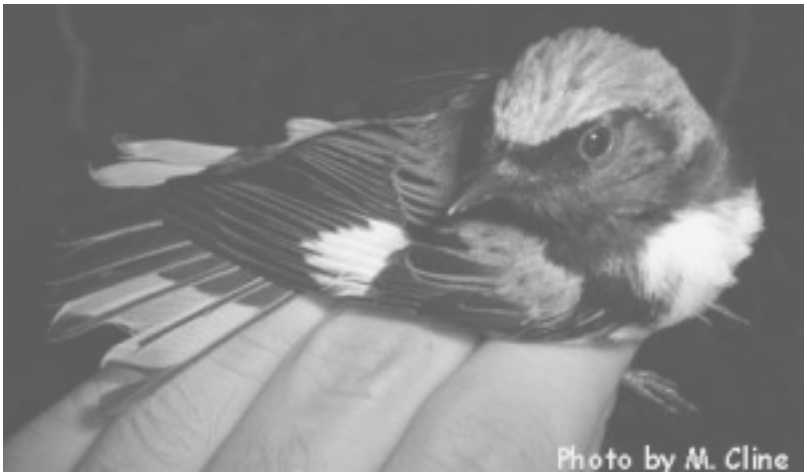
What Limits the Reproductive Success of Migratory Birds?
A Population Ecology Module



Teacher Notes

The population ecology module *What Limits the Reproductive Success of Migratory Birds*? originally appeared entirely in HTML online. Though it worked well for college undergraduate and advanced high school classes, feedback from teachers indicated that the content presented needed to be broken down into smaller chunks, with greater opportunity for students to interact with the information.

Based on this feedback, the revisions we've made are built on effective teaching techniques that emphasize student engagement, student collaboration and activation of higher order thinking skills.

A suggested plan for a progression of lessons is included in this section. Using the content and conceptual framework in the website, these lessons engage high school biology and ecology students in a real-world scientific investigation.

Major topics in the lessons follow the website's format: Background, Biology, Method and Results. Each topic consists of a number of brief essays about the Black-throated Blue Warbler, a migratory bird that summers in eastern North America. The essays also include questions for group discussion and suggestions for brief group presentations to the class. This can be accomplished by individuals in groups being responsible for answering a question and explaining the answer to the rest of the group, by a group of students interacting with the whole class in group presentations, and by higher-order questioning from the teacher. Three additional resources are included: a Student Notes handout, intended to help students take notes during group presentations, and student and teacher rubrics, designed to assess group presentations.

In addition to the essays, optional assessments and assignments are also included. Teachers may select from four assignments and one multiple choice assessment designed to reinforce and further explore these concepts. While one assignment contains standard short answer questions, another asks students to graph and analyze data from Hubbard Brook to explore factors influencing reproductive success, a third allows students to use a model to simulate the effects of various factors on reproductive success, and a final assignment provides for advanced data analysis.

Teacher Preparation:

- Study the Hubbard Brook Research Foundation's website found at: http://hubbardbrookfoundation.org/. Go to "Education and Outreach," "Middle and High School," and click on "Population Ecology Module," listed on right under Classroom Resources.

- Decide on the number of collaborative groups you need for each class period; usually, six groups of four students per group worked well for the teachers who've used this resource. Make copies of the essays so that each student has a copy of his or her assigned essay (usually 4 copies per essay).

- If following the lesson progression suggestions, a class can get through six essays per period. The following is a complete list of the essays:

Background
- 1 Introduction (do not make copies, no group work)
- 2 Why Study Demography
- 3 Predation
- 4 Food
- 5 Density

Warbler Biology
- 1 Study Species
- 2 Breeding Biology

Methods
- 1 Study Site
- 2 Reproduction
- 3 Predators
- 4 Food and Density

Results
- 1 Reproduction Success
- 2 Predation
- 3 Food
- 4 Density
- 5 Yearly Recruitment
- 6 Conservation Implications (do not make copies, no group work)

- Make copies of Student Notes so that each student can write summaries of and provide rubric scores for each group presentation. (Suggestion: Make students responsible for summarizing on the Student Notes page by having them show you the page as they pass out the door at the end of class.)
- Students will need a document reader to show images, graphs or maps during their presentations to the rest of the class. Alternatively, use the PowerPoint™ file called Images_Hubbard Brook that contains photos, maps or graphs used during student presentations.
- Prepare an engaging "hook," a 5 or 10-minute introduction to the module. This begins the learning cycle called the "5-Es", that is, Engage, Explore, Explain, Extend and Evaluation [Bybee, R.W. et al. (1989)]. Suggestions for the hook can be found in any one of the related readings or videos below. (The video of the incredible migration of the Arctic Tern is a good example: http://www.arctictern.info.)
- Decide beforehand the student makeup of the groups. You may want to have one group that has a few of the more capable students in it for the more challenging essays, such as, Background, Essay #2 "Why Study Demography?"

