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The efficacy of feral cat, fox and rabbit exclusion fence designs for threatened species protection

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ABSTRACT

Pen and field trials were used to test the effectiveness and cost-efficiency of wire netting and electric fence designs as barriers to feral cats, foxes and rabbits in northern South Australia. A 180 cm high wire netting fence with foot apron and a curved 'floppy' overhang effectively contained most rabbits, feral cats and foxes during pen trials and proved effective with intensively monitored paddock-scale exclosures. A reduced height fence of 115 cm did not reduce effectiveness of the fence during fence trials but paddock-scale trials are yet to be completed. Conventional 40 mm diameter hexagonal "rabbit netting" was not an effective barrier against young independent rabbits and it is recommended that 30 mm hexagonal netting should be used. A 60 cm wide external netting overhang, curved in an arc and supported by lengths of heavy gauge wire, effectively precluded more feral cats and foxes than a 30 cm wide overhang angled upwards. The 30 cm foot apron was augmented in erosion-prone dunes and watercourses by the addition of wider netting or rubber matting to prevent incursions. Posts, and particularly corners, were targeted by feral cats and foxes and the efficacy of the fence was improved by using steel, rather than timber posts. Electric wires offset from the netting at heights of 120 and 150 cm provided a shock to animals exploring the base of the overhang and further improved the fence efficacy. PVC conduit rollers on the top wire were not effective.

Material costs ranged from AUD $8814 per km for the 115 cm high fence to AUD $12,432 per km for the 180 cm high fence with two electric wires. The non-standard 30 mm hexagonal netting accounted for 57% of the material costs of the low netting fence. Increased demand for this netting may reduce the expense of rabbit exclusion. Expenses could also be reduced where existing stock fences are modified by the addition of netting.

1. Introduction

Exclusion fencing is used extensively in Australia and elsewhere to protect biodiversity, agriculture and stock from pest animals (McKillop et al., 1988; McKillop and Sibly, 1988; Long and Robley, 2004). The feral cat (*Felis catus*), red fox (*Vulpes vulpes*) and European rabbit (*Oryctolagus cuniculus*) are three species commonly targeted for exclusion by land managers and conservation agencies. All three species were introduced to Australia by Europeans and have successfully colonised much of mainland Australia (Environment Australia, 1999a,b,c). Exclusion fencing in Australia has a long history. The 'dog fence' is the oldest exclusion fence in Australia and was originally constructed in an attempt to halt the spread of rabbits

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in the 1860s and 1870s (McKnight, 1969) before being modified to exclude dingoes (*Canis lupus dingo*) from southern sheep grazing areas (Fleming et al., 2001). More recently, attempts to protect threatened plants and wildlife from feral animals has led to an increase in the use of exclusion fencing for biodiversity conservation (Long and Robley, 2004). Many government and private conservation organisations now rely on exclusion fencing on mainland Australia for successful in situ protection or re-introduction of threatened species including the eastern barred bandicoot (*Perameles gunnii*) (Arnold et al., 1990), mala (*Lagorchestes hirsutus*) (Gibson et al., 1994), burrowing bettong (*Bettongia lesueur*) (Short and Turner, 2000), greater bilby (*Macrotis lagotis*) (Moseby and O'Donnell, 2003) and western barred bandicoot (*Perameles bougainville*) (Richards and Short, 2003).

Most Australian exclusion fences have not been subjected to experimental trials (Coman and McCutchan, 1994; Long and Robley, 2004), although electric and barrier fences to exclude rabbits have been extensively trialed in the United Kingdom (McKillop and Wilson, 1987; McKillop et al., 1992, 1993). Barrier exclusion fences are extremely expensive to construct. Material costs alone can reach AUD $130,000 per km for fences that also exclude mice (Karori Reservoir Wildlife Sanctuary Steering Committee, 1994) although figures of between AUD $6500 and AUD $11,000 are more typical for feral cat and fox exclusion fences (Long and Robley, 2004). Testing of exclusion fences will help to maximise both effectiveness and cost-efficiency, which will improve the viability and size of fenced exclosures for biodiversity conservation.

