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Population modeling for the reintroduction of Mexican gray wolves as predators to decrease the feral hog population in the Southern United States.

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Abstract:

Invasive species are a problem in the United States. As their populations continue to increase in size they disrupt ecological systems. One of the most notorious invasive species is the feral hog. In Texas, the hog populations cause ecological and agricultural damage that costs the state $52 million annually. The reason for the large continuously growing population is that the feral hogs, unlike its relatives in Europe, have no natural predators and hunters cannot suppress the population growth. In Europe, the gray wolf is a predator to the European wild boar. However, wolves in the U.S. have been extirpated from most of the continental U.S. If gray wolves could be reintroduced into hog habitat, and had similar predation rates as their Europe relatives, could they reduce the feral hog invasion? A theoretical population model was designed in excel where it used life-history information for wolves and feral hogs to simulate their population sizes for 50 years. Three different predation rates were simulated on the feral hog population, and population rates were compared to the control that had no wolf predation. The results showed that medium and high predation rates significantly reduce the hog population. This research is intended to show a natural and sustainable approach to solving the feral hog problem while aiding conservation efforts for the gray wolf. To further this research, the next objectives would be to add a habitat model and perform a field experiment.

Keywords: European wild boar, predator-prey dynamics, invasive species, Blue Range Wolf Recovery Area, stochastic population model

Introduction:

Biological invasions result from humans expanding the natural range of a species to a novel range. In these novel ranges these species are released from limiting factors, greatly increase their population size, and disrupt natural ecological systems (Hierro, et.al. 2005). The feral hog (*Sus scrofa*) is one of the most notorious invasive species in the United States today. They were brought into the New World in the late 1600s with the first settlers as livestock. Throughout numerous instances farmers abandoned these domesticated pigs into the wild, and in the 1800-1900s hunters would release European wild boars from Europe into the United States for sport. The free-ranging pigs and wild boar hybridized through generations resulting in the currently known feral hog population (Mapston, et. al., 2007).

Feral hogs are found primarily throughout the southern half of the United States. The State with the largest population of feral hogs is Texas ranging from 1 to 2 million individuals. These hogs in Texas have caused millions of damages to the state, by eating the agricultural crops, animal feed, and predating of livestock youth. They prey on wildlife, erode wetlands, and damage fertile soil by wallowing and rooting. They pose a serious threat to humans through transmission of diseases, and physical harm (Mapston, et.al. 2007). It is estimated that the average hog causes the state $200 in damages, and assuming there are 4 million hogs in the U.S the cost is about $800 million/year (Pimentel, et. al., 2005). The reason for the hogs' success is due to their high reproductive rates, lack of a predator and competition, and large food availability.

The main difference between the United States feral hog population and the Europeans boar population are that in Europe the gray wolves (*Canis lupus*) control the boar populations (Mattioli, et. al. 2011). An annual gray wolf diet consists between 24 to 60% wild boar, depending on the density (Newsome, et. al. 2016). In the United States gray wolves have been extirpated from most of their pre-settlement native range, so neither the feral hogs nor the gray wolves ranges overlap. However, since 1998 there has been an increase in population size of 97 individuals in the wild, and 300 in captivity of Mexican gray wolves (*Canis lupus baileyi*) that occupy Arizona and New Mexico (USFWS & AGFD, 2015). The consensus is that wolves prefer to prey on ungulates. Additionally, wolves prey on the species that are the most abundant (Newsome, et. al. 2016). If hypothetically the Mexican gray wolves could be reintroduced into

Texas, and their predation rates mimicked the rates that their cousins in Europe produce, could they mitigate or suppress the feral hog invasion?

Stochastic population modeling is designed to estimate various effects imposed on a group (i.e. death, birth, food availability) within a population to determine its size throughout time (Hale & McCarthy, 2005). Stochastic population modeling can be used to estimate the effects of placing a novel predator into a predator-prey system. The hypothesis is that the reintroduction of Mexican gray wolf (*Canis lupus* baileyi) as predators would significantly decrease and regulate the feral hog (*Sus scrofa*) population in Texas.

Methods:

The stochastic population model was created using MS Excel. Mexican gray wolves were the predator for the feral hogs because they were once indigenous and better adapted to Texas's ecosystem. Additional reasons cover that their mortality and reproductive rate would be more accurate as the Blue Range Wolf Recovery Area (BRWRA) is adjacent to Texas and has a similar economy and environments (Weiss, 2014) (USFWS & AGFD, 2015). Continuing, if one compares Mexican gray wolves to other North American subspecies, Mexican wolves consume a high percentage (92.8%) of large-bodied prey compared to the others in America (58.5-82.9%); (Reed, et. al. 2006). In 2015, it was estimated that elk comprised of 88% of the diet for an average Mexican gray wolf and was calculated that one wolf killed around 14 elk annually (Kreutzian, 2016).

