Guided Study Program in System Dynamics
System Dynamics in Education Project
System Dynamics Group
MIT Sloan School of Management[1]

Solutions to Assignment #27
Monday, July 5, 1999

Reading Assignment:

Please refer to Road Maps 9: A Guide to Learning System Dynamics (D-4508-1) and read the following papers from Road Maps 9:

- *Generic Structures: Overshoot and Collapse, by Lucia Breierova (D-4480)*
- *A Skeptic's Guide to Computer Models, by John Sterman (D-4101-1)*

<u>1.   Generic Structures: Overshoot and Collapse</u>

A. Describe one or more systems that you think exhibit or may exhibit overshoot and collapse.
- *What would be the variables in the system corresponding to the "stock" and "resource" of the generic structure?*
- *How does the "stock" deplete the "resource," and why is the "loss fraction" of the "stock" dependent on the amount of "resource"?*
- *Is the "resource" renewable? If so, how does the renewal of the "resource" affect the system?*
- *Over what time horizon does the behavior of overshoot and collapse occur?*
- *Once the "stock" collapses, has all the "resource" been depleted? Why or why not?*

If you have extra time, feel free to model the system that you described and submit your model.

Although fisheries can be stable or cyclical, newly developing fisheries often exhibit the overshoot and collapse behavior. This is particularly true if the product is a particularly valuable one that attracts rapid investment. Often the collapse is followed by a long period of recovery after which another overshoot and collapse may occur thus producing cycle-like behavior. This produces a behavior similar to that of the deer population model.

In this case, the "stock" would be the participants in the fishery, which could be expressed as number of boats. The "resource" would be the fish population.

The stock will deplete the resource because the consumption is greater than the growth rate of the resource. This consumption rate may remain high (given a high value product) even when the resource amount drops to fairly low values.

In this case, the resource is renewable if given a chance to recover. The overshoot and collapse phenomenon occurs under conditions where the stock's consumption of the resource is greater than the resource's growth. If the stock drops sufficiently (following the resource collapse) then the resource can recover, and another "cycle" could occur.

I would expect the time horizon for this type of behavior would be 5 to 15 years.

Normally the collapse would occur prior to the disappearance of all the resource. Often a sufficient amount of "stock" (boats) remain to prevent the resource (fish population) from recovering. Although fishing usually does not remove the very last fish, it may be possible for fishing to reduce a population to levels where it might become extinct for other reasons such as pollution, habitat destruction, other changes in the ecosystem.

Every once in a while a "management fad" becomes immensely popular in a very short time period. Examples of these management fads are Total Quality Management, Business Process Redesign, Organizational Learning, Activity Based Costing, ISO quality certification, the Balanced Business Scorecard, MRP, JIT, the Value Chain concept, etc. Each of these techniques is meant to improve business performance.

-The first firms starting up an improvement program may, under guidance of founders of the same technique, accomplish substantial improvements (and, of course, these results are often published in roaring stories in leading management literature). The effect is that more and more companies want to start up their own version of the improvement program prevailing at that moment. Consulting firms will increasingly offer their "expertise" in the program, and more improvement programs will be initiated. So demand for expertise is high, causing even more consulting firms to offer services in order to get their piece of the pie.

One may start to suspect that the experience offered by the consulting firms is not as solid as may seem. After all, in a new, emerging field, where did the experience come from? Thus, the average quality of the expertise being offered and the average quality of new programs being initiated decreases. So a depletion of the resource of potential client companies for the consultants occurs through two outflows: companies that already started their program and companies that become less eager to start up an improvement program because of the decreasing quality and success rate of such programs are both depleted from the resource. After some time, the number of firms willing to invest in expensive reorganization programs is dramatically lowered, causing consulting firms to withdraw from the field of the improvement program.

The number of consulting firms performing activities in the specific field is the stock in the system, the number of companies willing to start up an improvement program is the resource.

More consulting firms offering their services resulting in actual improvement programs with clients will deplete the resource of potential clients. When the number of potential clients decreases, consultants will pull out from the field and direct their attention to other emerging management fads. The lower the resource of potential clients becomes, the greater the loss fraction.

The resource is not renewable (at least for that specific improvement program). Other new rewarding improvement programs, however, fill a new resource of potential clients.

The time horizon for the overshoot and collapse behavior is between two and five years I guess.

The stock will probably not collapse completely. Some of these improvement techniques are very valuable, especially when used by the real experts. So I expect that the real experts will become niche players in the consulting market and will continue doing wonderful projects with their clients.

