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Contributed Paper

Costs and Benefits of Trap-Neuter-Release and Euthanasia for Removal of Urban Cats in Oahu, Hawaii

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Abstract: *Our goal was to determine whether it is more cost-effective to control feral cat abundance with trap-neuter-release programs or trap and euthanize programs. Using STELLA 7, systems modeling software, we modeled changes over 30 years in abundance of cats in a feral colony in response to each management method and the costs and benefits associated with each method . We included costs associated with providing food, veterinary care, and microchips to the colony cats and the cost of euthanasia, wages, and trapping equipment in the model. Due to a lack of data on predation rates and disease transmission by feral cats the only benefits incorporated into the analyses were reduced predation on Wedge-tailed Shearwaters (*Puffinus pacificus*). When no additional domestic cats were abandoned by owners and the trap and euthanize program removed 30,000 cats in the first year, the colony was extirpated in at least 75% of model simulations within the second year. It took 30 years for trap-neuter-release to extirpate the colony. When the cat population was supplemented with 10% of the initial population size per year, the colony returned to carrying capacity within 6 years and the trap and euthanize program had to be repeated, whereas trap-neuter-release never reduced the number of cats to near zero within the 30-year time frame of the model. The abandonment of domestic cats reduced the cost effectiveness of both trap-neuter-release and trap and euthanize. Trap-neuter-release was approximately twice as expensive to implement as a trap and euthanize program. Results of sensitivity analyses suggested trap-neuter-release programs that employ volunteers are still less cost-effective than trap and euthanize programs that employ paid professionals and that trap-neuter-release was only effective when the total number of colony cats in an area was below 1000. Reducing the rate of abandonment of domestic cats appears to be a more effective solution for reducing the abundance of feral cats.*

Keywords: bird depredation, cat colony, pet abandonment, policy, population dynamics

Costos y Beneficios de Captura-Esterilización-Liberación y Eutanasia para la Remoción de Gatos Urbanos en Oahu, Hawaii

Resumen: *Nuestra meta fue determinar si es más rentable controlar la abundancia de gatos ferales con programas de captura-esterilización-liberación o con programas de captura y eutanasia. Utilizando STELLA 7, software para modelar sistemas, modelamos cambios a lo largo de 30 años en la abundancia de gatos en una colonia feral en respuesta a cada método de manejo, así como de los costos y beneficios asociados con cada uno. En el modelo incluimos los costos asociados con la alimentación, el cuidado veterinario y los microchips para la colonia de gatos y el costo de la eutanasia, los salarios y el equipo de captura. Debido a la falta de datos sobre las tasas de depredación y de transmisión de enfermedades por gatos ferales, la reducción de la depredación sobre* Puffinus pacificus *fueron los únicos beneficios incorporados en el análisis. Cuando no hubo abandono adicional de gatos por sus dueños y el programa de captura y eutanasia removió 30,000*

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gatos en el primer año, la colonia fue extirpada en por lo menos 75% de las simulaciones del modelo en el segundo año. Tomó 30 años para que la captura-esterilización-liberación extirpara la colonia. Cuando la población de gatos fue suplementada con 10% del tamaño poblacional inicial por año, la colonia regresó a la capacidad de carga en 6 años y se tenía que repetir el programa de captura y eutanasia, mientras que la captura-esterilización-liberación nunca redujo el número de gatos a casi cero en los 30 años del marco de tiempo del modelo. El abandono de gatos domésticos redujo la rentabilidad tanto de la captura-esterilización-liberación como de la captura y eutanasia. La implementación de la captura-esterilización-liberación costó casi el doble que el programa de captura y eutanasia. Los resultados de los análisis de sensibilidad sugirieron que los programas de captura-esterilización-liberación que emplean voluntarios son aun menos rentables que los programas de captura y eutanasia que emplean profesionales pagados y que la captura-esterilización-liberación solo fue efectiva cuando el número total de gatos en un área era menor a 1000. La reducción de la tasa de abandono de gatos domésticos parece ser una solución más efectiva para reducir la abundancia de gatos ferales.

