Predicting feral cat-reduction targets and costs on large islands using stochastic population models

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Declaration of interest

NIL

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Abstract

Feral cats are one of the most destructive invasive predators worldwide. Due to the high risk of pushing native species to extinction in Australia, density-reduction or eradication campaigns can greatly improve the persistence probability and recovery of native fauna. Kangaroo Island — Australia's third-largest island — was recently nominated as a complete cat-eradication site by the federal government. Because most population density-reduction campaigns are costly and not effective in the long term, mathematical models predicting optimal culling regimes can guide management plans, especially if they include estimates of costs under different policy decisions. We constructed a stochastic population model with cost estimates to test the relative effectiveness and cost-efficiency of two main culling scenarios for Kangaroo Island to 2030: (1) constant proportional annual cull, and (2) high initial culling followed by a constant proportional maintenance cull. We also examined the effectiveness of a trap-neuter-return scenario to compare with the culling outcomes. We found that an average culling proportion of ≥ 0.3 would reduce the population to ≤ 10% of the founding population, while a two-phase cull where an initial cull of ≥ 0.6 was followed by a maintenance cull of ≥ 0.45 would reduce the final population to 1% of its initial size by 2030. Costs estimates varied widely depending on capture techniques used, but a combination of *Felixer*™ cat-eradication units, conventional traps, and hunting was the most cost-effective (minimum costs estimated at AU$46.5 million–AU$51.6 million). Our model results provided direction for the efficient eradication of feral cats on Kangaroo Island and can be transferred to feral-cat management elsewhere.

Key words: Leslie matrix, matrix population model, feral cats, invasive species, eradication costs, Kangaroo Island, culling model

Introduction

Since domestication approximately 10,000 years ago, the common house cat *Felis catus* has spread throughout the globe and become established in most habitat types (including most islands) (Fitzgerald et al. 1991, Medina et al. 2011, Woinarski et al. 2015), due to both accidental and deliberate human facilitation. Because they are generalist predators, feral cats

are today one of the most destructive invasive mammal predators worldwide (Lowe et al. 2000), contributing many or most of the predation-induced terrestrial extinctions recorded globally (e.g., > 63 species, including 26% of bird, mammal and reptile extinctions) (Doherty et al. 2016).

Cats are also opportunistic hunters and scavengers that are able to adapt easily to fluctuating prey availability, switching between small invertebrates to mammals as large or larger than themselves (Barratt 1997, Bonnaud et al. 2011, Moseby et al. 2015). They can also easily adapt to arid and hostile environments, surviving with minimal access to fresh water (Fitzgerald and Turner 2000, Medina et al. 2008, Woinarski et al. 2015). This makes cats particularly destructive to island ecosystems, because they have the added vulnerability of naïve endemic prey (Close 2005, Bonnaud et al. 2011, Medina et al. 2014, Doherty et al. 2016). Australia in particular is itself a large island, disproportionately represented in mammal extinctions since European settlement (Abbott 2002, Abbott 2008) so that in combination with foxes (*Vulpes Vulpes*), cats have become one of the most prolific killers across the continent (Dickman 1996, Doherty et al. 2016).

The most effective method for reducing feral cat populations and their associated predation on native species is eradication wherever possible (Andersen et al. 2004, Schmidt et al. 2009), particularly in insular environments (Bester et al. 2002, Nogales et al. 2004). Alternative approaches (trap-neuter-release) exist (Gibson et al. 2002, Wallace and Levy 2006, Longcore et al. 2009, Miller et al. 2014), but the threat cats pose to native fauna makes such methods too slow and ineffective for an ecologically meaningful reductions in cat densities and predation rates (Longcore et al. 2009). While the approach might appeal to a section of society that does not agree with killing to control (Andersen et al. 2004), the high expense of implementing the approach at sufficiently broad scales, coupled with its low effectiveness (Longcore et al. 2009), mean that it is not widely used for feral cat management.

Most density-reduction campaigns based on direct killing have been typically implemented *ad hoc* because of the imminent threat cats posed to threatened species and the requirement to achieve outcomes quickly (Bester et al. 2002, Denny and Dickman 2010). As such, available funds or resources are often used up quickly without the benefit of long-term planning based on the projections of empirical density-reduction models (Denny and Dickman 2010). Unsurprisingly, this unplanned approach typically renders such eradication attempts unsuccessful (Bester et al. 2002). Campbell et al. (2011) found that inappropriate methods and poorly timed roll-out were attributed to most island eradication failures.

Custom-designed culling models that take habitat-specific population dynamics into account while planning the most efficient and cost-effective application of resources are therefore ideal precursors to any eradication program (Smith et al. 2005, McMahon et al. 2010).

Harvest (culling) models are effective because of their ability to consider real-time population dynamics and resources available to recommend feasible density-reduction plans. Many types of culling models exist depending on the choice of scenario to reduce the population, such as constant proportional culling (McCarthy et al. 2013), or a high initial proportional culling rate followed by a constant proportional maintenance thereafter (a two-phase reduction model) (Campbell et al. 2011). Such models are instrumental in guiding successful eradication by providing targets and parameters that lead to efficient population reduction of the target species (Smith et al. 2005). Eradication often employs a three-part strategy: (*i*) an initial high cull, (*ii*) a consistent maintenance cull to ensure continued population decline, and (*iii*) a final 'clean up' stage. In the clean-up stage, management typically needs to switch eradication tactics to remove the last remaining individuals in the population as they become more difficult to detect (Bester et al. 2002, Nogales et al. 2004).

