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Richard M. Engeman
USDA-APHIS-Wildlife Services, s_r100@yahoo.com

Bernice Constantin
USDA/APHIS/WS

Stephanie A. Schwiff
USDA/APHIS/WS National Wildlife Research Center, stephanie.a.shwiff@aphis.usda.gov

Henry T. Smith
'Florida Department of Environmental Protection

John Woolard
USDA/APHIS/WS

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Richard M. Engeman[1], Bernice Constantin[2], Stephanie A. Shwiff[1], Henry T. Smith[3] and John Woolard[2]

[1]National Wildlife Research Center, 4101 LaPorte Ave, Fort Collins, CO 80521-2154
[2]USDA/APHIS/WS, 2820 East University Ave., Gainesville, FL 32641
[3]Florida Department of Environmental Protection, Florida Park Service, 13798 S.E. Federal Highway, Hobe Sound FL 33455

ABSTRACT: Swine adversely affect the environment in most places around the world where they have been introduced into the wild. In many of those places swine removal is key to protection of a variety of special habitats, wetlands in particular. We have pursued several avenues of research and technique development to enhance swine removal efforts, primarily in Florida. An easily-applied passive tracking index (PTI) with good statistical properties has been effective for monitoring swine distribution and relative abundance, thus aiding the location of control method applications and the evaluation of control results. A quadrat sampling methodology used in conjunction with the PTI population surveys was developed to estimate the amount of habitat damaged by swine in an area. Another method employs a series of transects specially developed to efficiently estimate damage to the exposed portions of the last remnant of a formerly extensive basin marsh system in Florida. Besides estimating damage levels, we developed credible means for monetarily estimating the value of the damage based on the dollar amounts that wetland regulators have allowed permit applicants to spend in mitigation attempts to replace lost wetland resources. Estimation of damage levels and their associated economic values before and after swine control permitted economic analyses of the removal efforts. Universally, the economic analyses demonstrated enormous benefit-cost ratios for swine removal, as well as large values per swine removed.

INTRODUCTION

Feral swine (*Sus scrofa*) are a particularly destructive exotic species in many places around the world (e.g., Seward *et al.* in press). They negatively impact the environment through habitat degradation, predation on native species, and competition with native species (Choquenot *et al* .1996; Taft 1999). Swine were first introduced into the wild in North America by DeSoto in the 1500's in Florida (Towne and Wentworth 1950), where today they flourish and cause widespread damage. The species possesses the highest reproductive potential of any large mammal in North America (Wood and Barrett 1979, Hellgren 1999), and the species currently inhabits many areas in such large numbers that it adversely impacts the environment and surrounding agriculture. Over 500,000 have been estimated to inhabit Florida (Layne 1997). Feral swine also can harbor a number of diseases transmittable to livestock or humans (e.g., Conger *et al.* 1999, Romero and Meade 1999, Taft 1999, Becker *et al.* 1978). In particular, the swine industry in the USA has nearly eradicated swine brucellosis and pseudorabies, but feral swine serve as a potential reservoir from which these diseases can be transmitted to domestic stock (Taft 1999, Taylor 1999). In Florida, large proportions of unique natural environments have been lost to urban development and agriculture. The U.S. Department of Agriculture/Wildlife Services (USDA/WS), the USA federal agency mandated to resolve human-wildlife conflicts, has been actively engaged to protect these increasingly rare and fragile natural habitats by removing the feral swine inhabiting them. Here we describe research thrusts aimed at supporting and enhancing the swine removal efforts.

