NATIONAL CENTER FOR CASE STUDY TEACHING IN SCIENCE

The Mystery of the Missing Martens

by
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Part I – Where Are the Martens this Year?

In summer 2015, after a long week in the field, Aubrey and Mike returned to the Forest Service bunkhouse on an island in Southeast Alaska just in time to answer a phone call from their supervisor, Dr. Kelly James.

Dr. James: Hi team! How has the last week of marten trapping been going? Any new captures?

Aubrey: Hi Dr. James! Well, we captured one new male and have had a couple of recaptures, but compared to the trapping success in the previous two years, we're not catching nearly as many martens. The ones we are catching look thin and their fur doesn't seem to be in very good shape.

Mike: When we were fueling the truck this morning, a neighbor was also at the gas station and told us he didn't have as much luck this past winter fur trapping. He's hoping for better luck this coming winter but didn't seem very hopeful.

Aubrey: We also ran into the field crew from Montana two days ago and they mentioned how busy they are this year trapping and tagging mice compared to last year. They acted jealous of our relaxed field season and low number of captures.

Mike: I just hope we're not doing something wrong that is causing this low capture success.

Dr. James: I know you two are doing a great job in the field, so I'm sure the low captures are not related to something you're doing. It might be helpful for us to start asking around about any big changes in forest management or other observations that might help explain this.

Aubrey: The locals are convinced that there is a disease wiping out the martens. Nothing else has changed in the forest that could explain the decline in the marten numbers.

Dr. James: Okay—well, keep your eyes and ears open and let me know if you run across anything unusual.

Questions

1. What is a marten? Why would locals be interested in trapping this animal?

2. What might be some causes for the apparent marten decline on Aubrey and Mike's field site?

Part II — Marten Biology

After checking traps Thursday, Aubrey and Mike head to the local library to use the internet. They remotely log into their university library and begin to search for information regarding marten ecology and population dynamics. Their research produces some tantalizing information (expressions in boldface are defined in the glossary; see pp. 5–6):

Two species of martens, American and Pacific, occur in North America (Dawson and Cook, 2012). American martens *(Martes americana)* are distributed from the Atlantic coast through the boreal forests of Canada to Alaska. Pacific martens *(Martes caurina)* are found from the Rocky Mountains to the Pacific coast and from California to Southeast Alaska. Both species are closely associated with and heavily dependent on **old-growth** forests (Buskirk, 1992). Multiple studies across the ranges of the two species revealed that these mustelids rarely use open-**canopy** forest **habitats** and their **abundance** is lower in areas where large swaths of old-growth forests have been logged (Godbout and Ouellet, 2010). Although American and Pacific martens naturally occurred (separately) on several islands in the Alexander Archipelago of Southeast Alaska, in the 1930s the Alaska Game Commission (the federal agency that managed wildlife resources in the territory before Alaska became a state in 1959) introduced animals (mostly American martens) from the mainland to some of the larger islands (e.g., Chichagof and Prince of Wales) to provide economic opportunities for rural communities (Paul, 2009).

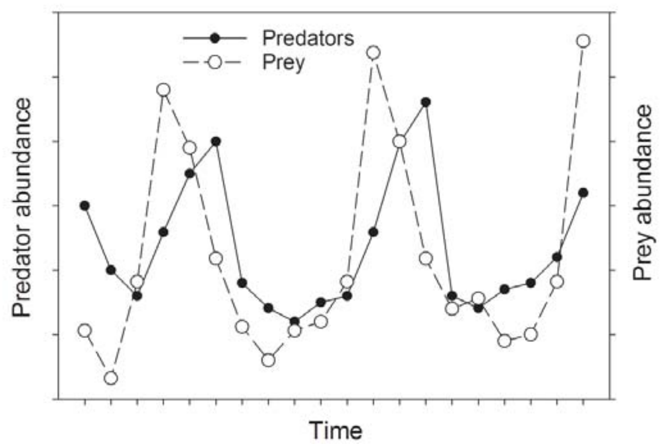


Figure 1. A theoretical representation of predator-prey cycles illustrating a 1-year time lag between the change in predator numbers and the change in prey.

In many northern latitudes, **predators** and their **prey** exhibit cyclic **dynamics**. Predator numbers rise following an increase in prey abundance and then decline when prey populations crash, usually exhibiting a **time lag** (Figure 1). This relationship is driven by the effects of food availability on survival and reproduction of predators.

