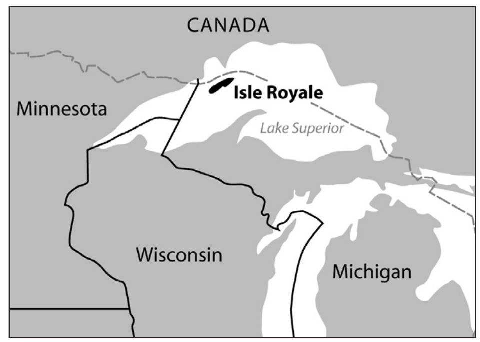
SimBio Virtual Labs®: EcoBeaker®

Isle Royale

Introduction

The Wolves and Moose of Isle Royale



If you were to travel on Route 61 to the farthest reaches of Minnesota and stand on the shore of Lake Superior looking east, on a clear day you would see Isle Royale. This remote, forested island sits isolated and uninhabited 15 miles off of the northern shore of Lake Superior, just south of the border between Canada and the USA. If you had been standing in a similar spot by the lake in the early 1900s, you may have witnessed a small group of hardy, pioneering moose swimming from the mainland across open water, eventually landing on the island. These fortunate moose arrived to find a veritable paradise, devoid of predators and full of grass, shrubs, and trees to eat. Over the next 30 years, the moose population exploded, reaching several thousand individuals at its peak. The moose paradise didn't last for long, however.

Lake Superior rarely freezes. In the 1940s, however, conditions were cold and calm enough for an ice bridge to form between the mainland and Isle Royale. A small pack of wolves found the bridge and made the long trek across it to the island. Once on Isle Royale, the hungry wolves found their own paradise — a huge population of moose. The moose had eaten most of the available plant food, and many of them were severely undernourished. These slow-moving, starving moose were easy prey for wolves.

The Isle Royale Natural Experiment

The study of moose and wolves on Isle Royale began in 1958 and is thought to be the longest-running study of its kind. The isolation of the island provides conditions for a unique natural experiment to study the predator-prey system. Isle Royale is large enough to support a wolf population, but small enough to allow scientists to keep track of all of the wolves and most of the moose on the island in any given year. Apart from occasionally eating beaver in the summer months, the wolves subsist entirely on a diet of moose. This relative lack of complicating factors on Isle Royale compared to the mainland has made the island a very useful study system for ecologists.

The EcoBeaker® Version of Isle Royale

During this lab, you will perform your own experiments to study population dynamics using a computer simulation based on a simplified version of the Isle Royale community. The underlying model includes five species: three plants (grasses, maple trees, and balsam fir trees), moose, and wolves. If you were actually watching a large patch of moose-free grass through time, you would observe it slowly transforming into forest. Likewise, the simulated plant community exhibits a simple succession from grasses to trees.

While the animal species in the Isle Royale simulation are also simplified compared with their real-world counterparts, their most relevant behaviors are included in the model. Moose prefer to eat grass and fir trees. Wolves eat moose, more easily catching the slower, weaker moose. Each individual animal of both species has a store of fat reserves that decreases as the individual moves around and reproduces, and increases when food is consumed. Both moose and wolves reproduce; however, for simplicity, the simulation ignores gender. Any individual with enough energy simply duplicates itself, passing on a fraction of its energy to its offspring. Death occurs when an individual's energy level drops too low. Because weaker moose move at slower speeds, they take longer to find food and move away from predators, so their chance of survival is lower than for healthier moose. In the EcoBeaker® simulation, wolves hunt alone, whereas in the real world, wolves are social animals that hunt in packs. These simplifications make the simulation tractable, while still retaining the basic qualitative nature of how these species interact.

Some Important Terms and Concepts

Population Ecology

Population ecology is the study of changes in the size and composition of populations and the factors that cause those changes.

Population Growth

Many different factors influence how a population grows. Mathematical models of population growth provide helpful frameworks for understanding the complexity involved, and also (if the models are accurate) for predicting how populations will change through time. The simplest model of population growth considers a situation in which limitations to the population's growth do not exist (that is, all necessary resources for survival and reproduction are present in continual excess). Under these conditions, the larger a population becomes, the faster it will grow. If each successive generation has more offspring, the more individuals there will be to have even more offspring, and so on. This type of population growth is described with the exponential growth model.

