A REPORT FOR THE AUSTRALIAN GOVERNMENT DEPARTMENT OF THE ENVIRONMENT AND HERITAGE

Experimental Trials to Determine Effective Feral Cat and Fox Exclusion Fence Designs

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Executive Summary and Recommendations

Feral cats (*Felis catus*) are believed to be responsible for the extinction or decline of native marsupials and birds in Australia and are listed as a known or perceived threatening process for 58 native species under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Foxes (*Vulpes vulpes*), which have been shown to eat a wide range of native species (reviewed in Robley et al. 2004), are a known or perceived threat to 34 native species (Environment Australia Biodiversity Group 1999a) and are thought to have played a major role in the decline of many ground-nesting birds, small to medium sized mammals and reptiles.

Exclusion fencing is increasingly being used to protect areas of high conservation value or to create 'islands' of protected habitat for native fauna. It has proven a particularly valuable tool in aiding the reintroduction of threatened species to areas from which they have been previously eliminated by threatening processes, including the predatory and competitive impacts of feral animals (e.g. Dufty et al.1994, Gibson et al.1994, Short et al. 1994, Moseby and O'Donnell 2003). The knowledge gaps in the design of these fences have been highlighted by Long and Robley (2004).

The Department of the Environment and Heritage (DEH) commissioned the Arthur Rylah Institute for Environmental Research (Department of Sustainability and Environment, Victoria) to develop an effective fence for the exclusion of European red foxes and feral cats based on the recommendations in Long and Robley (2004).

The objectives of this study were to identify a combination of fence designs to be tested and modify components in stages to determine the optimum physical and/or electrical barrier required to prevent feral (non-domestic) cats and foxes breaching a fence.

Six fence designs were tested. Feral cats and foxes were placed in pens and were filmed testing each separate design. The 'best' fence design, based on Long and Robley (2004), was used as the starting point. This fence of 1.8 m height was modified in four stages. Fence Designs 2 and 3 had single electric wires placed at different heights, e.g. low and high. Fence Design 4 had a single electric wire placed at the end of the overhang. Fence design 5 had no electric wire and Fence Design 6 was 1.2 m high with an overhang and no electric wire. Fence Design 6 was included as it is currently being used in the Arid Recovery Program at Roxby Downs and is a marked shift from the conventional designs.

Neither cats nor foxes were able to breach the 1.8 m fence by climbing over it regardless of the presence or absence of electric wires. One fox successfully breached the 1.2 m high fence by jumping onto the overhang and climbing over.

The absence of electric wires at the height of the animals' snout resulted in an increased number of times foxes pulled and chewed the mesh at the base of the fence. This resulted in foxes being able to create holes at the base and push through the fence on four occasions. Feral cats did not chew or dig at the base of any of the fence designs.

The quality of fencing mesh in our trials was inferior to that normally used in predator exclusion fencing as we were not directly testing an animal's ability to breach fences by chewing holes in the mesh. The experiment created a contrived situation in which animal interactions with the fence were exaggerated. The enclosed nature of the trial pens increased the pressure on the base of the fence beyond that generally expected when encountered by wild animals. We did not have the facilities to assess feral cat and fox interactions with corners.

We recommend that fences designed to exclude feral cats and foxes be: 1.8 m high; have an overhang that is at least 600 mm in circumference, be curved or shaped

in such a way that prevents animals climbing over; and have an apron of high quality mesh. The use of electric wires is not essential in preventing animals from breaching fences. The omission of electric wires will provide significant savings in building and maintenance costs for exclusion fencing.

1. Introduction

Through the Natural Heritage Trust, The Department of the Environment and Heritage (DEH) is working to develop and implement coordinated actions to reduce damage caused by feral animals to the natural environment and primary production. Feral animals are thought to be responsible for the loss and decline of a wide range of native species. *The Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) recognises, among others, the following key processes as threats to Australia's native species and/or communities:

- Predation by the red fox
- Predation by feral cats

Both state and Australian governments annually commit significant funds to manage or control the impact these vertebrate pests have on our environment. Control strategies include poison baiting, shooting, trapping, den/burrow fumigation, the release of biological control agents and exclusion fencing. Exclusion fencing was first used on a large scale in Australia to try and halt the spread of the European rabbit in the 1860s and 1870s, and soon after to exclude dingoes (*Canis lupus dingo*) from pastoral areas (McKnight 1969). This history of extensive exclusion fencing is unique to Australia and has been attributed to the relatively flat terrain and sparse vegetation across much of the country which makes fencing feasible. The pattern of differential land use, that made the exclusion of 'vermin' to the less inhabited interior of the continent a favourable concept (McKnight 1969), also makes fencing feasible.

Exclusion fencing is being increasingly used to protect areas of high conservation value or to create 'islands' of protected habitat for native fauna. It has proven a particularly valuable tool in aiding the reintroduction of threatened species to areas from which they have been previously eliminated by threatening processes, including the predatory and competitive impacts of feral animals (e.g. Dufty et al.1994, Gibson et al.1994, Short et al. 1994, Moseby and O'Donnell 2003).

The design of an exclusion fence must be specific to the behaviour of the animals it aims to exclude. It must also take into consideration the native animals it encloses and those that may be affected by its presence. There are also a variety of environmental and landscape features to be considered that may reduce the effectiveness or durability of a fence. Exclusion fences tend to be designed based on past experience rather than through a process of experimental trials. Hence, their effectiveness (or lack of) is only discovered after construction. Consequently, there may be a cycle of modification and re-development to overcome unforseen problems. This process has been undertaken independently by organisations and individuals across Australia and throughout the world; therefore, a myriad of fence designs for a diverse range of situations exists.

Long and Robley (2004) and Coman and McCutchan (1994) conducted comprehensive reviews of fox and feral cat exclusion fencing in Australia that have become invaluable guides for many fence managers. A key finding of the Long and Robley (2004) review was that there is a paucity of experimental testing on feral animal exclusion fences. Therefore, there is incomplete knowledge of the capabilities of the targeted pest species at breaching given fence designs. Consequently, it is not always possible to identify if a fence design is going to prove inadequate or over-engineered in a given environment. Filling these knowledge gaps will allow cost-effectiveness of fence designs to be optimised.

This document expands on the fence designs identified in Long and Robley (2004). It experimentally tests variations to find the most effective feral cat and fox exclusion fence design and to determine if a more cost effective design can be identified.

1.1. Limitations of this report

This report provides results of tests of six fence designs (4 electric wire placements and 2 overhang/height designs) based on the most effective fence design identified by Long and Robley (2004). However, every fencing situation is unique, and variation in the quality of fencing material, geographic position and environment can affect fence effectiveness.

Information provided is not intended to act as a substitute for the advice that can be obtained from qualified fencing contractors or consultants (preferably those that have had substantial involvement in the construction of exclusion fencing). No exclusion fence will be effective unless it is meticulously planned, constructed and maintained. Features of fences that present unique challenges, such as gully and creek crossings, corners and gates, were not tested in our trials. Long and Robley (2004) address these issues and present recommendations in relation to designs for these situations.

2. Background

2.1. Study species

Feral cats (*Felis catus*)
Cats probably became established in Australia soon after the arrival of the first Europeans. Feral populations now occupy most parts of the mainland, Tasmania and many offshore islands. A number of studies reviewed by Fitzgerald (1988) suggest a strong link between the dramatic decline of several species of island and continental bird and mammal populations and the introduction of cats. In a small number of studies there is compelling evidence domestic and stray cats have minor or major impacts on native wildlife, sometimes at the level of regional populations but mostly usually on local populations (Dickman 1996).

Red Foxes (*Vulpes vulpes*)
The red fox was deliberately introduced into Australia in the mid to late 1800s. Foxes are now common throughout most of Australia, except the tropical north and some offshore islands. Foxes occupy many habitats, including urban, alpine and arid areas, but are most common in woodland and semi-open habitats (Saunders et al. 1995). Foxes have been shown to eat a wide range of native species (Saunders et al. 1995) and are thought to have played a major role in the decline of many ground-nesting birds, small to medium sized mammals and reptiles.