The simulation was set up to resemble the reintroduction plan by the Yellowstone National Park (YNP) gray wolves in 1995-96. In two consecutive years the YNP released 14 the first year, then 17 the next year. This model was designed for 10 adults (2yr+) to be released for two consecutive years in the spring (USFWS, 1994). The model is set up into two parts. Part one was Mexican gray wolves' annual cycle, and the part two was feral hogs annual cycle, although part one has information that flows into part two.

<u>Part one:</u>

Mexican gray wolves were divided into four age groups; Age 0 (pups), Age 1 (yearlings), Age 2yr+ (adult), and Breeder (only female) (USFWS, 2016). All except Breeder had sub groupings of male and female. The Mexican wolves' annual cycle contained three stages spring, summer, and winter populations. Spring population started with reintroduction of four adult males, four adult females, and two breeder females. Then the individuals move to the summer population stage, were fecundity rates are used to calculate number of pups. In Excel "RANDBETWEEN" (RB) is a function that randomly assigned a number within or between an upper and lower limit. The formula for Age 0 used was the number of spring population breeders multiplied by RB for the upper and lower fecundity rates multiplied by the sex ratio. Refer to Table 1 for parameter data. The sex ratio of wolves is 50/50 (USFWS, 2016). This equation was used for both male and female cells for Age 0 in the summer population.

Survival rates were used to calculate the winter population for each age class for each year. The formula was the summer population of each age class (n) for each sex multiplied by the RB for the upper and lower survival rates. The winter population cells were carried over into next year's spring population. Each age class moves to the next age class (Age 0 to Age 1 and Age 1 to Age 2+), except the Age 2yr+ remains. Breeder class was calculated by Age 2yr+ males and females divided by RB of the upper and lower pack sizes plus the previous winter Breeders. The spring population moved into the summer population as stated previously, although for the second years and years after carrying capacity was used to calculate fecundity rates. The carrying capacity was estimated for a Mexican gray wolf is one wolf per 163km^2 (USFWS & AGFD, 2015). Given that Texas is 695,662 km^2, it is calculated that 4,264 wolves would be the carrying capacity in Texas. The formula for the carrying capacity (K) was calculated with an 'IF' statement from Excel. The formula was 'IF' the sum of the winter population of the previous year was less than K than Rmod would equal 0.1, however if it was greater than K, Rmod would equal K minus the winter population divided by K. Rmod is the 'IF' statement of the previous year. The summer population was then calculate using the Rmod for Age 0 were spring breeders were multiplied by the RB fecundity rates and sex ratio, and then multiplied by the Rmod for the previous year. Finally using the steps stated above the annual cycle was ran for 50 years.

Table 1: Mexican gray wolf parameters used to calculate the wolves' reproduction and survival rates.

	Mexican gray wolf parameters					References
	Age 0	Age 1	Age 2	Breeder		
Fecundity	0	0	0	6	Upper	USFWS, 2016
	0	0	0	4	Lower	
Survival	0.85	0.82	0.82	0.82	Upper	USFWS & AGFD, 2015, Carrol, et. al., 2013
	0.55	0.73	0.73	0.73	Lower	
Pack size	10				Upper	Cochrane, et. al., 2003
	6				Lower	

Part two:

Texas' feral hog population was estimated to be 1,800,000 (Mellish, et.al. 2014). The initial population was divided into age classes (Age 0, 1, 2-4, 5yr+) (EXtention, 2012). The initial population was divided with a sex ratio of 50/50 (Mellish, et.al. 2014), and the initial population numbers were Age 1 male 450,000, Age 1 female 450,000, Age 2 to 4 male 360,000, Age 2-4 female 360,000, Age 5yr+ male 90,000, and Age 5+ female 90,000. This was estimated by the initial population, and divided by 50% Age 1, 40% Age 2-4, and 10% Age 5yr+ (EXtention, 2012). The annual cycle stages for feral hogs were spring population, summer population, winter mortality.