- Decide on criteria for the group presentations to the class; some teachers encourage student buy-in by collaborating on presentation criteria with them. See Developing a Criteria Chart and Rubric for Student Classroom Presentations. Many additional rubrics are available on the Internet.
- The file Multiple Choice provides 10 multiple choice questions that can be used to assess student learning. These questions are meant to be examples and not an attempt to be a comprehensive (summative) assessment of the module. The file Multiple Choice with Explanations contains the same questions, but with extensions for students to explain why they chose the response they did. This provides students with the opportunity to express their understanding of the concept or concepts in the question. An assessment question of this type leads to an understanding of assessment as "*assessment **for** learning*" rather than traditional multiple choice questions which is an "*assessment **of** learning*."

Suggested Lesson Progression: (Each lesson lasts 50 minutes.)

Lesson 1- Introduction

Learning Target:
Students use higher-order thinking skills in a discussion of the ecology of migratory birds.

Hook (10 minutes)
Teacher engages students by providing an interesting story of bird migration, or 10 facts of bird migration, or by asking students what they already know about bird migration.

Introduction to Population Ecology Module (20 minutes)
Teacher uses the essay ***Background***, Essay #1 Introduction
A typical inquiry-based script follows:

T. "Where is New Hampshire?" (U. S. map, image)
T. "Anyone from New England?"
Migratory birds arrive in spring
Many winter in tropics
What are some advantages of birds leaving Tropics and migrating to New Hampshire?
Summer insects abundant in NH
Long daylight – more time to forage for food
Some species of migratory birds have been in decline across N. America
Researchers are trying to figure out why
T. "What could be reasons why the migratory bird population is declining?"
T. Conducts a Think-Pair-Share
In the "Share" portion T. records students' answers on board or projected.
T. "So how do you study bird populations to find out which of these factors are causing the decline?"
T. Conducts a Think-Pair-Share
Conclusion:

T. "This investigation (the next few lessons) will focus on the black-throated blue warbler, (project image from Images Hubbard Brook) that summer, nest, bear and raise young, in NH."

T. "We will be looking at possible answers to the question:

What limits the reproductive success of black-throated blue warblers?"

T. Writes on Board: Background, Biology, Methods, Results
and explains that these are the main topics of the lessons.

Introduction to Student Presentation criteria (10 minutes)

Assignment of Groups for next lessons (10 minutes)

Lesson 2- Background and Biology

Learning Targets:

Students explore and explain background information and the biology of black-throated blue warblers in the Hubbard Brook Experimental Research Forest of New Hampshire.

Groups of students present summaries of their findings to the rest of the class.

Hook (5 minutes)

Group Work – Round 1 (45 minutes)

All students are given a copy of Student Notes sheet.

Groups are given their essay assignments.

If 6 groups of 4 students each: then the essays are: ***Background*** Essay #2 Why Study Demography, Essay #3 Predation, Essay #4 Food, Essay #5 Density; ***Warbler Biology***, Essay #1 Study Species, and Essay #2 Breeding Biology.

Lesson 3-

Learning Targets: Methods and Results

Students explore and explain methods and results of scientific research regarding the Black-throated Blue Warbler in the Hubbard Brook Experimental Forest of New Hampshire.

Groups of students present summaries of their finding to the rest of the class.

Hook (5 minutes)

Group Work – Round 2 (45 minutes)

All students are given copies of Student Notes sheet.

Groups are given their essays.

If 6 groups of 4 students each: then the essays are: ***Methods,*** Essay #1 Study Site, Essay #2 Reproduction, Essay #3 Predators, Essay #4 Food and Density; ***Results***, Essay #1 Reproductive Success, and Essay #2 Predation.

Lesson 4- Results

Learning Targets:

Students explore and explain the results of the research regarding the Black-throated Blue Warbler in the Hubbard Brook Experimental Forest of New Hampshire.

Groups of students present summaries of their finding to the rest of the class.

Hook (5 minutes)

Group Work – Round 3 (25 minutes)

All students are given copies of Student Notes sheet.

Groups are given their essay assignments.

If 6 groups of 4 students each: Since there are only three essays left, have 2 groups work on each essay, and randomly call on one group to give the presentation for each essay: ***Results,*** Essay #3 Food, Essay #4 Density, Essay #5 Yearling Recruitment.

Data Analysis (20 minutes)

T. Project the image of the three graphs found on slide 19 of Images Hubbard Brook.

The data comes from study data found in the **Assignment** Section of the Website.

T. Asks class: "What do you see?" (Gives students opportunity to focus, understand and comment on what they see.)

T. "Let's look at the year 1988 in all three graphs. Do you see a pattern? Can you explain it?"

T. Conducts a Think-Pair-Share (Students should conclude that in 1988 since predation was low, and food was abundant, reproductive success should be high…and indeed it was the highest in the years studied.

Find other years and see if they can spot more patterns, or conflicting patterns.

Lesson 5- Effect of Climate Change on Habitat

Learning Target:

Students extend their understanding of the factors that affect the reproductive success of black-throated blue warblers by applying higher-order thinking skills in a discussion of the prospects of climate change.

