Mexican Gray Wolf Reintroduction

New Mexico
Supercomputing Challenge
Final Report
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EXECUTIVE SUMMARY:

As a result of human expansion, the Mexican gray wolf—a species native to the Southwest region—has become endangered. Remaining wolves were reintroduced into the Blue Range Wolf Recovery Area (BRWRA) in eastern Arizona and western New Mexico with the aim of reestablishing a wild population.

The purpose of this project is to model Mexican gray wolf interaction with the environment within the BRWRA to predict wolf populations in the future and analyze the BRWRA's qualifications as a region to foster growth in population size. These standards were achieved through incorporating information regarding the wolves and environmental aspects, thus creating an abstracted ecosystem in which experiments could be run to determine the effects of certain variables on wolf population expansion.

Two main environments were created: the portion of the BRWRA in Arizona, and the portion in New Mexico. Then, experiments were run in which the wolves traveled different distances per day (10 miles per day, 20 miles per day, etc.) to interpret how available their food sources are in the BRWRA and how the population growth would be affected. The results of the experiments are both validating and informational. The experiments in which the wolves traveled 10 or 20 miles per day yielded similar results; the food sources for the wolves in the reintroduction area are plentiful enough that both distances encounter the prey required for survival (no wolves died). The projected population for the Arizona territory after 50 years is approximately 81 wolves, while the New Mexico territory after 50 years is approximately 114 wolves. The population estimates are in accordance with the observed population growth in the reintroduction program thus far.

These results not only predict continued Mexican gray wolf population growth, but also indicate that the BRWRA is a suitable region where the wolves have the ability to prosper to a degree at which the wolves will become capable of independent population maintenance.

INTRODUCTION:

Problem-

The Mexican gray wolf (*Canis lupus baileyi*) is the southern-most and most genetically distinct gray wolf subspecies in North America. Due to human expansion, these wolves decreased in population over the previous century until only a handful remained. The wolves were recognized as endangered in 1976 and a reintroduction program began in 1998 in the Southwestern United States. (US Fish and Wildlife Service, 2006) A small group of wolves was released into the Blue Range Wolf Recovery Area, with hopes of a stable wild population in the future. The Blue Range Wolf Recovery Area resides in eastern Arizona and western New Mexico; this ecosystem has the potential to illuminate where the Mexican gray wolves will best thrive. While this reintroduction program has merited moderate successes, more attention must be provided to their dilemma in order to reach a stable, wild Mexican gray wolf population.

Purpose-

As a real-world project, the goal was to make the subject as applicable to the community as possible. Mexican gray wolf reintroduction has been a debated topic in recent years. Since a relatively small range of data is available for use and application, I set out to compile scattered data and create a flexible model which helps to ascertain population growth and beneficial conditions in the allotted Blue Range Wolf Recovery Area.

DESCRIPTION:
Materials-

The research conducted involved much data and behavior analysis to determine how the Mexican gray wolves interact with their environment. At the outset of the project, a wildlife specialist (Mara Weisenberger) was consulted. Mrs. Weisenberger helped provide research and data unavailable to the general public. The Game and Fish Department and Fish and Wildlife Department for both Arizona and New Mexico were contacted by phone; they each directed research questions to a representative for the Mexican gray wolf reintroduction program. The Final Environmental Impact Statement (1996) supplied by Mara Weisenberger provided predictions of how the Mexican Gray Wolf reintroduction program should affect the environment over the next 15 years. The U.S. Fish & Wildlife Service have made available official reintroduction statistics from 1998-2012 regarding population growth, mortalities and releases/translocations, from which general growth patterns in New Mexico and Arizona were derived for the model. The wolf-prey interaction for the model was extracted from a 2006-2007 summer study of the diet of Mexican gray wolves that shows that elk consist of 80% and cattle consist of 17% of the wolves' diet. (Ballard, Krausman, Merkle, Oakleaf, Stark, 2009) This wolf-specific data, along with other environmental information, contributed to the model with the aim of creating an accurate representation of the abstracted ecosystem.

