THOUSAND MILES FROM HOME

— Elk Reintroduction to the East

HIMCM 2012

TEAM#3432

1. Introduction

While some elks are wandering on the vast plain in the Yellowstone, some are still struggling on the brink of endangerment or extinction. Ever since Europeans step on the land of the great United States of America, they encountered the elks and later the have struggled to survive. In order to enhance the bio-diversity in the East, we have to consider the practice of reintroducing these mammals to their original habitats.

The entire process is time-consuming. This also includes the preparation stage,since the suitability of various elks and possible destinations has to be evaluated. Elk population is related to a wide range of ecological factors (e.g. habitat suitability, predators abundance, wildlife health and species-habitat interactions) and socio-economic and cultural factors (e.g. agricultural impact, human-elk conflict). Our evaluation will focus on these major factors accordingly.

Generally, we analyze historical data of elk population in the western states. Several kinds of elks will be picked out, and by quantification of the different characteristics of the habitats they are in, we come up with a model States, or namely a model environment. Subsequently, our discussion will, by comparing the model environment to the Eastern States, determine the possible habitats. Consequently, a number of suitable states will come out in the wash judging from the effect of post-introduction.

The value of this model is magnificent. We could achieve a adequate result on the combination of different elks in different states; more importantly, this model can foresee the growth rate of elks in the future, providing the local authorities with a suggestion on the regulations and management on the topic, to ensure a sustainable development for re-introducing elks into the East of America.

Part I:Determining Species & Location

2.1 Introduction

Most of us did not know much about the elk before,thus the first thing to do is to gather background information.Equipped with these knowledges,we can cope with future problems better.According to the encyclopedia,there are four living species of elks in North America,each having different characteristics.We discussed their advantages and disadvantages individually in order to evaluate their adaptability. The United States has vast area, hence a lot of eastern states have potential as elk habitats. The optimal condition for elk survival is determined according to data from western states, therefore providing criteria for further selection.This is similar to the so-called feasibility study.

2.2 Elk Selection

The elk family can be divided into two groups: the North American elks and their counterparts in Asia--the wapiti. Our available options are:the tule elk (*C. canadensis nannodes*), the Manitoban elk (*C. c. manitobensis*), the Rocky Mountain elk (*C. c. nelson*) and finally the Roosevelt elk (*C. c. roosevelti*). According to our analysis, only the last three kinds are considered adaptable to the Eastern States.

The tule elk is a subspecies of elk found only in California. It likes to eat,uh,tule. Since its natural habitats range from grasslands to marshlands of the Central Valley and its favorite food is only found in western America, it can be qualified as unique to the western US.Moreover, ever since the 1602 exploration of Vizcaíno, these species have been living in and only in the west. It is therefore unlikely to have a high adaptability and in a word, the tule elk is excluded.

There's not much that we can know about the Manitoban elk. However,there must be a reason for its appearance on the problem sheet.Thus, we are firmly convinced of its capability and give it a decisive "yes".

On the other hand, the Rocky Mountain elk and the Roosevelt elk are more reliable choices. The Roosevelt elk, though initially living in the rain forest of the Pacific

Northwest, was introduced to Alaska and Raspberry Island. It feeds on woody plants, including high bush cranberry, elderberry devil's club, blueberries, mushroom and salmonberries. It also enjoys a relatively long life-cycle of 12 to 15 years, some even to a surprisingly 25 years. The adaptability, the diverse diet and a long life-cycle to give birth to more calves clearly indicate that this is it! The Roosevelt elk shares the similar characters. However, one essential problem remains - several indigenous butterfly and plants are harmed when the elks are introduced to the Rocky Mountain National Park and the Estes Park. The environment was disrupted, the common food resources taxed, the local bio-diversity threatened. We will take it into consideration in the following parts of this essay.

The Rocky Mountain Elk herd has been diagnosed with a serious disorder called Chronic Wasting Disease (CWD). CWD affects the brain tissue of infected elk and is similar in symptoms to bovine spongiform encephalopathy (BSE), commonly known as mad-cow disease (MCD). There will also be later discussion of its influence.

2.3 Model State Selection

In order to determine which states to reintroduce the elks to,we hope to find a model state from the current western elk-residing states and use it as a template for our further selection.Since the western states are variegated,we seek to introduce an index to summarize the states' suitability of elk residence.There are multiple factors to be taken into consideration,e.g. weather,landscape,etc,which are,after careful discussion,circumstantial and indirect.The direct indications of elk population status are:elk population,population density and population growth.Later discussion will shed light on their differences.

2.3.1 Population,Density & Their Weaknesses

It is self-evident that the elk population most directly represents its current residential status.Simply choosing the state with the largest elk population would seem fairly reasonable and tempting,but it ignores one major factor:the area of the state.

Having noticed the flaw of using only elk population as indicator,we rest our eyes upon the population density,which seemingly resolved the area disparity between big states and small states,and density has always been used to describe unit distribution.Unfortunately,it also fails to take elk habitat distribution into consideration.Suppose a big state has a relatively considerable elk population,but the elks are concentrated in several particular national parks.The population density of the parks are noticeable,but that of the state as a whole is greatly impaired and would possibly be outweighed by other small states with equal elk population density.Thus we decided to look at the problem from a different perspective and agreed upon using population growth rate as the prime indicator.

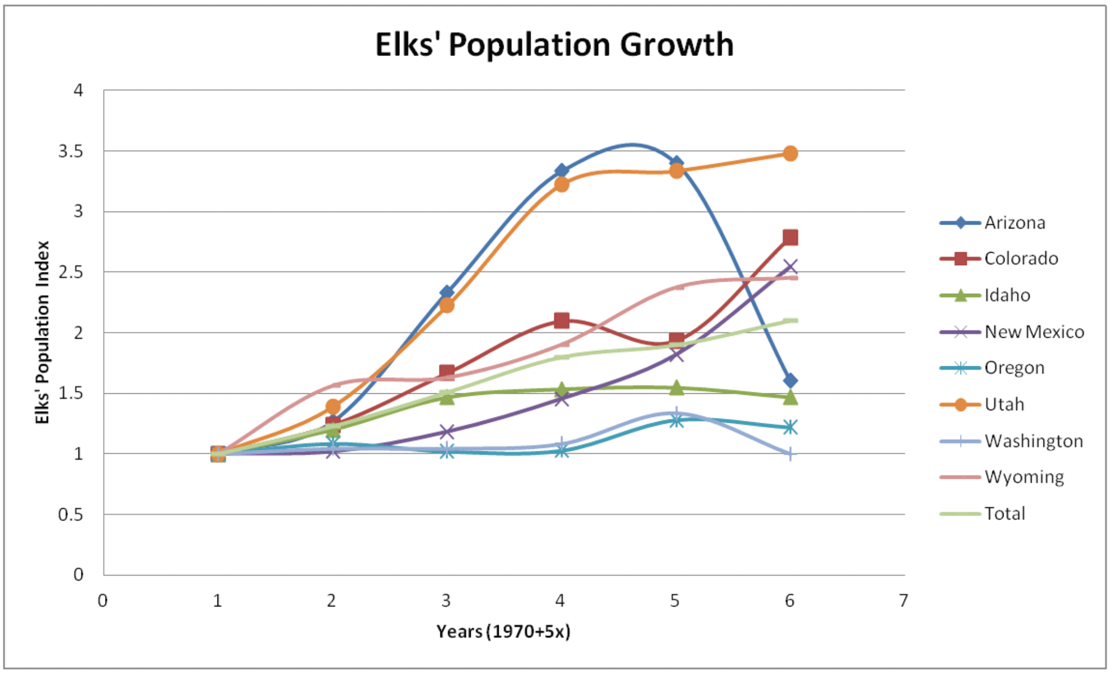
2.3.2 Population Growth Rate

The population growth rate (hereinafter referred to as PGR)basically describes the growth speed of the elks.It successfully avoids the influence of land area and can most directly represent the elks' residence status,since a good habitat is the prerequisite of regular mating and low calf mortality.From the following chart,we can have a clear view of the elk population status over year 1975-2000.

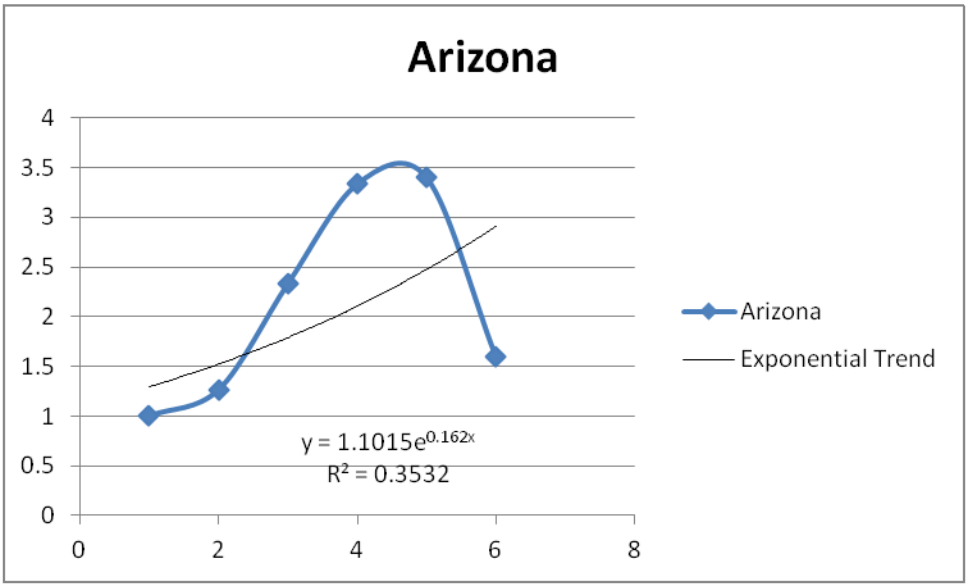
	1975	1980	1985	1990	1995	2000
Arizona	15000	19000	35000	50000	51000	24000
Colorado	105000	130000	175000	220000	203000	292580
Idaho	75000	90000	110000	115000	116000	110000
New Mexico	27500	28000	32500	40000	50000	70000
Oregon	50000	54300	51150	51500	64000	61000
Utah	18000	25000	40000	58000	60000	62635
Washington	23000	24000	24000	24900	30700	23000
Wyoming	43178	67465	70352	82128	102439	105868

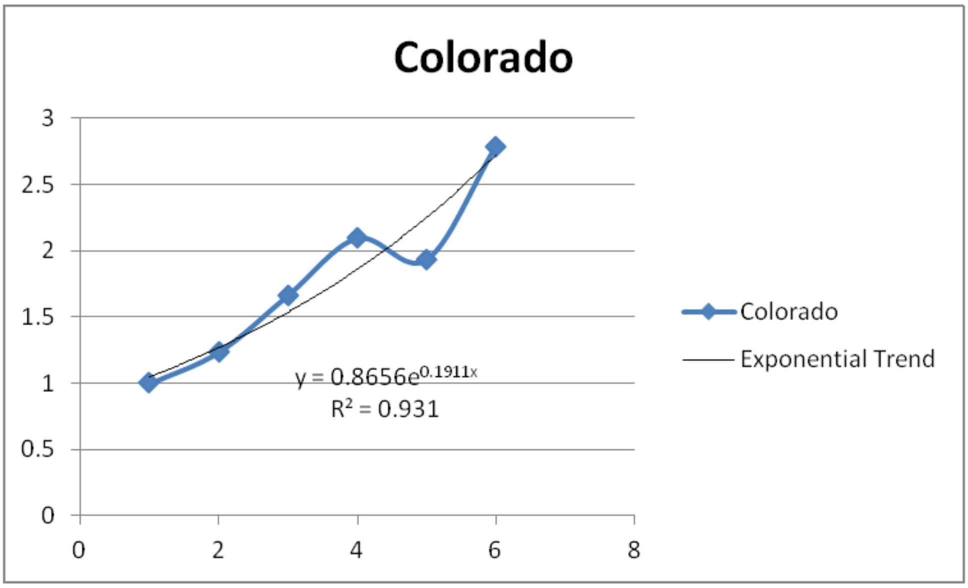
But how do we compare their growth speed?The 1975 elk population of a specific state is set to 1,representing the base line.Then the elk population from 1980 to 2000 are divided by the 1975 population.A result greater than 1 indicates increase in population,while a value smaller than 1 indicates decrease in population.It's very similar to calculating its percentage growth.