Palabras Clave: Abandono de mascotas, colonia de gatos, depredación de aves, dinámica de poblaciones, política

Introduction

Feral cats (*Felis silvestris catus*) (Driscoll et al. 2007), that is domestic animals that have returned to a wild state and are not maintained by humans (Case et al. 2006), are thought to cause billions of dollars' worth of damage to the natural environment (Pimentel et al. 2005) through predation (Lepczyk et al. 2004) and disease transmission (Conrad et al. 2005). For example, feral cat populations have been linked to reduction in bird diversity (Sims et al. 2008), extirpation of insular species (Medina et al. 2011), and toxoplasmosis (*Toxoplasma gondii*) infections in otters (*Enhydra lutris nereis*) (Miller et al. 2008), monk seals (*Monachus schauinslandi*) (Honnold et al. 2005), and dozens of species of birds (Work et al. 2002; Dubey 2010). Colonies of semiferal cats (i.e., cats that consume some food and water provided by humans, including garbage) have a similar variety of effects on the environment in California (Hawkins et al. 2004), Brazil (Mendes-de-Almeida et al. 2007), and Europe (Bonnaud et al. 2011).

Feral cats are frequently managed via trapping and euthanasia (Short et al. 2002; Hess et al. 2009); however, urban semiferal cats are difficult to manage with trap and euthanasia because the close proximity of people restricts the use of potentially dangerous or emotionally upsetting methods of removal. Hence, many jurisdictions in the United States have adopted programs or policies in which urban semiferal cats are trapped and sterilized and then returned to the environment to be fed and cared for by volunteers (Longcore et al. 2009). These programs are commonly referred to as trap-neuter-release programs. Cats managed via trap-neuter-release frequently form high-density populations or colonies at feeding sites (hereafter colony cats). The act of feeding colony cats may result in other free-roaming unsterilized cats joining existing colonies. Ideally, these new cats are trapped, sterilized, and returned to the colony.

Management of urban semi-feral cats is controversial. Supporters of trap-neuter-release assert that abundance of cats in managed colonies decreases as mortality exceeds fecundity (Levy 2003; Winter 2004). In many situations, however, trap-neuter-release programs are either unable to sterilize enough colony cats for mortality to exceed fecundity or immigration maintains high abundance (Clarke & Pacin 2002; Schmidt et al. 2009). For example, an assessment of 10 years of trap-neuter-release in Rome, Italy (a country that does not allow feral cats to be killed) concluded that trap-neuter-release was "a waste of time, energy, and money" if domestic cats were abandoned because they immigrate to colonies (Natoli et al. 2006). Similarly, in Florida (U.S.A.) immigration caused cat colonies to increase in size (Castillo & Clarke 2003). People who highly value the lives of individual cats tend to favor trap-neuter-release, whereas people who highly value the natural environment and wild animals tend to be less supportive of trap-neuter-release. Because of this value difference, management of feral cats has become a politically sensitive issue.

The economics of cat management, particularly in urban areas, generally have not been estimated. Few researchers have attempted to estimate the costs associated with feral cats. Loyd and DeVore (2010) connect estimates of operational costs and conditional probabilities of management outcomes of 3 variations of trap-neuter-release, plus trap and euthanize, and a do-nothing scenario into a Bayesian decision network, but they did not compare the economic costs and benefits of each trap-neuter-release and trap and euthanize program.

Our goal was to determine whether trap-neuter-release or trap and euthanize programs are cost-effective methods of managing cats. We conducted our work in Hawaii because it has a feral-cat problem (Smith et al. 2002; Hess et al. 2009). Due to Hawaii's tropical climate and lack of larger predators, free-roaming cats face few threats and may form large persistent colonies. Hawaii also has a preponderance of endangered species (USFWS 2009*b*), which may be threatened by the predation (Smith et al. 2002) and disease risk posed by cats (Work et al. 2000). In Hawaii cat colonies occur in urban and semiurban environments. Cat ownership regulations and urban cat management are the prerogatives of state and county legislatures. Therefore, economic models that cross state boundaries may be less effective at informing policy and management.

Methods

In Hawaii cats are typically managed in one of 2 ways, either through trap and euthanasia performed by wildlife professionals or through the trap-neuter-return-manage program supported by the Hawaii Humane Society on Oahu (Hawaii Humane Society 2012). Under the trap-neuter-return-manage program cat colony caretakers, members of the general public, register for the program by signing an agreement stating that they will provide basic care and management for each cat. Basic care and management includes sterilizing all colony members, removing kittens or socialized cats, providing necessary food, veterinary care, and microchip identification. Cats are trapped via cage traps. The Hawaii Humane Society charges caretakers a subsidized fee of $25 per cat sterilized under the trap-neuter-return-manage program.