Arid Recovery is a conservation project in arid South Australia (30°29′S, 136°53E, Fig. 1) focusing on a fenced 60 km^2 reserve from which rabbits, feral cats and foxes have been removed. Feral cat and fox densities around the reserve are both typically at least 0.6–0.9 per km^2 (Read and Bowen, 2001) whilst regional rabbit densities can exceed 200 per km^2 (Bowen and Read, 1998). Experimental pen trials were conducted at Arid Recovery to test the efficacy and cost-efficiency of exclusion fences for rabbits, feral cats and foxes. Three of the designs tested during the trials were used to construct adjacent large scale exclosures. Results from up to six

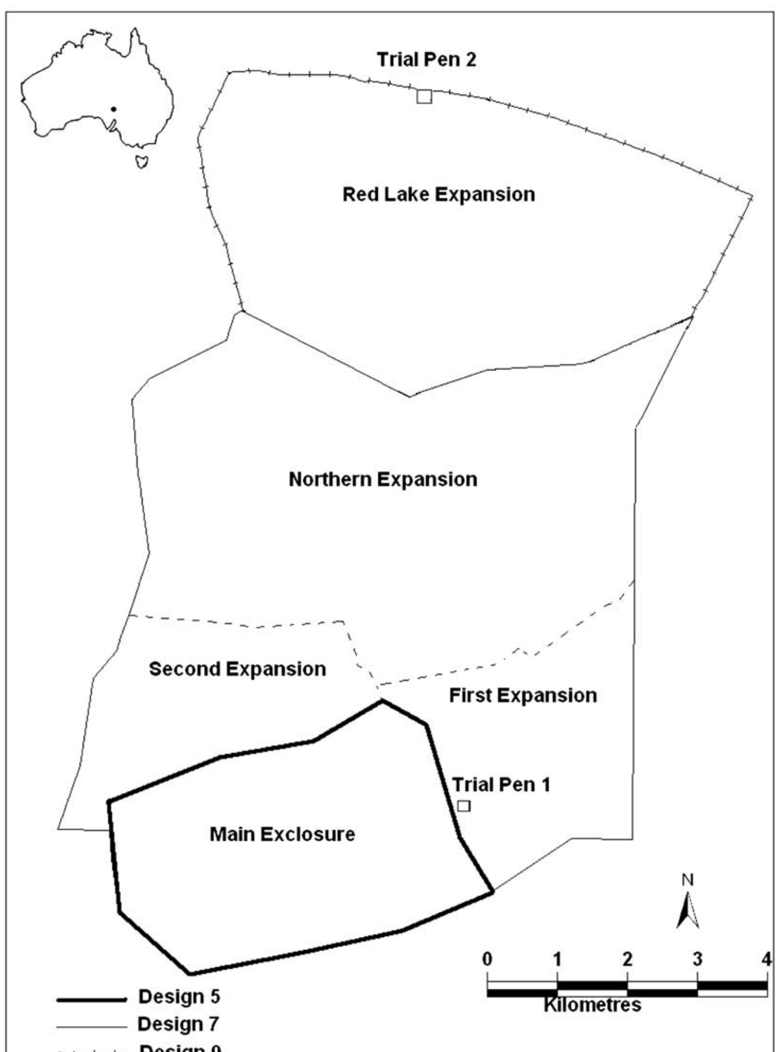

Fig. 1 – Map of the Arid Recovery Reserve showing the location of the reserve, the two trial pens and the in situ fence designs.

years of in situ monitoring are compared with the pen trial results.

2. Methods

2.1. *Trial 1 – cats*

Trial 1 was conducted between March 1998 and August 1999. A 20 m × 20 m pen was constructed in chenopod (saltbush (*Atriplex* spp.)/bluebush (*Maireana* spp.)) low open shrubland (Fig. 1). The pen was based on a fence design used on Wardang Island, South Australia to exclude feral cats from areas containing rabbits used in Rabbit Calicivirus Disease (RCD) field trials (Ray Wallace pers. com.). An L-shaped pen design (Fig. 2(a)) ensured that one external corner, the corner usually targeted by animals attempting to breach exclosures, was included within the pen. Chromated copper arsenate-treated pine (Permapine) posts were installed every 10 m and at every corner, and extended from ground level to a height of 180 cm. Seven selvage wires were strained at 30 cm intervals. "Rabbit proof" wire netting (40 mm diameter × 1.4 gauge × 90 cm wide; Waratah-BHP wire products, Australia) was clipped to the selvage wires between ground level and a height of 90 cm using ring fasteners. A foot apron of 40 mm diameter × 1.4 mm gauge × 30 cm wide wire netting (Waratah – BHP products, Australia) was clipped to the bottom selvage wire, extended out along the ground for 30 cm inside the pen and buried. Wire netting of 50 mm diameter × 1.4 mm gauge × 120 cm height (Waratah – BHP products, Australia) was clipped to the top section of the fence from a height of 90 cm with the uppermost 30 cm extending above the top selvage wire. Fencing wire cut to lengths of 90 cm was vertically woven into the uppermost 60 cm of the netting and bent slightly to form a 30 cm, 45° non-rigid overhang into the pen. Food, water and shelter in the form of a pile of dense vegetation were provided in the pen.

