CHAPTER 7 SUMMARY OF PROGRESS AND INTERIM FINDINGS

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Abstract

The responses to the report of woylie declines in the Upper Warren included an initial situation assessment of woylie populations throughout the southwest, an early-response workshop, the establishment of the Woylie Conservation Steering Group and the development of the Woylie Conservation Research Project (WCRP). Using a decline diagnosis framework broadly based on the 'declining-population paradigm, the WCRP consists of three major components; I) Upper Warren fauna monitoring that built on, enhanced and co-ordinated previously independent existing activities, II) Meta-analysis of existing datasets that were aggregated into a single database, and III) a population comparison study (PCS) designed to discriminate factors and attributes associated with contemporary declines. The PCS has five main lines of enquiry; a) woylie density and demographics, b) woylie survival and mortality, and investigations into the key putative agents of decline, c) predators, d) resources, and e) disease.

Although it remains premature to identify the possible cause(s) of the woylie declines, the preliminary results can provide some early hints regarding what ongoing work is likely to suggest might be the likely agents of decline. Factors that are not probably the primary agents of decline include habitat loss / modification, fire, direct human interference from trapping and resources including food. Climate may be associated with woylie declines at Venus Bay Peninsula (VBP), South Australia and cannot be ruled out as a factor in Western Australia, but seems unlikely for the Upper Warren populations at least. Given the lack of fox activity or density monitoring data associated with most of the observed woylie declines it is not possible to determine whether they may be a major agent of decline. This is, however, considered unlikely for the Upper Warren region given that during the WCRP, foxes only accounted for 15% of the implicated primary predators/scavengers associated with observed mortalities and none of the mortalities at the Balban PCS site (which underwent a >80% decline in 12 months) were attributed to foxes.

The rapid and substantial woylie declines are driven at least by increased adult mortality. Emigration of animals elsewhere is not supported by the evidence. Whether recruitment into the adult (breeding) population is involved in the declines can not yet be established, however, the preliminary exploration of the data suggests breeding rates (prevalence of pouch-young) are not associated with the declines.

The leading speculative hypothesis (i.e. untested) for the cause(s) of the declines is presented. In summary, multiple interactive factors are expected responsible, with disease considered the most likely primary and ultimate agent of decline. The symptoms and unequivocal confirmation of the disease and the related interacting factors remain elusive at this stage, although some key suspects have been identified including *Toxoplasma*, *Trypanosoma sp. nov.*, possible synergistic effects between the two parasites and the involvement of stressors that may trigger the disease. Other infective agents may also be involved. As a consequence of the disease(s), opportunistic and exploitative predation/scavenging, predominantly by cats, are likely the most proximately-related factor associated with the deaths of the woylies. Whether the predation/scavenging occurs on moribund or dead animals that would die regardless, or whether in the absence of predation in general, the woylies would otherwise recover and survive remains unknown.

7.1. Summary of progress

In response to the initial report (26 October 2005) of a suspected woylie decline at a site in the Upper Warren, a preliminary investigation of available data and additional field surveys were conducted between November 2005 and February 2006 to assess the situation. This work was led by Science Division in close collaboration with Nature Conservation personnel in Manjimup. In February 2006 a three-day workshop on the 'Recent Mammal Declines in the Southwest' was convened at Perup Ecology centre and attended by 32 Departmental personnel directly associated with woylie and fauna monitoring, research and/or conservation and management. The objectives of the workshop were;

1. Provide an overview and understanding of the recent mammal declines in the southwest
2. Examine the potential cause(s) of these recent declines and associated evidence
3. Identify improvements to mammal monitoring protocols for the Upper Warren (a model for Corporate-level improvements via *Western Shield*)
4. Follow-up task force meeting to determine future directions (priorities, strategies, plans, organisational structure, improved mammal monitoring protocols, actions, budget, and links with other corporate working groups)

Among the outcomes of the workshop was the transformation of the initial response task force into the 'Woylie Conservation Steering Group' with broader Departmental representation. Response priorities included the development of a research and monitoring program proposal to investigate the causes of the woylie declines (i.e. WCRP), invoke a moratorium on the movement and translocation of woylies, inform and instruct all Districts/Regions and researchers associated with woylie populations, complete a woylie conservation status review, establish a 'monitoring protocols review panel' that would report to the *Western Shield* Operations Research Committee (WSORC) and initiate collaborations with existing mesopredator research programs.

A situation report and WCRP proposal was presented to the Corporate Executive in May 2006 and the project commenced in July 2006 having received support from the Director General and 12–months funding via the 'Saving Our Species' (Biodiversity Conservation Initiative) program.

The WCRP has been addressing the first five steps of the woylie decline diagnosis framework during 2006 and 2007 (*sensu lato* declining-population paradigm, Caughley, 1994).