2.2. Objectives

The objectives of this study were to:

- Identify a combination of fence designs and modify components in stages to determine the optimum physical and/or electrical barrier required to prevent feral (non-domestic) cats and foxes scaling fences. This includes mesh overhangs, various arrangements of offset electric wires and constitutes the minimum set of fence design requirements (materials and configuration of electric wires etc).
- Analyse the behavioural responses of contained feral animals to fence designs with a focus on determining the most efficient design in both function and cost.

2.3. Requirements for assessing exclusion fencing designs

Long and Robley (2004) identified a combination of fence components that have been widely used but rarely, if at all, tested in an experimental manner, including electric offset wires and overhangs. The initial experimental fence design was based on the composite fox, feral cat and rabbit fence identified in Long and Robley (2004). This fence represents the best possible design, based on information collected by the authors. We then modified components in stages to test the capacity of either species to breach each new fence design. The project investigated the behaviour of exotic predators (feral cats and foxes) at electrified and non-electrified fences to determine potential weak points in fence designs that may compromise their effectiveness. The project objective is consistent with objectives in the Threat Abatement Plan for Predation by Feral Cats and the European Red Fox (Environment Australia Biodiversity Group 1999a and b).

The use of energised 'electric wires' has been used to prevent movement of a number of feral species such as foxes and feral cats (Short et al. 1994, Algar and Smith 1998). We considered the behaviour of feral cats and foxes in evaluating the possible weak points in various designs, and how the designs might be improved. Overhangs of various designs have also been extensively used in a range of fence designs. We will consider these in combination with 'electric wires' to determine the optimum configuration.

3. Methods

3.1. Experimental Fence Designs

We tested 6 fence designs. Designs 1 - 4 looked specifically at the location of electric wires to deter feral cats and foxes. Designs 5 - 6 looked specifically at the use of “floppy top” overhangs and fence height.

Figure 1. Fence of 1.8 m height as used in designs 1 - 5, shown here with no electric wire attached.

Figure 2. Fence Design 6 of 1.2 m height.

Fence Design 1
This design is based on that identified in Long and Robley (2004). This fence had 2 electric wires, a low wire to prevent animals scaling the fence from its base and a second wire placed at a height that feral cats and foxes might initially jump to in attempting to scale a fence.

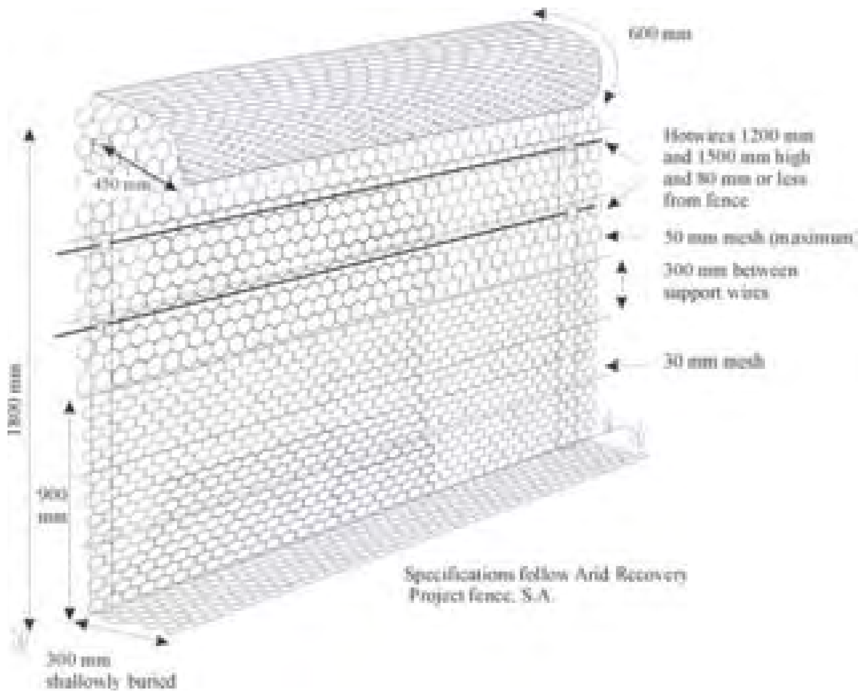


Figure 3. Fence Design 1. This fence is widely considered the most effective at excluding feral cats, foxes and rabbits.

Fence Design 2

This design is the same as fence design 1, with the exception that it has a single electric wire at a lower position. This design tested the use of an electric wire set low to deter attempts to scale the fence from its base.

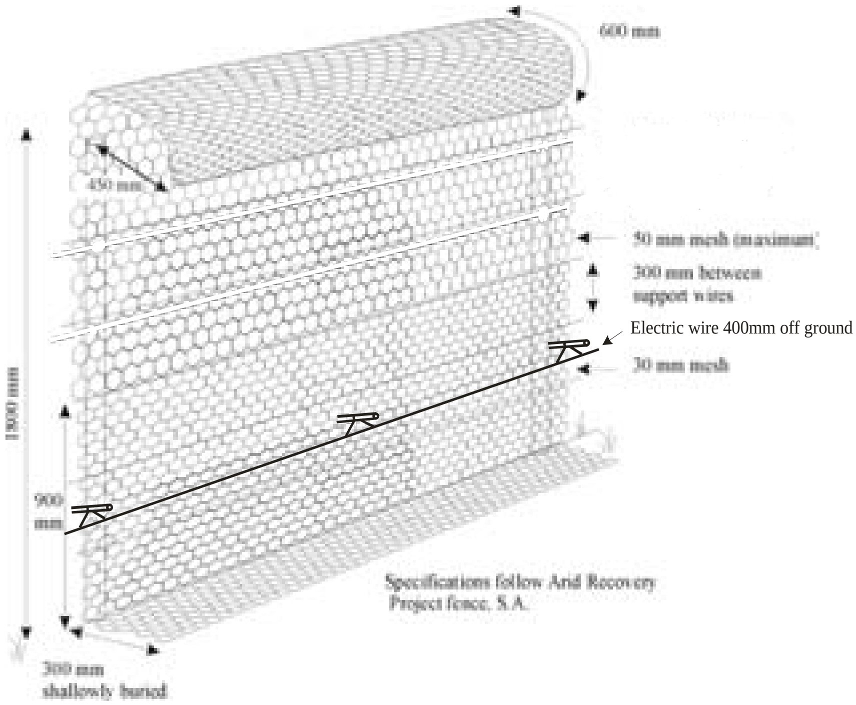


Figure 4. Fence Design 2. This design tested the use of an electric wire set low to deter attempts to scale the fence from its base.

Fence Design 3

In this design the single electric wire was placed above the height of an assumed initial jump, thus the animal would need to negotiate the wire while holding onto the fence.

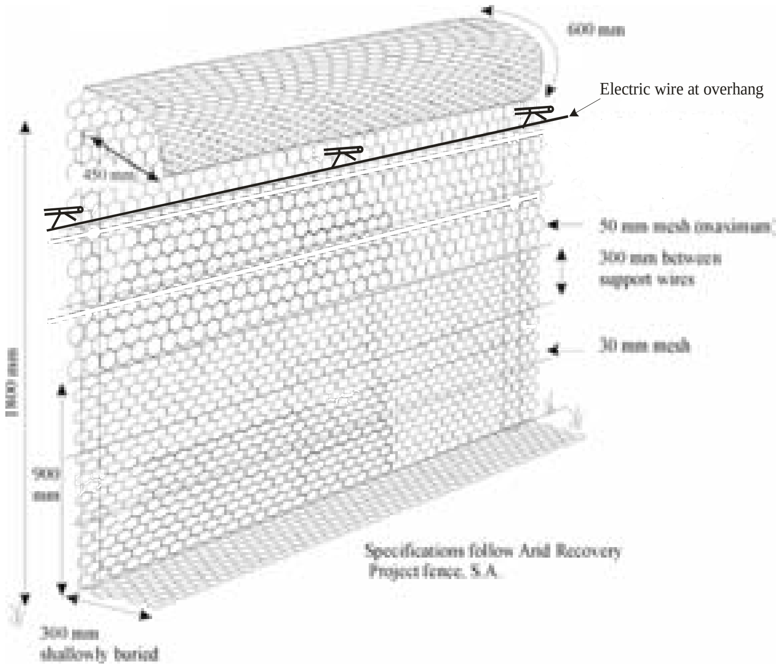


Figure 5. Fence Design 3. Electric wire set above initial jump height.

