

RESEARCH ARTICLE

Planning and optimizing neutering programs for free-roaming cat populations: An interactive tool for cost-effective management in closed systems

Martina Cecchetti^{1,2}  | Luca Nelli³ 

¹Research Institute of Biomedical and Health Science (IUIBS), University of Las Palmas de Gran Canaria, Las Palmas de Gran Canaria, Spain

²Environment and Sustainability Institute, University of Exeter, Penryn Campus, Penryn, UK

³School of Biodiversity, One Health, and Veterinary Medicine, University of Glasgow, Glasgow, UK

Correspondence

Luca Nelli

Email: luca.nelli@glasgow.ac.uk

Handling Editor: Abishek Harihar

Abstract

1. The management of free-roaming cat (*Felis catus*) populations is a complex eco-sociological dilemma. Cats with outdoor access pose significant threats to wildlife through direct predation and indirect effects, leading some conservationists to advocate for stringent control measures, including lethal methods for managing unowned cat populations. However, public sentiment, alongside evidence that lethal methods often lack long-term efficacy and cost-effectiveness, often supports the adoption of non-lethal methods, such as Trap-Neuter-Return (TNR). In certain European countries, TNR is the only legally permissible method. Despite its widespread adoption, a limited understanding of cat population dynamics, combined with inadequate planning and resource allocation, can lead to ineffective outcomes, potentially exacerbating the growth of cat populations.
2. We used the free-roaming cat population (both unowned and owned cats) on Linosa—a small Mediterranean island of high biodiversity importance—as a case study. Census data were collected over three consecutive years, and a Bayesian statistical model was developed to estimate population dynamics and assess the varying impacts of neutering efforts over time, extending the analysis to 60 months beyond the latest census. The model also evaluated different budget scenarios based on the intensity of neutering efforts applied.
3. The model highlighted the importance of high-frequency, female-focused neutering efforts to achieve long-term population control and cost efficiency. Additionally, it demonstrated that in our study population, such intensive efforts improved the precision of population estimates, thereby reducing uncertainty in management outcomes.
4. To translate the model to an accessible tool for conservation planners, animal welfare organizations, and policymakers, we developed an interactive and user-friendly dashboard, available at https://boydorr.gla.ac.uk/lucaelli/Cats_PVA/. This tool allows users to customize scenarios by inputting initial estimates of the free-roaming cat population and its characteristics.

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2025 The Author(s). *Journal of Applied Ecology* published by John Wiley & Sons Ltd on behalf of British Ecological Society.

5. *Synthesis and applications.* Our interactive tool enables data-driven planning of neutering programs, helping stakeholders optimize resource allocation and improve long-term outcomes. This approach enhances management effectiveness and can be adapted to similar closed systems, offering a scalable solution for balancing ecological and societal concerns.

KEYWORDS

Bayesian model, cost-effective management programs, free-roaming cats, neutering, population dynamics, population management, Trap-Neuter-Return

1 | INTRODUCTION

Hunting behaviour and population management of free-roaming domestic cats (*Felis catus*) are among the most prominent and enduring conservation conflicts (Peterson et al., 2012; Trouwborst et al., 2020). The ecological damage caused directly and indirectly by unowned and owned cats with outdoor access is well-documented by a vast and growing body of literature. Cats prey upon wildlife (Blancher, 2013; Loss et al., 2013; Woinarski et al., 2017; Woolley et al., 2020), can exert 'fear effects' over wild animals by roaming (Beckerman et al., 2007), and have been found to cause changes in their prey behavioural patterns and activities (Bonnington et al., 2013; Webster et al., 2018). They can also transmit diseases to wildlife and humans (Gerhold & Jessup, 2013; Kellner et al., 2018). Even when an individual cat's predation rate appears relatively low, their high and unnatural population densities result in a cumulative effect that has been shown to contribute to an enormous number of deaths annually (Baker et al., 2005; Loss & Marra, 2017). Owned and unowned cat populations are directly or indirectly sustained by humans, and their dynamics are not regulated by prey availability or fluctuations (Bradshaw et al., 1999; Loss & Marra, 2017; Maeda et al., 2019). Despite differences in their life histories and reliance on humans, owned and unowned cat subpopulations are interconnected, with movement and breeding among them affecting overall population dynamics (McDonald et al., 2023).

Although domestic cats have negative impacts on wild populations, they share a long history with humans, evoking positive and compassionate emotions from a cultural and social perspective (Vigne et al., 2011). This affinity leads people to value them as pets and support numerous colonies of unowned cats by feeding and caring for them. The dual roles of cats as beloved pets and predators have created significant conflicts among stakeholders, particularly animal welfare advocates, who prioritise the well-being of cats, and wildlife conservationists, who focus on the detrimental effects cats have on wildlife populations (Crowley et al., 2020). This division extends to the management strategies adopted for reducing unowned free-roaming cat populations. Specifically, conservationists often suggest lethal methods, which the public frequently finds unethical. Beyond ethical concerns, evidence suggests that lethal approaches often fail to deliver long-term, cost-effective outcomes, as they do not adequately address issues such as abandonment, immigration, and

insufficient implementation intensity (Benka et al., 2022). Instead, the public tends to support controlling cat fertility through the Trap-Neuter-Return (TNR) method and its variants (Boone et al., 2019; Neal & Wolf, 2023; Wolf & Hamilton, 2022; Wolf & Schaffner, 2019). This strategy involves trapping, neutering, and releasing unowned cats back to their original locations, where they are then fed and taken care of by volunteers, with the goal of achieving a long-term reduction in the population. Neutered cats show increased welfare and survival, and reduced nuisance behaviours associated with reproduction (Gunther et al., 2018, 2022; Ireland & Neilan, 2016). Ecologically, they show reduced home ranges (Ferreira et al., 2020) while decreased predation upon wild fauna is still an assumption. Clearly, neutering does not entirely eradicate the negative impacts cats have on wild populations, unlike culling. While culling could theoretically achieve this, its effectiveness is often undermined in open or semi-open environments, such as mainland regions with unrestricted movement, urban areas with partial barriers, or large islands, where recolonization and compensatory immigration prevent long-term elimination of cat populations (Palmas et al., 2020).

Addressing the conservation conflicts related to cat populations involves balancing ecological impacts with ethical considerations regarding animal welfare, as well as considering both near- and long-term population dynamics, resource allocation, and sustainability of management efforts. Due to moral constraints and public acceptance, TNR has increasingly been implemented, and in some European countries, it is the only viable method, as non-killing policies for unowned cats have been introduced (e.g. Italy—Law 280/91 and Spain—Law 7/2023).

Both simulation and practical studies have suggested that TNR can achieve long-term control of free-roaming cat populations if implemented with sufficient intensity and complemented by approaches such as the removal and adoption of sociable kittens and adults, reduction in pet cat abandonment, early desexing of pet cats, and euthanasia of sick individuals (Benka et al., 2022; Gunther et al., 2022; McDonald et al., 2023). In closed contexts, such as small islands, achieving population reduction solely through TNR of the unowned cats, combined with the neutering of pets, may be potentially effective because there are no immigrant cats.

In terms of costs, maintaining high-intensity neutering over long periods can be particularly expensive, especially due to the significant decrease in trapping efficiency as the percentage of neutered

cats increases (Gunther et al., 2022). Therefore, a thorough assessment of the budget for such neutering campaigns is essential. This budget should be optimised based on the demographics of the cat population to effectively reduce their numbers over time. Effective planning and scheduling of these actions require accurate estimates of basic cat population dynamics and predictions of the necessary effort, making it a challenging task for municipalities and welfare associations. Although existing ecological models are valuable for understanding and predicting population dynamics, as well as testing the impact of management strategies, they have become so complex that policymakers or organizations can rarely use them (McNie, 2007).

Our study aims to provide a practical tool to plan the most effective and cost-efficient neutering program for managing free-roaming cat populations. The tool is based on the example of the cat population on Linosa, a small Italian island (5.45 km²) situated in the middle of the Mediterranean Sea and a biodiversity hotspot. In Italy, national Law 280/91 introduced a no-kill policy for cats. To control the cat population on Linosa, a Trap-Neuter-Return approach for unowned cats and the neutering of owned cats has been implemented, coordinated by Martina Cecchetti in collaboration with the Public Health Authority of Palermo. However, due to the inability of public authorities to ensure regular yearly neutering sessions, these efforts have been inconsistent. Consequently, since 2021, neutering sessions have been organized with a private veterinarian to achieve consistent results. While the model and online dashboard are grounded in this case study, they are most applicable to small, closed populations, such as islands, where cat immigration is negligible and population dynamics are relatively contained. These limitations must be carefully considered when extrapolating results to larger or open systems with different ecological and demographic contexts.

The main objectives of our study were to: (a) estimate cat population dynamics on Linosa, reconstructing unobserved data over time; (b) evaluate the effects of neutering on population structure when applied at different intensities (both in terms of sessions per year and the number of neutered females and males per session); (c) design a simulation to evaluate the cost-effectiveness of various neutering scenarios, assessing their financial viability; (d) develop an interactive and accessible tool to enable managers, policymakers, and welfare organizations to generate real-time predictions of the model outputs under different hypothetical neutering scenarios.

