4.3. Survival and mortality

Colin Ward, Adrian Wayne, Bruce Ward, Marika Maxwell, Brian Whittred, Chris Vellios, Julia Wayne, Jamie Flett.

Department of Environment and Conservation, Manjimup

Abstract

A woylie 'search and rescue' exercise (June 2006) aimed to recover sick and dead woylies that might provide evidence for the recent declines. A total of 15 searches within four forest blocks in the Upper Warren (two supporting moderate woylie densities and two where woylies recently declined) involved 66 DEC personnel and volunteers and resulted in the recovery of 17 woylie bodies (all in advanced stages of decomposition) and no sick woylies, among other finds.

The survival and mortality of 58 radio-collared woylies were examined at the Upper Warren population comparison study sites, July 2006 – June 2007. Monitoring of the mortality-sensitive radio-collars was generally conducted every weekday. Radio-collars were removed from 16 individuals (two were later recollared) during the study and collars fell off another three animals (one of which was subsequently recollared). A total of 21 mortality events were observed. Forensic evidence collection included the body site, animal remains (in the field and lab), necropsy (when possible), DNA, and forensic odontology.

This study demonstrates that the woylie declines result in part, at least, from mortality and not loss through emigration. Survival was substantially reduced while the declines were occurring at Balban relative to other sites not presently declining or having previously declined. Predation/scavenging is proximately associated with 20 of the 21 mortalities observed. Preliminary evidence indicates that cats were primarily associated with 13 woylie mortalities, four with raptor and three with fox. Chuditch were implicated at nine carcasses (DNA and odontology) but were generally considered secondary scavengers based on the field evidence. Based on the available evidence it is hypothesized that the ultimate factor(s) related to woylie mortalities (and population declines) is not predator related, rather predators are exploiting a prey made more vulnerable by other factor(s).

4.3.1. Introduction

Population decline may result from reduced recruitment (i.e. reproduction and/or immigration) and/or increased loss (i.e. mortality and/or emigration) of individuals from the population. The early results from the situation assessment to determine if woylies had declined in the Upper Warren (Wayne, 2006; Wayne *et al.,* 2006) demonstrated that the woylie declines were rapid (25-90% per annum). These rates of decline were greater than what might be possible if recruitment failure was complete (i.e. assuming woylies lived for 5-6 years the rate of decline due to complete reproductive recruitment failure could be no greater than 16-20% per annum). It was therefore clear that the woylie declines resulted, in part at least, from an *increased loss* of individuals from the population. As a result of this important finding, this study focused on the potential factors associated with the loss of woylie individuals from the Upper Warren Population Comparison Study (PCS) sites. A good understanding of these factors was considered critically important to providing clues, if not direct evidence, of the principle cause(s) behind the woylie declines.

The principal objectives of this study were to determine if there were differences between woylie populations at difference stages of decline with respect to i) survival, and ii) mortality.

4.3.2. Methods

4.3.2.1. Woylie 'search and rescue' area searches

A woylie 'search and rescue' exercise on 17 June 2006 aimed to recover sick, moribund and dead woylies that might provide evidence for the recent declines. Two forest blocks were selected that had most recently undergone substantial declines in woylie numbers (Chariup and Yendicup).

Another two forest blocks were surveyed that still supported moderate densities of woylies (Balban and Keninup). Area searches were conducted using similar methods to those used by the SES and Police to search for lost people, bodies and/or evidence. SES volunteers provided support in the execution of these searching methods. A total of 66 DEC personnel and volunteers, including year 12 students from Bunbury Cathedral Grammar School were organised into five search teams. Each team conducted three searches, one each at Chariup and Yendicup, and another at either Balban or Keninup. Each search was conducted for around 60 minutes. A wildlife veterinarian team from Perth Zoo was on site to manage any sick or moribund woylies that were recovered.

4.3.2.2. Radio-collared cohorts

Cohorts of radio-collared individuals were used as the principle means of investigating the survival and mortality of woylies. Beginning in July 2006, cohorts within each of the five Upper Warren PCS woylie populations were collared with two-stage mortality-sensitive radio-transmitters (Biotrack, U.K.). Using the trapping activities on the grids associated with the woylie demographics study (Section 4.2 Demographics), adult individuals were selected for collaring with the objective of getting at least six males and six females at each site. Only individuals from these grids were selected for radio-collaring to maximise the likelihood of repeat captures for close examination and because of the substantial logistic benefits of having the study subjects in close proximity to each other. Young subadult animals were not radio-collared because of equipment limitations and welfare considerations of having fixed-diameter collars on growing animals.

