

Simulating Potential Population Growth of Wild Pig, *Sus scrofa*, in Texas

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Abstract - Understanding the interrelationship of environmental and biological factors that influence population growth rates of invasive *Sus scrofa* (Wild Pig) is a requisite for population management of the species. Such information can be used to evaluate various types of population control to ensure that the most cost-effective damage-abatement methods are used. We developed a sex- and age-structured model to simulate general population dynamics of Wild Pigs in Texas. Our objectives were to estimate potential statewide Wild Pig population-growth rates for Texas, identify model parameters that most influenced population trajectories, and compare resulting model predictions with ancillary population-trend data. Our Wild Pig simulation model estimated a mean annual growth rate of 0.32 (SE = 0.01), and stochastic model projections of Wild Pig population sizes ranged from 3.6 million to 16.9 million after 5 years. To evaluate parameter sensitivity, we recast our simulation results into a Bayesian belief network, and evaluated input-parameter influence based on variance reduction using Shannon's measure of mutual information. Our results indicated that the most influential model parameters within our simulation were number of litters per female and number of piglets recruited into the population, while adult and juvenile survival had little influence on Wild Pig population size within our simulations. Overall, our results suggest that natural resource managers should focus efforts towards reducing Wild Pig reproductive success, as opposed to attempting to increase adult mortality, when conducting Wild Pig population-control campaigns.

Introduction

Wild Pig L. (*Sus scrofa*) management in the United States is becoming increasingly necessary due to wide-ranging negative impacts to ecosystems and the environment (Campbell and Long 2009). Free-ranging Wild Pigs are a non-native invasive species that exhibit one of the highest reproductive rates of any ungulate (Taylor et al. 1998). Intentional and unintentional releases of domestic swine have resulted in establishment and current expansion of feral animals (West et al. 2009), which has led to environmental impacts including competition with native wildlife, damage to native vegetation, and increased risk of pathogen transmission (Campbell and Long 2009). Annual agricultural damage caused by Wild Pigs in Texas could potentially exceed \$50 million (Higginbotham et al. 2008).

Approximately 1.5–2 million Wild Pigs reside in Texas (Mapston 1997). Although increases in Wild Pig abundance are believed to have occurred over the last

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20 years, population trends in Wild Pigs are poorly understood because reliable survey methods for Wild Pigs do not exist (Reidy et al. 2011) and the relationship between population growth and demography is understudied (Adams et al. 2005). Our objectives were to simulate likely Wild Pig population dynamics, identify model parameters most influential on population trajectories, and compare model estimates with statewide harvest trend data. In so doing, our goal was to test the population model with ancillary data, estimate growth rates, and identify control methods most effective at limiting that population growth.

Methods

Model structure and parameterization

We used a stochastic age- and sex-structured model written in R (R Core Development Team 2004) for our simulations (Fig. 1; see Supplemental R code, available online at <http://www.eaglehill.us/SENAonline/suppl-files/s13-2-2055-Collier-s1> and, for BioOne subscribers, at <http://dx.doi.org/10.1656/S2057.s1>). The model tracked, on a semi-annual basis, population size and demography of both sexes (male, female) in 3 mutually exclusive age classes: piglets (P; birth to 6 months old), juveniles (J; 6 months to 1 yr), and adults (A; ≥ 1 year old). Optimally, age- and sex-specific population-demographic estimates would be available for the population of interest in Texas, but this information is unavailable for Wild Pigs in most states because research efforts focused on Wild Pig demography are limited (Ditchkoff et al. 2012). Thus, we conducted a literature review and compiled a suite of demographic-parameter estimates, from which we based age-specific estimates for use in our simulations (Table 1). We used model expressions and incorporated demographic variation using binomial or Poisson random variates within the simu-