B. Turn back to section 4, "Table Functions in the Generic Structure." It is possible to generate the unrealistic behaviors of S-shaped growth or even exponential growth by simply altering one of the table functions. Which one of the table functions should be changed? How would you change the table function so that the model produces S-shaped growth, what assumptions would this change in the table function represent, and why are these assumptions unrealistic? What about for exponential growth?
Hint: You may want to refer to *Road Maps 9: Mistakes and Misunderstandings: Table Functions.*

The table function that should be altered in order to obtain the unrealistic behavior of S-shaped growth or exponential growth is the "effect of resource on loss fraction." This table function controls the maximum value that the "loss fraction" can reach when the "Resource" has been depleted. Initially, the "loss fraction" is lower than the "COMPOUNDING FRACTION," so the "Stock" increases exponentially. As the "Resource" is depleted, however, the "effect of resource on loss fraction" becomes greater, and the "loss fraction" increases. In the overshoot and collapse behavior, the "outflow" becomes greater than the "inflow" when the "Resource" is sufficiently depleted. When the "Resource" is sufficiently depleted, the "loss fraction" must reach values greater than the "COMPOUNDING FRACTION." In the generic structure the table function "effect of resource on loss fraction" is formulated so that the "loss fraction" does indeed reach values greater than the "COMPOUNDING FRACTION."

If the range of values of this table function is altered so that its maximum value still makes the "loss fraction" lower than the "COMPOUNDING FRACTION," the initial exponential growth cannot be stopped. The difference between the "COMPOUNDING FRACTION" and the "loss fraction" is always positive. The net flow into the "Stock" is then also positive and increasing, generating the exponential growth of the "Stock." For example, suppose that the "COMPOUNDING FRACTION" is equal to 0.3 and the

"NORMAL LOSS FRACTION" is equal to 0.1. Then, setting the maximum value of the "effect of resource on loss fraction" to a value of 2 will result in a maximum possible value of "loss fraction" of 0.1 * 2 = 0.2, which is still lower than the "COMPOUNDING FRACTION."   The growth fraction for the net flow into the "Stock" is then 0.3 – 0.2 = 0.1. The result will be an exponential behavior with a growth fraction of 0.1.

S-shaped growth would be obtained if the range of values of the table function is altered so that when the "effect of resource on loss fraction" reaches its maximum value, the "loss fraction" equals the "COMPOUNDING FRACTION."   With such a table function, as the "Resource" is depleted, the difference between the "COMPOUNDING FRACTION" and the "loss fraction" keeps decreasing but remains positive until it reaches zero. The net flow into the "Stock" is always positive, initially increasing and later decreasing, until it reaches zero. Such a behavior of the net flow typically generates S-shaped growth.   As in the example above, suppose that the "COMPOUNDING FRACTION" is equal to 0.3 and the "NORMAL LOSS FRACTION" is equal to 0.1. Then, setting the maximum value of "effect of resource on loss fraction" to 3 will result in a maximum possible value of the "loss fraction" of 0.1 * 3 = 0.3. The "loss fraction" then equals the "compounding fraction," and the net growth fraction and hence the net flow is 0. Because zero is the minimum value of the net growth fraction, the "Stock" shows a typical S-shaped growth before reaching some maximum value and remaining at that value.

Both exponential growth and S-shaped growth are unrealistic behaviors because they would imply that the "Resource" may by depleted without affecting the maintenance and growth of the "Stock."   Because the "Stock" keeps increasing (in the case of exponential growth) or remains at some maximum value (in the case of S-shaped growth), the "Stock" consumes the "Resource," so the "Resource" is depleted until it reaches a value close to zero. The relationship between the "Stock" and the "Resource" has been defined in such a way, however, that the "Resource" is absolutely necessary to allow the growth and even the maintenance of the "Stock."   Therefore, a high value of the "Stock" is not possible in the presence of a low or zero value of the "Resource."   A model exhibiting exponential or S-shaped growth would not represent real-life cases where the stock strictly depends on a certain resource.

2.   Independent Exercise: Sensitivity analysis of table functions

In this exercise, you are going to explore the sensitivity of model behavior to changes in table functions. Before you tackle the exercises, please read the following introduction to the topic, taken from a paper in progress.

Table functions, also known as graphical functions, are useful tools for representing nonlinear relationships between variables in a model. The reasons for performing sensitivity analysis on table functions are similar to the reasons for testing the effects of changes in constant parameters. Table functions often express a modeler's crucial assumptions about the relationship between two variables. A modeler should, therefore,

simulate the model with alternative formulations of table functions to see how the model behavior changes under different assumptions. If sensitivity analysis shows that the model behavior is relatively insensitive to changes in the shape of a table function, then the modeler would not have to specify the table function with extreme precision in order to generate the observed behavior. Thus, the modeler can be more certain about the model's behavior, since the behavior remains the same even if the table function changes slightly. Sensitivity analysis also allows a modeler to better understand the dynamics of the system being modeled and to investigate the behavior under extreme assumptions.

Before exploring in detail how changes in table functions affect the behavior of a model, it is necessary to understand what table functions are and how they should be formulated.

A table function is a graphical tool used to model a causal, usually nonlinear relationship between two variables in a model. Table functions model relationships that would be difficult to specify in mathematical terms. For example, a time series (a function in which a variable's value changes with respect to time) can be incorporated into a model as a table function; however, exogenous time series should seldom be used in a system dynamics model. More frequently, a table function represents an effect of one variable on another variable. In such cases, the function is referred to as a multiplier because it multiplies a normal, or reference value of a variable. A normal value, defined by the modeler, represents the normal, or reference conditions of the system, in which the variable being multiplied by the multiplier is equal to its normal value.

