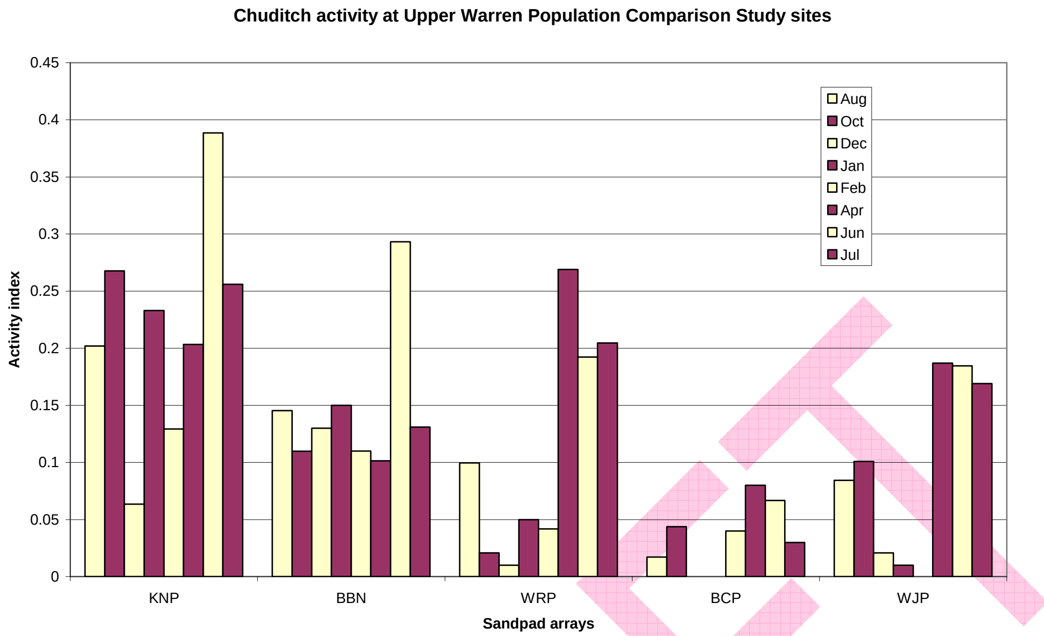


Figure 4.4.12. Chuditch activity index for each session at all Upper Warren PCS sites.

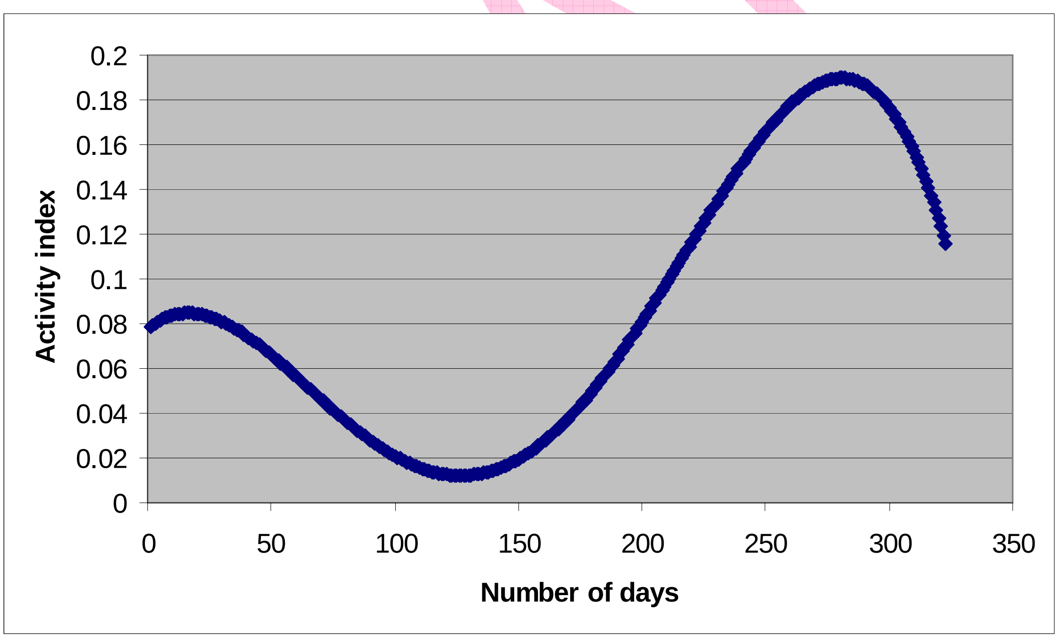


Figure 4.4.13. Temporal differences in the chuditch activity index for Upper Warren PCS sites.

Woylie activity indices

A highly significant difference between sites existed for woylie activity ($p=<0.0001$, $df=4$), particularly due to a significantly higher activity observed at Keninup than all other sites. Warrup activity was then significantly higher than the next highest site Balban. Winnejup then Boyicup had the lowest activity index (Figure 4.4.14.). In the case of Boyicup this equated to, on average, less than one woylie record per day (Table 4.4.9.).

There was a significant change in activity over time (p<0.05, df=4). Overall the trend was for a slight decline in activity (Figure 4.4.15.), due predominantly to the declines observed at Balban. There was some decrease in the AI at Keninup but this then increased again. Winnejup and Boyicup fluctuated with very low woylie records (Figure 4.4.14.).

Table 4.4.9. Summary of woylie activity.

Site	No. +ve records	% of the raw total	Activity Index	SE
Keninup	264	77.4	0.366	0.020
Balban	95	84.8	0.109	0.027
Warrup	173	92.0	0.233	0.024
Boyicup	28	87.5	0.042	0.011
Winnejup	45	86.5	0.077	0.023
Total	**605**	**83.5**		

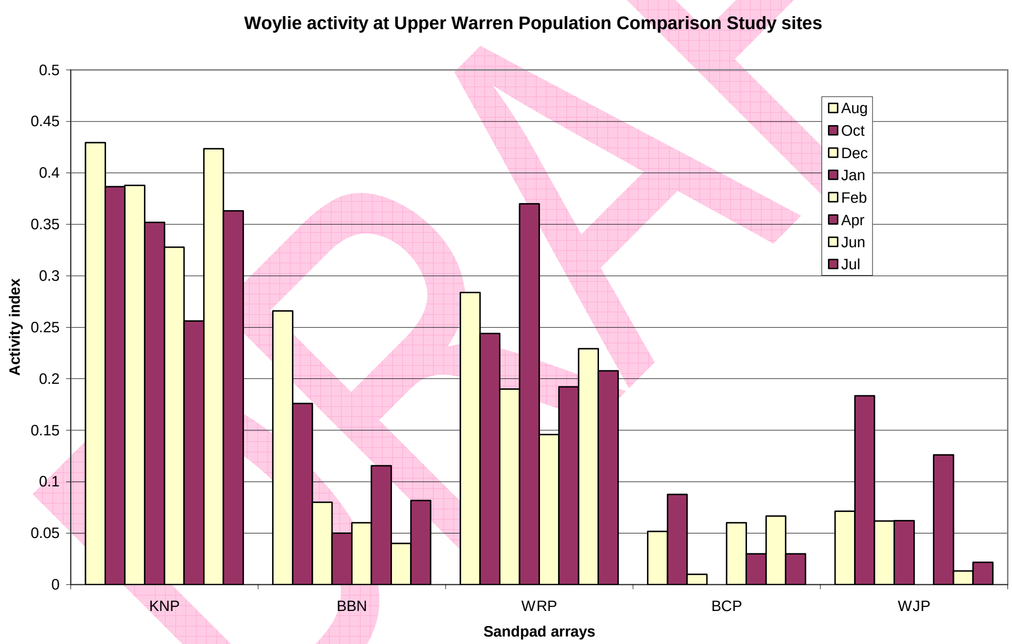


Figure 4.4.14. Woylie activity index for each session at all Upper Warren PCS sites.