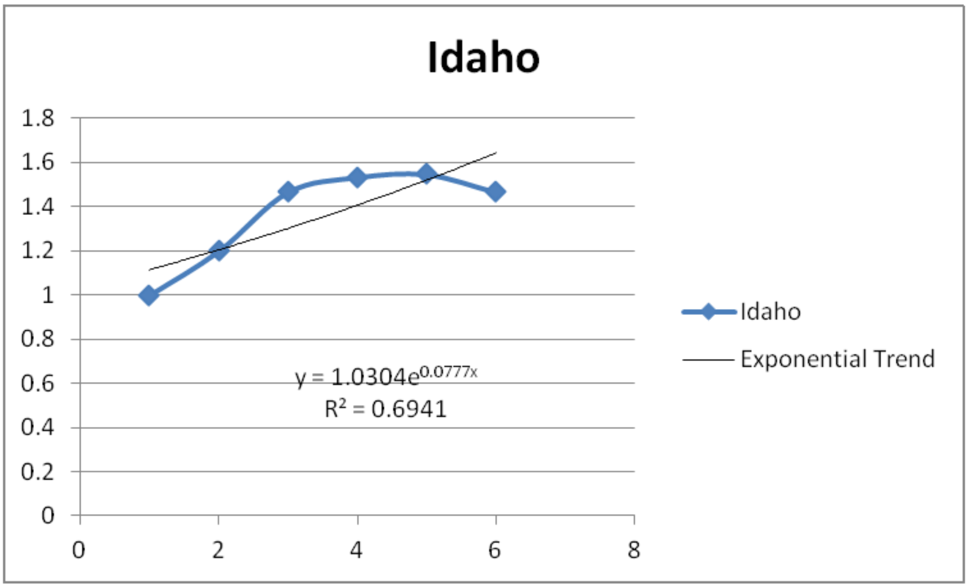
The following graph using the "standardized" data above demonstrates the approximate trend of growth speed.

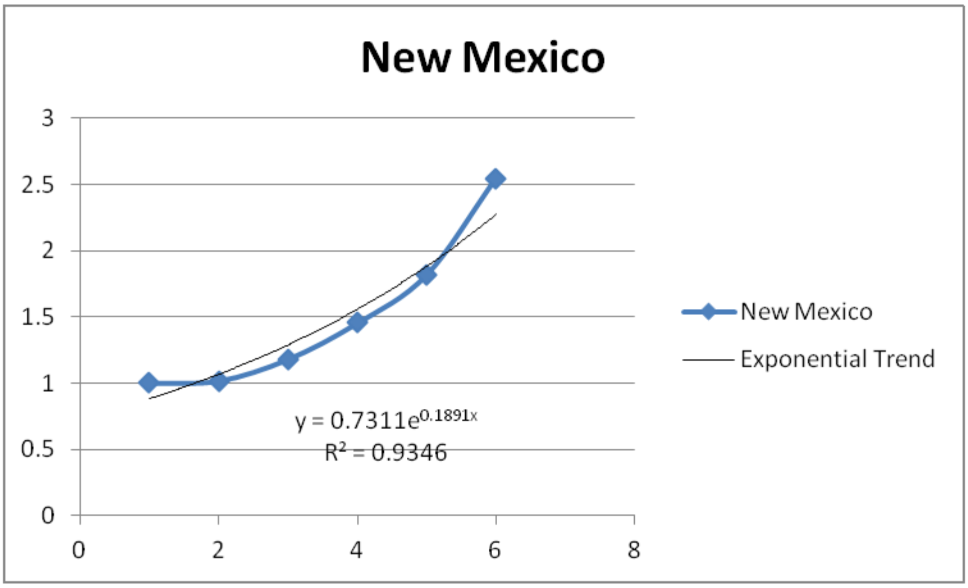


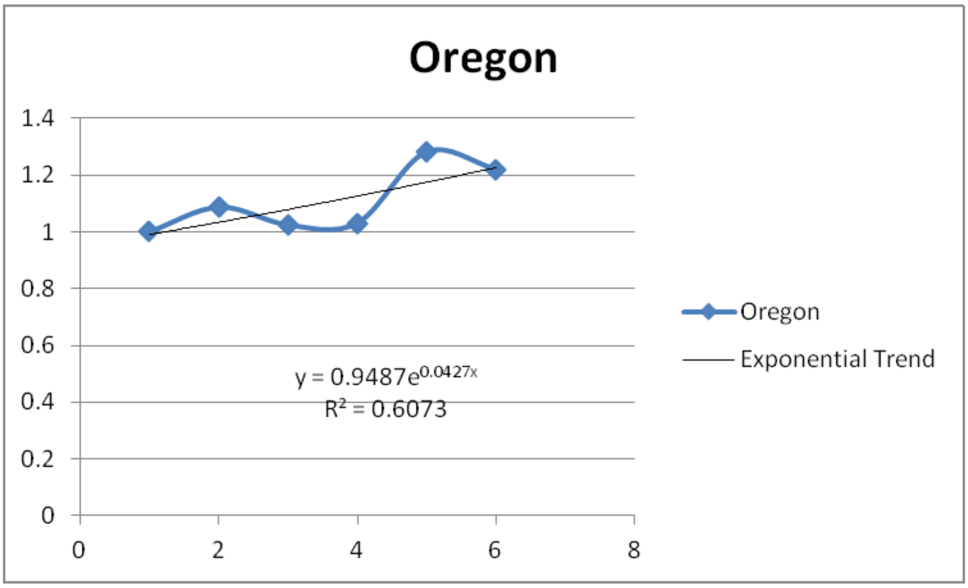
For each state,we apply exponential regression to its elk population in order to get the approximate population growth curve and PGR.The graphs are presented below.

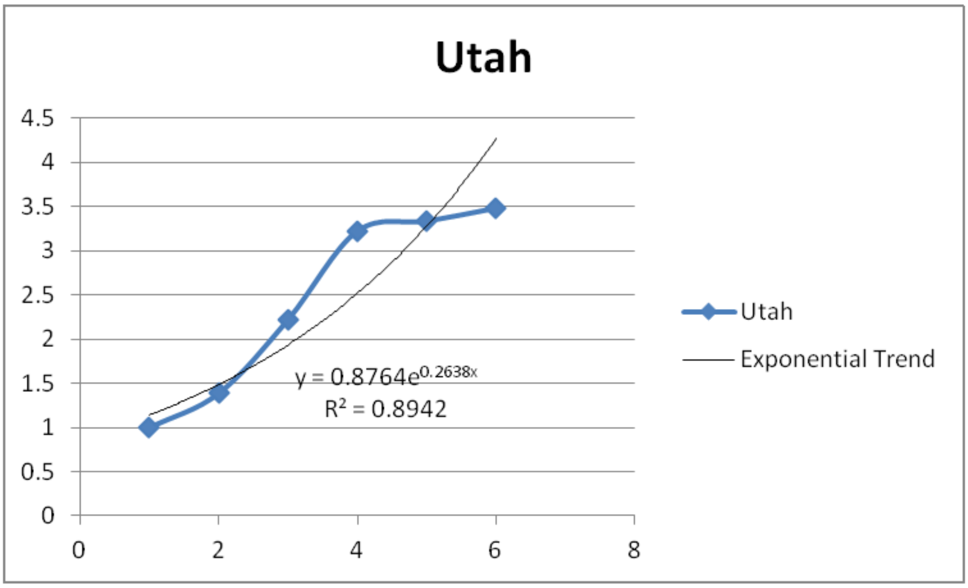


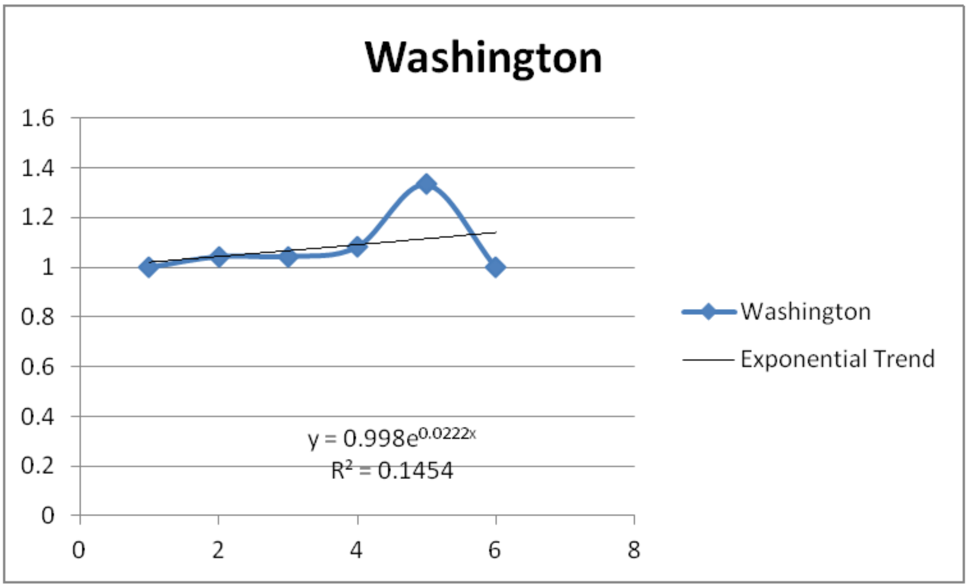

Colorado
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
y = 0.8656e^0.1911x
R² = 0.931
Colorado
Exponential Trend

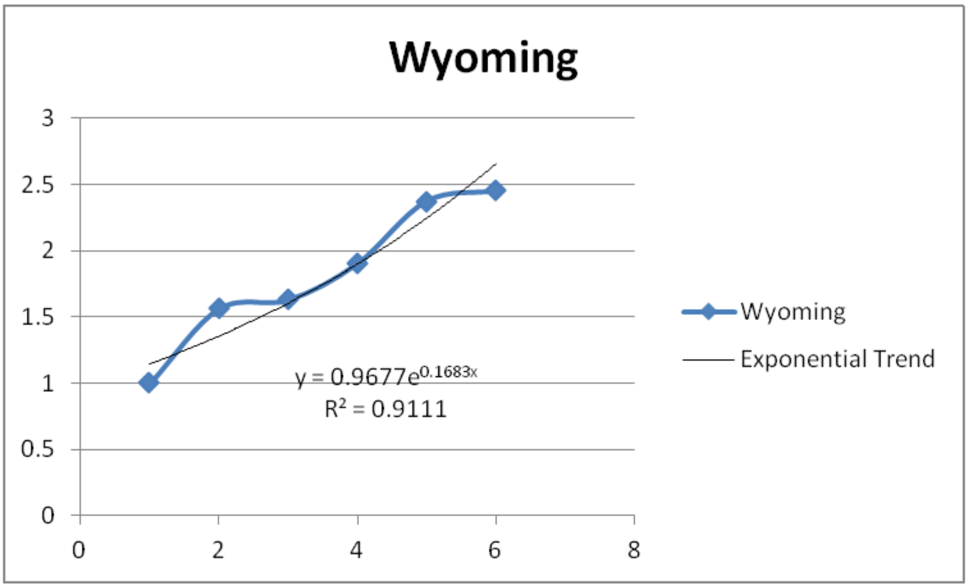

Idaho
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
y = 1.0304e^0.0777x
R² = 0.6941
Idaho
Exponential Trend


New Mexico
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
y = 0.7311e^0.1891x
R² = 0.9346
New Mexico
Exponential Trend


Oregon
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
y = 0.9487e^0.0427x
R² = 0.6073
Oregon
Exponential Trend


Utah
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
y = 0.8764e^0.2638x
R² = 0.8942
Utah
Exponential Trend


Washington
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
y = 0.998e^0.0222x
R² = 0.1454
Washington
Exponential Trend



The equation for PGR is:

$$PGR = \frac{\ln P(t_2) - \ln P(t_1)}{t_2 - t_1}$$

This reminds us of the derivative function:

$$f'(x) = \frac{f(x+\Delta x) - f(x)}{(x+\Delta x) - x}$$

Let $t_2 = t_1 + \Delta t, F(t) = \ln P(t)$,

$$PGR = \frac{\ln P(t_1 + \Delta t) - \ln P(t)}{(t_1 + \Delta t) - t} = F'(t),$$

which implies that PGR approaches the logarithmic derivative of the population function.

From the graphs above we can get a PGR table of the western states.