Woylie decline diagnosis framework

1. Is the decline real?
2. Decline characteristics
3. Understand the species' ecology
4. Identify all potential causes
5. Shortlist using circumstantial evidence
6. Direct evidence –test putative causes
7. Conservation and management responses (experimental)

The WCRP has three major components that together, address the first five steps of the above diagnosis framework.

1) Upper Warren Fauna Monitoring – an enhancement and co-ordination of existing monitoring and research activities – that provides;

a) six-monthly information up-dates on population change and associated characteristics at the regional scale and,

b) a regional-scale means of collecting data on woylies and putative agents of decline to complement the finer-scaled population comparison study.

2) Meta-analysis of existing data sets (aggregated into a single relational database providing data on 25,479 woylie captures over 33 years) to;

a) Confirm that the declines are real

b) Quantify the spatial, temporal and demographic characteristics of the woylie decline, which in turn will,

c) Provide circumstantial evidence that will aid in the identification of the possible causes of decline.

3) Population Comparison Study (PCS) is a detailed investigation of woylies and the possible agents of decline. This principally involves six sites that support populations at different stages of decline;

- Declined populations now at low densities: Boyicup and Winnejup (Upper Warren Region)
- The last remaining moderate-density woylie populations in the Upper Warren region: Keninup, Warrup and Balban
- High-density and stable population - Karakamia Wildlife Sanctuary (50 km east of Perth), a fenced (i.e. closed) population

The five main lines of enquiry to be investigated at the population comparison study sites are;

a) Woylie density and demographics

b) Woylie survival and mortality

c) Predators

d) Resources

e) Disease

Field work was largely completed by August 2007. Data and information management and the commencement of preliminary analyses have ensued.

7.2. Summary of key findings

7.2.1. Preliminary inferences (i.e. early hints) regarding possible causes of recent woylie declines

Extreme caution is required when inferring from the premature results and analyses generated to date. It must be emphasized that all results presented in this report are preliminary and require substantial development and verification before any reasonable levels of confidence can be attributed to them. Having considered this, and within the context of an urgency to appropriately respond to the rapidly changing situation with respect to the woylie declines, it is possible to draw some early hints from the balance of associative evidence collected and processed to date. The use of these early hints *must* be regarded in this context and any responses made on these hints alone have the potential to jeopardize the recovery and long-term conservation of the woylie (e.g. the conservation efforts for the California Condor inadvertently facilitated the species extinction in the wild in the 1980's; Caughley 1994). The intent of this summary is therefore strictly to provide managers and collaborators with a coarse-resolution anticipation of what subsequent and more complete analyses may well indicate as being *some* of the *primary* agents of recent woylie declines.

7.2.2. Comparison of postulated responses with available evidence

Table 7.2.1 summarizes the result of the application of logic in an analysis of the data available for, and relevant to, determining the hierarchy of causes of the decline of the woylie. A truth table or logic matrix assists in the ordering of the research data acquired, reducing the risk of missing potentially relevant factor. It can also aid in the selection of variables worth measuring. This table helps communicate some of the complexity and nuances associated with this investigation. As with any conceptual model, the truth table is a means to an end, and is not the end in itself.

Models simplify reality and are not intended to accommodate all of the available information. Assumptions and limitations of this truth table include; i) primary factors are initially considered in isolation when multiple interacting factors are more likely responsible; ii) focus on linear/mechanistic treatment of potentially non-linear/biological relationships; iii) generalisation and restriction of response behaviours to only the potentially most prominent (i.e. limited capacity to consider secondary relationships); and, iv) limited capacity to discriminate between cause and effect.

The truth table, being a condensation of many facts, does not distinguish quality of evidence, the full diversity and variability of the evidence or the inferential power of the evidence (e.g. the result of no change/difference may be due to evidence limitations, i.e. potentially falsely summarised). While relative weighting and other adjustments are possible, the complexity of the model and the necessary associated assumptions substantially escalate when doing so, with potentially greater risk of becoming a less realistic model.

Expert judgement was used to limit the most likely variable behaviours under the key putative agents of decline and the preliminary evidence results – based on available evidence that may or may not have been fully communicated within this report. When the preliminary evidence is subsequently compared with the postulated behaviour of the selected variables, eight key discriminating factors emerged. On this basis, the results of this exercise suggest that the weight of available evidence supports disease as the most likely principal factor associated with the woylie declines in the Upper Warren region.

The most valuable outcome of the truth table is likely to be the stimulation that it offers for further discussion and development of the research agenda, consideration of the evidence, and progress towards identifying the chain of cause involved in recent woylie declines.

Table 7.2.1. Truth table (logic matrix) of postulated direct causal relationships of selected variables (table rows), assuming a single primary cause for recent woylie declines (columns 2-5).