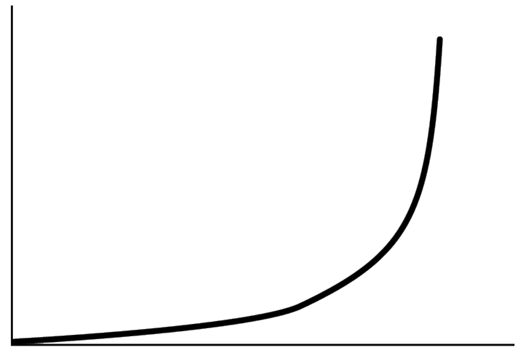
The exponential growth model assumes that a population is increasing at its maximum per capita rate of growth (represented by 'r_{max}') also known as the "intrinsic rate of increase". If population size is N and time is t, then:

$$\frac{dN}{dt} = r_{\max}N$$

The notation '*dN/dt*' represents the "instantaneous change" in population size with respect to time. In this context, "instantaneous change" simply means how fast the population is growing or shrinking at any particular instant in time. The equation indicates that at larger values of *N* (the population size), the rate at which the population size increases will be greater.

The following graph depicts an example of exponential population growth. Notice how the curve starts out gradually moving upwards and then becomes steeper over time. This graph illustrates that when the population size is small, it can only increase in size slowly, but as it grows, it can increase more quickly.

Exponential Population Growth



Carrying Capacity

In the real world, conditions are generally not so favorable as those assumed for the exponential growth model. Population growth is normally limited by the availability of important resources such as food, nutrients, or space. A population's carrying capacity (symbolized by 'K') is the maximum number of individuals of that species that the local environment can support at any particular time. When a population is small, such as during the early stages of colonization, it may grow exponentially (or nearly so) as described above. As resources start to run out, however, population growth typically slows down and eventually the population size levels off at the population's carrying capacity.

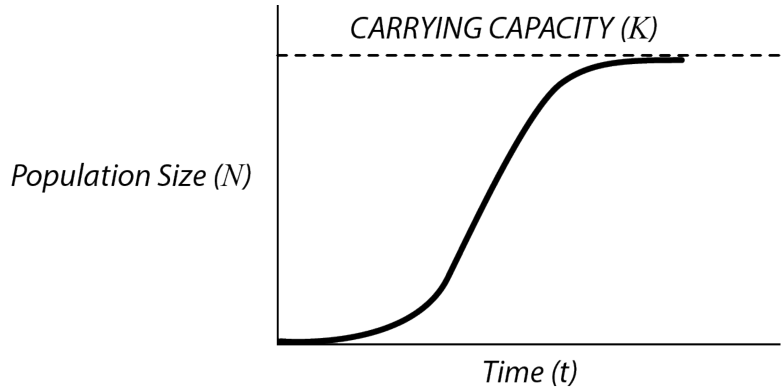
To incorporate the influence of carrying capacity in projections of population growth rate, ecologists use the logistic growth model. In this model, the per capita growth rate (r) decreases as the population density increases. When the population is at its carrying capacity (i.e., when $N = K$) the population will no longer grow. Again, using the 'dN/dt' notation, if the maximum per capita rate of growth is r_{max}, population size is N, time is t, and carrying capacity is K, then:

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

When the population size (N) is near the carrying capacity (K), K-N will be small and hence, $(K\text{-}N)/K$ will also be small. The change in the population size through time (dN/dt) will therefore decrease and approach zero (meaning the population size stops changing) as N gets closer to K.

The following graph depicts an example of logistic growth. Notice how it initially looks like the exponential growth graph but then levels off as N (population size) approaches K (carrying capacity).

Logistic Population Growth



While the logistic model is more realistic than the exponential growth model for most populations, many other factors can also influence how populations change in size through time. For example, the growth curve for a recently-introduced species might temporarily overshoot the population's carrying capacity. This would happen if the abundance of resources encountered by the colonizing individuals stimulated a high rate of reproduction, but the pressures of limited resources were soon felt (i.e., individuals might not start dying off until after a period of rapid reproduction has already taken place).

Graphs based on real population data are never such smooth, neat curves as the ones above. Random events almost always cause population sizes and carrying capacities to fluctuate through time. Interactions with other species, such as predators, prey, or competitors, also cause the size of populations to change erratically. To estimate carrying capacity in situations such as these, one generally calculates the median value around which the population size is fluctuating.