Feral cats were captured in baited wire cage traps in a variety of natural and artificial habitats within 20 km of the trial pen. Traps were opened in the late afternoon and checked early the next morning. Where possible, trapped feral cats were weighed and sexed before being released into the pen. Thirty three feral cats (12 male, 15 female, 6 unknown) were tested during trial 1. The behaviour of each feral cat upon release was recorded by an observer using a hand held video recorder. Each feral cat was observed until it either escaped from the pen or retired to the shelter for more than 15 min. Escaping feral cats left footprints in the 2 m of swept sand surrounding the pen, allowing the location of escape to be identified. Feral cats that had not escaped overnight were killed using a single shot to the head at point blank range with a 0.22 calibre rifle the following morning.

As feral cats escaped, the pen fence design was incrementally modified (Table 1). Firstly, 1.5–1.8 m lengths of corrugated roofing iron were nailed to the posts to prevent feral cats securing purchase on the posts (Design 2). Secondly, an extra 30 cm of netting was added to the 45° corner overhangs (Design 3), thirdly electric wires were added (Design 4) and finally the width of the 45° netting overhang over the entire pen was extended by 30 cm to a total of 60 cm and bent over to form an arc (Designs 5–7). Thicker lengths of 4 mm gauge high tensile spring steel were installed to support the wider 'floppy' overhang. Electric wires (7 kV) were powered using an energiser (Gallager®) and 12 V car battery and spaced at varying distances from the wire netting using plastic ring and porcelain bull-nose insulators.

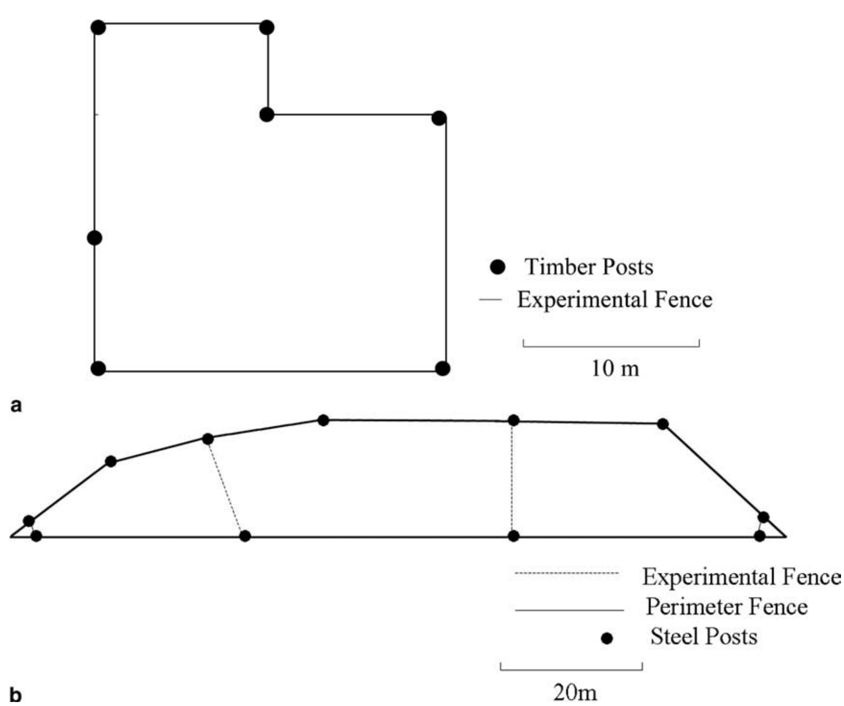

Fig. 2 – Aerial view of trial pen 1 (a) and 2 (b) showing the location of posts and corners.

Table 1 – Fence designs tested during trial 1 including specifications, number of cats tested and successful escapes

Fence design stage	Extra specifications	No. cats tested	No. cats escaped	Method of escape
1	Original design with 30 cm 'floppy' overhang and wooden posts	2	2	Climbed up wooden posts
2	Design 1 plus roofing iron on posts	2	1	Climbed over 'floppy' overhang at corners
3	Design 2 plus extra netting on corners only	5	1	Climbed over 'floppy' overhang between posts
4	Design 3 plus 2 electric wires (ht 30 and 135 cm)	4	2	Climbed over 'floppy' overhang regardless of shock
5	Design 4 plus 'floppy' overhang extended to 60 cm, no electric wires	9	2	1 – grabbed edge of 'floppy' overhang 2 – sat on iron and pulled down 'floppy' overhang
6	Design 5 plus extra 'floppy' overhang, 2 electric wires (ht 30, 170 cm)	5	0	
7	Design 6 plus extra 'floppy' overhang, 2 electric wires (ht 130, 160 cm)	5	0	
	Total	32	8	

2.2. *Trial 2 – feral cats and foxes*

Trial two was conducted between February 2004 and December 2004 to the north of the Arid Recovery Reserve (Fig. 1). Both feral cats and foxes were trialed within a 119 m long × 25 m wide rectangular pen located within chenopod shrubland. The substrate was stony gibber-strewn clay with a sandy drainage line running through the middle of the pen. The perimeter of the pen was constructed using Design 5 (Table 1) to contain animals within the pen. Two internal fences were used to test different fence designs (Fig. 2(b)). Pens contained water, food and shelter in the form of piles of thick vegetation. A densely vegetated drainage line in the central section encouraged feral cats and foxes to breach the experimental fences to reach this area of greater cover.