In Southeast Alaska, marten numbers track those of long-tailed voles *(Microtus longicaudas)* and Keen's mice *(Peromyscus keeni)*. To determine the relationship between these small mammals and abundance, survival, and reproduction (**vital rates**) of martens, scientists from state and federal agencies (Alaska Department of Fish and Game [ADFG], US Forest Service [USFS], and US Fish and Wildlife Service [FWS]) and several universities have conducted long-term studies on several of the islands and the mainland of Southeast Alaska (Ben-David et al., 1997; Flynn and Schumacher, 2009; Pauli et al., 2012). In these studies, martens were **live-captured**, fitted with **radio-transmitters** (Figure 2) and followed through several months to years to determine

Figure 2. An American marten on Chichagof Island wearing a collar with a radio-transmitter. This individual and many others like him were followed for several months to years to determine habitat use and survival rate. Photo by Gail Blundell, used with permission.

survival (Flynn and Schumacher, 2009). Concurrently the abundance of small mammals was quantified using various trapping methods. Finally, marten carcasses (which are usually discarded after the skin is removed) were purchased from fur trappers and used to investigate the **body condition** of the animal (in terms of fat reserves) and reproduction as indicated by **corpora lutea counts** in the ovaries (for females only), which represent the number of kits born (Flynn and Schumacher, 2009).

On Chichagof Island marten **fecundity** varied from 0.44–2.70 kits per female (in some years many females did not produce any young so on average each had 0.44 of a kit; in other years each female produced 2–4 kits and on average each had 2.70). As shown in Figure 3, fecundity was dependent on the abundance of small mammals (Flynn and Schumacher, 2009). Marten annual survival ranged from 0.34–1.00 (or the number of marked animals that survived each year ranged from 34% to 100%). Although the relationship with the availability of small mammals was not as clear, in years with high abundance of these prey, most martens survived (0.65–0.82). In years after the mice and voles declined, few martens survived (0.34–0.54). In the three years when small mammal abundance was low, mortality from **fur trapping** was 62.5–93.8% of the total (Flynn and Schumacher, 2009). The strong relationship between marten abundance and that of small mammals with a 1-year time-lag was also observed when data from all marten studies in Southeast Alaska were combined (Flynn et al., 2004; M. Ben-David, unpublished data).

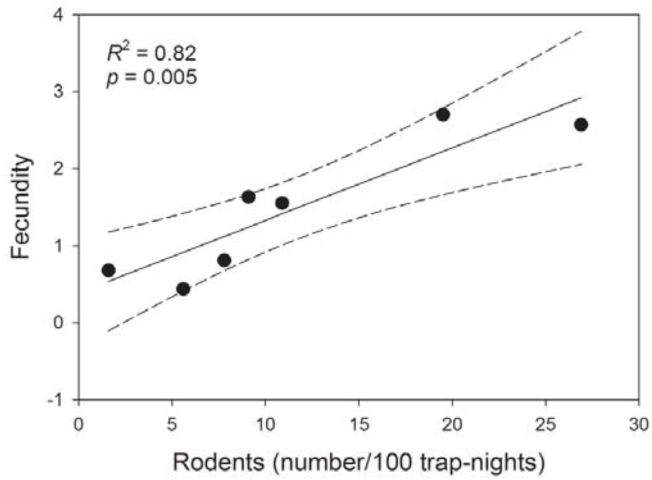
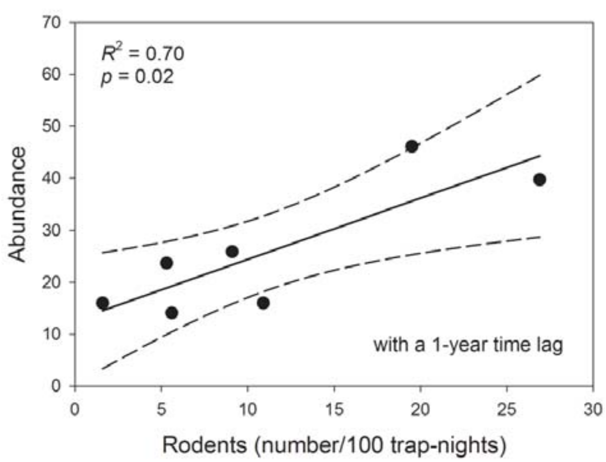


Figure 3. The relationship between the index of rodent abundance (represented as the number captured in 100 trap nights) and the fecundity of martens on Chichagof Island, Alaska. Fecundity was measured as the number of corpora lutea counts in the ovaries of adult females. The solid line is the regression and the dashed line the 95% confidence intervals around that line. This figure was created from data published by ADFG Biologists Rod Flynn and Tom Schumacher (Flynn and Schumacher, 2009).