We built a model that projected cat abundance in response to each management technique and estimated the costs and benefits of each technique over 30 years. We built the model with STELLA 7.0.3, a systems-modeling program (Gilad et al. 2008; Schmidt et al. 2009). Because survival rates, number of kittens per litter, and percentage of females breeding varied randomly (normal distribution) (Table 1), we averaged outputs from 1000 iterations of each model simulation to generate abundance, cost, and benefit estimates. Discount rates of between 0.5% and 10% (used to convert future price estimates to their present value) rendered cost and benefit estimates accrued after 30 years negligible (<$100/year) (Federal Reserve 2009). Increasing the discount rate had a negative but not statistically significant effect on the costs and benefits of removing feral cats from the environment. We report the results of a model with a discount rate of 0.5%. For the results of our other model simulations see Supporting Information.

We made several assumptions in the design of our model due to a paucity of data on cat colony demographics or costs and benefits associated with cat colonies. First, we assumed the cats formed a single super colony rather than a metapopulation or multiple discrete colonies. Hence, we did not include cat density (density of populations) and area occupied by the colony in our model. Second, although we included an estimate of the dollar value of a bird's life, we could not include an estimate of the value of a cat's life in the model because to our knowledge no research has estimated the economic value of a feral cat to society. Third, we assumed the trap-neuter-release program provided funds necessary for purchasing cat food and veterinary care. In Hawaii caretakers of cat colonies are required to provide food and veterinary care, however, the funds are provided by the individual caretakers rather than an organization.

Estimates of Cat Population

The demographics portion of the model consisted of 5 life stages: year 0–1 birth, some young are lost to mortality events, others are captured for adoption, and the remainder are recruited into the breeding population (recruitment = number of females × number of litters × number of kittens [1 – (mortality rate + adoption rate)]); years 1–5 adults, demographic profile described in Table 1; year 4–5 death. We used Euler's method, in which calculations are made at the beginning of each time interval, to calculate abundance of cats per year. Outflows from a life stage were prioritized such that cats were trapped and treated according to a management program before natural mortality events occurred, and both events occurred before cats progressed to the next life stage. The total abundance of cats was equal to the sum of all of the adult life stages.

We based the initial number of colony cats on Oahu (16,700) on surveys indicating that each cat colony caretaker on Oahu manages approximately 13.9 cats (Zasloff & Hart 1998). We multiplied this average by 1200, the number of registered colony caretakers on Oahu (Table 1) (Williams 2009). Because populations of feral cats are frequently at carrying capacity (Gibson et al. 2002), we set the carrying capacity for the super colony at 25,000 individuals, which is greater than the initial abundance of colony cats. Because colony cats receive supplemental food and veterinary care, the true carrying capacity for colony cats cannot be estimated without measuring the maximum level of food and veterinary care caretakers are prepared to supply (Schmidt et al. 2009). The values for the sex ratio (Gibson et al. 2002; Andersen et al. 2004), age of first reproduction in years (Scott et al. 2002), maximum age of reproduction in years (Clarke & Pacin 2002), number of kittens per litter (Scott et al. 2002), number of litters per female (Levy & Crawford 2004), and annual adult survival rate (Andersen et al. 2004) were taken from studies on colony cats conducted in other tropical or subtropical climates (Table 1). The colony was assumed to have a stable age distribution (Say et al. 1999). The reproductive rate of females was set at 75% (Nutter et al. 2004). We set the baseline sterilization rate for the trap-neuter-release models at 15% because the Hawaii Humane Society sterilizes a mean of approximately 15% of the registered colony cats per year (Hawaii Humane Society, unpublished data). The survival

Table 1. Cost ratio of trap-neuter-release (TNR) to trap and euthanize (TE) and discrete benefits to cost ratios for TNR and TE.