Cat eradication is currently underway on part of Kangaroo Island, Australia's third-largest island. The initial planning stages of the eradication began in 2016, with a proposed completion date of 2030. The management strategy for eradication is as follows: 2016-2019: planning and trialling control techniques, 2019-2023: create a safe haven by eradicating cats from the Dudley Peninsula on the east of the island, and 2023-2030: eradication on the remainder of island, with full eradication complete by 2030 (Natural Resources 2013, Department of the Environment and Energy 2015). The program directors plan to use three main techniques for feral cat eradication: trapping, hunting, and *Felixers*™ (an automated toxin-delivery system that uses rangefinder sensors to distinguish target cats and foxes from non-target species and spray targets with a measured dose of toxic gel; thylation.com). Although poison baiting (using 1080 or PAPP) has been proposed, the approach is not currently being considered for Kangaroo Island due to potential risk to domestic animals and native animal species.

Our aim was to design an ideal set of culling conditions that will most efficiently reduce feral cat densities on Kangaroo Island following the timeline established above. More specifically, we (1) constructed a culling model that can be applied to guide cat eradication on Kangaroo island, (2) identified the relative costs of employing different combinations of the methods available, and (3) used the culling model to identify a regime that will most effectively reduce the feral cat population by the 2030 deadline. We hypothesise that a two-

phase eradication program, with a high initial proportional reduction and steady maintenance culling thereafter, will reach the target population density by 2030 more efficiently than a constant annual culling rate. The two-phase model will likely be the most effective in reducing feral cat densities because high initial effort tends to be the cheapest and most effective means of achieving high rates of reduction (Bester et al. 2002, Nogales et al. 2004, Robertson 2008, Denny and Dickman 2010), but maintenance culling is required thereafter to prevent the population from recovering. Specifically, we tested the efficacy (proportion of the population reduced, and over what time) of two culling methods: constant proportional annual culling, (*ii*) high initial culling followed by a constant maintenance cull.

Methods

Study site

Located approximately 12 km south of the Fleurieu Peninsula (South Australia) at its nearest point, Kangaroo Island is Australia's third largest island (155 km long and 55 km wide), covering ~ 4400 km^2 (Masters et al. 2004, Higgins-Desbiolles 2011) (Figure 1). The island has retained around 53% of its native vegetation, with 35% of the remaining land cover devoted to dryland agriculture (Willoughby et al. 2018). The island is uniquely absent of invasive European rabbits (*Oryctolagus cuniculus*) and is one of the few locations in Australia free of red foxes (*Vulpes Vulpes*); resident cats can therefore feed on a wider range of native species than elsewhere on mainland Australia (Bonnaud et al. 2011). For our study, we separated the island into the Dudley Peninsula (east of the narrowest point of Kangaroo Island, adjacent to Pelican Lagoon; Figure 1) and the western side (west of the narrowest point), to reflect the management strategy for the entire island.

Feral cat densities on Kangaroo Island are thought to range from 0.15 to 2.97 km^{-2}, with a median of 0.7 km^{-2} on the western end (Hohnen et al. 2020). Taggart et al. (2019) estimated that relative feral cat densities in eastern Kangaroo Island were 10 times higher than on the adjacent mainland.

Model

We constructed Leslie matrices to represent age-specific fertility and survival (Caswell 2001) for the cat population. Leslie matrices (also known as population demographic matrices) represent age-specific fertility and survival for a given population (Caswell 2001). We obtained cat fertility and survival estimates from six studies of domestic, stray and feral cat

population across the USA and Australia (Budke and Slater (2009) and summarised the population dynamics from a study in Western Australia done in the preliminary stages of cat eradication (Short and Turner 2005). We calculated mean and standard deviations of the age-specific demographic rates (i.e., survival, fertility) necessary for stochastic representations of the model (see below). We only used these fertility and survival estimates for females, assuming a 1:1 sex ratio (Bloomer and Bester 1991, Budke and Slater 2009).

The maximum age for feral cats on Kangaroo Island is 6 years; however, we split the initial year into two sections: pre- and post-breeding. The pre-breeding time step incorporates animals < 10 months of age, because feral cats reach sexual maturity at around 10 months; this was represented as individuals in this stage having zero fertility. For all resulting predictions of changing population size, we assumed that survival was the same for males and females.

We stochastically resampled the deterministic matrix $\boldsymbol{A}$ in all subsequent projections by resampling based on the standard deviation estimated from minimum and maximum fertility and survival values (Budke and Slater 2009), which incorporates both measurement error and inter-annual variability (process error). We assumed a Gaussian distribution around the mean using the standard deviations for resampling (Table 1).

Untreated population

To simulate how incrementing intensities of reduction change the projected population size, we first simulated a population not exposed to any culling as a benchmark. We defined the population's stable age distribution (Caswell 2001), and then multiplied this stable age structure by a starting population size of 3083 (approximation from density estimates on the Dudley Peninsula and western side of island) (Taggart et al. 2019, Hohnen et al. 2020). We then expressed all subsequent projections as a proportion of this founding population size to avoid the uncertainty in initial population size estimates. Because Kangaroo Island is insular, we assumed a closed population structure (i.e., no immigration or permanent emigration). Although cats could be brought to the island or domestic cats can be abandoned, there are insufficient data to consider the population as demographically open.