The summer population stage had Age 0 born using this formula for the first year, and in the years after the Rmod for feral hogs were multiplied to the formula. The summer population formula for Age 0 was calculated by Age classes 1, 2-4, and 5yr+ females multiplied by the RB for each age classes upper and lower annul litter, the RB upper and lower number of piglets per litter, and the 50/50 sex ratio. Each Age classes Age 0 produced were added for the total Age 0 for the specific year. Sows can have multiple litters all year round and can be able to reproduce as young as 8 -10 months of age. To simplify reproduction, it was decided to have all litters accounted in the summer, and the minimum age to produce offspring was set for Age 1 (Timmons, et. al. 2015). The K-value for the Rmod formula for feral hogs was estimated by using the most conservative estimate of 3,600,000 population growth by Mellish, et. al. 2014. Age class 1 and older were carried over from the spring population to the summer population.

The winter mortality was calculated using each age class survival rates. The formula for winter mortality was each Age class for the summer population multiplied by the RB upper and lower survival rates. The following years' spring population stage carried over all age and sex class cells from the results of the winter population, and the annual cycle was ran for 50 years.

Table 2: Feral hog parameters used to calculate the hogs' reproduction and survival rates.

	Texas Feral hog parameters					References
	Age 0	Age 1	Age 2 - 4	Age 5+		
Number of litters per year	0	1.7	1.9	0.94	Upper	Mellish, et. al., 2014, Timmons, et. al. 2015, Bieber & Ruf, 2005
	0	0.56	1.6	0.56	Lower	
Number of piglets in litter	0	6.5	6.7	4.5	Upper	Bieber & Ruf, 2005, EXtention, 2012
	0	4.5	6.3	3.5	Lower	
Survival	0.25	0.60	0.71	0.50	Upper	EXtention, 2012, Bieber & Ruf, 2005
	0.20	0.31	0.58	0.45	Lower	

<u>Wolf Predation:</u>

Wolf predation were found by literature review based on different European wolf population predation rates. Wolf predation was added as a fourth stage, if applicable to each model, to the feral hogs' annual cycle after winter mortality. Excel's MAX statement was used to prevent predation to subtract below zero. Each feral hog sex and age class cell was calculated by the each hogs Age class (n) minus the wolves winter population for the corresponding year, multiplied by the RB upper and lower predation rate determined by the model, and multiplied by the RB percentage of wolf diet for the specific age class. Wolf predation rate parameters can be found on Table 3. Microsoft Excel sheet were divided to create four models. Within the four models were a low predation, medium predation, high predation, and no predation (control) model.

Table 3: Wolf predation parameters that were used and assigned two the three models with predation rates.

Predation Per Wolf Annually			References
	Lower	Upper	
Low Predation	1.6	2.5	Nores, et. al., 2008
Medium Predation	11.9	19.5	Jedrzejewski, et. al., 2002
High Predation	25	40	Heptner, et. al., 1988
Percentage of Wolf Diet on Boar Age Class			
Piglet (Age 0)	0.83	0.95	Mattioli, et. al., 2011
Adult (Age 1+)	0.05	0.17	Mattioli, et. al., 2011

Wolf predation rates were calculated by;

Low predation - State 17.5 boars were killed in 1994 and 1995. These killings were to be used as annual estimates by wolves, which they explain was 7 individuals. The average 17.5 boars killed within the two years was divided by the 7 individuals equalling 2.5. Additionally stated, wolves could consume 1.6 wild boars annually (Noara, et. al., 2008).

Medium– Estimate that 31 to 39 wild boars are killed annually by wolves in a $100km^2$ area in Poland. Also, was estimated that 2-2.6 wolves live in a $100km^2$ area. Those estimates were used to calculate 11.9 lower and 19.5 upper predation rate (Jedrzejewski, et. al., 2002).

High– On page 72 of *Mammals of the Soviet Union*, it states that one individual wolf annually consumes 50 to 80 wild boars. These predation estimates were halved for a more conservative estimate (Heptner, et. al., 1988).

Statistics:

All simulations were ran 100 times, and a mean from the 100 simulations was calculated. The mean of the population sizes of predation (low, medium, and high) and no predation (control) models for feral hog populations over time were compared with each model by a one-way ANOVA test to identify significance between the simulations. Standard error bars were used to further identify significance for each model's average. The three predation population rate models were compared to the no predation population rate model to identify the average number of hogs added or removed throughout the 50 years. This information was then used to calculate amount Texas would save having wolves reintroduced to the state.