Most striking is the relationship between small mammal abundance in one year and marten abundance in the following (which is a result of high fecundity and high survival in years with many rodents, and low fecundity and low survival in years with few prey; Figure 4). The strong relationship between marten abundance and that



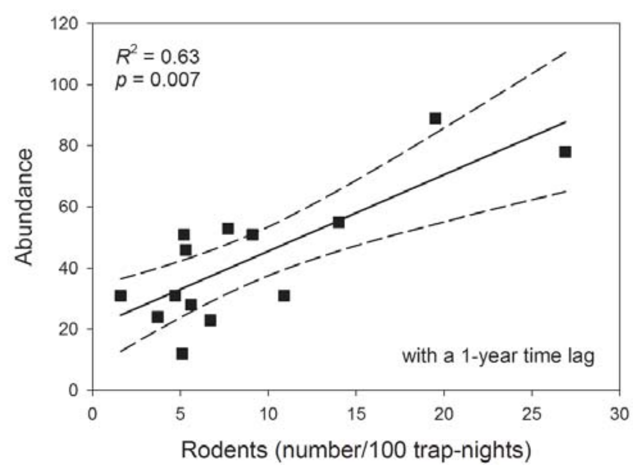


Figure 4. The relationship between the index of rodent abundance (represented as the number captured in 100 trap nights) and the abundance of martens on Chichagof Island (on the left) and across several sites in Southeast Alaska (on the right). Because the area trapped varied at the different sites, marten abundance was normalized to the same area (16,200 ha).

of small mammals with a 1-year time-lag was also observed when data from all marten studies in Southeast Alaska were combined (Figure 4).

Both male and female martens reach sexual maturity at around 15 months of age, and approximately 80% of females are sexually mature in their second year of life (Age Class 1; Clark et al., 1987). However, even these females will not give birth until their third year (Age Class 2). Martens, similar to many other mustelids, have a unique reproductive strategy. Following mating, the fertilized eggs develop into blastocysts (tiny embryos composed of about 128 cells), which stop developing for another 190–250 days (Clark et al. 1987). This **delayed implantation** of embryos ensures that kits are born during the best time of year in terms of food availability. Thus, similar to survival, fecundity of martens changes with age.

Aubrey and Mike are excited (and relieved)! Maybe the low capture success is indeed not their fault! Maybe martens on this island show cyclic population dynamics similar to those found on Chichagof Island. But they need more information. First, they stop by the neighbor's house and ask him how long he's been trapping martens and if he's seen any similar declines of these furbearers in the past.

Aubrey: Hi Steve – we've been thinking more about what you said at the gas station the other day about not trapping as many martens this last winter as you had in the past. How long have you been trapping here?

Steve: Oh, I've been trapping since high school, so at least 25 years. That's how I made enough money to buy my first car.

Mike: Have you ever had similar years with low success?

Steve: Well, I've had some good years and some not so great years but none as poor as this one.

Aubrey: Do you think the number of people trapping martens or their trapping effort has changed? Have you noticed any other changes around here that you think could impact the martens?

Steve: You know, I've thought about this quite a bit and just can't think of anything that's changed. I know that the number of people who are trapping hasn't changed and we all continue to run our old trap lines. It's not like someone went out and set 100 more traps. There's still some logging happening, but that's always been the case around here. I really think there's a disease going through the marten population that's killing them off. I just don't know of any other explanation.

Mike: Thanks, Steve. We really appreciate your time and if you think of anything else, let us know!

Questions

1. Can you predict the fecundity of martens if the index of rodent abundance is 18 per 100 trap-nights? What did you base your answer on?
    a. What would be the most likely range of fecundity values?
        i. How would you determine that?
    b. What do you expect the marten abundance to be for that value of rodents?
    c. What do the R^2 and p (probability) values indicate (in Figure 4)? If you don't know the answers to these questions, consider using Google for assistance.
2. Why would the abundance of small mammals (rodents) influence the fecundity and abundance of martens? (*Hint:* consider the energy a marten invests in searching for food and the returns it gains after catching prey.) Why would reproduction be dependent on prey availability?
3. What other variables related to the natural history of martens might impact their abundance?
4. What information would Aubrey and Mike need in order to assess the potential persistence of martens? How can they project the number of martens into the future?

Glossary

Abundance – the number of animals in the population or population size. (Beware, this word has different meanings in the various scientific fields.)

Age class – a group of animals (or people) that are approximately the same age.