2 | MATERIALS AND METHODS

2.1 | Study area

Linosa (35°51'33" N; 12°51'34" E) is a small volcanic island (5.45 km²) in the Mediterranean Sea, located halfway between Italy and Africa (Figure 1). It is part of the Pelagie Archipelago and the Natura 2000 Network. Linosa is home to the largest European colony of Scopoli's shearwater (*Calonectris diomedea*) and other endemic species of

conservation concern, such as the eyed skink (*Calcidiscus ocellatus*), the big-head cricket (*Brachytrupes megacephalus*), and the Filfolia lizard (*Podarcis filfolensis*). Due to its strategic location, Linosa also serves as a stopover for many migratory birds during their long-distance flights in spring and autumn, many of which are classified as Species of European Conservation Concern (SPEC) and/or included in Annex 1 of the Birds Directive (e.g. the Great Snipe *Gallinago media*, SPEC 1, Annex 1).

The island has a population of approximately 400 residents and was first permanently colonized in 1845. Throughout the years, various invasive mammals have been introduced, including wild rabbits (*Oryctolagus cuniculus*), black rats (*Rattus rattus*), and house mice (*Mus musculus*), as well as domestic animals such as dogs (*Canis familiaris*) and cats.

On Linosa, cat ownership and management practices vary, ranging from owned cats receiving different levels of care to unowned cats living in colonies and being fed by caretakers. Nearly all cats on the island are free-roaming, posing a threat to the endemic wildlife species (Cecchetti et al., 2023). However, we found that there are no truly feral cats on the island (personal communication), which we define as unowned, unsocialized cats that live and reproduce independently of humans (RSPCA Australia, 2018).

2.2 | Data collection: Census of the cat population and neutering sessions

The census of the cat population was conducted annually from 2021 to 2023 through a door-to-door questionnaire administered to all inhabitants (see Appendix S1). Prior to administering the questionnaire, participants were informed of the study's aims and assured of the voluntary and anonymous nature of their participation. Completion of the questionnaire was taken as an indication of informed consent. Given Linosa's small size and tightly knit community, we consider our survey to be an exhaustive census. The island's entire population is highly familiar with the presence and status of individual cats, allowing us to track ownership, outdoor access, and turnover with high accuracy. For each cat, the following information was collected: age (or age class if the exact age was unknown), sex, colour, fur type and pattern, reproductive status (including willingness to sterilise if unneutered), feeding habits (e.g. cat food, leftovers, pasta meals) and outdoor access (indoor, indoor/outdoor, outdoor). Each cat was assigned a unique ID, consisting of its name (or 'cat' or 'no name' with a sequential number if unnamed) and the owner/caretaker ID (a sequential number). The location of each cat's house or colony was recorded using GPS, and photographs of each cat were taken.

From May 2021 to November 2023, six neutering sessions were carried out, involving TNR of unowned and unsocialised cats, along with the neutering of owned cats. Each session spanned 4–5 days and included trapping and surgical procedures.

This study did not require formal ethical approval as it involved only non-invasive population monitoring and routine veterinary procedures performed by licensed veterinarians in accordance with



FIGURE 1 Location of Linosa in the Mediterranean Sea. Background image: Orthophoto from the Geoportale Nazionale—Ministero dell'Ambiente e della Sicurezza Energetica, 'Ortofoto a colori anno 2012,' accessed via WMS service at <http://wms.pcn.minambiente.it> on 10 August 2024.

Italian animal welfare regulations (D.Lgs. 26/2014) and in agreement with the ASP (Public Veterinary Service of Palermo) and the Comune of Lampedusa and Linosa. All procedures complied with national guidelines for animal welfare, and written informed consent was obtained from all cat owners and caretakers prior to neutering (see [Appendix S2](#)).

2.3 | Statistical analysis

2.3.1 | Population dynamic model

We developed a Bayesian statistical model to estimate the dynamics of the cat population from March 2021 to November 2023. Given the sparse nature of our data—with census recorded only at three time points (March 2021, October 2022, and November 2023)—this approach offered key advantages. Specifically, it allowed us to leverage the available data to reconstruct missing population dynamics (in this case with a monthly resolution), providing a more continuous understanding of birth and death rates over time. The Bayesian framework allowed us to explicitly incorporate uncertainty

into the model's parameters and predictions. Priors based on literature and biological expectations ensured robustness while letting the observed data primarily shape the posterior estimates. This approach is particularly useful for sparse datasets with limited time points, balancing prior knowledge with data-driven inference. Additionally, we investigated the effects of neutering—considering the frequency of neutering sessions per year, the number of cats neutered, and their sex in each session—on the population structure over time.

The population dynamics were modelled using the structure described below.

Births

For each month t , the number of new births (B_t) was modelled as a binomial process dependent on the number of adult unneutered females ($F_{a,u,t}$) and the birth probability per female (p_{birth}):

$$B_t \sim \text{Binomial}(F_{a,u,t}, p_{\text{birth}}),$$

with:

$$p_{\text{birth}} = \frac{\lambda \times I}{12},$$

where:

- λ is the annual fecundity rate (number of pregnancies per year per female).
- I is the average litter size (number of kittens per pregnancy).

The sex ratio at birth r was used to allocate new births into females and males respectively F_j and M_j sexually immature until they reach the 4 months of age:

$$F_{j,t} = \frac{B_t}{1+r}, \quad M_{j,t} = B_t - F_{j,t}.$$

While cats on Linosa exhibit oestrous cycles 3–4 times a year with fluctuations in intensity, these do not follow a regular seasonal pattern based on our available census data. Therefore, we modelled births as constant throughout the year as a simplification ensuring consistency and interpretability in our predictions while accommodating the limits of the data (Vansandt, 2022). However, we recognize that in many free-roaming cat populations, seasonal peaks in reproduction have been documented (e.g. Jennett et al., 2015). This simplification may affect the generalizability of our findings, and future work incorporating higher-resolution data could refine this aspect of the model.

Mortality

Mortality rates were applied monthly and stratified by population groups, including sexually immature and mature individuals, to reflect age-specific differences in survival (Gunther et al., 2011). Mortality rates were further adjusted to account for density-dependent effects specific to each group. The adjusted mortality rate (m_t) for each group was calculated as:

$$m_{t,g} = m_{0,g} \left(1 + \frac{N_{t-1}}{K_g} \right),$$

where:

- $m_{0,g}$ is the base monthly mortality rate for group g (unneutered females, neutered females, unneutered males, neutered males, sexually immature females, sexually immature males).
- N_{t-1} is the total population at time $t - 1$.
- K_g is the carrying capacity for group g .

While this structure does not explicitly account for interactions between groups (e.g. how neutered males might influence unneutered males through reduced aggression), it indirectly incorporates group-specific density effects through separate carrying capacities for each group. This ensures that the mortality dynamics are responsive to density changes within each group while maintaining the simplicity of the model. The number of deaths for each group was modelled using a binomial distribution:

$$D_{t,g} \sim \text{Binomial}(N_{t-1,g}, m_{t,g}).$$

Population updates

The population for each group was updated each month according to the following equations:

$$F_{a,u,t} = F_{a,u,t-1} - D_{t,F_{a,u}} + F_{j,t-4} - S_{t,F},$$

$$F_{a,n,t} = F_{a,n,t-1} - D_{t,F_{a,n}} + S_{t,F},$$

$$M_{a,u,t} = M_{a,u,t-1} - D_{t,M_{a,u}} + M_{j,t-4} - S_{t,M},$$

$$M_{a,n,t} = M_{a,n,t-1} - D_{t,M_{a,n}} + S_{t,M},$$

where:

- $F_{a,u,t}$ and $F_{a,n,t}$ are the number of unneutered and neutered females at time t , respectively.
- $M_{a,u,t}$ and $M_{a,n,t}$ are the number of unneutered and neutered males at time t , respectively.
- $S_{t,F}$ and $S_{t,M}$ are the number of individuals neutered at time t , specifically females and males, respectively.
- $D_{t,F_{a,u}}$, $D_{t,F_{a,n}}$, $D_{t,M_{a,u}}$, and $D_{t,M_{a,n}}$ are the number of deaths in the respective groups at time t .
- $F_{j,t-4}$ and $M_{j,t-4}$ are the number of female and male sexually immature that mature into sexually mature individuals at time t , respectively.

Inference methodology and prior distributions

The Bayesian model was fitted using the program JAGS (Plummer, 2003) interfaced with the statistical environment R (R Core Team, 2024) via the package *rjags* (Plummer et al., 2016). The annual fecundity rate λ was assigned a prior Uniform(0,2) distribution. The average litter size I was modelled with a Uniform(1,8) distribution. The sex ratio at birth r was assigned a Normal(1,0.2) distribution, centered around an equal ratio but permitting natural variation. For the carrying capacity K_g of each population group, a Uniform(100,1000) distribution was used, reflecting uncertainty in environmental limits on the population size. Lastly, the base monthly mortality rate $m_{0,g}$ for each group was modelled with a Beta(2,200) distribution, yielding a low mean of around 1% with moderate variability, in line with the expected mortality rate in the population (personal communication).