If a table function is a multiplier, the input (the independent variable on the horizontal, or x-axis) as well as the output (the dependent variable on the vertical, or y-axis) of the table function must be dimensionless because a table function cannot change the units of one variable to the units of another variable. In addition, the table function should be robust; both the input and the output should be allowed to vary over their entire possible ranges.

When formulating a table function, several important characteristics of the function should be determined: slope, shape, reference points, and reference lines.

The slope *of a table function represents the direction of the relationship between the variables. When the relationship is positive, so is the slope; an increase in the value of the independent variable causes an increase in the value of the dependent variable. A negative slope means that the relationship is negative; an increase in the value of the independent variable causes a decrease in the value of the dependent variable.*

The shape*, or curvature, of a table function shows the strengthening or weakening effect of the independent variable on the dependent variable. When the curve of the table function becomes steeper, the effect of the independent variable on the dependent variable is stronger. A weakening effect of the independent variable on the dependent variable is indicated by a flattening of the curve.*

If the table function is a multiplier, it multiplies the normal value of a variable. In a multiplier, a reference point *is a point for which the multiplier outputs the value of 1, so that the dependent variable is equal to its normal value. A value of 1 for the multiplier means that the independent variable has no effect on the dependent variable, which occurs under the normal conditions of the system.*

    A reference line, *for example y = x (the dependent variable equals the independent variable), can help to identify reference conditions of the system as well as weakening and strengthening effects of the table function.*
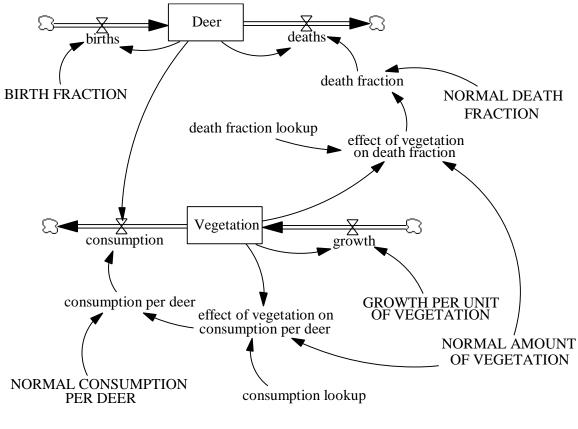
    In addition, it is often helpful to determine the coordinates of the extreme values of the independent and dependent variables shown in the table, as well as the coordinates of the points where the independent variable is equal to 0 and to 1, and where the dependent variable is equal to 0 and to 1.

Now please work on the following problems:

A. Choose one of the four models presented in Generic Structures: Overshoot and Collapse. *Build the model in Vensim PLE and simulate the base run, as presented in the paper. In your assignment solutions document, please include the model diagram, documented equations, and graphs of model behavior in the base run.*

We will be working with the deer population model.

Model diagram:

Model equations:

BIRTH FRACTION = 0.5
        Units: 1/Year
        Number of deer born per deer every year.

births = Deer * BIRTH FRACTION
        Units: deer/Year
        Number of deer born every year.

consumption = Deer * consumption per deer
        Units: unit of vegetation/Year
        Rate of consumption of vegetation.

consumption lookup ([(0,0) - (1,1)], (0,0), (0.1,0.305), (0.2,0.545), (0.3,0.72), (0.4,0.835), (0.5,0.905), (0.6,0.945), (0.7,0.97), (0.8,0.985), (0.9,1), (1,1))
        Units: dmnl
        The table function specifying the effect of vegetation on consumption per deer.

consumption per deer = NORMAL CONSUMPTION PER DEER * effect of vegetation on consumption per deer
        Units: (unit of vegetation/deer)/Year
        Amount of vegetation consumed per deer per year.

death fraction = NORMAL DEATH FRACTION * effect of vegetation on death fraction
        Units: 1/Year
        Fraction of deer dying each year.

death fraction lookup ([(0,0) - (1,10)], (0,10), (0.1,7.15), (0.2,5.05), (0.3,3.15), (0.4,2.15), (0.5,1.6), (0.6,1.35), (0.7,1.15), (0.8,1.05), (0.9,1), (1,1))
        Units: dmnl
        The table function specifying the effect of vegetation on the deer death fraction.

deaths = Deer * death fraction
        Units: deer/Year
        Number of deer dying every year.

Deer = INTEG (births-deaths, 100)
        Units: deer
        The population of deer.

effect of vegetation on consumption per deer = consumption lookup (Vegetation / NORMAL AMOUNT OF VEGETATION)
        Units: dmnl
        Effect of the availability of vegetation on consumption per deer.

effect of vegetation on death fraction = death fraction lookup (Vegetation / NORMAL AMOUNT OF VEGETATION)
        Units: dmnl
        Effect of the availability of vegetation on the deer death fraction.

growth = Vegetation * GROWTH PER UNIT OF VEGETATION
    Units: unit of vegetation/Year
    Rate of regeneration of the vegetation.