Hook (5 minutes)

Conservation Implications and Summary (25 minutes)

Teacher uses the essay ***Results***, Essay #6 Conservation Implications

Suggestions for an inquiry-based discussion:

T. "So far we have seen how certain factors like food, predators, and density affect the reproductive success of black-throated blue warblers."

T. "Another factor, climate, plays an important role in the future success of these migratory birds."

T. "The consensus among scientists is that regions where the black-throated blue warbler makes its summer home will experience warmer summers."

T. "How do warmer summers affect the reproductive success of these birds?"

Project photo of representative high, medium, and low habitats (slide 17 of Images_Hubbard Brook).
Describe how the "high" habitat is the one that provides the best conditions for reproductive success. (See Results, Essay #6 Conservation Implications)
T. "How would a rise in average summer temperature affect the size (area) of the "high" habitat?
T. Conducts a Think-Pair-Share. (Alternatively for "Think" students are given 1 minute to write an answer to the question, then compare their written answers in pairs.)
During the class discussion of the question, T. projects the illustration of the effect of temperature change on high-quality habitat. (slide 18 of Images_Hubbard Brook).

Reflect on Learning (Evaluation) (20 minutes)
T. Poses a question that asks students to reflect on what they learned.
Some suggestions:

- How can what they learned in this module be applied to other species? (Extend)
- What is the significance of climate change to the survival of species, especially endangered species? (Extend)
- Reflect and write about the complexity of an ecosystem ("Would you describe an ecosystem such as the one in which the Black-throated Blue Warblers live as complex? Why?)
- There are more questions available in the Assignment section (see Short Answer Questions).

Alignment with Science Standards

Next Generation Science Standards (released April 2013)
This module aligns well with the LS2 Disciplinary Core Idea, **Ecosystems: Interactions, Energy, and Dynamics**, and especially with the two sub-ideas of

- Interdependent Relationships in Ecosystems
- Ecosystem Dynamics, Functioning, and Resilience

Within the LS2 DCI, "high school students can use mathematical reasoning to demonstrate understanding of fundamental concepts of carrying capacity, factors affecting biodiversity and populations, and the cycling of matter and flow of energy among organisms in an ecosystem. These mathematical models provide support of students' conceptual understanding of systems and their ability to develop design solutions for reducing the impact of human activities on the environment and maintaining biodiversity. Crosscutting concepts of ***systems and system models*** play a central role in students' understanding of science and engineering practices and core ideas of ecosystems."

There are two performance expectations within the LS2 DCI that directly relate to the *Population Ecology Module*:
HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales. [Clarification Statement: Emphasis is on quantitative analysis and comparison of the relationships among interdependent factors including boundaries, resources, climate, and competition. Examples of mathematical comparisons could include graphs, charts, histograms, and population changes gathered from simulations or historical data sets.] [Assessment Boundary: Assessment does not include deriving mathematical equations to make comparisons.]

HS-LS2-6. Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. [Clarification Statement: Examples of changes in ecosystem conditions could include modest biological or physical changes, such as moderate hunting or a seasonal flood; and, extreme changes, such as volcanic eruption or sea level rise.]

Common Core State Standards (2011)
Reading Standards for Literacy in Science and Technical Subjects 6–12
Key Ideas and Details:

2. Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. (Grades 9-10)
2. Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. (Grades 11-12)

Craft and Structure:

5. Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy), viz.* reproductive

success, density. Grades (9-10)

5. Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas. (Grades 11-12)

Integration of Knowledge and Ideas:

7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (Grades 9-10)

7. Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (Grades 11-12)

Related Reading

Population Ecology
http://www.nature.com/scitable/knowledge/library/population-limiting-factors-17059572

Significance of Bird Migrations
http://www.worldmigratorybirdday.org/2012/index.php?option=com_content&view=article&id=18&Itemid=4

Bird Migration Facts
http://birding.about.com/od/birdbehavior/a/15-Fun-Facts-About-Bird-Migration.htm

The Fantastic Voyage of the Sooty Shearwater
http://news.bbc.co.uk/2/hi/science/nature/5242360.stm

Video

Arctic Tern, Encyclopedia of Life Google Earth Tour (6.06 minutes)
http://www.arctictern.info

Arctic to Antarctic
http://www.naturefootage.com/stockfootage/Arctic_Tern

"The Case of the Missing Songbirds"
Global Change Research Information Organization
http://www.gcrio.org/CONSEQUENCES/vol3no1/songbirds.html

"Feathered Clues Give Up Migration Mystery"
Environmental News Service
http://www.ens-newswire.com/ens/feb2002/2002-02-08-06.html

Criteria Chart and Rubrics

Developing a Criteria Chart for Student Classroom Presentations

If you a have not developed criteria charts with your students, you may want to reflect on the suggestions below.