		Variable elasticity[a]		
Model subset and parameter	*Baseline value*	*TNR:TE cost ratio*	*TNR benefit:cost*	*TE benefit:cost*
Demographics				
number of cats (range)	16,700 (1,000–20,000)	0.00009	−0.0002*	−0.0005*
carrying capacity	25,000	-	-	-
sex ratio	50:50	-	-	-
% adult survival (SD)	75 (10)	-	-	-
% kitten survival (SD)	50(10)	-	-	-
litters/female	1.5	-	-	-
number kittens/litter (SD)	3.6 (0.2)	-	-	-
% females breeding (SD)	75 (10)	-	-	-
% abandonment (range)	0 (1–10 of initial cat population)	−0.05**	−0.086**	−0.50**
Cost				
wages TNR:$/hour (range) TE:range $/hour (range)	TNR: 7.50 (0–7.50) TE: 7.50 (7.50–15)	−0.06**	0.01**	−0.10
equipment ($/trap)	68.26	−0.002	−0.0009	−0.01
identification TNR only ($/cat trapped)	5	-	0.007	-
food TNR only ($/cat/year)	61.17	-	−0.008**	-
veterinary care TNR only ($/cat/year)	$56.20	-	−0.009**	-
sterilization TNR only (% females,% range, and $/female)	15, 0–25, 50	-	0.01**	-
			−0.002	
% adoption of kittens born TNR only (range)	40 (0–40)	-	0.09*	
euthanasia TE only ($/cat)	25	-	-	−0.16*
trapping intensity TE only (range)	30,000 (25,000–35,000)	-	-	0.0004
% discount rate (range)[b]	0.5 (0.5–10)	−0.10	−0.12	−0.73
Benefits				
initial number of birds (range)	30,550 (1000–30,550)	0.000001	0.00005**	0.0003**
% predation rate (range 0	21 (10–90)	−0.0004	0.07**	0.41**
monetary value ($/bird) (range)	1,500 (1–15,000)	0.000001	0.0009**	0.006**

[a] *To generate estimates of the elasticity of each model parameter, baseline values for costs and benefits were increased or decreased by 10% or 25% unless a range of alternative values are specified (* $p < 0.05$; ** $p < 0.010$).*
[b] *Discount rates used to convert future price estimates to their present value.*

rate of kittens born to colony cats was set at 50% (Nutter et al. 2004). At least 40% of kittens born needed to be adopted for trap-neuter-release to extirpate the modeled cat colony (Table 1).

The ideal trap and euthanize program would remove all of the colony cats in the shortest possible time, which, because the temporal resolution of our model was 1 year, would be 1 year. The intensity of the trap and euthanize program affects the probability of extirpating the colony within 1 year (Supporting Information). More than 30,000 cats needed to be removed in the first year for the likelihood of extirpation to be >75%. The demographic parameters we used created a high population growth rate (approximate $\lambda = 2$); hence, more cats than the number estimated in the initial population need to be trapped to ensure the new generation is also removed and the colony is extirpated. To test for the effect of abandonment of pet cats near cat colonies, we added 0%, 1%, 2%, 5%, or 10% of the initial population to our simulated cat colony per year.

Costs of Trap and Euthanize or Trap-Neuter-Release

Equipment, identification, sterilization, euthanasia were all functions of the number of cats trapped for each management program. The number of cats trapped for the trap and euthanize program was assigned, whereas the number of cats trapped for the trap-neuter-release program was a function of the number of cats sterilized (cats trapped TNR = total abundance [2 × sterilization rate] + [number of kittens born × adoption rate]). Cost of food and veterinary care were functions of the number of cats remaining in the population. Wages were a function of the number of cats trapped and the number of traps that could be maintained by one person per day (wages = [number of cats trapped/trap success rate]/[number of traps per person per day × wages per day]). Total cost was calculated as sum costs/(1 + discount rate) ∧ time.

The costs of trap and euthanize and trap-neuter-release are not the same. Trap and euthanasia incurs a monetary cost of euthanasia, whereas trap-neuter-release incurs the monetary cost of sterilizing and implanting a microchip (an electronic form of identification) in each cat and the continued cost of caring for each cat for the rest of its life. The trap-neuter-release program in Hawaii does not include vaccinations (Hawaii Humane Society 2012).

Estimates of the total number of colony cats in any given year are needed to determine the costs of managing the cats in situ or removing them (see Results). Our rate of trapping success was 2.56 cats/100 trap nights (Hess et al. 2009). We assumed a professional trapper could maintain 100 live-capture traps in an 8-h work day (M. Lohr, personal communication). The minimum hourly wage for the state of Hawaii in 2012 was $7.25 (U.S. Department of Labor 2012), and we used this amount to estimate labor costs. The cost of euthanasia varies widely depending on the service provider. We used the price listed by The Humane Society of Kent County, Michigan (U.S.A.) (2002), which provides low-cost cat euthanasia for $25 per cat. The cost of spaying and neutering cats in Hawaii is frequently subsidized by the state government and costs $50/ female and $40/male (City and County of Honolulu 2009). Microchips cost $5/cat and are required for all colony cats (Hawaiian Humane Society 2009). The cost of cat food ($61.17/cat/year) and veterinary care ($56.20/cat/year) was derived from survey data (Zasloff & Hart 1998).