Environment-

The scope of this project, upon research, generally encompasses the effects of wolf predation factors on predicted wolf population. To begin this project, the environment surrounding the Mexican gray wolves in the Southwest needed to be established. An application that determines the area of irregular shapes on a map provided the area of the Blue Range Wolf Recovery Area (BRWRA) in Arizona (2,175 square miles) and New Mexico (4,679 square miles). Each patch in the model was determined to be 1/10 mile by 1/10 mile. Thus, the total patches needed to emulate both the New Mexico and Arizona areas were calculated through algebra and incorporated into the model. Also, according to the 1996 Environmental Impact Statement (EIS), there are “approximately 82,600 total cattle present in the area,” as well as a projection of 14,000 elk. (Fish and Wildlife Service, 1996) Thus the elk and cattle populations for both New Mexico and Arizona were derived; the proportional number of each animal to the area in New Mexico and Arizona of the BRWRA decided the quantities (see Figure 5).

Wolves-

In addition to accurately representing the environment, wolf and prey interactions had to be determined. The 1996 EIS predicted a result of 1,550 less elk as a result of wolf predation after 15 years, and 263 less cattle. (Fish and Wildlife Service, 1996) Using the population statistics of the actual program (see Table 2), it was calculated that these numbers suggest each wolf would require approximately 2.4 elk and .41 cattle for survival per year. This calculation is validated through the fact that gray wolves “can survive on about 2 1/2 pounds of food per wolf per day, but they require about 7 pounds [of food] per wolf per day to reproduce successfully.” (International Wolf Center, 2014) Because the typical elk weighs 600 pounds and the typical cow weighs 1,350 pounds, it was calculated that with 2.4 elk and .41 cattle per year, the wolves in the model would consume 5.46 pounds of food per day. It is important to note that this model accounts for fluctuation in wolf predation success. The procedure dictates that if the wolf fails to reach the milestone of 5.46 pounds per day after a year has passed, the wolf dies and disappears from the model, lowering the wolf population. If all wolves have reached the necessary energy to survive for the year, additional wolves are added.

The quantity of wolves added per year depends on the location in the BRWRA; New Mexico has a different historical growth rate of the Mexican gray wolves than does Arizona. Microsoft Excel was used to process the data and produce a line of best fit for both New Mexico and Arizona that determined how the wolves are likely to increase population in each environment (see Figures 3 and 4). For Arizona, it was determined that the wolf population increases at an approximate rate of 1.5 additional wolves per year. Thus, in the Arizona model (assuming that all wolves have reached the necessary energy to reproduce) there is a 50% chance that 1 additional wolf will survive into the next year, and a 50% chance that 2 wolves will be added to the model. For New Mexico, it was determined that the wolf population increases at about 2.25 more wolves each year. In the New Mexico model, there is a 75% chance that 2 wolves will be added for the next year, and a 25% chance that wolf population will increase by 3 wolves.

Wolf-Environment Interaction-

The basic premise for this model is to predict future wolf populations, taking into account the estimated available resources for the wolves to thrive. The wolves travel for the equivalent of a year in the model before food and reproduction is considered. At the end of the year, if their path through the representative environment has allowed them to intake at least 2.4 elk and .41 cattle, they are able to bolster the wolf population; if an individual wolf fails to come across the needed survival energy, it diminishes the population levels.

An important note involves how the model determines whether or not a wolf is able to capture its prey. A wolf cohabitating with a cattle of elk within a 1/10 square mile patch denotes that the wolf will successfully hunt its prey (1/10 square mile is equal to approximately 6 acres). The accuracy of this assumption is impossible to precisely decipher; however, it is sufficient for the aims of the model (is not too radical in either direction).