We included a logistic compensatory density-feedback function by reducing survival when the population exceeded double the size of the current population of the form:

$$S_{\text{mod}} = \frac{\kappa}{1 + \left(\frac{N}{\tau}\right)^{\theta}}$$

where, S_{mod} is the proportion of realised survival (survival modifier) as a function of the population's proximity to carrying capacity (twice the founding population size, $K = 6166$), N is the population size, and κ, τ and θ are constants: $\kappa = 0.998$, , $\tau = 14821.78$ and $\theta = 2.835$. We thus assumed survival to reduce as population approaches carrying capacity, with no changes to fertility because landscape managers currently consider the population to be sub-optimal with respect to available food resources (Jones and Coman 1982, Read and Bowen 2001). Most research on feral cat population control does not consider the habitat's carrying capacity (Andersen et al. 2004); however, feral cats seem to maintain consistent fertility regardless of population density, although average survival tends to decrease as the population approaches carry capacity (Courchamp and Sugihara 1999, Nutter 2006).

Reduction scenarios

1. Trap-neuter-release

To compare the efficacy of all proposed density control and reduction scenarios with fertility-reduction methods, we constructed a model that simulated a trap-neuter-release scenario. In this model, no animals are removed from the population; however, fertility is reduced to simulate sterilisation. We ran this model using the same methods for an unculled population, but we ran an incrementing overall reduction in fertility from 50–99%.

2. Culling model

We ran each culling scenario for (*a*) the entire island, (*b*) the Dudley Peninsula, and (*c*) the western side of Kangaroo Island to reflect the current management plan. We constructed two culling models: (*i*) constant proportional annual culling, and (*ii*) a high initial proportional cull in the first two years, followed by a constant proportional maintenance cull. In each model, we removed individuals from the population vector proportional to the total culling invoked in that time step and the stable age distribution. We ran each model for 10,000 iterations (randomly sampling 10,000 times from the stochastic survival and fertility vectors) to calculate the mean and 95% confidence bounds for minimum proportional population size. Projection intervals varied depending on the geographic scale: ten years (2020–2030) for the entire island, three years (2020–2023) for the Dudley Peninsula, and seven years (2023–2030) for the western side of the island.

For the constant cull, we simulated constant proportional annual culling (c) (i.e., we reduced the population each year by the same proportion for the duration of the projection interval) from $c = 0.10$ to 0.90. Once we determined the minimum initial culling proportion

that precipitated a decline, we refined the c proportions considered from 0.50 to 0.99 in 0.01 intervals. For the two-phase approach, we applied high initial culling only to the first two years of the eradication project (c = 0.50–0.99), with the maintenance culling applied to all years thereafter (c = 0.01–0.50) until the end of the projection interval. For all iterations of both models, we recorded the minimum projected proportional population size (pN) for each value of c, with a culling proportion interval of 0.01.

Cost

Based on previous information regarding the reduction in capture efficiency as population density declines (Bloomer and Bester 1992, Nogales et al. 2004, Parkes et al. 2014), we assumed an eradication technique's efficiency (f, ranging from 0 to 1) follows a Type III functional response (i.e., sigmoidal; (Nunney 1980, Denno and Lewis 2009) relative to proportional population size:

$$f = \frac{\alpha}{1 + (\beta e^{-\gamma \mathrm{p}N})}$$

where f is the relative efficiency of the culling technique, α, β and γ are constants: α = 1.01 (± 0.01), β = 85.61 (± 15.40) and γ = 8.86 (± 0.41), and pN = proportional population size. We assumed the same efficiency reduction across trapping, hunting and *Felixers*™ as a function of population size, such that the smaller the remaining population of cats, the less-efficient each method was relative to the start of the eradication campaign. We then applied this reduction to the culling model with pre-set costs for each technique (see below), to estimate the total cost of eradication.

We sourced trapping and shooting cost data from Holmes et al. (2015), with additional trapping costs from trapping supplies (traps.com.au) and *Felixer*™ data from Hodgens (2019). We summarised the catch rates and costs for each technique: (*i*) *Felixer*™ — each unit costs AU$13,000. Based on trials on Dudley Peninsula, 6 *Felixer*™ units were successful in killing 13 cats over 38 days, which translates to an annual kill rate of 0.080 (cats killed unit^{-1} year^{-1}). (*ii*) Traps — each trap costs between AU$157 and AU$297 (sampled uniformly). Again, based on trials on Dudley Peninsula, 40 traps caught 21 cats over 148 days, which translates to an annual trap rate of 0.198 cats trap^{-1} year^{-1}. (*iii*) Shooting — from Holmes et al. (2015), we estimated a kill rate per person-hour based on 1044 kills (872 direct + 172 from wounds) over 14,725 person-hours (= 0.071 cats killed person^{-1} hour^{-1}). Ammunition and labour costs equate to AU$25.92 hour^{-1}.