2.3.2 | Cost-effectiveness neutering simulations

We conducted a 60-month simulation starting from the latest census to assess the overall cost-effectiveness of various neutering scenarios, integrating operational costs to determine their financial viability. For the analysis, we used the average costs reported by Benka et al. (2022), where the average expense of neutering a single cat was 65.54€ (including surgery, ear tipping, vaccine, short-term sheltering, care and return to the point of origin), and the average daily trapping cost was 10.92€. While trapping on Linosa was carried

out on a voluntary basis, we relied on reported trapping costs from the literature, as the economic value of volunteer time was not directly quantified in our study.

Recognizing the logistical challenges associated with trapping efficiency—specifically, the increased effort required as the proportion of neutered cats rises—we introduced a mechanism to dynamically adjust the trapping effort based on the proportion of the population already neutered. To explore plausible scenarios, we arbitrarily set the trapping effort factor as follows: a factor of 1 for up to 25% of the population neutered, increasing to 2 for 26% to 50%, 3 for 51% to 75%, and reaching 4 when over 75% of the population has been neutered. This model feature captured the anticipated increase in resource allocation necessary to neuter the remaining unneutered cats.

To illustrate the varying impacts of neutering efforts on cat population dynamics over time, we conducted predictive simulations, running 10,404 neutering scenarios. These simulations varied the number of neutered individuals per session (ranging from 0 to 50, in increments of 1), their sex, and the annual frequency of neutering sessions (1 to 4 times). Each scenario was iterated 1000 times.

2.3.3 | Interactive dashboard

To facilitate the exploration of cost-effectiveness across various neutering scenarios and their impact on cat population dynamics, we developed an interactive dashboard using R's Shiny framework (Chang et al., 2024). Through an intuitive graphical user interface (GUI), users can manipulate key parameters including the prediction horizon (number of months ahead), the frequency and scale of neutering efforts (number of neutering events per year and number of males and females neutered per event), and the associated costs (per cat neutering and trapping event).

3 | RESULTS

A total of 389, 485 and 506 cats with outdoor access were recorded in 2021, 2022 and 2023 respectively. Due to a lack of information regarding sex, reproductive status and approximate age, we excluded from the model 5 cats in 2021, 24 cats in 2022 and 16 cats in 2023 (Table 1).

The following numbers of cats were neutered during each session: in May 2021, 14 females and 22 males; in November 2021, 36 females and 8 males; in February 2022, 34 females and 29 males; in

November 2022, 40 females and 22 males; in June 2023, 19 females and 9 males; and in November 2023, 30 females and 17 males.

3.1 | Population dynamic model

Detailed results of the Bayesian statistical model, including full posterior distributions for all model parameters, are shown in Table 2. See also Appendix S3 for a comparison of prior and posterior distributions. The model allowed us to reconstruct the cat population dynamics on Linosa over the observed period, showing an increase in the total number of cats in the population over the years (Figure 2).

The model estimated the annual fecundity rate at 0.739 (95% credible intervals: 0.701–0.849), while the average litter size was 3.667 (95% CI 2.148–5.837), with a balanced sex ratio at birth of 0.967 (95% CI 0.806–1.185). The estimated monthly mortality rate

TABLE 2 Summary of estimates derived from the Bayesian model, including the mean of the posterior distribution, standard deviation (SD), 95% credible intervals (CI) and effective sample size (n_{eff}) for each parameter.

Parameter	Mean	SD	95% CI	n_{eff}
λ	0.739	0.041	0.701–0.849	390
l	3.667	1.041	2.148–5.837	312
r	0.967	0.117	0.806–1.185	379
$K_{F_{a,u}}$	453.904	77.629	309.000–590.000	1400
$K_{F_{a,n}}$	537.795	52.384	406.975–598.000	1400
$K_{M_{a,u}}$	456.281	89.136	306.000–594.000	2800
$K_{M_{a,n}}$	471.706	82.980	316.000–595.000	3000
K_{F_j}	455.059	86.990	309.000–594.000	3000
K_{M_j}	451.434	86.188	308.000–593.000	850
$m_{0,F_{a,u}}$	0.017	0.006	0.007–0.026	421
$m_{0,F_{a,n}}$	0.006	0.000	0.006–0.007	900
$m_{0,M_{a,u}}$	0.013	0.005	0.006–0.024	579
$m_{0,M_{a,n}}$	0.008	0.002	0.006–0.012	690
m_{0,F_j}	0.015	0.006	0.006–0.025	350
m_{0,M_j}	0.016	0.006	0.006–0.025	310

Note: λ : annual fecundity rate, l : average litter size, r : sex ratio at birth, K : carrying capacity for each population group (F: female, M: male, a : sexually mature, j : sexually immature, n : neutered, u : unneutered), m_j : base monthly mortality rate for each population group.

TABLE 1 Summary of the yearly number of cats with outdoor access on Linosa.

Year	Unneutered F	Neutered F	Unneutered M	Neutered M	Immature F	Immature M
2021	83	124	128	36	8	5
2022	57	180	95	82	29	18
2023	15	243	84	122	13	13

Note: The number of unneutered and neutered females and males are reported, as well as the number of sexually immature ones (kittens <4 months).

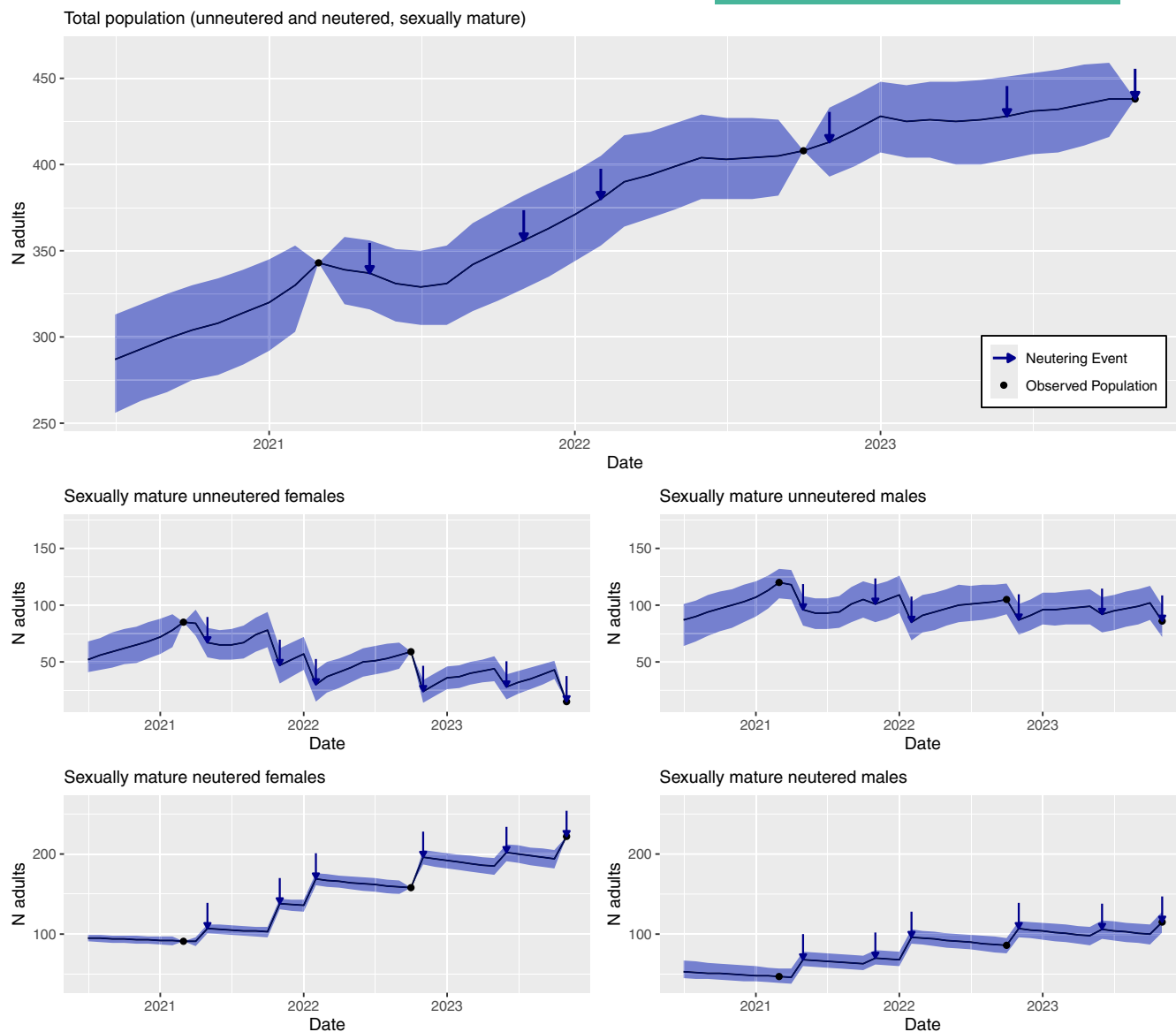


FIGURE 2 Dynamic changes in the free-roaming cat population from 2021 to 2023. The top panel displays the overall trend in the sexually mature cat population, combining both unneutered and neutered individuals, with observed data points (census) represented as black dots and neutering sessions denoted by arrows. The smaller panels break further down the population into unneutered and neutered females and males. For all groups, blue ribbons indicate 95% credible intervals around the mean population estimates.

for unneutered females was three times higher than that for neutered ones, whereas that for unneutered males was twice as high as that of neutered ones; mortality rates for sexually immature females and males were identical (Table 2).