RESULTS:

The experiments that were run with this model involved manipulations of the miles-per-day variable to 1) predict wolf population in future years, and 2) observe how different amounts of wolf movement would affect how they are able to function in their allotted Blue Range Wolf Recovery Area. For each trial, the number of remaining wolves and the number of dead wolves were recorded to understand how the wolves fare in relation to their available food sources. Each set of established variables, of course, were tested in both the Arizona and New Mexico environments. The experiments were run for 50 simulated years each, thus generally predicting the wolf population around 2048. Since it is known that gray wolves can travel up to 50 miles per day, this model used a starting point to test for travel distance of 20 miles per day. After the experiments were run, it was determined that 0 wolves died; that is, a 20-mile-per-day average for traveling wolves is sufficient to run across the needed amount of prey per year in the BRWRA. The averaged resulting population after 50 years (as shown in Table 1 and Figure 1) in New Mexico was approximately 114 wolves, while the Arizona population averaged out at 80 wolves. Significantly, these growth patterns, because all wolves were able to survive, are based on the observed growth patterns of the previous reintroduction statistics (see Figures 3 and 4).

Logical deduction provides that because no wolves died in traversing 20 miles per day, they would also encounter no problems finding prey if they are tested at 30 miles per day. Hence, the next set of tests was run with wolves traveling 10 miles per day to see whether or not this number would prevent a certain number of wolves from finding the necessary yearly prey. Once again, no wolves died; there was enough food in their path traveling 10 miles per day to receive a sufficient diet of elk and cattle. In addition to this data, the population averages for New Mexico and Arizona were 114 wolves and 81 wolves, respectively. This makes sense because given the fact that the wolves still encountered enough food, their general reproduction rates should have been similar to the wolf simulation of 20 miles per day.

The last test was run more for the purpose of model validation and demonstration. This test involved a wolf average of .2 miles per day. Although this is highly improbable, the results display data that is beneficial for making inferences. In this model, wolves did die, which altered the generally stable population estimates after 50 years (as shown in Table 1 and Figure 2). Firstly, New Mexico had an average population after 50 years of 104 wolves; an average of 11 wolves died in the 50 year span. This is the result of some wolves failing to come across enough food, while others were able to encounter a sufficient amount. In Arizona, approximately 74 wolves were living after 50 years, and an average of 5 wolves died in that time span. This is important information in making conclusions about the validity and meaningfulness of this model.

Mexican Gray Wolf Reintroduction Experimental Data (50 year development)													
			Trial #										
			1	2	3	4	5	6	7	8	9	10	Average
.2 miles per day	NM	# of wolves	106	105	104	101	97	102	107	106	104	107	103.6667
		# dead	5	11	10	16	12	10	10	14	8	9	11.11111
	AZ	# of wolves	69	71	72	72	72	74	79	72	79	74	73.88889
		# dead	3	9	3	6	8	4	3	4	6	3	5.111111
10 miles per day	NM	# of wolves	117	114	117	114	111	117	111	115	112	118	114.3333
		# dead	0	0	0	0	0	0	0	0	0	0	0
	AZ	# of wolves	83	84	81	79	84	85	80	81	80	77	81.22222
		# dead	0	0	0	0	0	0	0	0	0	0	0
20 miles per day	NM	# of wolves	114	114	113	117	112	118	113	108	116	113	113.7778
		# dead	0	0	0	0	0	0	0	0	0	0	0
	AZ	# of wolves	78	79	80	75	81	85	85	74	77	84	80
		# dead	0	0	0	0	0	0	0	0	0	0	0

Table 1 - Mexican Gray Wolf Reintroduction Experimental Data (50 Year Development)