1. **Clarify the purpose of student presentations**. Two days before the first presentation, explain the purpose of a 1 to 2 minute student group presentation on the Population Ecology Module. Students will present the key idea(s) of the section of the Module they have been assigned.
2. **State the two main features of a classroom presentation**: 1) Content 2) Delivery.
3. **Encourage student buy-in**. Create a chart by asking for student suggestions (while you write their suggestions on the board or type them on a projection) as to what makes a quality presentation in terms of content and/or delivery. You may make your own suggestions and write them into the prompts as needed.
4. **Present students with clear expectations**. Summarize and edit the suggestions and present them to the whole class on chart paper visible to all students before the first presentation. Keep the criteria to a small number, for example, 2 or 3 criteria for content and the same for delivery. See examples below of how criteria from a chart can become a rubric.
5. **Plan for student assessment**. If you want students to assess the presentations, have them score each presentation with 4 to 1 for content and 4 to 1 for delivery, and average the two scores. (see *Student Notes and Presentation Assessment* sheet.) Values should be given to the scores, such as: 4 – Excellent, 3 – Good, 2 – Fair, 1- Needs Improvement
6. Students can give you an overall impression of the quality of the presentations. Using and scoring a rubric can keep students engaged in the presentations

Student Rubric For Classroom Presentations of the Population Ecology Module					
	4	3	2	1	Score
Content	Clear Main Idea ……..…No main idea Good Science …….. Science unclear Answered all questions ……Questions unanswered				
Delivery	All participated……..Only one student spoke Talked to audience…….Read from notes Loud enough ……..…….Could not hear				

Criteria Chart and Rubrics

7. You can make up a more thorough rubric for scoring the presentations. This may be too complex for student use.

Teacher Rubric For Classroom Presentations of the Population Ecology Module					
Trait	4	3	2	1	Score
Content					
Main Idea	Group clearly presented main idea(s) of their prompt	Group presented main idea(s) of their prompt with minimal misunderstandings	Group presented main idea(s) of their prompt with some necessary clarification	Group did not present or misrepresented main idea(s)	_____
Scientific Accuracy	Group clearly presented good science	Group presented good science with minimal misunderstandings	Group presented good science with some necessary clarification	Presentation was scientifically inaccurate	_____
Thoroughness	Group clearly answered all the questions in their prompt	Group answered the questions in their prompt with minimal omissions	Group answered the questions in their prompt with several omissions	Group was off topic or did not answer the questions	_____
Delivery					
Collaboration	All group members contributed equally to the presentation	All group members contributed but one or two predominated	Not all group members participated	One group member presented everything	_____
Spontaneity	Group presented with a minimum of notes	Group occasionally spoke directly to the audience	Group seldom spoke directly to the audience	Group read from notes	_____
Attributes	All group members could be easily heard, and were enthusiastic	Audience had to strain to heard at times and/or group members seems to be moderately engaged	Audience had to strain to heard and/or group members seemed to be minimally engaged	Audience could not hear presentation and/or group members seem to be disengaged	_____
Total Score					_____

What Limits the Reproductive Success of Migratory Success of Migratory Birds?

Student Readings

Name _____

What Limits the Reproductive Success of Migratory Birds?

Main Topic:	
1.	Presenter names:
Main Idea	
	Rubric Score
2.	Presenter names:
Main Idea	
	Rubric Score
3.	Presenter names:
Main Idea	
	Rubric Score
4.	Presenter names:
Main Idea	
	Rubric Score
5.	Presenter names:
Main Idea	
	Rubric Score
Today I learned …	

Student Rubric For Classroom Presentations of the Population Ecology Module					
	4	3	2	1	Score
Content	Clear Main Idea ……..No main idea Good Science …….. Science unclear Answered all questions ……Questions unanswered				
Delivery	All participated……..Only one student spoke Talked to audience……Read from notes Loud enough ……..Could not hear				

Teacher Rubric For Classroom Presentations of the Population Ecology Module					
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Attributes	All group members could be easily heard, and were enthusiastic	Audience had to strain to heard at times and/or group members seems to be moderately engaged	Audience had to strain to heard and/or group members seemed to be minimally engaged	Audience could not hear presentation and/or group members seem to be disengaged	_____
Total Score					_____

Introduction

Background essay #1

Each spring, the forests of New Hampshire come alive with the arrival of migratory birds. Many migrate from wintering areas in the tropics to take advantage of the abundant insects and the long summer days of northern areas, which are beneficial when raising young. This annual spring migration to northern regions is a pattern that has repeated itself since the last Ice Age, but it is one that has led to considerable conservation concern in recent years.

Migratory birds have been declining in abundance across North America, and researchers are scrambling to figure out why. Is it because of changes on the breeding grounds? Or changes where the birds winter? Or changes along their migratory pathways? Is it habitat loss, changing weather patterns, or some other factor? One of the ways to get at those questions is to understand what factors in the environment influence how migratory birds survive and how many young they produce.

Male Black-throated Blue Warbler (photo by B. Griffith)

At the Hubbard Brook Experimental Forest in central New Hampshire, researchers have been studying birds since 1969 and have detailed information about the breeding biology of the Black-throated Blue Warbler. We will explore what has been learned over the course of the long-term research on this migratory bird species. Here are some of the questions we will ask:

- How do you study birds?