GROWTH PER UNIT OF VEGETATION = 0.1
    Units: 1/Year
    Units of vegetation regenerated per unit of vegetation every year.

NORMAL AMOUNT OF VEGETATION = 10000
    Units: unit of vegetation
    The normal amount of vegetation in the area.

NORMAL CONSUMPTION PER DEER = 1
    Units: unit of vegetation/(Year * deer)
    Number of units of vegetation that a deer consumes per year if there is enough vegetation available.
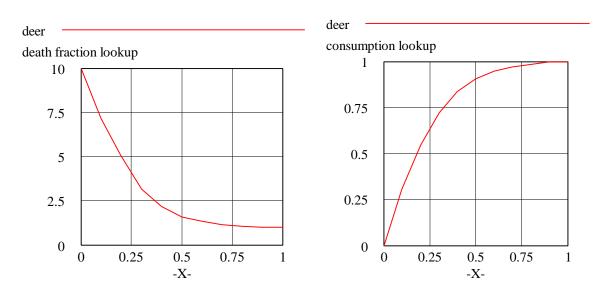
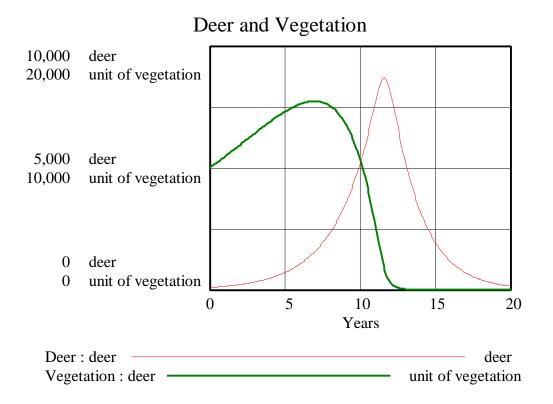NORMAL DEATH FRACTION = 0.1
    Units: 1/Year
    Fraction of deer dying per deer every year when there is enough vegetation available.

Vegetation = INTEG (growth-consumption, 10000)
    Units: unit of vegetation
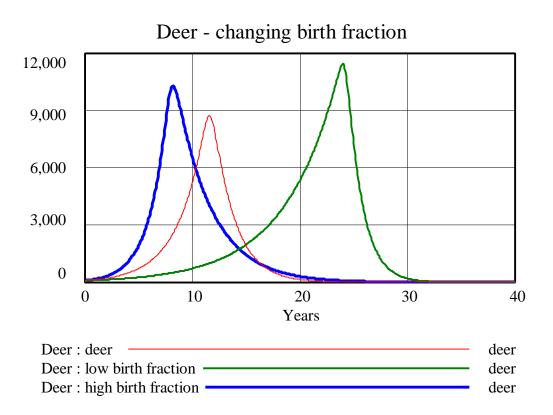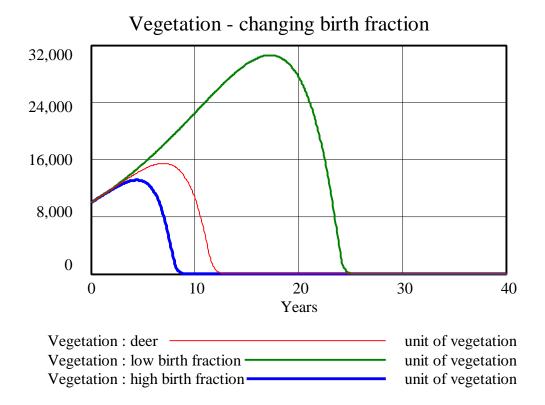   Amount of vegetation present in the area.

deer
death fraction lookup

deer
consumption lookup

Base run behavior:

Deer and Vegetation

10,000	deer
20,000	unit of vegetation
5,000	deer
10,000	unit of vegetation
0	deer
0	unit of vegetation

Years

Deer : deer ——————————————————————— deer
Vegetation : deer **————————————** unit of vegetation

B. Conduct parameter sensitivity analysis on the model you chose in part A. In your assignment solutions document, include graphs to show the results, and summarize your findings.
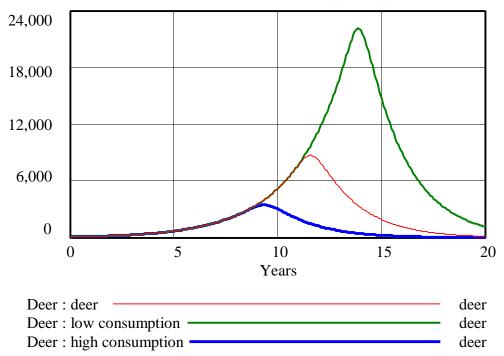
Let's start by changing the value of "BIRTH FRACTION." With a lower value of "BIRTH FRACTION," the initial exponential growth of "Deer" is slower, so "Vegetation" can increase to a higher value. Eventually, however, the "Deer" population becomes so large that even the greater amount of "Vegetation" is not sufficient to support all the "Deer," and the population collapses and "Vegetation" is depleted. With a higher value of "BIRTH FRACTION," on the other hand, the exponential growth of "Deer" is faster, hindering the growth of "Vegetation" through increased "consumption." The amount of "Vegetation" does not rise enough to support the high population of "Deer," and the overshoot and collapse behavior is again generated. The following figures compare the base run behavior (deer simulation run) of "Deer" and "Vegetation" to a simulation with "BIRTH FRACTION" equal to 0.3 (low birth fraction simulation run) and to a simulation with "BIRTH FRACTION" equal to 0.7 per year (high birth fraction simulation run):

