



*Research*

## **An Evaluation of Feral Cat Management Options Using a Decision Analysis Network**

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**ABSTRACT.** The feral domestic cat (*Felis catus*) is a predatory invasive species with documented negative effects on native wildlife. The issue of appropriate and acceptable feral cat management is a matter of contentious debate in cities and states across the United States due to concerns for wildlife conservation, cat welfare, and public health. Common management strategies include: Trap-Neuter-Release, Trap-Neuter-Release with removal of kittens for adoption and Trap-Euthanize. Very little empirical evidence exists relevant to the efficacy of alternative options and a model-based approach is needed to predict population response and extend calculations to impact on wildlife. We have created a structured decision support model representing multiple stakeholder groups to facilitate the coordinated management of feral cats. We used a probabilistic graphical model (a Bayesian Belief Network) to evaluate and rank alternative management decisions according to efficacy, societal preferences, and cost. Our model predicts that Trap-Neuter-Release strategies would be optimal management decisions for small local populations of less than fifty cats while Trap-Euthanize would be the optimal management decision for populations greater than 50 cats. Removal is predicted to reduce feral cat populations quickly and prevent cats from taking a large number of wildlife prey.

**Key Words:** *decision analysis network; feral cat management; lethal control; Trap-Neuter-Release; wildlife conservation*

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### **INTRODUCTION**

Domestic cats have been identified as one of the world's worst invasive species (Lowe et al. 2000) at a time when non-native, invasive species are widely considered to be the leading cause of species endangerment in the United States (Wilcove et al. 1998, Czech et al. 2000, Clavero and Garcia-Berthou 2005). The number of feral cats, that is, abandoned, stray and unowned cats, is estimated to be in the tens of millions, ranging from 70 to 100 million in the United States today (Jessup 2004, Mott 2004). The issue of how to manage these populations is a topic of growing concern to diverse stakeholders in communities hosting populations of feral cats (Longcore et al. 2009), with implications for wildlife populations, cat welfare (Jessup 2004), and human health (Centers for Disease Control and Prevention 2004, 2008).

Feral cats pose a significant threat to the birds, herpetofauna, and small mammals that they prey upon (Crooks and Soule 1999, Kays and DeWan 2004, Lepczyk et al. 2004, Nogales et al. 2004, Dauphine and Cooper 2009). They are implicated in a number of species extinctions, especially within island habitats (Nogales et al. 2004), but have also been found to have significant negative effects in non-insular environments (Crooks and Soule 1999, Baker et al. 2005). Since cats hunt instinctively, provisional subsidies do not curb their natural inclination to hunt wildlife prey (Liberg 1984, Warner 1985). The common practice of providing food subsidies to feral cat colonies (Centonze and Levy 2002) may actually lead to hyperpredation by allowing cats to persist at high densities even when prey is scarce or in decline (Courchamp et al. 2000, Woods et al. 2003). Since cat densities generally exceed those of like-sized predators by a factor of 10-100 (Liberg et al 2000), predation pressure can

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be extreme. Feral cats can also have a considerable impact on the broader health of ecosystems by outcompeting native predators (George 1974) and by changing the community composition (Crooks and Soule 1999).

Suburban and campus environments, where feral cats are especially abundant (Crooks 2002), serve as habitat to a diverse number of mammals, reptiles and amphibians as well as resident and migratory songbirds and birds of prey (Angold et al. 2006, Pennington et al. 2008). These environments contain fragmented islands of natural habitats, surrounded by roads and development which act as barriers to wildlife movement and exert other anthropogenic influences on the health of natural systems, such as pollution, sediment run-off, loss of plant food sources, bird collisions with windows, etc. Depredation of local wildlife by feral cats is a valid conservation concern threatening remaining biodiversity in such habitats. Because cat predation is especially influential in insular habitats (Nogales et al. 2004) and cat abundance generally increases with increasing habitat fragmentation (Crooks 2002), these systems should be regarded with additional concern. However, while other invasive predators, such as foxes and brown tree snakes, are often controlled without incurring substantial debate, the issue of cat control remains contentious (Ash and Adams 2003), perhaps due to a societal predisposition for forgiveness in the face of companion animal “misbehaviors” like predation (Rajecki et al. 2007), because of a perceived human–cat bond (Centonze and Levy 2002), or due to a failure to recognize a relationship between feral cat control and the preservation of native species (Lauber and Knuth 2007).

Although cats are abundant exotic predators, many cat advocates maintain that predation by feral cats is natural, filling a pre-existing niche, and does not negatively influence native wildlife (Alley Cat Allies 2005). There is a little information about the human dimensions of cat management (Ash and Adams 2003, Loyd and Miller 2010) and we have yet to understand why some demographics may support cats in the environment or if some groups value feral cats more than wildlife or view them as wildlife. Considering the issue as an extension of the Animal Rights Movement (Muth and Jamison 2000), it may be fair to assume that some cat advocates are most concerned with preventing the death of individual cats while wildlife advocates are

concerned with conservation of entire populations of native animals.

While residents and biologists may harbor concerns about impacts on wildlife and the natural environment, there is also a large group of stakeholders concerned with the welfare of abandoned and feral cats. Disease and injury are much more prevalent among cats living in feral colonies than owned cats. Norris et al. (2007) found rates of feline immunodeficiency virus (FIV) to be more than twice as high in unowned cats and Nutter et al. (2004a) recorded significantly higher rates of bacterial infection and parasites in feral cats when compared to pet cats. Feral cats are subject to environmental extremes, vehicle trauma and predation, all of which contribute to high mortality rates (Nassar and Mosier 1982, Warner 1985, Andersen et al. 2004, Nutter et al. 2004b) and relatively short lifespans (Warner 1985). This has led some animal rights groups to promote euthanasia as the most humane management option (People for the Ethical Treatment of Animals 2009); however, some groups favor the maintenance of feral cat colonies over any management actions that include lethal control (Ash and Adams 2003, Alley Cat Allies 2009).