3.2 | Cost-effectiveness neutering simulations

We present the results of three selected examples from the 10,404 simulations, each representing different levels of neutering efforts: low, intermediate, and high.

In the first scenario, a low neutering effort targeted 10 males and 10 females once per year. Initially, the population size decreased due to the immediate effects of neutering. However, this was followed by a

significant increase in population size (Figure 3), with an estimated cost of 6690€ (95% CI 6674€–6707€) over a 60-month period.

The second scenario involved an intermediate effort, where 10 males and 10 females were neutered twice per year. This approach resulted in a relatively stable population over the 60-month period, suggesting a balance between neutering and natural population growth (Figure 4), with an expected cost of 12,644€ (95% CI 8018€–13,534€).

In the high-effort scenario, 15 males and 15 females were neutered three times per year, leading to a rapid and sustained population decline (Figure 5), at an expected cost of 9508€ (95% CI 7788€–11,917€).

In addition to these examples, Table 3 summarizes 36 additional scenarios, offering further insights into population control dynamics and associated costs on Linosa. Increasing the frequency of neutering, from one to four times per year, consistently resulted in greater

Example 1 – Low neutering effort (10 females and 10 males, once a year)

Total population (unneutered and neutered, sexually mature)

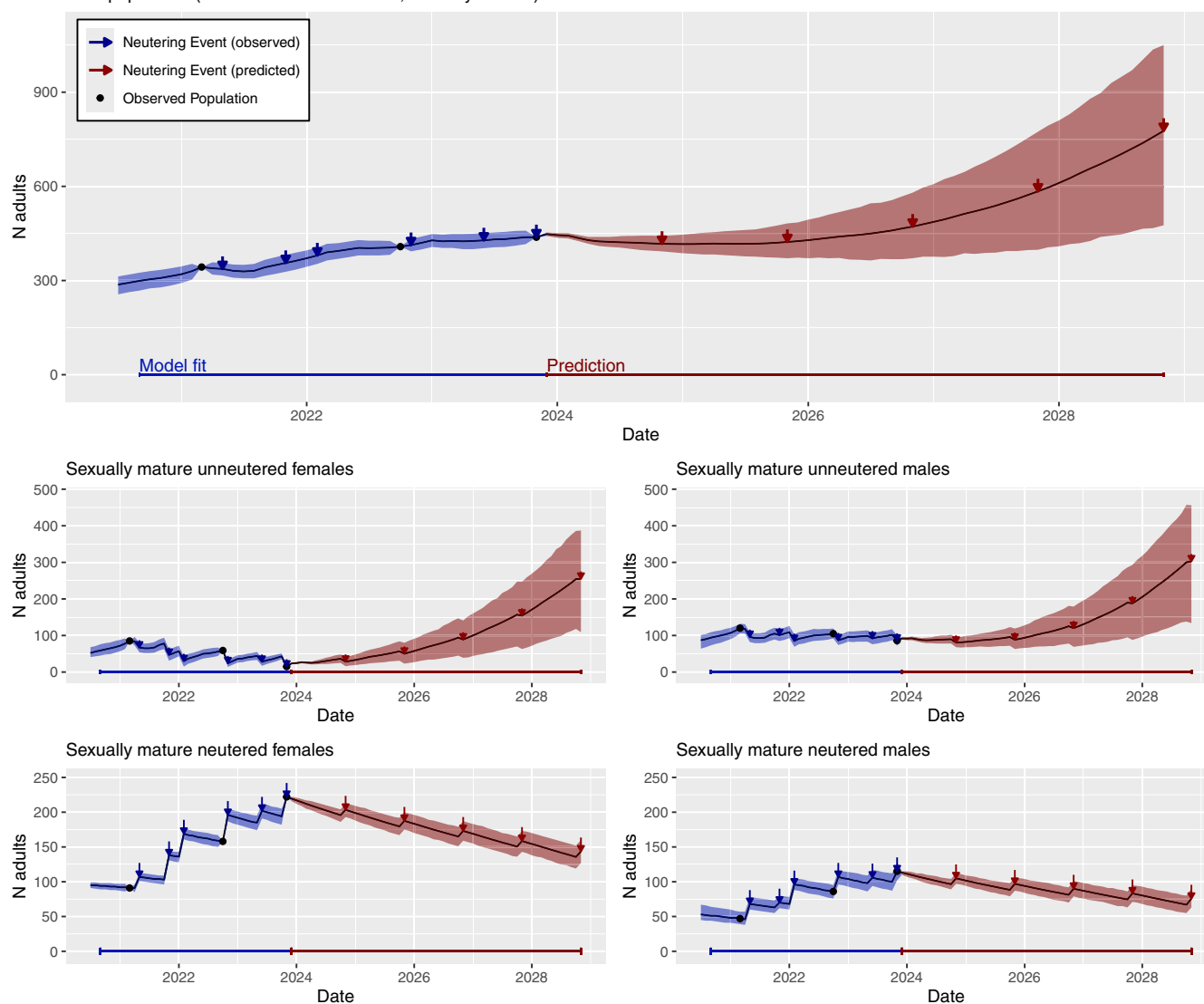


FIGURE 3 Impact of low neutering effort, targeting 10 males and 10 females once per year on cat population dynamics over a 60-month simulation period. The graphs present the trajectory of the total cat population, with red projections denoting the simulation period beyond the latest observed data point, showcasing an increased population trend.

population reductions and more precise estimates, as indicated by narrower confidence intervals. For instance, neutering 20 males and 20 females once per year led to an estimated 32.0% population decrease after 60 months, though the wide confidence intervals crossing zero (−47.5% to +5.5%) indicated uncertainty in the outcome.

Furthermore, scenarios focusing on neutering a higher number of females compared to males (e.g. 20 females and 5 males) consistently produced more significant population reductions across all neutering frequencies, even when performed at lower frequencies. For example, neutering 20 females and 5 males twice per year reduced the population by 45.4% (95% CI −50.2% to −39.9%) after 60 months, far more effective than neutering equal numbers of males and females or predominantly males (Table 3). Targeting more females also resulted in narrower confidence intervals, indicating greater reliability of the estimated population changes.

While higher neutering frequencies and a focus on females generally led to better outcomes in terms of population control, they also incurred higher costs (Table 3). However, these costs were partially offset by the significant population reductions achieved, resulting in the most cost-effective scenario.

Figure 6 further illustrates the relationship between neutering scenarios, total costs (left column), and population changes (right column). The left column shows that increasing both the number of animals sterilised and the frequency of sterilization consistently raised total costs. Meanwhile, the right column demonstrates that targeting more females for neutering, especially when combined with more frequent sessions, consistently resulted in greater population declines. Notably, scenarios focusing on female sterilization achieved more substantial reductions in population size, even at lower frequencies. In contrast, strategies involving the

Example 2 – Intermediate neutering effort (10 females and 10 males, twice a year)

Total population (unneutered and neutered, sexually mature)