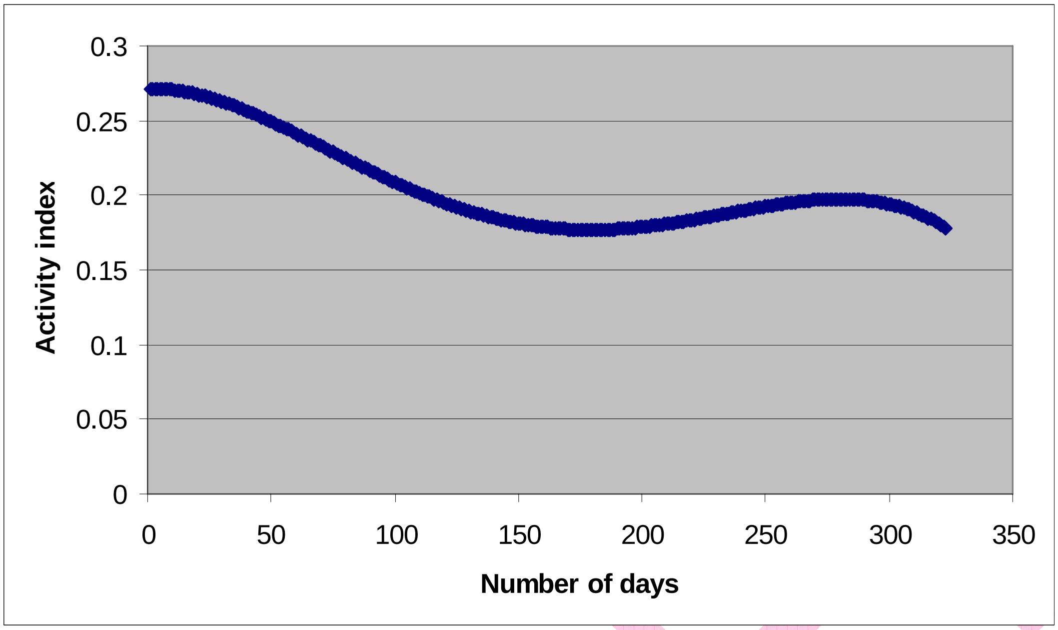


Figure 4.4.15. Temporal differences in the woylie activity index for Upper Warren PCS sites.

Koomal activity indices

Koomal were well represented at all sites during all sessions (Figure 4.4.16.). The percentage of total records used for the AI calculation was relatively high for all sites (Table 4.4.10.). This is reflective of possum prints not being readable on sandpads subjected to heavy rain. Presence of koomal foot prints were found in this study to be a reliable indicator of sandpad condition.

Differences in koomal activity levels were highly significant between sites (p=0.0001, df=4) Overall koomal mean activity was significantly higher at Balban than all sites, other than Winnejup. Winnejup, Warrup and Boyicup were similar in koomal number and Keninup had the lowest record of koomal (Table 4.4.10.). There was a significant temporal difference (p<0.05, df=4), and an apparent trend for activity to be higher through the summer months at all sites (Figure 4.4.17.)

There was a significant difference in the koomal activity pre and post baiting (p=0.0231, df=1) (Table 4.4.11.), with koomal activity increasing after baiting.

Table 4.4.10. Summary of koomal activity.

Site	No. +ve records	% of the raw total	Activity Index	SE
Keninup	187	85.4	0.269	0.034
Balban	389	96.5	0.512	0.046
Warrup	274	90.7	0.395	0.051
Boyicup	252	91.0	0.354	0.050
Winnejup	261	88.8	0.427	0.041
Total	**1363**	**91.2**		

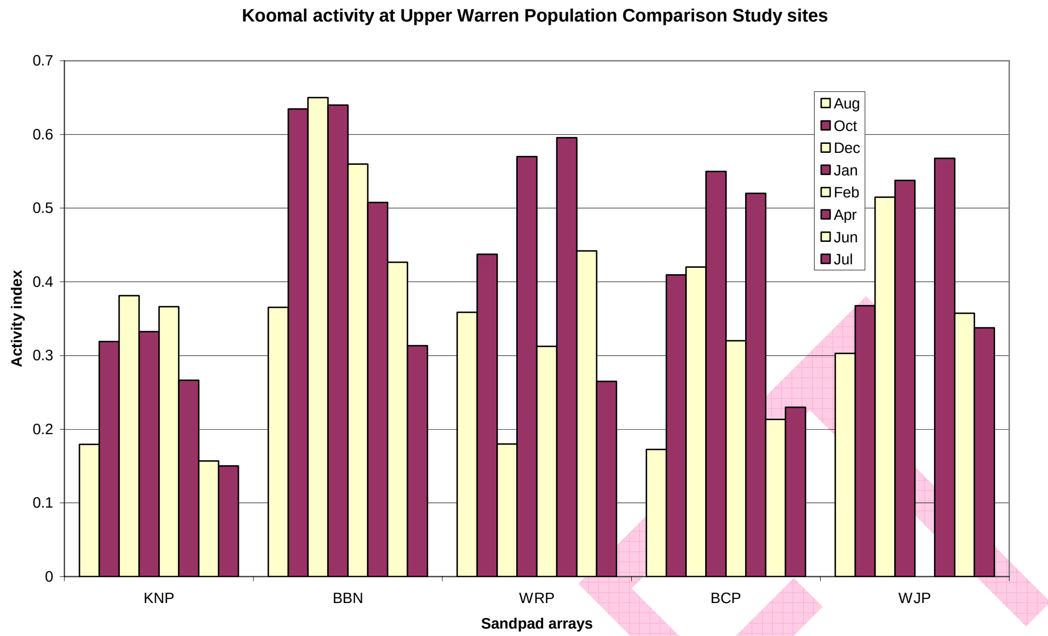


Figure 4.4.16. Koomal activity index for each session at all Upper Warren PCS sites.

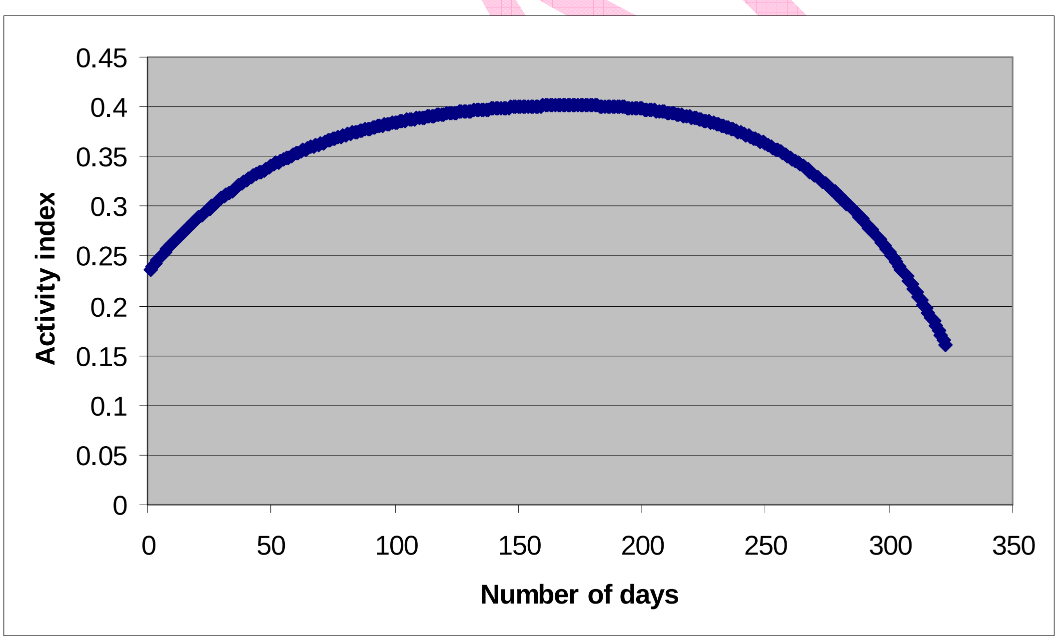


Figure 4.4.17. Temporal differences in the koomal activity index for Upper Warren PCS sites.

Macropod activity indices

Macropod activity does not distinguish between the western grey kangaroo, tammar and western brush wallaby records. Woylies were always recorded separately.

There was a significant difference between sites for macropod activity (p=0.0001, df=4), with Keninup highest (similar to woylie activity) and Winnejup and Boyicup the least (Table 4.4.12. and Figure 4.4.18.). There was a significant difference over time in macropod activity (p<0.05, df=4) and similar to koomal, the AI was higher over the summer period (Figure 4.4.19.).

There were significantly more macropod records post baiting (p=0.0019, df=1) (Table 4.4.12.), similar to koomal.

Table 4.4.11. Summary of macropod activity.