Deer - changing birth fraction

Deer : deer	deer
Deer : low birth fraction	deer
Deer : high birth fraction	deer

Vegetation - changing birth fraction

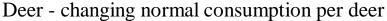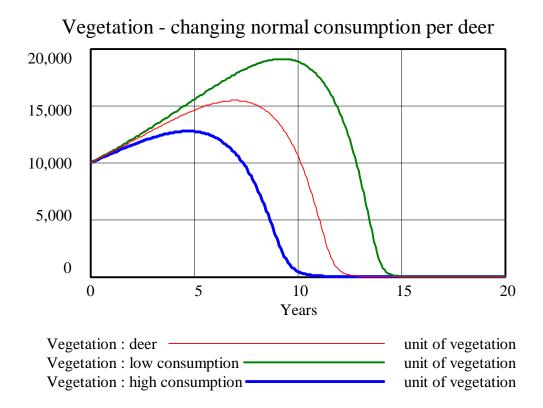|	
Vegetation : deer	unit of vegetation
Vegetation : low birth fraction	unit of vegetation
Vegetation : high birth fraction	unit of vegetation

Because the system behavior is mainly affected by the relative values of "BIRTH FRACTION" and "NORMAL DEATH FRACTION," one would expect that decreasing the "NORMAL DEATH FRACTION" would have similar effects on model behavior as increasing the "BIRTH FRACTION." Similarly, increasing the "NORMAL DEATH FRACTION" should have similar effects as decreasing the "BIRTH FRACTION."
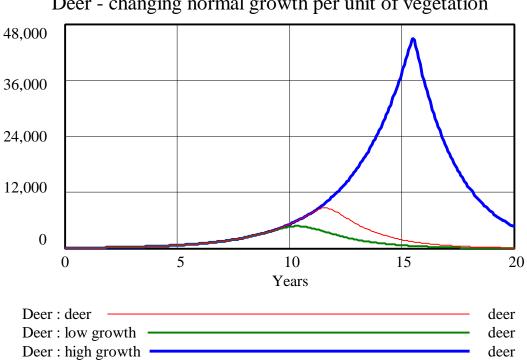
Let's now study changes in the "NORMAL CONSUMPTION PER DEER." When "NORMAL CONSUMPTION PER DEER" is lower, the depletion of "Vegetation" by the "Deer" is slower, so the amount of "Vegetation" and hence the "Deer" population can rise to higher values. The higher "Deer" population, however, increases the total amount of "consumption," so "Vegetation" eventually starts decreasing, causing the collapse of "Deer." With a higher value of "NORMAL CONSUMPTION PER DEER," on the other hand, the depletion of "Vegetation" is faster. Therefore, "Vegetation" and "Deer" cannot grow to as high values as in the base case before the "Vegetation" is greatly depleted, followed by the collapse of "Deer." The following figures compare the base run behavior (deer simulation run) to a simulation with "NORMAL CONSUMPTION PER DEER" equal to 0.5 (low consumption simulation run) and to a simulation with "NORMAL CONSUMPTION PER DEER" equal to 2 units of vegetation per deer per year (high consumption simulation run):

Deer - changing normal consumption per deer

Deer : deer	deer
Deer : low consumption	deer
Deer : high consumption	deer

Vegetation - changing normal consumption per deer

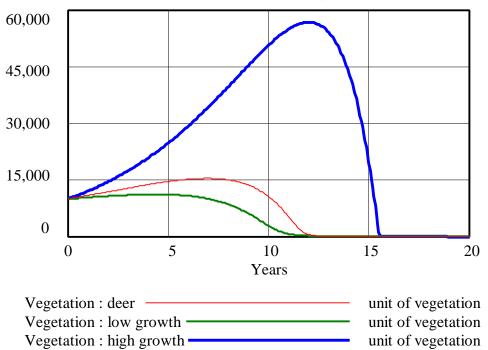| Vegetation : deer | —————————— | unit of vegetation |
| Vegetation : low consumption | —————————— | unit of vegetation |
| Vegetation : high consumption | —————————— | unit of vegetation |