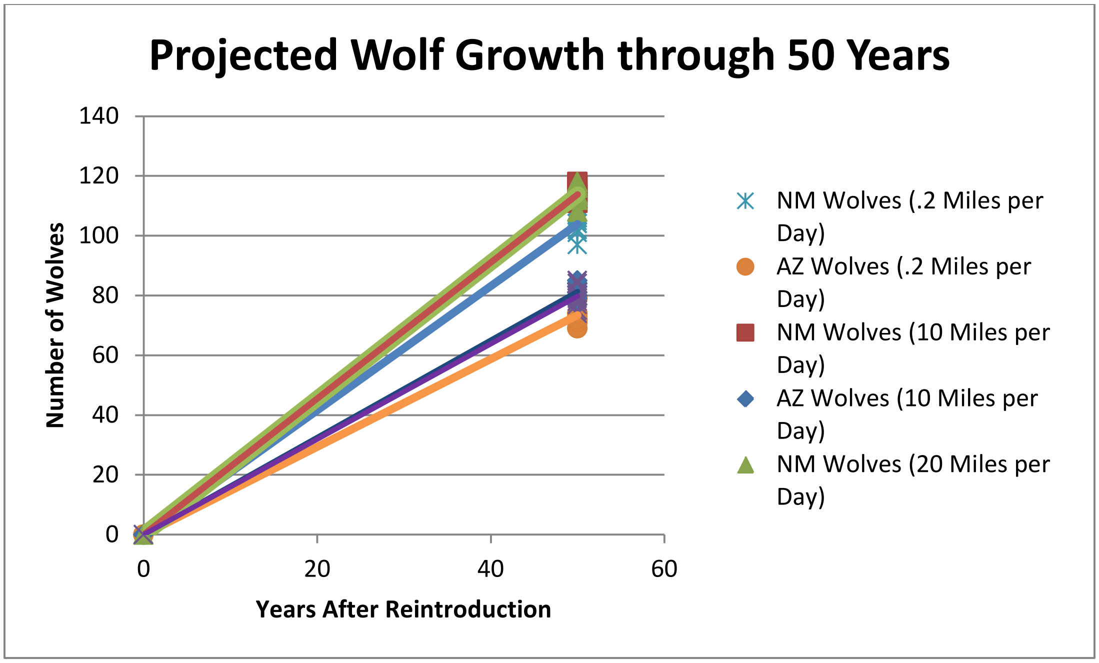

Figure 1 – Projected Wolf Growth through 50 Years

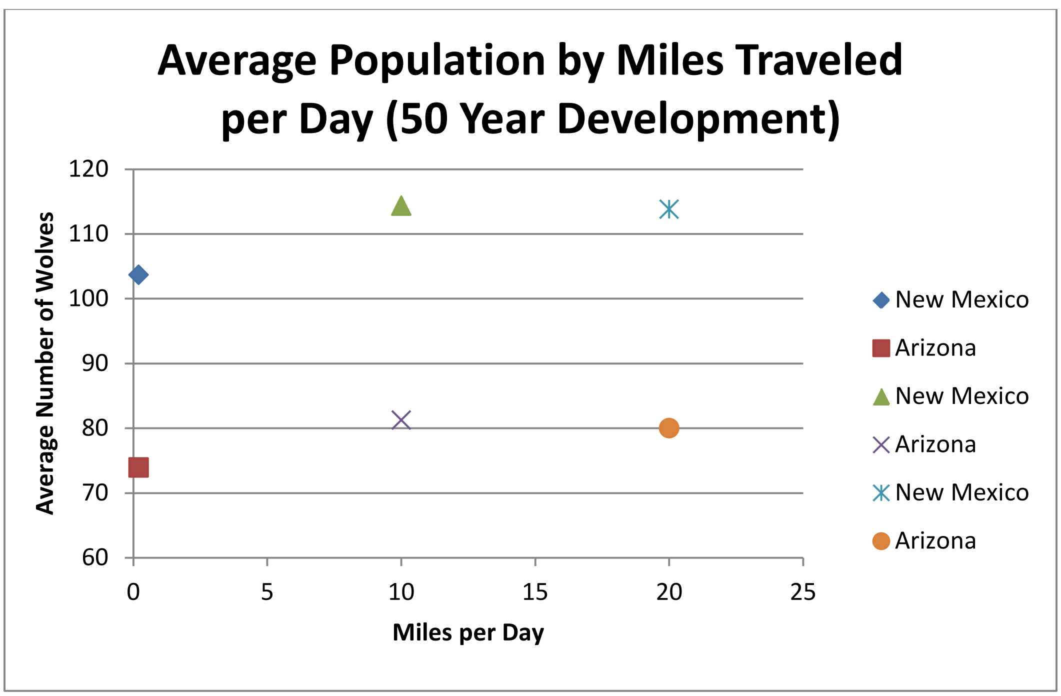

Figure 2 - Average Population by Miles Traveled per Day (50 Year Development)