Assuming the same density of *Felixers*™ and traps on Dudley Peninsula applied to the entire island based on a comparison of relative areas (Dudley Peninsula = 37,500 ha; Kangaroo Island = 440,500 ha), we tabulated the number of cats killed by these two methods combined for the incrementing proportional cull, and then calculated the shortfall of cats not killed to meet the proportional cull required for that year. We considered three different approaches to meeting this shortfall: (*i*) increasing the number of *Felixers*™ only, (*ii*) increasing the number of traps only, or (*iii*) meeting the shortfall entirely with follow-up hunting. In each shortfall scenario, we tabulated the total costs across the projection interval and expressed these as a function of the increments in proportional culling.

Results

Untreated population

An untreated (no-cull) population is expected to increase to a median of 1.8 times the founding population (i.e., to 5525 individuals when starting with 3083) by 2030 (95% confidence limits: 1.39–2.21) (Figure 2a). The instantaneous rate of change (r) from the deterministic matrix for the Kangaroo Island population is 0.167. The deterministic (mean) matrix gave a generation length of 4.7 years. The population is projected to approach carrying capacity (set arbitrarily at twice the current population size) by 2026.

Trap-neuter-release

We simulated a trap-neuter-release fertility reduction to compare its efficiency to direct killing methods. Reduced total fertility of 50% and 80% yielded r = 0.10 and -0.19, respectively. A reduction of 80% fertility each year reduced the population to a median proportion of 0.0754 (0.048–0.12), with 50% fertility control only reducing the population to 0.66 (0.041–0.974) of the founding population.

Culling

Dudley Peninsula 2019–2023: A consistent yearly harvest of ≥ 0.52 reduced the population to ≤ 0.10 of the founding population, with an annual cull of 0.68 and 0.88 resulting in 0.032 and < 0.01 of the founding population, respectively. A two-phase model reduced the population ≤ 0.10 with an initial cull of ≥ 0.70 and a maintenance cull of ≥ 0.45, while a combination of ≥ 0.7 (initial) and ≥ 0.65 (maintenance) would reduce the population to ≤ 0.036.

Western Kangaroo Island 2023–2030: An annual proportional cull of ≥ 0.3 would reduce the population ≤ 10%, while an annual cull of ≥ 0.45 would reduce the population to 0.01 of its original size. To reduce the population to < 0.10, a two-phase cull of ≥ 0.6 and ≥ 0.2 would be required. An initial cull of ≥ 0.6 followed by a maintenance cull of ≥ 0.45 would reduce the population to ≤ 0.01.

The entire island 2019–2030: For the constant proportional cull, the population will be reduced to ≤ 0.10 of the founding population with an annual proportional cull of ≥ 0.3. An annual cull of ≥ 0.45 would reduce the population to ≤ 0.01 (Figure 2b). A two-phase cull with ≥ 0.60 (initial) and ≥ 0.2 (maintenance) would reduce the population to ≤ 0.10. To achieve ≤ 0.01, ≥ 0.60 (initial) and ≥ 0.45 (maintenance) is required (Figure 3).

Cost

To reduce the entire Kangaroo Island population to a 0.10 of its original size using a two-phase cull, a minimum of AU$6.1 billion (AU$5.1 billion–AU$6.8 billion) would be required if *Felixer™s* were used to make up the yearly shortfall (using the same densities of *Felixers*™ and traps as on Dudley Peninsula). In contrast, making up the shortfall with additional traps would place total costs at AU$53.1 million (AU$40.5 million–AU$69.1 million) for the same target. Finally, making up the shortfall with hunting would cost a total of AU$25.0 million (AU$22.7 million–AU$26.5 million).

Changing the target population size to 0.01 of the original, the total minimum costs would increase to AU$16.9 billion (AU$15.8 billion–AU$18.0 billion) if the shortfall was made with *Felixers*™, AU$129.3 million (AU$94.0 million–AU$167.8 million) if the shortfall was made with traps, or AU$49.1 million (AU$46.5 million–AU$51.6 million) if the shortfall was made with hunting (Figure 4).

Discussion

In each cull scenario we considered, a successful reduction of the feral cat population on Kangaroo Island to below 0.01 of its original size is achievable, but the minimum costs involved according to the different scenarios we ran could range from AU$46.5 million (AU$10 ha^{-1}) to AU$18 billion (AU$40,863 ha^{-1}) depending on the method used and the inherent uncertainty in the parameters we estimated. Whether these costs are a true reflection of the actual costs depends on our untested assumption of the functional response, and the per-unit outlay of the different methods to meet the annual shortfall for the different

intensities of cull. However, the lower end of our estimates for Kangaroo Island are cheaper than the costs to remove cats from Macquarie Island (AU$258 ha^{-1}), likely due to the latter's remoteness (Robinson and Copson 2014). Nonetheless, our comparisons do illustrate that high initial culls (> 45%) followed by moderate maintenance culls (20–45%) would be sufficient to reduce the population to 1-10% of its original size, and that hunting is the most cost-effective way to meet these targets (especially if other methods are rolled out simultaneously).

That hunting is cheaper than other methods is unsurprising given that no hardware other than rifles and ammunition are needed to be purchased outright, in contrast to the higher overheads associated with traps or *Felixer*™ units (Holmes et al. 2015, Hodgens 2019). Additionally, hunting is considered more humane due to the minimised contact with the animal and the instant death with a correctly executed headshot (Sharp and Saunders 2011). However, hunting requires many people working full time, whereas the other techniques are more passive. Of course, complete eradication would necessarily entail additional costs as the final individuals were identified, hunted, and destroyed (Bester et al. 2002, Nogales et al. 2004). This would be more expensive than normal eradication efforts and would require a more strategic isolation of remaining individuals.