Whether stakeholders are motivated by concerns for wildlife, cat welfare, or human health, there is general agreement that the number of abandoned and feral cats must be reduced. Because the number of cats is growing and the costs of dealing with them are great, planning for the best use of scarce resources is essential. The efficacy and viability of the two central management schemes used to control feral cats is a matter of continuous debate. One approach involves the permanent removal of cats, which are then euthanized (Trap-Euthanize or TE), while the second approach involves the capture, sterilization, rabies vaccination, and return of cats to their colonies (Trap-Neuter-Return or TNR). In some cases basic TNR programs may be augmented with disease testing and vaccination for feline immunodeficiency virus (FIV) and feline leukemia virus (FeLV) and monitoring efforts (Trap, Test, Vaccinate, Alter, Return and Monitor or TTVARM) or by the permanent removal of kittens through adoption (TNR+) (Hughes and Slater 2002).

Despite the increasing availability of scientific literature on feral cats and their impact on wildlife,

the issue of feral cat management is principally influenced by the opposing interests and beliefs of passionate stakeholder groups. Management is a hotly debated and highly publicized topic in municipalities throughout the U.S. and stakeholders seem to exert greater influence over the decision makers than the available scientific information on feral cat populations and environmental effects. For example, as a result of campaigns by the public and cat advocacy groups, Trap-Neuter-Return has been adopted by some cities, such as Baltimore, MD (Allen 2007) and Athens, GA, and states, such as Illinois (Illinois General Assembly 2006) as the sanctioned method of feral cat control, though it lacks scientific validation. A model-based approach is necessary to quantify and evaluate the outcomes of such management decisions.

A structured decision network was chosen to address this management issue because such networks can be particularly helpful in difficult management situations, including those involving invasive species, in which the outcomes of management alternatives are uncertain and in which numerous stakeholders with opposing positions are involved (Maguire 2004). Bayesian belief decision networks are graphic models that represent probabilistic cause and effect relationships between variables. They can help connect ecological findings to management concerns and decisions. The use of a Bayesian Belief Network allows our analyses to become a tool for future management, and one to be updated as additional information on cat population dynamics, the impact of cat predation on wildlife, and attitudes of stakeholders becomes available. This process can help to ensure that the control ethics being used are knowledge-based (Warburton and Norton 2009). In addition to predicting the future population status of cat populations under five management alternatives, our model incorporates analyses of costs, stakeholder values, and wildlife take by cats, thus considering both scientific and social aspects of the feral cat management problem.

The Fundamental Project Objective is to reduce native wildlife prey take by feral domestic cats, while the Means Objective is to reduce abundance of feral cats through the use of effective and acceptable management practices.

## METHODS

Management decisions that address value-laden resource descriptions, such as animal welfare and wildlife preservation, defy easy analysis and quantification. We constructed a Bayesian Belief Network (BBN) in Netica (Norsys Software, 2009) to assist in cat management decision analysis. Decision analysis is a process of weighing alternative scenarios with respect to the costs, benefits and probability of success of each. A BBN is composed of states of nature nodes, such as population status; decision nodes, such as alternative feral cat management schemes; and a utility node, which incorporates operational costs and societal values. The overall model is graphically represented as an influence diagram in Figure 1. Figure 2 illustrates how we meet our fundamental objective; the BBN is guided by this specific influence diagram. Environmental states were assigned to each model component and connected by directed arcs which indicate casual relationships between model components; for example, future population size is influenced by management decisions. The model is in the form of a network that links relationships among components using probabilistic dependencies based on Bayes Rule, conditional probability theory. Simply, Bayes rule can be expressed as Probability (b conditional on a) or  $P(b|a) = [P(a|b) \times P(b)] / P(a)$ . For example, in our model, beginning with a large population size and TNR management, the  $P(\text{high wildlife take} | \text{lg. initial pop. size}) = P(\text{lg initial pop. size} | \text{high wildlife take}) \times P(\text{high wildlife take}) / P(\text{lg initial pop size}) = (66 \times 99) / 100 = 65$ .

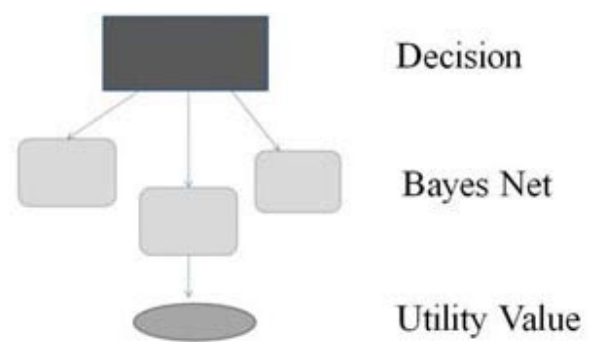
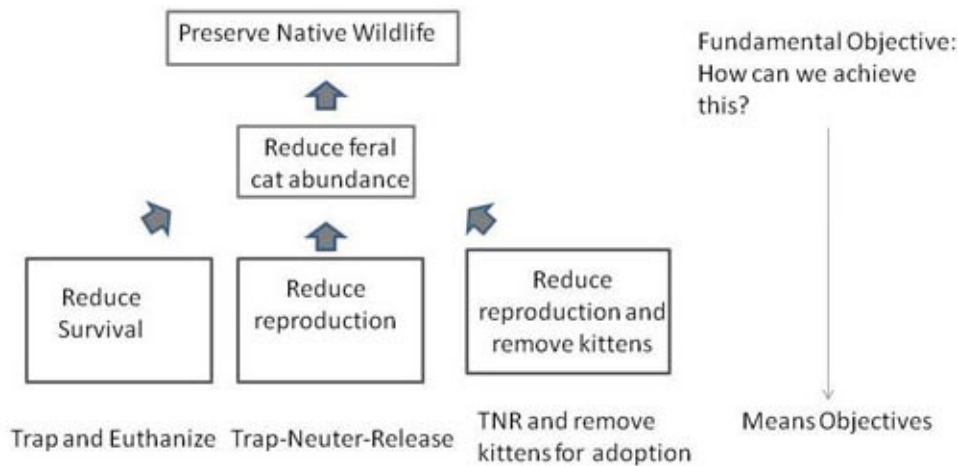