State	PGR
Arizona	0.162
Colorado	0.1911
Idaho	0.0777
New Mexico	0.1891
Oregon	0.0427
Utah	0.2638
Washington	0.0222
Wyoming	0.1683

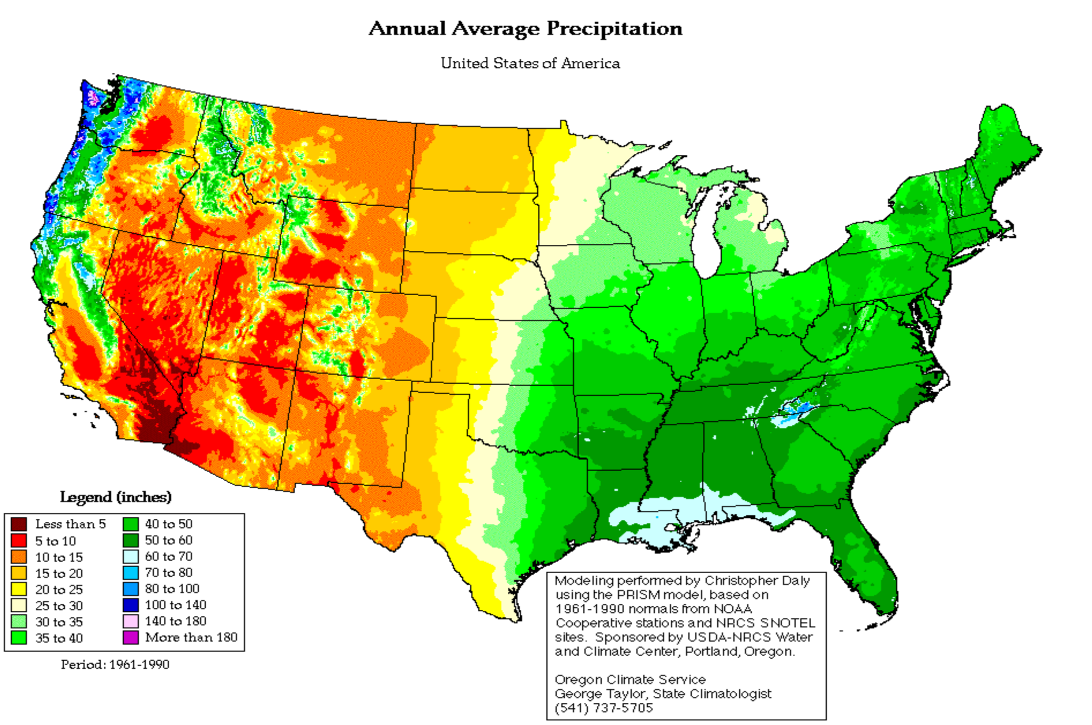
There's still one thing to be clarified.The PGR of Arizona does not perfectly describe the actual population growth of the elks there,since the it is seriously affected by an outlier in year 2000.The sheer drop does not conform with the natural progression of population,hence it can only result from external anomalies.Since we are only looking for states with the most suitable conditions,such deviation must be excluded.Actually,if we compare the curves of Arizona and Colorado in the summary graph,the Arizona curve has an apparent higher growth speed.

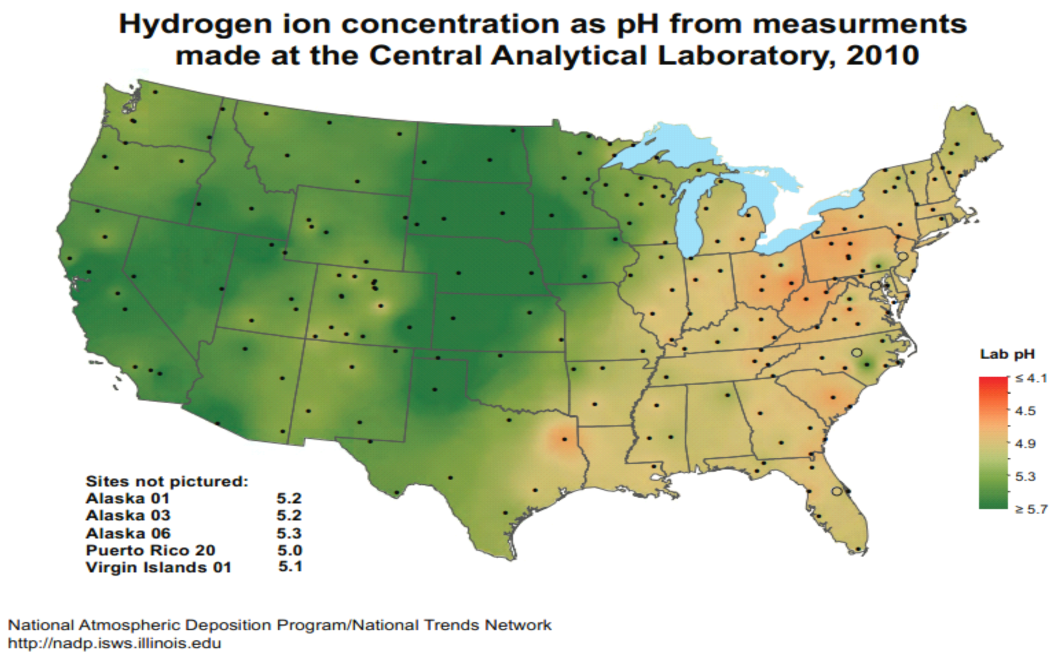
Thus,by comparing the PGR of each individual state,we can conclude that Utah and Arizona are the most suitable states as elk habitats,since the elk herd there has been populating with highest efficiency.Thus,it is reasonable to use these states as models or templates in the following selection of destination habitats.

2.4 Optimal Destination State Selection

Compared with the western United States,the eastern is wetter,a bit more developed and more densely populated.In addition,the major industrial area is concentrated in northeastern US.The condition there is probably no better than that in the west,and the translocation of the elks from west to east requires quite a lot acclimation.Though the eastern metropolises,which used to be the homeland of their forebears two centuries ago,are now captured by humans,it is our mandate to bring them back to where they belonged and secure a shelter for these survivors of indiscriminate hunting.

Before we get started, we should be aware of the pre-existing condition limitations.Let's take a look at these two pictures showing the precipitation distribution and its pH across the States.





Why is there such a huge discrepancy?Firstly,the climates are different in western and eastern US.Secondly,eastern US is the origin of US industry and has always had a high concentration of industrial area.The more factories there are,the more pollution there is,Thus,we can't expect the eastern states to be as good as the western states.But even if the overall condition isn't quite ideal,there must be a place for the elks to live.

2.4.1 Further Use Of Regression Model

Since multiple factors of different weights are involved in the selection of the optimal habitat location,we must build a comprehensive model.Under this circumstance,a direct approach would be another multivariate linear regression model.We simply have to enter the respective Indices of each state and choose the one with the greatest PGR.

In the evaluation of a habitat's suitability,only the PGR itself does not suffice,and the intrinsic properties of the habitat is actually affecting the PGR.After cautious discussion and speculation,we obtained the following major factors that may contribute to the overall competence of the habitat:

Temperature	Precipitation	Forest Coverage	Forage Coverage	Pollution

However,these factors,when quantitated,each have different magnitudes,which may impair the reliability of our regression model.Therefore,we must introduce a scaled index for each factor,which has a constant magnitude and is commensurable.The extent of each factor is scaled from 0% to 100%,and the actual value of that factor can be scored in this way.There will be later discussion of the scaling method.

Firstly,the general linear model that we are going to use is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \ldots + \beta_p X_{ip} + \epsilon_i.$$

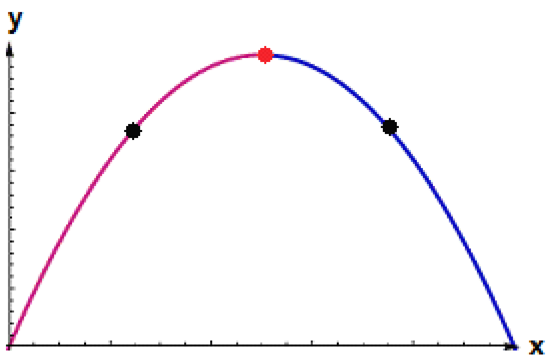
Where in this case,x=Xip are scaled factors of each state,Yi is PGR,and βp are multipliers.Since the scaled factors are commensurable and the model is linear,the multipliers also represent the weight of each factor.

In our previous regression model of PGR,Utah and Arizona prove to be the most suitable states for elks.Thus,it can be inferred that their environmental factors are closest to the optimal combination.However,the discrepancy between their respective factors is noticeable,leading us to the following speculation.

Since some of the environmental factors (forage coverage,etc) have linear correlation with PGR in a specific range,while others (temperature,etc) have not,we suggest that there must exist a polynomial correlation in between.

-Polynomial correlations

The graph below demonstrates the approximate correlation.



Let's use temperature as an example.Utah and Arizona have distinct annual average temperatures,but their elk PGRs are much the same.Thus the points representing their temperature must be on different sides of the vertex,as is demonstrated above.The equation of the axis symmetry is $x=\frac{x_1+x_2}{2}$,indicating that the optimal temperature is between that of the two states,hence their average.

The difference between the actual value of a factor and its optimal value is called deviation.

The equation of deviation is as follows:

$$D_i = \frac{|V_i - V_o|}{V_o} * 100\%$$

The following chart lists the deviations of temperature factors of some sample states.These deviations indicate their proximity to the optimal value.

State	Average Annual Temperature,Vt (°F)	Dt (Vo=54.73°F)
Arizona	60.58	10.69%
Utah	48.88	10.69%
Colorado	45.45	16.96%
Idaho	44.57	18.56%
New Mexico	53.65	1.97%

The second factor to consider is precipitation.The chart for precipitation is as follows:

State	Average Annual Precipitation,Vp (inch)	Dp (Vo=12.57 inch)
Arizona	13.08	4.06%
Utah	12.05	4.14%
Colorado	15.78	25.54%
Idaho	18.78	49.40%
New Mexico	14.27	13.52%

Next comes the forest coverage.Since elk ranges are mostly open forests and woodlands,a too dense forest isn't advantageous for its growth,hence the polynomial correlation.

State	Approximate forest coverage by	Dc (Vo=29.6%)

	percent,Vc	
Arizona	25.6%	13.51%
Utah	33.5%	13.18%
Colorado	34.3%	15.87%
Idaho	39.8%	34.45%
New Mexico	21.4%	27.70%

-Linear correlations

As for other factors that have a linear correlation with PGR,we apply a more direct method.Let's use forage distribution as an example.Obviously,the more food there is,the more quickly the elks will grow.Since the elks are especially fond of aspen sprouts,we use aspen density to indicate forage coverage.

Equation for aspen sprout density is:

$$\rho_A = \frac{Area_{Aspen}}{Area_{Forest}} = \frac{Area_{Aspen}}{Area_{Total} * \rho_{Forest}}$$

State	ρA	By percent
Arizona	0.001551	0.1%
Utah	0.07846	7.9%
Colorado	0.048718	4.9%
Idaho	0.029179	2.9%
New Mexico	0.008397	0.8%

Finally,the extent of pollution is probably the only factor with a negative correlation.Since acid rain resulted from factory pollution disposals,it can be used as indicator of industry density to some extent.Therefore,we use precipitation pH as pollution indicator.From the following chart it's ease to see that most states suffer from acid rain.

State	Precipitation pH
Arizona	5.5
Utah	5.5
Colorado	5.3
Idaho	5.6
New Mexico	5.1

Here we have a complete chart of different factors and deviations of each sampled state.

State	Dt	Dp	Dc	Vf	Va
Arizona	10.69	4.06	13.51	0.16	5.5
Colorado	16.96	25.54	15.88	4.87	5.3
Idaho	18.56	49.40	34.46	2.92	5.6
New Mexico	1.97	13.52	27.70	0.84	5.1
Oregon	11.31	115.91	67.57	3.84	5.2
Utah	10.69	4.14	13.18	7.85	5.5
Washington	11.58	204.93	72.30	3.83	5.2
Wyoming	22.97	1.11	38.18	1.79	5.5
Above:western states			Below:eastern states		
Illinois	5.134296	200.8751	54.72973	N/A	4.9
Indiana	5.42664	219.0135	29.39189	N/A	4.8
Kentucky	1.790608	276.3723	58.78378	N/A	4.8
Maine	24.7579	237.5497	204.0541	N/A	5.1
Maryland	1.881966	242.8799	38.51351	N/A	4.9
Missouri	0.511602	227.6054	14.18919	N/A	4.7
New York	17.4493	210.7399	106.0811	N/A	4.6

North Carolina	7.929837	294.4312	102.7027	N/A	5
Ohio	7.436506	203.0231	4.72973	N/A	5.1
Pennsylvania	10.63402	218.6158	95.94595	N/A	4.6
Tennessee	5.846885	314.7176	74.32432	N/A	4.8
Virginia	0.767404	239.459	109.4595	N/A	4.7
West Virginia	5.280468	251.2331	163.5135	N/A	4.6
Wisconsin	21.54212	149.8807	59.7973	N/A	5.5

It is time to introduce the scale.

$$S_i = \frac{V_i - V_{\min}}{V_{\max} - V_{\min}} * 100\%$$

The scaled factors represent their relative positions in the entire range so that they will have the same magnitude.Again,let's use temperature as an example.Since the highest temperature deviation is 24.76 (Maine),and the lowest deviation is 0.77 (Virginia),the scaled temperature deviation of Arizona is

$$S_{TArizona} = \frac{D_{Arizona} - D_{\min}}{D_{\max} - D_{\min}} * 100\% = 41.4\%$$

The following chart is a list of scaled factors.