Initially prepared in February 2006, the postulated responses are compared with the preliminary results from the WCRP in the Upper Warren region.
Warning: this table needs to be interpreted within the context intended (see text).
Note: the key discriminating variables are highlighted

General indicators	Live trapping	Food Resources	Predators	Disease	Initial evidence
POPULATION MECHANICS					
Immigration	↔ / ↑	↔ / ↓	↔ / ↓	↔ / ↓	↔
Recruitment	↔ / ↓	↔ / ↓	↓	↔ / ↓	↔
Emigration	↔	↑	↔ / ↑	↔	↔
Mortality	↔ / ↑	↔ / ↑	↑	↔ / ↑	↑
WOYLIE CAGE TRAPPING					
Trap shyness – learned avoidance	↑	↔ / ↓	↔ / ↑	↔	↔
Trapping intensity / frequency	↑	↔	↔	↔ / ↑	↔ / ↓
WOYLIE DEMOGRAPHICS					
Risk with increasing woylie density	↔ / ↓	↑	↓	↑	↑
Animal condition	↔ / ↓	↓	↔ / ↑	↔ / ↓	↔ / ↑
% Adult Females breeding	↔ / ↓	↔ / ↓	↔ / ↑	↔ / ↓	↔
Age structure (SA: Adult ratio)	↓ / ↑	↓ / ↑	↓ / ↑	↔ / ↓ / ↑	↔
Male: Female Ratio by age class	↓ / ↑	↓ / ↑	↔ / ↓ / ↑	↔ / ↓ / ↑	↔
Population turnover (% New adults)	↑	↔ / ↑	↔ / ↑	↔ / ↑	
Animal longevity	↔ / ↓	↔ / ↓	↔ / ↓	↔ / ↓	
OTHER SPECIES					
Competitor abundances	↔	↓ / ↑	↔ / ↑	↔ / ↓ / ↑	↔ / ↓ / ↑
Analogous prey species	↔	↔	↓	↔	↔ / ↓
Taxonomically-related species	↔	↔ / ↓	↔ / ↓	↔ / ↓	↔
Ecologically-related species	↔	↔ / ↓	↔	↔ / ↓	↔ / ↓
Fox activity/abundance	↔	↔ / ↓	↔ / ↑	↔ / ↑	↔
Cat activity/abundance	↔	↔ / ↓	↔ / ↑	↔ / ↑	↑
Chuditch abundance	↔	↔ / ↓	↔ / ↑	↔ / ↑	↔
Raptor abundance	↔	↔ / ↓	↔ / ↑	↔ / ↑	↔ / ↑
Fox control effort/regime changes	↔	↔	↔ / ↑	↔	↔
Fox control timing relative to heavy rain	↔	↔	↔ / ↑	↔	↔
WOYLIE RESOURCES					
Food	↔	↓	↔	↔	↔
Diet	↔	↓	↔	↔	↔
Shelter	↔	↓	↔	↔	↔
Vegetation change/differences	↔	↔ / ↑	↔ / ↑	↔	↔
LANDSCAPE PROCESSES					
Weather pattern changes	↔	↔ / ↑	↔	↔ / ↑	↔
Extreme weather events	↔	↔ / ↑	↔	↔ / ↑	↔
Changed fire regimes	↔	↔ / ↑	↔ / ↑	↔	↔
Jarrah Dieback prevalence	↔	↔ / ↑	↔ / ↑	↔	↔
Logging / other mechanical disturbance	↔	↔ / ↓ / ↑	↔ / ↑	↔ / ↑	↔
Habitat loss (e.g. landclearing)	↔	↔ / ↑	↔ / ↑	↔ / ↑	↔
WOYLIE HEALTH					
Clinical signs of disease	↔	↔	↔	↔ / ↑	↔
Pathological evidence of disease	↔	↔	↔	↔ / ↑	↔
Incidence of field health reports	↔ / ↑	↔ / ↑	↔	↔ / ↑	↑
Tally of key discriminating evidence	5	3	6	8	

7.2.3. Not primary agents of decline

Based on the available evidence, the following factors are considered in all likelihood not to be primary factors causing decline either in isolation or in association with other factors;

- Habitat loss / modification (including logging)
- Fire (prescribed burning or wildfires)
- Direct human interference (live-trapping)
- Resources

7.2.3.1. Why resources are not considered as a primary agent of woylie decline

Resources may potentially limit and/or cause faunal declines due to changes in the abundance and/or availability of resources. Changes in resource abundance may result from environmental change, management practices (e.g. fire, logging, etc), introductions (e.g. weeds, diseases such as *Phytophthora cinnamomi*), and/or over exploitation. Changes in resource availability or access primarily result from competition.