Fig. 1. The structure of a Bayesian Belief Network

**Fig. 2.** Influence diagram guiding development of our feral cat management Bayesian Belief Network



Nodes are structured by a conditional probability table, an example of which can be seen in Table 1, showing assigned output under various combinations of input. The BBN calculates the probabilities and easily recalculates when new probabilities are assigned or evidence changes. Our BBN illustrated in Figure 3 is a decision analysis network to assist with a very controversial issue and thus mixes values with probabilities in analyzing decisions. The utility node Stakeholder Values is linked to the decision node and represents various combinations of operational costs, social values, and outcomes. The model determines the decision pathway that minimizes operational costs and maximizes benefits, that is, satisfies our objective and considers social preference. Selection of the best decision is achieved by choosing the decision giving the highest expected value. The expected value is calculated by multiplying the utility value of an event by the probability of that event. By weighting all possible outcomes in accordance with stakeholder satisfaction and calculating the probabilities for a scenario, an optimal decision may be selected.

The BBN allows decision making under uncertainty through the application of alternative states within population size, as well as predictions under alternative models. Information collected through empirical research or population monitoring can

update the model by supporting belief in one alternative state over others and can reduce uncertainty in assigned probabilities. Our BBN was constructed following guidelines for development and testing as described by Marcot et al. (2001, 2006). Bayesian belief networks have been constructed to address conservation and management issues ranging from habitat suitability for an endangered mammal (Smith et al. 2007), to sport fisheries management (Peterson and Evans 2003) to worldwide polar bear status (Amstrup et al. 2007). Our model components are as follows:

### Decision node

The following management decisions were evaluated in our BBN: TNR, TNR+ kitten removal, TTVARM, Trap and Euthanize, and Do Nothing. TNR+ considers removal of just 25% of kittens because of the vast number of cats already awaiting adoption within shelters and TNR programs. We excluded management suggestions typically deemed inappropriate in the U.S., for example, cat hunting or culling is not evaluated. Additionally, placing trapped cats in a cat sanctuary is rarely practiced due to excessive cost and limited space for continued intake. A brief internet search through Google turned up less than five cat sanctuaries in the U.S. today.

**Table 1.** An example of a Conditional Probability Table (% Probability)

Management Decision	Initial Pop. Size	Probability of Future Population Size			
		Small	Medium	Large	Extra Large
Trap-Neuter-Release	Small	45	53	1	1
Trap-Neuter-Release	Medium	1	15	80	4
Trap-Neuter-Release	Large	0.5	0.5	40	59

Andersen et al. (2004) predicted effective cat control through annual spaying/neutering of at least 75% of the population. Simulation exercises conducted to develop the population dynamics within this model also predicted that a 75% monthly capture rate would allow for population stabilization, whereas 50% monthly capture rates would fail to prevent chronic population increases unless supplemented with kitten removal. We therefore assumed that each of our management decisions involved capture rates of 75% of the initial population.

### Initial population size

Initial population sizes are continuous ranges, small, representing < 50 cats, medium, representing 50-100 cats, and large, representing 100-200 cats. We varied initial population size by choosing belief in one size (100% probability) and also by setting the node finding to Unknown, so each size is weighted with an equal probability of 33.3333%. This allowed exploration of optimal management decisions with varying input and allowed us to predict the response of alternatively sized populations to chosen management decisions.