At the time of radio-collaring, individuals were given full clinical health checks, and extensive sampling for disease and dietary analyses (blood, scats, ectoparasites, and ear tissue for DNA) to develop as complete a health profile as possible. Subsequent recaptures of these individuals during the PCS demographics study and Upper Warren Fauna Monitoring (Chapter 2) involved routine detailed health checks and the non-invasive sampling of faeces and ectoparasites for disease screening. Repeat sampling of blood was predominantly limited to approximately 6 months (re-collaring and cohort supplementation) and 12 months (collar removal) after first collaring, and individuals opportunistically captured along the Upper Warren Fauna Monitoring transects (October-November 2006 and March-April 2007).

The monitoring of the radio-transmitters commenced immediately after the first animals were collared. The objective was to monitor all animals every weekday over a 12-month period. When this was logistically not possible due to poor weather conditions or resource limitations, every effort was made to ensure no more than two days elapsed between monitoring events. The approximate location of the animals were recorded, particularly those instances when individuals were not located on the PCS demographics study grids. The monitoring of the radio-transmitters was preferentially conducted by fixed-wing aircraft principally because of the efficiency and economic advantages. Monitoring from the ground was done when it was possible to be associated with other WCRP field work (e.g. trapping and predator sandpad monitoring). No fine-scale animal movement or habitat use data were collected from radio-collared woylies given the resource limitations and priorities.

All mortality events were intensively investigated to collect as much forensic evidence as possible. This included evidence from the site where the body and/or radio-collar were recovered, animal remains (examined in the field and laboratory), necropsy (when possible, by the Duty Pathologist at Murdoch University), forensic DNA (Dr Oliver Berry, University of Western Australia), and forensic odontology (Denice Higgins, University of Adelaide). A more complete account of the methodology associated with this study is provided in the WCRP Operations Handbook (Volume 3)

4.3.3. Results

4.3.3.1. Woylie 'search and rescue' area searches

The search effort from each of five teams (total of 66 people), each completing three one-hour exercises resulted in 9061 people-minutes of searching (Table 4.3.1). The finds included 17 woylie remains, 13 woylie nests and five live woylies (Table 4.3.2). Remains located during the searches were generally in advanced stages of decomposition. No sick or moribund animals or fresh carcasses were located.

Table 4.3.1. The search effort for the woylie 'search and rescue' in the Upper Warren, 17 June 2006.

	Chariup	Yendicup	Balban	Keninup
Woylie capture rate (%; Apr06)	6	8	36	51
% Woylie extant (Apr06)	10	11	54	-
Number of area searches	5	5	3	2
Total search effort (min)	1980	3758	1815	1508
Minutes per woylie body found	495	1879	605	188
Minutes per live woylies	N/A	N/A	N/A	302
Minutes per woylie nests	1980	3758	908	168

* search time (person-minutes) per unit find

Woylie capture rates and % extant sourced from Upper Warren Fauna Monitoring data (April 2006)

Table 4.3.2. Summary of the finds from the woylie 'search and rescue' exercise in the Upper Warren region, 17 June 2006.

Woylie body remains	17
Woylie nests	13
Woylies alive	5
Koomal body remains	3
Chuditch body remains	1
Macropod body remains	8
Bobtail body remains	1
Raptor sign	1 (pellet)
Predator Scats	6
Other animal material	14

* Macropods includes, tammar, western brush wallaby and western grey kangaroo

4.3.3.2. Radio-collared cohorts

Radio-collars were fitted to 58 woylies. The number and gender of woylies collared was limited by the availability of suitable individuals caught at each of the five Upper Warren PCS sites except Keninup (Table 4.3.3). All radio-collared woylies displayed territorial behaviour, each consistently remaining within the same area throughout the period in which they were monitored. There was no evidence of emigration or relocation by any of the radio-collared adult woylies.

Mortalities for the period July 2006 to June 2007 totalled 21 (Table 4.3.3). Six deaths occurred at Keninup, Balban had eight, Warrup had three, Boyicup one and Winnejup three.

Because of skin lesions associated with the radio-collar, 16 were removed to ensure there was no compromise to the welfare of the woylies (or the integrity of the study and its results). Three collars fell off woylies when the epoxy resin joining the brass collar to the radio-transmitter separated.

At completion of the study, 17 collars were recovered from live woylies. One collar and animal were not recovered after the radio-signal was lost at the end of the radio-telemetry monitoring and trapping efforts did not managed to relocate the individual.

Most collars were fitted in July-August 2006. Most mortality events occurred August to November 2006 (Figure 4.3.1). The radio-collared cohorts were then supplemented in December 2006 (12 in Keninup and two in Balban). This included the recollaring of three individuals whose minor neck lesions had completely healed after the earlier removal of their collar. Those collars removed in May and June 2007 were removed at the completion of the project.

Table 4.3.3. Summary details of the radio collared woylies at the PCS grids in the Upper Warren region.