Of the resources needed for the persistence of fauna populations, food is considered the most likely limiting resource that may be a putative agent of the woylie declines. Water is not considered to be an issue given woylies reportedly source all of their requirements directly from their food. Shelter is unlikely to be a limiting resource given woylies build their own nests in low understorey vegetation and there have been no apparent substantial structural or floristic differences in the vegetation associated with the declines. Space is not considered limiting given there has not been a reduction in native vegetation cover on the DEC-managed lands in the Upper Warren region, Dryandra, Batalling, etc and changing densities of other fauna species cannot satisfactorily account for the woylie declines in this manner. Access to reproductive mates are not considered a primary factor in the decline of the woylie given the pre-decline densities, however, this may well be a limiting factor for the recovery of the species.

Preliminary evidence from the population comparison study provides several lines of evidence consistent with food resource limitations not being associated with woylie declines. This includes;

Evidence from Karakamia

- History of population establishment (1995) is temporally comparable to the recovery and/or establishment of other wild woylie populations and continues to support a very high density of woylies in the absence of predators (~2 / ha).
- The average weight and size of woylies has reduced at Karakamia since the population was established, i.e. in association with the density of woylies increasing and stabilizing. Karakamia woylies are now significantly lighter than woylies at Upper Warren and elsewhere - this reduction/difference in weight/size has been interpreted as a response, in part at least, to food resource limitation, having reached carrying capacity.
- Woylies have a seasonal breeding pattern with little or no breeding occurring over the summer months, in contrast to other woylie populations that display continuous breeding – this has been interpreted as a response to seasonal food resource limitation.

Evidence from Upper Warren

- Adult male condition (biometric function of size/weight relationship) remained stable in association with the population decline at Camelar. Adult female condition increased in association with the population decline at Camelar (Wayne 2006 – Mammal decline workshop). This is inferred as indicating that the population was not resource-limited during the declines.
- Although there were site (spatial) differences in the biometric condition of woylies, the meta-analysis found no relationship with population decline.

Evidence from the woylie diet and food resources

- No apparent significant vegetation structure or floristic changes associated with declines or between population comparison sites (substantially more analyses required to verify this). This includes no apparent gross changes in *Phytophthora cinnamomi* (jarrah dieback) infections at the PCS sites or in association with declines.
- Hypogeal fungi are considered a primary (but not exclusive) dietary component. The harvesting of the fruiting bodies by woylies and other animals are considered extremely unlikely to negatively-affect subsequent fruiting. Rather quite the opposite is expected, with fauna such as the woylie being necessary for the dispersal of hypogeal fungi throughout the environment.
- Preliminary data from the dietary analysis of woylies using scats indicates that there are no substantial spatial differences in the fungi consumed between Upper Warren PCS sites, however, there are substantial temporal differences (common across Upper Warren PCS sites) in the species composition.

Despite food resources not being considered at this stage as a primary agent of decline this does not negate the possibility of food resources being involved in some way. Furthermore, being able to unequivocally disregard food resources as a putative agent of decline is as important as establishing cases for other key putative agents of decline. Irrespective of the role of food resources in the decline of woylies, a solid understanding of this component of woylie ecology may play an important role in managing the recovery of the species. For these and other reasons, it remains important to continue the current PhD research into the food resources of woylies in relation to the recent woylie declines.

7.2.4. Possible primary agents of decline

7.2.4.1. Climate

Notwithstanding the inherent complexity, climate is possible but not likely to be a direct or primary agent of woylie declines in the Upper Warren, however, this remains to be more satisfactorily verified. There is some weak associative evidence that climate may be associated to woylie declines in the drier, inland populations of woylies such as those in the WA wheatbelt. Anecdotal evidence also indicates that the decline of woylies at Venus Bay Peninsula (VBP) may be related to drought and extreme weather events in association with cat predation.

A more detailed and rigorous assessment of climate changes and differences associated with woylie population declines is required. The differences observed between populations may be indicative that the declines observed in South Australia are to some extent due to different causal relationships from those in Western Australia, however, it is far too premature to regard this as anything beyond purely speculative.

7.2.4.2. Fox predation/scavenging

Fox predation and habitat loss/modification have historically been attributed as the key agents for the substantial range contractions and woylie declines across the Australian continent during the 19th and 20th Centuries. The subsequent recovery and re-establishment of woylie populations since the 1970s in the presence of fox control provides compelling evidence that foxes have indeed been a primary agent in historic decline of this and other species (e.g. Burbidge and McKenzie 1989; Kinnear 1994, Kinnear *et al.* 1998, 2002; Start *et al.* 1995).