Site	No. +ve records	% of the raw total	Activity Index	SE
Keninup	252	75.2	0.345	0.042
Balban	231	87.2	0.301	0.026
Warrup	147	81.7	0.214	0.032
Boyicup	166	87.4	0.227	0.017
Winnejup	135	75.0	0.228	0.032
Total	**931**	**81.0**		

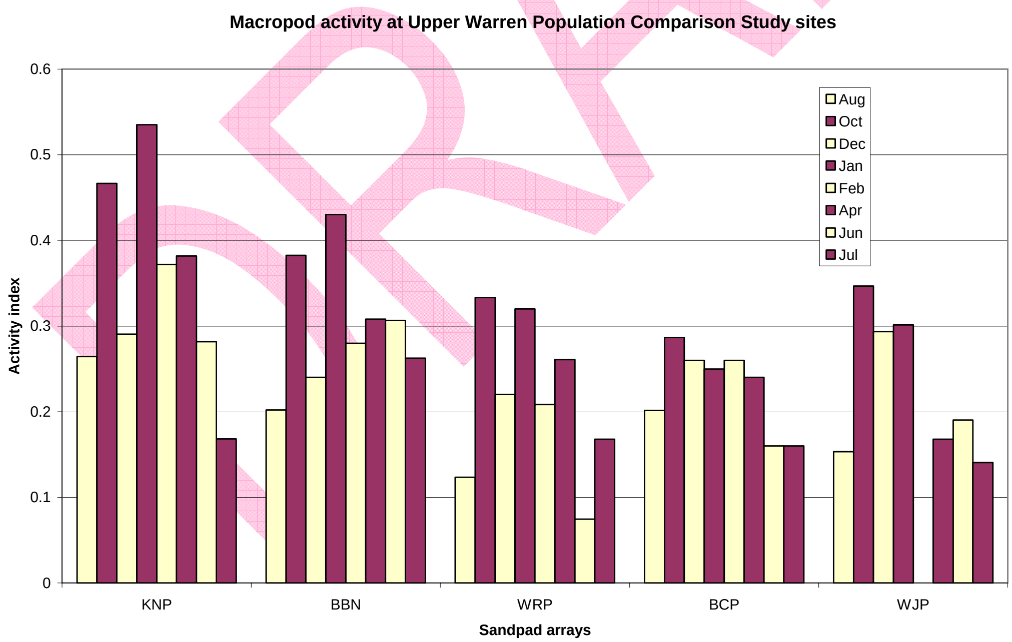


Figure 4.4.18. Macropod activity index for each session at all Upper Warren PCS sites.

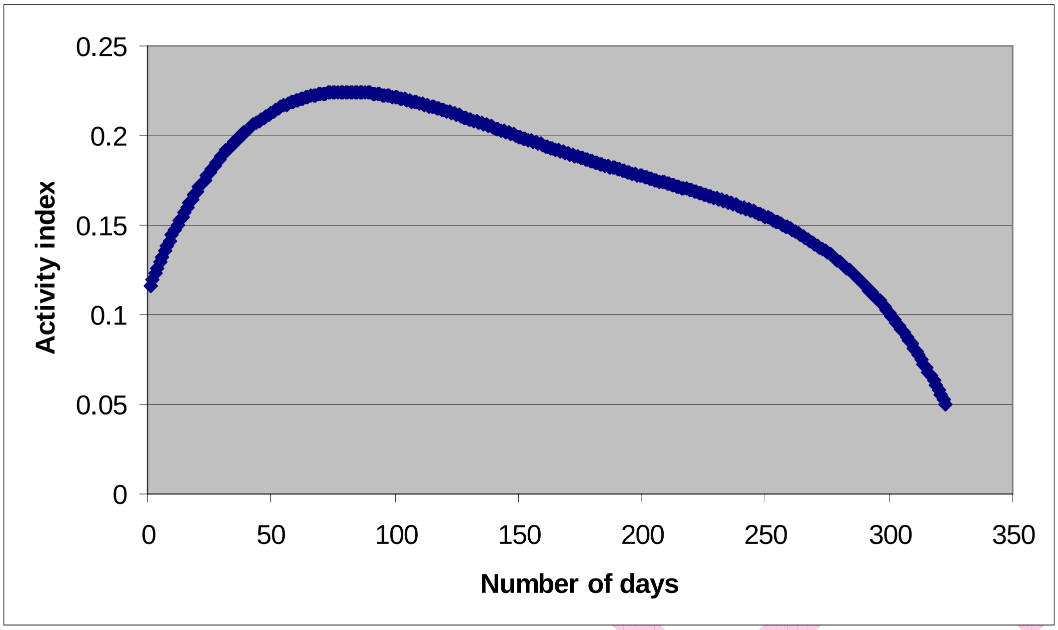


Figure 4.4.19. Temporal differences in the macropod activity index for Upper Warren PCS sites.

Table 4.4.12. Significance tests for the activity indices of introduced predators and native mammals derived from sandpad surveys at the Upper Warren PCS sites.

Cat

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0047	3.16	0.0311
site	4	0.0016	1.07	0.3927
treat	1	0.0032	2.17	0.1534
site x treat	4	0.0016	1.06	0.3945
error	25	0.0015		

Fox

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0102	3.70	<0.05
site	4	0.0072	2.62	0.0593
treat	1	0.0024	0.88	0.3581
site x treat	4	0.0038	1.37	0.2712
error	25	0.0028		

Chuditch

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0266	8.70	<0.05
site	4	0.0357	11.67	<.0001
treat	1	0.0037	1.23	0.2786
site x treat	4	0.0030	0.99	0.4293
error	25	0.0031		

Woylie

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0079	2.84	<0.05
site	4	0.1425	51.12	<.0001
treat	1	0.0035	1.27	0.2706
site x treat	4	0.0038	1.37	0.2710
error	25	0.0028		

Koomal

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0696	9.80	<0.05
site	4	0.0651	9.17	0.0001
treat	1	0.0416	5.86	0.0231
site x treat	4	0.0099	1.40	0.2634
error	25	0.0071		

Macropod

Source	DF	Mean Square	F Value	Pr > F
time covariate*	4	0.0331	11.81	<0.05
site	4	0.0257	9.16	0.0001
treat	1	0.0336	11.99	0.0019
site x treat	4	0.0039	1.40	0.2638
error	25	0.0028		

*Average of Type I linear, squared, cubic and quadratic day value variables. Other source variables derived from Type III SS. Critical value is 2.76 for time covariate.

Predator activity in relation to woylie populations

Figures 4.4.20. - 4.4.25. relate the fox and cat activity indices derived from the sandpad surveys with the capture rates of woylies derived from the PCS trapping grids (Section 4.2 Demographics).

Keninup: The woylie capture rates (%) decreased from February 2007 in conjunction with an increase in the fox activity index (Figure 4.4.20.). Keninup had considerably higher woylie capture rates (%) compared to the other Upper Warren PCS sites

Balban: The decline in woylie capture rates has occurred generally in the presence of higher cat activity compared to the other sites, particularly at the beginning of the survey (Figure 4.4.21.). This cat activity however, was not significantly different at Balban compared to other sites. Balban was, the only site in a state of woylie decline during the study period. Similar to Keninup there was also a general increase in fox activity over time.

Warrup: Woylie capture rates fluctuated the least in comparison to other Upper Warren PCS sites (Figure 4.4.22.). Cat and fox activity was variable over time with no striking trends.

Winnejup and Boyicup: Very low (hence relatively variable) woylie capture rates over the period of the predator surveys make it difficult to relate this data to cat and fox activity (Figures 4.4.23. and 4.4.24.).

In general, the woylie activity indices calculated from the sandpads approximately related to the same trends observed in the capture rates derived from the PCS trapping grids in the same area. For example, relative activity levels between sites ranked similarly to the relative capture rates (i.e. greatest at Keninup, followed by Warrup, Balban, Winnejup and least at Boyicup) and the declining woylie trends at Balban are very similar between the two independent datasets (Figure 4.4.25.).

Koomal capture rates continued to increase over time at the Balban PCS site, with a dip in February 2007 in conjunction with a spike in the fox activity index (Figure 4.4.26.). A similar trend in koomal capture rates also occurred at other PCS sites. Koomal capture rates also increased in the Balban Upper Warren Fauna Monitoring transect from 7% to 36. 5% from Mar 2006 to Mar 2007.