PCS Grid		Collars Fitted	Collars removed during study	Collars removed at end of study	Collars broken	Fate Unknown	Animal Mortality
Keninup	Male	13	4	5	1		3
	Female	14	2	7	1	1	3
	Total	**27**	**6**	**12**	**2**	**1**	**6**
Balban	Male	8	3				5
	Female	4	1				3
	Total	**12**	**4**				**8**
Warrup	Male	6	3		1		2
	Female	5	2	2			1
	Total	**11**	**5**	**2**	**1**		**3**
Boyicup	Male	2	1				1
	Female						
	Total	**2**	**1**				**1**
Winnejup	Male	5		3			2
	Female	1					1
	Total	**6**		**3**			**3**
All Grids	Male	**34**	**11**	**8**	**2**		**13**
	Female	**24**	**5**	**9**	**1**	**1**	**8**
	Total	**58**	**16**	**17**	**3**	**1**	**21**

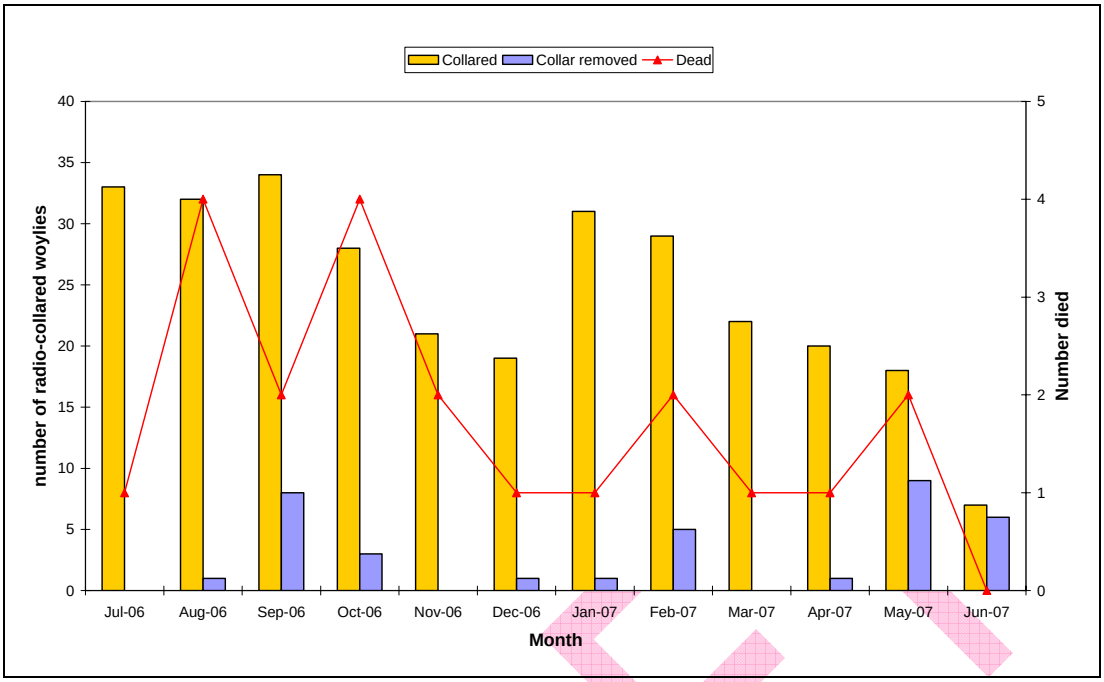
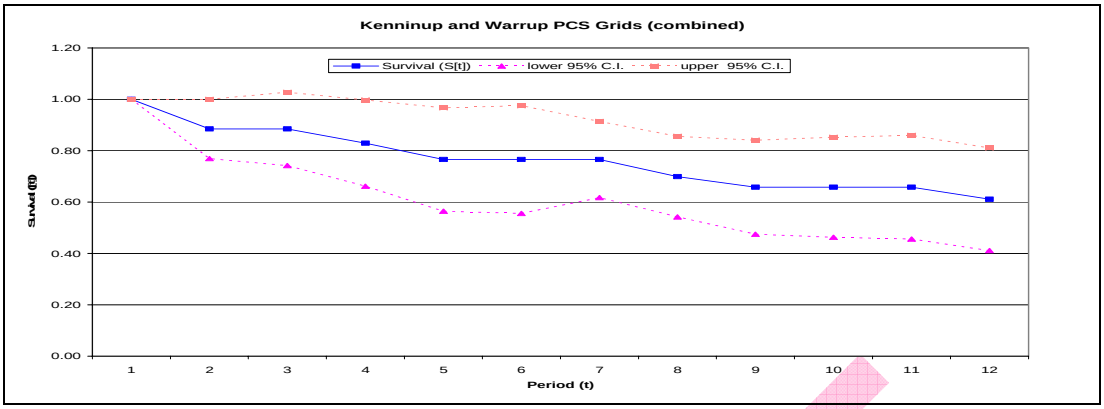