RESULTS

Population indexing

Due to the logistical and theoretical difficulties associated with density estimation methods (e.g., see Leidloff [2000] for an excellent overview of potential problems with capture-recapture methods), indices of abundance, rather than absolute abundance estimates, were the only practical means for monitoring swine (Choquenot *et al.* 1996). For our purposes, a passive tracking index (PTI) has been an efficient means to monitor feral swine (Engeman *et al.* 2001). The method originated for monitoring wild canids in Australia (Allen *et al.* 1996) and in the U.S. (Engeman *et al.* 2000), and also proved simultaneously effective for swine (Engeman *et al.* 2002a). This low-tech method places a series of tracking plots throughout the area of interest. At each plot, the number of swine track sets (number of intrusions into the plot) is recorded for two consecutive days at each assessment time. After 24 hours, the plots are examined for spoor and resurfaced (tracks erased and surface smoothed) for the next day's observations. The PTIs and associated variances are calculated according to Engeman (in press) and Engeman *et al.* (1998) where a mixed linear model (e.g., McLean *et al.* 1991; Wolfinger *et al.* 1991) describes the number of intrusions on each plot each day. The mean number of track intrusions on each plot is calculated for each day, and the index value is the mean of the daily means. Adding to the robustness of the index, the variance formula derivation was based on a nonzero covariance structure among plots and among days, that is, without assumptions of independence among plots or days (Engeman *et al.* 1998). Maintaining permanent passive tracking plot locations maximizes index comparability across time (Ryan and Heywood 2003), providing a useful means to assess the changes in feral swine abundance while simultaneously providing information to describe the spatial distribution of their activity. Applications of the tracking plot information and the PTI included 1) optimizing the timing and strategy for swine removal, 2) minimizing labor by identifying areas where swine removal would have maximal effect, 3) assessing efficacy of removal efforts, and 4) serving as a detection method for re-invasion and identifying directions from which re-invasion occurs.

Damage assessment

Due to variability among habitats and associated difficulty in traversing the terrain, different sampling methods are more efficient for estimating damage in different circumstances. We applied quadrat and line-intercept, or transect-based, methods for sampling swine damage to natural environments. Swine damage was identified as ground overturned during foraging (rooting) activity. Tracks verified the species responsible. Armadillos (*Dasypus novemcinctus*) are the only other species in Florida that could produce superficially similar (small) patches of damage, which are easily distinguished from swine damage by examining tracks and whether the ground was overturned, or dug by forefeet.

Quadrat based

A quadrat sampling method was developed to use in conjunction with the PTI plot locations for estimating habitat damage by swine (Engeman *et al.* 2003). Each tracking plot location defines the location for 2 damage assessment plots. On one side of the road, a damage plot is established 1 m perpendicularly outward from the road edge. Each damage plot is a 5 × 1 m rectangle, with the long dimension paralleling the road, 1 m outward from the road. Each 5 × 1 m plot is established using a 1 × 1 m square constructed of PVC pipe. This square is folded over 4 more times beyond its initial placement to establish the plot. Cryptically placed, sand-coloured, wooden stakes in diagonal corners define the plot for future reference. The second damage plot defined at the same road location is constructed in the same manner on the opposite side of the road beginning 3 m in the opposite direction from the first plot, and leading away from the opposite damage plot.

The 1 × 1 squares are used to provide accurate and readable measurements of the area damaged within the 5 × 1 m plots to the nearest 5%. String is placed in a "+" sign across the 1 × 1 square to divide the area into 4 equal quadrants. Thus, damage is measured over 20 of these 0.25 m^2 quadrants for each of the 5 × 1 m plots. Damage is estimated as the mean percent of area of damage across the plots.

Transect based

In habitats where it is possible to follow a straight-line transect, damage is sampled on transects spaced through the area. This was particularly effective for assessing damage to the exposed portion of the last remnant of a once-extensive basin marsh system in Florida (Engeman *et al.* 2004b, in press), where tape measure transects were placed along the perpendicular distance from the water's edge to the interface between the marsh and the surrounding community of upland vegetation (Engeman *et al.* 2004b, in press). The total distance of each transect is measured, as well as the distance directly on the transect that was damaged by swine. This amount could represent a single patch of damage or the combined distances of multiple patches. Damage not lying directly under on the transect is not recorded. Damage is estimated as the mean percent of length of damage length across the transects.