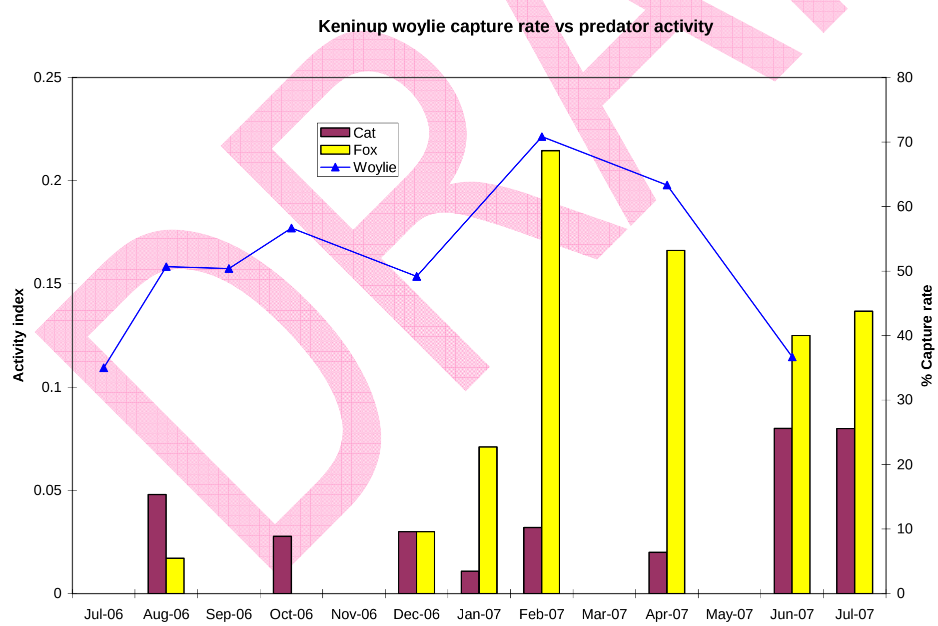


Figure 4.4.20. Keninup woylie capture rate in relation to the fox and cat activity index.

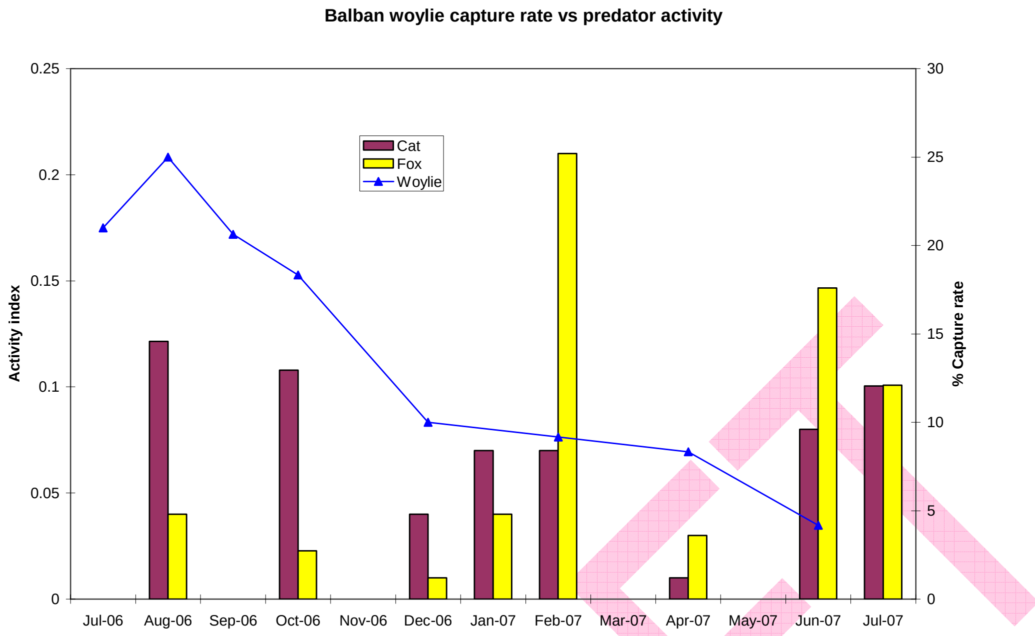


Figure 4.4.21. Balban woylie capture rate in relation to the fox and cat activity index.

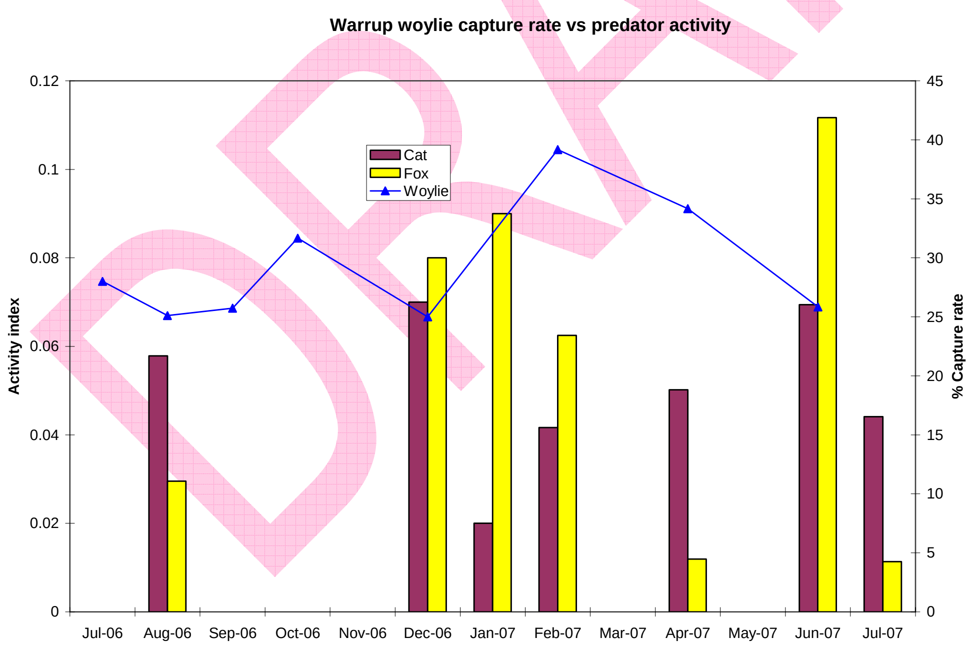


Figure 4.4.22. Warrup woylie capture rate in relation to the fox and cat activity index.

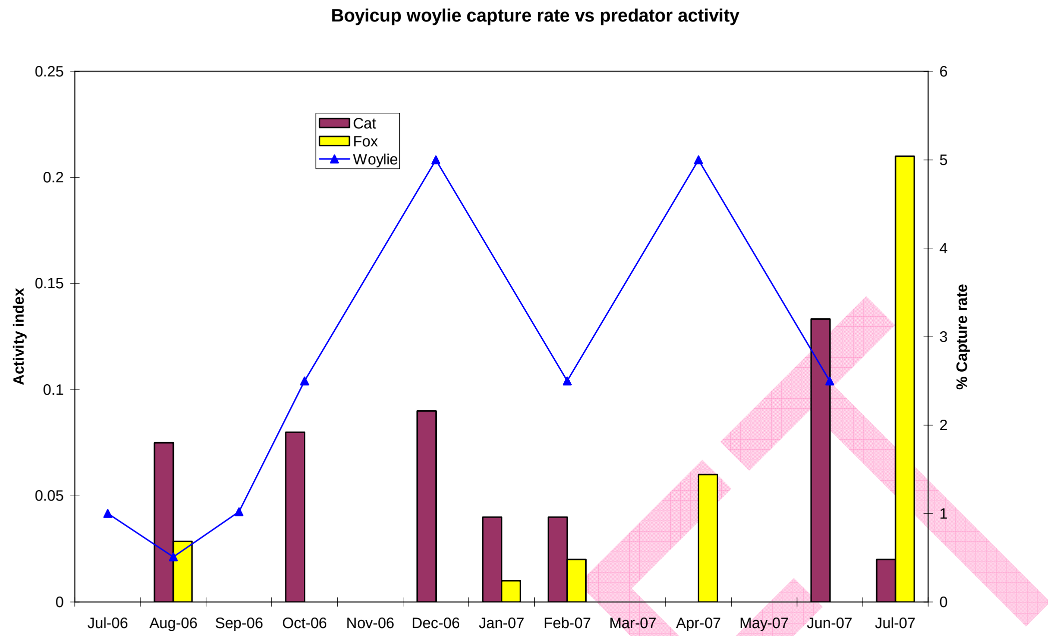


Figure 4.4.23. Boyicup woylie capture rate in relation to the fox and cat activity index.