More Information

Links to additional terms and topics relevant to this laboratory can be found in the SimBio Virtual Labs® Library which is accessible via the program's interface.

Starting Up

[1] Read the introductory sections of the workbook, which will help you understand what's going on in the simulation and answer questions.

[2] Start **SimBio Virtual Labs®** by double-clicking the program icon on your computer or by selecting it from the Start Menu.

[3] When the program opens, select the Isle Royale lab from the **EcoBeaker®** suite.

When the **Isle Royale** lab opens, you will see several panels:

- The **ISLAND VIEW** panel (upper left section) shows a bird's eye view of northeastern Isle Royale, which hosts ideal moose habitat.
- The **DATA & GRAPHS** panel to the right displays a graph of population sizes of moose and wolves through time.
- The **SPECIES LEGEND** panel above the graph indicates the species in the simulation; the buttons link to the SimBio Virtual Labs® Library where you can find more information about each.

[4] Click 'Moose' in the **SPECIES LEGEND** panel to read about moose natural history, and then answer the following question (you can read about other species too, if you wish)

[4.1] Based on what you find in the Library, answer the following: could a moose swim fast enough to win a swimming medal in the Olympics (where the fastest speeds are around 5 miles / hour)?

Yes No (Circle one)

[5] Examine the bottom row of buttons on your screen. You will use the **CONTROL PANEL** buttons to control the simulation and the **TOOLS** buttons (to the right) to conduct your experiments. These will be explained as you need them; if you become confused, position your mouse over an active button and a 'tool tip' will appear.

Exercise 1: The Moose Arrive

In this first exercise, you will study the moose on Isle Royale before the arrival of wolves. The lab simulates the arrival of the group of moose that swam to the island and rapidly reproduced to form a large population.

[1] Click the **GO** button in the **CONTROL PANEL** at the bottom of the screen to begin the simulation. You will see the plants on Isle Royale starting to spread, slowly filling up most of this area of the island.

Grass starts out as the most abundant plant species, but is soon replaced with maple and balsam fir trees. The Isle Royale simulation incorporates simplified vegetation succession to mimic the more complex succession of plant species that occurs in the real world. After about 5 simulated years, the first moose swim over to the island from the mainland and start munching voraciously on the plants.

[2] You can zoom in or out using the **ZOOM LEVEL SELECTOR** at the top of the **ISLAND VIEW** panel. Click different Zoom Level circles to view the action up closer or further away. After watching for a bit, click on the left circle to zoom back out. You can zoom in and out at any time.

[3] Reset the simulation by clicking the **RESET** button in the **CONTROL PANEL**. Confirm that the simulation has been reset by checking that the **TIME ELAPSED** box to the right of the **CONTROL PANEL** reads "0 Years".

[4] Click the **STEP 50** button on the **CONTROL PANEL**, and the simulation will run for 50 years and automatically stop. Watch the graph to confirm that the size of the moose population changes dramatically when the moose first arrive, and then eventually stabilizes (levels out).

★ *You can adjust how fast the simulation runs with the* **SPEED** *slider to the right of the* **CONTROL PANEL**.

[5] Once 50 years have passed (model years — not real years!), examine the moose population graph and answer the questions below. (NOTE: if you can't see the whole graph, use the scroll bar at the bottom of the graph panel to change the field of view.)

[5.1] What is the approximate size of the stable moose population? _________

[5.2] What was the (approximate) maximum size the moose population attained? _________

[5.3] **Using the horizontal and vertical axes below, roughly sketch the population size graph showing the simulated moose population changing over time. Label one axis "POPULATION SIZE (N)" and the other one "TIME (years)". You do not need to worry about exact numerical values; just try to capture the shape of the line.**

[5.4] **Examine your graph and determine the part that corresponds to the moose population growing exponentially. Draw a circle around that part of the moose population curve you drew above.**

[5.5] **The moose population grew fastest when it was:**

Smallest   Medium-sized   Largest   **(Circle one)**

[5.6] **What is the approximate carrying capacity of moose? Draw an arrow on your graph that indicates where the carrying capacity is (label it "K") and then write your answer in the space below:**