Age structure – the distribution of age classes in a population. In healthy growing populations, the largest segment is the juveniles, followed by 1-year-olds, then by 2-year-olds, etc. The population can be drawn as a pyramid. In declining populations, where recruitment of juveniles is low the graphic representation of the age structure can be an inverse pyramid or not resemble a pyramid at all.

Average – also known as "mean," is a value calculated by adding numbers and dividing by their count. For example, the average of 2, 4, and 6 is 4 (2 + 4 + 6 = 12; 12/3 = 4).

Body condition – the amount of fat and protein reserves accumulated by an animal. Good body condition is characterized by high levels of fat and protein, low or poor body condition means the animal has too few reserves to survive without feeding.

Canopy – the upper layer or crown of the trees in a forest, composed of branches and leaves.

Conifers – woody plants that produce cones. Examples include pines, spruce, cedar, and the giant redwoods in California.

Corpora lutea counts – A corpora lutea (or yellow/white body) is the group of cells left in the ovary after the ova ("egg") has left and migrated to the uterus. Each corpora lutea represents a single embryo (unless after fertilization the embryo is halved yielding identical twins, which is rare).

Delayed implantation – a reproductive strategy common to mustelids and a few other mammals. It is similar to the reproduction of marsupials (pouch animals such as kangaroos) in that the embryo stops developing after a few cell divisions and remains in diapause (dormancy) for several months. Only then it will implant into the uterine wall and the placenta will develop (in marsupials it will move into the pouch instead). The rest of the pregnancy proceeds similar to other mammals.

Deterministic – as in model, where each of the parameters has only one fixed value without consideration of any possible variation. The result is determined based on those values and the model equations.

Dynamics – a pattern or process of change used to describe population growth.

Extinction – the death of all members of a species.

Fecundity – The ability of females to produce young, or in other words, the number of young produced by a female.

Fur trapping – The killing of animals for their fur. Usually the dead animal is stripped of its skin and the carcass is discarded. Between the 17th and 19th centuries, fur trapping and trading was a major economic activity. The development of alternative clothing materials (from oil products) and growing concern for animal welfare reduced the global demand for furs.

Habitat – a natural area inhabited by certain organisms (such as plants and animals) and has the conditions (moisture, light, temperature, etc.) that facilitate their existence.

Landscape – the visible features (scape) of an area of land including attributes such as mountains, valleys, lakes as well as vegetation and human structures.

Life-table – a numerical representation of the dynamics of a population. It is based on age-specific abundance, survival and reproduction.

Live-capture – trapping of live animals and their subsequent release mostly for scientific investigations.

Old-growth – Forest stands that have never been logged and thus maintain their complex structure.

Over-harvest – Killing of a large portion of a population to levels that threaten successful reproduction or survival.

Overstory – the layer of branches and leaves in the tree canopy.

Parameters – components of a model. For example, survival and birth rate are parameters in a population growth model.

Persistence – Long-term existence despite changes to the environment.

Population growth – change in the number of animals in the population after mortality and biths occurred. Population growth is positive if the number of animals is increasing ($\lambda > 1$). Population growth is negative is the number of animals is decreasing ($\lambda < 1$).

Predators – animals that subsist by consuming other animals.

Prey – Animals that are consumed by others.

Radio-transmitters (telemetry) – small devices that transmit a simple radio signal. The radio signal is translated into an audible one, which can help track the location of the transmitter.

Reproduction – the production of young by living organisms.

Stochastic – as in models that include the variation associated with their different parameters. Such models can be very complicated and require special software to construct.

Survival – the condition in which an organism continues to live and does not die. Survival rate is the portion of the population that survives year to year.

Time lag – the period during which an event or activity is delayed.

Viability – the ability of organisms (such as plants and animals) to maintain their numbers or recover from declines in their numbers.

Vital rates – attributes of a population such as reproduction, survival, mortality, and dispersal (emigration and immigration).

Part III – Modeling the Marten Population

Aubrey: Mike, do you remember that in our population ecology class we learned how to model population dynamics and forecast population growth? I went back through our notes yesterday and I think we have all of the information necessary to develop a life-table model for the martens! This would let us evaluate what a typical marten population would look like over time.

Mike: I think that's a great idea! We have tomorrow off and my laptop has Excel. Let's give it a try. We can call Dr. James and ask about the population abundance estimates starting in 2012.

Task

Your task now is to develop the life table suggested by Aubrey and Mike to evaluate the characteristics of a typical marten population over time. The following material will guide you through the steps of developing a life table in Excel or another spreadsheet software package and includes review information from Aubrey and Mike's population ecology course. Please open Excel on your computer and follow along with Aubrey and Mike as they construct the first model on Mike's laptop.