Fence Design 4

A single electric wire was placed at the end of the overhang. It was thought this placement would prevent breaches of the fence if feral cats and foxes climbed to the end of the overhang.

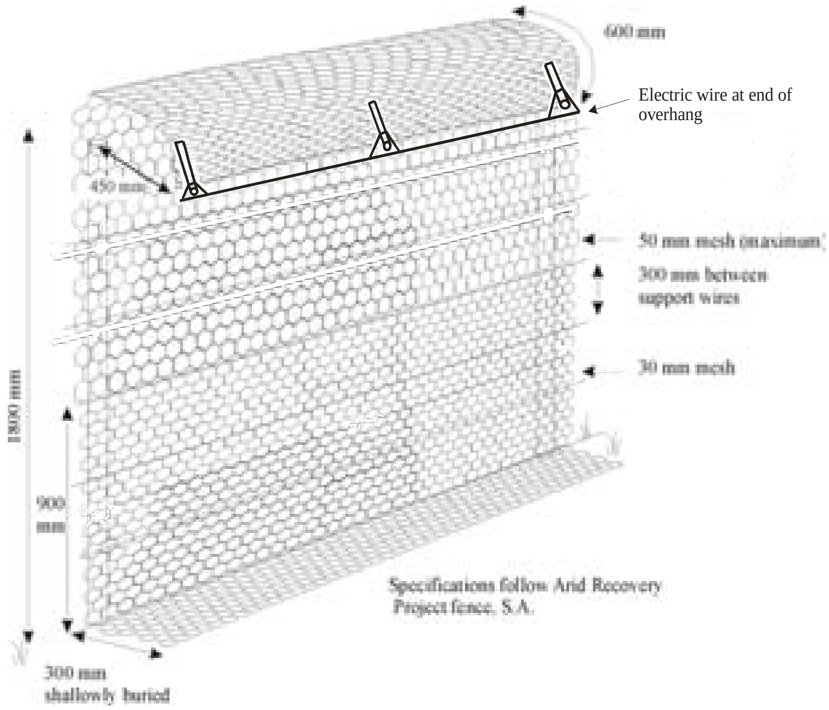


Figure 6. Fence Design 4. Electric wire set at end of overhang.

Fence Design 5

This fence design had no electric wires, and relied on the overhang and the height of the fence to prevent animals breaching it.

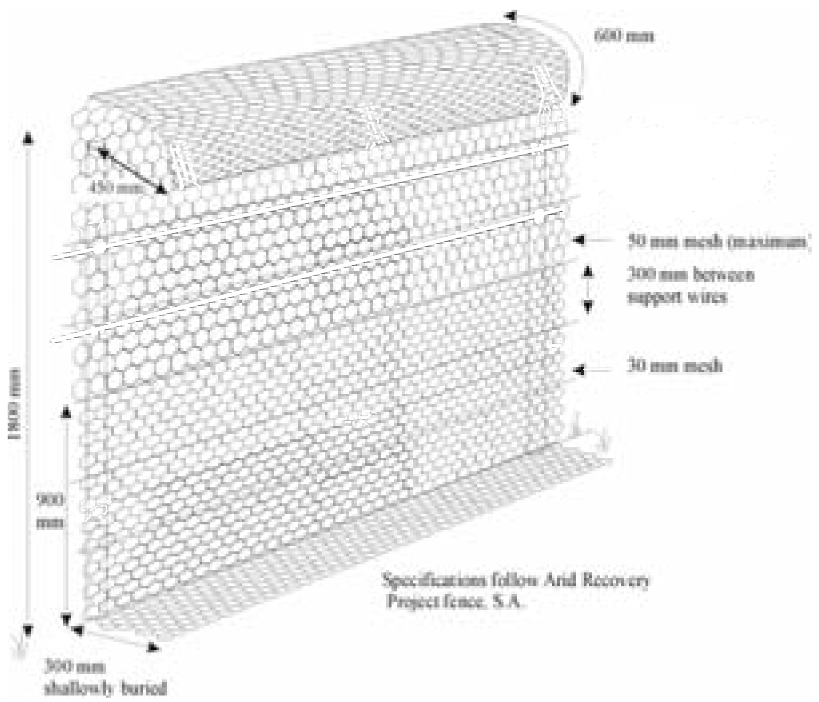


Figure 7. Fence Design 5. No electric wire.

Fence Design 6

This design was first trialled and subsequently used by the Arid Recovery Program, based at Roxby Downs in South Australia (Moseby and Read 2005). We included it in our trials to assess it against Fence Design 5 as this fence is considerable shorter and hence less costly than Fence Designs 1-5.

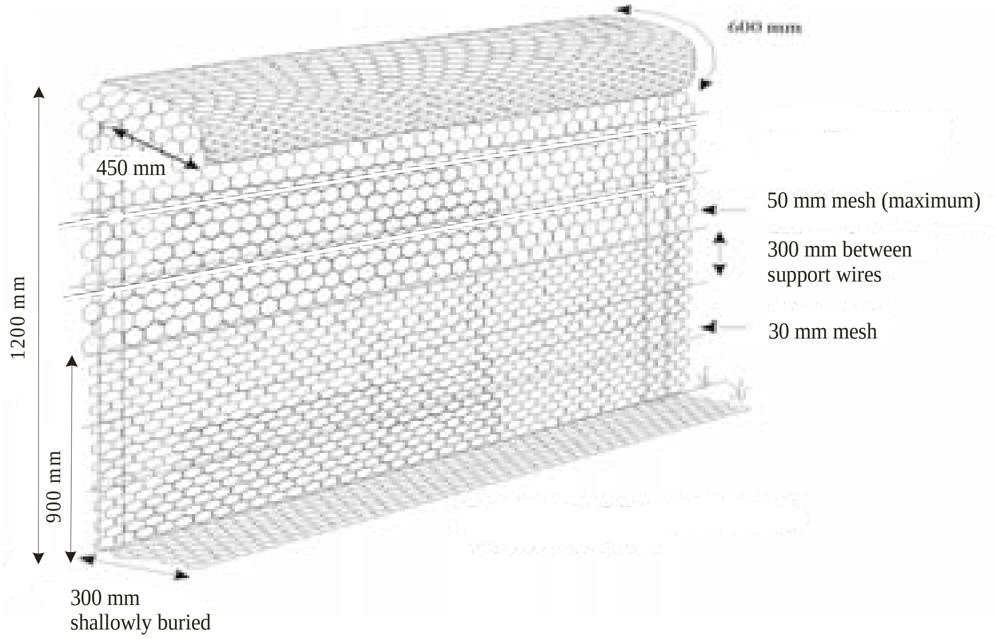


Figure 8. Fence Design 6. This short version of design 5 is only 1.2 m high.

3.2. Pen Construction

Planning and site preparation began in April 2005 and construction began in May 2005. All six pens were completed in late June 2005.

Six 20 m x 20 m pens were constructed (Atlas Rodek Fencing, Knoxfield) at the Keith Turnbull Research Institute (KTRI) Department of Primary Industries site Frankston. These were 2.4 metres high, constructed of 60 mm x 50 mm diameter steel posts concreted into the ground and covered with Cyclone galvanised chain mesh (40 mm pitch x 2.50 mm). A vehicle access gate was included under which a concrete plinth was placed to prevent animals digging under. A horizontal 'T top' (1.2 m wide) was added to the fence top and an apron of galvanised chain mesh 1.2 m width (600 cm each side) was pinned and buried under the fence to prevent animals climbing over or digging under the perimeter fence. The T top (Fig. 9, 11 and 13) and apron were constructed from galvanised 40 mm pitch x 1.5 mm chain mesh.

Figure 9. The T-top on top of the pen.

Shade cloth (Coolaroo 96% UV exclusion, Gale Pacific) covered the fence that surrounded the 'active' half of the pen where the animals were initially introduced (Fig. 10), while on the other side the fence remained uncovered. The idea being that this would focus the animals' attention to the unrestricted view or perceived freedom

past the experimental fence which divided the pen and thus provide added motivation to challenge the experimental fence.