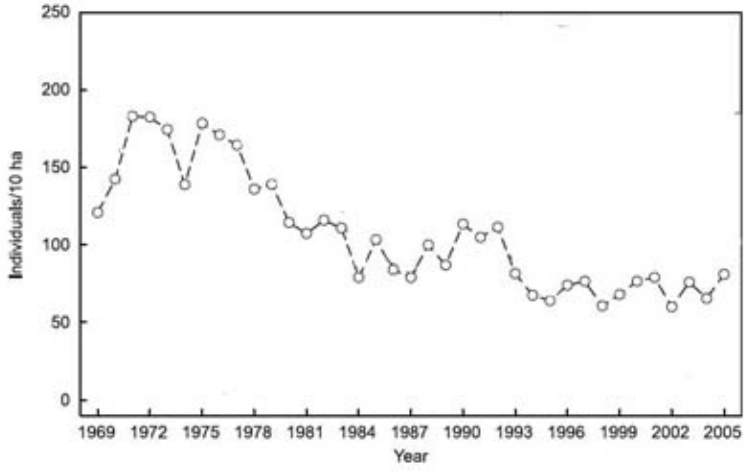
- What factors influence the breeding success of warblers?

- How might changes in climate impact this species?

Demography

Background essay #2

Demography is the study of the birth and death rates of a population. It's used anytime people are interested in the health of a single population or in comparing multiple populations. Medical researchers study human demography to understand how different countries or areas compare in their birth and death rates, and this information is used to make decisions about how to invest money in health care or to predict how quickly the population is growing. Ecologists study the demography of wild populations mainly to answer two questions: 1) is the population growing, shrinking, or staying stable, and 2) why does the population have the trend that it does? To figure out how the number of animals is changing through time, animals are counted. But to answer the second question, and understand why the size of the population is changing, we need to study demography.



Number of migratory birds on a 10 ha plot within the Hubbard Brook Experimental Forest, from 1969 to 2005 (from Holmes 2007 Ibis).

Researchers and wildlife managers want to understand why population sizes change in order to effectively manage them. For example, deer populations have increased in many parts of the country, leading to problems with overgrazing, more car/deer collisions and conflicts with humans. There are a variety of reasons for the population increases including less severe winters, imbalance with natural predators, changes in habitat that makes it easier for deer to get food. Wildlife managers keep track of current deer populations, so they can adjust the numbers of deer taken in a particular area by adjusting the number of deer that can be harvested. This way, they try to maintain deer populations at levels that are appropriate for the habitat to support.

So you can see, a key part of the puzzle is figuring out what factors are causing the population to change in size. A population might be declining if the death rate is too high, if the birth rate is too low, or both. Figuring out which of these is going on is an important first step to designing a management and recovery plan. However, sometimes it's difficult for researchers to tease

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

apart all the environmental factors that can positively or negatively affect a population. It can be especially hard with migratory birds, which often fly thousands of miles between where they breed in the summer and where they spend the winter. To make matters even harder, many birds die during migration, and it's hard to tell if these deaths are due to bad weather, not enough food, predation or other factors.

Yet, despite all these difficulties, scientists are learning a lot about how migratory bird populations are limited. Most studies have focused on what affects the number of offspring migratory birds raise during the breeding season, which scientists call their reproductive success. These studies have found that the abundance of predators that eat their eggs and young, the amount of food in the environment, and the number, or density, of a bird species breeding in a particular area are some of the most important ecological factors that may limit a population. In this module, we'll explore how each of these affects the reproductive success of Black-throated Blue Warblers.

Background essay #2: Demography

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.)

1. What does a biological demographer study?
2. What are two questions that wildlife demographers are trying to answer?
3. How is **reproductive success** an effective measure of demography?
4. What factors affect the reproductive success of Black-throated Blue Warblers?
5. (For the group) What does the graph measure? Note: 10 hectares (ha) is a measure of area, about the same area as the length of 3 football fields (including the end zones) on each side.

What would be important to tell the class about **Demography** in a **3-minute presentation**? (Include the graph in your presentation. Place the graph on the document reader or your teacher will have a projector slide of the graph.)

Predation

Background essay #3

Black-throated Blue Warbler nest with four eggs (photo by S. Sillett).

The nests of songbirds are vulnerable to predators because nestlings cannot run or fly until they are just about to leave the nest, and even their parents can't prevent most predators from eating their eggs and nestlings. Common nest predators for small songbirds include bigger birds like jays and hawks, small mammals like squirrels, chipmunks, and mice, and reptiles like snakes. Birds build their nests in many different types of places, from the ground to the treetops, but no nest site is completely safe from the many species of mammals, snakes, and birds that feast on protein-rich eggs and nestlings. Nest predators are the dominant cause of nest failure for songbirds, and so the types and abundance of nest predators can have a huge effect on how successful birds are in raising their young.