CONCLUSIONS:

Based on the experiments run in this project, the location of the Blue Range Wolf Recovery Area is clearly a sufficient area to attempt to reestablish a wild wolf population. Not only are the populations in both New Mexico and Arizona growing at a steady rate, but only in highly unlikely situations will a wolf be likely to die of starvation. Only a small portion of the wolves that traveled .2 miles per day were unable to locate enough food; this suggests that the density of Mexican gray wolf prey is quite favorable in the BRWRA for population expansion. With this in mind, the (basic) model predicts, based on factors of predation, that Mexican gray wolves have the capability to increase population numbers to the point where the wolves can begin to maintain and add to their population independently. It is important to note that this model validates the choice to reintroduce wolves into the Blue Range Wolf Recovery Area which was, in fact, a region of their existence prior to endangerment.

RECOMMENDATIONS:

This is a basic model; there are many variables in the wild that it does not account for. Further research and programming could implement the following aspects into the model to improve results: Within the existing model, certain aspects could be added to better emulate the actual environment. For example, wolves, elk, and cattle are not randomly dispersed throughout the BRWRA. Wolves travel in packs of several wolves up to twenty wolves, elk group into herds, and cattle reside on ranches. Thus, in the case of my experiments with population growth and death, while some wolves may need to travel very little to encounter an elk herd and thus a large source of prey, some wolves may have a great distance between themselves and an elk herd and fail to encounter enough prey to live. Another aspect that could be improved is the actual predation interaction; the elk and cattle could be given life and death and move around the environment. The problem that was encountered with this is the processing speed, which would be extremely slow; however, if the model could be processed in a faster manner, this would make the results more accurate.

Additionally, this model has a focus on predation and the starvation aspect of life and death for the Mexican gray wolves. Other factors are at play, including human interaction (illegal kills, car collisions, etc.), reintroduction program interference (permanent removals, relocations), and other natural causes (disease, drought, competition within and between wolf packs, etc.). Any number of these factors could be incorporated into the model to make results and findings more representative of the actual environment in which the Mexican gray wolves participate.

ACKNOWLEDGEMENTS:

Thank you to Ms. Hagaman for providing advice in the construction of my model and the development of my project. Additionally, thanks to my mentor, Mara Weisenberger, for providing me with data and information vital to my model. Thanks to both LD Landis and Patty Meyer for reviewing my Proposal and Interim Report.

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APPENDIX:

Year	Minimum Population Estimate	Arizona Population Estimate	New Mexico Population Estimate
1998	4	4	0
1999	15	9	6
2000	22	15	7
2001	26	21	4
2002	41	34	7
2003	55	42	13
2004	44-48[a]	26	18
2005	35-49[a]	24	18
2006	59	25	34
2007	52	29	23
2008	52	29	23
2009	42	27	15
2010	50	29	21
2011	67	32	35
2012	75	37	38

Table 2 – US Fish and Wildlife Service Estimated Wolf Population by Year by State