Figure 10. Shade cloth covering the active side of pens.

Pens 1, 2 and 3 were allocated for feral cats and pens 4, 5 and 6 for foxes. Feral cat and fox pens required further and differing escape-proofing. Both species were able to climb horizontally and vertically along the mesh of the perimeter fence to reach and escape over the experimental fence. A number of 2-3 mm thick, 1 m x 2.2 m flat plastic sheets were attached to the junction of the external fence and the experimental fence to prevent animals reaching the top of the experimental fence in this way.

During initial pre-trial tests, cats were able to jump to the top of cameras positioned in pens to record the animals' behaviour (see 3.5) and use them as a platform to gain access to the top of the trial fence. In the cat pens 1 m diameter disks were cut from the plastic sheeting and attached to encircle the poles approximately 30 mm below the cameras. These remained a floppy, unstable surface and prevented the animals seeing or reaching the cameras from beneath.

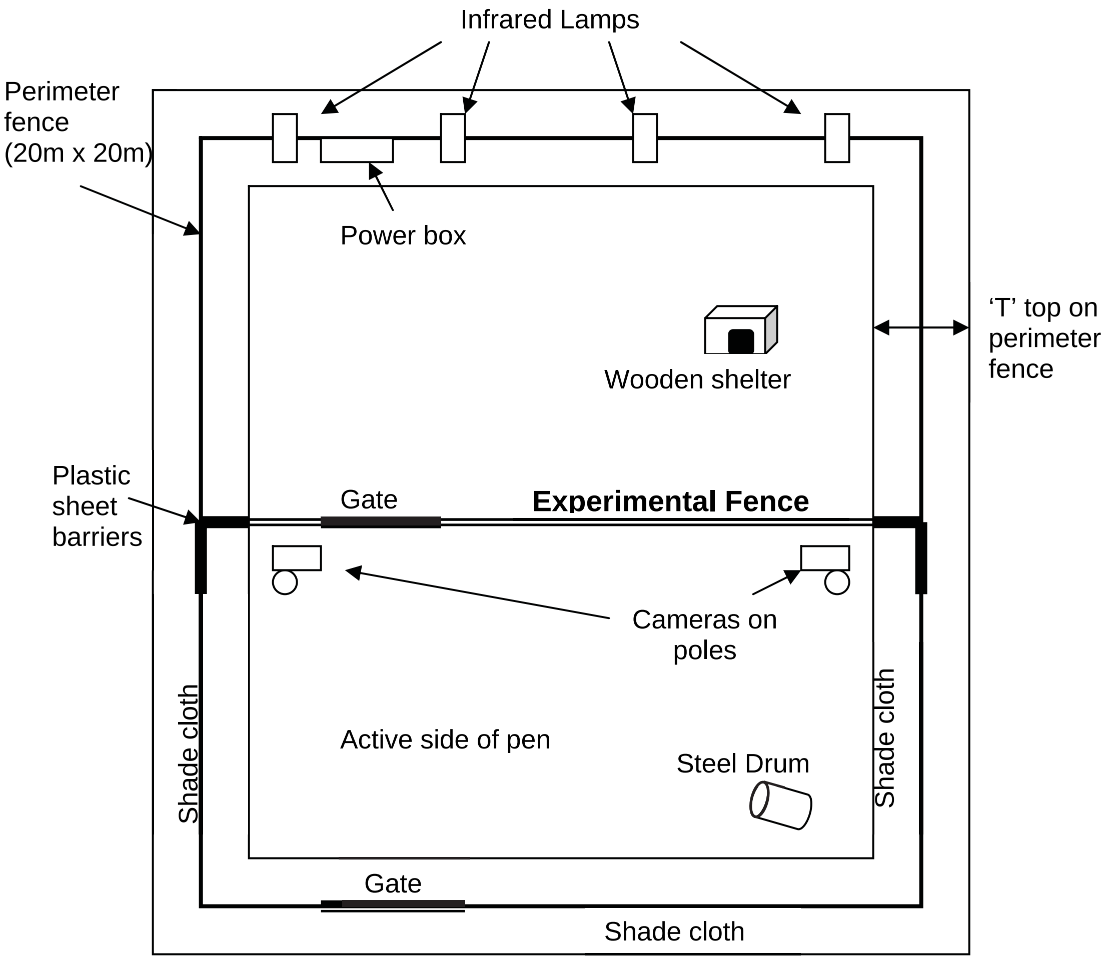


Figure 11. Plan of pens bisected by experimental fence.

3.3. The Experimental Fence

Each pen was bisected by the experimental fence (single panel of 20 m), creating a 10 m x 20 m area either side of it. This fence also included a vehicle gate with concrete plinth. The fence was constructed so that various elements (such as electric wires) were able to be progressively repositioned or removed for each trial fence design. Steel posts were used at the gate while all other fence posts were star pickets. A mesh overhang at the top of the experimental fence was constructed of flat steel arches, 20 mm wide with an arch diameter of 500 mm and supported with a brace. These were tied to the fence star pickets with wire while the fence's mesh continued over the arches to create the overhanging barrier (Fig. 12).

Figure 12. Overhang of experimental fence.

Figure 13. Overview of pens showing T top, shade cloth and experimental fence.

3.4. Experimental Fence - Electric Wires

The experimental fence presented some unique challenges in the design of the electric offset wires. Normally these would be fixed into place; however, we required them to be easily moved up or down, and potentially in and out from the fence.

Stainless steel MIG weld wire (1.57 mm) was used for the electric wires. This was used to give a durable wire of longevity that would stand up to intensive and potentially exaggerated pressure from the captive animals. The wires' ends had tension springs (The Spring Shop, Dandenong) attached. These springs in turn were hooked onto clips that could be clipped and unclipped to 10 mm diameter fibreglass rods of 200 mm length.

Recycled 100 mm by 50 mm timber was secured upright to every second post of the experimental fence. Holes were drilled at the various heights required for the electric fence through all stages of the fence trial. The fibreglass rods could then be inserted into these holes at heights required for each design of the experimental fence, and the electric wires clipped to the rods. All six systems were powered by a 1 joule Gallagher energizer.

In Fence Design 4 the fibreglass rods were tied by wire to the end of the steel hoops supporting the overhang.

3.5. Surveillance of Animal Response

Video-monitoring equipment enabling us to record and analyse fox and feral cat behavioural responses to the various fence designs was installed in each pen (Omnivision Pty Ltd, Melbourne).

Initially one pen was set up as a test scenario to determine the best surveillance equipment for our unique situation. The trial pen retained its two trialled cameras and for all other pens the system utilised a pair of Bocsh ½" super low light high resolution B/W Charge Coupled Device (CCD) cameras in each pen. Cameras were positioned at either end of the experimental fence (Fig.11) with their field of view including the furthest half of the fence. All cameras fed back to a 16 channel digital video recorder (DVR). The DVR was equipped with a 120 Gigabyte Hard drive. The DVR unit had the capacity to record and display a maximum of 200 frames per second; shared across the 16 channels. Surveillance software recorded digital video footage in MPEG4 format (Fig. 14). This software allowed us to detect and record motion. Surveillance monitoring of feral cats and foxes only recorded events when an animal approached to within 2 m of the fence. This reduced the amount of video footage to a manageable amount.

Figure 14. Image of fence and fox as seen in footage from surveillance system.