Finally, let's study the changes in behavior resulting from changing the "NORMAL GROWTH PER UNIT OF VEGETATION" to see how the rate of regeneration of a renewable resource affects the behavior of overshoot and collapse. When the "NORMAL GROWTH PER UNIT OF VEGETATION" is low, the "growth" of "Vegetation" is slower, so "consumption" exceeds "growth" earlier, leading to an earlier decline of "Vegetation." As a result, the "Deer" population is not able to grow to very high values and collapses earlier. When the "NORMAL GROWTH PER UNIT OF VEGETATION" is high, on the other hand, the "growth" of "Vegetation" is faster, and it takes longer for "consumption" to exceed "growth." Therefore, "Vegetation" grows for a longer time and to a higher value, allowing the population of "Deer" to also grow to a high value before collapsing. If the "NORMAL GROWTH PER UNIT OF VEGETATION" is set high enough, the model will generate exponential growth of both the "Deer" population and the amount of "Vegetation." Such a situation is unrealistic, however, because of biological facts about plants, and because other land area pressures would control the growth of "Vegetation." The following figures compare the base run behavior (deer simulation run) to a simulation with "NORMAL GROWTH PER UNIT OF VEGETATION" equal to 0.05 (low growth simulation run) and to a simulation with "NORMAL GROWTH PER UNIT OF VEGETATION" equal to 0.2 per year (high growth simulation run):
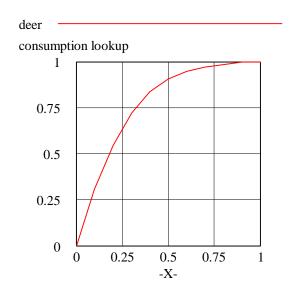
Deer - changing normal growth per unit of vegetation

Deer : deer	———————	deer
Deer : low growth	———————	deer
Deer : high growth	———————	deer

Vegetation - changing normal growth per unit of vegetation

Vegetation : deer	———————	unit of vegetation
Vegetation : low growth	———————	unit of vegetation
Vegetation : high growth	———————	unit of vegetation

C. In the model, identify the table function corresponding to the "effect of resource on consumption per unit of stock" table function from the generic structure. Characterize the slope, shape, reference point(s) and any other interesting characteristics of the function, and explain the modeler's assumptions in formulating the table function. Describe any alternative assumptions that one might have about the relationship between the amount of resource and the consumption per unit of stock, and specify table functions corresponding each of those assumptions. For each specification of the table function, simulate the model, and submit a graph of the table function and a graph of the model behavior. Explain how and why the particular table function specification resulted in any observed changes in the behavior of the model.

The table function corresponding to the "effect of resource on consumption per unit of stock" is the "effect of vegetation on consumption per deer":
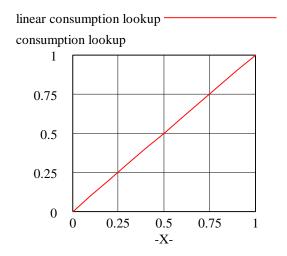

The slope of the table function is positive for all values of the ratio of "Vegetation" to "NORMAL AMOUNT OF VEGETATION," indicating that the higher the amount of "Vegetation," the higher the "consumption per deer."

The curve becomes increasingly flat as the value of "Vegetation" increases, which indicates that the effect of "Vegetation" on "consumption per deer" weakens for increasing amounts of "Vegetation." The modeler assumes that when the amount of "Vegetation" is close to the "NORMAL AMOUNT OF VEGETATION," the ability of deer to find and consume "Vegetation" is not greatly affected, so their consumption is close to the "NORMAL CONSUMPTION PER DEER." If "Vegetation" is very scarce, however, the ability of deer to find and consume "Vegetation" diminishes quickly.
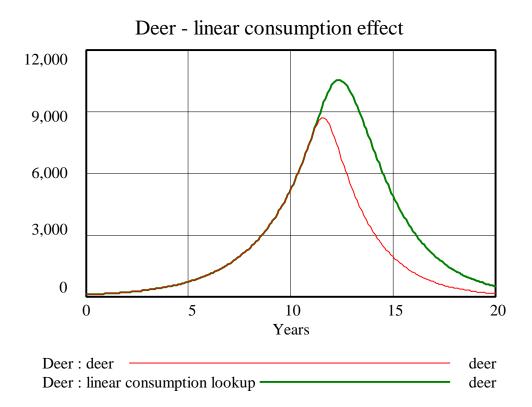
A reference of the table function is the point (1,1), indicating that when "Vegetation" equals the "NORMAL AMOUNT OF VEGETATION," "consumption per deer" also equals the "NORMAL CONSUMPTION PER DEER." Also, if "Vegetation" exceeds the "NORMAL AMOUNT OF VEGETATION," the modeler assumes that "consumption per deer" does not exceed the "NORMAL CONSUMPTION PER DEER."
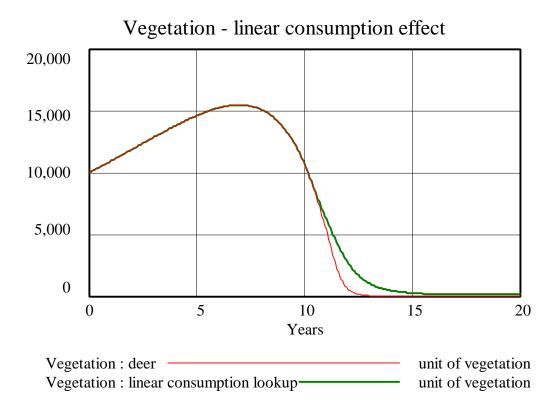
Another reference point is the point (0,0), indicating that when all "Vegetation" has been depleted, the "Deer" cannot consume anything, so "consumption per deer" must be 0.