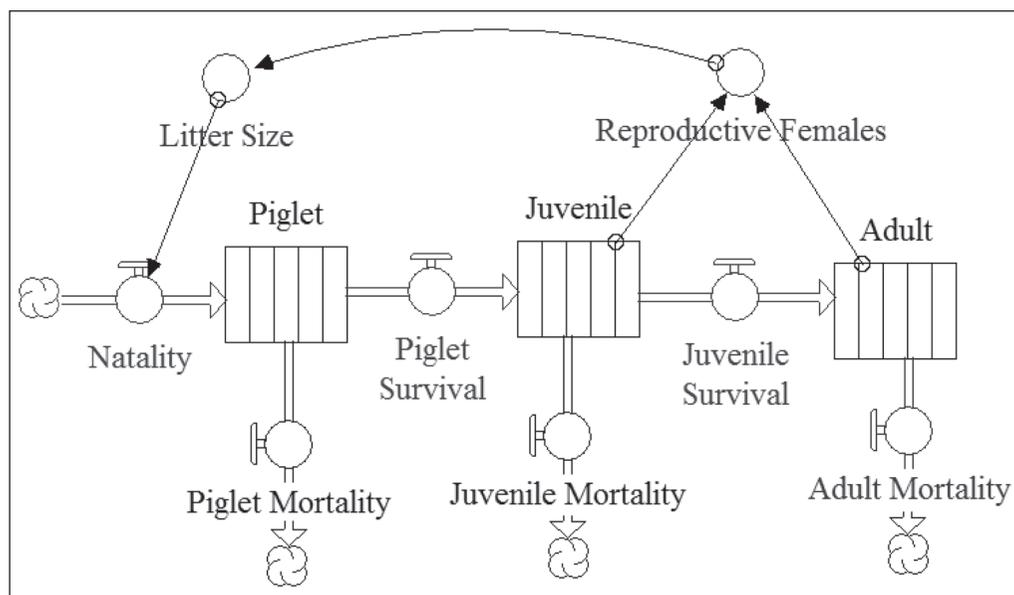


Figure 1. Conceptual model for simulation of Wild Pig population dynamics in Texas.

lation model following Phillips and White (2003). We conducted 1000 simulations using random combinations of demographic parameters drawn from a uniform distribution bounded by the minimum and maximum estimated values we garnered from the literature.

Statewide population data

Three separate, statewide data sources were used to independently estimate trends in harvest of Wild Pigs in Texas, and to evaluate the model population trajectories from our study. We estimated growth rate from these harvest-trend data sets and compared those results to our model projections. The first data set was based on aerial-eradication permits granted during 2005 to 2008 to private landowners by Texas Parks and Wildlife Department (TPWD). The second data set was based on the number of live-trapped Wild Pigs in Texas sold to processing plants for human consumption, which we obtained for the period 2004–2008 from the Texas Department of Agriculture. Finally, we obtained 2000–2008 data

Table 1. Baseline population estimates (mean [M], low [L], high [H]) for parameterizing the Wild Pig simulation model.

Age class	Mortality rate ¹	Sex ratio (m:f) ²	Reproductive age ³	Litter size ⁴	Litters/year ⁵	Juvenile:adult ratio ⁶	Initial abundance ⁷
Piglet	0.14 (M) 0.16 (L) 0.12 (H)	0.5					391,111
Juvenile	0.15 (M) 0.16 (L) 0.14 (H)	0.5					195,556
Adult	0.08 (M) 0.1 (L) 0.06 (H)	2.0					1,246,666
Combined		0.50 (M) 0.48 (L) 0.52 (H)	6 months (M) 7 months (L) 5 months (H)	5.64 (M) 5.34 (L) 5.94 (H)	1.50 (M) 1.33 (L) 1.67 (H)	1:2.0 (M) 1:1.6 (L) 1:2.5 (H)	1,833,333 (M) 1,666,666 (L) 2,000,000 (H)

¹Data sources: Adkins and Harveson (2007), Baber and Coblentz (1987), Barrett (1978), Diong (1982), Gabor et al. (1999), Hayes et al. (2009) Saunders (1993), and Wood and Brenneman (1977).