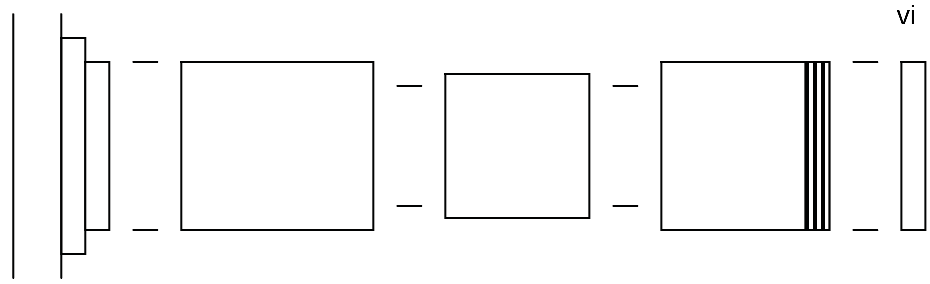


Figure 15a (i). Components of IR lamp

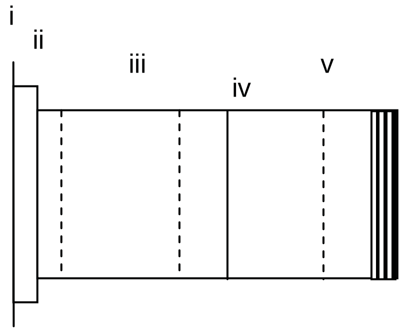
3.6. Infra-Red lighting

Four infra-red lamps were used to illuminate the active side of each pen around the base of trial fence.

We constructed the IR lamps (Fig 15a – 15c) based on earlier designs of Marks et al. (2003). Each lamp was constructed from the following plastic plumbing components (refer to Fig 15a)
(i) Black Perspex ICI 962 sheet
(ii) Stormwater grate with the end 20 mm cut off
(iii) Slip socket 160 mm in diameter
(iv) Plain stormwater pipe 150 mm diameter cut to 180 mm length
(v) Threaded access coupling 160 mm in diameter
(vi) Stormwater threaded access cap to suit. Components were glued together with iPlex pipelines type N PVC-U pipe glue.

Fig 15b shows the assembled lamp. Black Perspex ICI 962 sheet cut to a length of 210 mm, to match the size of the stormwater grate's face, was attached with silicon sealant and four small bolts used to fix it in place.

We bolted a lamp mount centrally to the inside of the threaded cap (Fig 15c). A Par 38 12v 120 Watt globe was used in each lamp set which sat a minimum of 120 mm (1 mm per watt, Marks et al. 2003) behind the black Perspex.



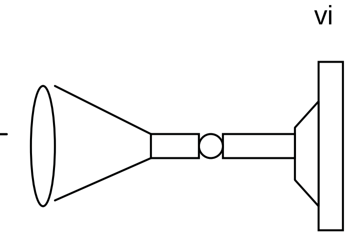


Figure 15a (ii). Stormwater grate **Figure 15b.** Assembled lamp

Fig 15b shows the assembled lamp. We bolted a lamp mount centrally to the inside of the threaded cap (Fig 15c). A Par 38 12v 120 Watt globe was used in each lamp set which sat a minimum of 120 mm (1 mm per watt, Marks et al. 2003) behind the black Perspex.

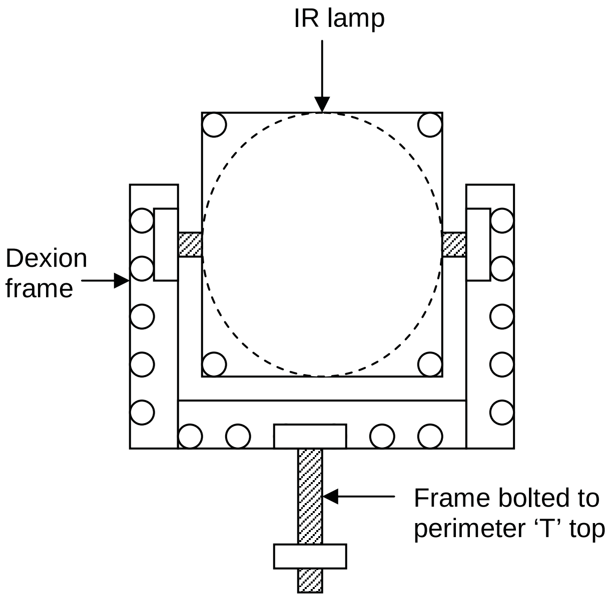


Figure 15c. Front view of an IR lamp mounted on Dexion frame.

Lamps were bolted to a Dexion frame we constructed (Fig 15c.) which was mounted on top of the perimeter fence opposite the active side and directed back at the trial fence.

3.7. Collection of subject animals

We engaged several vertebrate pest control contractors to collect adult foxes and feral cats. All cats were caught using cage traps from National Parks at Point Nepean, Gembrook and French Island during a number of trapping regimes by Parks Victoria and pest control contractors. Fox trapping contractors provided us with foxes caught using soft-jaw leg-hold or cage traps in National Parks and urban areas from their control contracts. Only animals assessed as adult (feral cats over 2 kg, foxes over 3.5 kg) were used. Animals were assessed for condition and injury. If injured, the animals were disposed of humanely according to procedures approved by the Department of Primary Industries Metropolitan Animal Ethic Committee Protocol number 2680. Animals were caught in hand nets, restrained and sedated (8 mg/kg Zoletil) and given an intra-cardiac injection of sodium pentobarbital (1 ml /2 kg body weight).

3.8. The Trial

Three foxes and three feral cats were introduced to the active side of their respective pens and left to challenge the experimental fence for three days, after which time they were removed. This constituted a single trial of a particular fence design. This replication was required to reduce random chances that individual animals may display ‘abnormal’ behaviour (i.e. are overly ‘athletic’ or docile) and to ensure a robust test of each fence design. Experimental fences were then modified to the next design and a new group of animals introduced to each pen for the next trial.

Food was limited to a minimal daily requirement sufficient to prevent any degree of starvation, but little enough to ensure that the animals were food challenged. Basic shelter in the form of a steel drum was placed in the active side of the pen where the animal was first released, while a more robust over-turned wooden crate was placed on the opposite side of the experimental fence. These methods, in addition to the shade cloth that enclosed the active side of the pen, were intended to act as enticements and increase the animals’ desire to escape through the trial fence toward the other side of the pen. The objective was to intensify their interaction with the limited length of experimental fence and present a worse case scenario to challenge it. Surveillance equipment recorded the animals’ interaction with the fence over a 24 hour period of each day of the trial. Categories of behaviour were identified through video footage of earlier pilot trials. These behaviours included a comprehensive list of typical behavioural interactions with the experimental fence. Assessment of each fence design used these categories to assess the responses of the feral cats and foxes to various fence designs and their components.

3.9. Behavioural Response Categories

We used the following categories to count the response behaviour of each species to each of the 6 designs tested in these trials:

Behaviour	Description
Base	Worrying of fence at its base, e.g. digging or chewing. A single 'base' event may last for several minutes e.g. a fox digging. After >30 seconds rest, continuation of 'base' behaviour is recorded as a new event.
Below	Interacting with the fence below the current electric wire position (e.g. running into, standing against, tugging, chewing, crouching and pushing face into fence)
Below (Fence Design 5 & 6)	Interacting with the fence (as above) below the overhang. For foxes a single 'below’ event may include an uninterrupted (i.e. with break of <few secs) combination of any of tugging, standing, jumping to below the electric wire.
Above	Interacting with the fence above the current electric wire position.
Electric Wire	Receiving a shock from the electric wire ('above' not counted if animal receives shock after reaching 'above'.
Overhang	Reaching the overhang by climbing or jumping over or past electric wires (when present)

Video footage was reviewed and the number of contacts based on each category was recorded for a 24 hour period. We used Etholog free software (Ottoni 2000) to transcribe behavioural categories while viewing the footage. This proved a very useful tool for our purposes.

It can be downloaded at
http://www.geocities.com/ebottoni/ethohome.html
To avoid duplication of recorded observations of activity we noted the point of overlap between the two cameras. Animal responses were recorded for each half of the pen only.

3.10. Data Analysis

We used descriptive statistics to report the instances where feral cats of foxes breached the fence by digging underneath or chewing through. This was not considered a breach of the fence in these trials as we were not specifically testing the base and apron as part of the trial designs.

We first used a general linear model (GLM) to test for interactions between animal and fence design in relation to responses to the various fence components. In cases where there was no significant interaction we undertook no further analysis. In cases where fence interaction was significant we used one-way ANOVA to test the difference in the mean number of contacts each species made with each of the response variables Base, Below, Above, Electric Wire and Overhang for each of the fence designs. Data were transformed using the 4th root transformation to normalise the distribution prior to analysis (Quinn and Keough 2002). Multiple comparisons of means were tested using Tukey's test (Zar 1999).