[6] The following logistic growth equation should look familiar (if not, revisit the Introduction):

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

[6.1] **What does** *"dN/dt"* **mean, in words?**

[6.2] **Think about what happens to dN/dt in the equation above when the population size (N) approaches the carrying capacity (K)? Think about the case when the two numbers are the same $(N = K)$. Rewrite the right-hand side of the equation above, substituting K for N. Write this new version of the equation below:**

dN/dt = __________________ *when* $N=K$

[6.3] **Look at the equation you just wrote and figure out what happens to the right-hand side of the equation. Then complete the following sentence by circling the correct choices.**

According to the logistic growth equation, when a growing population reaches its carrying capacity $(N = K)$,

$dN/dt = \; 0 \; / \; 1 \; / \; K \; / \; N \; / \; r_{max}$ **(Circle one)**,

and the population will

grow more rapidly / stop growing / shrink **(Circle one)**

[7] **Look at the graph on Page 5 that depicts an example of logistic growth and compare that to your moose population growth graph.**

[7.1] **Sketch both curves in the spaces provided below. (Don't worry about the exact numbers; just show the shapes of the curves. Be sure to label the axes!)**

[7.2] **How do the shapes of the curves differ? Describe the differences in terms of population sizes and carrying capacities.**

[7.3] **Provide a biological explanation for why the moose population overshoots its carrying capacity when moose first colonize Isle Royale. (HINT: consulting the Introduction might help.)**

[7.4] **At year 50 or later, with the moose population at its carrying capacity, what would happen if an extra 200 moose suddenly arrived on Isle Royale? How would this change the population graph over the next 20 to 30 years? In the space provided, draw a rough sketch of what you think the graph would look like under these conditions. Be sure to label the axes.**

[8] Now you will test your prediction by increasing the number of moose on the island. Click the **ADD MOOSE** button in the **TOOLS** panel. With the **ADD MOOSE** button selected, move your mouse to the **ISLAND VIEW**, click and hold down the mouse to draw a small rectangle. As you draw, a number at the top of the rectangle tells you how many moose will be added. When you release the mouse, the new moose appear inside your rectangle. Add approximately 200-300 moose.

★ *HINT: To obtain the exact moose population size from the graph, click the graph to see the x and y data values at any point (population size is the y value).*

[9] Click **GO** to continue running the simulation for 20 to 30 more years and watch what happens to the moose population. Click **STOP** to pause the simulation. Then answer the following questions:

[9.1] **Did you predict correctly in question 7.4? ________**

[9.2] **What is the carrying capacity of moose on Isle Royale after adding 200-300 new moose? ________**

[10] Click the **TEST YOUR UNDERSTANDING** button in the bottom right corner of the screen and answer the question in the window that pops up.

Exercise 2: The Wolves Arrive

One especially cold and harsh winter in the late 1940s, Lake Superior froze between the mainland and Isle Royale. A small pack of wolves travelled across the ice from Canada and reached the island. In this second exercise, you will investigate how the presence of predators affects the moose population through time.

[1] To load the next exercise, select "**The Wolves Arrive"** from the **SELECT AN EXERCISE** menu at the top of the screen.

[2] Click **STEP 50** to advance the simulation 50 years. You will see moose arrive and run around the island eating plants as before. Next, you will add some wolves to the island, but first answer the following question:

[2.1] How do you predict the moose population graph will change with predatory wolves in the system? Will the moose population grow or shrink?

[3] Activate the **ADD WOLF** button in the **TOOLS** panel by clicking it. Add 20-40 wolves to Isle Royale by drawing small rectangles on the island (they will fill with wolves) until you have succeeded in helping the wolf population to get established.

[4] Run the simulation for about 200 years (you can click **STEP 50** four or five times). Observe how the moose and wolves interact, and how the population graph changes through time. (To better observe the system you can try changing the simulation speed or zoom level.)

[4.1] In the space below, copy the moose-wolf population graph starting with the time when wolves were established. Make sure you label the axes.

★ *NOTE: if you have trouble estimating the wolf population size from the graph, hold down your mouse button and move the pointer along the graph line to see the x and y values represented.*

[4.2] **Did the introduction of wolves cause the moose population size to decrease or increase? If so, how much smaller or larger (on average) is the moose population when wolves are present?**

[4.3] **You should have noticed that the populations of moose and wolves go through cycles. (If not, run the simulation for another 100 years.) Describe the pattern and provide a biological explanation for what you observe. Does the moose or the wolf population climb first in each cycle? Which population drops first in each cycle?**

[5] If you haven't already, click **STOP**.