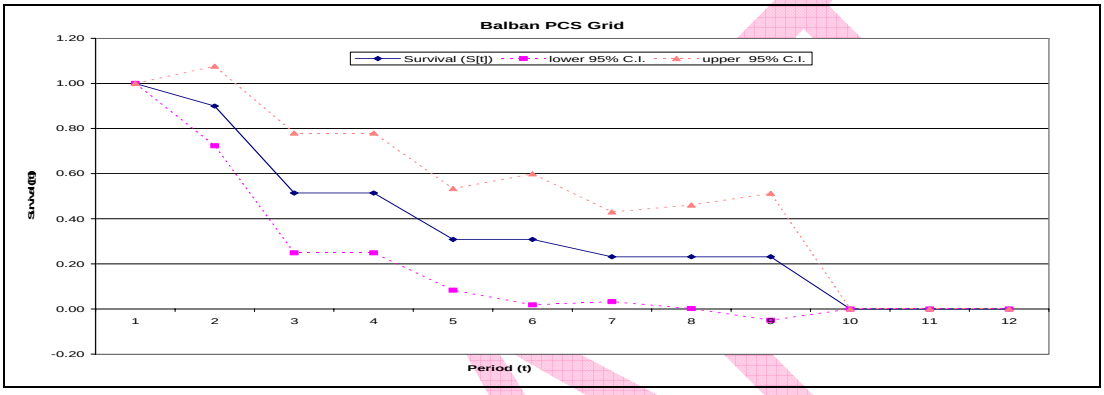
Figure 4.3.1. The fate of radio-collared woylies at the Upper Warren PCS grids (July 2006 to June 2007).

The Kaplan-Meier survival function for the combined sites with relatively stable, moderate densities of woylies (Keninup and Warrup), demonstrated a slower rate of decline compared with Balban (Figures 4.3.2a and 4.3.2b), which was undergoing a significant decline in woylie numbers over the same period (81% decline in capture rates in the same 12 months, see PCS demographics Section 4.2). Woylie survival had declined to zero at Balban by period 10 (30 days per period, '*t*'), compared with 0.66 at the moderate density sites. The mortality rate of the radio-collared cohort at Balban was approximately four times greater than at Keninup (i.e. 0.37% mortality per day versus 0.11% per day respectively). The survival function of the combined sites which declined, now stable, low density woylie populations (Boyicup and Winnejup) had particularly large 95% confidence intervals given the very small cohort sizes (Figure 4.3.2c).

4.3.2a



4.3.2b



4.3.2c

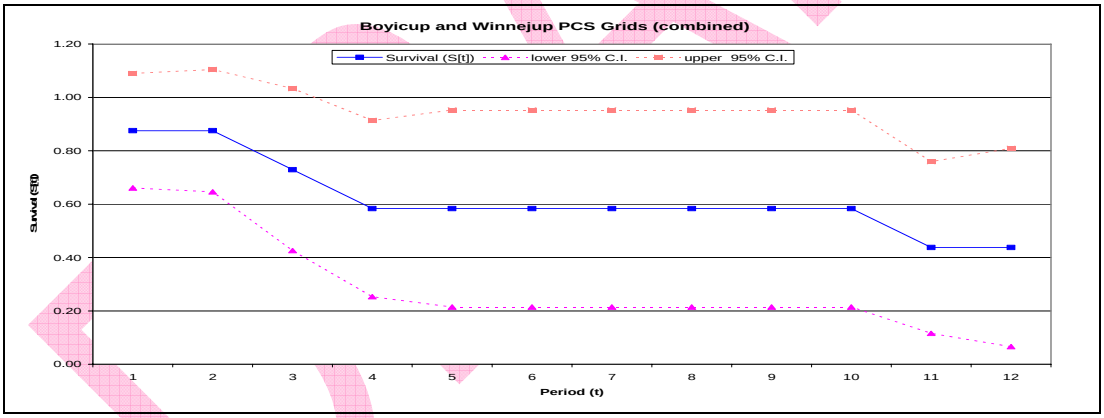


Figure 4.3.2. The Kaplan-Meier survival function for the a) combined moderate-density woylie populations at Keninup and Warrup, b) transitional population at Balban, and c) combined declined, now low-density populations at Boyicup and Winnejup in the Upper Warren region.

Of the 21 mortality events, predation and/or scavenging was evident at all except one body (the inconclusive case from Winnejup; Table 4.3.4). The principle predator or scavenger associated with the mortalities was based on the evidence collected from the location where the body was recovered and the body remains. This evidence was collectively reviewed by most of the authors in a subsequent group workshop. On this basis, the principal predator/scavenger associated with the woylie mortalities was the cat in 13 cases, raptor in four, fox in three and one case remained inconclusive (advanced state of decay and no signs of predation/scavenging). DNA results of samples from mortalities have returned weak amplifications or results and require further work.