Results:

After performing a one-way ANOVA test on the four models it was found that all were significantly different. The F-distribution was F= (3,196) = 378.82 with a p-value of less than 0.0001, and the critical f value was 9.20. Each model had a significant characteristic of population size over time. The Mexican gray wolf population had population growth until it plateaued at its K value, which indicates that the reintroduction was successful at implementing a sustainable population. The Mexican gray wolf simulation is shown in Figure 1.

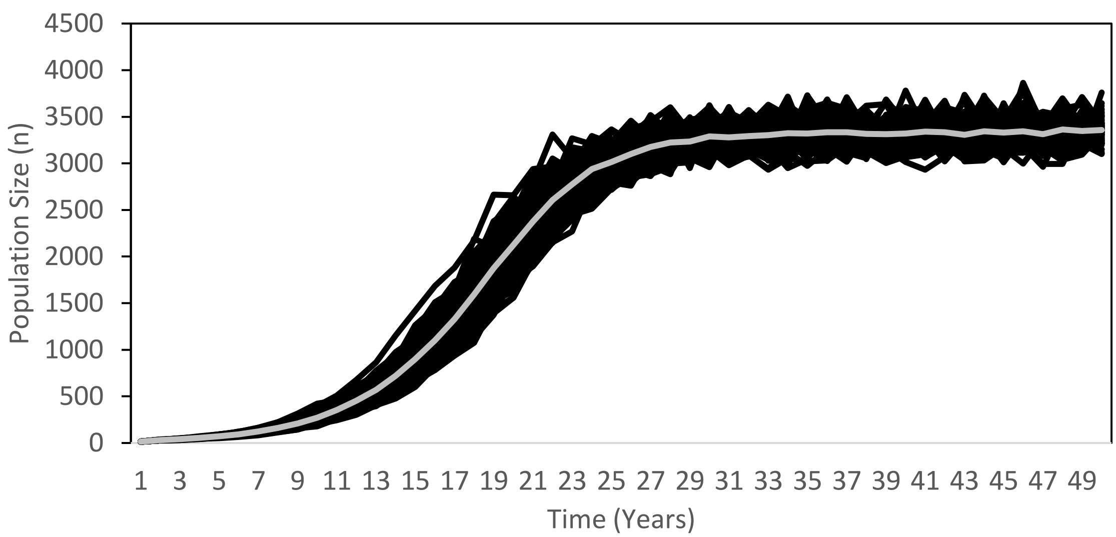

Figure 1: The Mexican gray wolf population growth rates over 50 years. The black lines are the 100 simulations of the gray wolf simulation, and the light gray line is the average of the simulations

Standard error bars were used to identify significance of each models average within Figure 2. The control simulation for the feral hog population was similar to the wolf population trendlines. The low predation treatment was found to increase the feral hog population to a higher K-value, but in the medium predation treatments it lowered the K-value below the controls. In the high predation simulation, the feral hog population displayed a downward trendline to zero, although its 100 simulations had the most variance. Figure 2 shows the mean of the 100 simulations for the four models.