Fox predation/scavenging was associated with the mortality of 15% of the radio-collared woylies in the Upper Warren region (i.e. comparable to the incidence of raptors and a third of the incidence of cats). None of these fox cases were associated with the woylie mortalities observed at Balban (i.e. during which 81% declines occurred in 12 months). Nonetheless, it is not possible to know the extent to which fox predation/scavenging was associated with woylie declines elsewhere within the Upper Region, given that they occurred in the absence of suitable monitoring data (i.e. no survival and mortality investigation of woylies and extremely limited available data on predator activities).

It is likely that fox densities have been highly variable over time in the Upper Warren region and elsewhere. This is particularly so given the likelihood for extended periods when fox control may have had reduced effectiveness (i.e. long interval times, timing associated with heavy rainfall events, bait interference, timing suboptimal according to fox biology, etc). Despite this, there is no compelling indirect evidence of these possible fox fluctuations resulting in substantial periodic declines in other prey species, either simultaneously or sequentially to the woylie declines.

These factors considered, it remains possible but speculated to be less likely than other agents, that fox predation has been a primary cause of the woylie declines in the Upper Warren region. By comparison, fox predation/scavenging was associated with about half of woylie mortality events observed in a comparable and concurrent study being conducted in Dryandra and Tutanning (Nicky Marlow, pers. comm.). It is therefore possible that foxes may have had a greater role in woylie declines elsewhere. Substantially more investigation is required to understand the strength and nature of the association between foxes and recent woylie declines. Nevertheless, highly effective fox control is highly likely to be a critical success factor for the rapid and robust recovery of the woylie, which is necessary for the long-term viability and conservation of the species.

7.2.5. Likely primary agents of decline

7.2.5.1. Mechanics of decline

Increased mortality is a likely primary mechanism causing the declines. Evidence for this includes;

- Reduced survivorship of the Balban radio-collared cohort associated with concurrent declines.
- The observed rates of decline (25% - 95% per annum) have been greater than can be attributed by a complete failure of recruitment by reproduction (i.e. 16% - 20% per annum based on a life expectancy of 5-6 years).
- The sudden loss of previously frequently-trapped woylie individuals from the grids and transects associated with woylie populations currently undergoing declines.

Emigration is highly unlikely based on there being no evidence of substantial movement and relocation of radio-collared woylies at Balban in association with the woylie declines. Furthermore, although further work is required, preliminary exploration of the extensive trapping data for the region has not detected any evidence of significant movements by substantial numbers of woylies.

Quantifying recruitment by reproduction into the adult population is inherently problematic. Based on the proportion of adult females with pouch-young recorded present, breeding does not appear to differ in association with spatial and temporal changes in woylie populations. However the power and sensitivity of these statistical inferences are yet to be quantified. The prevalence of subadults in the populations were very low and therefore the limited sample sizes collected at declining and declined populations have so far prohibited reliable statistical inference. The incidence of new (trapped for the first time) animals as a surrogate for adult recruitment has not yet been adequately examined but is also likely to be problematic due to low capture rates associated with declining and declined populations. Therefore it is premature to speculate or determine to what extent changes of recruitment into the adult population may be associated with the woylie declines.

7.2.5.2. Cat predation

Preliminary evidence that cat predation may be associated with woylie declines in the Upper Warren region include;

- Higher levels of cat activity associated with concurrent woylie declines at Balban.
- Cat predation was associated with 65% of the mortalities of radio-collared woylies for which some factor(s) associated with mortality could be attributed (i.e. 1/21 mortality cases was inconclusive).

However, not all evidence is consistent with predation/scavenging being a primary, ultimate and/or sole agent of decline, including;

- No or limited evidence of sympatric prey species (e.g. quenda, koomal, large reptiles, etc) declining either simultaneously or sequentially (e.g. prey switching). Note: statistical associations of woylie declines with quenda and koomal (Section 3.3. Meta-analysis) require further investigation.
- No evidence of a substantial and/or rapid increase in cat density/activity that could potentially drive such a rapid decline in species that was previously at high densities and with a high reproductive capacity. However, caution is required given the limited data available to examine this in the absence of extensive routine monitoring of predators. More thorough examination of the limited available data from long-term research in the Upper Warren (Kingston Study and Perup/Bushrangers) and other possible sources elsewhere is needed.
- If/where there is an increased activity or density of predators associated with a woylie decline, it is still necessary to establish whether this association is related or coincidental, and particularly whether it is a cause or effect of the woylie declines (i.e. experimental testing or equivalent is required to confidently discriminate).
- It is difficult to attribute the extent of declines (i.e. 0-5% of former woylie densities) solely to a predator given the reduced efficiency of continuing to hunt a prey at extremely low densities, particularly when the spatial pattern of declines is indicative of nearby forest concurrently supporting higher densities of woylies. It would reasonably be expected that at low woylie densities, a predator would seek a more efficient hunting strategy; either switch to an alternative prey source and/or move to an alternative area with higher woylie densities. On this basis declines as great as 100% can not be readily explained by predation alone.