State	St,%	Sp,%	Sc,%	Sf,%	Sa,%
Arizona	41.97438	0.93861	4.40678	34.31487	90
Utah	67.82216	7.787925	5.59322	51.04952	70
Colorado	74.45365	15.39827	14.91525	18.89291	100

Idaho	6.028636	3.957382	11.52542	34.06844	50
New Mexico	44.53655	36.60578	31.52542	0	60
Oregon	41.97438	0.963978	4.237288	100	90
Washington	45.66692	64.99239	33.89831	13.00196	60
Wyoming	92.61492	0	16.77966	0.315448	90
Above:western states			Below:eastern states		
Illinois	19.06556	63.69863	25.08475	N/A	30
Indiana	20.27129	69.4825	12.37288	N/A	20
Kentucky	5.275057	87.7727	27.11864	N/A	20
Maine	100	75.3932	100	N/A	50
Maryland	5.651846	77.09285	16.94915	N/A	30
Missouri	0	72.22222	4.745763	N/A	10
New York	69.85682	66.84424	50.84746	N/A	0
North Carolina	30.59533	93.5312	49.15254	N/A	40
Ohio	28.56066	64.38356	0	N/A	50
Pennsylvania	41.7483	69.35566	45.76271	N/A	0
Tennessee	22.00452	100	34.91525	N/A	20
Virginia	1.055011	76.00203	52.54237	N/A	10
West Virginia	19.66843	79.75647	79.66102	N/A	0
Wisconsin	86.737	47.43785	27.62712	N/A	90

At this stage we have two summary charts,one for original factors D_i and one for scaled factors S_i .For the sake of precision and inclusiveness,we decided to apply linear regression to both charts.Then we substitute the data above (western states only) for the X_{ip} in the general linear model. Y_i will be PGR of each state.

After several trials,we discovered that some factors have no apparent linear correlation,contract to our previous speculation.Thus,forage coverage and pollution are temporarily put aside,the reason for which will be discussed later.

Regression of the remaining three factors resulted in the following models:

$PGR = 0.25285 - 0.00189Dt - 0.00045Dp - 0.00175Dc$ (using original factors)

$PGR = 0.24252 - 0.00378St - 0.0014Sp - 0.00042Sc$ (using scaled factors)

The square of the correlation coefficient (R^2) of these two regression equations are 0.803633 and 0.80369712,respectively,indicating that both models have satisfactory accuracy.

Now that the models have been acquired,we can use them to estimate the PGR of eastern states.The results are as follows:

State	PGR (1st model)	PGR (2nd model)
Illinois	0.057678	0.070571
Indiana	0.093499	0.063298
Kentucky	0.02329	0.088206
Maine	-0.25779	-0.28305
Maryland	0.073588	0.105974
Missouri	0.125657	0.139264
New York	-0.06013	-0.13654
North Carolina	-0.07343	-0.02476
Ohio	0.140074	0.044313
Pennsylvania	-0.03295	-0.03172
Tennessee	-0.02873	0.004657

Virginia	-0.04724	0.109868
West Virginia	-0.15586	0.022889
Wisconsin	0.040402	-0.16344

It's easy to notice that there are many negative values,which never existed in the western part.How can this be explained?First of all,our model for optimal state selection is a macroscopic model,implying that only macroscopic factors are considered.Secondly,this is a minor flaw of linear regression model itself.But it can't deny the fact that some states stood out during the estimation,which is exactly the reason why we built this model at the first place.

The two models coincide with each other on some cases while having contradictions on others.Yet they both agree that Missouri is possibly the most suitable state,each giving it high PGR estimation.Looking back on its exact temperature,precipitation and forest land area,we realize that it really has relatively high approximation to the optimal value of both three factors.

Missouri is second to none,which states are second to Missouri? From the table above we can see that Maryland and Ohio are also acceptable.So far the Best Elk State Competition - East Zone has come to its end,care for a victory speech?

2.4.2 Analysis and Evaluation

The first thing to clarify is why we eliminated those two factors (forage coverage and pollution) and how we are going to deal with them.After having discovered their inconsistency with the PGR trend during the testing stage,we tried to reason out why the result contradicted our initial guess.

It is fairly convincing that these two factors have certain correlation with PGR.However,statistics of aspen (the primary food source of elk) distribution in United States is limited.Furthermore,most western states suffer from a strange phenomenon called Sudden Aspen Decline (SAD),which resulted in the inaccuracy of aspen statistics.There will be further discussion about this sad situation.

On the other hand,the pollution level is also related to forest land area.Apparently,the more forest a state has,the cleaner it is likely to be.Since forest coverage has a nonlinear correlation with PGR,it is inappropriate to assume the linear correlation of precipitation pH.

However,it is also irrational to simply ditch these factors.Therefore,we will reformulate them in a microscopic manner in order to explore their relationships.

Now it's time for introspection.As is mentioned before,this model only took macroscopic factors into consideration and hence gave only a grand-scale approximation of PGR trend.Nonetheless,the result came out as satisfactory and sufficient for our further modeling.Secondly,the two forms of variable input, D_i and S_i ,resulted in different results.The original factor D_i describes the proximity to the optimal value from a quantitative aspect,but this method fails to level the magnitude of different factors.We postulated that S_i would bring these factors on the same level while preserving other characteristics of D_i .It did,to some extent.The coefficients of S_i surely carry different weights, but in order to make these factors commensurable,the difference between the maximum and minimum values has to be either stretched or compressed.In case of factors with large base and small difference,it can sometimes exaggerate the deviation and thus impair the state's competence.Even though they each have weaknesses,since we adopted both methods,the combined result can somehow redress this imbalance.

Finally,let's take a closer look at the elks' future residence.The first prize winner of the Best Elk State Competition - East Zone,Missouri,boasts a temperate and humid weather (54.45 °F,41.18 inches) and a 33.8% forest coverage,which is already close to optimum.To our surprise,the Missouri Department of Conservation has also conducted a feasibility study in 2000,which pointed out that the biological conditions of Missouri are able to sustain an elk reintroduction.Here is a scoring sheet of major land cover classes in Missouri.

Land Cover Class	Scores Forage	Cover
Cropland	.75	0
Evergreen Forest (>75% Evergreen Canopy)	.25	.75
Deciduous Upland Forest (>75% Deciduous Canopy)	.75	.75
Deciduous Bottomland Forest	.50	.75
Mixed Evergreen-Deciduous Forest	.50	.75
Dense Woodland (Tree Canopy 50-80%)	.50	1.0
Deciduous Upland Woodland (>75% Canopy Deciduous)	.75	1.0
Deciduous Bottomland Woodland	.50	1.0
Mixed Evergreen-Deciduous Upland Woodland	.50	1.0
Evergreen Sparse Woodland/Savanna	.75	1.0
Deciduous Sparse Woodland/Savanna	1.0	1.0
Mixed Evergreen-Deciduous Sparse Woodland Savanna	1.0	1.0
Shrubland (>25% Shrub Cover)	1.0	1.0
Grassland (Upland Graminoids > 50% Cover); includes pasture, etc.	0	.75
Wet Herbaceous (Herbaceous Wetlands)	.5	1.0
Open Water	0	0
Barren Sparsely Vegetated	0	.25

However,an anticlimax at the end of the research suggested that the Missourians are not quite in favor of this project because of personal concerns.The following table showed farmers' divided opinions about elk conservation.

Opinions About Elk Restoration Farmer-Operator Mail Survey	
"Would you favor an experimental elk restoration program in remote areas south of the Missouri River?"	**Elk-Feasible Counties**
Favor	46%
Would not favor	48%
No Opinion	5%
No answer	1%

Nonetheless,we are convinced that elk reintroduction in Missouri is possible and practical,as long as it is conducted gradually and smoothly.With the elks' high adaptation ability,we can actually reintroduce them to anywhere they like,as long,so long as we persist in the conservation of wildlives.

In a nut shell,this regression model fulfilled its duty,bringing us the desired elk haven-to-be and a reason to go "forward" with the reintroduction.

2.4.3 Model Testing Using GSMNP

Since the introduction of manitoba elk to the Great Smoky Mountains National Park (GSMNP) is mentioned in the problem sheet,it is appropriate to use this designated destination region as a sample to test the accuracy of our model.

According to statistics,the GSMNP has annual temperature of 54.417 °F,annual precipitation of 53.94 inches and a 39.795% forest coverage.Thus,we substitute these data into the functions and get the result:

	PGR (1st model)	PGR (2nd model)
GSMNP	0.068524	0.098127

As we can see ,although the estimated PGR isn't among the highest ones,it still indicates a favorable elk habitat.Plus if we take a closer look,the temperature and forest coverage are just about the optimal value,while only the perhumid weather affected its overall suitability.The model proved its reliability,but there must be a reason for choosing GSMNP.Since the existing elk reintroduction cases in Wisconsin and Minnesota confirmed the elks' great adaptability,we believe that they will surely acclimatize to the life in Tennessee and the reintroduction in GSMNP will be just as successful.

3 Part II:Growth Estimation & Influencing Factors

3.1 Introduction

In the previous chapter,we discussed how to build a general linear model to select the most suitable states for elk herds,which is a macroscopic approach to solve the problem.In the following chapter,we are going to introduce an microscopic analysis of the population of a specific elk herd in a given habitat,in order to take both grand-scale and small-scale aspects of the problem into consideration.This population model will be based on the Gompertz function,one of the sigmoid functions often used to estimate population growth,and will show both the estimated maximum elk population (or the carrying capacity) of a certain habitat and the trend of population growth rate.Combining these two factors,we can obtain the optimal elk population,at which the herd has highest growth rate.Finally,several small models of individual factors are presented to demonstrate their respective influence on the population.With these data we can put forward a few practical measures to ensure the safety and vitality of the elk herds.

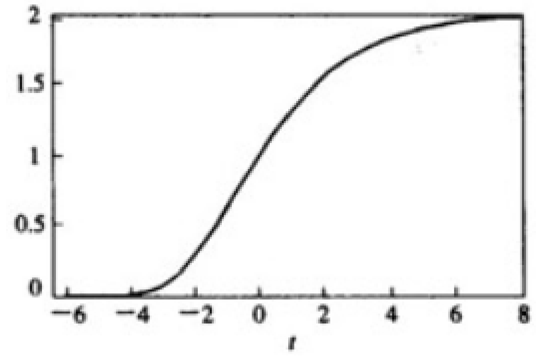
3.2 Small-scale Growth Curve:Improved Gompertz Model

Since we are doing a small-scale model,we need a specific habitat to rest our eyes on.Where then?The answer is obvious:The Great Smoky Mountains National Park (GSMNP).A table of elk status in GSMNP is already stated in the problem sheet.But due to the scarcity of mass data,extrapolation of growth pattern is hard to achieve.Yet,the existing logistic regression method,which have been frequently used in population growth models,has provided us a tool to tackle the problem.Among the various models with differently shaped curves,the Gompertz Model is the most suitable one,with a slightly elongated S curve and an upper asymptote indicating the maximum value.

The Gompertz function,named after Benjamin Gompertz,has different forms.It can either be:

$$y(t) = ae^{be^{ct}} \quad \text{Or} \quad y(t) = KA^{B^t}$$

In this case,we choose to use the first one.In the Gompertz function,constant K is the upper asymptote,indicating the maximum value.In the following graph of one particular form of Gompertz curve,A>0,0<B<1.



Variable t indicate the change of time period.Since Gompertz function requires a special regression method,we decided to use coefficient approximation,which is both simple and of sufficient accuracy.

3.2.1 Data Refinement

Since the given data is limited,we consulted the website of GSMNP and other national parks that are involved in elk reintroduction project,and developed an estimated table of elk population.

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
t	1	2	3	4	5	6	7	8	9	10	11	12
P(t)	12	40	57	53	56	67	86	96	107	124	140	180

Here we need to clarify some of the data changes.Elk reintroduction took place twice in year 2001 and 2002.This will result in a abrupt population growth and does not conform with the model.Hence,the population in year 2001 is refined to $\frac{25}{2} \approx 12$,and the corrected population in year 2002 is $25+\frac{27}{2} \approx 40$.After 2002,there is no significant external influence on elk population (the 5 new elks in 2007 won't affect the herd too much),so there is no need for correction.Another national park with similar habitat area and elk population claims to have 180 elks this year,which is also a credible reference for our model.

3.2.2 Coefficient Approximation

The regression of the Gompertz model can be achieved in different ways,but they either require specific softwares or complicated calculations.That's we adopted a simplified method,i.e. Coefficient approximation.