Our results identify that fertility-reduction using trap-neuter-release control methods are an ineffective option for reducing pest densities (Longcore et al. 2009), even though it often remains attractive for predator control in the public's eye because it does not involve direct killing (Robertson 2008). Instead, our model outputs show that a realised annual fertility equivalent to ≤ 25% of expected values (i.e., pre-fertility treatment) would reduce the population to ≤ 10%. In other words, managers would have to maintain at least 75% of the female cat population sterilised each year from 2019-2030 for the program to reduce the population to ≤ 10% of its original size. Whether this is feasible or cost-effective is beyond the scope of our study, but it does demonstrate that fertility-reduction is a much less efficient method to eradicate cats than culling. Additionally, sterilised individuals returned to the population could still continue to eat native fauna until they perished due to natural causes, so the overall ecological impact would be necessarily greater than a culling-based program where individuals are removed permanently when treated.

If left unmanaged, cats pose a serious threat to the persistence of native species. Indeed, cats have been identified as one of the greatest threats to birdlife globally (Butchart et al. 2006), being major contributors or the sole source of predation and extinction of bird species from New Zealand to Mexico (Nogales et al. 2004, Medina et al. 2011). Further, Smith and

Quin (1996) cite cats as the best predictor of population decline in small conilurine rodents in Australia. The successful eradication of cats, especially from islands, has shown that in the absence of cat predation, native fauna is often able to recover to viable population sizes within a few generations (Bester et al. 2002, Hughes et al. 2008).

We conclude that the most appropriate approach to reduce cat densities on Kangaroo Island is a two-stage method, with a high initial reduction of at least 60–70% and a maintenance cull of 50–65%. Although a constant proportional annual cull can be effective, it is generally less efficient than a two-stage approach. As culling reduces density and drives the population closer to extinction, it becomes progressively more difficult and expensive to cull remaining individuals (Nogales et al. 2004, Parkes et al. 2014). This is because most culling methods are passive and rely on a 'non-negligible probability' of the target animal encountering *Felixers*™ or traps (Moseby and Hill 2011). Although these techniques can be accompanied by visual, scent or sound lures, the target animal still needs to be in range to be enticed by them. Thus, encounters at low densities become increasingly less likely (Veitch 2001), and rising per-capita food abundance as the predator's population dwindles can make baits or food lures less attractive (Parkes et al. 2014). Cats in particular are intelligent and can learn to avoid traps. Thus, while trapping is generally considered effective for density reduction (Nogales et al. 2004), it is most effective in the early stages of eradication programs (Nogales et al. 2004). Therefore, a two-stage approach allows for the implementation of widespread control that is effective at high densities, followed by a more targeted approach through consecutive maintenance as the population continues to decline.

Because the Kangaroo Island trial eradication program is still in its infancy, many of the demographic, effectiveness, and cost parameters are not yet available specifically for this region, lending further uncertainty to our conclusions. For example, we were obliged to obtain demographic rates from data published for cat populations elsewhere (Budke and Slater 2009), and we do not yet have access to spatially variable data with which to parameterise spatially explicit models that could potentially improve realism (McMahon et al. 2010). A better quantification of carrying capacity, as well as the mechanisms by which density feedback operates on the demographic rates would also improve predictive accuracy.

Many attempts to eradicate cats have been made, but they vary widely in success (Algar et al. 2002, Bester et al. 2002, Nogales et al. 2004, Algar et al. 2011, Campbell et al. 2011, Parkes et al. 2014). For effective eradication to be achieved, culling programs must be based on empirical data and ideally, directed by models like ours. Our model should allow practitioners to plan their culling programs better, and to allocate the resources needed to

achieve their targets efficiently and cost-effectively. As more site-specific data become available, we expect the model's predictions to become ever-more realistic to identify the most plausible and cheapest pathways to eradication.

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Figure Captions

Figure 1 – Map of Kangaroo island relative to the Australian mainland. The shortest distance from the mainland (southern tip of Fleurieu Peninsula) to Kangaroo Island is approximately 14 km.

Figure 2 – (a) Average proportion of the initial cat population (N_1) on Kangaroo Island projected from 2020–2030 for the unculled scenario. Black line indicates the median value from 10,000 iterations, along with 95% confidence intervals (dashed lines). (b) Minimum proportion of the Kangaroo Island feral cat population remaining after a constant proportional annual cull ranging from 0.5 to 0.9. Solid black line represents median minimum proportion of the initial population (N_1) after 10,000 iterations with 95% confidence intervals indicated as dashed lines.

Figure 3 –Estimated median minimum proportion of the final population remaining (relative to start population N_1) for combinations of initial proportional (i.e., *initial cull*: 0.5–0.9) and maintenance proportional (i.e., *maintenance cull*: 0.1–0.5) culling. Proportion of population remaining after culling scenarios represented by colour bar (from purple to yellow – lowest to highest remaining proportional population).

Figure 4 – Estimated median total costs of feral cat eradication on Kangaroo Island for combinations of initial proportional (i.e., *initial cull*) and maintenance proportional (i.e., *maintenance cull*) culling, where the shortfall in the number of cats killed from *Felixer*™ units and traps is provided by (a) additional *Felixer*™ units, (b) traps, or (c) hunting. Cost of eradication (in AU$, adjusted for 2020) indicated by colour bar (from purple to yellow – lowest to highest costs). Contours and white values indicate cost in $AU millions or billions accordingly. Note different *z*-axis (contour) scales in a, b, and c.