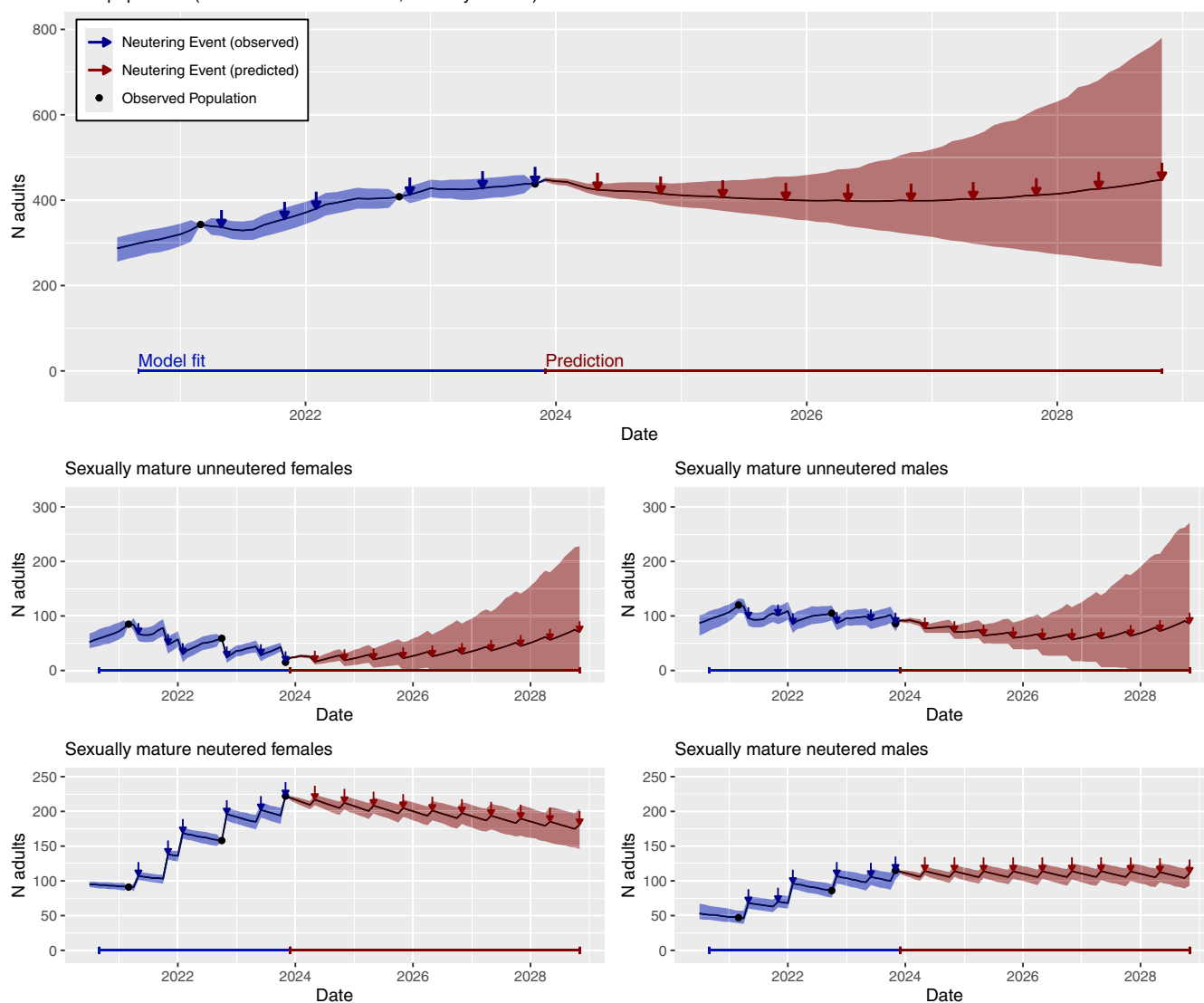


FIGURE 4 Impact of intermediate neutering effort, targeting 10 males and 10 females twice per year on the cat population over a 60-month simulation period. The graphs present the trajectory of the total cat population, with red projections denoting the simulation period beyond the latest observed data point, showcasing a stable population trend.

neutering of more males yielded the highest costs with minimal benefits for population control, as shown in the bottom right corners of both columns.

3.3 | Online dashboard

The online dashboard is available at https://boydorr.gla.ac.uk/lucanelli/Cats_PVA/. In the first panel, users can explore the predicted outcomes of custom neutering scenarios related to the current study by specifying the frequency of neutering sessions and numbers of neutered females and males per session (Figure 7a). Beyond the GUI, the dashboard incorporates interactive 3D plots that provide a deeper visualization of the population dynamics and cost implications associated with different neutering efforts

(Figure 7b). As a further customization, the dashboard includes an additional panel where users can specify parameters for custom simulations (Figure 7c). This allows users to input their initial population levels, including the number of males and females, their reproductive state, and the number of sexually immature individuals. Users can also adjust average litter size, average monthly mortality rates, and average birth rates, enabling tailored simulations that reflect specific population scenarios and management strategies.

4 | DISCUSSION

Our Bayesian statistical model provided insights into the dynamics of the cat population on the island of Linosa and the effectiveness,

Example 3 – High neutering effort (15 females and 15 males, three times a year)

Total population (unneutered and neutered, sexually mature)

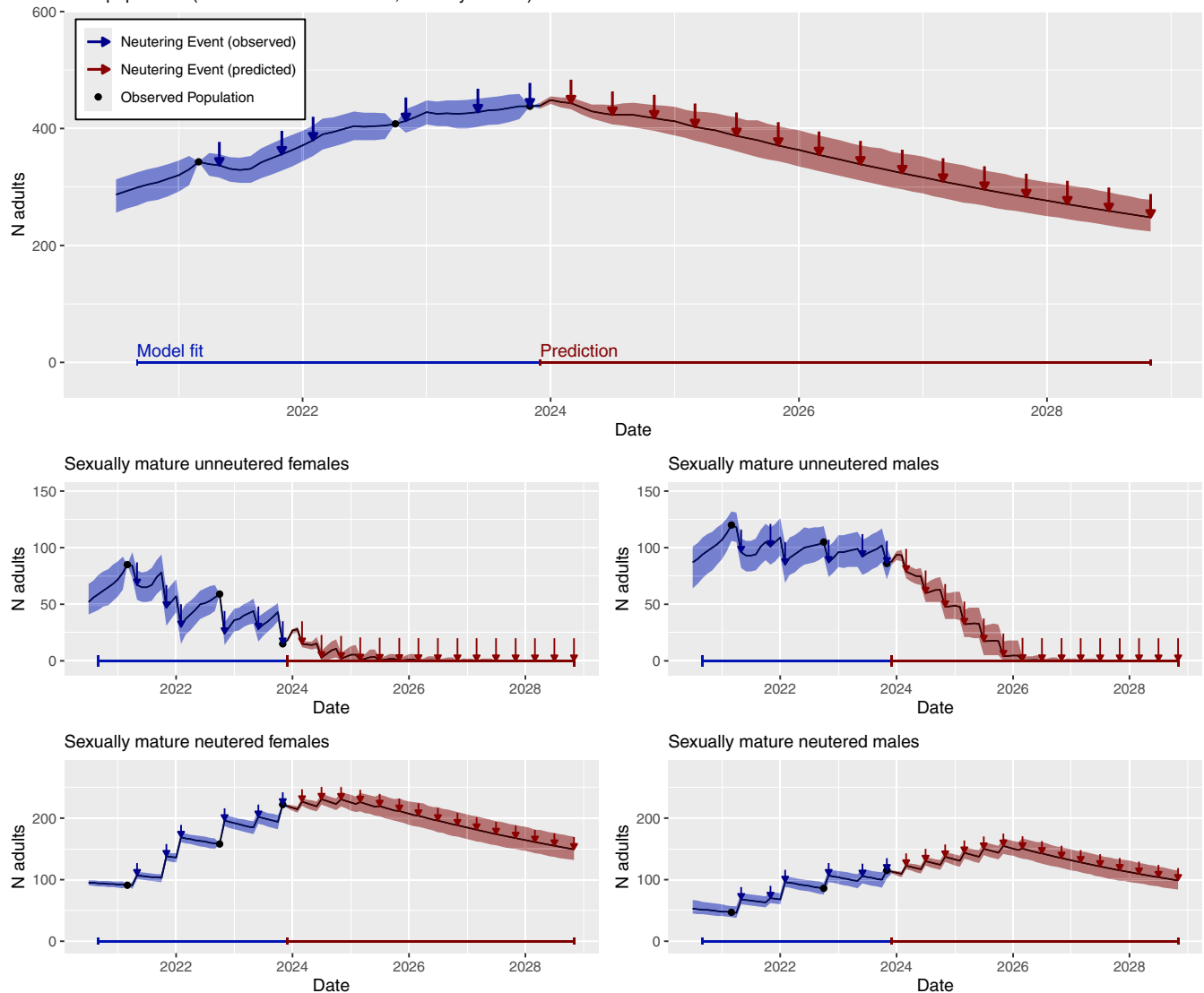


FIGURE 5 Impact of high neutering effort, targeting 15 males and 15 females three times per year on the cat population over a 60-month simulation period. The graphs present the trajectory of the total cat population, with red projections denoting the simulation period beyond the latest observed data point, showcasing a decrease in the population trend.

as well as the various costs, associated with different neutering scenarios. Our model was not individual-based, which allowed us to focus on population-level dynamics. This approach provided a computationally efficient and practical framework, enabling us to estimate overall population trends and the impacts of neutering scenarios effectively, even with the limitations of the available data.

Over the three-year study period, the cat population increased, which may be partly explained by the reduced mortality of neutered individuals compared to unneutered ones. This reduction in mortality can be attributed to several factors, including a decrease in morbidity likely resulting from reduced roaming (Ferreira et al., 2020) and reproductive behaviours, and improved body condition, which enhances cat welfare and increases survival rates for free-roaming neutered cats (Gunther et al., 2018, 2022).

Moreover, specific local attitudes and beliefs about neutering may have contributed to an initial population increase. Misconceptions—such as the belief that ‘neutering males is unnatural’ or that ‘neutered cats stop catching mice’—have limited the effectiveness of some sterilization efforts. While we were prepared to sterilize a larger number of cats, these attitudes constrained participation, and the total number of neutered individuals (280 across six sessions) did not approach the full population of free-roaming cats on the island. This underscores the importance of organizing pre-neutering campaigns to raise awareness, correct misinformation and foster positive community attitudes, ensuring full participation and cooperation from local residents (McDonald et al., 2018).

Our model highlighted the significance of high-frequency, female-focused sterilization efforts for achieving long-term population control and cost efficiency. These findings can inform strategic planning and

TABLE 3 Summary of the possible neutering scenarios, each based on 1000 simulations.