Feral cats and foxes were captured using soft rubber leg hold traps (Victor Soft Catch®) set around the reserve fence (Moseby et al., 2004). Only un-injured, vigorous animals were tested, others were killed immediately using a 0.22 calibre rifle. Feral cats and foxes deemed suitable for testing were placed in cage traps after capture, transported to the pen by car and released. Released animals were observed until they escaped or retreated to shelter. Tracks could not be distinguished due to the hard surface substrate, instead signs such as the location of fur caught on netting and dents and rips in netting were used to indicate night-time escape points. Animals that remained in the pen the following morning were killed as per trial 1.

Two lower fence designs were tested during trial 2. These designs were intended as a simple modification of stock fences, requiring low maintenance and allowing large native animals such as kangaroos and emus to readily jump over. The first design (Design 8) used 30 mm diameter × 1.4 mm gauge × 120 cm width netting placed as a 90 cm vertical barrier and 30 cm horizontal foot apron. The netting was reinforced with a barbed wire 7.5 cm above the top of the netting. Fifteen centimetres above the barbed wire, at a height of 112.5 cm, 10 cm lengths of PVC conduit were strung on a plain wire. These lengths of conduit rotated freely in an attempt to prevent feral cats and foxes from securing purchase on the uppermost wire if they attempted to climb or jump onto the top of the fence.

The second design (Design 9) retained the successful 60 cm curved 'floppy' overhang of Design 5, but the overall height of the fence was reduced to 1.15 m (Fig. 3). Shorter 165 cm steel droppers were spaced 10m apart and five selvage wires were strained at heights of 0, 30, 65, 90 and 115 cm. The bottom netting was 30 mm diameter × 1.4 mm gauge × 120 cm width (BHP – Waratah Wire Products). Two cheaper nettings were also trialed on sections of this pen. A finer 0.9 mm gauge netting, also manufactured by BHP – Waratah Wire Products and 1.2 mm gauge × 120 cm netting (imported from Asia by Sunrise Marketing), labelled as 30 mm diameter but was actually highly variable and averaged 37 mm diameter. The 120 cm width bottom netting consisted of a 30 cm horizontal foot

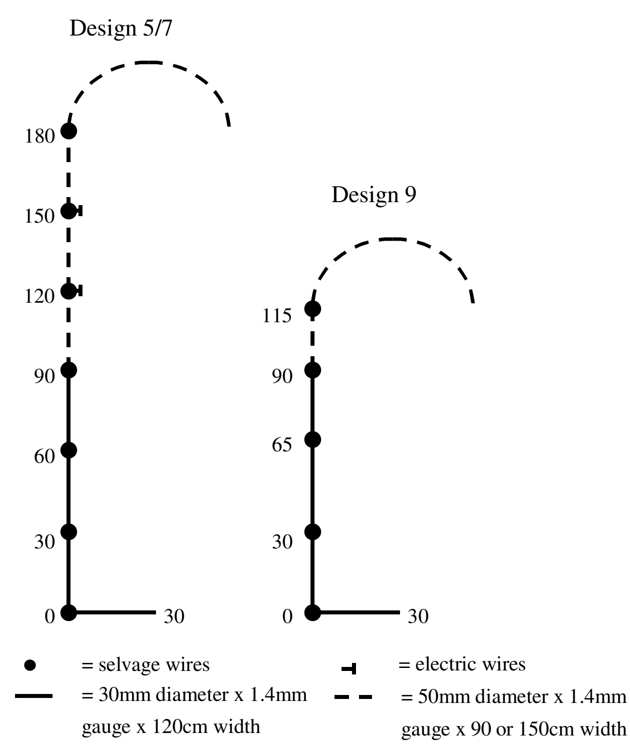

Fig. 3 – Side view of fence Designs 5, 7 and 9 including location of selvage wires, electric wires and 'floppy' overhang.

netting and 90 cm vertical panel. Top netting of 50 mm diameter × 1.4 mm gauge × 90 cm width, was used and included a 60 cm 'floppy' overhang and 30 cm of vertical netting (Fig. 3).

The weights of feral cats and foxes tested during trials 1 and 2 were compared with weights of 1173 feral cats and 173 foxes shot and trapped in the Roxby Downs region between January 1998 and January 2004 in order to establish whether tested animals were representative of the size of feral cats and foxes in the local population.