Table 1 – Demographic rates (survival probability and fertility — kittens/female) used in the stochastic matrices to project the cat population under different culling scenarios (Budke and Slater 2009).

	minimum	**mean**	**maximum**
fertility			
pre-breeding juvenile	0.00	0.00	0.00
subadult	0.35	0.75	1.58
adult	1.98	2.52	3.78
survival			
pre-breeding juvenile	0.27	0.46	0.73
subadult	0.27	0.46	0.73
adult	0.55	0.70	0.78

pre-breeding juvenile: < 10 months old; not sexually mature

Figure 1

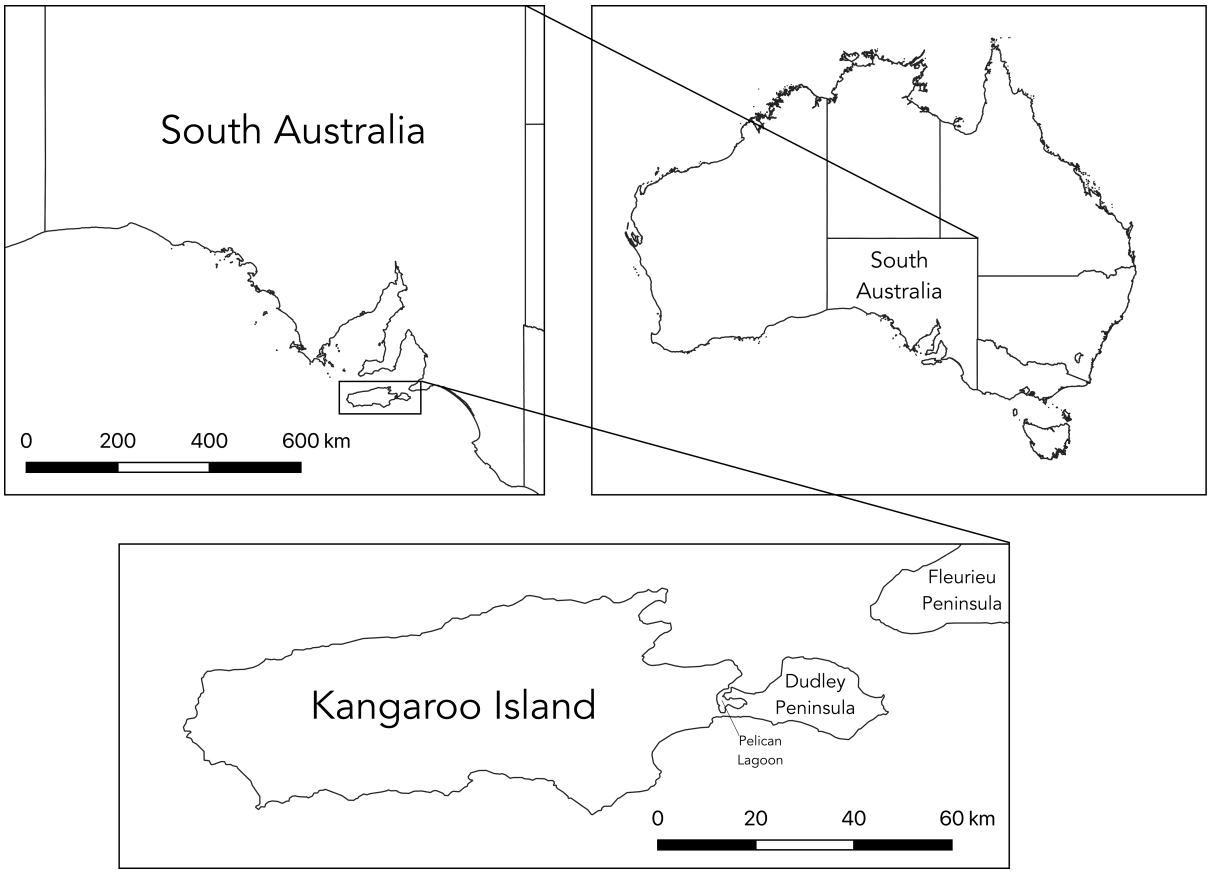

South Australia
0
200
400
600 km
South
Australia
Fleurieu
Peninsula
Kangaroo Island
Dudley
Peninsula
Pelican
Lagoon
0
20
40
60 km