4. Results

4.1. Breaches of Fences

4.1.1. Foxes

One animal breached Fence Design 6 by going over the floppy top. However, this was immediately after we had exited the pen after providing food, thus it is likely human presence in the pen added extra motivation to jump over the overhang. Four of the 15 individuals managed to dig under the base of Fence Designs 3 (1 of 3), 4 (1 of 3), 5 (1 of 3), and 6 (1 of 3) (Fig 16). One animal managed to chew through the base of Fence Design 1 and breach it. This individual managed to do so on more than one occasion, despite repairs to the base each time the fence was breached indicating a learned response. Animals that breached Fence Designs 1, 3, 4 and 5 were the third animal in the pen. It is possible that the previous foxes had weakened the mesh or loosened the soil beneath the apron. Fences were checked and repaired and holes filled in as necessary prior to a new animal entering the pen in an attempt to reduce this possibility. No animal chewed or dug through the base of Fence Design 2.

Fox number 3 (female), chewed a hole in Fence Design 1 after 30.5 hours of being in pen number 5. Forty-nine percent of all fence interactions were at the Base of the fence, and 46% of interactions were Below the electric wires. This animal made contact with electric wires on 10 occasions (3%), all on the first day.

Fox number 9 (male) breached Fence Design 3 after digging underneath the apron 36 hours after being placed in pen number 6. This animal was only recorded at the Base (39%) or Below the electric wire (61%).

Fox number 12 (female) breached Fence Design 4 after digging underneath the apron 9 hours after being placed in pen number 4. This animal was also only recorded at the Base (60%) and Below (40%).

Figure 16 Foxes dug at the base of the fence and were able to breach the fence on four occasions.

Fox number 15 (male) breached Fence Design 5 by digging underneath the apron 10.5 hours after being placed in pen number 4. 55% of interactions were recorded at the Base and 43% Below the overhang. This animal reached the overhang on 6 occasions (2%).

Fox number 16 (male) breached Fence Design 5 by digging underneath the apron of the fence 68.1 hours after being placed in pen number 6.

Fox number 18 (male) breached Fence Design 6 by jumping onto the overhang and climbing over 19.5 hours after being released into the pen. This behaviour once learnt was repeated several times.

4.1.2. Feral Cats

None of the 18 feral cats breached any of the fence designs tested in these trials. However, one female feral cat, not a subject of the experiment, was housed in pen 5 and was seen to jump with ease to the top of Fence Design 6 (1.2 m) and breach it several times.

4.2. Interactions with Fence Designs

4.2.1. Foxes

Analysis showed that there was no significant difference in the number of contacts made with the base of the fence or with the overhang for Fence Designs 1 to 6. There were significant fence effects for contacts made below electric wires (Fence Designs 1 to 4; $F_{3, 32}$ = 8.25 P <0.001) with more contacts made with the fence below the electric wire in Fences Design 2 than Fence Design 1, 3 and 4 ($_{F3, 32}$ = 9.78 P <0.001; Fig. 17). There were also significance fence effects for contacts made Above the electric wires (Fence Designs 1 to 3; $_{F2, 26}$ = 13.20 P <0.001) with more contacts made with Fence Design 2 above the electric wire compared to Fence Design 3 ($F_{2, 25}$ = 13.27 P <0.001; Fig. 18), and a significant difference in contacts with electric wires (Fence Design 1 to 4; $F_{3, 32}$ = 3.35 P <0.05) with more contacts made with wires in Fence Design 2 than Fence Design 4 ($F_{3, 32}$ = 3.35 P <0.05; Fig. 19). Eleven of the eighteen foxes tested reached the overhang. However they did so infrequently. Of the total number of contacts made with the fence, contacts with the overhang averaged 3% (standard deviation 4%).

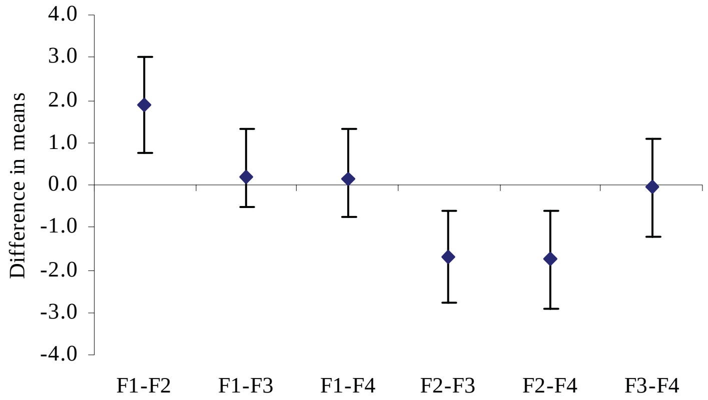


Figure 17. Difference in mean number of fox contacts Below electric wires. Bars are 95% confidence limits based on the pooled standard deviation.

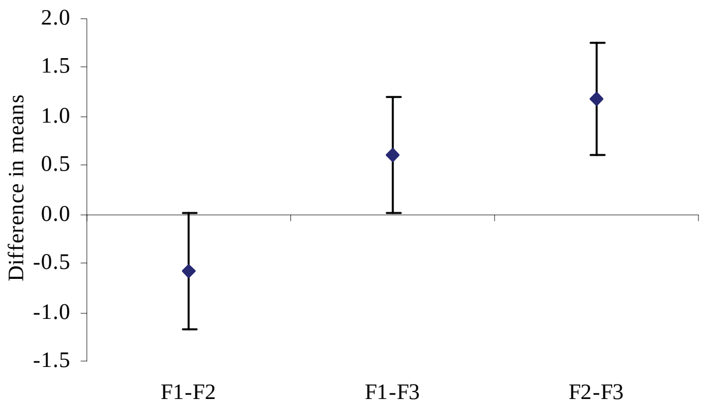


Figure 18. Difference in mean number of fox contacts Above electric wires. Bars are 95% confidence limits based on the pooled standard deviation.

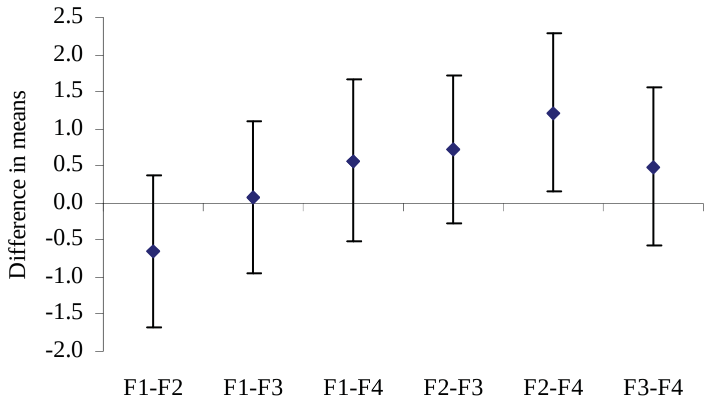


Figure 19. Difference in mean number of fox contacts with Electric Wires. Bars are 95% confidence limits based on the pooled standard deviation.

4.2.2. Feral Cats

Analysis showed that there was no significant difference in the number of contacts made with the base of the fence (Fence Designs 1 to 6) or above electric wires in Fence Designs 1 to 3. There were significant fence effects for contacts made below electric wires (Fence Designs 1 to 4; $F_{3, 35} = 3.36$ $P < 0.05$). One-way ANOVA indicated that there was a significant difference between fence designs ($F_{3, 35} = 3.37$ $P < 0.05$), however Tukeys pair wise test failed to determine which pair were different. There were also significant fence effects for contacts made with electric wires (Fence Design 1 to 4; $F_{3, 25} = 4.97$ $P < 0.05$; Fig 20) more contacts with electric wires in Fence Design 2 compared to 3 and 4 ($F_{4, 44} = 7.06$ $P < 0.001$). There were also significant overall fence effects for the number of contacts made with the overhang ($F_{5, 51} = 3.08$ $P < 0.05$). However, One-way ANOVA was insignificant at the 0.05 level ($P = 0.059$). A plot of the average number of contacts feral cats made with the overhang for each fence design indicates that there was a trend in increased numbers of contacts with the overhang as the electric wires were moved higher or removed altogether (Fig. 21).