Based on the balance of available evidence, it remains entirely possible that multiple factors may be involved in the woylie declines. Conversely, there is no evidence or reason to expect that the woylie declines are the result of a solitary factor. Furthermore, other factors may be predisposing an increased vulnerability to predation and/or carnivores are opportunistically exploiting a moribund or carcass resource being made more readily available. It is possible that different and/or multiple predators are exploiting the more susceptible woylies in different circumstances. This is one explanation, for example, why foxes are predominantly (but not exclusively) associated with woylie mortalities in Dryandra and Tutanning and why cats are predominantly (but not exclusively) associated with woylie mortalities in the Upper Warren region and VBP

7.2.5.3. Disease

Preliminary evidence that disease may be primarily associated with woylie declines in the Upper Warren region include;

- The rates and temporal characteristics of the declines are consistent with an epidemic disease agent.
- The spatial pattern of the decline within the Upper Warren (i.e. epicentre approximately at the Perup Ecology Centre and radiating out to the periphery and the last remaining moderate-density populations) is consistent with an agent with limited mobility (e.g. transmitted by direct contact or a vector with limited mobility such as lice, fleas, ticks and those transmitted in faecal matter).
- The spatial pattern of the declines within southwestern Australia and South Australia, superficially may also be consistent with the spread of an agent of decline. Substantially more spatial and temporal analyses at multiple scales are required to substantiate this.
- It is possible that there is a density dependency relationship to the declines, given the largest and densest woylie populations appear to have been most affected. Declines have not been detected in many small, isolated, peripheral and very low-density woylie populations – although this may be an artefact of very poor sensitivity to detect population changes with small sample sizes. A density dependency relationship is consistent with

the epidemiology of some disease agents as well as other factors such as resources and predators.

- An exceptionally high prevalence of coat and skin problems were associated with the concurrent declines at Balban, compared with other PCS sites. The extent to which observer differences might account for some of this difference is yet to be determined. While these symptoms in themselves are unlikely to be directly responsible for animal mortalities they have the potential to be general indicators of stress and/or related to other factors that might be directly involved in the declines.
- An acute response by individuals to the agent(s) of decline, resulting in mortality, seems a particularly likely function of the decline. This is speculated using the balance of evidence including the general condition of the animals monitored being generally good; the sudden loss of previously frequently-trapped woylie individuals associated with woylie populations currently undergoing declines; and recovered bodies show no evidence of emaciation or poor condition that can be attributed to a chronic problem.
- *Toxoplasma* has been detected in the Upper Warren but not in the unaffected population at Karakamia. This (and the absence of introduced predators) is one of the key distinguishing discriminating differences to arise from the population comparison study that may provide associative evidence of a potential agent of decline.
- The change in the prevalence of *Toxoplasma* in the Upper Warren region over time (i.e. 6% to 0%) is superficially consistent with the epidemiology of an agent of decline.
- The *Trypanosoma sp. nov.* prevalence and infection rates are likely to be another key distinguishing discriminating difference between Karakamia (stable) and Upper Warren (declined) woylie populations.
- Pathological (synergistic) interactions between *Toxoplasma* and *Trypanosoma* have been demonstrated in other species and circumstances, and therefore have the potential to be involved in some way with the woylie declines.

Limitations in attributing disease as a key agent of woylie declines include;

- Symptoms (gross, haematological, etc) of disease have not been recognised except for the potential association of poor coat and skin condition at the declining Balban site.
- There have been mortalities of apparently grossly healthy woylies at both the Upper Warren, and Dryandra / Tutanning that evidently do not involve predation or physical trauma. In all of these cases the cause(s) of death has been inconclusive.
- Necropsies and pathology have not detected evidence of disease(s) recognized as potentially capable of being associated with the woylie declines. The ability to do so has been substantially compromised by the limited woylie remains submitted for examination. The loss and/or consumption by predators/scavengers of all or most of the vital organs necessary for diagnosis means that in almost all cases it has been impossible to examine for diseases.
- There are hundreds of known diseases that potentially may be involved in the woylie declines, many of which require complex, problematic and/or specific (and often expensive) tests to identify their presence (e.g. many viruses).
- No direct and definitive tests of specific disease agent(s) to examine their capacity to reduce the fitness, condition, reproduction or survival of woylies have yet been conducted.
- Understanding the potential role(s) of disease in the woylie have been substantially constrained by the depauperate knowledge-base of what wildlife diseases are present in the woylie and other Australian wildlife, as well as their prevalence, ecology, epidemiology, pathogenicity and other host impacts (e.g. behaviour, reproduction, condition, etc), etc.
- Consideration of the unknown is necessary given that it is possible that disease agents currently unknown in this context may be involved.