2.3. *Rabbits*

Two juvenile rabbits that had survived independently for several days inside the original exclosure were captured by hand and placed inside trial pen 1. These rabbits were video-taped as they attempted to breach the fence. The efficacy of 30, 37 and 40 mm diameter netting at excluding small rabbits was also tested by attempting to pull dead juvenile rabbits of different sizes through each netting type.

2.4. *In situ testing*

The 180 cm electrified 'floppy' overhang fence design (Design 7, Table 1) was used in the construction of the 14 km long fence of the main exclosure of the reserve in 1997 (Fig. 1). Minor alterations were made including positioning electric wires adjacent to selvage wires at 120 and 150 cm for greater support. The voltage of electric wires was maintained at between 5 and 7 kV. Also, smaller gauge 30 mm netting was eventually placed over the 40 mm netting on the lower 90 cm of the fence to prevent incursions by subadult rabbits. The last feral cat and fox were removed from the 14 km^2 main exclosure in February 1999 and the last rabbit in early 1999. Rabbit, feral cat and fox incursions to the reserve were monitored between July 1999 and January 2005 through weekly vehicle-based spoor searches along sandy tracks around the inside of the reserve fence and quarterly foot-based traverses of two 5 km longitudinal dunes. Predator incursions were also monitored through radio-tracking the fate of re-introduced mammals from 1999 to 2004.

A non-electrified version of the 180 cm 'floppy' overhang fence design (Design 5, Table 1) was used in the construction of 28 km of perimeter fence in the 1st, 2nd and northern expansion areas of the reserve (Fig. 1). Alterations included the use of steel posts (recycled bore casing), spacing star droppers every 6 m and using 120 cm width netting on the lower part of the fence to allow a continuous 30 cm horizontal foot apron and 90 cm vertical panel. A netting diameter of 30 mm rather than 40 mm wide netting was used after trials proved that subadult rabbits could penetrate the 40 mm netting. Enclosing a combined area of 46 km^2, the external expansion fence was completed in December 2000 with all rabbits, feral cats and foxes removed by December 2001. Monitoring for rabbit, feral cat and fox incursions included weekly vehicle checks as outlined previously in addition to quarterly foot-based transects.

A slightly modified Design 9 (trial 2), with steel dropper spacing reduced to 7 m to minimise sagging of the 'floppy' overhang, was used in the construction of the Red Lake Expansion fence in January 2005 (Fig. 1). This design was further modified by the addition of an internal foot apron to prevent bilbies and other re-introduced animals from digging out from the reserve.

3. Results

3.1. *Trial 1 – feral cats*

The average weight of feral cats used in trial 1 was 2.9 kg (SE = 0.26, range 1–6 kg), comparable to the average weight of feral cats sampled in the region (average = 3.3 kg, SE = 0.40, range 0.19–7.3 kg). Eight feral cats (24%), including five females, two males and one of unknown sex, escaped from the pen during the trial. Escaped feral cats ranged in weight from 1.3 to 4.9 kg.

One feral cat escaped by forcibly pushing at the netting with its head and expanding a small gap in the join between two sections of netting. The remaining feral cats escaped from the pen by climbing or using a combination of climbing and jumping. Feral cats either began climbing the netting from ground level or jumped onto the fence at a height of between 1 and 1.7 m and then climbed. No feral cats escaped from the pen by digging, chewing through or jumping on top of the fence (Table 2).

The original fence design (Design 1) was ineffective as a barrier to feral cats (Table 1). The two adult feral cats tested (one male and one female) both escaped within 3 min by climbing up the wooden posts, pulling down the 30 cm

Table 2 – Methods of escape attempted by feral cats and foxes

Method	Trial 1	Trial 2	
	No. cats attempted	No. cats attempted	No. foxes attempted
Biting or pulling at netting with paws	3	2	20
Digging	5	2	13
Bashing or pushing at netting with head	5	11	25
Total climbing	22	18	19
(Climbing at corner posts)	16	13	8
(Climbing between posts)	13	14	11

Total of 33 feral cats trialed during trial 1, 27 feral cats and 29 foxes during trial 2 but some animals attempted multiple methods whilst others tried none.

'floppy' overhang with their front feet and jumping out of the pen. Sheets of roofing iron nailed onto the wooden posts to a height of 180 cm (Design 2) prevented feral cats from climbing the posts but instead allowed them to jump to the top of the iron. Increasing the width of the overhang to 60 cm at the corners prevented cats from pulling down the overhang at the corners (Design 3) but one 2 kg female feral cat still escaped by pulling down the overhang between the posts where it had not been extended. Even the addition of two electric wires (Design 4) did not prevent feral cats from escaping between the posts using this method; most feral cats had climbed or jumped past the electric wires and pulled down the 30 cm overhang with their front feet so quickly that they either did not receive a shock or they were already in motion over the fence when the shock registered.