DNA and forensics odontology provide opportunities for the collection of other supporting evidence. DNA sampling was conducted on several of the woylies particularly the tooth marks on the radio-collars and bite marks or chewing sites on the woylie bodies. The DNA results are still

pending as attempts to improve tests to produce a more conclusive outcome continue. The forensic odontology from the radio-collars in some cases directly supported the primary predator/scavenger but in 10 cases identified a different species. In eight of these cases chuditch were identified by markings on the collar from bodies otherwise thought to have been predated /scavenged by cats. In two cases, field and preliminary DNA evidence identified fox but odontology identified cat marks on the collars.

Two of the radio-collared woylie bodies were sent for necropsy at Murdoch University. Woylie Do 3901/02 was found fresh and almost entirely intact - only the tail was missing with no signs visible of the cause of death. The second necropsy was from a woylie (K 657/658) that died shortly after collaring and before release. There was little opportunity for necropsy on most mortalities because predation/scavenging left very little internal tissues/organs available for examination – most remains consisted of skin, muscle tissue and skeleton only. Occasionally brain material was available for examination.

Necropsy of Woylie DO 3901/02 found moderate autolysis of the spleen, small and large intestines and stomach. Liver, adrenal gland, kidney, lung, heart and brain appeared normal. Multiple puncture wounds were present over the neck and multiple ribs were fractured, consistent with predation.

Woylie K 567/568 pathology reported no distinct cause of death however mild pulmonary oedema and moderate acute subdural / subarachnoid haemorrhage of the brain were present.

Woylie DO 3810/11 was considered a cat predation from physical evidence at the body site. A scat associated with the body was later identified as fox from DNA analysis. This provides an example of the challenges associated between discriminating predator from subsequent scavenging or visits by other animals to the body.

4.3.3.3. Wildlife forensics course and workshop

A 2-day wildlife forensic training course and 1-day applied wildlife forensics workshop was held in October 2006 at the Kensington office of the Department of Environment and Conservation. The course objectives were to improve the understanding and skills of conducting forensic investigations into mortality events and to use this knowledge to develop better forensic investigation protocols. The workshop involved wildlife practitioners and researchers and aimed to compare and share existing methods and experience, and develop where possible, a strategy for collective improvement and learning in wildlife forensic methods. The course was attended by 26 people, principally from the mesopredator research projects, personnel from Species and Communities Branch and Wildlife Officers, and Australian Wildlife Conservancy collaborators.

At the course, evidence collection principles, chain of continuity, documentary procedures and scene evidence photography were presented by Sergeant Mark Reynolds (WA Police Academy). Animal taphonomy, which documents the physical signs and time line of decomposition of a carcass, was outlined by Christopher O'Brien (Centre for Forensic Science, UWA). Forensic entomology presented by Ian Dadour (Centre for Forensic Science, UWA) described the chronological development of fly larvae and beetles to determine time since death. Practical field exercises were also involved.

Table 4.3.4. Predators/scavengers identified from forensic investigations on woylie mortalities.

Site	Date	Woylie ID	Primary Predator / Scavenger	Confidence	Other Evidence Recent health check	DNA Collar	DNA other	Odontology Collar
Keninup	11/08/2006	K653 K654	Cat	60%		Pending		Chuditch
	19/08/2006	DO3810 DO3811	Cat	50%		Pending	Scat-Fox	Chuditch
	29/08/2006	DO3907 DO3908	Raptor	70%	Fur loss on rump	Pending		Inconclusive
	15/11/2006	DO3901 DO3902	Cat	80%	Skin lesions, heavy lice load	Fox?	No result	Inconclusive
	26/02/2007	DO5011 DO5012	Raptor	75%		Chuditch		Inconclusive
	2/06/2007	DO3781 DO3782	Cat	60%	Heavy tick load, old scar	Pending	Pending	Chuditch
Balban	12/08/2006	DO3921 DO3922	Cat	50%		Pending		Chuditch
	12/09/2006	DO3824 DO3873	Cat	70%		Pending		Chuditch
	29/09/2006	WB2711 WB2710	Cat	70%		Pending		Chuditch
	5/10/2006	WB2749 WB2750	Cat	60%	Heavy lice load	Pending		Cat
	8/11/2006	DO3821 DO3820	Raptor	80%	Heavy lice load	Pending	Body-Fox?	Inconclusive
	4/12/2006	WB2742 DO2743	Cat	60%		Pending		Inconclusive
	30/01/2007	DO7305 DO7306	Cat	60%		Pending	Pending	Cat
	9/04/2007	WB2631 WB2360	Cat	80%		Pending	Pending	Chuditch
Warrup	21/10/2006	DO1869 DO1870	Cat	60%	Fur loss around eyes, old scars	Pending		Chuditch
	26/02/2007	DO3845 DO3846	Fox	90%		Fox?	Pending	
	30/03/2007	DO1842 DO1843	Fox	80%		Fox?	Body-Fox?	Cat
Boyicup	25/10/2006	DO2871 DO2872	Raptor	90%		Pending		Peck mark?
Winnejup	22/07/2006	DO3931 DO3932	Fox	20%		Pending		Inconclusive
	21/10/2006	DO3867 DO3868	Inconclusive	-		Fox?		Inconclusive
	21/05/2007	K276 K277	Cat	60%		Pending		Cat