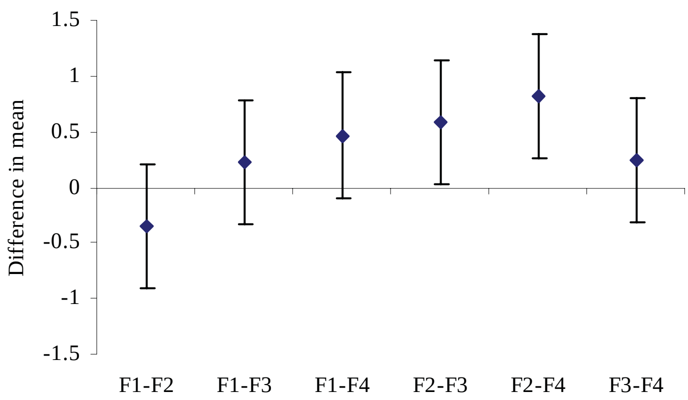


Figure 20. Difference in mean number of feral cat contacts with Electric Wires. Bars are 95% confidence limits based on the pooled standard deviation.

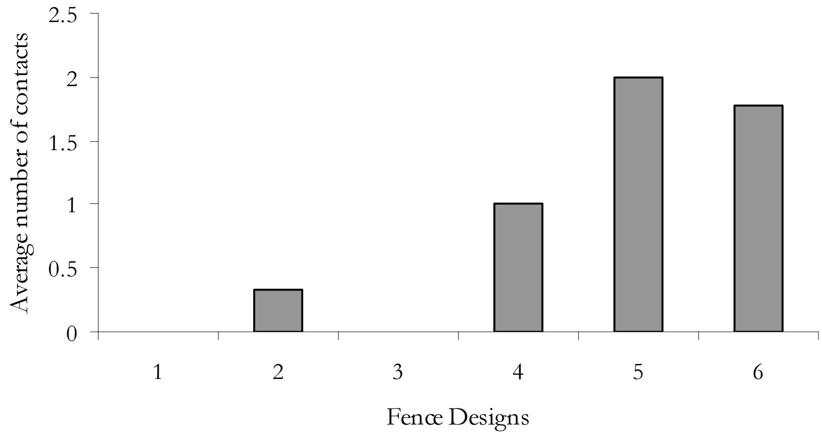


Figure 21. Average number of contacts feral cats made with the overhang in each fence design trial. Three feral cats were exposed to each fence design for three days each and the number of contacts with the overhand recorded.

4.3. Overhang (Designs 1 - 6)

4.3.1. Foxes

There was no significant difference in the mean number of contacts with the overhang for any of the fence designs. Eleven of the eighteen foxes tested reached the overhang. However, of the total number of contacts made with the fence, contacts with the overhang averaged 3% (standard deviation 4%).

4.3.2. Feral Cats

There was no significant difference in the mean number of contacts with overhangs for feral cats for any of the fence designs. However, feral cats failed to reach the overhang on Fence Designs 1 and 3, and only 1 feral cat reached the overhang in Fence Design 2 on four occasions on the first day of its trial. Two of the three cats trialled against Fence Design 5 reached the overhang and all three cats reached the overhang in Fence Design 6.

4.4. Costing

Long and Robley (2004) provided estimates for the cost of the floppy-top fences, for foxes, cats and rabbits, that Fence Design 1 was based on. They estimated that this fence would cost $10,300/km or $9,700/km without the electric wires (excluding labour). The additional cost of labour to plan and construct the fence may comprise up to 50% of the final budget.

These prices should be used as guides only as material costs are likely to vary considerably across Australia depending on the cost of freight and the availability of raw materials. We note that costs for raw materials has increased substantially since 2004. Advice should be sought from local fencing contractors when planning an exclusion fence as the spacing between posts and end assemblies, and hence the cost, will vary appreciably between locations according to the terrain and the shape of the area to be fenced.

Durable, high quality products should always be purchased to minimise future maintenance requirements and maximise the long-term cost-effectiveness of the fence. For example, the imported mesh we used at the base of the fence was easily broken by foxes which enabled them to breach the fence. Long and Robley (2004) indicate that using cheaper imported mesh can reduce the cost of the fence by $1000/km, but we do not recommend this for areas that are likely to have a high amount of fox pressure on the fence.

Long and Robley (2004) also recommend Ironbark droppers, or those made with similarly dense timber, in some of the cost-estimates. These droppers provide a high resistance so that electric wires do not require additional insulators, at least in short and medium length fences. They should also be used in all areas except those that are subject to very high rainfall or salt spray (McCutchan 1980). Cost savings will be made in fences that do not use electric wires as material for droppers can be minimized.

5. Discussion

The trial design provided a contrived situation where animals were held in a restricted area (20 m x 10 m). The expectation was that they would exhibit exaggerated interaction on a limited length (20 m) of the trial fence, thus testing it rigorously beyond what it would experience in a typical application. Evidence of intensified attention placed upon the fence was seen at the instance of and following each subject's release into the pens. At this time animals ran toward the trial fence. This was the only direction that an impression of freedom could be perceived as all other sides of the pen were covered by shade cloth. In many cases animals interacted with the fence repeatedly along its length while little attention was given to other sides of the pen. During this time the animal may have received one or more electric shocks in the case of Fence Designs 1 – 3, but in their confusion did not comprehend the source of the shock. In the case of Fence Design 2 the electric wire was at a particularly accessible height which may have increased the number of interactions with it at this time.

Foxes

Six occurrences of foxes breaching trial fences occurred. One chewed through the fence, four dug under it and one jumped over the lower Fence Design 6. No fox breached Fence Design 2. This design had an electric wire placed 400 mm above the ground and was approximately at the level of a fox's snout when standing. Foxes had more contacts with the electric wire at this height than any of the other fence designs that had electric wires placed higher up the fence. Foxes did not make contact with the base of Fence Design 2, and significantly fewer contacts were made below electric wires with Fence Design 2 than other designs. However, there were significantly more contacts above electric wires on Fence Design 2 than 3, indicating that foxes were capable of jumping or pushing past the lower wire in Fence Design 2.

No fox was recorded breaching Fence Designs 1-5 by passing over the overhang either by jumping directly onto it or by climbing past it. This suggests that regardless of the presence of electric wires foxes were not able to negotiate the overhang. This is supported by observations under field conditions, where the feral animal pressure is less than that in the experimental enclosure. At the Arid Recovery Project Site, monitoring of regular track transects has shown that the floppy-top fence without electric wires has successfully excluded foxes and cats from a 6000 ha area since December 2001 (Moseby and Read 2005).

Placement of an electric wire at the base of fences is not recommended for the exclusion of foxes as: a) this report indicates that it is not necessary; b) non-target animals can be harmed or killed by these wires (see Long and Robley 2004 for a review); and c) the additional cost of establishment and maintenance is not warranted. Predator fence trials in New Zealand have found that a fence with a well engineered barrier, such as an overhang, is more effective than a fence relying on electric wires as the barrier to pest animals (Day and MacGibbon 2002). Additionally, fenced reserves to house and protect native fauna currently in use and proving successful in New Zealand do not have an electric wire component (Karori Wildlife Sanctuary Trust Inc 1998).

After a reduction in height from the original 1.8 m fence to 1.2 m in Fence Design 6, one fox achieved a breach by jumping onto the overhang. The construction of the fence's overhang was not as floppy as had been intended. The type of steel used for the overhang supports was relatively strong (20 mm flat steel) and provided a somewhat rigid surface upon which the animal was able to gain some purchase. While the animal was able to reach the top of the fence in a single jump it was not clear whether a more floppy overhang would have prevented this animal from gaining a purchase. Moseby and Read (2005) found that a reduction in fence

height from 1.8 m to 1.1 m did not reduce the effectiveness of the fence during pen trials. However, the pen in which foxes were tested was slightly larger than our own and other sides of the enclosure had not been covered using shade cloth. Therefore, the animals may not have been focussed so strongly towards their experimental fence. Also the subject's time in the pen was much less, sometimes less than twenty four hours, and not always including a night.