Benefits of Trap and Euthanize and Trap-Neuter-Release

The initial cost of predation was an assigned value we based on data in the scientific literature (initial cost of predation = initial number of birds × predation rate × value of a bird). Because predation rate may be affected by the number of interactions between cats and birds, we assumed the initial cost of predation would be equally distributed among the number of cats (monetary damages per cat = initial cost of predation/initial number of cats). We also assumed that cats continue to cause a consistent level of damage over time (future cost of predation = number of cats × monetary damage per cat) and that benefits accrue from either management program was the result of the reduced level of future damage provided by removing cats from the environment (benefits = (initial cost predation – future cost of predation)/(1 + discount rate) ∧ time).

The benefits associated with reducing the number of free-roaming cats via either management technique cannot be easily assigned a market value. Although the literature links feral cats to predation of numerous animal species (Hu et al. 2001; Smith et al. 2002) and transmission of diseases to wild animals (Work et al, 2002; Honnold et al. 2005; Miller et al. 2008), current rates of predation and transmission of disease from colony cats to other species, including people, are not available. Hence, assigning a dollar value to these effects is difficult. Willingness-to-pay (WTP) assessments are often used as a method of estimating the economic value of an animal. For example, Pimentel et al. (2000) estimated that a wild bird in the continental United States was worth $30. Another option for assigning a value to native or endangered birds is to use the value of an individual bird as set by federal law. Under the U.S. Migratory Bird Treaty Act (USFWS 2009*a*) a person may be fined up to $15,000 for killing a single protected bird. Thus, a case can be made that a single bird is worth $15,000. We assessed a range of estimates for the benefits associated with reducing cat predation on Wedge-tailed Shearwaters (*Puffinus pacificus*), a native Hawaiian bird present on Oahu. The minimum dollar value of an individual bird was set at $1, and the maximum dollar value was set at $15,000 (Table 1). We based the annual proportion of Shearwaters killed by cats on the depredation rate (42%) reported in Smith et al. (2002).

Sensitivity Analyses

To further examine the relative costs of trap-neuter-release and trap and euthanize programs, we performed a sensitivity analyses on the trap-neuter-release to trap and euthanize costs ratio, the trap-neuter-release benefit to cost ratio, and the trap and euthanize benefit to cost ratio (Table 1). We tested the sensitivity of these parameters against changes in the number of cats, abandonment rate, sterilization rate, trapping intensity, number of birds, predation rate, and the dollar value per bird and against changes in the cost of wages, equipment, identification, food, veterinary care, sterilization, adoption, and euthanasia (Table 1). We generated 104 model simulations (60 trap-neuter-release; 44 trap and euthanize) for sensitivity analysis of model parameters (Supporting Information). Seventy-two model simulations (36 paired simulations) could be used to calculate the trap-neuter-release to trap and euthanize costs ratio (Table 1). We report the trap-neuter-release to trap and euthanize costs ratio and the benefit to cost ratio for each management technique for the baseline model. Results of our other model simulations are in Supporting Information. The trap-neuter-release to trap and euthanize costs ratio reveals which management technique is cheaper to implement, whereas the benefit to cost ratios indicate the parameter levels required for either technique to be cost effective. To estimate the sensitivity of most model parameters we either increased or decreased the baseline value by 10% or 25%. We varied other inputs on the basis of information in the literature (e.g., 30,550