4.3.4. Discussion

4.3.4.1. Woylie search and rescue

No sick or moribund woylies were detected during the woylie search and rescue (SAR) area searches. The many challenges of detecting unfit woylies include competition with predators (foxes, cats, chuditch, raptors, etc) that are likely to readily and quickly exploit such prey, animal concealment and the significantly lower densities of woylies in areas that had undergone substantial decline. Considering these factors, the use of such a large number of people in the SAR exercise was intended to improve the odds of detecting a sick woylie. Had a sick woylie been found the value to diagnosing the woylie population declines was potentially immeasurable. That no sick or moribund woylies were found does not provide, in itself, any evidence whether or not reduced fitness of woylies is a primary mechanism in the recent and rapid declines because of the associated low probabilities of detection.

The relatively high number of woylie carcasses recovered compared with other abundant mammals (koomal, macropods, etc) is generally consistent with other evidence suggestive of mortality being associated with declines, notwithstanding the potential for differential detection rates of animal remains (e.g. species size and densities, behaviour and ecology). There was no apparent association in the relative detection rates of woylie remains and the woylie population status at the four forest blocks examined, however, a closer examination of the data may be more revealing. Similarly an examination of the forensic evidence associated with the woylie remains may also provide clues related to the cause(s) of the recent declines.

4.3.4.2. Survival and mortality of the radio-collared cohorts

The preliminary results of this study provide direct and compelling evidence that the woylie decline in the Upper Warren is associated with the loss of individuals from the population. Furthermore, this loss has not resulted from adult emigration but through adult mortality. The rate of mortality at Balban, where declines were current, was approximately four times greater than at Keninup, where declines have not yet been apparent.

The rate of mortality was also substantially greater at Balban (approximately three times greater) than at Boyicup/Winnejup (combined) where woylies had recently declined but were at very low and relatively stable densities. The 95% confidence intervals associated with the Kaplan-Meir survival functions indicate that while the mortality rates at Balban are probably significantly greater than at the other sites, there is no significant difference between Keninup and Boyicup/Winnejup – because of the small cohort sizes at the latter sites. This suggests that what may have caused these populations to decline was not still functioning in the same manner after the decline had reduced these populations to less than 5% of their former size. This finding highlights the importance of identifying the agent(s) of decline *while* the declines are occurring, because it seems likely that they may not still be operating and/or as evident after the declines are largely complete. It might also imply that there may be some potential for these populations to recover, if other factors do not maintain the populations at low densities.

While mortality has been directly associated with concurrent woylie declines, this does not indicate in any way whether or not reduction in recruitment is also involved. Further statistical analysis is required to more rigorously determine the survival and mortality differences between these radio-collared cohorts.

4.3.4.3. Factors associated with woylie mortalities

Based on a review of all of the preliminary forensics evidence available to date feral cats appear to be a major predator/scavenger of woylies, particularly in northern Perup at Balban (where declines were current) and Keninup. It is more likely that the cats are predators of woylies, given that it is unusual for cats to scavenge (e.g. Molsher *et al.,* 1999). Cats are also known to be capable of predating similarly-sized prey (e.g. boodie, ngwayir, dalgyte, quenda, chuditch, mala, etc) (e.g. Christensen and Burrows, 1994; Gibson *et al.,* 1994; Dickman, 1996; Short and Turner, 2000)