[6] The **MICROSCOPE** tool lets you sample animals to determine their current energy reserves. Activate the **MICROSCOPE** tool by clicking it. Then click several moose to confirm that you can measure their 'Fat Stores'. These reserves are important health indicators for moose; the greater a moose's fat stores, the more likely it will survive the winter and produce healthy, viable offspring.

[6.1] **All else being equal, which do you think would be healthier (on average), moose on an island with wolves or moose on an island without wolves? Explain your reasoning.**

[7] You will now test your prediction. **RESET** the simulation and then click **GO** to run the simulation without wolves until the moose population has stabilized at its carrying capacity. Click **STOP** so you can collect and record data. Decrease your zoom level to see as much of the island as possible.

[8] Randomly select 10 adult moose and use the **MICROSCOPE** tool to sample their fat stores. Record your data on the left-hand side of the table below. Do NOT sample baby moose; they are still growing and so do not store fat as adults do.

[9] When you are done, activate the **ADD WOLVES** button as before, and add 10-20 wolves. Click **GO** and run the simulation until the moose and wolf populations have cycled several times. **STOP** the simulation when the moose population is about midway between a low and high point (i.e. at its approximate average size).

[10] Randomly select another 10 adult moose and use the **MICROSCOPE** tool to sample their fat stores.

[10.1] Record the values on the right-hand side of the table.

WITHOUT WOLVES		WITH WOLVES	
Moose	Fat Stores	Moose	Fat Stores
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	
9		9	
10		10	
MEAN =		MEAN =	

[10.2] Calculate and record the mean fat stores of adult moose with wolves absent and present in the table above. (You can open your computer's calculator by clicking the CALCULATOR button near the lower right corner of your screen.) Provide a biological explanation for any differences you have observed.

[11] Click the **TEST YOUR UNDERSTANDING** button and answer the question in the pop-up window.

Exercise 3: Changes in the Weather

You have probably heard that scientists are concerned about climate change and the effects of global warming due to increasing atmospheric greenhouse gases. Recent evidence suggests that temperatures around the world are rising. In particular, the average yearly temperature in northern temperate regions is expected to increase significantly. This change will lead to longer, warmer spring and summer seasons in places like Isle Royale. The duration of the growing season for plants will therefore be extended, resulting in more plant food for moose living on the island.

How would a longer growing season affect the moose and wolf populations on Isle Royale? Would they be relatively unaffected? Would the number of moose and wolves both increase indefinitely with higher and higher temperatures, and longer and longer growing seasons?

One way ecologists make predictions about the impacts of global warming is by testing different scenarios using computer models similar to the one you've been using in this lab. Even though simulation models are simplifications of the real world, they can be very useful for investigating how things might change in the future. In this exercise, you will use the Isle Royale simulation to investigate how changes in average yearly temperature due to global warming may affect the plant-moose-wolf system on the island.

[1] Use the **SELECT AN EXERCISE** menu to launch "**Changes in the Weather"**.

[2] Click **STEP 50** to advance the simulation 50 years. You can zoom in to view the action up close. The moose population should level out before the simulation stops.

[3] Activate the **ADD WOLF** button in the **TOOLS** panel. Add about 100 wolves by holding down your mouse button and drawing rectangular patches of wolves. Remember to look at the number at the top of the rectangle to determine how many wolves are added.

[4] Advance the simulation 150 more years by clicking **STEP 50** three times. Watch the action. The simulation should stop at Year 200.

[4.1] **Estimate the average and maximum sizes for moose and wolf populations after the wolves have become established. Record these values below:**

Maximum moose population size: __________________

Maximum wolf population size: __________________

Average moose population size: __________________

Average wolf population size: __________________

[5] In the **PARAMETERS** panel below the **ISLAND VIEW** you will see "Duration of Growing Season" options where you can select different scenarios. The default is **Normal**, which serves as your baseline – this is the option you have been using thus far.

– The **Short** option simulates a decrease in the average annual temperature on Isle Royale. The growing season is shorter than the baseline scenario, which results in annual plant productivity that is about half that of **Normal**.

