Invasive Animals Cooperative Research Centre

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Trophic Responses to Lethal Control of Placental Predators in Australia: Proceedings of an Expert Workshop, Sydney, 19th October 2012.

Guy Ballard and Peter J.S. Fleming (Eds)

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About the Editors

Dr Guy Ballard is a researcher with the Vertebrate Pest Research Unit of Biosecurity NSW, NSW Department of Primary Industries based at the University of New England, Armidale. Guy has experience in field-based ecological research into predator interactions, impacts and management in Central Australia and north east NSW. Currently, Guy is undertaking experiments related to the co-management of free-ranging dogs, foxes and feral cats in north east NSW. This Invasive Animals CRC research is investigating population, social, economic and trophic responses to wild canid management. Guy has considerable experience in facilitation of both management groups and research workshops.

Dr Peter Fleming has been undertaking research into the management of invasive vertebrates since 1983. He is leader of the Invasive Animals CRC's Wild Dog Theme and is based at the Vertebrate Pest Research Unit of Biosecurity NSW, NSW Department of Primary Industries, Orange. Peter has a long-standing interest in the management of wild canids for conservation and agricultural protection.

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Background

Introduction

The effects of lethal control of predators, particularly dingoes and other wild dogs (*Canis lupus dingo, C. l. familiaris* and *C. l. dingo X C. l. familiaris*) in Australia, is subject to much controversy and recent debate among ecologists. To devise a framework for understanding and researching predator and prey interactions in response to management of predators, a group of ecologists at the forefront of publication, debate and current research were invited to participate in an expert workshop. The workshop was to pay particular consideration to the expected responses of predators and prey following lethal control of predators, such as wild dogs, European red foxes (*Vulpes vulpes*) and feral cats (*Felis catus*), at World Heritage sites.

A group of experts were invited to participate in a facilitated discussion of predator and prey responses to lethal control of wild dogs, foxes and feral cats. This workshop differed from previous ones about dingoes, biodiversity and required research held in Australia during the last 10years in that it concentrated on determining the expected trophic responses to lethal predator control. Invitees were selected primarily on the basis of their active involvement in research dealing with predator and/or prey ecology and secondarily to provide a breadth of experience across a range of WHAs and similar ecosystems.

Participants and observers were given the opportunity to review these proceedings but the editors take final responsibility for the content.

Participants

This document records the proceedings of the expert workshop, which was held in the Cootamundra and Albury Rooms, NSW Energy, Level 17, 227 Elizabeth Street, Sydney at 9:30, on Friday 19th October, 2012. The discussion was facilitated by Guy Ballard and the invited participants are listed below:

The participants in the workshop were: Chris Johnson (University of Tasmania), Peter Fleming (NSW Department of Primary Industries), Menna Jones (University of Tasmania), Mike Letnic (University of NSW), Malcolm Kennedy (Department of Agriculture and Food, WA), Nicky Marlow (Department of Environment and Conservation, WA), Benjamin Allen (Biosecurity Qld) and Matt Hayward (Australian Wildlife Conservancy). The discussion was facilitated by Guy Ballard. Apologies were received from Chris Dickman (University of Sydney), Andrew Claridge (NSW Office of Environment and Heritage), Alan Robley (Vic Department of Sustainability and Environment) and Al Glen (Landcare Research NZ), all of whom were unable to attend.

Observers

Les Russell (Department of Agriculture Fisheries and Forestry), Andreas Glanznig (Invasive Animals CRC), Tony Pople (Biosecurity Qld), Nick Reid (University of New England), Cameron Allan (Meat and Livestock Australia) and Greg Mifsud (Invasive Animals CRC) were involved in the workshop as observers. All were asked to observe but not participate in discussions between the expert participants during the sessions. Observers were able to provide the facilitator with feedback to assist in optimising outcomes from the discussion. Observers and participants were free to interact with each other only during breaks.

Objectives

The objectives of the expert workshop were:

1. to identify Australian terrestrial World Heritage Areas with objectives to conserve terrestrial faunal biodiversity, which listed the dingo as an animal of conservation interest or which listed introduced predators as a threat to faunal conservation (this was undertaken as preparation for the workshop);
2. to identify likely predator and prey responses to lethal control of placental predators, that is wild dogs, foxes and feral cats; and

3. to review the findings in relation to predator management in Australian World Heritage Areas.

The workshop was undertaken as a series of structured discussions about lethal control effects on various components of communities, including placental predators, their native prey and sympatric native predators, and vegetation.

Terrestrial World Heritage Areas

Australia has 19 properties inscribed on the UNESCO World Heritage List. Many of the Australian World Heritage Areas (WHAs) have faunal biodiversity as a criterion for their listing, including those in Table 1. Other, such as the Greater Blue Mountains Area WHA and Kakadu National Park WHA, support diverse faunas and have fox and feral cat management programs despite these not being listed as threats under the documentation supporting inclusion on the WHA list.

Invasive mesopredators, including feral dogs, foxes and feral cats, have been identified as threats in most of the Australian terrestrial World Heritage Areas.