The numbers of nest predators can vary a lot over time and between different locations, so differences in nest success between years or between different habitats can be due to differences in the number or types of nest predators. For example, squirrel populations change between years depending on how many acorns and other seeds the trees produced the year before. So, even though small birds don't eat acorns, the number of acorns can actually end up having a huge effect on their reproductive success! The way humans affect natural landscapes is also having a big effect on nest predator communities. Roads and development lead to habitat fragmentation, which is the breaking up of large pieces of habitat into smaller pieces. Studies have shown that habitat fragmentation can lead to higher numbers and different species of nest predators, causing higher nest predation rates. Differences in nest predation rates between habitats can also occur naturally, without any human impacts, simply if the types or number of predators is different, or if the predators have more or less other food to eat.

To see a video of a predation event in action, go to http://hubbardbrookfoundation.org/migratory_birds/Pages/Background/Video.html .

Background essay #3: Predation

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.

1. What animals prey on the eggs of Black-throated Blue Warblers?

2. Warblers don't eat acorns. Yet the abundance of acorns can have a huge effect on the reproductive success of the Warblers. How is this so?

3. How do humans have an effect on the abundance of nest predators?

4. View the video of hawk predation.

What would be important to tell the class about **Predation** in a **2-minute presentation**? (Include the video in your presentation if you can.)

Food

Background essay #4

Black-throated Blue Warbler nest with 3 nestlings (photo by N. Desnoyers).

Breeding birds have a lot of mouths to feed, and successfully raising their young depends on being able to find enough food. All songbirds feed their nestlings insects. Insects are full of protein that a growing bird needs. Insect availability can affect the number of young that survive, as nestlings can starve when food is limited. Also, the weight of the nestlings when they leave the nest can have an important effect on their future survival. In some species, heavier nestlings have been found to be more likely to survive and reproduce. Yet the effects of food can also be much less obvious. For example, the strategies of parents can differ depending on how much food is available. Birds can change the number of eggs they lay in each nest depending on how much food they have or expect to have (scientists are still working to figure out what environmental cues birds use to estimate how much food they will have several weeks later).

When predators eat eggs or nestlings, the adult birds often start the nest over by building a new nest and laying new eggs. Migratory birds can re-nest after predation several times, depending on when in the breeding season their first nest fails and how much more time they have before they have to leave on migration. Field researchers think that food availability is one of the most important factors affecting how many nests a bird will build in a season. After all, the females needs to be well fed to lay her eggs as they are full of protein and fat and each nestling has to be fed hundreds or even thousands of insects before it will be big enough and old enough to be independent.

Background essay #4: Food

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.)

1. How are insects an important part of the diet of nestlings (young birds)? How many insects will a typical nestling eat?

2. How does the number of insects available affect the ability of nestlings to survive? How is the time between feeding trips of the parent birds affected by the abundance or scarcity of insects?

3. Do birds always lay the same number of eggs in a nest? If they don't, what is one factor that seems to control the number of eggs in a nest?

4. Warblers can build several nests in a season. How does the abundance of food affect the number of nests a pair of Warblers builds in a season?

What would be important to tell the class about **Food** in a **2-minute presentation**?

Density

Background essay #5

Young Black-throated Blue Warbler that just left its nest (photo by M. Cline).

One of the oldest questions in ecology is: Why don't population sizes keep on increasing? For example, if an average pair of American Robins can raise four young each year and each bird can breed for three years, then every two birds would produce twelve in their lifetimes! If those reproductive rates continued, pretty soon the world would be teeming with robins. Yet scientists have recognized that those demographic rates don't continue, and either life spans get shorter or reproductive rates get lower when population sizes are very large. Populations have been observed to grow quickly when numbers are low and conditions are good, but population growth then slows once there are so many individuals that conditions for each individual become worse. This process is called density-dependence, and it is thought to be a very important process in regulating - or controlling - the size of natural populations. Density dependence stabilizes a population at its carrying capacity, which is the population size that can be stable over time.

Population density is the number of individuals in a given area, so the term density-dependence refers to the fact that the demographic rates vary in relation to density. When density is low, and the population is below its carrying capacity, each individual has plenty of the resources—food, water, nest sites—it needs. Individuals in these good conditions can survive longer and/or breed more successfully, so the population grows. Yet once the population is large, more individuals have to compete for the same amount of resources, so the average share for each one is lower. This leads to lower survival or reproductive success, so the population can stabilize at the carrying capacity. Finally, when there are more individuals than the environment can support, death rates will be high or reproduction will be unsuccessful, causing the population to decline back to the carrying capacity.

Background essay #5: Density

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.

1. What is biological density, and give some examples.

2. How is the size of the warbler population dependent on density?

3. What is 'carrying capacity'?

4. How does a stable population at the carrying capacity benefit the birds' reproductive success?

What would be important to tell the class about **Density** in a **2-minute presentation**?

Essay #2, Why Study Demography?

1. What does a biological demographer study?
A biological demographer studies a population is growing, shrinking or staying stable and determines why the population has the trend it does.