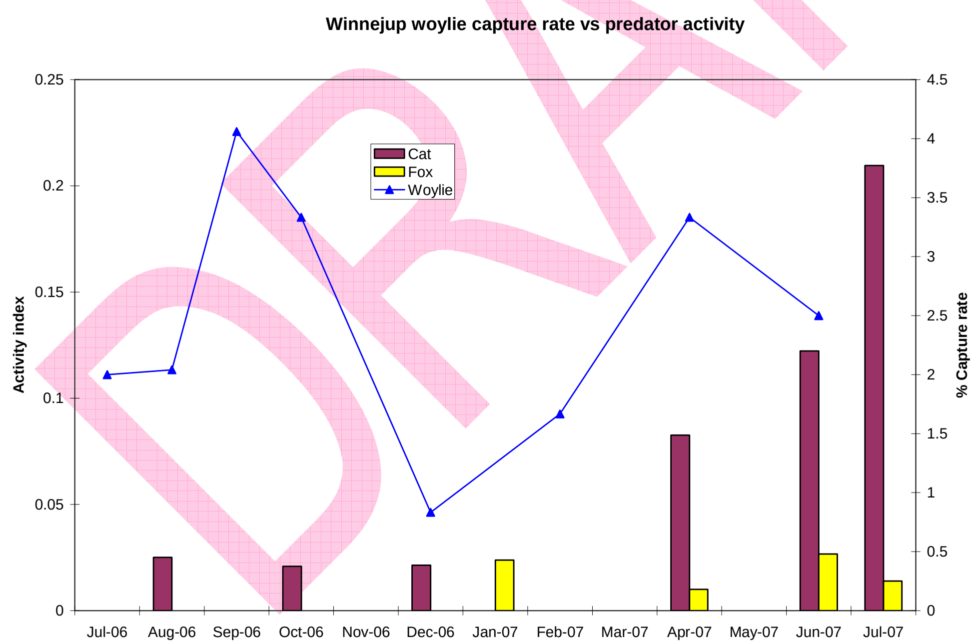


Figure 4.4.24. Winnejup woylie capture rate in relation to the fox and cat activity index.

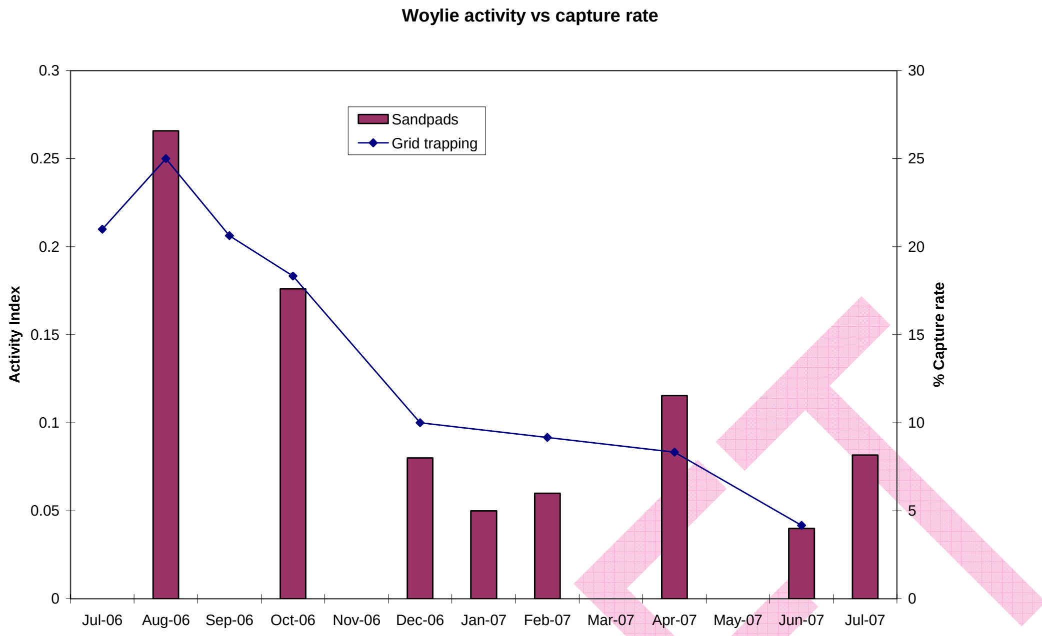


Figure 4.4.25. Woylie activity index in relation to capture rate at the Balban PCS site.

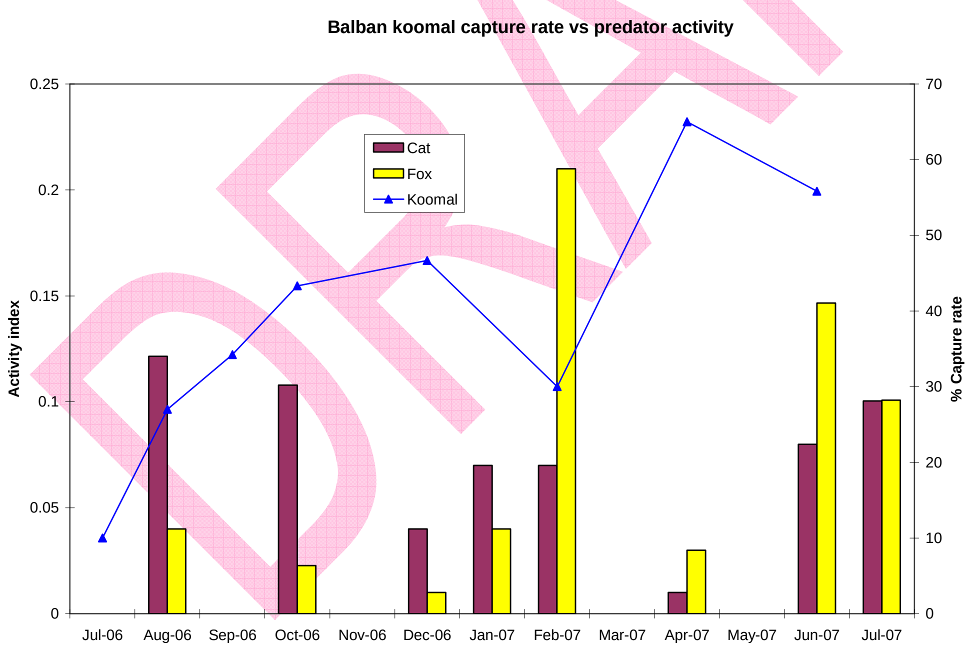


Figure 4.4.26. Balban koomal capture rate in relation to the fox and cat activity index.

4.4.3.4. Other results relating to methodology

A number of results from the sandpad surveys may be relevant to the survey methodology, and help to inform how future sandpad surveys may be conducted. Some of these are very briefly addressed here in point form.

Assessment of passive and active pad methods

- Using all available data and having adjusted for the difference in numbers of active and passive sandpads, the incidence of fox prints on passive sandpads was twice as high at that on active sandpads (6.8%, 3.4% respectively). Similarly cat activity was found to be greater on passive sandpads than active sandpads, however the difference was less marked, only 1.3 times higher (6.3%, 4.7% respectively). Conversely chuditch activity on active sandpads (15%) was 2.5 times that of passive sandpads (6.2%).
- There were inconsistencies between sites and observers on the level of detail recorded about predator behaviour on the sandpad. This detail was recorded more consistently in later surveys upon review of the results.
- Despite the large percentage of "not recorded" in most tables there are some clear trends in relation to the oil lure and FAP (Table 4.4.13.).
- Cats generally did not venture near the oil and there was a greater percentage that did not visit the FAP. Many cats were detected at the end of the sandpad opposite the FAP. Again this observation was not apparent until later in the study and hence this behavioural observation was often not recorded. In general cats walked directly across the sandpad.
- Of the 35% of foxes recorded on active pads there was less dissimilarity in oil visitation than for the other predator species. There was a slight bias to not visiting the FAP.
- There was a clear trend for chuditch to visit either the FAP or the oil, and often both. The chuditch would often also scrape or dig at the oil and defecate on the sandpad. Behavioural activity differed considerably between active and passive sandpads, with many footprints observed on active sandpads, often superimposed, compared to only one set of tracks on passive sandpads. The large size of the sandpads meant that clear identification of prints was still possible.