Neutering frequency	Neutered females	Neutered males	Average total cost (€)	Average population change (%)
1/year	5	5	3437 (3430/3452)	87.7 (24.4/153.2)
	5	10	5079 (5068/5101)	87.5 (32/156.2)
	5	20	8364 (8345/8389)	88.1 (27.8/153.8)
	10	5	5080 (5068/5112)	31.1 (-35.0/101.9)
	10	10	6715 (6641/6772)	32.5 (-35.0/99.6)
	10	20	9998 (9984/10,049)	35.1 (-28.6/109.0)
	20	5	5955 (4020/8040)	-34.1 (-48.1/12.0)
	20	10	7678 (5593/9689)	-33.4 (-47.9/3.2)
	20	20	10,299 (7062/12,999)	-32.0 (-47.5/5.5)
2/year	5	5	6890 (6849/6958)	49.8 (-20.5/121.0)
	5	10	10,187 (10,142/10,257)	52.2 (-14.9/122.4)
	5	20	16,465 (13,900/16,800)	54.7 (-12.3/122.8)
	10	5	7721 (5746/10,257)	-35.0 (-48.5/14.1)
	10	10	10,091 (6925/13,545)	-34.1 (-47.4/9.5)
	10	20	11,970 (8005/20,066)	-32.3 (-47.4/23.1)
	20	5	6323 (5483/7450)	-45.4 (-50.2/-39.9)
	20	10	7717 (6466/9481)	-44.4 (-49.2/-38.2)
	20	20	8847 (7515/10,727)	-43.7 (-49.0/-37.9)
3/year	5	5	10,166 (7634/10,486)	12.9 (-43.9/89.4)
	5	10	14,498 (9044/15,402)	12.4 (-42.3/79.7)
	5	20	19,413 (10,290/25,086)	14.0 (-41.7/94.2)
	10	5	7756 (6323/10,159)	-43.9 (-49.4/-37.4)
	10	10	8873 (7240/11,210)	-43.4 (-49.3/-37.8)
	10	20	9901 (8127/12,880)	-42.7 (-48.3/-34.6)
	20	5	7099 (6126/8323)	-45.6 (-50.5/-40.2)
	20	10	8175 (7078/9831)	-44.6 (-49.5/-39.0)
	20	20	9033 (7865/10,879)	-44.2 (-49.0/-39.0)
4/year	5	5	11,510 (7454/13,982)	-23.9 (-47.1/36.1)
	5	10	14,053 (8476/20,536)	-25.2 (-46.2/42.3)
	5	20	16,260 (9228/28,507)	-21.0 (-46.3/50.8)
	10	5	7924 (6738/9297)	-44.9 (-50.0/-40.0)
	10	10	8838 (7690/10,508)	-44.4 (-49.6/-39.0)
	10	20	9652 (8345/11,263)	-43.8 (-48.5/-38.4)
	20	5	7474 (6641/8673)	-45.9 (-50.8/-41.4)
	20	10	8411 (7590/9590)	-45.3 (-50.5/-40.7)
	20	20	9153 (8214/10,477)	-44.9 (-49.0/-40.2)

Note: Showcases 36 scenarios from over 10,404 of those analysed, highlighting differences in neutering frequency (from one neutering session to four per year), the possible number of gender-targeted individuals, estimated total costs (mean and 95% Confidence Intervals) and average population change over 60 months reported in percentage (mean and 95% CI), across the four frequency categories.

resource allocation for future population management initiatives on Linosa, ensuring interventions are both sustainable and effective.

Our analysis revealed that intense neutering efforts, particularly those targeting females, do not necessarily result in proportionally higher long-term costs. This outcome is likely because a rapid decline in the fertile population reduces the need for future sterilization, lowering ongoing expenses. In scenarios involving the most intense

neutering efforts—both in frequency and the number of cats neutered—costs did not increase proportionally to the intensity of the efforts. This effect is due to the swift reduction in unneutered individuals, ultimately decreasing the number of animals requiring further intervention. In contrast, lower-intensity neutering programs, while still reducing population size over time, generally were less cost-effective than more intensive approaches (Benka et al., 2022).

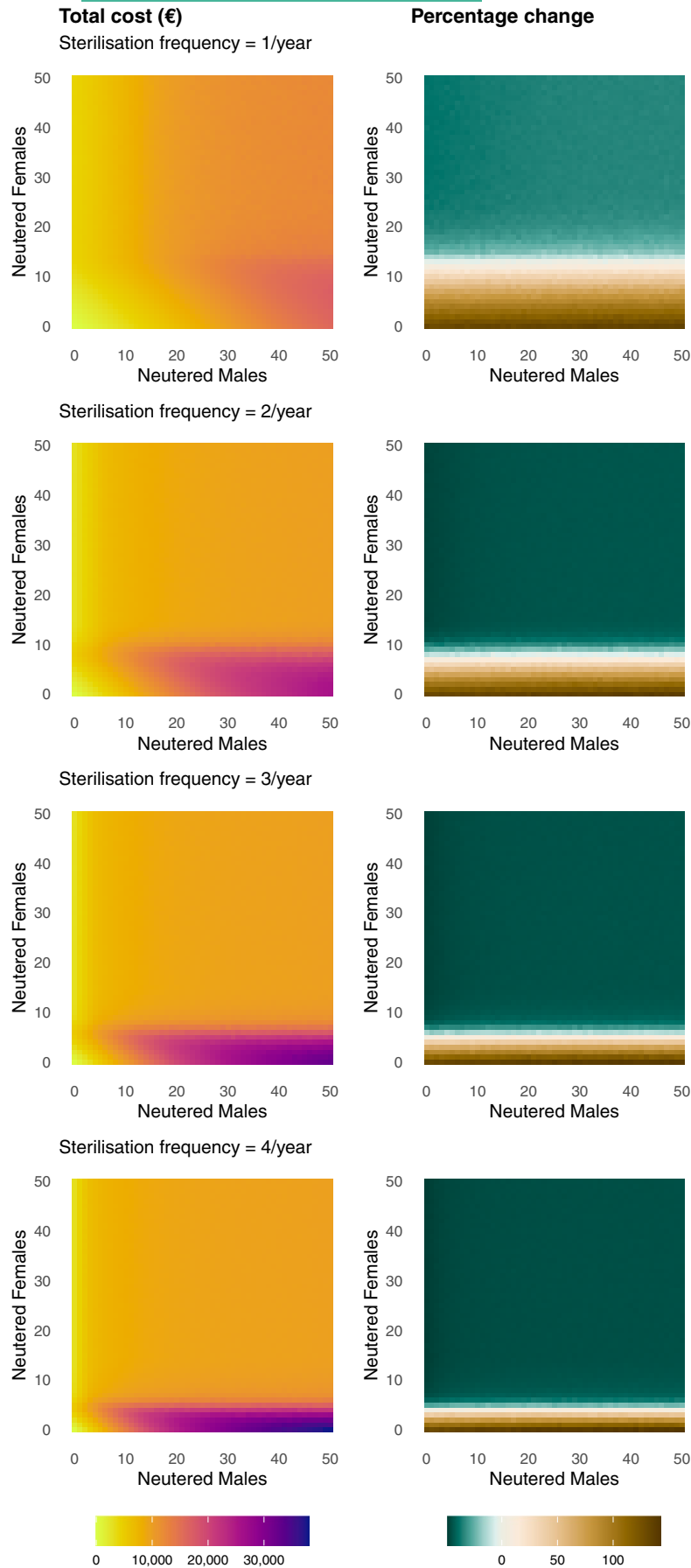


FIGURE 6 Comparative analysis of simulated neutering scenarios on the number of males and females, total cost (€), and percentage population changes over 60 months. The plots are divided into four neutering frequency categories (1/year, 2/year, 3/year, 4/year). The left column shows the total cost associated with each scenario, and the right column displays the percentage change in the cat population.