To forecast the number of martens into the future, managers use the age-specific estimates of abundance, **survival**, and fecundity and model the **population growth** from one year to the next by using **age classes**. In a given year, the number of animals in Age Class 1 will be the number (N) of animals that were juveniles (Age Class 0) the year before multiplied by the survival rate (S; the proportion of animals that survive) from Age Class 0 to Age Class 1 (Figure 5), or:

$$N_1 = N_0 \times S_{0-1}$$

The number of animals in Age Class 2 will be the number of animals that were 1-year old (Age Class 1) the year before multiplied by the survival rate from Age Class 1 to Age Class 2, or:

$$N_2 = N_1 \times S_{1-2}$$

To obtain the total number of animals, we calculate the number in each age class and sum across all age classes (Figure 5).

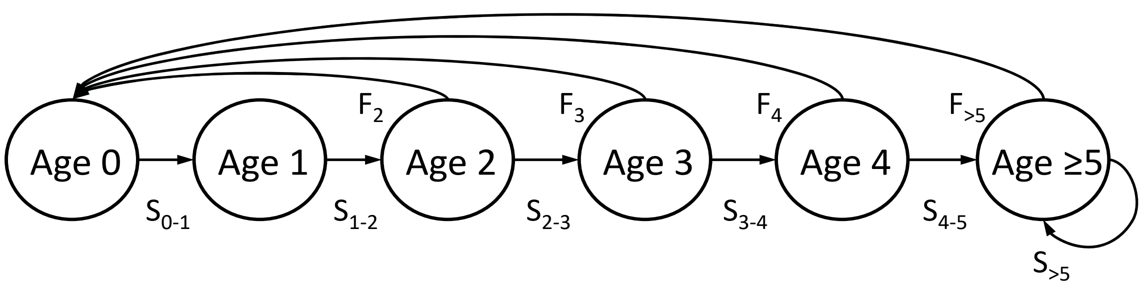


Figure 5. A schematic diagram illustrating age specific survival and reproduction for martens. Circles represent the number of individuals in each age class. S is survival rate from one age class to the next. F is age-specific fecundity. Only females two years and older reproduce and give birth to the individuals that will be in Age Class 0.

To calculate the number of individuals in Age Class 0 each year, we need to know how many females survived year to year and multiply their numbers by age-specific fecundity. For example, if there were 24 females in Age Class 2 and survival rate is 0.5 then 12 females will be in Age Class 3 the following year. If the age-specific fecundity of martens in Age Class 3, is 2.2 kits per female that year then these 12 females will contribute 26 juveniles to the overall population (actually 26.4 but we can't have 0.4 animals, so we round up or down). This type of population forecasting is called a "population **life-table**" or a population matrix.

Let's try forecasting a marten population. In Table 1 you will find the number of martens in each age class for the field site in 2012. The starting population number (N) is based on data collected in previous field seasons by Dr. James' field crews.

Also in Table 1 are the age-specific sex ratio of females, fecundity or "birth rate" (b) and survival (s). Life tables are usually constructed for females only because they are the segment of the population producing kits. For that reason we will first calculate the number of females based on the sex ratio. The sex ratio for this species is roughly 1:1 at birth but increasingly favors females as the animals get older. We will also halve the birth rate. In this example we used the maximal birth rate observed at the field site (i.e., 2.7 kits per female or 1.35 females per females assuming the 1:1 sex ratio at birth) and then adjusted this overall population mean for the different age classes. Because only 2-year old and older martens produce kits, birth rate for Age Class 0 and 1 is zero. Survival rate is similar for males and females so we only adjusted the overall high survival rate and assigned different rates to the various age classes (Table 1). We will forecast the marten population using a spreadsheet-software (such as Microsoft Excel). Therefore Table 1 lists the row numbers and column letters, which correspond with the appropriate cells in your spreadsheet.

Table 1. Age class, number of martens in each age class in 2012 (N_{2012}) on Admiralty Island Southeast Alaska, as well as sex ratio of females, birth rate (b) and survival (s) in each age class. The numbers in the first column represent the spreadsheet rows; the letters in the top row represent the columns. In cell B8 is the formula to calculate the total number of martens. In cell D2 is the formula to calculate the number of juvenile (Age Class 0) females.