An alternative assumption about the "effect of vegetation on consumption per deer" is that the relationship is linear:

A linear shape of the table function would mean that the ability of the "Deer" to find and consume "Vegetation" depends linearly on the existing level of "Vegetation," which is probably not a realistic assumption. With a linear "effect of vegetation on consumption per deer," "consumption per deer" starts decreasing earlier and faster than in the base run after "Vegetation" falls below its normal value. The total amount of "consumption" every year therefore also starts declining earlier and more slowly, so "Vegetation" also decreases more slowly. Hence, the "Deer" population peaks at a higher value, and its collapse occurs later, as shown in the following figures:

Deer - linear consumption effect

Deer : deer ——————————————————— deer
Deer : linear consumption lookup ——————————— deer

Vegetation - linear consumption effect

Vegetation : deer ——————————————— unit of vegetation
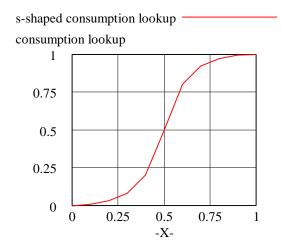Vegetation : linear consumption lookup ———— unit of vegetation

As one can see from the above graphs, the assumption of a linear relationship between the amount of "Vegetation" and the "consumption per deer" does not have significant effects on the model behavior.

Another assumption about the "effect of vegetation on consumption per deer" is that the curve becomes steeper for higher value of the ratio of "Vegetation" to "NORMAL AMOUNT OF VEGETATION." Such a shape, however, is unrealistic: it does not seem likely that a change in "Vegetation" when it is close to its normal value would have an equal or stronger effect than when "Vegetation" is very scarce.

One can also assume that the relationship between "Vegetation" and "consumption per deer" is an S-shaped curve:
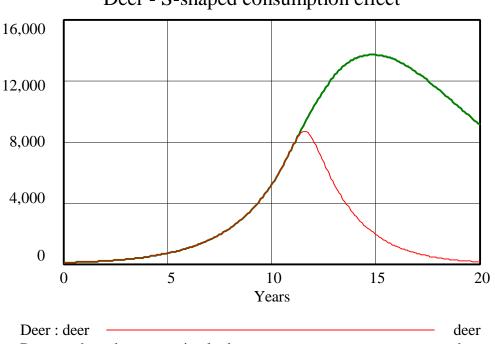

The S-shaped curve corresponds to the assumption that the central region of possible values of "Vegetation" is more sensitive to small changes than the extreme regions. The flat part of the curve in the region where "Vegetation" is close to "NORMAL AMOUNT OF VEGETATION" can be explained by the same reasoning as the table function from the base run. When "Vegetation" is close to "NORMAL AMOUNT OF VEGETATION," small changes in "Vegetation" do not have a strong effect on "consumption per deer." When "Vegetation" becomes more scarce, as in the middle region, however, even a small change in "Vegetation" has a strong impact on the ability of "Deer" to find and consume "Vegetation," so the curve is decreasing steeply. There may, however, be a threshold value of "Vegetation" below which consumption is almost impossible. Hence, when "Vegetation" approaches such a threshold value, "consumption per deer" is almost non-existent, and a further reduction of "Vegetation" cannot make "consumption per deer" much lower.

With an S-shaped "effect of vegetation on consumption per deer" table function, the multiplier becomes close to zero earlier, so "consumption per deer" decreases faster and earlier, which slows down the decline of "Vegetation." As a result, the population of "Deer" can grow for a longer time and to a higher value. Because "consumption per deer" becomes close to zero before all "Vegetation" is depleted, the S-shaped table
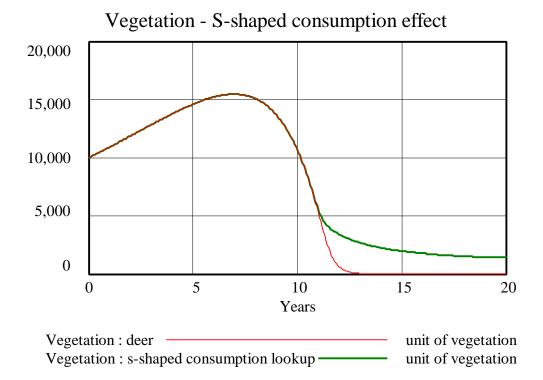
function results in positive values of "Vegetation" and "Deer" after the collapse of the "Deer" population, as shown in the following figures:

Deer - S-shaped consumption effect

Deer : deer ——————————— deer
Deer : s-shaped consumption lookup ——————— deer

Vegetation - S-shaped consumption effect

Vegetation : deer ——————— unit of vegetation
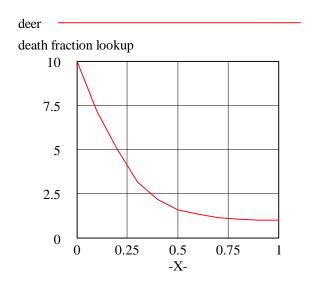Vegetation : s-shaped consumption lookup ——— unit of vegetation

Again, as one can see from the above graphs, the assumption of an S-shaped relationship between the amount of "Vegetation" and the "consumption per deer" does not affect the overall behavior of overshoot and collapse generated by this model. The true table function depends on the deer and type of vegetation. Data collection and research would be required to accurately draw the table function.

D. Repeat part C for the table function corresponding to the "effect of resource on loss fraction" table function from the generic structure.

The table function corresponding to the "effect of resource on loss fraction" is the "effect of vegetation on death fraction":
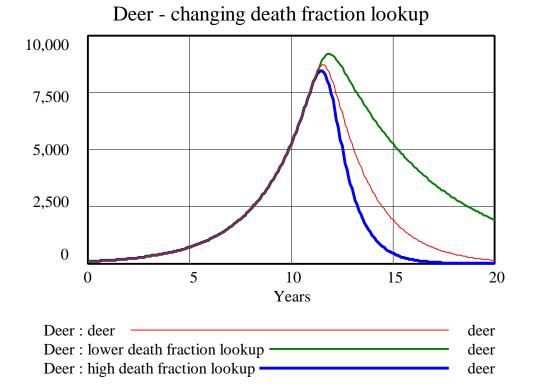

The slope of the table function is negative for all values of the ratio of "Vegetation" to "NORMAL AMOUNT OF VEGETATION," indicating that the lower the amount of "Vegetation," the higher the "death fraction."

The curve is becoming steeper for lower values of "Vegetation," which indicates that the effect of "Vegetation" on the "death fraction" becomes stronger as the amount of "Vegetation" decreases. The modeler assumes that when the amount of "Vegetation" is close to the "NORMAL AMOUNT OF VEGETATION," the life span deer is not greatly affected, so their "death fraction" is close to the "NORMAL DEATH FRACTION." If "Vegetation" is very scarce, however, the life span of "Deer" decreases quickly even for small changes in "Vegetation," and the "death fraction" increases.

A reference point of the table function is the point (1,1), indicating that when "Vegetation" equals the "NORMAL AMOUNT OF VEGETATION," the "death fraction" also equals the "NORMAL DEATH FRACTION." Also, if "Vegetation" exceeds the "NORMAL AMOUNT OF VEGETATION," the modeler assumes that "death fraction" does not fall below the "NORMAL DEATH FRACTION."

Another reference point is the point (0,10), indicating that when all "Vegetation" has been depleted, the "death fraction" becomes ten times its normal value. Unlike in the "effect of vegetation on consumption per deer" table function, the "effect of vegetation on death fraction" table function has a reference point that is crucially dependent on the modeler's knowledge of the life span of deer when "Vegetation" is almost exhausted. Clearly, the "death fraction" should be higher than the "BIRTH FRACTION," but the exact value of the maximum "death fraction" is not necessarily obvious. As was shown in part B. of Exercise 2, we know that the maximum value of the "effect of vegetation on death fraction" must be higher than 5; otherwise, the model generates unrealistic behaviors. The maximum point of the table function should be determined by finding the life span of deer in the absence of any vegetation.

One can therefore test the sensitivity of the model to alternative assumptions about the maximum value of the "effect of vegetation on death fraction." If the maximum value is lower (but still higher than 5), the population of "Deer" decreases more slowly because, when the "death fraction" surpasses the "BIRTH FRACTION," the negative net flow into the stock of "Deer" has a lower magnitude. Similarly, if the maximum value is higher, the "Deer" population collapses more quickly because the net flow has a higher magnitude. The overall behavior of overshoot and collapse, however, is unaffected by such changes. These results are shown in the following figure, comparing the base run (deer simulation run) to a simulation with the maximum value of "effect of vegetation on death fraction" at (0,7) (lower death fraction lookup simulation run) and at (0,15) (high death fraction lookup simulation run):

Deer - changing death fraction lookup

Deer : deer	———————————	deer
Deer : lower death fraction lookup	———————————	deer
Deer : high death fraction lookup	———————————	deer

E. Summarize your findings from parts C and D. What would you conclude about the sensitivity of model behavior to changes in table functions?

The effect of changes of table functions on model behavior is limited as long as the slope of the curve is unchanged. Changing the shape of the curve, as shown in part C., may have some effects on the time scale and magnitude of the behavior, but the overall pattern of behavior is unaffected.