7.3. Speculative hypothesis of the cause(s) for the recent woylie declines based on preliminary information

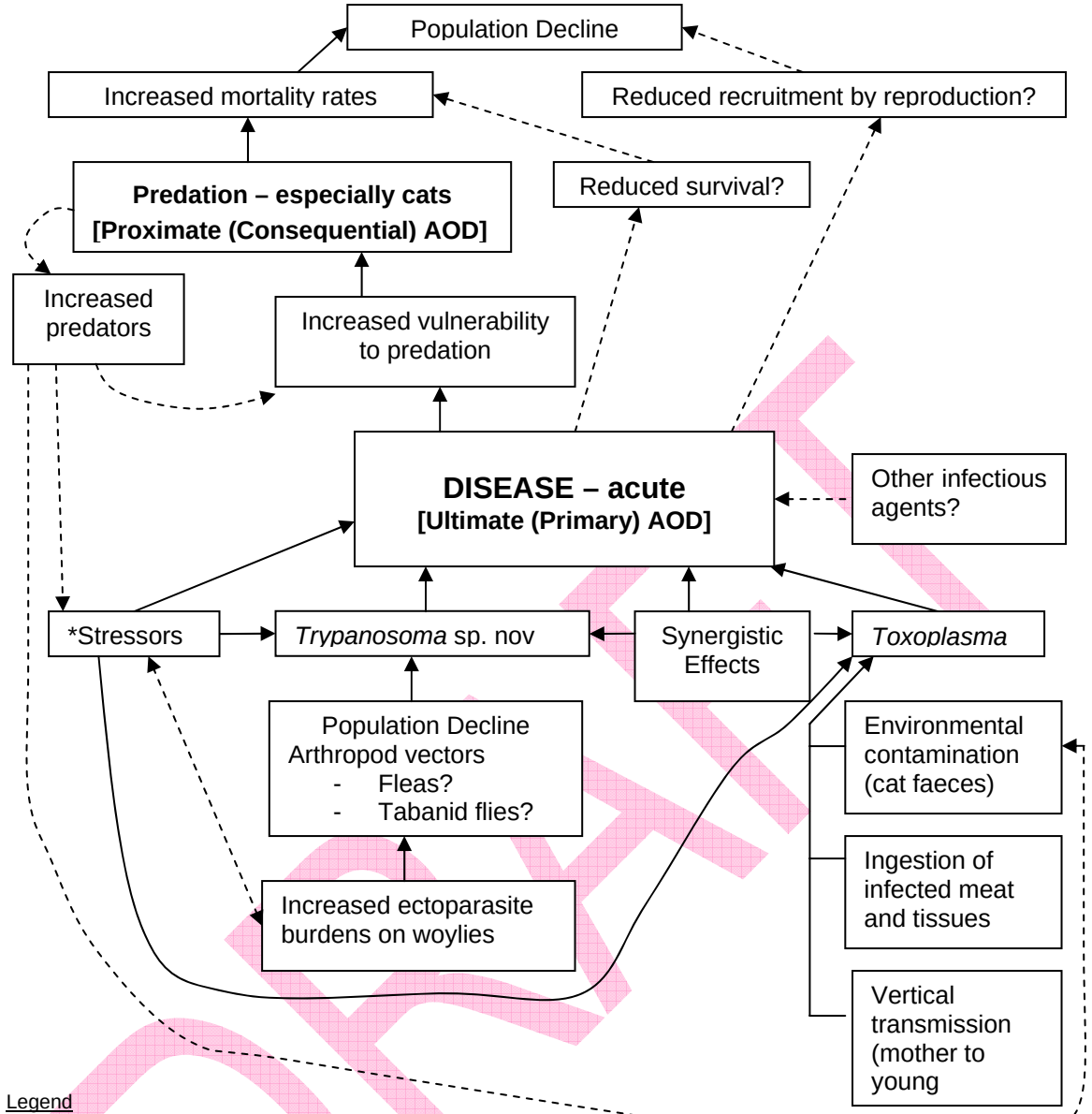
In summary, based on the preliminary evidence available for consideration, there is no single or simple compelling case evident as yet that can be strongly inferred as the fundamental cause(s) for the recent woylie declines. This is however, a 'work in progress' and there remains a substantial amount of work required to process, analyse, interpret and synthesise the data and information that has been collated and generated to date. Continuing this work should remain the highest priority given the investment to date and the anticipated returns for doing so. Despite the premature nature of the analyses it is possible to speculate and present the leading hypothesis of what may be causing the woylie declines based on the balance of emerging information. Again, it must be emphasised that this speculation be regarded appropriately given that it has not been rigorously tested.