### Future population size

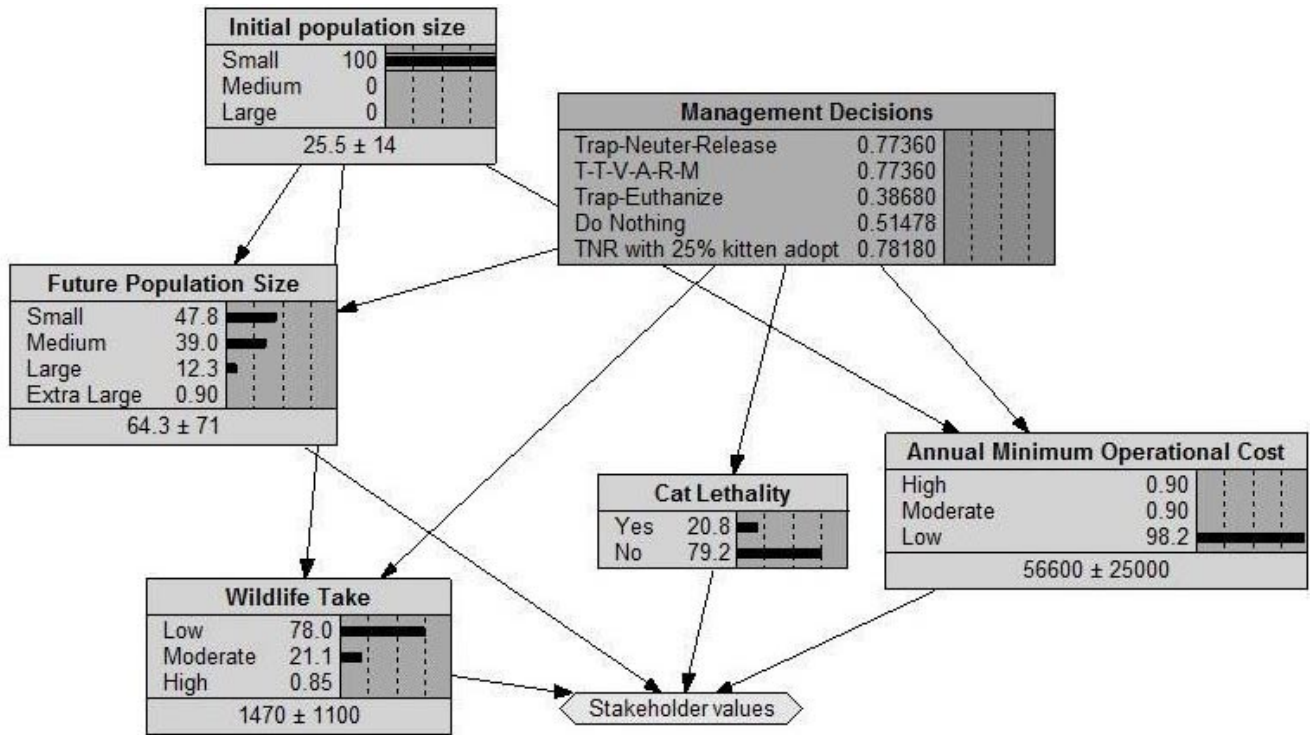
We informed this node by conducting modeling exercises (DeVore and Loyd, *unpublished data*) that investigated the impact of alternative feral cat management options on cat populations. Published data on cat life history and population dynamics (Table 2) was used to create a sex and age structured dynamic population model to predict the response of feral cats to common management options over

time. The model incorporated demographic and environmental stochasticity at each time step through the generation of appropriate statistical distributions. The models explore small (<50 cats), medium (50-100 cats) and large (100-200 cats) populations under Trap-Neuter-Return (TNR), Trap-Euthanize and Do Nothing management strategies with 50% and 75% monthly capture efforts and provide predictions of population response to alternative management decisions. We used population responses after one year to inform the BBN because this type of model (BBN) can only operate on one time step. A review of the literature on cat predation on wildlife helped determine our conservative estimate for wildlife take. We based the spatial extent assumptions (2.5 km<sup>2</sup>), and management cost estimates of the population model and this network on those of a local food subsidized feral cat colony on the suburban University of Georgia campus (Athens, GA).

### Minimum annual operational costs

Operational costs for alternative management strategies were estimated on a cost per cat basis and can be seen in Table 3. We multiplied the median of each Initial Population Size by 0.75 to represent the cost of capturing 75% of the average initial population. The cost of materials and staff time for the Euthanasia option was estimated by the Executive Director of the Athens Area Humane Society (AAHS), while the costs of the TNR, TTVARM, and TNR+ options represent an average cost acquired from 10 veterinary clinics in Athens, Georgia. The cost of trap and transfer efforts was assumed to remain constant across all management strategies and was thus not included in our cost

**Fig. 3.** The feral cat Bayesian Belief Network. Input: Small population size. Optimal management decision = TNR+ with the highest expected value (0.78).



estimates. TNR costs do not include future care because cats are unlikely to be re-captured for vaccination boosters or veterinary care. Food to maintain feral cat colonies is not accounted for because it is assumed to be continuously donated by TNR program volunteers. Calculations using the daily cost of cat care from the AAHS showed that after three months the cost for TNR plus the adoption of 25% of kittens would approach that of TNR. Though there is cost for care, which is figured at \$151/cat for 10 days of holding in the shelter, the removal of kittens keeps those animals from becoming a part of the TNR program, thereby preventing future sterilization and vaccination costs. Under this management strategy (TNR+) we assumed the new owner/ adopter of each kitten would be responsible for the cost of spay/neuter and vaccinations. The states were defined as follows: Low= <\$7500/year, Moderate = \$7500-\$15,000/year and High= >\$15,000/year.

### Cat lethality node

This node was included to simplify the process for assigning utility values to combinations of inputs. The TNR and Do Nothing management options have a 99% probability of no cat lethality, with lethality meaning lethal control, as these cats will expire at some point in the environment. The use of this yes/no lethality node greatly reduced the number of combinations to which advocacy group representatives assigned values.

### Wildlife take

The states of this node correspond to ranges of prey take; the estimates were also derived from the population simulations. Monthly prey take estimates were calculated from the monthly cat abundance estimates and randomly generated from a Poisson distribution with a mean equal to the

**Table 2.** Information used to parameterize population model

Node	Data Input	Source
Immigration	Frequent (>30%) Average (12-30%) Rare (<12%)	Castillo and Clarke 2003 Natoli et al. 2006 Centonze and Levy 2002
Survival	High (>0.8) Medium (0.56-0.79) Low (<0.56)	Andersen et al. 2004 Natoli et al. 2006 Andersen et al. 2004
Kitten Production and Survival to Six Months	High (>2 litters/year of >4 kittens, 3 survive) Medium (1-2 litters/year of 3-5 kittens, 2 survive) Low (< 1 litter/year, <4 kittens, 1 survives)	Andersen et al. 2004, Natoli et al. 2006 Andersen et al. 2004, Natoli et al. 2006 Schmidt et al. 2007, Scott et al. 2002
Future Population Status	Influenced by: initial population, survival, kitten production, immigration and abandonment	Scott et al. 2002

average per capita prey take, which is an average of three per month reported in the literature (Table 4). Cumulative prey take averaged from repeated iterations for one year was used to define the conditional probability table for wildlife take. The ranges of prey take represented by each node are arbitrary though we considered the spatial extent of our model and acceptability of opposing groups in choosing these. Less than 2000 animals/year was considered Low wildlife take, the Moderate prey take range is defined as 2000- 4000 animals and High by > 4000 animals a year. Understanding that this simplifies reality and that in some cases any prey take by an invasive predator may be considered too much, we included this node with the intent of providing a novel quantification of how alternative cat management options impact wildlife.