Table 4.4.13. Predator positive (+ve) or (-ve) visitation to oil lure and FAP.

Cat

Site	Oil (+ve) [dig at oil]		Oil (-ve)	Not recorded	Total	FAP (+ve)	FAP (-ve) [opp FAP]		Not recorded	Total
KNP	3	[1]	10	8	21	8	6	[3]	7	21
BBN	1	[0]	26	8	35	6	22	[7]	7	35
WRP	1	[0]	4	11	16	1	5	[4]	11	17
BCP	5	[3]	19	1	25	5	20	[5]	0	25
WJP	1	[0]	3	16	20	1	3	[3]	15	19
Total	11	[4]	62	44	117	21	56	[22]	40	117
%	**9.4**		**53.0**	37.6		**17.9**	**47.9**		34.2	

Fox

Site	Oil (+ve) [dig at oil]		Oil (-ve)	Not recorded	Total	FAP (+ve)	FAP (-ve) [opp FAP]		Not recorded	Total
KNP	12	[2]	18	4	34	13	17	[7]	4	34
BBN	10	[1]	8	2	20	5	13	[6]	2	20
WRP	2	[0]	2	10	14	2	2	[0]	10	14
BCP	4	[1]	3	2	9	2	5	[3]	2	9
WJP	0	[0]	3	3	6	0	3	[0]	3	6
Total	28	[4]	34	21	83	22	40	16	21	83
%	**33.7**		**41.0**	25.3		**26.5**	**48.2**		25.3	

Chuditch

Site	Oil (+ve) [dig at oil]		Oil (-ve)	Not recorded	Total	FAP (+ve)	FAP (-ve) [opp FAP]		Not recorded	Total
KNP	100	[47]	10	37	147	62	10	[0]	76	148
BBN	50	[22]	5	35	90	35	8	[0]	47	90
WRP	17	[2]	1	45	63	6	2	[0]	54	62
BCP	13	[1]	0	7	20	11	5	[0]	4	20
WJP	15	[0]	0	42	57	3	7	[0]	47	57
Total	195	[72]	16	166	377	117	32	0	228	377
%	**51.7**		**4.2**	44.0		**31.0**	**8.5**		60.5	

Scat collection

- A total of 147 scats were collected from the sandpads. Of these, 87 were fresh and collected during the survey and 59 were old, and collected during sandpad preparation on the first day of the survey.
- The majority of scats collected were from chuditch (e.g. 78/87 fresh scats). Only one definite (three possible) cat and 2 possible fox scats were collected.
- 76 of the 78 chuditch scats were collected from active pads. The scats were usually found on or adjacent to the oil lure.
- The number of scats on the sandpads (particularly chuditch) increased with the number of survey days, and hence is not independent. The greatest numbers of scats were

collected from sandpads during pad preparation. This suggests that the oil persists for sometime on the sandpads for the chuditch to continue digging at the oil and defecating.

General notes

- Cat and fox prints were often observed only within the wheel ruts of the sandpad.
- Fox urine scent was detected on some sandpads.
- Habitual patterns of fauna were recognized and may provide an insight to some extent of animal behaviour. The same records of fauna could be found on particular sandpads consistently. For example at Keninup, quenda activity was found on Pad 1 or 2 or both, on 62.5% of nights. Also at Keninup chuditch activity was observed on Pad 25 on greater than 50% of nights.
- In many instances sets of woylie prints were observed crossing a sandpad in a similar position each day. For example, Pad 4 at Keninup had a woylie crossing the pad lengthways on 81% of nights.

4.4.4. Discussion

Fox control

It is reasonable to expect that existing fox-baiting activities are effective to some extent in reducing, and possibly maintaining, fox numbers at levels lower than they would otherwise be. This has been shown elsewhere (Kinnear *et al.,* 1988; de Tores, 1999; Thomson *et al.,* 2000). Furthermore, evidence from the Upper Warren is also consistent with this; including reduced fox activity in baited forest relative to unbaited forest (J Rooney, 2001 Kingston Project Review (unpublished data)), and positive responses by native fauna in association with the commencement and/or increase in fox control (e.g. Burrows and Christensen, 2002; Morris *et al.,* 2001; Orell, 2004).

Nonetheless, it is evident from the records of fox-control since 1996 that the delivery has been highly variable in the Upper Warren. For example, the timing of the ground baiting in relation to aerial baiting has lagged by up to two months. The intervals between consecutive baiting sessions have ranged from 1 - 6 months for aerial baiting and 1 - 9 months for ground baiting. It follows that these variations and extended intervals are likely to increase the potential for the reinvasion of foxes into the managed forests and increase accordingly the predation pressure on the vulnerable native fauna that the fox control program is intended to protect.

Potentially more importantly, the timing of fox-baiting relative to when it is considered particularly effective, has also been variable. Despite a relatively more consistent *Western Shield* baiting program since 2002, extended baiting intervals have frequently occurred over the summer periods. For example, in 59% of cases (including five consecutive years from 2000 to 2004) there was no ground baiting conducted between January and March – when young foxes begin to disperse and when control is thought to be particularly effective in reducing fox numbers (Saunders *et al.,* 1995; Thomson *et al.,* 2000).

The effectiveness of fox baits may also be further compromised by heavy rainfall and wet conditions during and immediately after bait delivery. As a consequence of both the variability in the timing of aerial baiting and rainfall events only 30% of the years between 1997 and 2006 can be considered to have had a full complement of four presumed-effective baiting events per year.

In the absence of previous ongoing predator monitoring it is not possible to know directly what affects the variability in fox baiting may have had on predator numbers or how predators may relate to the woylie declines or any other native animals of interest. Extended periods of little or ineffectual baiting, are however, likely to result in periodic increases in foxes, which could consequently have substantial and longer-lasting impacts on some native species.

Reinvasion of foxes into the Upper Warren forests is likely to occur all year round, particularly given the proximity and distribution of agricultural sources for reinvasion. Due to the high reinvasion potential increased baiting frequency (i.e. reduced baiting intervals) and strategic considerations of the timing of baiting may be particularly beneficial to native fauna conservation. For example, the timing of baiting relative to fox biology (i.e. dispersal periods; Saunders *et al.,* 1995; Thomson *et al.*,

2000) and avoiding wet conditions are likely to have significant impacts. Improvements may also be achieved through spatial considerations such as varying baiting frequency and/or density relative to proximity to unbaited and agricultural land. de Tores (1999) recommends a baiting frequency of six times per year at the interface between baited and unbaited areas.

A more complete understanding of the factors influencing the effectiveness of fox control, if used operationally, could potentially achieve substantial improvements without significant impact on existing resources. The monitoring of predator (and prey) populations is essential in substantiating the effectiveness of these control measures and enables an active adaptive management approach that enables further improvements over time.

General temporal trends in AI

There were significant changes in the activity indices over time for all species examined. Some of these changes were consistent with expectations of seasonal differences in activity relating to reproduction, offspring dispersal and food resources. Multiple years of comparable data would be able to differentiate cyclical from other longitudinal changes and trends in activity indices, however, this is beyond the capacity of the one year of data collected in this study.

Cat

Cats persisted at all PCS sites and activity indices (AI) were not significantly different between sites. Cat AI did not differ significantly pre and post fox-baiting. This is expected since fox baits are not attractive to cats (Algar and Burrows, 2004) and have been found ineffective in control of feral cats (Christensen and Burrows, 1994; Risbey *et al.,* 1997). The overall increase in cat AI in the latter half of the study was influenced by a particularly large increase at Winnejup. The extent to which significant temporal changes in cat AI may be due to seasonal or longer-term trends remains unknown.

Fox

While the overall Upper Warren average AI for the fox and cat were similar (0.054 and 0.058 respectively), the variability in the fox AI's within sites generally tended to be greater. Higher population turnover and immigration from non-baited areas replenishing reduced fox numbers in baited areas is likely to account for at least some of this variance.