When the width of the 'floppy' overhang was increased to 60 cm and shaped to form a complete arc (Design 5), seven out of nine feral cats were prevented from escaping (Table 1). Feral cats would climb or jump to the base of the overhang and try unsuccessfully to force their way through the netting. The addition of electric wires (Designs 6 and 7) prevented the last 10 feral cats ranging in weight from 1.1 to 5 kg from escaping. Electric wires placed at heights of 30 and 170 cm were just as effective at containing feral cats as wires placed at 130 and 160 cm but most cats jumped over the wire placed at 30 cm. Only one feral cat touched the 30 cm electric wire with its nose, receiving a strong electric shock and causing it to retreat immediately to the shelter. Electric wires placed at a height of 160 or 170 cm and less than 8 cm out from the body of the fence made most frequent contact with feral cats, as cats placed their feet on the wire whilst trying to push at the base of the 'floppy' overhang. Lower electric wires or those placed at a greater distance from the body of the fence allowed feral cats to either jump over them or push between the wire and the fence, their thick fur partially insulating them from the electric shock.

In summary, only two out of 19 feral cats escaped over the trial fence when the 60 cm curved 'floppy' overhang (Designs 5–7) was trialed compared with 6 out of 13 feral cats when the short 30 cm 45° overhang (Designs 1–4) was trialed (Table 1). The two feral cats that escaped from fence Design 5 by climbing over the 60 cm overhang were a lactating 2.5 kg female and an adult female of unknown weight.

3.2. *Trial 1 – in situ testing*

Two of the fence designs tested during trial 1 (Designs 5 and 7) were used in the construction of the Arid Recovery Reserve. No feral cats or foxes were known to have breached the main exclosure (Design 7) or expansion fences (Design 5) as of July 2005, during monitoring periods in excess of 6 years and 3.5 years, respectively. No tracks or sightings of feral cats or foxes have been made inside the reserve and all predation events on re-introduced mammals have been attributed to aerial predators or goannas. A total of 111 feral cats and 130 foxes were captured in leghold traps set immediately outside the reserve fence between 1999 and 2004 suggesting they are frequently encountering the fence.

At least 12 subadult rabbits breached the 40 mm netting and gained access to the main exclosure. Fence pen trials suggested that subadult rabbits accessed the exclosure by squeezing through the 40 mm holes in the netting. After the fence was reinforced with 30 mm diameter netting, which was also used in subsequent expansions, six rabbits breached the fence in five years and close inspection revealed that each entry to the reserve was through holes dug in soft sand under the foot apron. Most of these holes were dug from the inside of the reserve by escaping bilbies when no internal foot-netting was present.

3.3. *Trial 2 – feral cats and foxes*

The average weight of feral cats tested in trial 2 was 2.6 kg (SE = 0.25, range = 0.9–4.65 kg) slightly lower than the average regional weight of 3.3 kg. The average weight of foxes tested during trial 2 was 3.7 kg (SE = 0.12, range = 2.45–5.1 kg) compared with the average regional weight of 4.3 kg (SE = 0.08, range = 1.9–6.8 kg).

The roller design (Design 8) was tested on two male foxes and both escaped within 2 min. One fox jumped and pushed itself through the fence between the barbed wire and the top of the netting, a gap of only 7.5 cm. The second fox climbed over the rollers at the corner of the pen where the roller fence met the external perimeter fence.

Twenty-seven foxes and 27 feral cats were tested using Design 9, the low 'floppy' overhang design. Climbing was the most common method of attempted escape for feral cats whilst bashing and biting the netting was most common for foxes (Table 2). Although feral cats and foxes showed no apparent preference to climb at posts in the Design 9 fence (Table 2), individuals that climbed at posts tended to spend considerably longer attempting to breach the overhang than those that climbed between the posts. No feral cats or foxes were observed to successfully jump or climb over the experimental fence during the trial. One 3.2 kg male feral cat escaped through the experimental fence via a hole chewed by a fox through the 0.9 mm gauge bottom netting. Two other male feral cats (4.4 and 4.7 kg) breached the the experimental fence by climbing the tall perimeter fence at the junction of the low fence (Fig. 2(b)). Additional netting was placed at this junction in an attempt to prevent this escape method but the remaining two feral cats that escaped from the experimental pen overnight (2.2 kg male and a 0.9 kg female) may have also taken advantage of this weak point in the pen design. No foxes were known to breach the experimental fence during testing of Design 9 (see Table 3).

Two feral cats and one fox escaped out of the perimeter fence before it was complete; the female fox pushed between an unclipped join in the netting and the two adult feral cats of unknown weight climbed over the perimeter fence before the 'floppy' overhang wires were inserted. One male fox also chewed a hole in the base of the perimeter fence where the 0.9 mm gauge netting was used and one 4.2 kg male fox escaped overnight through the perimeter fence using an undetermined escape method. Although the 1.2 mm gauge netting was seriously dented by the foxes, no holes were chewed through this netting during the trials.