Figure 2

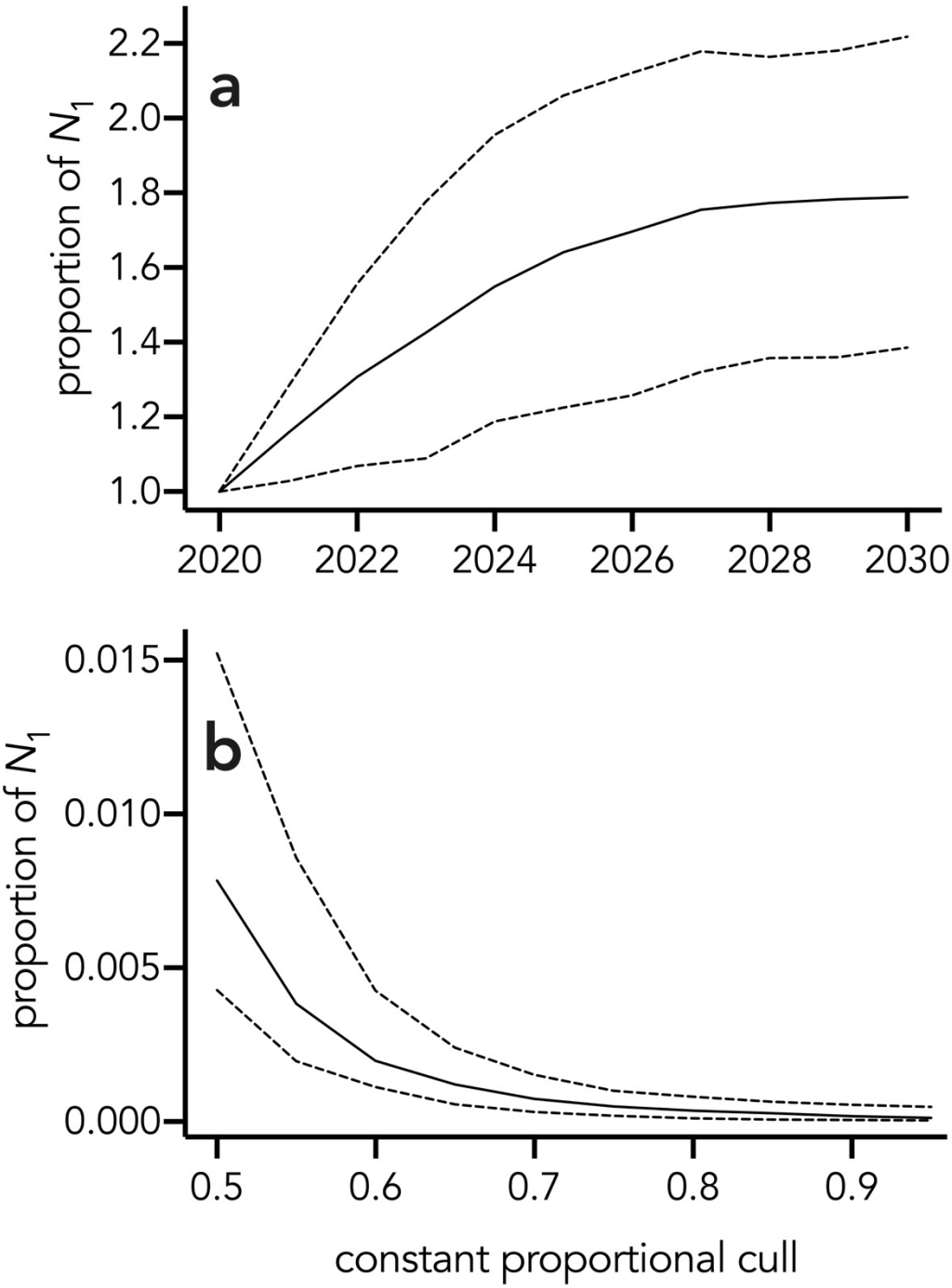

a
proportion of N_1
2.2
2.0
1.8
1.6
1.4
1.2
1.0
2020
2022
2024
2026
2028
2030
b
proportion of N_1
0.015
0.010
0.005
0.000
0.5
0.6
0.7
0.8
0.9
constant proportional cull