What other factors, such as disease, that may have increased woylie vulnerability to predation (e.g. reduced the fitness, changed behaviour and/or morbidity) remains unresolved by this study alone. While this study clearly demonstrates that predation is a major factor associated with the woylie declines the evidence to date indicates that multiple factors are, in all likelihood, involved. Evidence that does not support predation as the primary cause of declines includes; i) little or no evidence or biological capacity for a pronounced increase in predator numbers capable of synchronous 25% – 95% annual decline rates in woylie numbers through much of the Upper Warren or elsewhere, ii) limited evidence of a clear catalyst that could precipitate an acute predator increase of this magnitude at this time and at so many sites, and iii) no decline in other sympatric prey species such as other 'critical weight range' medium-sized mammals (Burbidge and McKenzie, 1989) and large reptiles such as *Varanus, Egernia, and Trachydosaurus*. Prey switching (e.g. Krebs, 1985) by itself is not a likely explanation as to why only woylies have been targeted by a predator because woylie numbers have been reduced well below densities by which it would efficient for a predator to continue targeting woylies and secondly there is no evidence of other sympatric prey species being subject to prey switching either pre or post woylie declines. The only possible exception is the wambenger (*Phascogale tapoatafa*) which underwent a substantial decline in the forested areas of the Upper Warren region in 1995, however, the temporal link is weak and associative evidence indicates that these declines were related to food resources (Scarff, 1998; Rhind, 2002; Rhind and Bradley, 2002; Wayne unpublished data).

In summary, while predation is a *proximate* mortality factor, the *ultimate* factor(s) that have lead to this endpoint are likely to be non-predator related (i.e. it is most likely that predators are effectively exploiting a prey resource made susceptible by other factors).

4.3.4.4. Predation and scavenging

The review of available forensic evidence at the completion of the field program was a particularly useful exercise. As well as providing a training and active learning opportunity for the personnel involved, it helped to standardise evidence collection recording and interpretation and clarify the similarities and differences between the mortality cases. The similarity of the body remains between woylies identified as having been primarily predated/scavenged by the same species was particularly striking. The strength of these similarities increased the confidence of the interpretation of the evidence and provides the opportunity to develop better 'profiles' for the predators involved.

In the same way that is often not possible to distinguish between a predation and the scavenging of a moribund animal or recent death, particular care is required to discriminate between the first predator/scavenger and subsequent visitors to a carcass. The limitations in being able to do this need to be acknowledged and the use of associated forensic evidence needs to be considered with this in mind. For example, chuditch were identified by forensic odontology to be associated with 10 woylie bodies. While in all of these cases the balance of evidence was interpreted to indicate secondary scavenging, it cannot be unequivocally rejected that chuditch may have been the primary predator/scavenger.

4.3.4.5. Operational considerations

Survival monitoring

- Aerial surveillance was a particularly efficient (time, cost and personnel resources) and effective means of scanning the radio-signals of Upper Warren cohorts.
- Radio-collar issues were a significant concern for this study. A conservative approach with respect to injuries was adopted in consideration of the welfare of the woylies involved (the highest priority at all times), and as a result a large proportion of collars had to be removed to prevent further skin lesions. The collar also often provided a site for ectoparasites (especially ticks) to aggregate, which in themselves could become sites for infection. Careful consideration of the design and application and monitoring of radio-collars is required to minimize any potential welfare issues.
- The rapid detection and recovery of animal remains as soon after mortality is critical to the successful identification of the factors associated with death. Every hour after death

increases the loss and/or confounding of evidence as a result of decomposition and reduces the ability to identify proximate and ultimate causes of death. Mortality-sensitive collars set to trigger after no more than 2-3 hours of no movement, and daily monitoring as close to sunrise as possible are important considerations.

Forensics

- The forensics course and workshop met its objective to bring more science, rigor and skills to evidence collection and interpretation. Given its importance to this and other studies, further improvement would be readily achievable through further co-ordinated and collaborative work and training. A Corporate-level management of this would be optimal given its relevance and broader application within DEC (especially Nature Conservation and Science Divisions).
- The development of predator/scavenger 'profiles' would be a particularly valuable improvement given the fragmented nature of the existing evidence (i.e. a number of individuals each have a few bits of evidence that, when combined are substantially more valuable than the sum of the fragments in isolation). Predator/scavenger profiling would be well suited to a forensics student project (i.e. evidence collation and development of the behaviour, preferences and characteristic differences in the method of killing and consuming carcasses by difference predators).
- The removal of vital organs and tissues by predation/scavenging results in removal/alteration of evidence needed to determine whether underlying factors were the principal cause of death and/or increased the susceptibility to predation. The extent of evidence loss by this means has significantly compromised evidence collection in this study.
- The collection of associated evidence from DNA and odontology has been especially informative in this study. The value of pathology has been limited by the amount of useful material recovered with the body. Further improvements would be gained by a further development and refinement of these tools and the identification of other possible methods.
- Complication factors include; potential for multiple visitors (predators/scavengers), rate of decay and loss/disturbance of evidence over time; habitat factors – i.e. sandier and more open environments can provide more readily detectable sign such as distinctive foot prints associated with the body, signs of struggle (i.e. predation vs scavenging), etc.