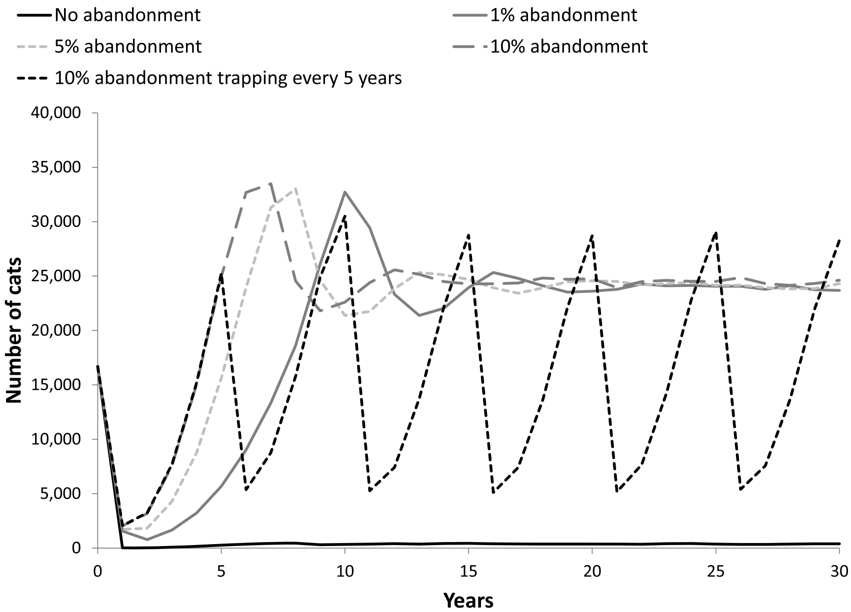

Figure 1. Average number of cats in a colony (mean of extant populations) subject to a trap and euthanize program when the colony is subject to a one-time trapping program that removes at least 30,000 cats in 1 year (no abandonment of pet cats); colony is subject to a one-time trapping program that removes at least 30,000 cats in 1 year and abandonment of pet cats is equivalent to 1%, 5%, or 10% of the initial abundance of colony cats; and colony is subject to trapping program that removes 30,000 cats in 1 year and trapping is repeated every 5 years due to 10% pet abandonment.

shearwaters on Oahu and nearby islets, but only 1650 on O'ahu alone) (Pyle & Pyle 2009) or on common knowledge of the system (e.g., trap-neuter-release programs frequently use volunteers to manage cat colonies [wages reduced to $0.00/hour) whereas professional trappers employed in trapping programs are frequently paid more than minimum wage [wages increased to $15.00/hour]). Each of the model parameters were altered separately of one another.

Results

In our model the probability of the colony being extirpated was >75% (assuming no immigration) for the trap and euthanize program when 30,000 cats were removed from the colony in the first year of the program (Fig. 1). If ≥167 cats immigrated to the colony/year (1% of initial abundance), then the cat population returned to carrying capacity within 10 years (Fig. 1). With a 10% abandonment rate, the modeled cat colony returned to carrying capacity within 6 years following a trap and euthanize program (Fig. 1). Our baseline trap and euthanize program was based on 30,000 cats being removed every 5 years. Trap-neuter-release resulted in a gradual decline in the total number of cats when the population was closed. If no cats were abandoned, trap-neuter-release reduced the number of colony cats to near zero within 30 years (Fig. 2).

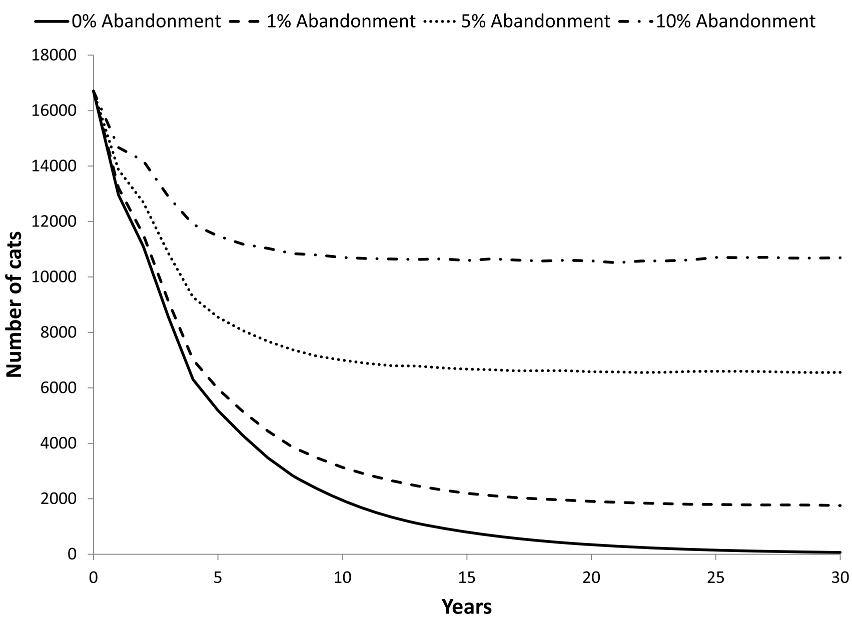

Figure 2. Mean size of extant populations of cats in a feral cat colony subject to a trap-neuter-release program and variable rates of cat abandonment (abandonment of pet cats equivalent to 1%, 5%, or 10% of the initial abundance of colony cats).