Assume the total number of data is $3n, n \in N^*$ .Firstly,the data of population is divided into 3 groups.Each group has n values and is summed up logarithmically.

$$S_1 = \sum_{i=1}^{n} \ln p(i), S_2 = \sum_{i=n+1}^{2n} \ln p(i), S_3 = \sum_{i=2n+1}^{3n} \ln p(i)$$

The equations for the three constants K,A,B is given below.

$$B = \log_n\left(\frac{S_3 - S_2}{S_2 - S_1}\right)$$

$$\ln A = \frac{(S_2 - S_1)(B-1)}{(B^n - 1)^2 * B}$$

$$\ln K = \frac{S_1 S_3 - S_2^2}{n(S_1 + S_3 - 2S_2)}$$

The results are listed in the following table:

Name	S1	S2	S3	B	lnA	lnK	A	K
Value	14.1871	17.2487	19.6277	0.93888	-3.7640	9.30610	0.02319	11005.0

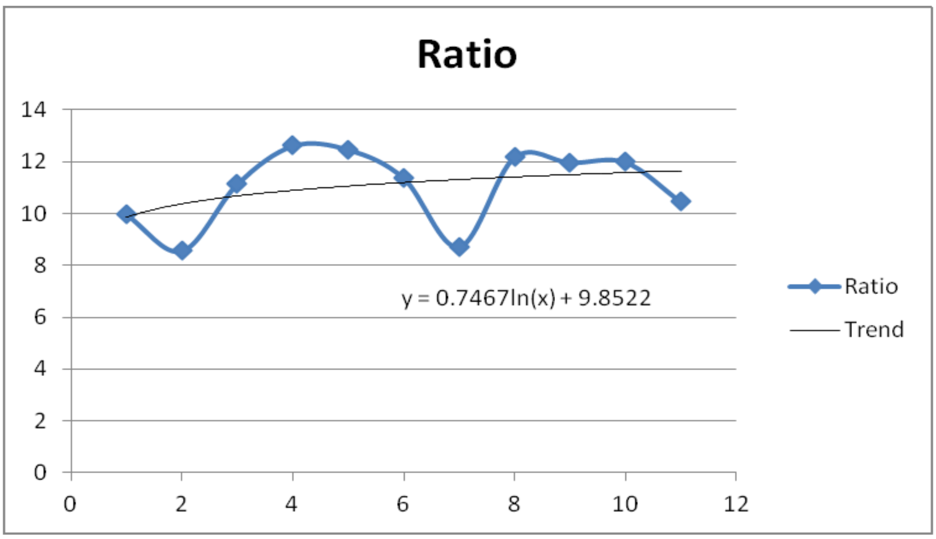
The preliminary regression function is:

$$P(t) = 11004.97 * 0.02319^{0.938879^t}$$

However,this function has some obvious errors.Firstly,according to the table above,the maximum population K of the park is over ten thousand elks,which is unbelievably exaggerated for a park.Secondly,there is a large discrepancy between the estimated population derived from this function and the actual value.How can we adjust this model to make it function properly?The answer is again scaling.

3.2.3 Improvement:Scaling

Scaling has proved to be efficient in leveling values of different magnitudes.The Gompertz model has a growth rate close to that of the actual population,yet they have different absolute values.If the entire function is divided by a certain number,it will be on the same level with the actual value.Obviously this denominator can't be a constant,since the ratio in between is possibly changing as t increases,it it likely that the denominator is also a function.

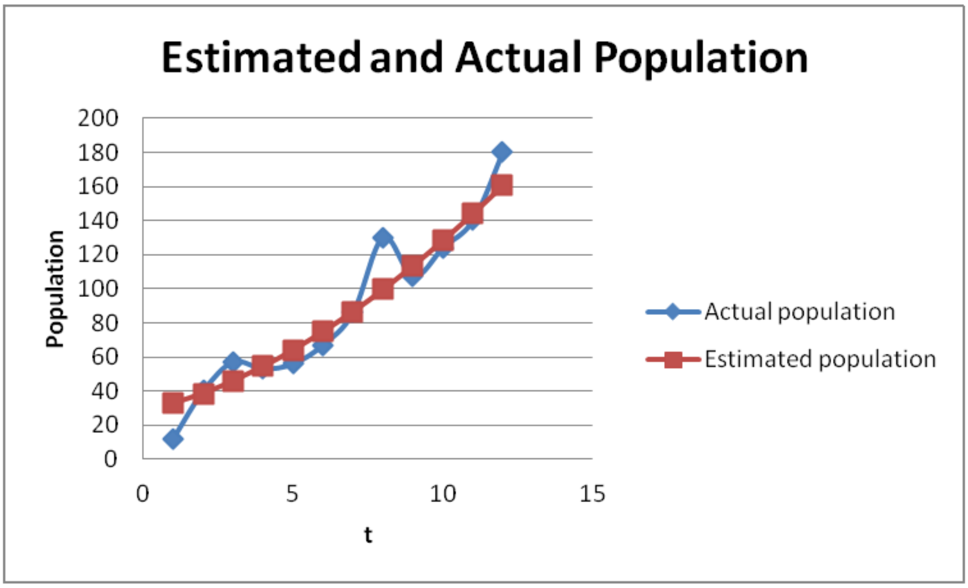


The graph above describe the trend of the ratio between the current function value and the actual value.Having ruled out linear correlation and other possible relationships,a logarithmic correlation seems most reasonable.

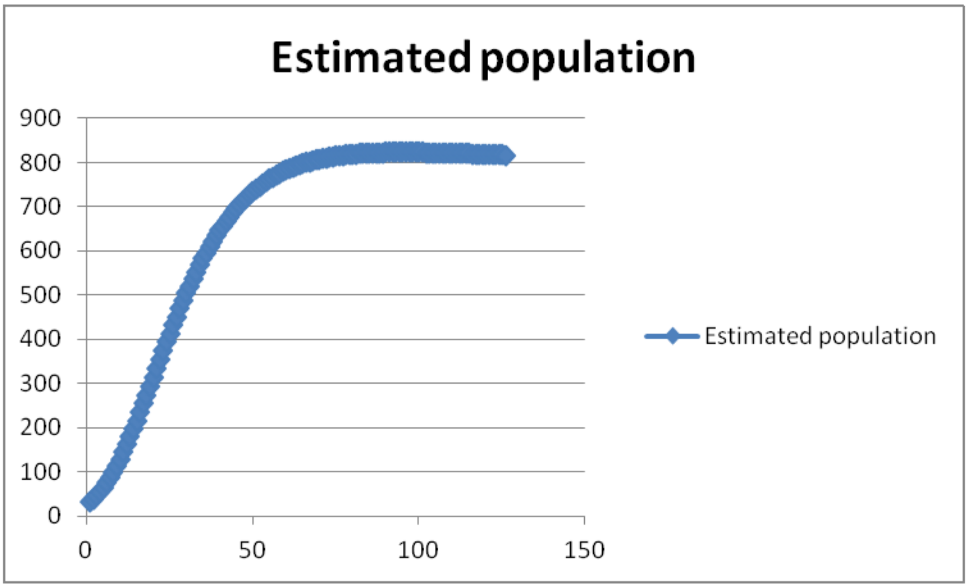
Thus,the final function of the improved Gompertz model is:

$$P(t) = \left[\frac{11004.97 * 0.02319^{0.938879^{t}}}{0.7467 \ln(t) + 9.8522} \right]$$

The front part of the curve is shown below as a comparison of the estimated and actual population.



Its partial graph is shown below:



From this graph we can see that:

1)The maximum population is about 800,which makes sense.

2)The greatest growth rate occurs at about x=25,which is also the function's point of inflection.The exact growth rate of each year can be obtained by using the derivative of this function (see below).In general.the population experiences rapid growth in the first 50 years and then gradually reaches equilibrium in the next 50-100 years.

$$P'(t)=\frac{3498.73[t\ln t-4.21243(1.0651^{t}-3.13233t)]}{t(\ln t+13.1943)^{2}}$$

3)In the year of greatest greatest growth rate,the population is about one half the carrying capacity,which is in accordance with mainstream speculations.

3.2.4 Evaluation

No man is perfect,so is no improved Gompertz model.This population growth curve simulates the current population status with satisfactory accuracy and estimates the future growth tendency with credibility,which is very valuable to further research.However,it only gives a gross approximation of population growth in a restricted time period.Influencing factors are not considered individually,and an overly long time period could possibly cause data overflow.How are we going to make this thing right?Firstly,individual analysis of various influencing factors will be presented below.Secondly,we can't even live to this model's date of expiration.So,all in all,this model ROCKS!

3.3 Influencing Factors

The reintroduction of the elks in their "hometown" can have reciprocal effects.The elks have to accustom theirselves to the new environment and learn to respect private properties;the local people can benefit from elk tourism,but sometimes they also have to put up with their not-exactly-qualified-as-new neighbors.What would be the impact and implication if elks were really moving to Missouri and other potential states?

3.3.1 Forage

Nowadays, elks are familiar with the food in the West,for example the aspen leaves, barks and grasses, for they have lived there for a very long time.If we want to move elks to the East, we must find some food similar to their former food or something that can replace their usual diet. Otherwise, elks cannot survive in the different environment in the East. According to the research before, we find that most areas in the West are covered with deciduous trees and deserts, while temperate broadleaf and mixed forest is the main food resources in the East.

Manitoba Elk’s favorite meal is aspen barks and leaves, which are native to cold regions with cool summers in the north of the Northern Hemisphere, extending south at high altitudes in the mountains. Due to aspen’s growth environment, there are less aspens for elks in the East of USA and the amount is especially tiny in the Southeast corner. The distribution of two kinds of most widespread aspens is shown below:

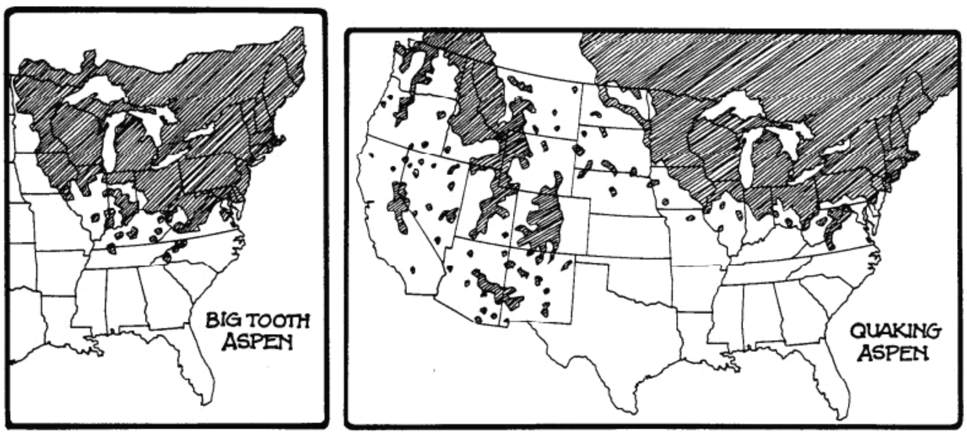


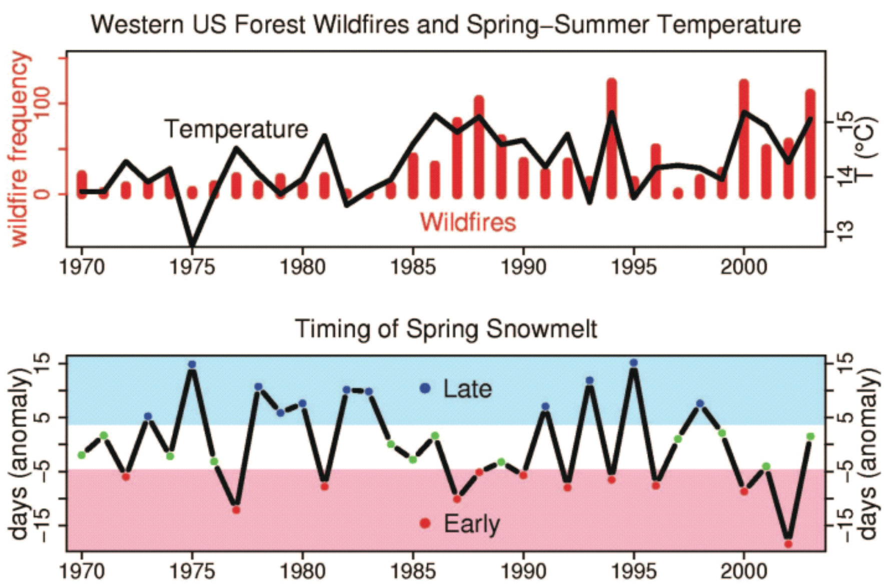
Figure 1. Distribution of bigtooth and quaking aspen in the U.S.

Why are there less aspens in the East than in the West?The aspens suffer from a strange phenomenon called Sudden Aspen Decline (SAD). The aspen covered area in some states like Arizona has shrunk by over 90%. Biologists are also baffled by SAD and proposed several hypotheses. These include one possible explanation from us.

Mainstream theory suggests that the lack of ecological disturbances resulted in SAD.In ecology,a disturbance is the temporary change in average environmental conditions that caused a pronounced change in ecosystem.This includes fire, flood, insect outbreak, etc. When a disturbance took place, the number of original species decreased significantly, providing an opportunity for succession of other species, that is the change in abundance of different species.