Australian World Heritage Area	**Date of inscription**	**Dingoes listed in nomination**	**Invasive animals threat listed in nomination**
Fraser Island	1992	Yes	Yes
Gondwana Rainforests of Australia	1986	No	Yes
Ningaloo Coast	2011	No	Yes
Purnululu National Park	2003	No	Yes
Wet Tropics of Queensland	1988	No	Yes
Uluṟu-Kata Tjuṯa National Park	1987/94	Yes	Yes

Table 1 Australian terrestrial World Heritage Areas with faunal biodiversity conservation objectives, or with dingoes listed as a species of interest in the WHA nomination documents, or with feral dogs and other invasive animals identified as

a threatening process in WHA nomination documents. (From available knowledge at 1st December 2012: source UNESCO World Heritage Centre, Australia website http://whc.unesco.org/en/statesparties/au)

Expert Workshop Proceedings

Workshop aim

The overarching aim of the workshop was to develop agreed, reasonable expectations regarding likely responses of predators and prey, to lethal control of placental predators, in Australian ecosystems. These discussions involved, but were not restricted to, lethal management of placental predators in WHA. Importantly, it was made clear to the participants that although the questions of whether or not managers *should* control wild dogs were related to the workshop aim, they were not the primary foci.

Why focus on placental predator management in Australia's World Heritage Areas?

Initial discussion focussed on whether or not it was appropriate to consider management of predators in a broad sense, rather than attempting to limit the discussion to WHA. Participants' concerns about taking a broad approach, rather than a wholly WHA-centric one, were based largely on two possibilities. Firstly, there was concern that ecological realities inside WHA may differ significantly from other areas. Secondly, participants suggested that real management constraints, in terms of the application of control techniques, may exist between WHA and other tenures (e.g. policies relating to bait rate, methods of bait deployment). Conversely, the primary argument for taking a broad approach, in the first instance, stemmed from an acceptance of the principle that nominal best practice for pest management involves planning and implementing control across-tenures. It was agreed, on the basis of this principle, that it was appropriate to at least begin discussions more broadly than just focussing on WHA.

Defining 'lethal control of placental predators'

To initiate discussion, participants were presented with the following definition: "Lethal control is achieved when managers kill enough of a placental predator population to alleviate its negative impacts". The group agreed that the definition was an acceptable starting point but the associated discussion revealed that much of the ongoing debate about responses of predators to lethal control has focussed on programs that use lethal control techniques, rather than programs that necessarily actually substantially reduce the target population of interest.

Predators of interest

In the context of predator management, participants identified the following as the key species targeted by lethal control programs:

- Wild dogs, including dingoes (*C. l. dingo*), domestic dogs (*C. l. familiaris*) and hybrids between them
- European red foxes, *Vulpes vulpes*
- Feral cats, *Felis catus*

With regard to wild dogs, participants were asked to comment on whether or not they believed there were likely to be any functional differences between pure dingoes and other wild dogs. The consensus was one of uncertainty about the relative ecological roles of various 'types' of dogs. It was noted that Australia's wild dogs tend to be smaller than the recognised body mass tipping point (i.e. 20-30kg) between medium sized and large predators (M Hayward, comment). Respondents did recognise that various subjective human assessments of the value of dingoes and other wild dogs influence their management in the Australian context.

Lethal Control Techniques

Participants indicated that lethal control of placental predators was likely to involve some variation on one or more of the following techniques: poison baiting, trapping and/or shooting. It was noted that standard operating procedures (SOPs) and codes of practice (COPs) for the lethal control of pest animals are freely available and should be adhered to in designing and implementing management programs. Between various jurisdictions, environments and tenures, different strategies and techniques are sometimes employed for controlling populations of the same predator species.

In the participants' experience, poison baiting for predator control was most often undertaken using sodium fluoroacetate (Compound 1080) but potentially also involves the use of strychnine (both in baits and in association with trapping in some States). Subject to its registration, future poison baiting programs may use para-amino propiophenone (PAPP).

Trapping for lethal control was described as capture using foot-hold or cage traps, followed by some method of euthanasia, such as shooting or , in the case of some foot-hold trapping programs, via 'lethal trap devices' such as strychnine cloths.

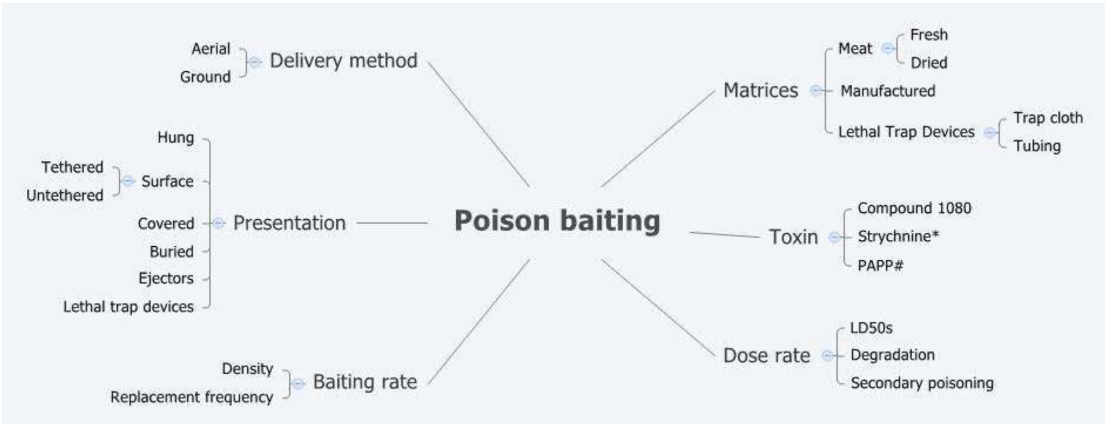
Shooting for predator control was described as normally being either via spotlighting at night or opportunistic efforts or coordinated drives during the day. For dogs and foxes, participants described controllers using auditory lures (e.g. howling or whistling, respectively) to bring the targeted animals to within safe and sure range of the shooter. Because wild dogs are shot from aerial platforms (helicopters) in some jurisdictions it was suggested aerial shooting be listed as a lethal control option, but participants agreed that it this was mostly opportunistic, occurring during programs that are targeting other pests, especially feral herbivores. Aerial shooting of wild dogs, on its own, was deemed unlikely to be a viable option for achieving lethal control, under the workshop definition.