Differences in the fox AI between sites was marginally significant. Keninup and Balban had particularly high fox AI's while Boyicup and Winnejup were relatively low. These AI's corresponded with the contemporary relative abundances of woylies at these sites. Fox AI's may also be related to some extent to the general levels of geographic exposure and proximity to unbaited forest areas and agricultural land, where fox numbers are likely to be higher (i.e. recruitment sources). Keninup has the greatest potential for immigration of foxes due to both proximity and large interface between forest and agricultural land. Balban also has a large unbaited corridor allowing for potentially greater reinvasion.

The temporal peak of fox AI at Keninup and Balban in February is consistent with the anticipated seasonal increase in fox activity associated with the independence and dispersal of fox subadults (McIntosh, 1963; Ryan, 1976). Over this period there were only three records of relatively small fox prints (two in January and one in April 2007). The lack of an apparent corresponding peak at the other Upper Warren PCS sites may be due to the varying potential for reinvasion between sites or could be related to the reduced effective sampling on these sites as a result of the heavy rainfall during the surveys and the inability (resource limitations) to resample these sites the following week, as was done at Keninup and Balban.

The significant increase in fox activity over the 12-month study (especially after February 2007) was particularly pronounced at Keninup (where woylie numbers were greatest), Balban (concurrently declining woylies) and later (July 2007) at Boyicup (woylies previously declined and sustained low). The possibility that the fox control since February 2007 has not been particularly effective is supported by the wet conditions associated with the June 2007 baiting event (Table 4.4.1.). However, the results must be viewed cautiously as activity levels may also be affected by seasonal behavioural changes, such as breeding behaviour (Phillips and Catling, 1991; Thomson, 1992).

Previous sandpad survey results within the Upper Warren region (1996-1999; 2005) found fox activity to be significantly higher in the unbaited versus baited areas and the fox activity on the forest / agricultural boundary to be significantly higher than the core (both baited and unbaited) (J Rooney, 2001 Kingston Project Review (unpublished data)). Unlike the current study, surveys were conducted only in September, when fox populations are considered the most stable (de Tores, 1999). Whether the observed increases in fox activity in this study are seasonal, periodic and/or part of a longer-term trend or cycle can only be verified with longer-term data.

Assuming that fox control remained effective to some extent during this study (discussed above), the insignificant difference between fox activity pre and post baiting found in this study is best explained by insufficient statistical power due to limited sampling, low fox print encounter rates and high variance. It is also possible that i) density-dependent effects on fox activity may mask reductions in actual fox numbers immediately after fox control. Fox control elsewhere has resulted in static or elevated AI due to changes in the activity of remaining foxes (Allen *et al.,* 1996). For example, foxes may extend the length of road walked per night due to altered territorial boundaries, and/or ii) as discussed previously fox reinvasion/recovery may be rapid, despite fox-control activities being effective in reducing general fox densities as has been shown in previous studies (Kinnear *et al.,* 1988).

It is also possible that baiting effectiveness may be reduced by non-target species, (e.g. chuditch, koomal and varanids), consuming baits and hence reducing overall bait availability to foxes (Algar *et al*., 2007). On this basis it is possible that baiting effectiveness in the Upper Warren is also influenced by the relatively high numbers of koomal in particular, as well as other native nontarget species (Chapter 3 Meta-analysis and Section 4.2 Demographics).

Chuditch

The significant site differences in chuditch AI generally corresponded to relative woylie abundance (i.e. highest at Keninup and lowest at Boyicup). Chuditch were found to be associated with a number of woylie mortality events based on forensic odontology, but chuditch are more likely to have been involved as secondary scavengers than a primary predator. There is no clear evidence to implicate chuditch in the woylie decline (Section 4.3 Survival and Mortality).

The significant temporal differences in chuditch AI were likely to be related to seasonal differences in chuditch behaviour. The pattern of chuditch activity is highly characteristic of a cyclical phenomenon and is consistent with our understanding of the biology and behaviour of the chuditch (Soderquist and Serena, 2000; Morris *et al.,* 2003). For example, the AI peak around May coincides with mating when males are highly mobile in the search for mates (Serena and Soderquist, 1989; Morris *et al.,* 2003).

Woylie

The strong association found in this study between woylie AI's (derived from sandpad methods) with capture rates (derived from concurrent WCRP trapping) is consistent with previous findings for the Upper Warren (Wayne, 2006). This relationship provides supporting independent evidence about the extent and magnitude of recent woylie declines. Furthermore, it provides an alternative or complementary non-invasive and relatively low cost means of monitoring populations.

Predator / Prey relationships

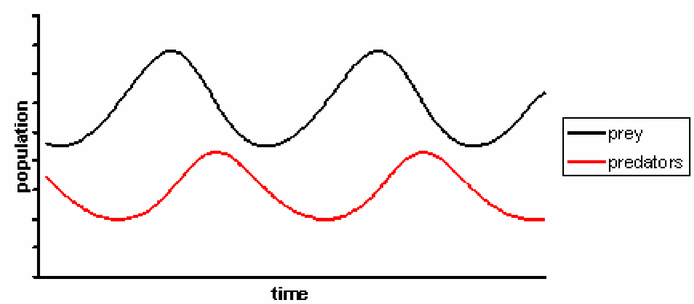
The fact that woylie populations have not shown a decline at effectively predator-free Karakamia and South Australian islands (Venus Bay Island A and St Peter's Island) supports the hypothesis that predators may be a factor in the woylie decline.

The extent to which predators such as the cat and fox are involved in recent woylie declines within the Upper Warren cannot be definitively answered with only 12-months of comparable predator activity data. It does, however, provide some preliminary clues, particularly when considered with other supporting evidence. For example, there may be a temporal association between increased cat activity and the decline of woylies at Balban. This is further implicated by i) the high incidence of cats associated with mortalities of radio-collared woylies at Balban during the period of woylie decline (seven out of eight cases) (Section 4.3 Survival and Mortality); ii) cat activity was greatest at Balban where woylies were declining and least where woylie abundance was relatively high and stable (i.e.

Keninup and Warrup); and, iii) Yendicup and Yackelup sandpad survey results, which commenced in 2000 and show a trend of increasing cat activity in association with declining woylie activity (Bruce Ward and Graeme Liddelow, pers. comm.).

However, evidence which is seemingly inconsistent with predators being a primary cause of decline is despite the similarities between Keninup and Balban in relation to cat and fox AI, Keninup woylies did not decline where they did so at Balban. Furthermore, the survivorship results from Keninup do not directly support fox as responsible because only two mortalities occurred during the period of increased fox activity from February – July 2007, and neither was associated with fox. (one cat, one raptor) (Section 4.3 Survival and Mortality).

Determining the nature of the relationship between predator activity and woylie abundance (and declines) is made more difficult in the fact that relationships between predator and prey abundance can be nonlinear and complicated by temporal differences (lags) (Figure 4.4.27- Theoretical model of predator / prey abundance over time).



(Source: http://commons.wikimedia.org/wiki/Image:Lotka-Volterra.png)

Figure 4.4.27. Lotka-volterra predator-prey model

For example, at any one point in time the predator densities at a site with low prey densities may be high because of previous or current exploitation of the prey resource, or low because the site can no longer sustain the predator densities that it previously did. As a result, suitable data over an extended period is required to reliably determine the nature of any associations between predator and prey abundances. To do this the study period needs to encompass sufficient time before, during and after a prey or predator population transition between low and high density or vice versa.

Hence, there is currently insufficient data and evidence within the Upper Warren to confidently determine what extent predators are involved in the woylie decline, however continued predator monitoring remains integral to rectifying this.

Koomal

If predators were the primary cause for woylie declines then it would be likely that other, similarly-sized prey species may also decline. Koomal AI was substantially higher than any other species detected on the sandpads. Therefore there remains substantial opportunity for introduced predators to encounter koomal on the ground. Despite this, koomal capture rates remained stable or increased during the same period that woylies have declined (Chapter 3 Meta-analysis and Section 4.2 Demographics). This was particularly obvious at Balban where there was a decline in woylie and an increase in koomal capture rates. Bearing in mind species differences in their vulnerability to predation, the koomal capture and sandpad data do not provide supporting associative evidence that predation may be a primary cause of the woylie declines.