A wildfire is generally considered as hazardous, but it is especially advantageous for aspens because they are capable of succeeding other species. Hence, a lack in disturbances prevents aspens from this ecological succession, leaving them no chance to expand their territories. Since they are shade-intolerable (unable to survive without enough sunlight), they may face the danger of being succeeded by shade-tolerable conifers if the situation does not change for a long enough time.

What are disturbances like wildfire related to? The first guess is temperature and precipitation. The following graphs describe the relationship between wildfire frequency and temperature and snowmelt.It's not hard to spot the obvious linear correlations.



Then,what is the situation in the east? Currently SAD hasn't been reported in the east,which is good news for us.The reason is probably that broadleaf forests that are not capable of succeeding other species prevail in the east. Yet, the eastern states have lower temperature and more precipitation in average.This is disadvantageous for wildfires to take place.

Steps must be taken to ensure regular wildfire occurrence and aspen prevalence.Firstly, on encountering wildfire in broadleaf forests, it may be an option to simply let the fire devour some trees in order to create chances of succession for aspens.Secondly, old and weak trees should be chopped down on a regular basis to give to aspens.

Here's an brief aside.Elks also likes other trees, especially the birches that has a great amount in the East. According to the report of the Great Smoky Mountains, elks there didn’t repel the birches. So the change of main food source from aspens to birches should not be a great problem for elks.

Moreover, we cannot deny that the adaptability of elks is very strong because reintroduced elks have adapted well to other countries, for example several in South America and Australia, where birches and aspens are much more difficult to find. Obviously, food won't trouble our omni-herbivorous elks.

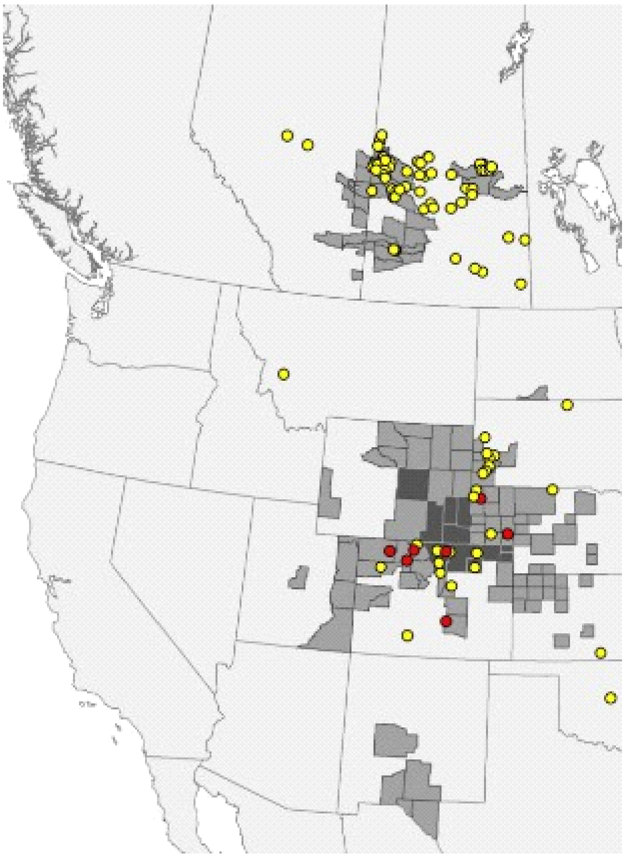
3.3.2 Disease

53 species of diseases and animal parasites have already been identified in elk herds, which means that we have to consider the effects of disease tolerance on elks when moving them to the East.

One of them is called Gram-negative bacterial disease, which occasionally affects elk in the western United States, especially in the Greater Yellowstone Ecosystem, where the disease is first discovered. The disease was originally caused by brucellosis in domesticated cattle and was transmitted to elk inadvertently in Wyoming and Idaho. However, the disease is transmitted only by animals, so if proper examination for this disease is conducted before the reintroduction, no elks will be affected in the East. On the other hand, researchers are attempting to eradicate the disease through vaccinations and herd management measures, which seems to be hopeful in the nnear future. Thus, Gram-negative bacterial disease will not affect elks too much.

Another disease is called Chronic Wasting Disease (CWD), which is an encephalopathy of mule deer, white-tailed deer, elk, and moose. First recognized in 1967 in mule deer in a research in northern Colorado, CWD has spread to lots of states in USA and two provinces in Canada. It is progressive and always fatal. The infected elks will firstly lose weight over time and begin to show behavior changes, including decreased interactions with other elks, listlessness, lack of facial expression, repeated walking in the same patterns and a smell like rotted meat. They may also include hyperexcitability and nervousness. Infected animals will continue to eat but may show decreased interest in food and most of them show increased drinking and urination.

The map below showed the distribution of chronic wasting disease in the western United States.



The gray parts indicate CWD in free-ranging populations and the dark gray parts indicate known distribution before 2000. The yellow points are CWD in captive facilities with decreasing intensity and red ones are current CWD in captive facilities.

However, things are quite different in the East for some elks have already been introduced to the East, to be more specific, the Great Smokey Mountain National Park.The brucellosis and CWD haven't shown up yet, which may imply that it's better to move elks to the East rather than leave them in the West.

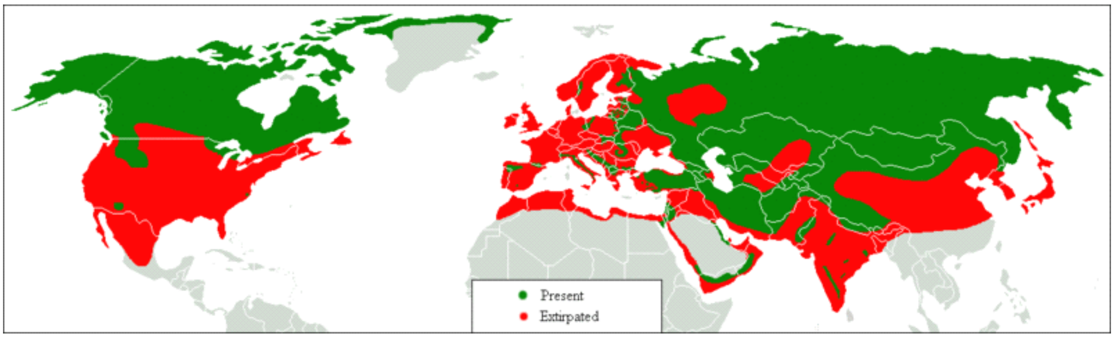
Furthermore, unlike western United States, the eastern is more developed and is equipped with more medical services, not only for people but also for animals such as elks.It seems that the elks have a better chance of staying healthy in the East.

3.3.3 Predators

Though it still seems hard to believe that a thousand-pound-weight elk would be so vulnerable to a hundred-pound-weight predators, mountain lions, wolves and Grizzly bears prey on elk all through the year, practicing their hunting methods uniquely. The mass of this animal, however, is what stop it from reacting quickly and escaping away.

Much to our pleasure, the all three predators don't live in the Northwest America, not to mention the states of Missouri and Tennessee. The following images show the current distribution of three kinds of predators.

Figure 1. Current and Historic Grizzly Bear Distribution in North America



However, the elk population will one day grow to the extent to harm the local agriculture if not controlled properly. Moreover, they could invade other herbivores' territories.Therefore we will have to predict how these predators could influence the population at a small scale and how the increase of the populations could have an impact upon the nature environment and more importantly, how should we react.

Generally, a discrete dynamical model is used to describe the interrelation between two objects in one or more systems, where concurrences in one system affect another. These, named as "predator-prey" model by Sandefur, are helpful when analyzing biological system.

A smaller-scale example is the spotted owl and wood rat in the forest of California. The initial populations are O_o (owl) and R_o (rat), assumed as O_1 & R_1. The population of owls and rats at any year k are related to the equation O_k & R_k. By adding a constant to the equation, we wipe out all the external factors, limiting these effects to a degree that can hold our calculation. We found a appropriate dynamical system with the best parameters a,b,c,d to describe the problem. The formula is as the following:

$$
\begin{aligned}
&O_o = O_1 \\
&R_o = R_1 \\
&O_k = aO_{k-1} \\
&R_k = -bR_{k-1} + cR_{k-1} \\
&a > 0.b > 0, c > 0
\end{aligned}
$$

As one variable does not depend on another, we are able to solve the system analytically. With the help of the data in certain area, we will be able to get different constants of different predators, judging from their sizes and other aspects. This process solves a first-order non-homogeneous linear recurrence relation with constant coefficients analytically. Although this is only a small example, it is easy to see that dynamical systems are useful when analyzing and predicting populations because some systems can be solved analytically, and experiences on elk and grey wolves can also be found. This will help us estimate the interrelations of both sides better.

Currently, we don't witness predators in that region, now what?

Deer rarely exceed their biological carrying capacity. Biological carrying capacity is the maximum number of individuals of a species that can exist in a habitat stably without threatening other species in that habitat. When scientists talk about overpopulation, they are usually referring to a population exceeding its biological carrying capacity.

When state wildlife management agencies advocate deer hunting, they rarely use the word “overpopulated” to describe the deer because it’s usually not true. Deer, like most animals, will self-regulate. If there is not enough food available to support the population, the weaker individuals will die and the does will absorb some embryos and fewer fawns will be born in the spring.

However in a recently released report, WGFD reports an estimated Wyoming elk population of 105,868; the WFG commission, which makes policy for the Department, has set a population objective of 78,235 elk. So the total number of Wyoming elk is 35% OVER their objective.

This failure of automatic balance remind us once again of the inefficient reaction, the state can use similar models we described to evaluate the tolerable population and control it by monthly hunting.

3.3.4 Interspecific Competition

Introduction:

The meaning of interspecific competition is a competition between two or more species for limited food, space, mates and other resource, which demand is greater the supply. Interspecific competition will negatively influence other weak species for example, the population sizes and growth rate and so on, when one species is a better competitor. To judge the interspecific competition, we try to use the Lotka-Volterra(LV) model for it can be used to understand what kinds of factors will affect the results of competition. By using LV model, we can answer question that under what circumstances can two species coexist or one outcompetes another.

Variables:

N	Population size
T	Time
K	Carrying capacity
r	Intrinsic rate of increase
a	Competition coefficient

Methods:

The equation below models a rate of population increase that is limited by intraspecific competition.

$$\frac{dN}{dt} = rN\frac{(K-N)}{K}$$

In the equation above, rN describes a population's growth in the absence of competition, [(K-N / K)] incorporates intraspecific competition into the model, and takes a value between 0 and 1. Since N approaches carrying K, the numerator (K-N) becomes smaller, while the denominator (K) stays the same and the second term decreases. The product of this term describes a rate of population growth that slows down when population size increases, until the population reaches its carrying capacity. So, the growth curve described by the equation is sigmoidal, and the rate of growth depends on the density of the population.

Both the effects of interspecific competition and the intraspecific competition can be included in by the equation as below. This model is consist of following equations for two population, N_1 and N_2:

$$\frac{dN_1}{dt} = r_1N_1\frac{(K_1 - N_1 - \alpha_{12}N_2)}{K_1}$$

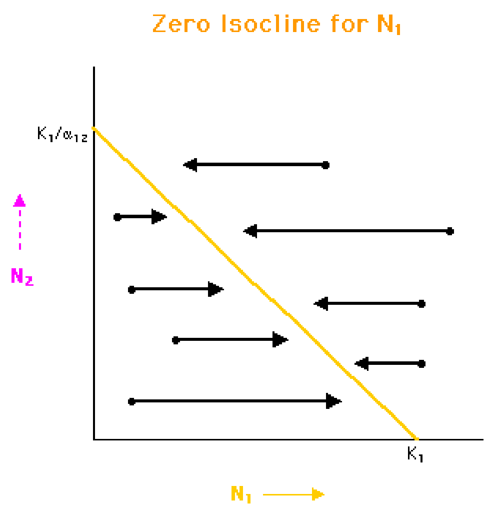
And

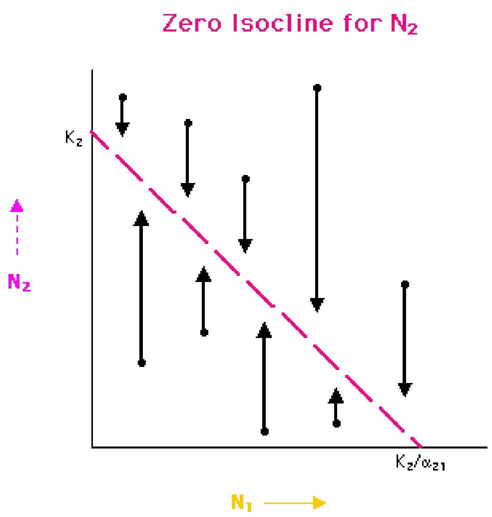
$$\frac{dN_2}{dt} = r_2N_2\frac{(K_2 - N_2 - \alpha_{21}N_1)}{K_2}$$

The difference is the term involving the competition coefficient, a, which represents the effect that one species has on the other: a_{12} represents the effect of species 2 on species 1, while a_{21} represents the effect of species 1 on species 2. In the competition coefficient, the first number is the species being affected, which means that the first equation of a shows the effect that species 2 on 1 and is multiplied by N_2, while the second shows the effect by multiplied by N_1.