Participants also discussed the occasional use of other lethal control options such as using vehicles to 'run over' animals or horse riders killing dogs with stirrup-irons. None of these techniques were believed to be viable options for achieving control and the former, in particular, was described as being unacceptably inhumane.

Non-target impacts of lethal control programs

The target specificity of control techniques was noted as being of key importance to considering impacts of lethal control of predators. Risk to non-target predators, was described as a function of the relative susceptibility of dogs, foxes and cats to each technique. When considering the likely impacts of predator control on multiple predator species, it was agreed that there was likely to be a much greater overlap in the susceptibility of dogs and foxes, than between other combinations of predator species, e.g. dogs and cats, or cats and foxes.

With particular respect to baiting, a range of permutations (Figure 1) including type of toxin, bait matrices, dose rates, methods of bait delivery and presentation were considered important not only for maximising control of target animals, but also for reducing impacts on non-target species.



* Australia-wide, the use of strychnine is being phased-out due to animal welfare concerns

PAPP has been trialled for use as a predacide in Australia but is currently not registered for use

Figure 1 – Diagrammatic synthesis of issues associated with poisoning for predator control.

Factors affecting the probability of achieving predator control

The following were nominated as key factors influencing the probability of managers achieving control of predator populations:

1. Immigration – Throughout the workshop, this recurred as a key confounding factor for achieving control of predator populations. There was an explicit belief that even in situations where managers controlled a local predator population, it was highly probable that immigration from other, source populations would undermine these efforts
2. Scale – Especially the relative scales of the 'problem' and the control program. While this is inherently linked to immigration, it also covers the issue of programs that operate at a scale less than the biological scale of local predators, both as individuals and as a population
3. Guild composition – Especially the absence of red foxes from northern Australian ecosystems and, until recently, from Tasmania. Similarly, loss of devils from Tasmanian ecosystems was deemed likely to have significant effects, particularly linked to changes in cat distribution, activity and/or abundance.
4. Resource availability – Abiotic factors, such as rainfall, temperature, abiotic soil factors, and biotic factors, such as prey availability (both native and introduced) and biotic soil factors (e.g. bacteria, fungi) were proposed as key factors impacting the probability of control being achieve
5. Extent of target population reduction
6. Topography and vegetation dimensionality of the environment, i.e. rugged versus flat and structurally complex versus simple environments
7. Fragmentation / isolation of the management area
8. Temporal scale of management programs, including the relative difference between the objectives and effects of management. It was noted that long-term objectives are often mismatched with short-term effects
9. Strategy - There are various aspect to strategy and effective strategy will account for the other issues raised (points 1 – 8, above). Linking strategy to knowledge of the ecology and subsequent behaviour of species within the management are of interest were highlighted as being extremely important.

What affects the impact of lethal control on predators?

Participants nominated four key issues affecting the outcome of lethal control targeting predator species (Figure 2).

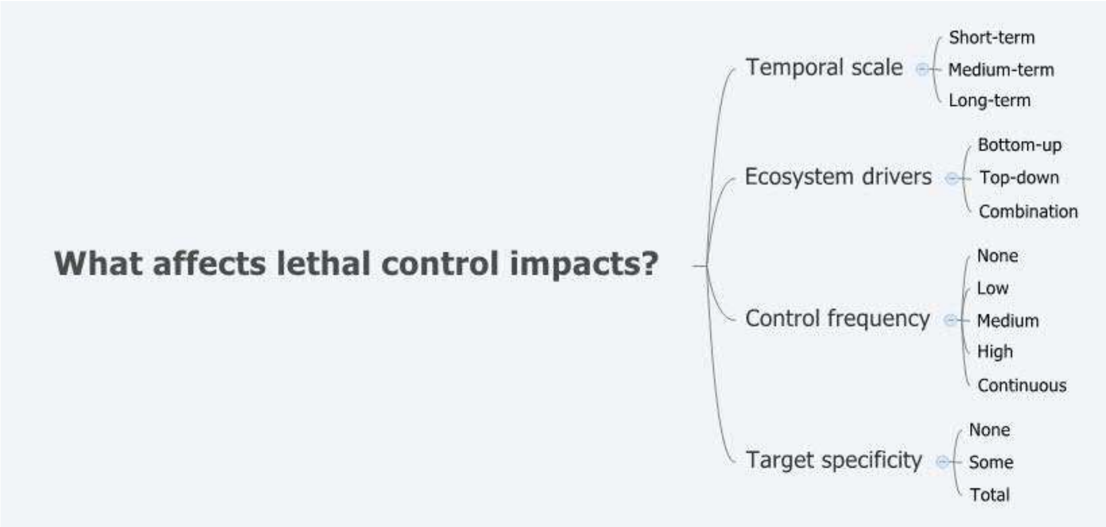


Figure 2 – Key factors influencing impacts of lethal control programs for predators