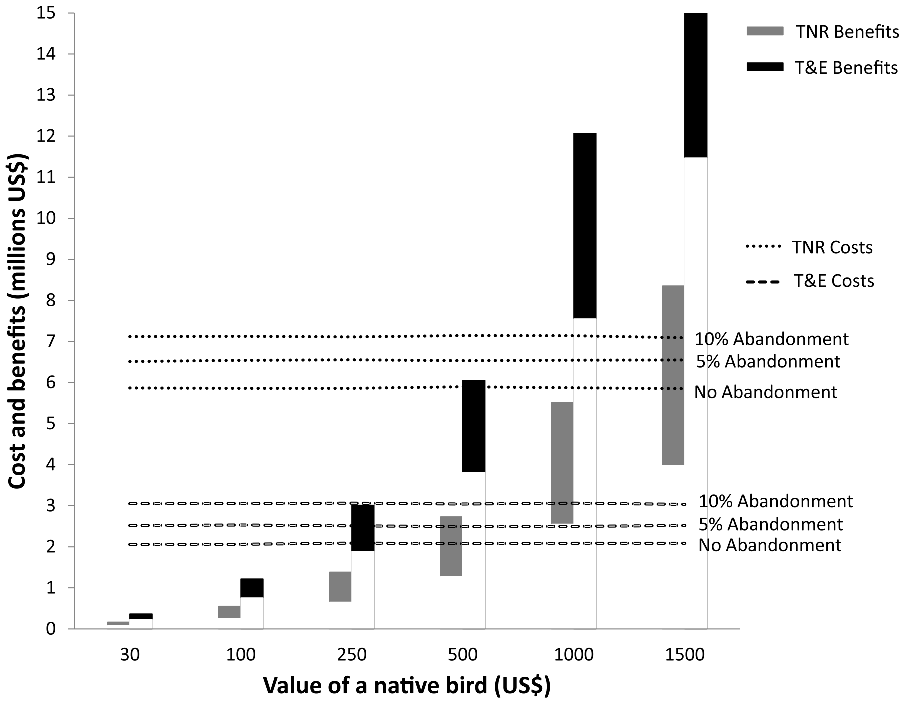

Figure 3. Range of costs and benefits associated with managing a colony of cats via trap-neuter-release (TNR) or trap and euthanize (TE) programs relative to the value of a native bird (abandonment of pet cats equivalent to 1%, 5%, or 10% of the initial abundance of colony cats). See Supporting Information for model outputs.

Trap and euthanize was the cheapest way to reduce the number of cats, regardless of abandonment rate (Fig. 3). With a 10% abandonment rate trap and euthanize programs had to be conducted every 5 years because the cat population approached carrying capacity, and the monetary cost of such a program over 30 years was $4.06 million cheaper than managing the same colony of cats via trap-neuter-release for 30 years. The benefits were limited to those that accrued as a result of the reduction in predation pressure on native Wedge-tailed Shearwaters over 30 years. The costs associated with trap-neuter-release programs outweighed the benefits unless shearwaters were valued at approximately $1500 each. However, a shearwater needed to be worth only approximately $250 each before the benefits of a trap and euthanize program began to outweigh the costs. The benefits decreased as the percentage of cats abandoned increase (Fig. 3).

Our sensitivity analyses revealed that trap and euthanasia was the more cost-effective option in 35 out of 36 paired model simulations (Fig. 4 & Supporting Information). Trap and euthanize programs remained the more cost effective option when the hourly pay for trap and euthanize trappers was increased to $15/hour and the pay for trap-neuter-release trappers was simultaneously reduced to $0/hour. Some model parameters, such as the predation rate and the dollar value of a bird did not affect the trap-neuter-release to trap and euthanize costs ratio, although they did significantly affect the benefit to cost ratio for both trap-neuter-release and trap and euthanize (Table 1). Trap-neuter-release was more cost-effective only when the initial number of colony cats was reduced to 1670 individuals (Fig. 4). The elasticity value for the effect of cat abundance on the trap-neuter-release to trap and euthanize costs ratio was not significant (Table 1) and thus suggests that the large variation in this ratio is an artifact of the large variation in initial cat abundance (1,000–20,000). The rate of abandonment and wages had a significant effect on trap-neuter-release to trap and euthanize costs ratio (Table 1).