²Data sources: Adkins and Harveson (2007), Baber and Coblentz (1987), Beldon and Frankenberg (1990), Diong (1982), Duncan (1974), Gabor et al. (1999), Hagen and Kephart (1980), Pine and Gerdes (1973), Saunders (1993), Sweeney et al. (1979), Taylor et al. (1998), and Wood and Brenneman (1977).

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⁵Data sources: Adkins and Harveson (2007), Baber and Coblentz (1987), Barrett (1978), Diong (1982), Pine and Gerdes (1973), Rollins et al. (2007), Taylor et al. (1998), and West et al. (2009).

⁶Data sources: Adkins and Harveson (2007), Diong (1982), Duncan (1974), and Gabor et al. (1999).

⁷Data sources: Rollins et al. (2007), and West et al. (2009).

based on aerial gunning and other damage-control activities (e.g., trapping, ground shooting) conducted as part of the Wild Pig damage-control program of the United States Department of Agriculture, Animal and Plant Health Inspection Services' Wildlife Services (WS) program in Texas. We had to assume that relative effort for each data set was consistent among years, and for plotting we scaled all time to start at year 1 for consistency.

Graphical causal model

We developed a Bayesian belief network (BBN) implemented in Netica (Norsys Software Corp.) to assist with model evaluation, as our BBN represents a causal model of the biological system under study (Fig. 2; Marcot et al. 2006, Pearl 1988). Bayesian belief networks use probabilistic expressions to describe relationships between model components conditional on knowledge (evidence) contained in other variables within the system (Peterson and Evans 2003). As belief can never be >1 , the allocation of belief within each node is used to show certainty (or uncertainty) associated with the state of each biological variable.

Model output consisted of input parameters and intermediate model-based estimates with ending population-simulation results output as a case file (database of findings; Lee and Rieman 1997, Peterson and Evans 2003). Within a BBN, parameters work in concert with each other (i.e., a change in one parameter could influence several model parameters). Thus, to evaluate parameter sensitivity, we used the internal sensitivity functions in Netica (Marcot et al. 2001) to calculate the reduction in variance using Shannon's measure of mutual information (Pearl 1988). Unlike typical sensitivity analyses where a single parameter is varied \pm some fixed percentage and compared to an arbitrary baseline, sensitivity analysis in a BBN evaluates changes to the probability distribution of the response variable based on changes to the probability distribution of causally related model nodes (Marcot et al. 2001). Sensitivity was expressed as the percent reduction in variance of the query variable (Q) or response variable of interest given the specification in the findings variables (F) or variables conditionally related to the query variable. We relate variance-reduction estimates from sensitivity analysis with reduced uncertainty in the predicted model outcome (Pearl 1988). Predicted variation was exhibited as the spread of the posterior probability estimates across the possible outcome states.

Results

Our Wild Pig model estimated that mean annual growth rate was 0.32 (SE = 0.01). Based on the range of input parameters used in our modeling exercise, simulated mean population size increased over a 5-year period from 1.8 million Wild Pigs to approximately 9.1 million. However, stochastic model projections of Wild Pig population growth ranged from 3.6 million to 16.9 million after 5 years. Based on our sensitivity analysis, parameters identified in our graphical causal model indicated that the number of piglets surviving to recruitment (variance reduction of 85.6%) and number of litters per female (variance reduction of 58%)