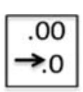
	A	B	C	D	E	F
1	Age Class	$N_{(2012)}$	Sex ratio of females	$N_{(2012)}f$	$b_{(age)}$	$s_{(age)}$
2	0	600	0.50	=B2*C2	0	0.50
3	1	323	0.50		0	0.75
4	2	213	0.57		1.2	0.90
5	3	164	0.57		1.5	0.90
6	4	82	0.60		1.4	0.62
7	>5	1	0.60		0.1	0.01
8	TOTAL	=SUM(B2:B7)				

Before we begin the forecasting exercise let's calculate the estimated total number of martens on the island. Then we will calculate the number of females in each age class.

Step 1: Enter the data from Table 1 into the spreadsheet.

Step 2: To determine the total number of martens we will need to sum the values in cells B2 through B7. All spreadsheet formulas begin with the equal sign so in cell B8 type =SUM(B2:B7). You don't actually need to type the cell values, instead you can highlight the cells B2 through B7 with your cursor after typing =SUM(. Then you need to close the parentheses and press enter. Hopefully you made no mistakes in entering the data and Excel calculated a total population size of 1,383.

Step 3: To determine the number of females in each age class you will need to multiply the number of martens in each age class by the sex ratio. In cell D2 type =B2*C2 and press enter. In the cell the number 300 should appear. Similarly, in cell D3 you'll need to type =B3*C3. If all is well, Excel will calculate the number of females as 161.5. But remember, we don't have fractions of animals so we'll need to round the number up. To do so press the button:



This button, referred to as "decrease decimal," is located in the ribbon above the cells in a spreadsheet on the Home tab.

You can continue typing the equations in cells D4 through D7 or simply copy the formula down (this is the beauty of using a spreadsheet!). The most efficient way is to highlight cells D2 and D3 and hover with cursor over the right bottom corner of D3. A small black "+" sign appears. Now click and hold the left side of the mouse and drag that + over all the cells to D7.

Step 4: Use the equation in Step 2 to sum the abundance of females across all age classes in column D. Did you calculate 726 in cell D8?

Step 5: Next we will calculate two **parameters** associated with life tables: mortality rate, q(x), and cumulative survivorship. Mortality rate is the complement of survival rate. It is therefore 1–survival. In cell G2 type: =1–F2. What is the output? If Excel calculated 0.5, you did well (if 50% survive then 50% had to die); if not, check your equation. Now simply copy that equation down through G7 (Table 2). Please be sure to only show 2–3 decimal places for rates.

Calculating cumulative survivorship will be a bit trickier. Survivorship, l(x) is the fraction of individuals that survive to age x. Survivorship in Age Class 0 is 1 because this is the first age class and there are no cumulative age effects yet. So in cell H2, type the number 1. For Age Class 1 the cumulative survivorship is the survival from Age Class 0 to Age Class 1 (S_{0-1}) so in cell H3 type =H2*F2. The output should be 0.5. Next in cell H4 type = H3*F3. What did you calculate? This is basically the estimated survival from Age Class 0 to Age Class 1 AND from Age Class 1 to Age Class 2: (S_{0-1}) AND (S_{1-2}). In mathematics "AND" is multiplication ("OR" is addition). You should calculate the same total if you multiplied the value in F2 by F3. The reason we don't use this equation in Excel is that we can't copy and paste that equation down the column. If we copied and pasted the equation =F2*F3 to cell H6 Excel will only calculate the product =F5*F6 and we need =F2*F3*F4*F5*F6 ($=S_{0-1} * S_{1-2} * S_{2-3} * S_{3-4} * S_{4-5}$). By creating a column in which the product of the cumulative survivorship is saved for each age class we circumvent the problem. So now you can copy and paste the equation from H3 down through H7 (Table 2).

Step 6: Finally we are ready to begin projecting the marten population into the future. First we start by calculating the number of animals in Age Class 1 through >5. The number of animals in Age Class 1 in 2013 will be the number of juveniles in 2012 multiplied by the survival rate from Age Class 0 to Age Class 1(S_{0-1}). In cell I3 type =D2*F2 and you can copy this equation down. Basically, the number of animals in Age Class 2 in 2013 will be the number of yearling (Age Class 1) times their survival rate and so on.

The question remains: how many kits will join the population in 2013? Or in other words: what equation do we need to write in cell I2? As shown in Figure 5 the number of young (in our case females only) is the summation of the number of kits produced by females in each age class. The number of kits is a function of the number of females in each age class times their survival rate to the next year times their birth rate. So in cell I2 we type =D2*F2*E2 + D3*F3*E3 + D4*F4*E4 + D5*F5*E5 + D6*F6*E6, which is: $N_0 * S_{0-1} * b_0 + N_1 * S_{1-2} * b_1 + N_2 * S_{2-3} * b_2 + N_3 * S_{3-4} * b_3 + N_4 * S_{4-5} * b_4$. Is your final total 300? Good! Now sum across all age classes for the total number of females in the population. How many males would there be? How will you calculate that value?