Recovery rates

It was postulated that population recovery rates, especially for wild dogs, may be complicated by an increased number of litters being produced by survivors, after lethal control has been implemented. It was suggested that this would be due to an increase in the proportion of females in the population that have litters, per annum because of social breakdown among dingoes (M Letnic comment). In the absence, or decreased presence, of wild dogs, it was postulated that other mesopredator populations (foxes and cats) could display ratcheting, disproportionately accelerating population growth relative to wild dog populations (presumably in the same way, i.e. not more litters per female, but more litters per population) (C Johnson and M. Letnic comments).

Impacts of dog control, on foxes

This was a point of recurring debate during the workshop. Points of view varied between, but were not limited to, arguments that dog control would result in release of foxes and that dog control could also result in control of foxes.

In support of the former, it was suggested that if foxes are able to recover more quickly than dogs, then dog control will result in fox population growth, in the medium term. It was further argued that foxes tend to recover from dog control programs more quickly than dogs, due to rapid immigration, increased juvenile survival and compensatory breeding, i.e. increased litter size, possibly due to increase in eggs produced per ovulation.

The competing suggestion was made that foxes were likely to be disproportionately affected by dog control, thus dog control could be expected to drive fox activity and abundance down. This was based on an observation that foxes do not necessarily recover from dog control, e.g. in NE NSW where fox activity has been observed to decrease in association with repeated, annual dog control programs (P. Fleming, comment).

Additional conjecture regarding fox responses to dog control focussed on the relationship between bait density and target population density. Specifically, it was speculated that if baits are 'too far apart' wild dogs may be disproportionately susceptible to control, compared to foxes, because foxes will tend to be at higher densities than dogs (M. Letnic, comment). This hypothesis suggests there may be bait intervals which control dogs but simultaneously do not control foxes. There was, unfortunately, not time to unpack this hypothesis during the workshop but it is worth noting that, whilst it is conceivable that relatively higher fox densities could reduce the probability of individual foxes encountering a bait, relatively higher fox densities could also increase the probability individual baits first being encountered by a fox, rather than a dog. An exception to this could occur if dogs functionally exclude foxes from focal locations where baits have been deployed.

Behavioural release

The impact of predators on fauna could be greater post-control than it was pre-control due to behavioural release facilitated by removal of top-predators (C. Johnson, comment). In the cases of foxes and cats, such behavioural release may be manifest as more time spent in optimal hunting areas, resulting in proportionally greater impacts on prey populations than would have occurred in the presence of wild dogs, pre-control.

Predator-predator interactions

The outcomes of direct agonistic interactions between predators were considered to be important influencing factors for behaviour. Factors influencing the outcomes of such interactions were suggested to include the relative size of the individuals involved (as larger predators were deemed likely to cause greater harm to smaller ones) and the relative age / experience of the individuals involved (experience was considered likely to be positively correlated with probability of survival).

Foxes were thought to be a key factor influencing the outcome of dog control impacts on cat populations, i.e. possible benefits to cats, in the absence or reduced density of dogs, may be obscured by cat-fox competition. Similarly, it was suggested that cats would inhibit any possible release of quolls after control of sympatric canids.

Temporal scale of control

The temporal scale of management was associated with varying expectations about impacts on target and non-target predators. Participants agreed upon three functional categories of time-scale for control programs. Short-term control was considered to be a period of less than a year, given that many fundamental annual cycles in the environment and relevant to predator biology occur on an annual basis. Medium-term was defined as greater than one to less than five years, to incorporate multiple breeding / demographic cycles and the likelihood of some ecologically relevant lag occurring. Lastly, long-term was defined as greater than 5 years, ranging up to 30 years. The broad range in the length of long-term cycles reflects consideration of likely function differences between ecosystems and attempts to account for boom and bust cycles.

It was agreed that the best means of determining probable response of predators, and prey, to lethal control was to consider various permutations of control frequency and response time-frame (Table 4). Due to time constraints, discussion of the impacts of repeated control events in the medium-term, was not addressed.

Table 4 – Time-frame / control frequency combinations discussed by expert participants

Time frame	Frequency of control	Status of discussion
Short term	Single event / program	Completed
Medium term	Single event / program	Completed
Medium term	Multiple events / programs	Not addressed due to time constraints
Long term	Single event / program	Assumed encapsulated in Long Term/ multiple events
Long term	Multiple events / programs	Completed

Predicting short and medium-term responses of predator populations to wild dog control

Tables 5-8 outline the participants agreed positions on population responses of predators to a number of scenarios with both short and medium term effects of lethal control. Using the definition of lethal control above, the participants tabled the expected responses to lethal control delivered either as a single event or as multiple events. Tables 9 and 10 summarise participants' expectations for long term control using multiple control events. A note was made as to whether long term control of these predators was currently achieved. These represent the tactics used for lethal control by managers in WHAs and elsewhere. As biodiversity changes are more likely to occur in response to long-term control, discussion below concentrates on long-term responses. It was noted that responses of cat populations were made assuming that there was an effective cat attracting bait (M Kennedy comment).