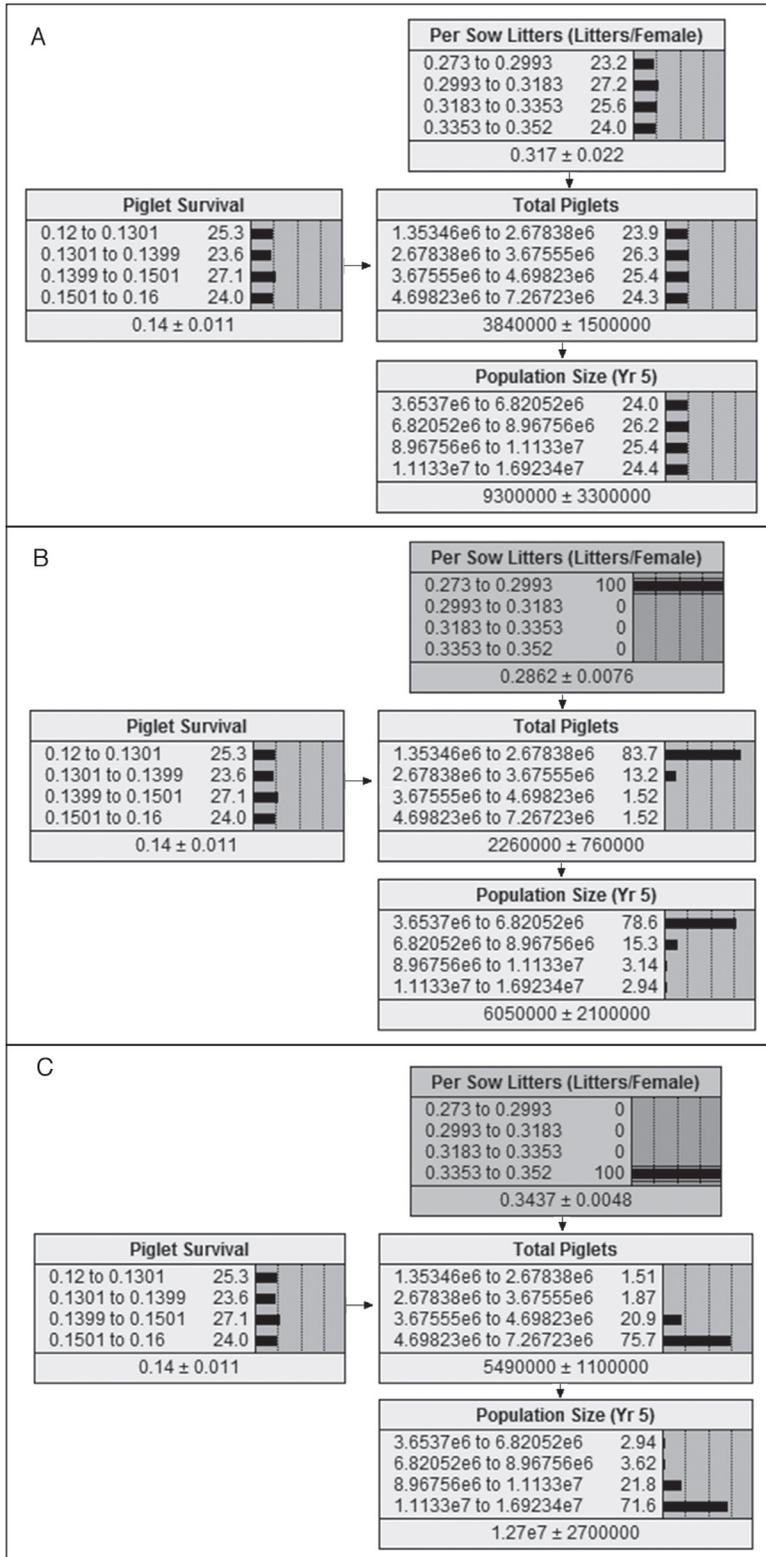


Figure 2. Predicted range of residual population size (expressed as a percentage of total population size) of Wild Pigs in Texas conditional on different specifications of knowledge regarding the number of litters per female (expressed as proportion). As an example, the belief histogram for node Population Size (Yr 5) shows the predicted belief (probability) that the residual population size at year 5 will be within a given size class, conditional on knowledge of the number of litters per female (expressed as proportion) using a scenario where no updating of knowledge has occurred (2a), a scenario where knowledge is added assuming the number of litters per female is within the minimum range based on the simulation input values (2b), and a scenario where knowledge is added assuming the number of litters per female is within the maximum range based on the simulation input values (2c).