Step 7: Next we need to estimate the number of female martens in 2014. I'm sure you are eager to copy the I column and paste the equations into the J column. Before using the great feature of equations in Excel, we need to make sure the program will use the correct cells. For example, if we simply copy the equation from I3 to J3, Excel will calculate =E2*G2 (b2*q2) instead of =I2*F2 (N_{2013} of Age Class 0 * S_{0-1}). To make sure Excel always goes back to the F column to retrieve survival rates we need to modify the equation for I3. It should be =D2*$F2. The dollar sign in front of the F is the code instructing Excel to use the values in the F column. Now that you have added the dollar sign to the equation in I3 copy it down to the rest of the cells. The values should not change! Now add dollar signs before each F and E in the equation in I2. Again this will instruct Excel to always retrieve survival rates from the F column and birth rates from the E column. When you are done copy the equations from the I to the J column. The only thing you'll need to change is the reference to the number of animals. For example, in I3 the equation reads =D2*$F2. Because the number of animals in 2013 is actually listed in column I you'll need to change E2 to I2. You'll need to make similar changes to the equation in cell J2 (Table 2).

Table 2. Equations that Aubrey and Mike used for calculating mortality rate, cumulative survivorship and projecting the number of martens into the future.

	D	E	F	G	H	I	J	K
1	$N_{(2012)}f$	$b_{(age)}$	$s_{(age)}$	$q_{(age)}$	$l_{(age)}$	$N_{(2013)}f$	$N_{(2014)}f$	$N_{(2015)}f$
2	=B2*C2	0	0.50	=1–F2	1	=D2*$F2*$E2+D3*$F3*$E3+D4*$F4*$E4+D5*$F5*$E5+D6*$F6*$E6+D7*$F7*$E7	=I2*$F2*$E2+I3*$F3*$E3+I4*$F4*$E4+I5*$F5*$E5+I6*$F6*$E6+I7*$F7*$E7	
3		0	0.75		=H2*F2	=D2*$F2	=I2*$F2	=J2*$F2
4		1.2	0.90		=H3*F3			
5		1.5	0.90					
6		1.4	0.62					
7		0.1	0.01					
8						=SUM(I2:I7)	=SUM(J2:J7)	

If your equations in column J2 are the same as those listed in Table 2, you will be able to copy and paste them into the following columns without additional changes. Now forecast the marten population until the year 2018.

Step 8: To help us quickly evaluate whether the population is increasing or decreasing we will calculate λ (lambda) or the finite population growth. To calculate λ we divide the total number in one year by the number of animals in the previous year. For example, to check if the marten population will increase between 2013 and 2014 we will divide N_{2014} by N_{2013}, or in Excel =J7/I7 (Table 2). If the value is greater than 1 the population is increasing if the value is less than 1 the population is decreasing. A value close to 1 suggests a stable population.

Let's calculate λ for the period 2012–2018. Remember that the number of females in 2012 is in column D not H so in I9 type =I8/D8. In the following cells you can type =J8/I8, K8/J8 etc. Or from K9 onward just copy and paste the equation. Will the population be increasing or decreasing? Is the value constant? No it is not. Is the population increasing on **average**? To calculate the average λ type in cell O9 =Average(I9:N9) and press enter. The answer you should get is 1.051 which suggests that the population will be increasing on average at a rate of 5.1% a year. That is good news for this carnivore population!

As you have read in Part II, marten fecundity and survival are not constant year to year. The model we constructed above, however, does not account for any variation associated with the vital rates of the population. It is a **deterministic** model. Constructing fully **stochastic models** will require more sophisticated software than Excel.

Part IV – Modeling to Solve the Mystery

Aubrey: Okay, so it looks like the marten population should be increasing over time if we use the birth and survival rates from the literature.

Mike: From the work Dr. James has been doing up here, that doesn't seem to be the case. Do you think some of the activities on the forest are impacting the martens?

Aubrey: Well, we've heard that they're still trapping martens each winter.

Mike: And we heard from the Montana team that the mice population crashed last year, which would affect the food supply for the martens.

Aubrey: We also saw new logging sites. They've been logging on the island for a while though.