Table 5 – Agreed probable population responses of placental predator species to SINGLE EVENT, lethal control programs, in the SHORT-TERM

	Dog control	**Fox control**	**Cat control:** **1080 poison baiting**[1]	**Cat control:** **Trapping / Shooting**
Dogs	CONTROLLED	DOWN	DOWN	DOWN or SAME[2]
Foxes[1]	DOWN or SAME[3]	CONTROLLED	DOWN	DOWN
Cats	SAME[4]	SAME[5]	CONTROLLED	

[1] 4.5mg 1080 baits are used for cat control in Western Australia, but not elsewhere

[2] When trapping and/or shooting, releasing non-target dogs was possible, hence SAME is possible. It was agreed foxes would also be considered a target in such programs.

[3] A behavioural release of foxes was considered to be possible

[4] If dogs are controlled, behavioural release, in terms of more track use and more day time movement of cats, was considered to be likely.

[5] If foxes are controlled, behavioural release, in terms of more track use and more day time movement of cats, was considered to be likely.

Table 6 – Agreed probable population responses of non-target species to SINGLE EVENT, lethal control programs, in the SHORT-TERM

	Dog control	Fox control	Cat control: 1080 poison baiting[1]	Cat control: Trapping / Shooting
Quolls	SAME	SAME	SAME[1, 2]	SAME[1]
Goannas	SAME	SAME	DOWN	DOWN
Corvids	SAME	SAME	SAME	

[1] Behavioural release of quolls, post-cat control was considered to be likely and indeed more likely than behavioural release of any other non-target fauna

[2] The soft bait matrix used for cat baiting was considered to potentially increase risk to quolls, relative to red meat baits used for foxes and dogs

Table 7 – Agreed probable population responses of placental predator species to SINGLE EVENT, lethal control programs, in the MEDIUM-TERM

	Dog control	**Fox control**	**Cat control: 1080 poison baiting**	**Cat control: Trapping / Shooting**
Dogs	DOWN or SAME	DOWN or SAME[1]	DOWN	SAME
Foxes	DOWN or SAME or UP[2]	DOWN or SAME	DOWN	SAME
Cats	SAME or UP	SAME or UP	SAME or DOWN[3]	

[1] If baiting, then DOWN, if shooting or trapping, then SAME

[2] In mesic environments, it was suggested dog control would result in DOWN or SAME. In xeric environments, it was suggested dog control would result in SAME or UP.

[3] SAME in mesic environments but DOWN in xeric ones.

Table 8– Agreed probable responses of non-target species to SINGLE EVENT, lethal control programs, in the MEDIUM-TERM

	Dog control	Fox control	Cat control: 1080 poison baiting	Cat control: Trapping / Shooting
Quolls[1]	UNSURE[2]	UNSURE[2]	SAME or UP[3]	SAME or UP[3]
Goannas[1]	SAME	UP	Unsure	Unsure
Corvids	SAME	SAME	SAME	

[1] Any positive response by quoll and/or goanna populations was thought to likely be as a result of activity release in the first instance, resulting in improved foraging success and, consequently, improved fecundity and survival rates.

[2] Quoll responses to dog and fox control were thought to probably be highly dependent upon the responses of cats

[3] If cats are SAME, medium-term then quolls will be likely stay the SAME. However, if cats go DOWN, then quolls were expected to go UP.

Table 9 – Agreed probable responses of predator species to MULTIPLE EVENT, lethal control programs, in the LONG-TERM

	Dog control	**Fox control**	**Cat control:** **1080 poison baiting**	**Cat control:** **Trapping / Shooting**
Dogs	DOWN	DOWN	DOWN	DOWN
Foxes	DOWN or SAME or UP[1]	DOWN	DOWN	SAME
Cats	SAME or UP	SAME or UP	DOWN	

[1] As for medium-term responses of foxes to dog control, participants suggested an increased likelihood of foxes going UP in xeric environments and an increased likelihood of foxes going DOWN in mesic environments under long-term dog control, with multiple control events. In both types of system, SAME was also considered possible.

Table 10 – Agreed probable responses of non-target species to MULTIPLE EVENT, lethal control programs, in the LONG-TERM

	Dog control	Fox control	Cat control
Spotted-tailed quolls	UP	UP	UP
Northern quolls	SAME or DOWN[1]	UP	UP
Eastern quolls	SAME or DOWN[1]	UP	UP
Western quolls	SAME or DOWN[1]	UP	UP
Phascogales	SAME	UP	UP
Goannas	SAME or UP	UP	UNSURE
Corvids	SAME	SAME	SAME

[1] Likely response assumes cats are UP, post-dog control

Predicting long-term responses of predator populations to wild dog control

In short, participants were unsure what would happen to cat populations where foxes are present in response to long-term lethal dog control due to expected complex interactions between dog, fox and feral cat populations (Tables 9-13). The expected responses of native predators listed in Table 14 were in response to selective control of each introduced predators.

Fox response to long-term dog control was the most difficult issue to find agreement on. Participants noted that the responses of any fox population would be dependent on multiple, closely interrelated issues (Figure 3).