Considerations of the use of a predator activity index (AI) in this study

The use of an activity index, such as has been used in this study, is considered a more conservative and more appropriate means of measuring predators from sandpad data, than deriving an estimate of predator abundance. This is foremost because fewer assumptions and interpretations of the sandpads and data are required to derive an activity index. Furthermore, a predator activity index can be used as a simple estimation of the probability of risk that a woylie may encounter a predator, which in itself is a useful means of considering associations between predators and woylie declines.

It is important to emphasize the limitations of the AI data derived from only eight sandpad survey sessions within a 12-month period. While these have provided substantial and valuable insight, a more extensive dataset collected over multiple years would be required to improve the statistical power of analyses, thus more confidently test the validity of these trends and particularly any possible associations with other factors (e.g. woylie abundance). The low and relatively variable detection rates of foxes and cats in particular, also limit the power of analysis. As such, the results to date need to be regarded accordingly – i.e. preliminary, and in many cases statistically untested patterns and associations.

This study found that in many cases both foxes and cats directly crossed over the sandpads in the wheel ruts. The fact that footprints were often completely obscured once a vehicle had passed over the sandpad, as a result of the prints being confined to the wheel ruts, reaffirms the merit in excluding sandpads from analyses that have been disturbed by vehicles in order to avoid sampling biases. Nonetheless, some sampling biases will still persist given the non-random nature of vehicle disturbance (i.e. more common close to farmland and generally more prevalent in some areas than others). In the case of this study, vehicle disturbance at Keninup was particularly high, especially close to private property. As a result, cat and fox AI at Keninup is likely to be particularly conservative.

Operational Considerations

- The monitoring of predator activity within the Upper Warren has ceased as part of this study. However, there are compelling reasons for continuing some level of predator monitoring within the Upper Warren region. In particular, the value of the information derived from predator monitoring is potentially critically important to the diagnosis of woylie declines, woylie recovery and ongoing fauna conservation and management more generally. Furthermore, given that the monitoring infrastructure is now established the costs to continue monitoring are relatively small. To improve the analytical power of the data, future predator monitoring should factor in the low detection rates and high variance by increasing the number of sandpads per site and particularly the number of sampling nights per survey session. The latter is especially useful for overcoming the problems and influence of undesirable weather such as heavy rain on an otherwise limited dataset.
- Weather, especially rain, had the greatest impact on data collection (i.e. complete or partial destruction of animal prints and signs), resulting in a significant reduction in sample size (i.e. 20% survey days lost due to heavy rain alone). Extended survey sessions would compensate for weather disruption.
- A less subjective method for determining sandpad decipherability is required. For example, an approach similar to that of Allen *et al.,* (1996) could be used, whereby a mark is left by the assessor on the sandpad to gauge pad condition. The same mark is placed consistently in the same place on each sandpad and whether this print is discernable the next day determines whether the pad is included in analysis. This would help account for sand condition, rain and wind effects.
- Consistency in pad preparation and recording between observers is particularly important. Efforts are required to ensure training, clear instruction and continual feedback is provided to maintain consistency.
- Development and use of other techniques to quantify predator activity, such as the use of sensor cameras and more particularly hair DNA analysis techniques. This would help determine baiting effectiveness and whether the increase in predator activity post-baiting is a result of behavioural changes or actual changes in fox density.'
- The results of this survey suggest that the passive sandpad method is sufficient for assessing activity of cats and foxes. However, a combination of FAP and "Pongo" (mixture of cat urine and faeces) may have provided different results than found with a FAP and oil lure. This combination of communicative and food lure, respectively, may

send mixed signals to cats and may explain why avoidance behaviour was observed. Ideally the FAP should be hidden and not clearly visible as in this study, and used in combination with another communicative lure, such as PONGO for best results (Dave Algar, pers. comm.). Due to the difficulties associated with the sourcing and use of Pongo it is still recommended that a passive method be used for future sandpad surveys in the Upper Warren. It is important that the sandpad covers the full width of the road from batter to batter to ensure prints are not missed. Not using lures associated with active sandpads reduces the cost and time required to prepare and conduct the predator surveys. It also reduces the potential for any avoidance behaviour (shyness), learned or territorial responses. As each day is independent, survey days within a session do not necessarily need to be consecutive which is logistically advantageous (i.e. can accommodate for weekends).

- Sandpad surveys can have multi-purpose value. They can be used as a non-invasive method for detecting presence of large mammals, such as macropods, difficult to trap species such as the numbat, as well as the detection of less common species. An example for the latter is quenda at Balban where only a very small number (four) have been captured over the history of trapping at the site, compared to 11 records from sandpads. Hence, recording of other species information and description of activity during predator surveys can be beneficial for other purposes. E.g. measurement of 1080 bait interference by non-target species and consideration and assessment of its potential influence on bait availability and control effectiveness.

4.4.5. Future work

The predator sandpad monitoring surveys have been suspended until the determination of the requirements for the next stage of the project. Expectation is that the Donnelly District will continue the surveys to some extent for general monitoring purposes once requirements for the woylie program are complete.

The refinement of the analyses of existing data, the development and relating to other available evidence, comparison of methodologies and results with mesopredator projects, and the subsequent publication of the results in a peer-reviewed journal, remains the current priority for this component of the WCRP.

4.4.6. Conclusions

- Fox control activities have been highly variable in the Upper Warren since 1996. More strategic spatial and temporal considerations of fox control, particularly in relation to fox biology, would be expected to deliver substantially better outcomes with negligible impact on existing resources.
- Without concurrent predator activity/abundance data collected over multiple years, it is not possible to know what the consequence of the baiting variability has been on predators nor is it possible to directly relate predators to woylie declines. Indirectly, however, the variability in fox control prior to the woylie declines in the Upper Warren is not strikingly different to baiting activities during or since the commencement of woylie declines.
- Fox activity did not differ significantly between pre and post fox-baiting. The most likely explanation for this is as a result of the insufficient statistical power due to limited sampling, low fox print encounter rates and high variance. Increasing the number of sandpads and/or number of sampling days within survey sessions is recommended to increase statistical power, as well as reduce the impact of adverse weather events.
- Ongoing monitoring of predator activity and/or abundance would be extremely valuable and highly recommended for the Upper Warren and other areas where predator control is conducted and fauna conservation is considered a high priority. Advantages include the ability to;

  i) monitor the effectiveness of predator control efforts and alert managers if/when an

issue arises.
ii) relate changes in native fauna directly to predator activity/abundance in the region.
iii) develop a better understanding of the factors associated with spatial and temporal differences in predator activity/abundance, such as discriminating seasonal and longer-term trends in predators.
iv) develop a better understanding of the predator-prey interactions at the population level.

- The significant temporal differences in activity observed for all species in this study cannot be satisfactorily explained without longer-term data (i.e. seasonal and longer-term trends, predator-prey interactions, etc).
- Although overall there were no significant site differences cat activity was substantially less at sites with stable and high woylie abundance and greatest at Balban where woylies were declining. The preliminary evidence remains consistent with cats potentially having a role in the decline of woylies, however, it is premature and there is insufficient data to determine the strength or nature of this association.
- There was a significant difference in fox activity between PCS sites, which generally was positively associated with woylie numbers. A similar trend was also observed for chuditch. There is no compelling evidence within the preliminary data that supports (or refutes) that foxes or chuditch are the principal cause for woylie declines.
- The general increasing trend in fox activity from February 2007, (when fox dispersal occurs) may be indicative of limited effectiveness in fox control during this period. Whether this is part of a longer-term trend remains to be seen.
- The high prevalence of koomal activity on sandpads indicates the potential risk of this species to predation. Despite this, koomal have not declined in association with woylies. This reduces the likelihood that foxes, in particular, may be principally involved in woylie declines given that koomal are also susceptible to fox predation (Morris *et. al.,* 1995). The extent to which cats predate koomal remains uncertain but it has been observed in the past (Wayne *et. al*., 2005).
- If predation is centrally involved in the woylie decline it is possible other underlying causes may predispose woylies to an increased risk of predation given that other prey species such as koomal have not also declined.
- It is recommended that an entirely passive sandpad methodology be used in the future. Cat activity on active pads was similar to passive pads, and of those pads that were active, most cats did not approach the oil and FAP.

4.4.7. Acknowledgements

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