Mike: Do you think all of these impacts could be working together to cause the decline?

Aubrey: Steve doesn't seem to think much has changed but he does acknowledge the lower trapping success.

Mike: Hey! Now that we have the basic population model, we can evaluate the impact of these different factors on our population.

Aubrey: I was thinking the same thing! First, we can model the effects of trapping on marten survival. I think we should assume that trapping reduces survival of juveniles by 20% because individuals from this age class are most likely to disperse and thus encounter the traps. They are also naïve and thus more curious than careful.

Mike: According to the Montana team, the mice declined from 25 per 100 trap-nights to 10 per 100 trap-nights. I think it's safe to assume that marten survival will also decline with fewer prey available. What do you think of using a conservative estimate of a –10% reduction for each age class?

Aubrey: I think it sounds good, and it's better to be conservative. Logging would reduce available habitat, which would result in a decrease in marten home ranges and also impact the small mammal populations. Both changes will likely increase the energy use of females because they will spend more time searching for food. So birth rate will likely decline as well.

Mike: Wow, it seems like the martens have a lot going against them. Let's grab my laptop and work on these new models. It might be helpful to begin with just one stressor and gradually add the other two to see the cumulative effect.

Task

Your task is to now modify your initial life table to model the impacts of these three stressors. Below are some hints to help you do this.

1. The new parameters are listed below in Table 3. In order to forecast the growth of the marten population, copy the entire model you created above and paste it in the same columns in a new worksheet (Sheet 2). This way, if you make a mistake, you will still have your original model and can easily start over. This is good practice with any modeling you might do in the future. Next change the survival rates for the trapping scenario and watch how Excel automatically adjusts all the values and calculates a new average λ.
2. Next add the effects of a crash in small mammal abundance in the winter of 2014–2015. We will assume that the index of small mammals declined from 25 per 100 trap-nights to 10 per 100 trap-nights. Using Figure 1, what would be the fecundity of martens in 2015? Assume that marten survival will also decline so we'll use a conservative estimate of a –10% reduction for each age class. The new fecundity and survival values are listed in Table 3. In order to forecast the growth of the marten population on this island with trapping and a small mammal crash, copy the entire model you created in Sheet 2 and paste it in the same columns in a new

worksheet (Sheet 3). You will only change fecundity and survival rates for the year 2015. It will be easiest to create two separate columns to the right of your table for b(2015) and s(2015). For the year of 2015, you will need to use the b(crash) and s(crash) values instead of the b(x) and s(x) values in the E and F columns. If you replace the E and F columns with the values you only want to use in 2015 to reflect the small mammal crash, your model will use those values for all of the years. Excel will automatically adjust all the total values at the bottom of each column and calculate a new average λ for this scenario as well.

3. Finally, add the effect of logging. As mentioned above, logging would reduce available habitat, which will result in an increase in marten home ranges and also impact the small mammal populations. Both changes will likely increase the energy use of females because they will spend more time searching for food. Therefore, birth rate will likely decline (see values in Table 3). Again copy the table and equations you created in Step 2 above into a new worksheet (Sheet 4) and change the birthrate values in column E. Again, Excel will automatically adjust the calculations for you. Because you are copying and pasting each new model you develop to complete the following step, you just modeled the cumulative effects of all three impacts on the marten population.

Table 3. Survival and reproductive values for scenarios involving fur trapping, small mammal crash in 2015 and logging for a hypothetical marten population on Aubrey and Mike's island in Southeast Alaska.

	Fur trapping	*Small mammal crash in 2015*		*Logging*
1	$s_{(age)}$	$b_{(age)}$	$s_{(age)}$	$b_{(age)}$
2	0.40	0	0.36	0
3	0.75	0	0.68	0
4	0.90	0.44	0.81	1.0
5	0.90	0.55	0.81	1.2
6	0.62	0.51	0.56	1.1
7	0.01	0.04	0.01	0.1

Questions

1. Which of the scenarios resulted in an increasing marten population and which resulted in a negative population growth?
2. Which demographic factors or vital rate appears to more strongly influence your population estimate? How would you quantify the difference in the effect of these two rates? (*Hint:* think about changing each by 25%.)
3. If you, Aubrey, or Mike were wildlife biologists working with the Forest Service, what vital rates would you monitor? Is monitoring abundance enough? What about λ?
4. Would you recommend continuing timber harvest? Why or why not?
5. Are Aubrey and Mike correct that these impacts are influencing the marten population causing the decline, or is Steve's suggestion that a disease or some other factor is most likely the cause of the population decline?