### Stakeholder values

The utility node is parameterized by stakeholder values, which are directly influenced by the management decision, the future population status, wildlife take, and the annual operational cost (High, Moderate or Low). Our utility node considers the

opposing groups most involved in the issue of feral cat management and their primary concerns: cat non-lethality and wildlife take. We recognize that other stakeholders exist, such as homeowners, whose primary concern may be public health risk of feral cat presence, but believe all stakeholders share a similar goal in the reduction of cat populations and believe that the homeowners or other stakeholders would not object to the selected management option taken as long as it is effective. The development of a relative scoring index for societal values is beyond the scope this project.

Utility values were assigned to each combination of influences by a representative of the Cat Advocacy and Wildlife Conservation sides of the debate. Options leading to various levels of cat population status and influence on wildlife received subjective values between 0 and 1. The final numeric value represents the mean of the values chosen by the opposing stakeholder groups. The cat advocate assigned lower values to combinations including cat lethality while the wildlife advocate did not devalue lethal management decisions as long as they were effective at reducing cat predation on wildlife. An example of values assigned under some combinations of conditions can be seen in Table 5.

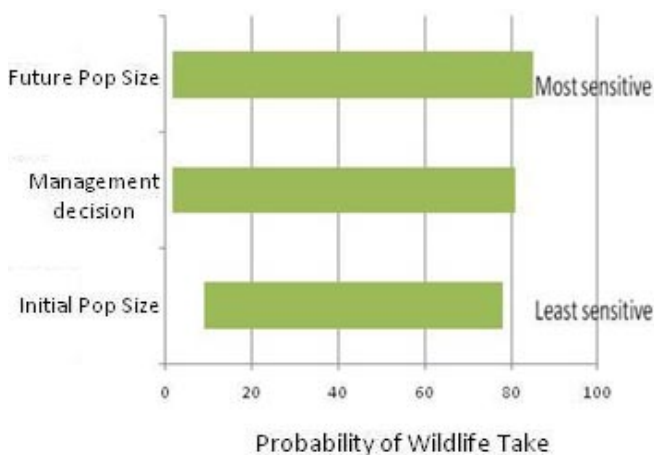
**Table 3.** Estimates from the literature used to inform the Wildlife Take node

Prey take per month per cat	References	Location
6.2	Lepczyk et al. 2004†	Michigan, USA
5.4	Kays and DeWan 2004	New York, USA
4.7	Crooks and Soule 1999†	California, USA
2.3	Woods et al. 2003†	Great Britain
1.2	Churcher and Lawton 1987†	Great Britain
1.1	van Heezik et al. 2009†	New Zealand
0.85	Barratt 1998†	Australia
3	Rounded mean per month	
36	Annual mean	

†homeowner survey

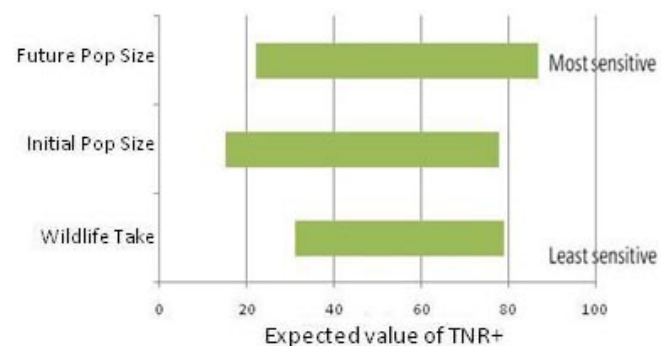
## RESULTS

Performing a sensitivity analysis can help validate accurate model structure and parameterization (Marcot et al. 2006). A sensitivity analysis conducted for the output node "Wildlife Take" revealed that the node was most sensitive to findings at "Future Population Status" followed by "Management Decision" (Figure 4).



**Fig. 4.** Tornado diagram of one-way sensitivity analysis for the Wildlife Take node. The probability of Wildlife Take is most influenced or sensitive to Future Population Size. The bar lengths represent the extent to which the probability of Wildlife Take varies in response to changes in the value of that model component.

Sensitivity analyses are reported as Tornado Diagrams, the bar lengths represent the extent (range) to which the probability of "Wildlife Take", for example, varies in response to changes in the value (states) of that model component (Peterson et al 2003). Our model results show that variation in the optimal management decision is related to initial population size, and the optimal decision only changes once when initial population size input is varied (Small, Medium, Large, Unknown). Sensitivities of the two optimal decisions chosen by the model, TNR+ and TE, are reported in Tornado Diagram (Figure 5 for TNR+) and (Figure 6 for TE).



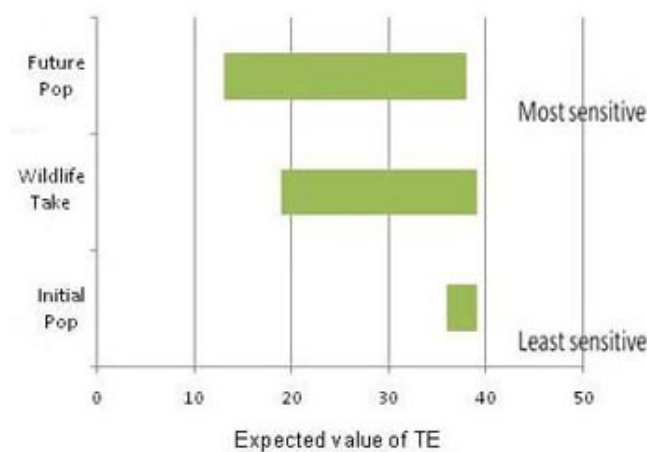
**Fig. 5.** Tornado diagram of one-way sensitivity analysis for the management decision TE.