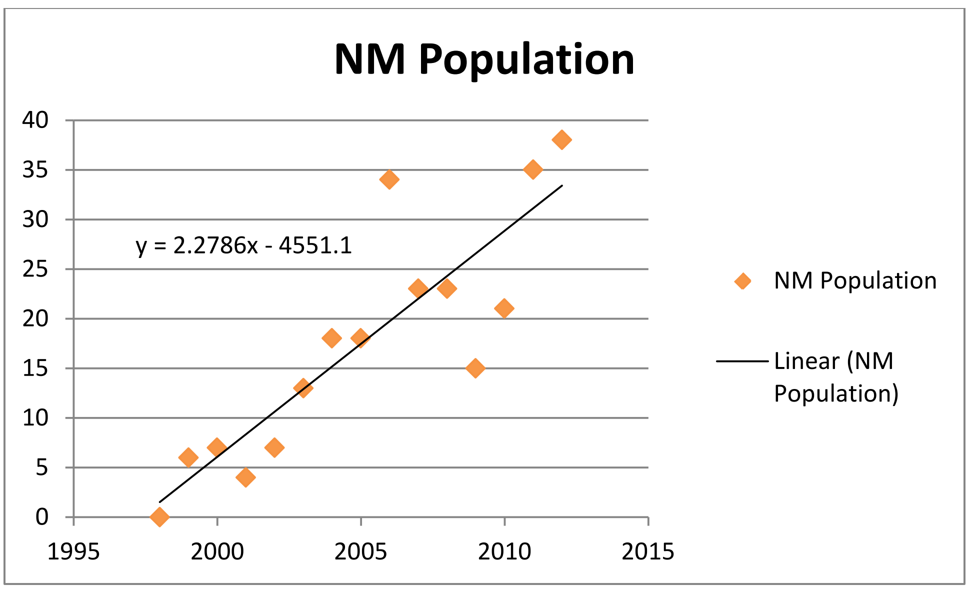


Figure 3 - NM Wolf Population Linear Growth Profile from Table 2 Data

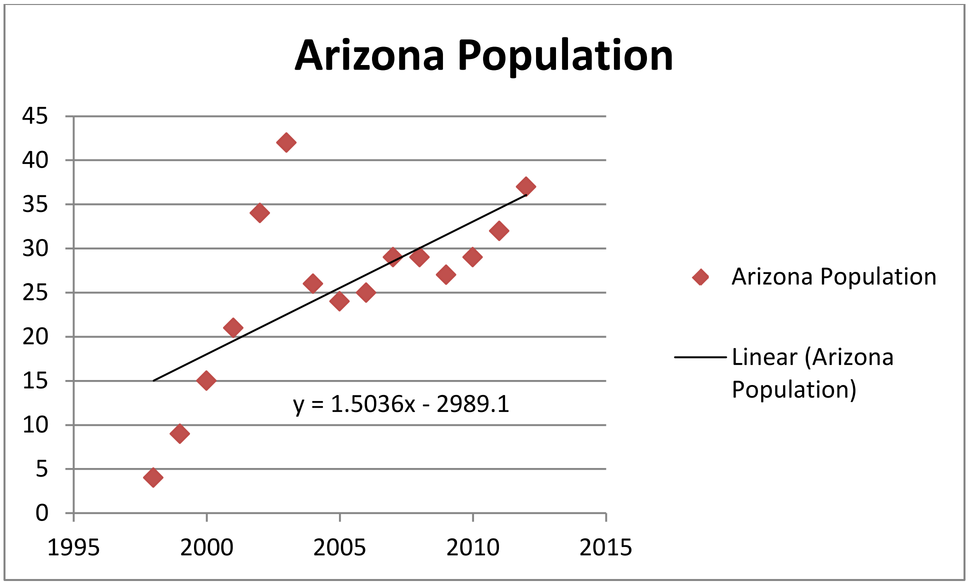
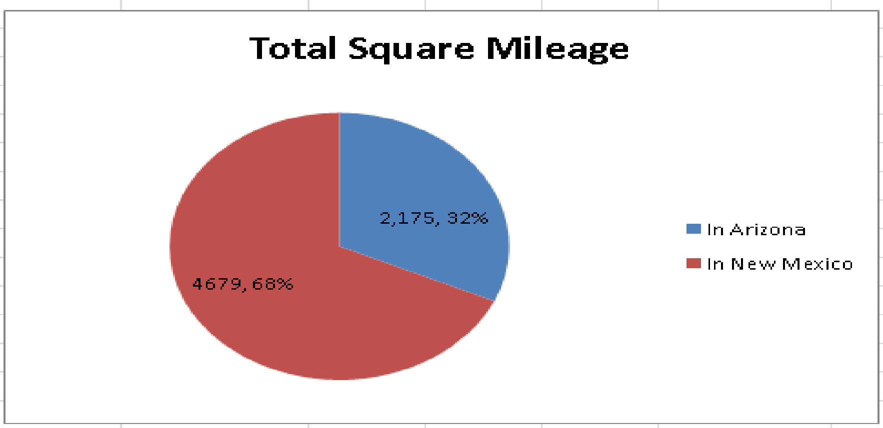