– The **Long** option simulates a warming scenario in which the growing season begins earlier in the spring and extends later in the autumn. Plant productivity is almost double that of **Normal**.

[5.1] **Predict how moose and wolf population trends will differ with the Short growing season compared to the Normal scenario. Will average population sizes be smaller or larger? Why?**

[6] Without resetting the model, select the '**Short**' growing season option.

[7] Advance the simulation another 100 years by clicking **STEP 50** twice (total time elapsed should be ~300 years).

[7.1] **Estimate the maximum and average sizes for moose and wolf populations after several cycles with a 'Short' growing season. Record these values below:**

Maximum moose population size: __________________

Maximum wolf population size: __________________

Average moose population size: __________________

Average wolf population size: __________________

[7.2] **How do these numbers compare to those you observed with the Normal growing season (Step 4 above)?**

[8] **In the Short growing season, the plant growth is half of what it was before.**

[8.1] **Based on your measurements, how much do you think the moose carrying capacity changed, and why?**

[9] Now it's time to consider the warming scenario.

[9.1] **How do you predict that moose and wolf population trends will differ with a Long growing season, and why?**

[10] Without resetting the model, select the 'Long' growing season option from the **PARAMETERS** panel.

[11] Click **GO** and monitor the graph as the populations cycle. If you watch for a while you should notice something dramatically different about this scenario, in which the plant productivity is high.

[12] Click **STOP** and estimate the maximum and average size for moose and wolf populations under the Long growing season scenario

[12.1] **Record these values below:**

Maximum moose population size: ___________________

Maximum wolf population size: ___________________

Average moose population size: ___________________

Average wolf population size: ___________________

[12.2] **If you watched for a while, you probably saw some species go extinct. If you didn't observe extinctions, you can continue to run the simulation until you see this dramatic phenomenon. Explain why you think extinction is more likely in this scenario than the other two (this is known as the "paradox of enrichment").**

[12.3] **Looking at your results from running the simulation under the normal climate conditions and the two alternative scenarios, were your predictions correct? Provide biological explanations for the trends and differences that you observed. Pay particular attention to how the population cycles changed (e.g., increased, decreased, became less stable) as the rate of plant growth changed.**

[12.4] **[Optional] If you have already talked about global warming and climate change in class, provide another example of how increased yearly temperature can affect an animal or plant population. In particular, think about pests, invasive species, disease, or species of agricultural importance.**

[13] Click the **TEST YOUR UNDERSTANDING** button and answer the question in the pop-up window.

Extension Exercise: What's the Difference?

In Exercise 2 you conducted an experiment comparing health of moose with wolves absent to health of moose with wolves present. You probably observed at least a small difference between the samples, but does that really indicate that moose have greater fat stores when wolves are present? The difference could be related to wolves, but it could also have arisen simply by chance. You might have accidentally selected very healthy moose one time and unhealthy moose the other. How can you know whether the difference in means between two samples is real?

The short answer is that you can't. But you can make a good guess using statistics. In fact, "inferential statistics" were invented to allow us to better uncover the truth and answer these sorts of questions. In this section, you will perform a simple statistical test, called a t-test, to decide whether or not the wolves' presence had a significant effect on moose fat stores. If we were to be very thorough and formal in our t-test lesson, we would include a lengthy discussion of such concepts as random variables, sampling distributions, standard errors, and alpha levels. These are important, but to keep this short, we will just focus on the core ideas underlying the t-test.

You start with a question: Is the mean moose fat stores different when wolves are present versus absent? The **null hypothesis** is a negative answer: there is no real difference. Under the null hypothesis, the difference in your samples arises from chance. The **alternative hypothesis** is that there is an effect of wolves on moose fat stores. In order to know which hypothesis your samples support, we examine the difference in means *relative to the variability* you observed.

[1] Look back at Exercise 2 where you measured the fat stores of adult moose with wolves absent and present, and record those values here. Note that the subscript 'p' represents samples with wolves present, while 'a' represents those with wolves absent.