**Table 4.** Cost per cat of each potential management method (cat capture, transfer and food cost to maintain colonies not included)

Management method	Cost per cat
Trap-Euthanize (TE)	\$71
Trap-Neuter-Release (TNR)	\$158
Trap-Neuter-Release Plus Kitten Adoption (TNR+)	\$158
Trap-Test-Vaccinate-Alter-Return-Monitor (TTVARM)	\$203
Do Nothing	\$0

The Bayesian Belief Network calculates the optimal decision for management of a small population of feral cats to be TNR+ kitten removal and for a medium or large population of feral cats to be Trap-Euthanize (Table 6). The expected value of the management decision TNR+ for a small population is twice as great as that for Trap-Euthanize and is closely followed by the other TNR management strategies, TNR and TTVARM. Figure 3 illustrates these results.



**Fig. 6.** Tornado diagram of one-way sensitivity analysis for the management decision TNR+.

Table 7 reports the probabilities of future population sizes and wildlife take under alternative

management decisions. Choosing TNR+ for managing small populations but TE for managing medium leads to a low wildlife take and low annual management cost (Table 7). These are the only options capable of meeting our objective of reducing wildlife take to low via feral cat management. Managing by TNR+ will lead to slightly lower probabilities of the future population growing to large and resulting in high wildlife take when compared to other TNR strategies. The first row of Table 7 displays predictions of population response, wildlife take and cost under TNR or TTVARM for a three-year period; TNR and TTVARM produced the same probabilities for future population size and wildlife take and thus are combined in this row. The population is predicted to grow annually under these options, inflicting greater wildlife take and higher management cost. This increasing population under TNR and TTVARM suggests that at some point a more effective management strategy, like Trap-Euthanize, will need to be employed. In contrast, managing via Trap-Euthanize for one year is predicted to rapidly reduce the population size. Figures 7 and 8 provide further examples of the BBN under TNR+ and TE management strategies for comparison.

## DISCUSSION

The results found through this decision analysis network indicate that the optimal management decision for most feral cat populations is Trap-

**Table 5.** Example of influences and the resulting utility values. This is an average of the values that the Wildlife Conservation and Cat Advocacy representative assigned to each combination.

Future Population Size	Wildlife Take	Minimum Operational Cost	Cat Lethality	Stakeholder Value
Extra-Large	High	High	Yes	.01
Medium	Medium	Low	No	.65
Small	Low	Medium	Yes	.375

Euthanize. This decision balances the public interest in cats with the value that stakeholders place upon the conservation of native wildlife. Our probabilistic network predicts that, in many circumstances, the high probability of wildlife take under Trap-Neuter-Return management strategies outweighs the possible benefits of preventing cat euthanasia. While TNR or TTVARM alone were not predicted to reduce or stabilize populations, supplementing the TNR program with kitten removal resulted in stabilizing small initial population sizes. This option may also be preferable because it prevents removed kittens from entering the TNR program as adults and, presumably, secures a better quality of life for those cats.

Trap-Euthanize strategies have proven effective at reducing cat populations and mitigating adverse effects on wildlife in a number of locations (see reviews in Nogales et al. 2004, Winter 2004). In contrast, TNR programs alone have never been shown to stabilize a feral cat population in the scientific literature (Zaubrecher and Smith 1993, Castillo and Clarke 2003, Natoli et al. 2006). Of the TNR studies reporting success, each program included removal of a significant number of animals for adoption (Centonze and Levy 2002, Hughes and Slater 2002, Levy et al. 2003a). While Trap and Euthanize efforts may have immediate benefits for the persistence of prey populations, TNR programs typically have a goal of slow attrition and maintenance of cat populations. Re-releasing exotic predators into the environment may actually increase the per capita impact of these cats as cat survivorship increases post-neuter due to decreased participation in risky behaviors, such as fighting and roaming (Yamane et al. 1996). This is an especially valid concern in habitats hosting threatened or

endangered species and high numbers of feral cats, such as California, Florida and Hawaii, but may exacerbate risk to suburban wildlife populations as well. Despite the possibility of preference from some segments of the public for non-lethal management (Lord 2008, Loyd and Miller 2010), a TNR strategy is inappropriate in ecologically sensitive locations (Schmidt et al. 2007).

Our model was developed for use in situations where species are not at risk of extinction and responsible managers should consider completing an environmental review or impact statement before adopting a management plan in systems hosting susceptible species. Re-releasing an exotic predator near threatened or endangered species is inadvisable and possibly criminal, under legislation of the Endangered Species Act or the Migratory Bird Treaty Act (Hatley 2003, Winter 2003). Requiring a formal environmental assessment when feral cat management decisions are formulated would necessitate input by scientists (Longcore et al. 2009) and balance quantitative predictions with the prevalent emotional arguments as influences to policy.