Economic evaluations

Besides estimating the quantity of habitat damaged by swine we also wished to apply a credible monetary valuation for that damage. Determination of monetary values for protected habitats is not a straight-forward nor precise process. A means of applying a monetary value on a unit-area basis to damaged native habitats is needed to estimate the unit (per-ha) and total cost of swine damage. Engeman *et al.* (2002b) discuss a variety of ways to apply monetary values to threatened and endangered animal species. Analogies to these methodologies were considered for application to habitat values, as well as other avenues specific to habitat issues (Engeman *et al.* 2004a). One simplistic consideration for valuation of habitat is to appraise the land on the basis of market value. However, special habitats such as wetlands have limited "market value", and if such habitat is selectively protected, the market value diminishes even further (King 1998). The use of contingent valuation surveys for special habitats, analogous to those applied to endangered animals, tend to be even more abstract appraisals of value (King 1998). Estimated costs for restoring habitat to pristine condition (replacement costs) frequently produce values well in excess of the public's "willingness-to-pay", and therefore also do not represent a realistic valuation. The most defensible, logical, and applicable valuation for the damaged habitat characteristic of our study site was to use expenditure data for permitted wetland mitigation projects in the United States. Such data represent an empirical demonstration of willingness-to-pay value. King (1998) presented the dollar amounts per unit-area spent in efforts to restore a spectrum of wetland habitat types. The numbers represent the dollar amounts that environmental regulators, and to a degree elected governments, have allowed permit applicants to spend in attempts to replace lost wetland services and values (King 1998). We identified the dollar value for the appropriate wetland habitat category from each of the two studies cited in King (1998) to apply for each of our habitat types under study.

Economic analyses

Estimation of the amount and the associated value of swine damage permits the application of benefit-cost analyses to evaluate the need and success of swine control from an economic perspective, or to economically compare swine management approaches. The benefit-cost model approach of the swine management involves estimating the monetary value of the benefits measured in per-ha damage saved versus the costs measured in per-ha damage lost plus control costs. The objective of minimizing opportunity costs is equivalent to maximizing net benefits (Boardman *et al.* 1996). Benefit-cost ratios (BCRs) are calculated using the standard format of the ratio of benefits to costs (Loomis and Walsh (1997), Boardman *et al.* (1996), Nas (1996), Zerbe and Dively (1994), and Loomis (1993)). If a BCR>1, then the rewards for swine removal exceeded the costs, whereas a BCR<1 suggests that swine removal conducted in that fashion was not economically efficient.

When comparing management approaches, the benefits of one approach are represented as the opportunity cost of pursuing an alternate approach. Measured this way, the benefits of following approach 1 in lieu of approach 2 are represented by per-ha value of damage saved by not pursuing approach 2. This implies that the benefits of approach 1 in comparison to approach 2 are represented by the opportunity costs of pursuing approach 1. Or seen in another way, the benefits that accrue to each approach will be measured in terms of the cost saving as compared to alternate approaches. The BCRs must be evaluated in terms of the other approaches available. The benefits accruing to approach 1 depend on the value of per-ha habitat lost in the alternate approaches not followed. For example, the benefits accruing under approach 1 in comparison to approach 2 are measured by the following equation:

$$BCR_{1,2} = \frac{\text{per-ha damage value saved by not following approach 2}}{\text{per-ha damage value for following approach 1}} = K.$$

In other words, the benefit in terms of damage amount of approach 1 (en lieu of approach 2) is K times greater than the cost of approach 2. For an approach to be considered feasible it should be the case that $K > 1$. If $K < 1$, then pursuing that approach is less cost-effective than the approach that is not being used under that scenario.

DISCUSSION

Each area of research has contributed substantially to the efficacy, efficiency, and perception of swine removal efforts. The PTI is an effective tool for planning and assessing swine removal efforts, as well as for follow-up monitoring to determine if and where additional control is needed. Protection and improvement habitats have been the ultimate goals of our swine removal efforts. Therefore, reliable and practical means to estimate damage levels provide true evaluations of the need and efficacy of swine control. The ability to value the habitat resource provides an effectual tool for evaluating conservation approaches. Economic analyses can greatly assist managers on how most efficiently and effectively to allocate limited funds towards habitat conservation. Ultimately, many conservation funding decisions are made on a political level by people without high levels of training or expertise in biological sciences. Placing conservation issues in an economic context can greatly enlighten the political decision making process.

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