[1.1] Mean fat stores of adult moose, wolves present ($\bar{x}_p$) : __________

[1.2] Mean fat stores of adult moose, wolves absent ($\bar{x}_a$) : ___________

[1.3] Calculate the difference in mean fat stores ($\bar{x}_p - \bar{x}_a$) : ____________

[2] Look at the following three hypothetical graphs. Each graph shows two distributions of moose fat stores, one with wolves present (lighter gray line) and one with wolves absent (darker line). Note that in each graph, mean moose fat stores are represented by dashed vertical lines, and the ***difference in means is the same for all three***. However, the ***variation*** in fat stores is smaller in the distributions on the left, and larger in those on the right.

[2.1] **Which of the above graphs (A, B, or C) would make the most convincing argument that the difference in fat stores is real, and not just due to chance?**

[2.2] **Explain your choice:**

If there is a lot of variability in the data sets you are comparing, you will more likely see a difference in their means just by chance, supporting the null hypothesis. Only if the difference in means is large compared to the amount of variability in the data do you suppose that the difference might be real. A statistic called *t* formalizes this intuition – in fact, *t* is calculated as a ratio of 'difference in means' to 'amount of variability'. Here is its formula (with the '*p*' and '*a*' subscripts referring to moose energy with wolves **p**resent vs. **a**bsent):

$$t = \frac{\text{difference in means}}{\text{variability in samples}} = \frac{\bar{x}_p - \bar{x}_a}{SE}$$

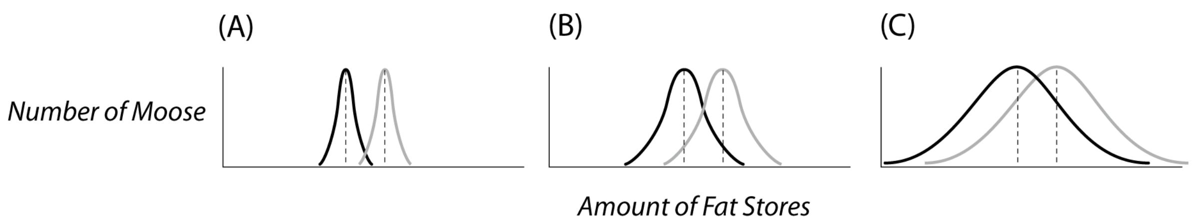
In the formula above, the mean values of the two samples is given by $\bar{x}_p$ and $\bar{x}_a$. The variability of values within the sampled data sets is incorporated into the denominator, where '*SE*' stands for the 'standard error of the sample-mean difference' (a fancy-sounding phrase for a simple concept: **variability**). Calculating this value is straightforward but requires a few steps if you are doing it 'by hand'; the formula is:

$$SE = \sqrt{\frac{\text{var}_p}{n_p} + \frac{\text{var}_a}{n_a}}$$

Here, var_p and var_a are the variances for each sample, a measure of the amount of variability in the values. Finally, n_p and n_a are the number of samples in each data set. If you have never calculated variance before, don't fret – this exercise will walk you through the calculation. Combining the two above equations yields the following formula for *t*:

$$t = \frac{\bar{x}_p - \bar{x}_a}{\sqrt{\frac{\text{var}_p}{n_p} + \frac{\text{var}_a}{n_a}}}$$

[3] Examine the formula for *t*.



[3.1] **Draw a square around the part of the formula for t that compares the means of the two data sets.**

[3.2] **Draw a circle around the part of the formula for t that describes the amount of variability in the data.**

[3.3] **If the means are close together, and the variability is high (so that the difference in means could more easily have arisen by chance), will the value of t be low or high?**

[4] You probably noticed a difference in the health of moose when wolves were present versus when they were absent. To find out whether this difference is large enough to distinguish it from the null hypothesis, you have to calculate the t statistic for your moose fat stores data. Start by estimating the variance in each population (with and without wolves) as follows.

[4.1] Go back to Section 2 and look at your table of adult moose fat stores. Copy the values from that table into the table below, in the column labeled 'Fat Store'. (Do this for both samples — with and without wolves.)

[4.2] Focus first on your samples WITHOUT WOLVES. For each fat store value in that sample, subtract the mean fat store with wolves absent ($\bar{x}_a$ from step [1.2] above), and enter this 'difference from the mean' in the column labeled $x - \bar{x}_a$. Remember you can click the CALCULATOR button near the lower right corner to open your computer's calculator.