When a12 is < 1 the effect of species 2 on species 1 is less than the effect of species 1 on its own members and vice versa. Then the product of the competition coefficient, a_{12}, and the population size of species 2, N_2, therefore represent the effect of an equivalent number of individuals of species 1, and are included in the intraspecific competition term.

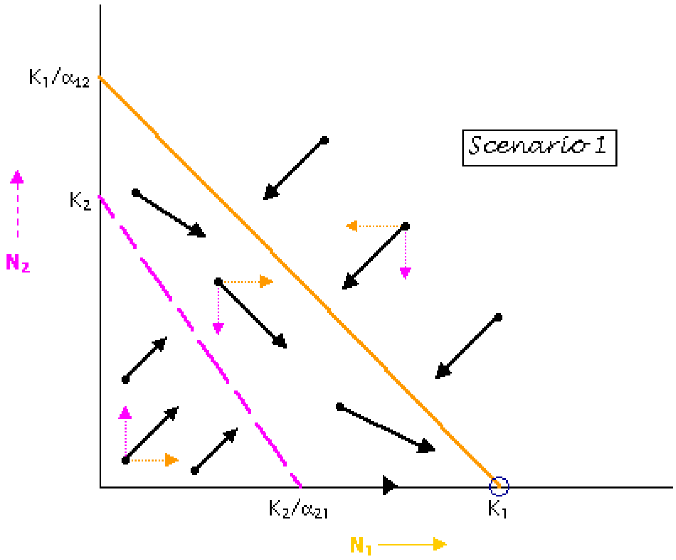
In order to understand the predictions of the model, it is helpful to look at graphs that show how the size of each population increases or decreases when we start with different combinations of species abundances. These graphs are called state-space graphs, in which the abundance of species 1 is plotted on the x-axis and the abundance of species 2 is plotted on the y-axis. Each point in a state-space graph represents a combination of abundances of the two species. For each species there is a straight line on the graph called a zero isocline, which represents a combination of abundances of the two species where the species 1 population does not increase or decrease for the zero isocline for a species is calculated by setting dN/dt, and the growth rate equals to zero and solving for N. The two graphs below show the zero isoclines for species 1 (above, solid yellow line) and species 2 (below, dashed pink line).



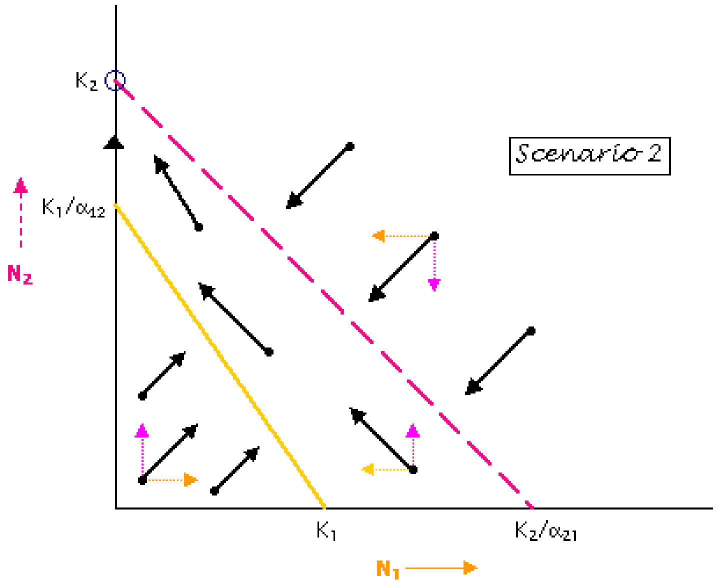


The zero isoclines divide each graph into two parts. Below and to the left of the isocline the population size increases because the combined abundances of both species are less than the carrying capacity of the one, while above and to the right the population size decreases because the combined abundances are greater than the carrying capacity. For the graph of the isocline of species 1, the isocline intersects the graph on the x-axis when N1 reaches its carrying capacity (K_1) and no individuals of species 2 are present. The isocline intersects the graph on the y-axis at K_1/a_{12}, when the carrying capacity of species 1 is filled by the equivalent number of individuals of species 2 and no individuals of species 1 are present. The intersections of the isocline for species 2 are essentially the same, but on different axes.

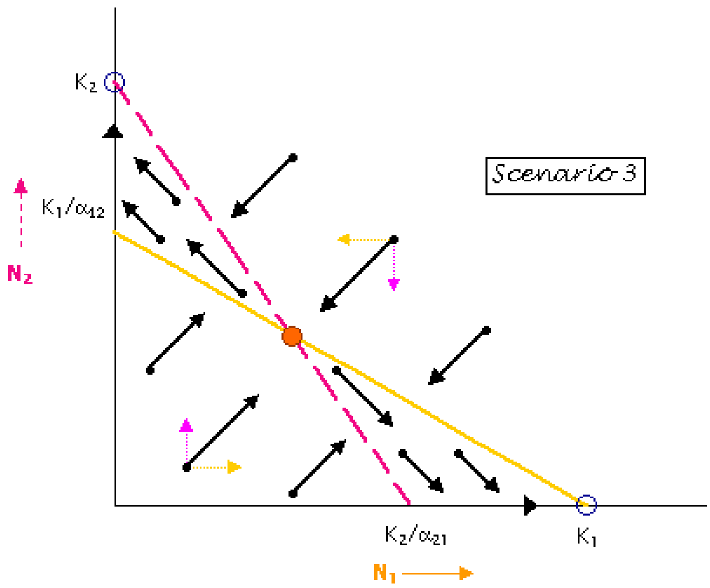
The following four graphs include both species' isoclines and illustrate the results of interspecific competition depending on the relationship. In each graph, the solid yellow line represents the isocline of species 1, and the dashed pink line represents the isocline of species 2. The thick black arrows represent the joint trajectory of the two populations, and the thinner colored arrows indicate the trajectories of the individual populations.



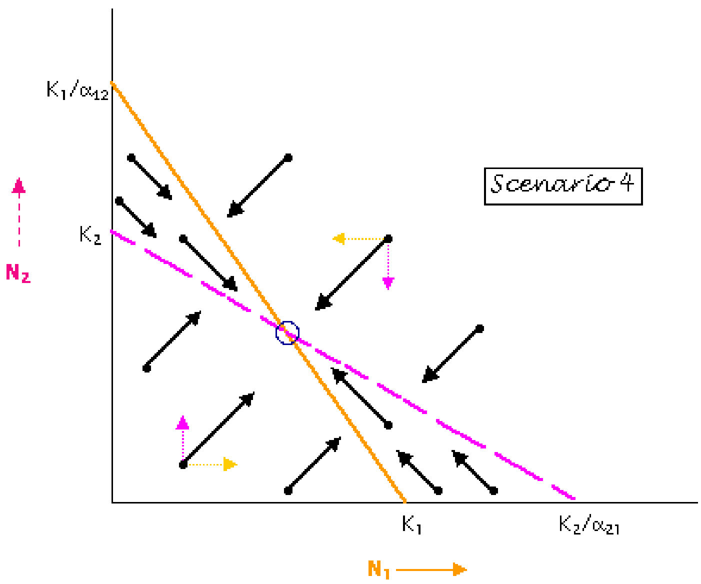
Scenario 1 shows the isocline for species 1 is above and to the right of that for species 2. Both populations are below their isoclines and both increase when points are in the lower left corner, while in the upper right, both species are above the isoclines and both decrease.



The upper right and below left of scenario 2 is just as scenario 1, while the other part is just the opposite.



Scenario 3, the isoclines of the two species cross one another. Below both isoclines and above both isoclines the populations increase or decrease as in the first two scenarios, and there is an unstable equilibrium point (closed circle) where the isoclines intersect. For points above the dashed pink line and below the solid yellow line, the result is the same as in the first scenario: competitive exclusion of species 2 by species 1. On the other hand, for points above the solid yellow line and below the dashed pink line, the outcome is the same as in the second scenario:



The upper right and below left of scenario 4 is just as scenario 3, while the other two parts are just the opposite.

Conclusions:

The Lotka-Volterra model of interspecific competition has been a useful starting point to think about the results of competitive interactions between species.

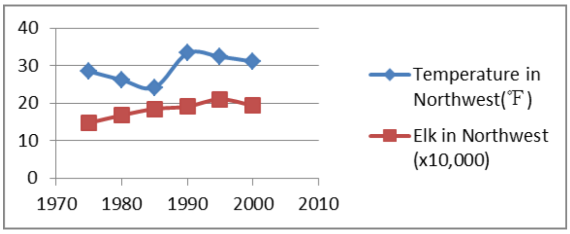
3.3.5 Extreme Weather

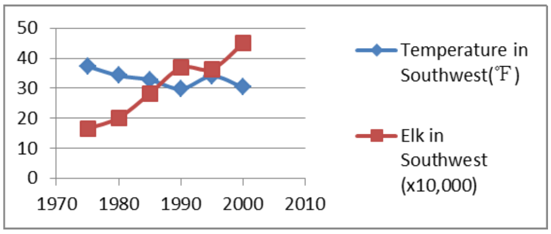
Different from the west, eastern states of the America are under control of monsoon climate. Monsoon is a seasonal reversing wind accompanied by changes in precipitation and other meteorological aspects. During summer time, warm southeastern winds from the Atlantic prevails in eastern states, which bring plenty of rainfall along with occasional hurricanes. The winter of the east is dominated by northwestern winds from the continent, causing drop in temperature and cold wave disasters. Therefore, it is highly necessary to study extreme weathers in the eastern states that may affect the population growth of the elks.

1) Low temperature

Winter monsoon in the northern United States causes low temperature in January, which is always the coldest month of the year. Cold weather may have negative impacts on elks' population. Low temperature may freeze elks to death, harm the vegetation they feed on and limit potable fresh water and potential shelters. We have studied the temperature of January in western United States and compared it with the elk population of the time.

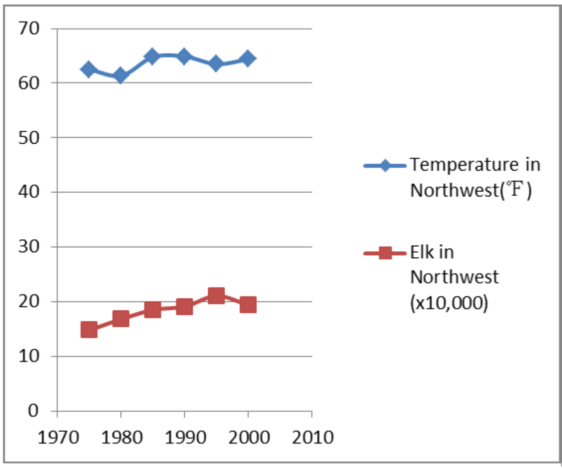
Year	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**
Temperature in northwest (℉)	28.5	26.2	24.2	33.3	32.4	31.1
Elks in northwest(x10,000)	14.8	16.83	18.515	19.14	21.07	19.4
Temperature in southwest(℉)	37.3	34.2	32.8	29.8	34	20.3
Elks in southwest(x10,000)	16.55	0.1	28.25	36.8	36.4	44.9215

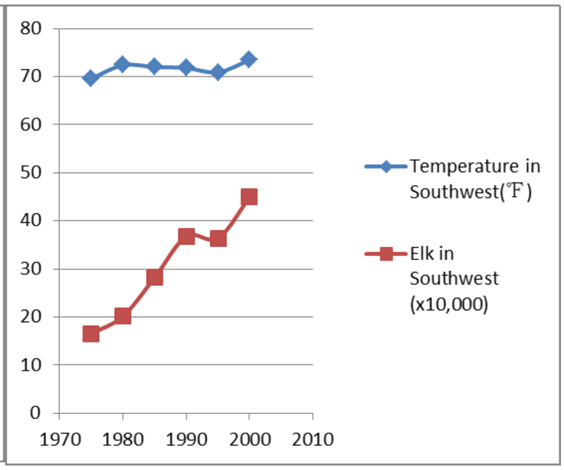




From the charts above , we can hardly find any linear relationship between the January temperature and the elk population. According to reports, there are cases that elks have dead because of cold weather. However, there are only a small amount of elks that die from freeze in winter time. All these are reginal cases and are considered unable to affect the total population of the elks in the region.