2. What are two questions that wildlife demographers are trying to answer? *Two questions that wildlife demographers are trying to answer are what is the population of a given species, and what factors in the environment might affect this population?*

3. What is **reproductive success**? *Reproductive success tells us how many birds are raised during the breeding season so it gives us an idea of how many young that are born and might survive to become adults.*

4. What factors affect the reproductive success of Black-throated Blue Warblers? *The factors that affect the reproductive success of Black-throated Blue Warblers include the abundance of predators, amount of food and the density of the bird species.*

5. (For the group) What does the graph measure? Note: 10 ha is a measure of area, about the same area as the length of 3 football fields (including the end zones) on each side.
This graph shows the number of birds on a ten acre plot at Hubbard Brook from 1969-2005.

What would be important to tell the entire class about **Demography** in a 3-minute presentation?

- *Demography is the study of populations and whether they are growing, shrinking or staying stable and why.*
- *Wildlife managers and researchers study populations to learn how many animals of a particular species there are and what are the environmental factors that affect them.*
- *The graph shows a population over time, but does not tell us why there is fluctuation.*

Essay #3, Predation

1. What animals prey on the eggs of songbirds? *Animals that prey on songbird eggs include small mammals like squirrels, birds like jays, crows and hawks, and reptiles like snakes.*

2. Warblers don't eat acorns. Yet the abundance of acorns can have a huge effect on the reproductive success of warblers. How is this so? *If there are lots of acorns, then there may be more squirrels that would eat more warbler eggs.*

3. How do humans have an effect on the abundance of nest predators? *Humans have an effect on the number of nest predators when we fragment habitat by building houses and roads. When habitat is fragmented, the numbers and types of nest predators increase, leading to greater numbers of eggs being eaten.*

What would be important to tell the class about **Predation** in a 2-minute presentation?

- *There are many kinds of predators on birds.*
- *When predator abundance is greater, reproductive success is lower.*
- *Smaller birds can not defend their nests against most predators.*
- *Humans have an effect on predator abundance through habitat fragmentation.*

Essay #4, Food

1. How are insects an important part of the diet of songbird nestlings (young birds)? How many insects will a typical nestling eat? *Insects are high in protein and help the birds to grow. A nestling may eat thousands of insects while in the nest.*

2. How does the number of insects available affect the ability of nestlings to survive? How is the time parents spend on feeding trips affected by the abundance or scarcity of insects? *The number of insects affects the weight of the nestling, if it is larger when it leaves the nest it is more likely to survive. If insects are abundant, the parent birds don't need to be away from the nest as long, looking for food.*

3. Do birds always lay the same number of eggs in a nest? If they don't, what is one factor that seems to control the number of eggs in a nest? *The number of eggs a bird lays in a nest is not always the same. One of the factors that may control the number of eggs is the abundance of food.*

4. Warblers can build several nests in a season. How does the abundance of food affect the number of nests a pair of warblers builds in a season? *If food is abundant a pair of warblers may nest several times.*

What would be important to tell the class about **Food** in a 2-minute presentation?

- *Food is important to the survival of young.*
- *Food abundance effects how often nestlings are fed and how much energy is expended by the adults when gathering food.*
- *Food abundance can have an effect on the number of eggs laid and whether a pair of warblers has more than one nest.*

Essay #5, Density

1. What is population density? *The number of individuals in a given area.*

2. How is the size of the warbler population dependent on density? *When the population size is low and below carrying capacity each individual has plenty of resources, food, water, and nest sites. If conditions are good, the adults are likely to live longer and have more young. When the population becomes high, the resources are limited and life span may be reduced and reproductive success lower.*

3. What is 'carrying capacity'? *Carrying capacity is the population size that can be stable over time (in a specific area).*

4. What happens to a population that is over its carrying capacity? *Death rates will be higher and reproductive success will be lower when a population is over carrying capacity.*

What would be important to tell the class about **Density** in a 2-minute presentation?

- *Density dependence is a important process in regulating or controlling the size of natural populations.*
- *Density can help stabilize a population at carrying capacity.*
- *When density is too high and carrying capacity is exceeded, death rates are higher and reproductive success is lower.*

Study Site

Warbler Biology essay #1

To learn more about how the environment affects the reproductive success of migratory birds, researchers have been studying black-throated blue warblers (*Dendroica caerulescens*) breeding at the Hubbard Brook Experimental Forest in New Hampshire. These birds are long-distance migrants, splitting the year between breeding grounds in the U.S. and Canada and wintering grounds in and around the Caribbean. Each spring, they fly north to breed in the forests of the northeastern U.S. and southeastern Canada and along higher elevation areas in the Appalachian Mountains. Across their breeding range they favor deciduous and mixed deciduous-coniferous forests, where they build their nests in the shrubby understory.

Map of the breeding (blue) and wintering (orange) ranges of the black-throated blue Warbler (from Birds of North America, http://bna.birds.cornell.edu/bna/).

These warblers are an excellent species to study because it is fairly easy to watch their behavior, find their nests, and monitor their breeding success. Also, their populations are not declining (luckily, this species tolerates some logging and other disturbances in its breeding and wintering habitat). Yet the factors that affect the reproductive success of black-throated blue warblers are likely to apply to many other species whose populations are smaller and harder to observe. In fact, research on this species has already taught scientists a lot about how populations are limited and regulated, and how migratory birds might respond to climate change.