Figure 4 - AZ Wolf Population Linear Growth Profile from Table 2 Data

82600 cattle total in BRWRA

14000 estimated elk total in BRWRA



Model			Model	
Arizona Cattle	New Mexico Cattle		Arizona Elk	New Mexico Elk
26432	56168		4480	9520

Figure 5 –Square Mileage Calculations

Code-

```
breed [wolves wolf]  ; creates breeds for wolves, elk, and cattle
breed [cattle cow]
breed [elks elk]

wolves-own [food-cattle food-elk] ; wolves are given agent variables

globals [yearsAZ yearsNM deadwolvesAZ deadwolvesNM] ; global variables count years in NM and AZ wolves dead in NM and AZ

to setupArizona ; AZ BRWRA
  repeat 2
  [
  clear-turtles clear-patches clear-drawing
  reset-ticks
  set yearsAZ 0 ; years begin at 0 (first year of reintroduction)
  set deadwolvesAZ 0
  set num_wolvesAZ 4 ; the initial amount of wolves released into Arizona
  create-cattle num_cattleArizona
  create-elks num_elksArizona
  create-wolves num_wolvesAZ
  resize-world -233 233 -233 233 ; representative of the Arizona area (2,175 square miles) in patches of 1/10 square mile
  set-patch-size .4

 ask patches
  [
    set pcolor 37
  ]

  ask wolves
  [
   set shape "wolf"
   set color black
   set food-elk 0
   set food-cattle 0
   set size 75
   setxy random-xcor random-ycor ; randomly distributed throughout the model
  ]

  ask elks
  [
    set shape "elk"
    set color 2
    setxy random-xcor random-ycor
    set size 10
  ]

  ask cattle
  [
    set shape "cow"
    set color 32
    setxy random-xcor random-ycor
    set size 2
  ]
  ]
end
```

```
to GoArizona
  ask wolves
  [
   move        ; calls procedures "move" and "eatArizona"
   eatArizona
  ]
  advanceyearsAZ ; calls procedure "advanceyearsAZ"
  tick
  if yearsAZ = endmodelyears
  [stop]
end

to move
  left random turn-degrees    ; wiggle walk
   right random turn-degrees
   forward 1
end

to eatArizona
   if any? elks-here
   [
    if (random 10) < 7   ; there is an 80% chance of wolves capturing elk on the same patch
     [
       set food-elk (food-elk + 1) ; the variable is increased by the number of elk caught
     ]
   ]

   if any? cattle-here
   [
    if (random 10) > 7 ; there is a 20% chance of wolves capturing cattle
     [
       set food-cattle (food-cattle + 1) ; the variable is increased by the number of cattle caught
     ]
   ]

end
```

```
to advanceyearsAZ
  if ticks >= (milesperday * 3650) ; if the ticks have reached the correct amount of ticks for a year with the entered number of miles per day
  [
    set yearsAZ (yearsAZ + 1) ; the year is advanced
    reset-ticks
    ask wolves
    [
     ifelse (food-cattle < .41) or (food-elk < 2.4) ;if the wolves have not reached either one of the parameters for needed food
   [
    set deadwolvesAZ (deadwolvesAZ + 1) ; the "deadwolves" variable is increased accordingly
    die ; and the wolf dies
   ]
   [
    set food-cattle 0 ; food variables reset to 0
    set food-elk 0
   ]
   ]
     ifelse (random 2) = 0 ; there is a 50% chance of 1 wolf being added at the end of the year, and 50% chance of 2 wolves being added at the end of the year
    [                      ; as accoring to the derived growth statistics for observed population growth in Arizona
      create-wolves 1
         [set shape "wolf"
          set color black