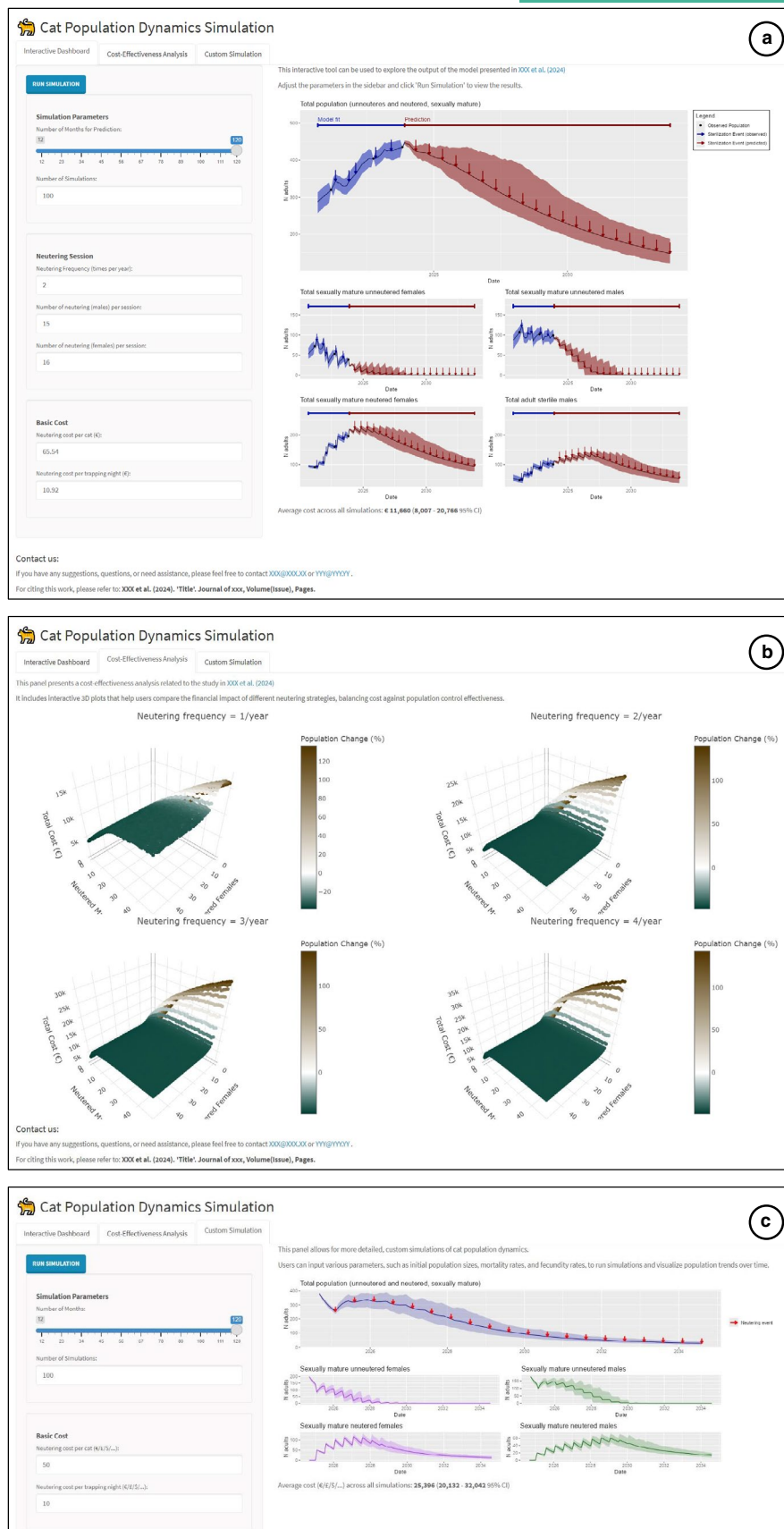


FIGURE 7 Screenshot of the interactive dashboard for neutering scenario visualization. The online tool allows users to modify parameters related to neutering efforts and visualize the outcomes through both GUI elements and 3D plots, illustrating the impact on cat population dynamics and associated costs. Accessible at https://boydorr.gla.ac.uk/lucanelli/Cats_PVA/.

Another important finding from our simulations was the variation in the precision of population estimates across different sterilization scenarios. Scenarios with high-frequency, female-focused sterilization efforts tended to result in narrower confidence intervals for the estimated population changes. This likely reflects the higher representation of neutered females compared to males in the study area, which reduces uncertainty in female-focused scenarios due to the structure of the underlying data. Consequently, these findings suggest that the model's precision may be enhanced in contexts where female neutering predominates. However, caution should be exercised when generalizing this result to other settings with different neutering distributions, as the asymmetry in the representation of males and females in the data could influence the model's performance. For example, scenarios with less frequent sterilization events showed greater uncertainty in their outcomes, indicating considerable variability. By contrast, more frequent neutering scenarios showed more pronounced population reductions and much narrower confidence intervals, indicating a higher level of precision and reliability in the results.

Thus, when planning management strategies, planners should consider not only the average expected outcomes in terms of cost and population reduction but also the precision of these estimates within the specific context of the model. Choosing strategies with narrower confidence intervals can help ensure more predictable results, thereby reducing the risks associated with uncertainty in population management. In our study, female-focused neutering scenarios showed narrower confidence intervals due to the model's structure, where more females were neutered, leading to reduced uncertainty in population estimates. However, this should not be interpreted as the sole reason to prioritize female sterilization for the sake of precision; rather, female-focused neutering is recommended because it is generally more effective in controlling population size.

The connectivity between cat subpopulations plays a significant role in population dynamics. Changes in the number of cats within each subpopulation can significantly impact the dynamics of the whole population (McDonald et al., 2023). Therefore, on Linosa, we targeted both unowned and owned cats for neutering. We strongly recommend that any neutering campaign address all subpopulations, given their dynamic and interlinked nature, with cats moving and breeding among them, to ensure a long-term reduction in the number of all free-roaming cats.

One limitation of our model and web application is that it is calibrated for a closed population of cats, where immigration rates are negligible, apart from sporadic adoptions from nearby islands. In an open environment, high-intensity neutering efforts are often counteracted by the immigration of intact cats from surrounding unneutered populations, highlighting the importance of implementing neutering in spatially contiguous areas to mitigate this effect (Gunther et al., 2022). Moreover, it is important to address social factors impacting the immigration of new cats (especially intact ones) and to ideally focus on areas for intervention that have some

natural or artificial barriers (e.g. bodies of water) to reduce immigration. Future improvements to our tool could involve incorporating estimates of immigration rates when applied to mainland settings or larger islands. Additionally, the model's results could be applied to urban environments, particularly in areas constrained by natural or man-made barriers such as highways or large water bodies, where immigration is similarly limited, resembling the dynamics of closed populations. Regardless of the context—open or closed—faster population reduction can be achieved by complementing neutering with the adoption of unowned, sociable kittens and adults (Benka et al., 2022). However, on remote islands like Linosa, such a complementary measure is unfeasible.

While neutering effectively reduces cat reproduction, it does not eliminate hunting behaviours. Thus, as long as cats remain free to roam, they will continue to pose a threat to wildlife. When funding allows, complementary strategies can be employed to reduce hunting tendencies, such as providing high meat content food and engaging in daily playtime (Cecchetti et al., 2021), or using collar-mounted devices like the BirdsBeSafe collar cover, especially when the conservation of birds is a priority (Cecchetti et al., 2021; Pemberton & Ruxton, 2019).

Managing free-roaming cat populations presents numerous challenges, including the need for effective collaboration among scientists, policymakers, and animal welfare organizations to develop practical, time-efficient, and cost-effective strategies for population control. Unlike previous empirical studies that rely on complex population models and offer only general guidance on neutering programs, our tool offers a customizable, user-friendly web application accessible to anyone involved in cat management, allowing them to generate detailed timelines and identify the necessary resources for effectively controlling cat populations over time.

Our tool is designed not only to identify the most cost-effective strategy for managing free-roaming cat populations but also to allow users to select neutering scenarios that offer the greatest precision in terms of estimated population changes. The ability to visualize confidence intervals for different management scenarios helps stakeholders balance cost considerations with the need for reliable and predictable outcomes. For example, while some strategies may appear cost-effective at first glance, they might also carry a high degree of uncertainty in their outcomes, as reflected in wider confidence intervals for population change. This functionality is particularly valuable when management resources are limited or when specific population targets are critical. Users can directly assess trade-offs between cost and uncertainty, selecting strategies that minimize the risk of unexpected outcomes and reduce the likelihood of needing additional interventions later.

AUTHOR CONTRIBUTIONS

Martina Cecchetti and Luca Nelli conceived the ideas and designed the methodology; Martina Cecchetti collected the data; Luca Nelli developed the model and analysed the data; Martina Cecchetti and Luca Nelli led the writing of the manuscript. All authors approved the final version for publication.

ACKNOWLEDGEMENTS

We thank all cat owners and caretakers for their participation; the Public Health Authority of Palermo and Paolo Santanera for performing surgeries; Giacomo Dell'Omo and Giulia Giambalvo for assisting in neutering activities; and Berta Maris and Ornis Italica for logistical support. In 2022, Action Project Animal provided financial support for the census and neutering sessions.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The cat census and neutering datasets are part of the ongoing 'Cats of Linosa' project, managed by Berta Maris. Data available via the Dryad Digital Repository <https://doi.org/10.5061/dryad.j9kd51cq8> (Cecchetti & Nelli, 2025).