While management decisions are under consideration, on the ground measures should be attempted to curb further cat population growth. Locally, growth in feral cat populations could be minimized via reductions in abandonment and cat feeding. Feeding and presence of cats has been found to result in increases in immigration and abandonment (Castillo and Clarke 2003, Jessup 2004). Continued immigration and abandonment in managed areas can effectively counteract the benefits of TNR management; for example, a long-term (>10 years), widespread TNR program in Rome was considered

**Table 6.** Optimal management decisions for populations under Small, Medium, Large or unknown population size.

Initial Population Size	Optimal Management Decision (Expected Value)
Small	TNR+ 25% Kitten removal for adoption (0.77)
Medium	TE (0.38)
Large	TE (0.35)
Unknown	TNR+ (0.39), TNR (0.38), TTVARM (0.38), TE (0.38)

to be a “waste of money, time, and energy” due to continued abandonment and immigration (Natoli et al. 2006). Currently, feral cat feeding is a widespread practice that occurs in 8% to 26% of households (Manning and Rowan 1992, Levy et al. 2003b, Lord 2008); discouraging feral cat feeding and reducing abandonment of animals would undoubtedly assist in resolving the feral cat problem. Mandatory spay-neuter laws and increased enforcement of existing policy regarding keeping domestic animals under owner control at all times would help to decrease new additions to the feral cat population as well as positively impact wildlife through reductions in prey take by owned cats.

Another social issue surrounding this debate is the inequality in stakeholder participation. Our decision network was constructed under the assumption that the opposing stakeholders would have an equal influence on model selection. In reality, this is unlikely to be the case. Although Trap-Euthanize is predicted to be an effective method of reducing feral cat populations, it is so vehemently opposed by cat advocacy groups that it is unlikely to be considered by some communities until the densities of cats are so high that they constitute a serious public health risk (Ash and Adams 2003). Currently, cat advocacy groups such as Alley Cat Allies spend millions of dollars annually lobbying for feral cat rights and promoting TNR management; in 2008, for example, this group alone took in more than \$4.8 million and spent \$3.8 million on public education and outreach (<http://www.charitychoices.com/charities/AlleyCat/questions.asp#quest4>, <http://www.charitynavigator.org/index.cfm?bay=search.history&orgid=5453>). Though the “Cats Indoors” campaign created by the American Bird Conservancy is reaching a growing audience, we believe wildlife, environmental and

conservation organizations will not have an equal influence on local management decisions unless they become stronger advocates for cat removal and begin educating a broader audience about the value of native wildlife and the impacts of cat predation. An educational campaign might help residents understand the conservation issue created by the presence of feral cats and alter their beliefs as to the optimal decision for their communities. Recognizing the extent to which the current feral cat management in many communities (e.g. TNR, TTVARM, TNR+) results in a sacrifice of native biodiversity may help stakeholders consider Trap-Euthanize for the sake of wildlife welfare.

### Uncertainty in our model

#### *System uncertainty*

We did not have information about every aspect of our system, system processes, or limiting factors. Some nodes are less informed than others and these uncertainties should guide future research on feral cats. Wildlife take and the effect of management options on future population size are two examples of model aspects in which further research is merited. These could be included in future models as information becomes available. BBNs can serve as tools for adaptive management, as monitoring of colonies can help to update the probabilities of alternative models, and management decisions can be re-evaluated after a period of monitoring.

Direct impact of a feral cat population on wildlife through predation necessitates further research to reduce uncertainty. Most studies on domestic cat predation (Warner 1985, Churcher and Lawton 1987, Woods et al. 2003, Lepczyk et al. 2004) collected information from homeowners on type

**Table 7.** The expected cost and probabilities of future population size and wildlife take under alternative management strategies for Small, Medium, Large and Unknown future population size.

Initial population size	Management decision	Future population size (probability)	Wildlife take (probability)	Annual cost
Small (year 1)	TNR or TTVARM	Medium (53)	Low (95)	Low
Medium (year 2)	TNR or TTVARM	Large (80)	Mod (50.5)	Moderate
Large (year 3)	TNR or TTVARM	X-Large (59)	High (99)	High
Unknown (year 1)	TNR or TTVARM	Large (40)	High (49.7)	Moderate
Small	Trap-Euthanize	Small (98)	Low (99)	Low
Medium	Trap-Euthanize	Small (95)	Low (95)	Low
Large	Trap-Euthanize	Small (90)	Mod(50.5)	Low
Unknown	Trap-Euthanize	Small (94.3)	Low (85)	Low
Small	Do Nothing	Large (58)	Mod(94)	Low
Medium	Do Nothing	Large (80)	High (99)	Low
Large	Do Nothing	X-Large(94)	High (99.9)	Low
Unknown	Do Nothing	Large (47.7)	High (66.6)	Low
Small	TNR+25% kitten removal	Small (50)	Low (96)	Low
Medium	TNR+25% kitten removal	Large (77)	Mod (51)	Moderate
Large	TNR+ 25% kitten removal	X-Large(54)	High (98)	Moderate
Unknown	TNR+ 25% kitten removal	Large (41)	High (49)	Moderate

and frequency of prey deposited by their cats at residences. These are assumed to be underestimates as cats do not bring all kills back to their homes, house cats spend only a portion of their time outside, and these cats are never dependent on wildlife for food. Kays and DeWan (2004) found that actual owned cat predation rates were more than three times higher than the rates measured by prey returns to owner residences and, although most studies only report take by owned housecats, Liberg (1984) estimated that wildlife take by feral cats is four times that of house cats. In addition to direct predation, cats may also cause mortality and reduced reproduction through indirect non-lethal effects (Beckerman et al. 2007). We therefore expect that the figure we used is a highly conservative estimate of prey take and that the feral cat populations may have a greater cumulative impact on wild prey populations. How this predation influences wildlife at a population level, and the degree to which this predation is additive or compensatory, is also an area that merits further research.