Table 3 – Feral cats and foxes trialed using Design 9

Design 9	Reason	Cats	Foxes
Number trialed		27	27
No. escaped – experimental fence	Through hole chewed in netting	1	
	At ineffective join between experimental and perimeter fence	2	
	Unknown	2	
No. escaped – perimeter fence	When perimeter fence incomplete	2	1
	Through hole chewed in netting		1
	Unknown		1
Total escaped		7	3

All but two of the 10 escapes were through inappropriate joins or through fine gauge netting. Only the two feral cats that escaped overnight can be regarded as having potentially breached the low 'floppy' overhang design (Design 9).

3.4. *Rabbits*

Two live juvenile rabbits (180 g and one of unknown weight) escaped from trial pen 1 within 30 s of release by squeezing through the 40 mm holes in the rabbit-proof netting. The 180 g rabbit repeatedly jumped into and out of the trial pen through the 40 mm netting. Inspection of stomach contents revealed grass and herb material, suggesting that these rabbits were independent. Further trials involving 21 dead juvenile rabbits ranging in weight from 148 to 918 g indicated that rabbits weighing up to 495 g could be pulled through the 40 mm netting. The 30 mm netting prevented all but one juvenile rabbit from being pulled through the netting.

3.5. *Fencing costs*

As of January 2005, fencing material costs per km were AUD $11,669.50 for Design 5, AUD $12,432 for Design 7 and AUD $8814.5 for Design 9. Material costs of Design 9 can be reduced to AUD $6939 per km by using 40 mm diameter netting instead of 30 mm netting if rabbit exclusion is not required. Steel post costs were minimised by using recycled bore casing. Extra costs such as clearing the fenceline, freight of materials, extra width foot aprons in erodable areas and labour for fence erection are not included.

4. Discussion

The 60 cm curved 'floppy' overhang was effective at both containing and excluding feral cats and foxes during this study. The overhang proved most effective when it was bent to form a rounded arc rather than a 45° straight overhang. Interestingly, foxes and feral cats did not breach fence designs that were low enough for many of them to jump over. Foxes and cats are known to be able to jump to a height of 180 cm (Long and Robley, 2004) and foxes have been observed leaping over farm fences 130 cm high (Coman and McCutchan, 1994) but neither species attempted to jump on top of, or over, the overhang, even at the lower height of 115 cm. Forster (1975) and Patterson (1977) found that 45 cm high electric fences also successfully excluded foxes. Animals in our study may have been discouraged from jumping because the overhang curved back behind the animal appearing to provide a continuous roof. Although cats are wary of climbing unstable surfaces (Day and MacGibbon, 2002), the 'floppy' nature of the curved overhang did not appear to contribute significantly to its success as few animals actually attempted to scale it. A similar curved fence 'cap' trialed in New Zealand was made from rigid steel and also proved successful at excluding cats (Karori Wildlife Sanctuary Trust Inc., 1998). However, a 'floppy' netting overhang is cheaper and easier to install than a rigid structure.

Animals may learn how to breach fences over time or by watching conspecifics (Bird, 1994; Day and MacGibbon, 2002) and thus the importance of in situ testing cannot be overstated. Pressure on the fence may also change according to local conditions and food availability (Long and Robley, 2004). Our success in excluding all feral cats and foxes from the reserve over a 3.5 year period suggests that the 180 cm high 'floppy' overhang design without electric wires (Design 5) is effective in arid Australia.

Corners and posts were typically targeted by feral cats and foxes as escape points during our trials and by other excluded animals in trials elsewhere (Thompson, 1997; Day and MacGibbon, 2002). Steel posts proved to be more effective at preventing escapes than wooden posts that provided greater purchase for cats. Better supported netting at posts and corners facilitated easier climbing. Therefore, corners need special consideration during fence planning and construction. It is recommended that steel posts are used and extra netting is added at corners to extend the width of the overhang. Wherever possible, internal corners on exclusion fences should be avoided.

Despite some feral cats breaching the non-electrified 'floppy' overhang fence (Design 5) during pen trials, this fence design proved just as successful as the electrified fence (Design 7) at excluding feral cats and foxes in the in situ field trials. The pressure on animals to breach the fence during pen trials would almost certainly be higher than in the field as animals are in an unfamiliar environment, scared of the observers and are primarily nocturnal animals being placed in the pen under diurnal conditions.

The size or sex of feral cats and foxes did not appear to influence their ability to escape during pen trials. Both small and large feral cats escaped, however no cats over 5 kg or foxes over 6 kg were tested during trial 2 despite 10% of regional feral cats and 5% of regional foxes falling into these size classes.