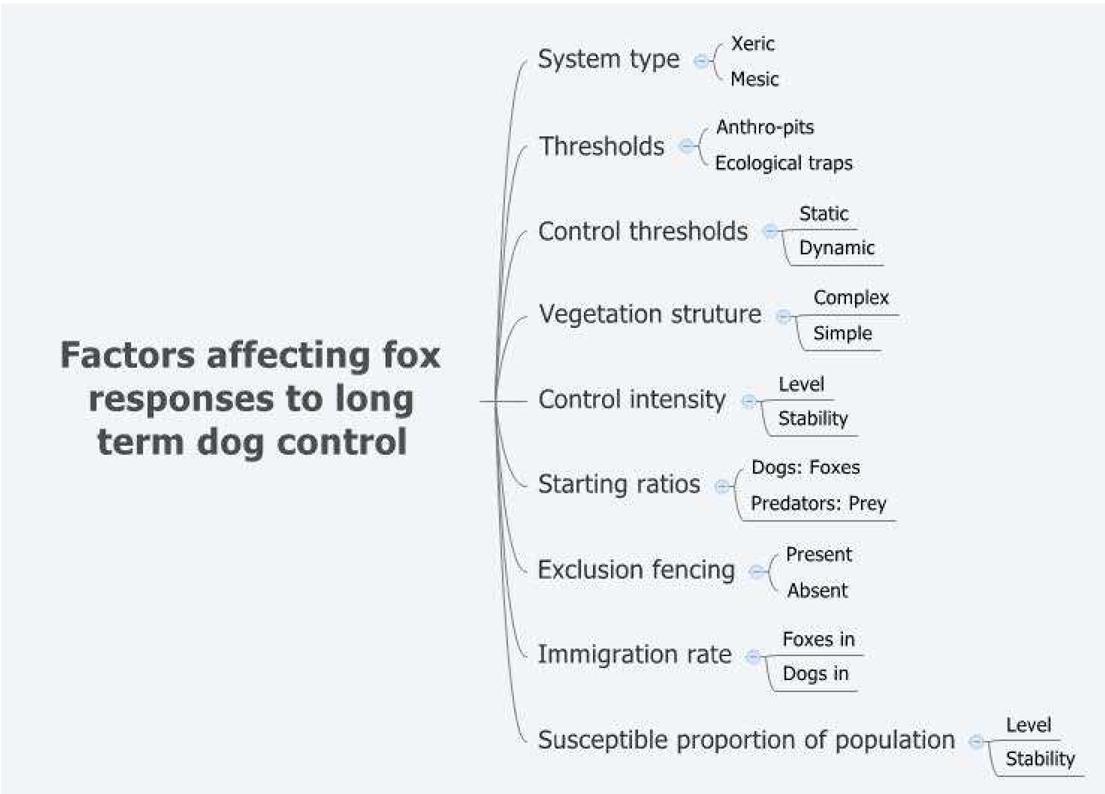


Figure 3 – Suggested factors influencing responses of foxes to long-term dog control

In planning for dog and fox control success, identifying and exceeding control thresholds for each species (Figure 3) was deemed particularly important. Participants suggested that if managers could exceed such thresholds it should be possible to create human-induced predator-pits in the environment. It is worth noting that some participants felt that foxes would likely escape these 'anthro-pit' scenarios, more rapidly than dogs, returning to the ongoing, inter-related issues of recovery-rates and immigration. Others (P. Fleming and N. Marlow, comments) were sure, on the basis of their experience, that all effective dog control would lead to contemporaneous control of foxes.

Would integrating multiple control techniques make a difference, long-term?

Despite being promoted on multiple occasions during the workshop, integration of control techniques was not likely to guarantee that control could be achieved, let alone maintained in the long-term, according to some participants. Rather, they suggested that risk aversion, and ongoing selection for it, as a behavioural trait would undermine predator control programs in the medium to long-term. To address this potential problem, it was suggested that control tactics (not just method but also intensity and frequency) may need to be varied in the short- to medium-term

Impacts of predator control, on prey species

Following discussion of predator responses to predator control, the focus of discussion shifted to how various prey might be affected by predator control.

In order to make this discussion manageable, participants were asked to suggest a means of categorising prey. Consequently, terrestrial vertebrate fauna (mostly mammals) were sub-divided into 5 size categories. The species in each category and participants' suggestions re those species' susceptibility to predator impacts and/or likely responses to predator control are outlined below.

Very large prey

This category was comprised mostly of large, introduced ungulates. Example species include Buffalo, camels, cattle, horses, donkeys, red deer and sambar deer.

Although wild dogs may prey upon these species, population regulation was considered unlikely. Rather, off-take was considered to likely be sustainable although this does not necessarily apply to calves in livestock production systems where economic sustainable losses are less than ecologically sustainable yields.

Foxes and cats were deemed unlikely to have any direct effect on these species.

Large prey

Large macropods (i.e. kangaroos and wallaroos), pigs, fallow deer, rusa deer, goats and sheep were identified as key species in this category.

It was thought possible that wild dogs regulate some deer populations in the wet tropics but this was not considered to be occurring in temperate areas of the continent. Indeed, in some areas where there are relatively high densities of wild dogs, deer appear to be increasing both in distribution and abundance.