were the primary population parameters driving growth. For example, as shown in Figure 2, subtle changes in the number of litters per female (changing from a maximum of 0.29 to 0.35) can cause significant changes in the predicted population size. We found only a limited impact of piglet survival (variance reduction of 1.72%) and sub-adult population size (variance reduction of 1.0%) on sensitivity of population predictions, and no other parameters within our model reduced variance $>1\%$. Additionally, our sensitivity analysis indicated that neither adult nor juvenile survival rate had any significant impact on Wild Pig population projections over the course of our simulations. Annual intrinsic growth rates from processing plant numbers, TPWD's aerial removal data, and removal data from Texas WS varied from 0.19–0.25, with a mean of 0.21 (Fig. 3). Observed increases in statewide Wild Pig population-trend data were significantly less than population trajectories simulated using our model ($r = 0.32$).

Discussion

Simulation models involving free-ranging *Sus scrofa* have been constructed to assess disease-control efforts in Australia (Pech and Hone 1988), harvesting strategies in Italy (Focardi et al. 1996), management actions in Switzerland (Neet 1995), and the influence of environmental conditions in Spain (Uzal and Nores 2004). As with any modeling exercise, the validity of the model output is dependent upon the quality of parameters used. Our model, which used available

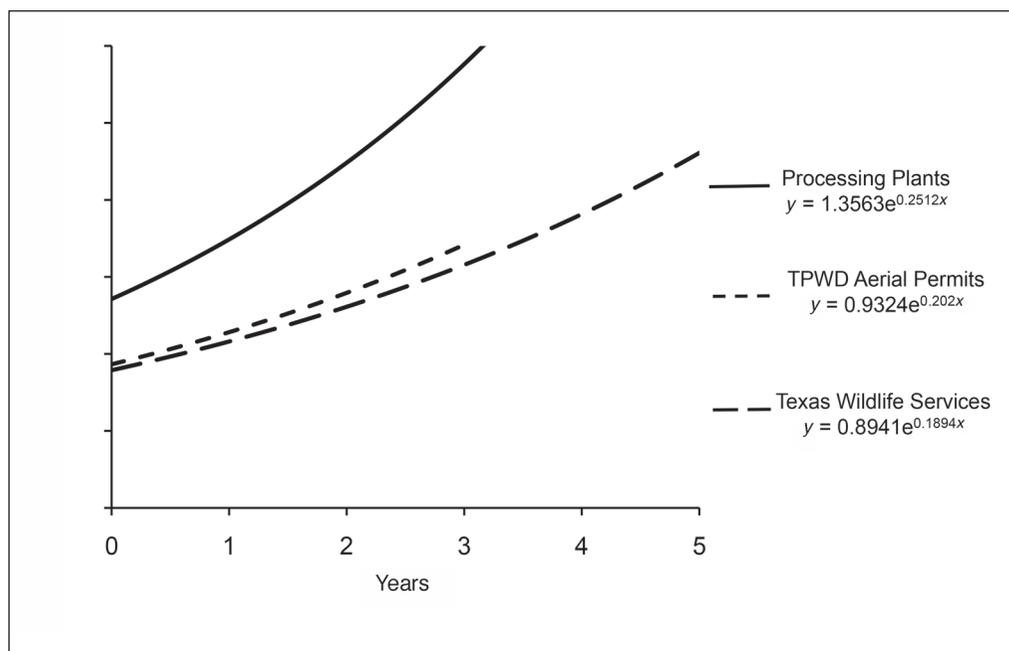


Figure 3. Intrinsic growth rates estimated based on Wild Pig processing plant numbers, Texas Parks and Wildlife Department's aerial removal data, and removal data from United States Department of Agriculture, Animal and Plant Health Inspection Services Wildlife Services program in Texas.