Discussion

Our results suggest that the economic benefits of removing colony cats are much greater than the costs of removal programs. Implementing trap and euthanize programs was considerably cheaper than implementing trap-neuter-release programs (trap-neuter-release to trap and euthanize cost ratio 2.5 with no abandonment and 2.1 with 10% abandonment). Both trap-neuter-release and trap and euthanize programs were less costly and resulted in greater benefits for Wedge-tailed Shearwaters when the percentage of abandoned cats was reduced.

Removing feral cats from Hawaii and elsewhere would generate numerous benefits. Aside from predation, cats are the definitive host of *T. gondii* and may have a high seroprevalence even in populations of low density, where transmission between cats is restricted (Hess et al. 2007). Toxoplasmosis kills several animal species (Migaki et al. 1990; Work et al. 2002; Honnold et al. 2005; Miller et al. 2008) and may also cause miscarriages or fetal abnormalities in pregnant women (Tenter et al. 2000) and animals. People are at a greater risk of being infected with

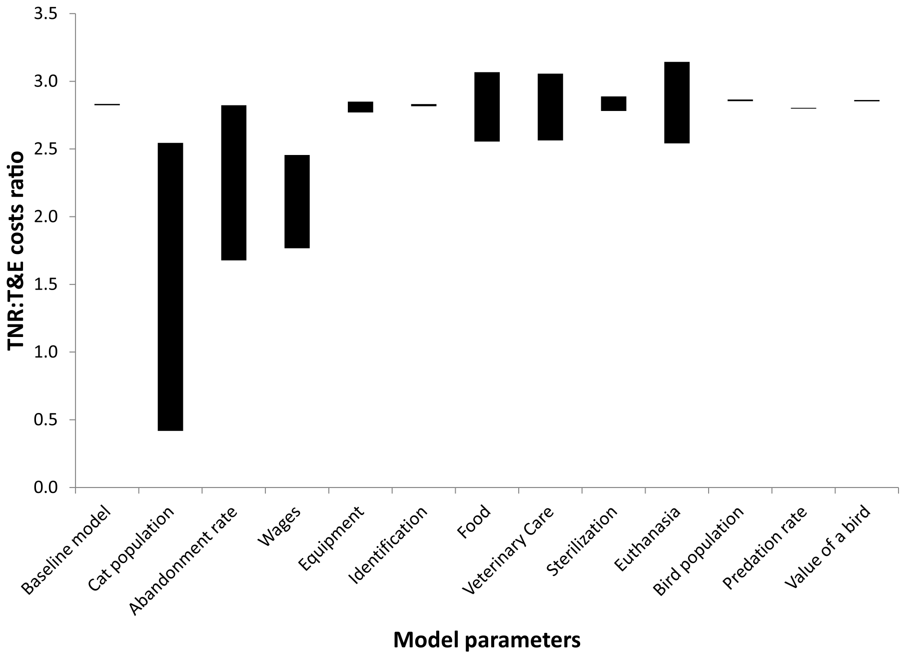

Figure 4. Variation of the trap-neuter-release (TNR) to trap and euthanize (TE) costs ratio on the basis of variation in model parameters. Values >1 indicate cases where TE is more cost effective or cheaper than TNR. We used 36 paired model simulations (72 models in total) to generate these results.

toxoplasmosis if cat colonies exist in the urban environment because contact with contaminated soil is enough to contract the disease (Cook et al. 2000; Dabritz & Conrad 2010).

All effects of feral cats could not be included in our economic analyses. Similarly we could not include potential benefits such as the reduction in the risk to human health, persistence of populations of native species, nuisance potential of cat colonies, or the value of a cat's life without considerable research into people's perceptions and values. The estimate of the total benefits that may be obtained by reducing the number of colony cats reported in this study, therefore, should be considered an underestimate of the true benefits that could be obtained by reducing the effects of cats on Hawaiian ecosystems.

If domestic cats are not sterilized, a surplus number of kittens may be on the market. Basic economic theory states that an increase in supply reduces price, making pet cats highly replaceable and potentially reducing the value of the average cat. Altering pet-ownership policies to create incentives to sterilize cats may reduce the abandonment rate for pet cats.

Ultimately trap and euthanize programs are cheaper and reduce abundances of feral cats more quickly than trap-neuter-release programs. However, there is a social cost associated with euthanasia. Furthermore, both techniques analyzed here address the outcomes of unwanted pets and not methods to reduce abandonment.

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Supporting Information

A table with the results of all 104 model simulations is available online (Appendix S1). The authors are solely responsible for the content of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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