          set food-elk 0
          set food-cattle 0
          set size 75
          setxy random-xcor random-ycor]
    ]
    [
      create-wolves 2
         [set shape "wolf"
          set color black
          set food-elk 0
          set food-cattle 0
          set size 75
          setxy random-xcor random-ycor]
    ]
    set num_wolvesAZ (count wolves)
  ]
end
```

```
to setupNM ; NM BRWRA
  repeat 2
  [
  clear-turtles clear-patches clear-drawing
  reset-ticks
  set yearsNM 0 ; years begin at 0 (first year of reintroduction)
  set deadwolvesNM 0
  set num_wolvesNM 1 ; the initial amount of wolves released into New Mexico
  create-cattle num_cattleNM
  create-elks num_elksNM
  create-wolves num_wolvesNM

  resize-world -342 342 -342 342 ; representative of the New Mexico area (4,679 square miles) in patches of 1/10 square mile
  set-patch-size .05
  ask patches
  [
    set pcolor 37
  ]

  ask wolves
  [
   set shape "wolf"
   set color black
   set food-elk 0
   set food-cattle 0
   setxy random-xcor random-ycor ; randomly distributed throughout the model
   set size 75
  ]

  ask elks
  [
    set shape "elk"
    set color 2
    setxy random-xcor random-ycor
    set size 10
  ]

  ask cattle
  [
    set shape "cow"
    set color 32
    setxy random-xcor random-ycor
    set size 2
  ]
  ]
end

to GoNM
   ask wolves
   [
    move      ; calls procedures "move" and "eatArizona"
    eatNM
   ]
   advanceyearsNM ; calls procedure "advanceyearsAZ"
   tick
   if yearsNM = endmodelyears
   [stop]
end


to eatNM
    if any? elks-here
    [
     if (random 10) < 7 ; there is an 80% chance of wolves capturing elk on the same patch
     [set food-elk (food-elk + 1)]; the variable is increased by the number of elk caught
    ]

    if any? cattle-here
    [
     if (random 10) > 7  ; there is a 20% chance of wolves capturing cattle
     [set food-cattle (food-cattle + 1)]  ; the variable is increased by the number of cattle caught
    ]

end
```

```
to advanceyearsNM
  if ticks >= (milesperday * 3650) ; if the ticks have reached the correct amount of ticks for a year with the entered number of miles per day
  [
    set yearsNM (yearsNM + 1) ; the year is advanced
    reset-ticks
    ask wolves
    [
     ifelse (food-cattle < .41) or (food-elk < 2.4) ;if the wolves have not reached either one of the parameters for needed food
   [
    set deadwolvesNM (deadwolvesNM + 1) ; the "deadwolves" variable is increased accordingly
    die ; and the wolf dies
   ]
   [
    set food-cattle 0 ; food variables reset to 0
    set food-elk 0
   ]
   ]
     ifelse (random 4) = 0 ; there is a 75% chance of 2 wolves being added at the end of the year, and 25% chance of 3 wolves being added at the end of the year
    [                      ; as accoring to the derived growth statistics for observed population growth in New Mexico
      create-wolves 3
         [set shape "wolf"
   set color black
   set food-elk 0
   set food-cattle 0
   setxy random-xcor random-ycor
   set size 75]
    ]
    [
      create-wolves 2
         [set shape "wolf"
   set color black
   set food-elk 0
   set food-cattle 0
   setxy random-xcor random-ycor
   set size 75]
    ]
    set num_wolvesNM (count wolves)
  ]
end
```

```
to resetdata
  clear-all ; clears the model
end
```