The most credible hypothesis for the recent woylie declines can be summarised as;

- Driven by adult mortality at least in part, probably by an agent(s) ultimately operating acutely on individuals. Changes in recruitment by reproduction may or may not be involved. Loss by emigration is not likely.
- Result from multiple factors operating either simultaneously or sequentially.
- Disease(s) are the most likely primary or ultimate agent of decline. These disease(s) may be either novel or previously present but now function within a novel context of other interacting factors that have precipitated the recent woylie declines (Figure 7.1). The primary or ultimate agent(s) of decline are considered the critically important factor(s), without which, the death of an individual (in this case) or the decline of a population, would not otherwise necessarily occur.
- The available evidence is suggesting that *Toxoplasma* and *Trypanosoma* sp. nov. may be associated with the woylie declines (Figure 7.1) and are therefore the most likely agents of disease.
- Synergistic effects of *Toxoplasma* and *Trypanosoma* sp. nov. have been recognised in other host species (Guerrero *et al.,* 1997; Cox, 2001). It is therefore possible that synergism may also be occurring with woylies
- Other stress factors and/or infectious agents may also be contributing to the declines as either triggers to the development of disease or as concomitant agents.
- Possible stressors include predation, competition, climatic factors, extreme weather, concurrent infections, disease reservoirs in sympatric species, ectoparasites, nutrition, and high population densities.
- Other infectious agents of note that may in themselves be significant agents of decline include Chlamydiales, Macropod Herpesvirus, Orbivirus, Encephalomyocarditis virus and *Neospora caninum*.
- Predators/scavengers are likely to be consequently and opportunistically exploiting woylies made more vulnerable to predation/scavenging as a result of disease(s) (i.e. changed behaviour and/or reduced fitness, condition, and/or survival) (Figure 7.1). While cats are the dominant predator/scavenger in the Upper Warren, and Venus Bay Peninsula (VBP), foxes may be the dominant predator scavenger elsewhere (e.g. Dryandra and Tutanning). Predation/scavenging is considered a 'proximate' agent of decline, because it is more immediately associated with the fatality.

- The woylie declines at VBP, South Australia although characteristically similar in some respects to those observed in Western Australia, probably result from agents of decline that differ to some extent.
- Based superficially on the characteristics of the decline, the primary and ultimate agents of decline operating in the Upper Warren are probably the same as those operating in Batalling. Whether they are the same as those in Dryandra is less certain given the earlier commencement of the declines and the apparently more linear and slower rates of decline at Dryandra.

The leading hypothesis presented here and summarised in Figure 7.1 can serve to focus future research priorities and efforts to test its validity. It should also serve as a point of collegial discussion and development tool to refine our understanding of the potential factors. Nevertheless, given that it remains speculative and untested it is also important that research resources and efforts should not be directed exclusively to the primary hypothesis. Other valid lines of enquiry that test alternative hypotheses are also necessary at least until more compelling evidence for the cause(s) are established. Having said this, the available evidence and information accumulated in this initial phase of enquiry can be used to develop a narrower focus than has been used in the initial phase of this endeavour. It also remains important to the expedient success of the research to remain flexible and responsive, within a critical and precautionary framework, to new and emerging evidence.



Legend
AOD = Agent of Decline
→ = 1st order factor / Higher confidence based on available evidence
- - -▶ = 2nd order factor / Likely relationships but less evidence available

Not primary factors of decline:

Habitat loss/modification	Direct human interference (live trapping)
Fire	Food resources

Population change – mechanical algorithm for Upper Warren Woylie Population:

	0	-ve?	0	+++
Recruitment (immigration + reproduction)	–	Loss (Emigration + Mortality)	⇒	Population decline

*Possible stressors include:

Predation	Ectoparasites
Competition	Nutrition
Climate factors / Extreme weather	Disease reservoirs in sympatric species
Concurrent infections	High density woylie populations

Figure 7.1. The leading (untested) hypothesis of the causes of woylie declines in the Upper Warren region based on preliminary and untested inferences.

7.4. Acknowledgements

Not enough thanks can be given to the collaborative, supportive and generous spirit of the very large number of people and organisations involved in the WCRP. This is the greatest success and asset of the project and provides the greatest ever potential to successfully diagnose the woylie declines and thus provide the best opportunity for a robust and sustained recovery and long-term conservation of the species. The achievements that have been made are a tribute to all of those involved, and testament to all that is good about the scientific and conservation management community and its ability to make great things happen.

Thanks to all those that have contributed to the development of data and evidence within the diversity of components associated with the project. Thanks also to the many and diverse conversations that have helped to develop the approach and our growing understanding of woylie ecology within the context of the current declines and the available evidence. Thanks to those that have provided critical comment on this section and its concepts, including Ian Abbott, Andrew Smith, Paul Eden, Andrew Thompson, Neil Burrows, and Keith Morris.

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