ORCID

Martina Cecchetti  <https://orcid.org/0000-0003-3962-8834>

Luca Nelli  <https://orcid.org/0000-0001-6091-4072>

REFERENCES

- Baker, P. J., Bentley, A. J., Ansell, R. J., & Harris, S. (2005). Impact of predation by domestic cats *Felis catus* in an urban area. *Mammal Review*, 35(3–4), 302–312.
- Beckerman, A. P., Boots, M., & Gaeston, K. J. (2007). Urban bird declines and the fear of cats. *Animal Conservation*, 10, 320–325.
- Benka, V. A., Boone, J. D., Miller, P. S., Briggs, J. R., Anderson, A. M., Sloomaker, C., Slater, M., Levy, J. K., Nutter, F. B., & Zawistowski, S. (2022). Guidance for management of free-roaming community cats: A bioeconomic analysis. *Journal of Feline Medicine and Surgery*, 24(10), 975–985.
- Blancher, P. (2013). Estimated number of birds killed by house cats (*Felis catus*) in Canada. *Avian Conservation and Ecology*, 8(2), 3.
- Bonnington, C., Gaston, K. J., Evans, K. L., & Whittingham, M. (2013). Fearing the feline: Domestic cats reduce avian fecundity through trait-mediated indirect effects that increase nest predation by other species. *Journal of Applied Ecology*, 50(1), 15–24.
- Boone, J. D., Miller, P. S., Briggs, J. R., Benka, V. A. W., Lawler, D. F., Slater, M., Levy, J. K., & Zawistowski, S. (2019). A long-term lens: Cumulative impacts of free-roaming cat management strategy and intensity on preventable cat mortalities. *Frontiers in Veterinary Science*, 6, 238.
- Bradshaw, J. W. S., Horsfield, G. F., Allen, J. A., & Robinson, I. H. (1999). Feral cats: Their role in the population dynamics of *Felis catus*. *Applied Animal Behaviour Science*, 65, 273–283.
- Cecchetti, M., Crowley, S. L., Goodwin, C. E. D., & McDonald, R. A. (2021). Provision of high meat content food and object play reduce predation of wild animals by domestic cats *Felis catus*. *Current Biology*, 31(5), 1107–1111.e5.
- Cecchetti, M., Janni, O., Corso, A., & Dell'Omo, G. (2023). Cat predation on wild birds and associated cat population management on Linosa Island. *Libro degli Abstract, XX Congresso Italiano di Ornitologia*, 2023.
- Cecchetti, M., & Nelli, L. (2025). Data from: Planning and optimizing neutering programs for free-roaming cat populations: an interactive tool for cost-effective management closed system. *Dryad Digital Repository*. <https://doi.org/10.5061/dryad.j9kd51cq8>
- Chang, W., Cheng, J., Allaire, J., Sievert, C., Schloerke, B., Xie, Y., Allen, J., McPherson, J., Dipert, A., & Borges, B. (2024). *Shiny: Web application framework for R*. R package version 1.8. 1.9000.
- Crowley, S. L., Cecchetti, M., & McDonald, R. A. (2020). Our wild companions: Domestic cats in the Anthropocene. *Trends in Ecology & Evolution*, 35(6), 477–483.
- Ferreira, G. A., Machado, J. C., Nakano-Oliveira, E., Andriolo, A., & Genaro, G. (2020). The effect of castration on home range size and activity patterns of domestic cats living in a natural area in a protected area on a Brazilian Island. *Applied Animal Behaviour Science*, 230, 105049. <https://doi.org/10.1016/j.applanim.2020.105049>
- Gerhold, R. W., & Jessup, D. A. (2013). Zoonotic diseases associated with free-roaming cats. *Zoonoses and Public Health*, 60(3), 189–195.
- Gunther, I., Finkler, H., & Terkel, J. (2011). Demographic differences between urban feeding groups of neutered and sexually intact free-roaming cats following a trap-neuter-return procedure. *Journal of the American Veterinary Medical Association*, 238, 1134–1140.
- Gunther, I., Hawlena, H., Azriel, L., Gibor, D., Berke, O., & Klement, E. (2022). Reduction of free-roaming cat population requires high-intensity neutering in spatial contiguity to mitigate compensatory effects. *Proceedings of the National Academy of Sciences of the United States of America*, 119(15), e2119000119.
- Gunther, I., Raz, T., & Klement, E. (2018). Association of neutering with health and welfare of urban free-roaming cat population in Israel, during 2012–2014. *Preventive Veterinary Medicine*, 157, 26–33.
- Ireland, T., & Neilan, R. M. (2016). A spatial agent-based model of feral cats and analysis of population and nuisance controls. *Ecological Modelling*, 337, 123–136.
- Jennett, A. L., Jennett, N. M., Hopping, J., & Yates, D. (2015). Evidence for seasonal reproduction in UK domestic cats. *Journal of Feline Medicine and Surgery*, 18(10), 804–808.
- Kellner, A., Carver, S., Scorza, V., McKee, C. D., Lappin, M., Crooks, K. R., Van de Woude, S., & Antolin, M. F. (2018). Transmission pathways and spillover of an erythrocytic bacterial pathogen from domestic cats to wild felids. *Ecology and Evolution*, 8(19), 9779–9792. <https://doi.org/10.1002/ece3.4451>
- Loss, S. R., & Marra, P. P. (2017). Population impacts of free-ranging domestic cats on mainland vertebrates. *Frontiers in Ecology and the Environment*, 15(9), 502–509.
- Loss, S. R., Will, T., & Marra, P. P. (2013). The impact of free-ranging domestic cats on wildlife of the United States. *Nature Communications*, 4, 1396.
- Maeda, T., Nakashita, R., Shionosaki, K., Yamada, F., & Watari, Y. (2019). Predation on endangered species by human-subsidized domestic cats on Tokunoshima Island. *Scientific Reports*, 9(1), 1–11.
- McDonald, J. L., Farnworth, M. J., & Clements, J. (2018). Integrating trap-neuter-return campaigns into a social framework: Developing long-term positive behavior change toward unowned cats in urban areas. *Frontiers in Veterinary Science*, 5, 258. <https://doi.org/10.3389/fvets.2018.00258>
- McDonald, J. L., Finka, L., Foreman-Worsley, R., Skillings, E., & Hodgson, D. (2023). Cat: Empirical modelling of *Felis catus* population dynamics in the UK. *PLoS One*, 18(7), e0287841.
- McNie, E. C. (2007). Reconciling the supply of scientific information with user demands: An analysis of the problem and review of the literature. *Environmental Science & Policy*, 10(1), 17–38. <https://doi.org/10.1016/j.envsci.2006.10.004>
- Neal, S. M., & Wolf, P. J. (2023). A cat is a cat: Attachment to community cats transcends ownership status. *Journal of Shelter Medicine and Community Animal Health*, 2(1), 62.
- Palmas, P., Gouyet, R., Oedin, M., Millon, A., Cassan, J.-J., Kowi, J., Bonnaud, E., & Vidal, E. (2020). Rapid recolonisation of feral cats following intensive culling in a semi-isolated context. *NeoBiota*, 63, 177–200.
- Pemberton, C., & Ruxton, G. D. (2019). Birdsbesafe® collar cover reduces bird predation by domestic cats (*Felis catus*). *Journal of Zoology*, 310(2), 106–109.

- Peterson, M. N., Hartis, B., Rodriguez, S., Green, M., & Lepczyk, C. A. (2012). Opinions from the front lines of cat colony management conflict. *PLoS One*, 7(9), e44616.
- Plummer, M. (2003). JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. *Proceedings of the 3rd international workshop on distributed statistical computing* 124(125.10), 1–10.
- Plummer, M., Stukalov, A., & Denwood, M. (2016). Rjags: Bayesian graphical models using MCMC. *R Package Version*, 4(6), 4.
- R Core Team. (2024). *R: A language and environment for statistical computing [computer software]*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- RSPCA Australia. (2018). *Identifying best practice domestic cat management in Australia*. <https://kb.rspca.org.au/wp-content/uploads/2019/01/Identifying-Best-Practice-Domestic-Cat-Management-in-Australia-RSPCA-Research-Report-May-2018.pdf>
- Trouwborst, A., McCormack, P. C., & Martínez Camacho, E. (2020). Domestic cats and their impacts on biodiversity: A blind spot in the application of nature conservation law. *People and Nature*, 2(1), 235–250.
- Vansandt, L. M. (2022). Feline estrous cycle. In *Feline reproduction* (pp. 11–22). CABI.
- Vigne, J.-D., Carrere, I., Briois, F., & Guilaine, J. (2011). The early process of mammal domestication in the near east: New evidence from the pre-Neolithic and pre-pottery neolithic in Cyprus. *Current Anthropology*, 52(S4), S255–S271.
- Webster, C., Massaro, M., Michael, D., Bambrick, D., Riley, J., & Nimmo, D. (2018). Native reptiles alter their foraging in the presence of the olfactory cues of invasive mammalian predators. *Royal Society Open Science*, 5(10), 180136.
- Woinarski, J. C. Z., Murphy, B. P., Legge, S. M., Garnett, S. T., Lawes, M. J., Comer, S., Dickman, C. R., Doherty, T. S., Edwards, G., Nankivell, A., Paton, D., Palmer, R., & Woolley, L. A. (2017). How many birds are killed by cats in Australia? *Biological Conservation*, 214, 76–87.
- Wolf, P. J., & Hamilton, F. (2022). Managing free-roaming cats in US cities: An object lesson in public policy and citizen action. *Journal of Urban Affairs*, 44(2), 221–242.
- Wolf, P. J., & Schaffner, J. E. (2019). The road to TNR: Examining trap-neuter-return through the lens of our evolving ethics. *Frontiers in Veterinary Science*, 5, 341.
- Woolley, L.-A., Murphy, B. P., Geyle, H. M., Legge, S. M., Palmer, R. A., Dickman, C. R., Doherty, T. S., Edwards, G. P., Riley, J., & Turpin, J. M. (2020). Introduced cats eating a continental fauna: Invertebrate consumption by feral cats (*Felis catus*) in Australia. *Wildlife Research*, 47(8), 610–623.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1: Cat census questionnaire.

Appendix S2: Example of written informed consent obtained from participants.

Appendix S3: Comparison between Prior and Posterior distribution for model parameters.

How to cite this article: Cecchetti, M., & Nelli, L. (2025).

Planning and optimizing neutering programs for free-roaming cat populations: An interactive tool for cost-effective management in closed systems. *Journal of Applied Ecology*, 62, 1421–1436. <https://doi.org/10.1111/1365-2664.70052>