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Investigations and Opportunities with Differential Equations

## STUDENT VERSION

### ACORNS, RODENTS, AND SNAKES

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#### STATEMENT

In forests there are many species of plants and animals. As an example, consider the temperate forests around West Point NY USA and the nearby Black Rock Forest where there are dens of northern timber rattle snakes. These snakes live by eating a few rodents per season. The rodent prey are found principally while the snakes are laying in ambush in sunny areas and wandering about their den area. The rodents eat many things, but a principle diet component is acorns from oak trees. Oak trees produce acorns in some regularity, but occasionally there will be a season in which the oaks mast, i.e. produce an enormous number of acorns. There are also leaner acorn production years. You may have experienced walking in the woods some years in which there is lots of crunching from stepping on a mat of acorns under foot and other seasons when the forest floor is smooth and almost clean of acorns. This is due to masting. It is believed that masting is a propagation mechanism. For if the oak trees produced the same (predictable) number of acorns each seasons the rodents who consume them would come to a population level at which there were just enough rodents to eat all the acorns. However, when the acorns mast they get way ahead of the rodents and the acorns (which are the seeds of the oak) germinate, take root, and begin the cycle of growth to the canopy that keeps the oak tree population alive in the woods.

We offer you some activities in which you will be guided to build mathematical models of this three trophic level phenomena: acorns, rodents, and snakes. In activities (1) - (8) you need not concern yourself with masting of acorns.

**Activity (1)**

Make a sketch and verbally indicate the relationship between acorns, rodents, and snakes. You may introduce other species and interactions, but we suggest you concentrate on just these three: acorns, rodents, and snakes.

**Activity (2)**

Make sketches of plots of what you believe are acorn numbers in a fixed amount of the forest, rodent population numbers in that same region, and snake population numbers in that same region, say over a 10 year period. Describe what is happening in the forest and how your sketched plots reflect this action description.

**Activity (3)**

Verbally describe the rate of change of acorn, rodent, and snake populations, over time where  $a(t)$  represents the number of acorns in a fixed region at time  $t$  in years,  $r(t)$  represents the number of rodents in the same fixed region at time  $t$  in years, and  $s(t)$  represents the number of snakes in the same fixed region at time  $t$  in years. What contributes to these changes and in what mathematical expression can we realize these contributions?

**Activity (4)**

Write down rate equations for  $a'(t)$ ,  $r'(t)$ , and  $s'(t)$ . Describe the variables, the parameters, the terms, the relationships, and the reasons for your arithmetic. Discuss with colleagues your models and defend your terms.

**Activity (5)**

Now be prudent about the numbers of acorns, rodents, and snakes in the woods, e.g., there probably are lots of acorns, but few snakes with more rodents than snakes, but not as many rodents as acorns. Then make reasonable estimates of your parameters in your rate equations as well as your initial populations of acorns, rodents, and snakes.

**Activity (6)**

One way to test the reasonableness of your model is to find equilibrium values. Remember these organisms have lived together in the forest for a long time so there must be some number for each at which they would stay steady, or at least go a bit above and then a bit below or hover around if no catastrophe occurs. For your model find the equilibria and determine their nature, either stable or unstable.

**Activity (7)**

Run your model forward in time, say for 10 years, i.e., solve your system of differential equations with numbers, and plot the numbers for the three organisms over that period of time. Comment on what your model is doing.

**Activity (8)**

Improve your model. You decide what criterion you will use to improve your results.

**Activity (9)**

Introduce masting as a sudden large increase in acorns and solve your model, again plotting the solutions and commenting on the reasonableness of your results. You determine the time and duration of the masting. Adjust values of the level of masting, run your model (i.e. solve your system of differential equations), plot your solutions, and see how masting changes the model. Explain whether or not this makes sense to you.

**Activity (10)**

Seek out some data to give realism to your model, e.g., how many rodents per season will a snake eat? How big a snake population might there be? How many acorns per acre, hectare, or square meter are there in a normal season? (See Figure 3 in [4] which gives a range of between 2.5 and 29 acorns per  $m^2$ .) In a masting season? (See [1] where we learn, “ Heavy acorn production, which generally occurs once every 2-5 years in deciduous forests, is an example of masting.”) How many acorns does a rodent eat per unit time (or take out of circulation, for you have seen squirrels burying acorns and do you think the squirrel finds every acorn buried in preparation for winter eating?) How many rodents might an acre or hectare support? Some of this you can estimate from your own experiences, e.g., you see chipmunks around your campsite in a state park and does that give you some idea of their density in the woods? Are rodents “breeders” and how often? You might find data on northern timber rattlesnakes, their den size, their rodent consumption, their roaming range, their birth rates, etc. See the references below. For data on acorn masting and rodent abundance over a 20 year period see Figure 1. Also we note the following

“Acorns are a highly nutritious food source for many species of mammals and birds, including white-footed mice. Mice store acorns for winter consumption, when food sources are generally scarce.

“We have used both long-term monitoring and experimental enhancement of acorn abundance to determine the effects of acorns on mouse populations. Long-term monitoring demonstrates that summertime abundance of mice is strongly correlated with acorn production during the prior fall. Experimental acorn additions indicate more mice survive the winter when acorns are abundant and winter reproduction only occurs when acorns are present. Following acorn

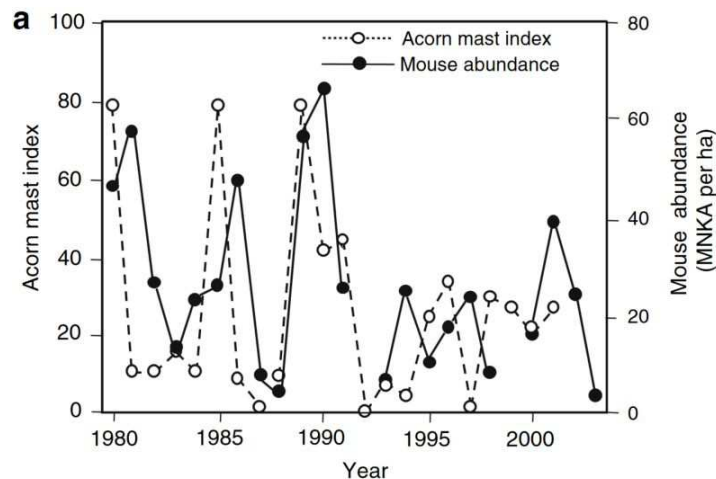
most years, as a result of higher over-winter survival and winter breeding, population growth starts earlier in the season, leading to higher peak densities of mice in summer.”[1]

A nice ”conceptual model of the relationships among key functional units in the oak forests of eastern North America” is offered in Figure 1 of [3, p. 324]

As more evidence of the strong relationship between acorn population and rodent population we read in [5, p. 17] that

“... the size of the autumn crop of acorns or other tree seeds is a strong determinant of rodent density the following year, often explaining over 80% of interannual variation.

Finally, we offer a convincing plot in Figure 1 depicting the relationship between acorn masting and mouse abundance. Notice that the mouse abundance peak is always one year or season after the acorn mast peak. And it would be reasonable to notice a comparable period of time between the mouse abundance peak and the snake population peak as more mice means more food and a more supportive environment for snake population growth.



**Figure 1.** From [2, p. 497] we show a plot of the relationship between acorn masting and mouse populations in a forest.

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