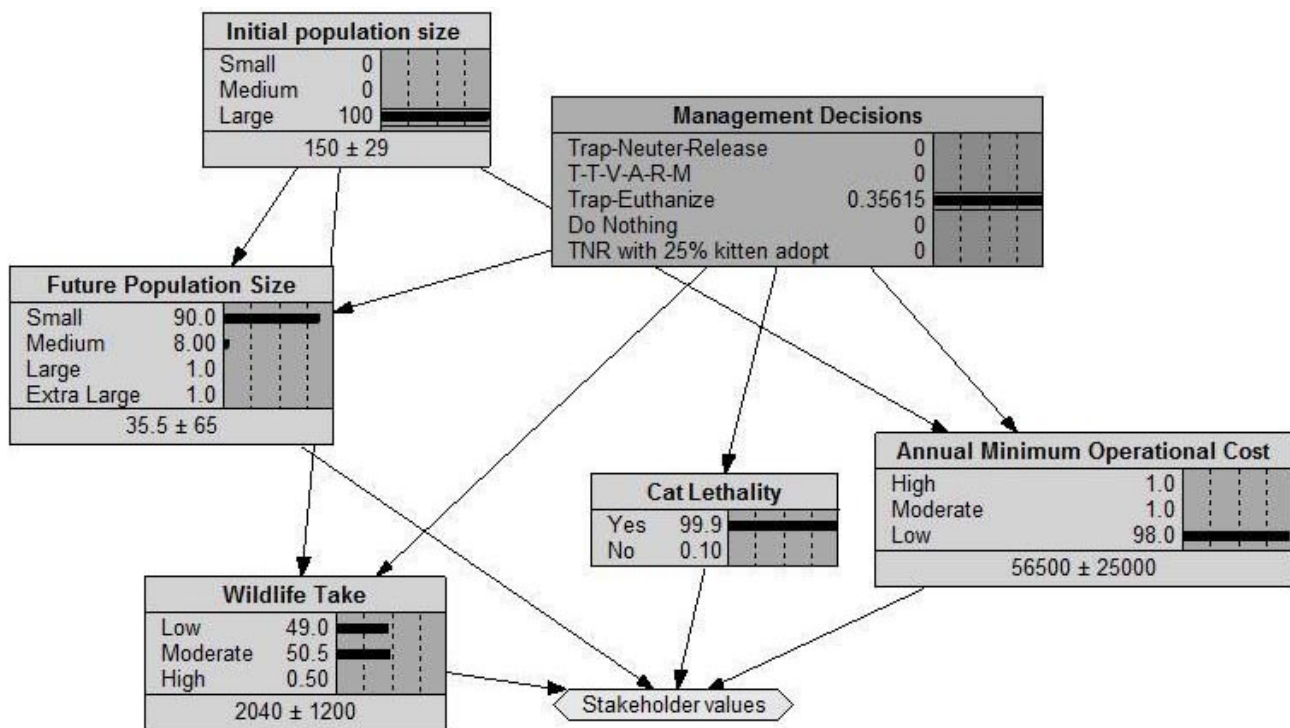
While not the focus of our model, feral cats also negatively impact native wildlife through

transmission of zoonotic diseases. Feline Leukemia (FeLV) has been reported to cause death in mountain lions (Jessup et al. 1993) and bobcats (Sleeman et al. 2001) in the U.S. Recently, FeLV was found in 46% of a small population of endangered florida panthers, believed to be initially contracted by consuming an infected feral cat (Cunningham et al. 2008). *Cytauxzoon felis* is a fatal protozoan receiving growing attention in the literature as an emerging threat to native felids. The popularity of TNR and free-ranging cat colonies in the U.S. over the past two decades may be related to growing infections of *C. felis* on the east coast (Birkenheuer et al. 2008). *Toxoplasma gondii*, a common feline protozoan parasite has been identified as a threat to marine wildlife on the west coast, including sea otters, Pacific harbor seals and California sea lions (Conrad et al. 2005). This is one consideration which was not included in our population model or BBN for lack of existing information.

#### *Public attitudes*

One of the most critical needs to guide management of feral cats nationwide is information on public

**Fig. 8.** Prediction of future population size and wildlife take under TE management



attitudes towards feral cats and their management. Managers lack information on cat management preferences of the general public as well as on the value assigned to wildlife. Some vocal stakeholders value cats more than native wildlife, but where does the general public stand? How much wildlife is too much to sacrifice for the continued persistence of feral cats? The information provided by a greater sample of representative stakeholders could be used to better inform our utility node and help assign values. These values influence the expected values for our management decisions and help to identify the optimal management decision.

#### *Partial observability*

Our parameter estimates affecting future population size) were informed by the literature and modeling exercises rather than through direct data collection; thus we did not have access to reliability information for most estimates. We acknowledge the existence of some bias and sampling error in parameter estimates and used an average of information found

in the literature rather than relying on a single estimate from one location.

#### *Intrinsic system variability*

We acknowledge the possibility of some uncertainty related to stochastic environmental effects. Severe weather may have a marked influence on feral cat populations that occur in harsh habitats. We expect these influences to be minimal within temperate climates of the southeast such as those found in Athens, GA. Since cats are very adaptable, switch prey readily, and often have access to subsidized food or shelter, it is likely that environmental effects are lessened within many U.S. populations.

## CONCLUSIONS

The social aspect of feral cat management has proven to be the greatest challenge to decision making and resulting action. Our decision network was constructed to address this issue and the

growing debate that has surrounded it. Through the adoption and use of this BBN, communities can help to improve its predictive power while addressing the priorities of the public. Conflict between animal rights groups and conservation biologists has prevented the effective management of a number of invasive species (Perry and Perry 2008); it is our hope that this decision network will help those faced with making these challenging decisions to choose the optimal strategy for the management of local feral cat populations.

A limited version of Netica software can be found here: <http://www.norsys.com/download.html>. Please contact the corresponding author for the feral cat management Netica file.

Responses to this article can be read online at:  
<http://www.ecologyandsociety.org/vol15/iss4/art10/responses/>

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