Figure 3

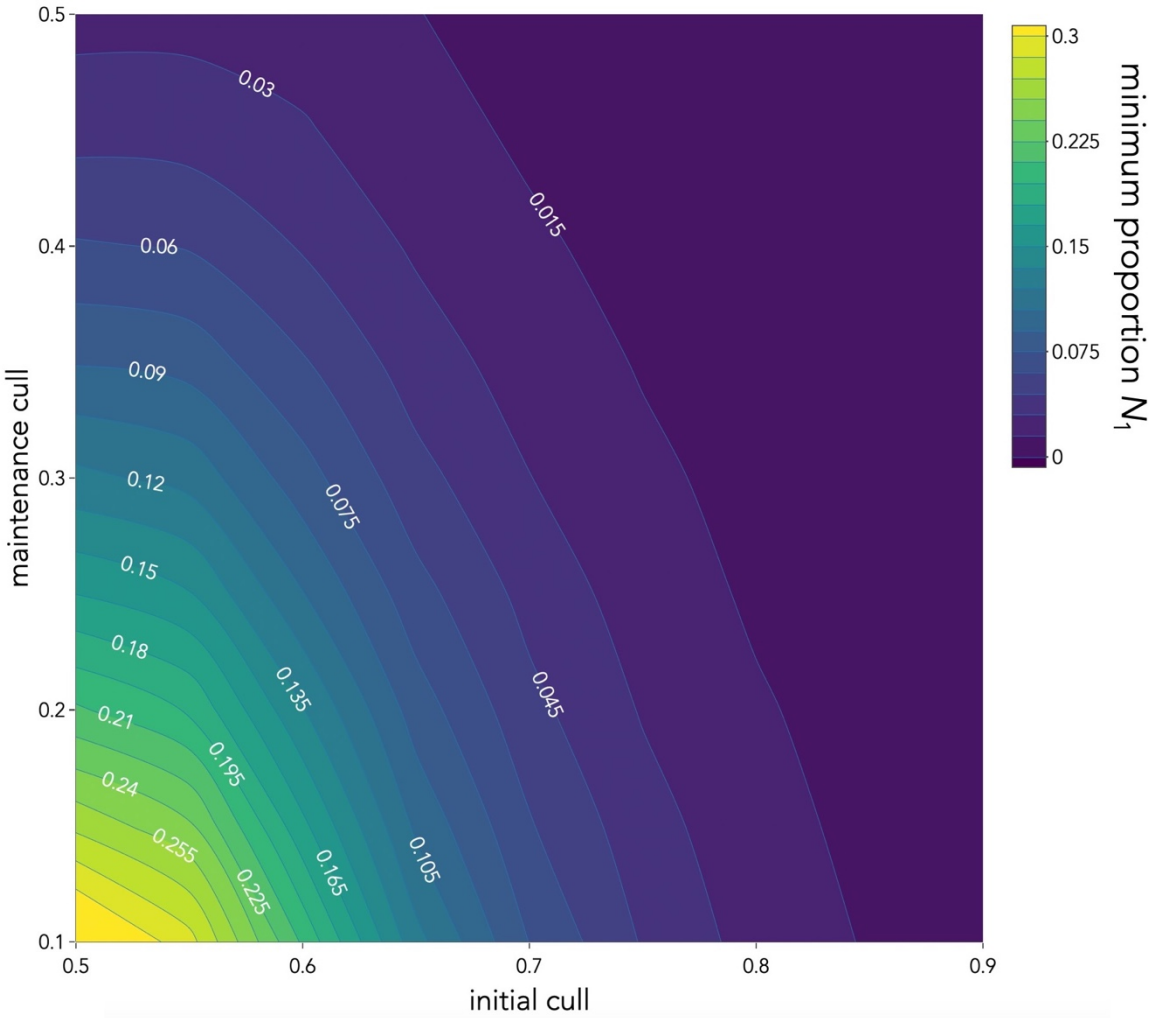
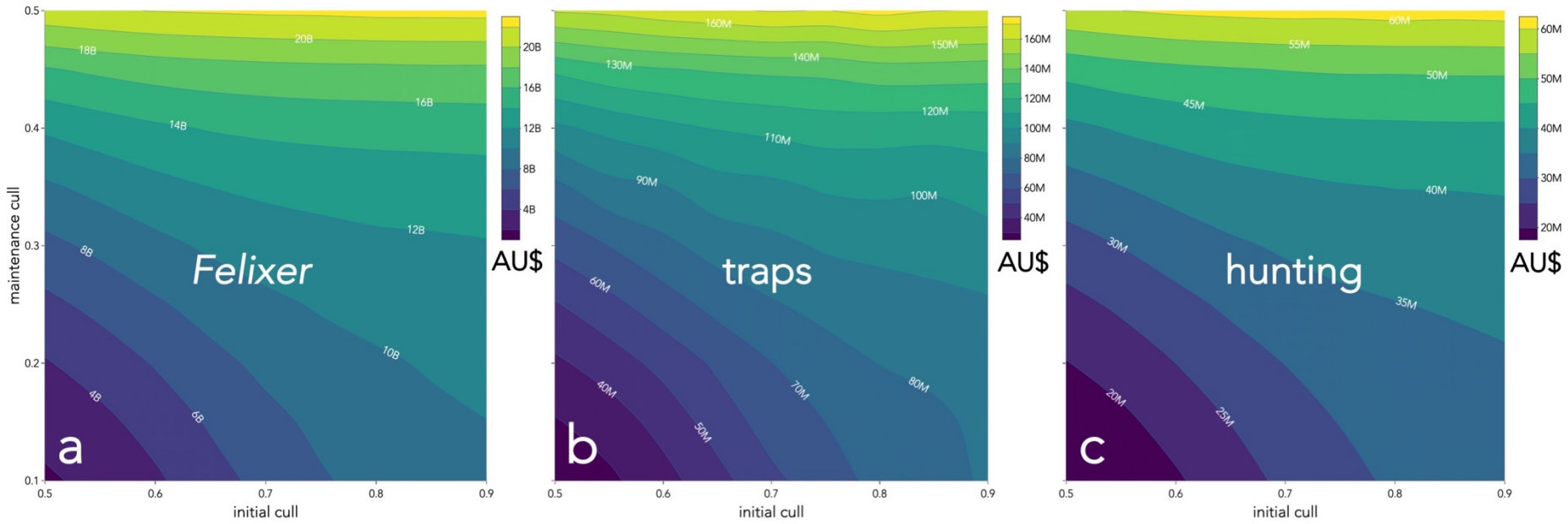

0.5
0.4
0.3
0.2
0.1
maintenance cull
0.5
0.6
0.7
0.8
0.9
initial cull
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.255
0.225
0.195
0.165
0.135
0.105
0.075
0.045
0.015
0.3
0.225
0.15
0.075
0
minimum proportion N_1

Figure 4


Felixer
a
maintenance cull
initial cull
AU$
20B
18B
16B
14B
12B
10B
8B
4B
traps
b
160M
150M
140M
130M
120M
110M
100M
90M
80M
70M
60M
50M
40M
hunting
c
60M
55M
50M
45M
40M
35M
30M
25M
20M