Digging under the fence was the most common method of breach with four of the six breaches occurring this way. The apron of the fence had been covered by several inches of soil and pegged down using sand pegs. In the normal application of a predator exclusion fence, the apron is often set more securely to the ground by placing heavy material on it such as rocks or large rubber matting (Moseby and Read 2005), largely to prevent wind erosion excavating the sand on the apron or left for grass to grow through the netting (Long and Robley 2004).

The contrived conditions created by the trial enclosure caused intensified interaction with a short section of fence. Best practice for the apron of a predator exclusion fence has been investigated (Karori Wildlife Sanctuary Trust Inc. 1998, Day and MacGibbon 2002). These studies conclude that horizontally buried aprons are more effective than those that are buried vertically as animals that encounter the latter situation sometimes continue to burrow down until they are able to pass under the apron. Apron sizes of 300 mm to 600 mm are frequently used, however, we are not aware of any research that determines the optimal apron size for Australian species, or ascertains if increasing the apron size increases its effectiveness where burrowing animals are particularly problematic. Research in New Zealand on brown rats (*Rattus norvegicus*), black rats (*Rattus rattus*), and stoats (*Mustela erminea*), all prolific diggers, showed that most diggings over a shallowly-buried 400 mm apron, occurred within 200 mm of the fence base, with only 11% of diggings occurring 200 to 400 mm from the fence, and 1.5% occurring further than 400 mm from the fence (Karori Wildlife Sanctuary Trust Inc. 1998). Other research in New Zealand using house mice (Mus musculus), black rats, brown rats, stoats, ferrets (*Mustela furo*), rabbits and common brush tail possums has resulted in similar findings (Day and MacGibbon 2002).

The failure of the base of Fence Design 1, where the fox chewed a hole in the mesh, may be partly attributed to the quality of materials. In order to remain within this trial's budget, and because the trial fence was only required to last for the duration of the trial, inexpensive fencing mesh was used (30 mm mesh x 0.9 mm gauge). For future trials the use of higher quality mesh is recommended. In a normal situation predator exclusion fences are subjected to many environmental extremes and required to last for as long as possible, therefore, more durable materials are used.

Feral Cats

Feral cats were capable of passing electric wires on all fences to reach the overhang, but on no occasion did any climb over the overhang. On several occasions, one feral cat was able to jump quite effortlessly to reach the overhang top of Fence Design 6. This feral cat had escaped prior to the experiment commencing, when teething problems with pens, including escape proofing, was being eliminated. Therefore, it had been exposed to an earlier design of the fence and so was not a complete novice to the trial conditions. This feral cat was recaptured by contractors after the completion of the trial and was being held in a pen temporarily. Cameras were still recording at this time. Acknowledgement of its success in frequently and easily jumping to the top of this lower fence design is worthy of inclusion in this report.

Feral cats made contact with the electric wire on Fence Design 2 more frequently than those on Fence Designs 3 and 4 but not Fence Design 1. This suggests that once shocked cats were less likely to climb, jump or attempt to jump above the electric wires. It also indicates that feral cats may not have learned to avoid the electric wire set low on Fence Design 2.

Alternatively, as described above, the electric wire on Fence Design 2 was at the animals' height as it ran toward and repeatedly tried to get through the fence on its initial introduction to the pen. This may have increased the frequency of an animal's interaction with the electric wire while it may not have realised the source of the shock in this period of confusion. The electric wire in Fence Design 2 may have acted as a barrier preventing interaction with the fence base.

Our prior assumption was that the placement of electric wires and prevention of access to the overhang were critical factors in successfully excluding feral cats and foxes from areas of high conservation value. However, under extreme pressure neither foxes nor feral cats were able to breach Fence Designs 1 - 5 by climbing over the floppy top, but were capable of passing the electric wires regardless of their location below the overhang.

Feral cats are less likely to breach fences than foxes. Feral cats spent very little time at the base of the fence trying to dig or chew their way through the fence. While for foxes this was their main activity, and most of the breaches that did occur were as a result of digging under or chewing holes through the fence.

Therefore, this report recommends that:

- Exclusion fences for feral cats and foxes do not require electric wires, providing the fence follows the remaining design aspects in Long and Robley (2004) for the feral cat, fox and rabbit exclusion fence.

- Quality horizontal mesh apron of at least 600 mm be used at the base of fences and that aprons are securely fixed, either mechanically (buried, weighed down) or by low level native vegetation (grasses) to prevent foxes (and other species) digging or chewing holes in the fence.

Feral cats were never observed chewing or digging at the base of the fences. This indicates that if only feral cats were present (as in some offshore islands) it would be possible to construct fences of a less gauge mesh, which would reduce costs. However, longevity of fences is affected by environmental conditions. Consideration should be given to material that does not corrode such as plastic mesh.

Recommendations

- Low (1.2 m) fences with overhang (Fence Design 6) not be used in areas where fox and feral cat control can not be regularly undertaken outside the enclosure.

- Durable quality fencing mesh be used in order to ensure longevity of exclusion fences against environmental pressures and to reduce the risk of foxes chewing through it.

Gaps in our Knowledge

- To determine the optimum apron size required to prevent pest and native species digging beneath fences. While it may be assumed that larger aprons are more effective, the digging behaviour of the species of interest may indicate that aprons that extend beyond a certain distance from the fence represent minimal gains in effectiveness.

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7. Appendices

Appendix 1. Details of captured feral cats used in the predator exclusion fence experiment.

Fence Design	Cat	Gender	Weight	Pen	Date in Pen	Breach	Capture type
1	1	m	4	1	23/11/2005	-	Cage trap
1	2	m	3.45	2	24/11/2005	-	Cage trap
1	3	f	3.3	3	1/12/2005	-	Cage trap
2	4	f	2	1	31/01/2006	-	Cage trap
2	5	m	3.8	2	31/01/2006	-	Cage trap
2	6	f	2.5	3	8/02/2006	-	Cage trap
3	7	m	3.6	1	1/03/2006	-	Cage trap
3	8	f	3.2	1	4/04/2006	-	Cage trap
3	9	f	2	2	4/04/2006	-	Cage trap
4	10	m	2.9	1	3/05/2006	-	Cage trap
4	11	m	3.8	1	15/05/2006	-	Cage trap
4	12	m	3.05	1	1/06/2006	-	Cage trap
5	13	m	2.7	2	2/06/2006	-	Cage trap
5	14	m	5.2	1	26/06/2006	-	Cage trap
5	15	m	4	2	26/06/2006	-	Cage trap
6	16	f	2.4	4	27/06/2006	-	Cage trap
6	17	m	3.3	4	3/07/2006	-	Cage trap
6	18	m	3.7	5	4/07/2006	-	Cage trap

Appendix 2. Details of captured foxes used in the predator exclusion fence experiment.

Fence Design	Fox	Gender	Weight	Pen	Date in Pen	Breach	Capture Type
1	1	m	4.4	4	16/01/2006	-	Leg-hold
1	2	f	3.6	6	18/01/2006	-	Leg-hold
1	3	f	5.6	5	8/02/2006	Chew through	Leg-hold
2	4	f	3.9	4	13/02/2006	-	Leg-hold
2	5	m	4	6	13/02/2006	-	Leg-hold
2	6	f	4	5	15/02/2006	-	Leg-hold
3	7	m	4.9	1	17/02/2006	-	Leg-hold
3	8	m	5	4	20/02/2006	-	Cage trap
3	9	m	6.2	6	24/02/2003	Dig under	Leg-hold
4	10	f	3.7	4	2/03/2006	-	Leg-hold
4	11	m	5.9	5	27/03/2006	-	Cage trap
4	12	f	4.9	4	4/04/2006	Dig under	Cage trap
5	13	m	5.6	5	5/05/2006	-	Leg-hold
5	14	m	7.9	5	26/04/2006	-	Cage trap
5	15	m	5.3	4	10/05/2006	Dig under	Cage trap
6	16	m	5.6	5	15/06/2006	Dig under	Cage trap
6	17	m	6.5	4	15/06/2006	-	Cage trap
6	18	m	6.5	4	21/06/2006	Jump over	Cage trap

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