More than 90% of fences surveyed during a recent study of exclusion fences in Australia used electric wires to exclude feral cats and foxes (Long and Robley, 2004). Electric wires proved useful during pen trials but only when the 60 cm 'floppy' overhang forced feral cats to pause long enough to receive an electric shock. We concur with (McKillop and Sibly, 1988) that electric wires used without an effective physical barrier, or wires placed at the end of an overhang will be ineffective. Deer and coyotes (McKillop and Sibly, 1988) receiving shocks have also forced their way through electric fences that lack sufficient physical barriers. The electric wire placed at a height of 30 cm was too low as most animals jumped over it, low wires would also be more likely to trap vegetation and short out the fence and cause deaths of non-target species such as echidnas and reptiles. Wires placed more than 80 mm from the netting allowed feral cats to climb between the netting and the wire without receiving a shock. Coman and McCutchan (1994) also recommended spacing electric wires between 70 and 90 mm from the netting for feral cats and foxes.

One disadvantage of barrier exclusion fences is that they can restrict movement of large non-target species. During in situ testing of the taller 'floppy' overhang fence (Designs 5 and 7), no emus or kangaroos were known to jump over the fence. Although several kangaroos dented the netting immediately after erection, within 6 months the incidence of damage reduced considerably as animals adapted their movement patterns. Damage caused by fighting male kangaroos only occurred in areas where the fence is not electrified (Design 5), suggesting that electric wires may reduce fence damage by kangaroos and other large mammals. Visual repellants, which reduce bird collisions along deer fences in the United Kingdom (Baines and Andrew, 2003), may also reduce wildlife impacts and increase barrier fence longevity.

Horizontal foot aprons of 15 cm in the United Kingdom (McKillop and Wilson, 1987) and between 30 and 60 cm width in Australia (Long and Robley, 2004) are commonly used as part of exclusion fencing. Most (87.5%) feral animal diggings at the base of exclusion fences in New Zealand were found within 20 cm of the fence (Karori Wildlife Sanctuary Trust Inc., 1998) which supports our findings that a 30 cm apron is generally suitable. However, we found that the Arid Recovery Reserve's 30 cm foot apron needed to be reinforced with wider netting or heavy rubber matting in areas of soft erosive substrate such as dunes and watercourses to prevent rabbit incursions. McKillop et al. (1998) also recommended increasing the horizontal foot apron by up to 1 m in areas favoured by digging rabbits. Use of a continuous roll of netting for the horizontal foot apron and the lower vertical part of the fence eliminated the need for clipping on a separate foot apron and the risk of feral animals exploiting gaps in the netting join.

Juvenile rabbits weighing up to 500 g could be pulled through 40 mm diameter hexagonal netting and an independent rabbit weighing 180 g was able to squeeze through netting of this diameter. Although the response of live and dead rabbits may differ, these results together with the in situ trials indicate that juvenile rabbits can breach 40 mm diameter netting. Thirty millimetre diameter netting was needed to exclude juvenile rabbits, concurring with results of a study by McKillop et al. (1988) that found hexagonal netting size of 31 mm was needed to exclude all age classes of rabbits in the United Kingdom. However, the non-standard 30 mm hexagonal netting was very expensive, accounting for 57% of the material costs of Design 9, the low netting fence. Increased demand for this size netting may reduce the expense of rabbit exclusion. Expenses could also be reduced if existing stock fences were modified by the addition of netting and by using standard 40 mm netting where complete rabbit exclusion is not required.

Foxes chewed through 0.9 mm gauge netting, as they did with plastic netting (Poole and McKillop, 2002), suggesting that thicker guage netting is desirable for fox exclusion. Weak points in the netting, including small holes or gaps in joins, were used as escape points by feral cats and foxes, as has been reported for foxes by other researchers (Poole and McKillop, 2002; Long and Robley, 2004). Where netting joins do not overlap, we recommend meticulous clipping at a maximum spacing of 10 cm to prevent feral cats and foxes from forcing their way through.

The low fence with 'floppy' overhang (Design 9) was just as effective as the taller version (Design 7) during pen trials. This design is cheaper than the 180 cm tall overhang (Designs 5 and 7), easier to install and may allow existing stock fences to be rendered feral cat/fox proof by simply adding extra netting. The lower design should also allow kangaroos and emus to disperse through the area by jumping over the fence. However, the potential exists for kangaroos, emus and cattle to damage the lower 'floppy' overhang. Design 9 is currently being tested in situ and in the interim it is recommended that the tall fence with 'floppy' overhang (Designs 5 or 7) is used where complete exclusion of rabbits, feral cats and foxes is required. Finally, despite no breaches of in situ fences by feral cats and foxes to date, infrequent rabbit incursions were recorded highlighting the importance of regular perimeter fence checks and monitoring within fenced areas.

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