4.3.5. Future work

- Analyses of the data and evidence remain to be completed, including; more sophisticated survivorship analyses (e.g. MARK), DNA evidence, trapping data to support evidence that emigration is not involved, etc.
- Karakamia radio-telemetry data associated with Andrew Hide's Honours research (Curtin University) will provide comparative survival data. Once the thesis is submitted, this will be available for comparison.
- Development of forensic profiles of common predators, particularly chuditch, fox, cat and raptors. This could be developed in collaboration with a forensics post-graduate student.
- Woylie 'search and rescue' forensic evidence has not yet been fully processed for evidence.

Operational matters

a. Improve DNA sampling and analytical techniques.
b. Improve collar design and application techniques to reduce adverse collar wear

Reduce the time from a mortality event until the forensic investigations is completed.

- Forensic training and development for personnel associated with any future work diagnosing woylie declines.

4.3.6. Conclusion

- Adult mortality is associated with woylie declines. The rate of mortality is higher in the declining population than the sites which had stable populations.
- The lack of predator data (activity and/or numbers) prior to this study means that it is not possible to examine the relationship and compare predators with earlier declines in the Upper Warren or elsewhere.
- Emigration is not involved in the loss of individuals from the populations undergoing decline.
- The cat was associated with most woylie mortalities. The fox has had a relatively minor association with woylie mortalities, which was equivalent to the level of mortalities associated with raptors.
- Chuditch has been commonly associated with woylie mortalities based on forensic odontology. Chuditch is more likely to be a secondary scavenger than a primary predator.
- Most of the predations involved almost complete consumption of the carcass, generally leaving little more than bones, skin and some muscle tissue (i.e. none of the major organs available for pathology). Therefore, identifying other possible factors associated with mortality have been substantially hampered.
- Predation is likely the *proximate* cause of mortality, the *ultimate* cause(s) of mortality (and woylie population declines) are likely to be something else other than predation, such as disease.

4.3.7. Acknowledgements

We are grateful for the contributions and assistance provided by countless individuals. In particular we thank the SES volunteers, community volunteers and Bunbury Cathedral Grammar students involved in the Woylie Search and Rescue exercise; presenters and contributors to the wildlife forensics course; project collaborators including Oliver Berry, Denice Higgins and Murdoch University Pathologists including Graeme Knowles, Phil Nicholls, Alexander McLachlan. Shane Raidal and Mandy O'Hara; DEC personnel based in Warren region that assisted with the collection and processing of forensic evidence in the field and laboratory. Colleagues associated with the mesopredator research program, particularly Neil Thomas, Nicky Marlow, Paul de Tores, Keith Morris and Dave Algar; and, the Manjimup Aeroclub, particularly the pilots Peter McGinty and Peter Davis.

4.3.8. References

Burbidge, A. A., and N. L. McKenzie. 1989. Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. Biological Conservation 50:143-198.

Christensen, P. E. S., and N. D. Burrows. 1994. Project Desert Dreaming: experimental reintroduction of mammals to the Gibson Desert, Western Australia. Pages 199-207 in M. Serena, editor. Reintroduction Biology of Australia and New Zealand Fauna. Surrey Beatty and Sons, Sydney.

Dickman, C. R. 1996. Overview of the impacts of feral cats on Australian native fauna. Australian Nature Conservation Agency, Canberra.

Krebs, C. J. 1985. Ecology: The Experimental Analysis of Distribution and Abundance. Harper Collins Publishers, New York.

Molsher, R., A. Newsome, and C. Dickman. 1999. Feeding ecology and population dynamics of the feral cat (*Felis catus*) in relation to the availability of prey in central-eastern New South Wales. Wildlife Research 26:593-607.

Rhind, S. G. 2002. Reproductive demographics among brush-tailed phascogales (*Phascogale tapoatafa*) in south-western Australia. Wildlife Research 29:247-257.

Rhind, S. G., and J. S. Bradley. 2002. The effect of drought on body size, growth and abundance of wild brush-tailed phascogales (*Phascogale tapoatafa*) in south-western Australia. Wildlife Research 29:235-245.

Scarff, F. R., S. G. Rhind, and J. S. Bradley. 1998. Diet and foraging behaviour of brush-tailed phascogales (*Phascogale tapoatafa*) in the jarrah forest of south-western Australia. Wildlife Research 25:511-526.

Short, J., and B. Turner. 2000. Reintroduction of the burrowing bettong *Bettongia lesueur* (Marsupialia: Potoroidae) to mainland Australia. Biological Conservation 96:185-196.

Wayne, A. F. 2006. Interim assessment of the evidence for a recent decline in woylie abundance in south-western Australia. Pages 1-28. CALM, Perth, Western Australia.

Wayne, A. F., I. Wilson, J. Northin, B. Barton, J. Gillard, K. Morris, P. Orell, and J. Richardson. 2006. Situation report and project proposal: identifying the cause(s) for the recent declines of woylies in south-western Australia. A report to the Department of Conservation and Land Management Corporate Executive. Pages 1-28. CALM, Perth, Western Australia.