An increase in feral pig abundance, associated with control of wild dogs, was considered possible but participants felt that such a response was likely to be localised and highly context specific.

Control of wild dogs was associated with an increase in the abundance of sheep and goats. Similarly, increases in the abundance of sheep and goats were expected with red fox control too.

Participants indicated that there was evidence that wild dogs can regulate kangaroo numbers in rangelands and that some livestock producers believe that wild dogs regulate populations of large macropods, such as red, eastern grey and western grey kangaroos, in other agricultural settings.

Medium-sized prey

Medium-sized macropods, such as wallabies and pademelons, along with exotic hog deer were included in this group.

Wild dogs can regulate some medium sized macropods, such as swamp wallabies and both foxes and cats can impact negatively on young at foot, pouch young and sub-adults of species in this category.

In terms of disease, there is a known relationship (for hydatids) between wild canids and some wallabies and cats may have a negative influence on medium-sized prey via transmission of toxoplasmosis.

It was suggested that complex predator interactions (how dogs, foxes and cats interact) becomes important in this size category and the two smaller size categories. For example, it was proposed that if, as a result of a decrease in dogs, there is an increase in activity or abundance of foxes and/or cats, then medium sized prey may be disadvantaged.

Critical Weight Range (CWR) species

As well as arboreal mammals, such as possums and large gliders, other native species such as bettongs, potoroos, bandicoots, numbats, echidnas and introduced species rabbits and hares, were allocated to this group.

Experience in Western Australia suggests lethal control of predators will result in increases in CWR species so long as cat and fox control is coordinated and has no gaps in time or space. Outside of predator exclusion fences, however, participants noted that it seems to be almost impossible to get predator densities low enough to derive benefit for native fauna in this group, especially in the arid zone. The Western Shield program has provided some quite outstanding responses to fox control for many years, though these have not been maintained in the long term. Where refuge areas are available (e.g. rock piles for rock wallabies) predator control is not so vital (N. Marlow comment).

Rabbits may 'complicate' the issue for other species by inflating/ sustaining predators/ predation, creating/ maintaining a pit for other, similarly-sized fauna.

In Tasmania and the wet tropics, CWR species living in complex habitats seem to be doing okay. In both scenarios, foxes are functionally or literally absent. However, it was noted that in Tasmania, a possible increase in cats, correlated with a decrease in devils, may result in future decreases in CWR animals, even in structurally complex habitats (M. Jones comment).

Small vertebrates

The group of the smallest vertebrate prey species included mammals such as pygmy possums, small gliders, rodents and small dasyurids, along with other fauna such as lizards and frogs.

In drier parts of Tasmania, where the habitat is more open, it was noted that small vertebrates appear to be vanishing (M. Jones, comment). This is relative to more structurally complex, wetter habitats where capture rates were relatively better. Similar results are evident for northern Australia and cats were suggested as a possible reason for this, but in northern Australia, negative impacts from fire and introduced herbivores are also important (C. Johnson, comment).

Kowaris (*Dasyuroides byrnie*), mulgaras (*Dasycerus cristicauda*) and dunnarts (*Sminthopsis spp.*) were thought to likely benefit from predator control. In this size category, black rats (*Rattus rattus*) and house mice (*Mus musculus*) may function like rabbits, inflating predator populations and impacts on less abundant small species.

In the arid zone, fox predation has driven rodents down in some areas and lizards increased post fox control at Yathong Nature Reserve in central NSW, but not elsewhere (M. Hayward comment).

In terms of complex interactions it was thought that controlling wild dogs could have indirect, adverse effects on rodents and dasyurids in arid sites, i.e. if foxes or cats increase when wild dogs are controlled.

Across the three smallest prey categories, it was noted that passerine birds could be particularly susceptible to population and behavioural release of cats (M. Kennedy comment). It was also noted that cat impacts appear to be shifting upwards, in the absence of larger mesopredators (dogs and foxes) from small vertebrates to CWR, thence to medium sized prey animals.

Regardless of size category, participants indicated that a range of factors were likely to define the response of affected prey species to predator control (Figure 5).