[4.3] Square each 'difference from the mean' and enter the squared value in the column labeled $(x - \bar{x}_a)^2$.

[4.4] Sum the squared differences. Enter the 'sum of squares' at the bottom of the table.

WITHOUT WOLVES				WITH WOLVES			
Moose	Fat Store	$x - \bar{x}_a$	$(x - \bar{x}_a)^2$	Moose	Fat Store	$x - \bar{x}_p$	$(x - \bar{x}_p)^2$
1				1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			
Sum of squared differences:				Sum of squared differences:			

[4.5] Divide the sum of squares by the 'sample size' minus 1 (n_a-1). Here, n_a is the number of moose whose fat stores you sampled. (Note that 'sample size' is different than 'population size'.) You will use the estimated variance in the t-test:

var_a = (sum squared differences)$_a$ /(n_a-1) = __________

[4.6] **Repeat the above steps ([4.2] through [4.5]) to calculate the variance for moose fat stores WITH WOLVES present. Remember this time to use the mean fat store with wolves present ($\bar{x}_p$ from step [1.1] above).**

var_p = *(sum squared differences)*$_p$ $/(n_p\text{-}1)$ = __________

[4.7] **Now that you have calculated variances, plug these values into the equation for the 'standard error of the sample-mean difference' to calculate an overall measure of variability in your samples. (And yes, you will divide by the sample sizes again!)**

$$SE = \sqrt{\frac{\mathrm{var}_p}{n_p} + \frac{\mathrm{var}_a}{n_a}} = \_\_\_\_\_\_\_\_\_\_$$

[4.8] **What is the value *t* of the t-test, given the difference in means and the standard error of the sample-mean difference you calculated above?**

$$t = \frac{\bar{x}_p - \bar{x}_a}{SE} = \_\_\_\_\_\_\_\_\_\_\_\_$$

The higher the value of *t*, the more confident you can be that the difference did not result from chance. But how confident are you? A common protocol is to say the difference is significant (that is, meaningful) if the "p-value" is less than 0.05. The "p-value" is simply the probability that the observed difference is due to chance. So, the lower the p-value, the more significant your t-test, because chance is less likely to play a big role in the observed difference.

How do you obtain a p-value? Given the value of *t*, and something called the "degrees of freedom" in your data, you can determine the p-value using a published statistical table, or, better yet, using SimBio Virtual Lab's handy-dandy t-test p-value calculator.

[5] **The number of degrees of freedom in your t-test is equal to the total number of samples (20 in this case) minus 2. That is,** *'degrees of freedom'*$=n_p+n_a-2$**.**

[5.1] **How many degrees of freedom do your moose fat stores data have? __________.**

[5.2] **Launch the t-test p-value calculator by clicking the 't-test' button on the TOOLS panel (very bottom right of your screen). In the dialog that appears, type in your *t* value and the degrees of freedom, and press the CALCULATE button. What is the probability of the null hypothesis being correct (i.e., that the difference was due to chance alone)?**

[5.3] **What can you say about moose fat stores with wolves absent vs. present, after performing the t-test?**

Key Publications

A few researchers have studied the population dynamics of wolves and moose on Isle Royale for a very long time, resulting in an exceptional continuity in research approach and data collection. The research program is currently directed out of Michigan Tech by John Vucetich and Rolf Peterson, both of whom have published extensively on moose-wolf population dynamics. Below are a few references regarding moose and wolves on Isle Royale, the contribution of Isle Royale studies to broader ecological issues, and the scientific and conservation challenges involved.

Peterson, R.O., & Page, R.E.. 1988. **The Rise and Fall of Isle Royale Wolves, 1975-1986**. *Journal of Mammology, 69: 89-99*.

Peterson, R.O. 1995. **The Wolves of Isle Royale: A Broken Balance**. Willow Creek Press, Minocqua, WI.

Vucetich, J.A., R.O. Peterson, & C.L. Schaefer. 2002. **The Effect of Prey and Predator Densities on Wolf Predation**. *Ecology, 83(11): 3003-3013*.

Vucetich, J.A., & R.O. Peterson. 2004. **Long-Term Population and Predation Dynamics of Wolves on Isle Royale**. In: D. Macdonald & C. Sillero-Zubiri (eds.), *Biology and Conservation of Wild Canids,* Oxford University Press, pp. 281-292.