Year	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**
Temperature in northwest (℉)	62.5	61.4	64.8	64.9	63.5	64.4
Temperature in southwest(℉)	69.6	72.4	72.0	71.8	70.9	73.5





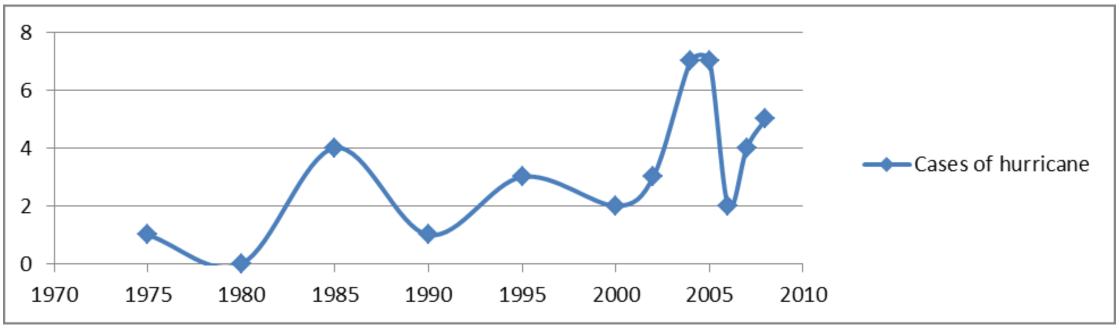
2)High temperature

High Temperature in summer time is another meteorological aspect that may affect the elk population. High temperature may cause diseases, droughts and other negative impacts. From the charts and tables above, we find out that there is little relationship between the summer time temperature and elk population. The effect of summer time high temperature is too minor to affect the total population of the animal.

According our studies of winter and summer time temperature in northwestern and southwestern states, we have reached the conclusion that seasonal change in temperature could hardly affect the population of elks. Thus, when reintroduced to eastern sates, the population of the elks would keep growing despite of the seasonal temperature changed caused by monsoon if the macro environment is suitable.

3)Hurricanes

Another meteorologic difference between the east and the west is hurricane. The west of the United States has never been affected by hurricanes or typhoons. However, the east sates are always influenced by hurricanes. We have studied the historical meteorologic data that records the hurricanes occurred in the past decades and counted number of case of hurricanes that influenced the eastern states where we are going to introduce the elks.



Annual number of hurricanes:y=-0.1263x-248.96 (R^2=0.4025)

The chart above shows cases of hurricane that attacked eastern United States between1970 and 2008. We find out that the number of hurricane cases is rising at a rate of 0.1263 according to linear fitted results. According to this rate, there would be 5 hurricanes attack the eastern Unites Sates in the year of 2012, which in fact finished 4 at this moment near the end of hurricane season.

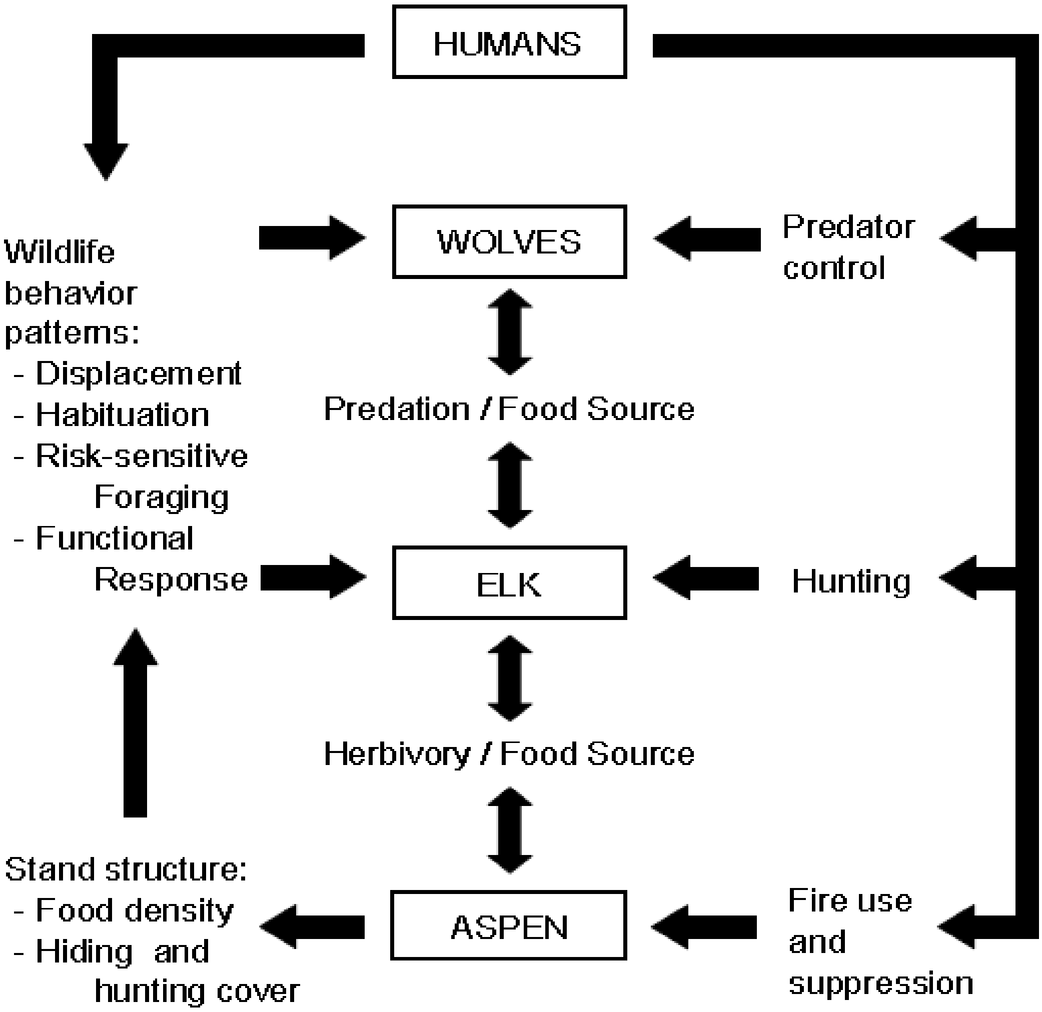
Hurricane attacks may bring sudden rainfall, force gales and cause geological disasters that by threaten elks' lives. To prevent elks dying from hurricane attacks, geological settings of the local area has to be checked. Elks should not be introduce into areas that take risks of collision or mudslides. Reservation areas should able to provide shelters like cave for elks to shelter from heavy rains and winds.

4)Conclusion

Extreme weathers in western states seem to have little impact on elk populations. Temperature of winter and summer times could hardly affect the growing rate of total elk population. However, secondary disasters caused by hurricanes may threaten elks' safety. Thus, observation of the influences by hurricanes has to be made at the beginning years of the reintroduction, and proper protection measures have to be put into action.

3.3.6 Interrelation

The interrelation between effective factors is also worth consideration. The factors as a whole are more complex than several different linear relationships with the elk population itself. For example the pollutants is a major concern of elk health, still it also has a undeniable effect on the forage--both of which has a direct or indirect relationship to elks' life and they also have interrelation upon one another.



The graph above demonstrates the relationship between predators, elks and their food. To make it easier to understand, we will put it like this: Wolves prey on elks, and elks feed on aspen. More wolves in a area means more risk to elks, thus elks immigrate. With less elk, aspens grow better and elks are attracted by the abondance and went back again. We don't know where it starts and where it should end. This endless process is unique but also ubiquitous. The predator-elk-forage interrelation is only one example, but still many other relationships can be taken into consideration.

3.4 Impact of Reintroduction

3.4.1Agricultural Impact

After a protection zone is built in the certain state we choose, the herd will harm the local farming programme, the conflict between elks and humans can not be solved so easily, as their diets have covered parts of the product list. The next issue is how the species might bring about to the zone. The disease for example, might not be absolutely from elk itself, but from the food it takes in in the original habitat. These disease might be less affective to some but the plants that first come across is fairly vulnerable. Moreover, the activity of elks may also have an impact on the local biodiversity. With less predators, elks are sure to grow faster, and eat more. The imbalance is breaking a link of the food chain and resulting a chaotic situation. Successively, they might replace the value of some of the animals that rely on the same kind of food to survive. These breakdown of the local biological environment can also harm the local agriculture.

The following steps can be taken into consideration as solutions to this problem:

✧ Establishing a unified coordination mechanism ranging from the park to the whole Eastern America

✧ Perfecting a risk assessment system, based on information we have mentioned as relative data, the biological characteristics, breeding and mode of transmission and the climate parameters, etc

✧ Establishing tracking monitoring system

✧ To set up a comprehensive governance system

✧ Strengthening quarantine work dynamics and establishing alien species epidemic reporting system and information sharing system

3.4.2 Sociological Impact

Moving the elk into Missouri also means a sociological problem--to determine the altitude and opinion of the local citizens. The following are three conclusions drawn:

- Parts of the landscape will support elk but they lack open public lands;

- The potential elk restoration area should have little agricultural activity and low road density, thus minimizing the conflicts with human;

- Promoting the growth of forage coverage.

One of a very essential way is hunting. In area where hunting is allowed or other disturbances are common, elk tend to avoid roads, in such way elks are able to acclimate to human activities.In addition, selecting Missouri elk range that has low road density could reduce the hidden risk for elk and vehicle accidents.

Furthermore, when competition with livestock for forage and damage to row crops are taken into consideration, the agriculture activities are minimized. Elks in Michigan have a major damage on crops as alfalfa, beans and corns and in Penn State corn, hay and oats are ruined. Elk population can also increase and expand to the private land, causing damages to fence, garden and food plot. To solve such experienced problem is difficult, and it only depends on a better prediction before the introduction to seek for the land or counties with the limited agriculture activities.

Other solutions do exist. Experience from other states suggests that potential problems can be minimized if the elk range includes a high percentage of public ownership. Thus forage need will be concentrated on public land, minimizing to opportunity for elks to move to private land.

State	Years of Introduction	Current Elk Population	Area of Elk Range	Density Number	% in Public Ownership
AR	1981-1985	450	492	0.9	35
KS	1981-1994	210	200	1	85
MI	1918	1250	800	1.6	50
MN	1915	35	-	-	40
OK Eastern	1969-1970	350	10	3.5	90
PA	1913-1926	566	227	2.5	36
WI	1995	100	288	0.4	81
KY	1997	900	4062	0.2	6

If asked only about the possibility of a restoration program, Most Missourians will say 'yes' . However in a state-wide survey 9 of 10 Missourian were concerned about the elk and vehicle collision. Over two-thirds of the Missourian are concerned about other conflicts.

Elk Restoration Telephone Survey		
Concerns About	State-wide Counties	Elk Feasible Counties
Elk and Vehicle collisions	86%	80%
Crop Damage	79%	68%
Elk poaching	71%	69%
Hunter or viewer trespass problems	68%	80%
Elk competing with deer for food	67%	-

4. A Letter to the Commissioner of the Department of Wildlife

To whom it may concern,

it is our honor to introduce our recent research on the conditions and influences of elk reintroduction.Elk conservation has become an increasingly popular topic in the field of ecology.The dreadful speed at which species are extirpating further urges immediate conservation actions including reintroduction.Therefore,we built the following models to explore the relationships in between in order to propose critical measures to ensure the safety of elk herds.

To begin with,we elected two model states with highest elk population growth rate, Utah and Arizona. The average environmental conditions of these two states are considered optimum. Then we apply multiple linear regression to the possible environmental factors of each state.The result suggests that the growth rate is mainly related to temperature, precipitation and forest coverage. The same criteria is applied to eastern states with reintroduction potential and the champion goes to Missouri, the most suitable elk habitat according to our research.

After a macroscopic overview comes a microscopic analysis. We chose one specific model from sigmoid curves, the Gompertz model, to estimate future population growth.The regression result suggests that the carrying capacity of Great Smoky Mountains National Park is about 800 elks and that in order to keep the elks at a high growth speed, the number is best controlled at about half the carrying capacity, that is to say 400. Then influences of individual factors are evaluated, and possible solution to certain problems are proposed.

Our models can have a profound influence on elk population development.It listed possible influencing factors of elk population, made suggestions for suitable elk habitats, predicted the future growth tendency and brought about corresponding measures to be taken. After the confirmation of reintroduction feasibility, it can be immediately brought into action. The sooner the elks are translocated to their new home,their native land, the better and faster they are able to adapt to the new environment.

Moreover, it can be the basis of further in-depth researches on the same topic or other similar issues.The emphasis of these researches may be different, but we are all working towards the same goal: bio-diversity and eco-harmony.We have witnessed the appalling aftermaths of indiscriminate pollution, hunting and mistreatment. The victims are pleading for protection, not disrespect. And we, as righteous fighters for equity, are obliged to stop these unjust depravities from any further infliction. With these models we've built, the resurgence of elks is within reach.

Yours sincerely,

Team 3432

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