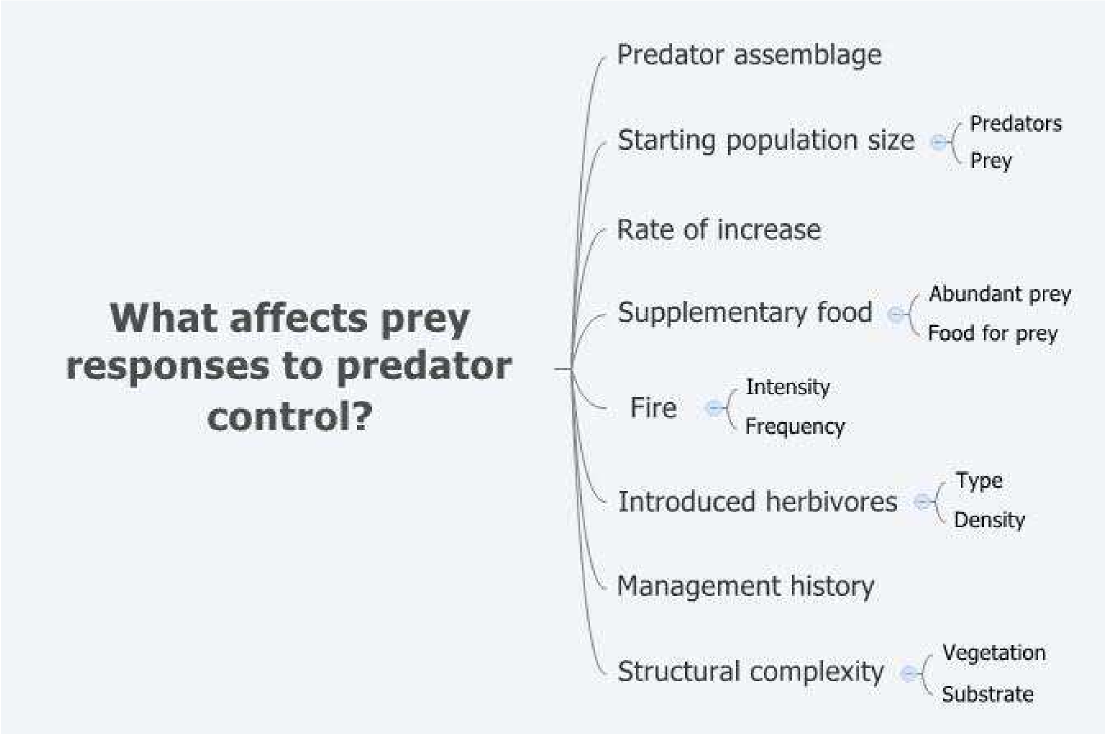


Figure 5 – Factors affecting impacts of predator control on prey

Five key management principles

To conclude the workshop, expert participants were asked to give some thought to key principles for managing predators in both WHA and other sites. From the resulting suggestions, five key principles were clear.

1. Control programs should be based on strategic plans, implemented in an adaptive management framework
2. Make the control area as big as possible, keeping in mind the need to ensure it is proportional to the scale of the species one intends to affect. The size of management units will be dependent upon the species involved. Scale up to the order of magnitude of the predators' home range if it is greater than that of the prey species of interest.
3. Scientific rigour is vital to management success. Consequently, professionals should be engaged to ensure the program has a robust statistical design and to ensure the results are 'written up'. Success and failures must be made publicly available to ensure that others can learn from these programs.

4. Before After Control Impact (BACI) should be the minimum standard for designs to assess lethal control effects. In the absence of appropriate nil-treatment areas it is impossible to demonstrate that population changes are associated with control efforts
5. "If you cannot commit to monitoring then do not start the program" (N Marlow comment).
    a. It is extremely important to monitor for both direct and indirect effects of predator control.
    b. It is important to know which species / variables should be monitored beforehand. This can be difficult, so managers may initially need to assess a wide range of variables in order to find the appropriate measures.
    c. It is important to record data related to effort (cost, person hours) to assess cost–effectiveness but don't assume that cost is all the monitoring that is required. Without a measure of effectiveness all one has is a measure of cost.

Key knowledge gaps identified from Workshop

The knowledge gaps were formulated into a series of questions. The knowledge gaps are not specific to particular systems and not all of them pertain to the management of WHAs.

1. What differences exist between target and non-target impacts in situations where: i) control is attempted and achieved, ii) control is attempted but not achieved and iii) control is not attempted?
2. Are there density-damage functions for various predators in various ecosystems (including agri-ecosystems) and, if so, what are they?
3. What are the relative ecological roles of dingoes, feral domestic dogs and hybrids?

4. Does population ratcheting occur, where densities of smaller predators increase in steps in response to control of larger predators, e.g. in fox and cat populations, in the wake of control programs targeting larger predators, e.g. dogs and foxes respectively?
5. What extent of predator population reduction is caused by control programs of different intensities, scales and duration?
6. What are the rates of recovery for predator populations following control programs?
7. What are the short term impacts of control on local predator populations?
8. Are the local effects of lethal predator control reflected at broader scales?
9. How is predator social organisation affected, in terms of promoting changes in activity and immigration, by lethal control programs? Do such changes alter function
10. Do region-dependent responses of predators to control programs exist, and if so, what are they?
11. What are the frequency and types of demographic lags that can be expected, in response to lethal predator control?
12. Over what timeframe can control efficacy declines be expected and how can we avoid them?

Concluding remarks

There are a number of questions that remain to be answered to assist World Heritage Area managers and other land managers in deciding whether to lethally control introduced predators on their lands. Some of these are:

1. Does lethal control of dingoes and other wild dogs cause release of red fox populations?
2. Does lethal control of dingoes and other wild dogs cause release of feral cat populations?

3. Does lethal control of foxes cause release of feral cat population?
4. If release does occur, does release of foxes and/ or feral cats cause negative impacts on threatened fauna?
5. Do these top-down processes affect rates of increase of endangered fauna, and, if so, when?
6. Do trophic cascade processes affect vegetation floristics and structure in WHAs, and, if so, when?
7. What is the experimental evidence for trophic cascade effects on herbivores and vegetation?
8. Do dingoes and other free-ranging dogs fill the same role in a particular ecosystem?
9. Which placental predators (if any) should be controlled for biodiversity gains in a particular WHA?

We hope this document provides a useful focal point for framing research questions and understanding of the roles of placental predators and trophic processes in Australian ecosystems.

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