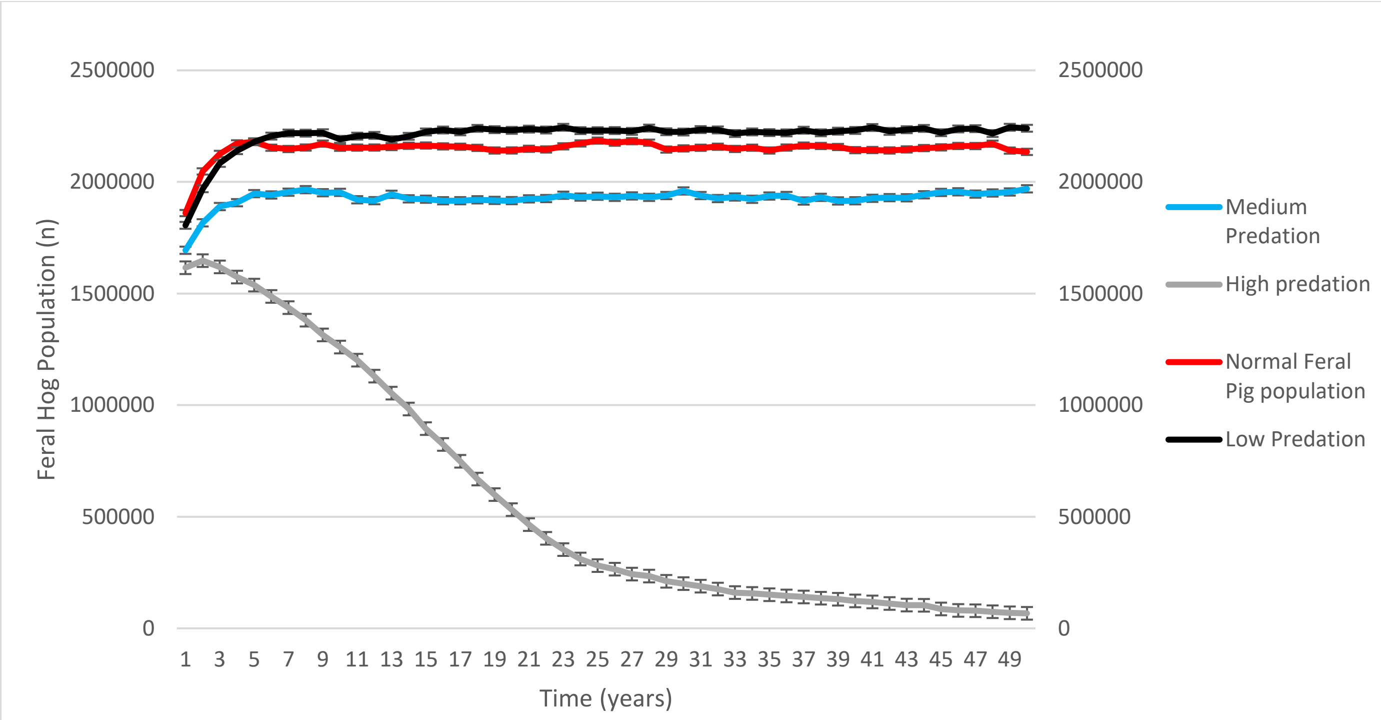

Figure 2: The means of each feral hog population that were simulated over 50 years. Standard error bars were placed to identify significance.

Each treatment's mean was compared to the control's mean to calculate the economic value that Texas would see within each simulation. When comparing the low predation to the control, Texas would have an additional 2,965,897 feral hogs, which would add a cost of $593 million in damages after 50 years. Although, in the medium predation compared to the control, 11,063,270 feral hogs were removed thus saving the state $2.2 billion after 50 years. When comparing the high predation rates to the control, there were 78,505,528 hogs removed from Texas. The high predation rate of wolves would save the state $15.7 billion after 50 years.

Discussion:

The simulated models were to assess if reintroducing of the Mexican gray wolf into Texas, from the BRWRA, would reduce the feral hog invasion. According to the results of the models, if wolves were to mimic medium and high predation rates then the wolves would be able to decrease the hog populations, which supports the hypothesis. Although, if the wolves were to mimic low predation rates it would increase the hog population size due to removing enough individuals to allow the population to move above the set K-value, which would reject the hypothesis.

To address the biggest concerns that the state of Texas would have toward having wolves be reintroduced is to discuss wolf depredation. Wolves generally are notorious for predating on livestock, and because of this there is an issue when reintroduction of wolves is proposed into more of the United States. Due to this issue, conservation efforts for the wolves has become increasingly more difficult as sociological groups try to halt efforts. Taking the data gathered in the BRWRA by the U.S. Fish and Wildlife Services (USFWS), they state that for every 100 wolves it is estimated that up to 26 cattle would be killed each year (USFWS &AGFD, 2015). By year 50 of the wolf reintroduction simulation there would be 3,357 depredation events. If the reintroduced wolf population at 3,357 individuals were to depredate at the same rate as projected by the USFWS there would be 772 domestic cows killed. The average reimbursement per depredation by wolves in Montana is $900, so if a similar reimbursement method was placed in Texas in year 50 the wolves would cost Texas $694,800 (Ramler et. al., 2014). Although, in a medium predation rates for hogs removed in that same year would still save Texas $32 million.

This research was intended to introduce one natural and sustainable solution to lowering the feral hog populations, instead of the control methods used today; trapping, hunting, and poisoning the hogs (Timmons, et. al., 2015). As the present control methods continue to falter, reintroduction of wolves should be looked at as a viable solution. Although, to use this research as evidence that the predator-prey dynamic will work would be foolish as many variables were assumed based on other geographic locations and different populations. To better support this research the next step would be to add regional data of feral hog populations, and place predator-prey dynamics into a habitat and population model. If results were to continue to support the hypothesis that wolves would lower the feral hog population, then a controlled lab experiment should be conducted to document Mexican gray wolves predating on the feral hogs and identify the natural variance of predation rates on the hogs.

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