estimates from the literature and encompassed a variety of regions and environments, suggests that annual population growth rate for Wild Pigs in Texas is approximately 0.32. The model's projection of a growing population is consistent with anecdotal reports of increases in Wild Pig damage and range expansion throughout Texas and the southeastern United States, but the rate generated is less than that indicated by available data on the recent growth trends in Wild Pigs harvested in Texas. If the processing and removal data reflects a consistent effort and efficiency of harvest over the years and thus accurately follows the trend of the actual population size of Feral Pigs, then our model would need to be adjusted in some manner to better reflect all of the factors that might in reality be affecting population growth of Feral Pigs. On the other hand, our model may indicate that over the years, the removal efforts have been getting less effective and are capturing a smaller and smaller percentage of the actual population. If that is the case, then we may be seeing a much larger increase in the number of Wild Pigs than might be expected based on the limited available data. Specifically, our population projections indicated that Wild Pig population size could, assuming our input parameters were accurate and our model structure appropriate, quintuple within a 5-year period.

If Wild Pig population parameters are more closely represented by the higher parameter estimates, then we expect the population after 5 years to approach 16 million, and if population parameters are more closely represented by the lower range of parameter estimates, then we expect the population after 5 years to be approximately 3 million. Obviously, no population is going to have consistent population parameters over a long time frame, so it is likely that the most-likely population growth will be intermediate to the extremes. We note that in all projected population-growth estimates, we did not account for density-dependence effects to determine the potential rate of growth of Wild Pigs in Texas. The functional form for dependence, at what scale density-dependence operates, or what vital rates density dependence would impact are unknown (Ditchkoff et al. 2012). However, density-dependence processes will likely play a role in Wild Pig population regulation as populations continue to expand, likely manifesting its impact through reductions in population-level recruitment.

Our sensitivity analysis, when couched in a graphical causal model, provides us with the ability to evaluate which parameters are most significantly influencing population growth predictions without having to hold other parameters static in concert with additional simulation runs. We identified 2 general parameter categories that should be addressed by managers. First, we found that efforts towards reducing survival of adults and juvenile Wild Pigs by managers will have poor success. Attempts to influence survival, of adults, while intuitive to some, has had little success at large scales for several species (Alisauskas et al. 2011, Brown et al. 2000); thus, it is not surprising that localized increases in adult mortality have little impact on range-wide dynamics (Hanson et al. 2009). However, in situations where short-term damage abatement is of primary concern (e.g., agricultural loss), then direct removal of Wild Pigs may have short-term and immediate local

impacts but contribute little to population-level reduction. Second, our results indicate that management should focus efforts on methods to reduce reproduction, specifically the number of litters per year and piglet survival. Work in developing a fertility-control agent for Wild Pigs in a disease-management context is underway (Campbell et al. 2010, Sanders et al. 2011). However, at present there is no oral fertility-control agent registered by the Environmental Protection Agency for use in Wild Pig populations.

We hypothesize that these targeted and intensive management strategies can result in population reductions at the scale that management is applied. In Texas, droughts are frequent and when they occur, Wild Pig fecundity is naturally reduced (Taylor et al. 1998). Furthermore, Wild Pigs are often concentrated near sources of free water during drought, and food resources are scarce then. Both of these conditions facilitate efficient lethal control at local scales (Muir and McEwen 2007). However, given our modeling results, it is likely that the use of a variety of control methods deployed in a purposeful and integrated fashion (Campbell and Long 2009) will be required to slow growth of Wild Pig populations. Our graphical causal model, while admittedly coarse, will benefit managers by simplifying interpretation of model results, allowing for updating when additional data are collected, and for testing of alternative structures (Marcot et al. 2001).

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