Warbler Biology essay #1: Study Site

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.

1. Where does this study of the black-throated blue warbler take place?
2. From where and to where do these birds migrate? When in the forests of North America, where do they prefer to live?
3. What makes the black-throated blue warbler an excellent species to study?

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

4. How can the study of black-throated blue warblers be used to understand environmental pressures on species that are in decline?

_____

What would be important to tell the class about **Study Species** in a **2-minute presentation**? (Include the map in your presentation. Place the map on the document reader or your teacher will have a projector slide of the image.)

Breeding Biology

Warbler Biology essay #2

Female sitting on a nest to incubate her eggs (photo by N. Kovacs).

At the start of the breeding season, males arrive and establish territories, which are areas they defend by singing and by chasing out other males. Each warbler territory is a patch of forest that is used for foraging and nesting—birds get all the food they need from within their territories, and prevent other individuals of their species from feeding or nesting within that area of habitat. As in many migratory birds, females arrive a few days or a week after males have arrived and established territories, and each female pairs with a male for the breeding season. Like many birds, black-throated blue warblers often return to the same territory year after year, where they may pair with their previous mate or with a new partner. The female isn't as brightly colored as the male, and looks so different that early naturalists thought the two sexes were different species!

Females build the nests, lay eggs (usually 4), and incubate them without help from the males. They have a special section of their belly, called a brood patch, which has no feathers and lots of blood vessels. When they sit on their eggs, they place the brood patch on them so that their warm skin keeps the eggs nice and toasty.

Male feeding a young bird that just left its nest (photo by M. Cline).

It takes about 12 days for the eggs to hatch, and the nestlings emerge unable to do much more than swallow their food. At this point the male helps care for the young; both parents feed them continuously through the long days of summer, and in just nine days they grow to adult size. Once birds leave the nest they are called fledglings, and are able to hop about and fly short distances. The parents continue to feed them for about two more weeks, at which point they are able to find enough food on their own.

Typically, each warbler pair has multiple nesting attempts during the course of the breeding season. Some nests are lost to predators, and when that happens, the birds will quickly build another nest and start the process anew. Even when they are able to raise young successfully, they sometimes try a second time when enough food is available to them. In this case the male will continue to feed the young from their first nest, and the female will build a new nest, lay eggs, and incubate once again. This phenomenon is called double brooding and has the potential to greatly increase the number of young a pair can raise in a year, but the success of this strategy is limited by the abundance of nest predators (since two nests need to survive through the nesting cycle) and food availability (since enough food must be available late in the season for birds to feed another nest full of nestlings).

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Warbler Biology essay #2: Breeding Biology

Questions for Group Discussion

Each person in the group is assigned a question and is responsible for answering and explaining the answer to the rest of the group.

1. Describe the behavior of a pair of black-throated blue warblers during breeding season.

2. How does a female black-throated blue warbler care for the eggs she lays?

3. Describe the time line of a young bird's life from the time it is hatched to the time it is a fledgling.

4. What is double brooding, and what are its advantages and limitations?

What would be important to tell the class about **Breeding Biology** in a **2-minute presentation**?

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Answer Key

Warbler Biology essays

Essay #1, Warbler Biology

1. Where does this study of the black-throated blue warbler take place?
This study takes place at Hubbard Brook Experimental Forest in New Hampshire.

2. From where and to where do these birds migrate? When in the forests of North America, where do they prefer to live?
The birds migrate from the Caribbean wintering grounds to the breeding grounds in northeastern United States and southeastern Canada. They favor deciduous and mixed deciduous-coniferous forests, where they build their nests in the shrubby understory.

3. What makes the black-throated blue warbler an excellent species to study? *The black-throated blue warblers are an excellent species to study as it is fairly easy to watch their behavior, find their nests and monitor their reproductive success.*

4. How can the study of black-throated blue warblers be used to understand environmental pressures on species that are in decline? *The factors that affect the black-throated blue warbler are likely to apply to many other species that are harder to observe.*

What would be important to tell the class about **Study Species** in a 2-minute presentation?

- *Black-throated blue warbler populations are somewhat stable.*
- *This species is fairly easy to observe and monitor.*
- *It is more tolerant to disturbance than other species.*
- *The factors that affect this species of bird are likely to apply to many other migratory species.*

Essay #2, Breeding Biology

1. Describe the behavior of a pair of black-throated blue warblers during breeding season.
The males generally arrive on the breeding grounds first and set up and defend a territory keeping other males out. When the females come they are attracted to the males and after courtship they build a nest and lay the eggs.

2. How does a female black-throated blue warbler care for the eggs she lays? *She has a brood patch on her belly which is full of blood vessels, and she places this part of her body over the eggs to keep them warm.*

3. Describe the time line of a young bird's life from the time it is hatched to the time it is a fledgling.
This is a time when it is called nestling and both parents take care for it and feed it continually throughout the long summer day. Nestlings go from having no feathers to having feathers.

4. What is double brooding, and what are its advantages and limitations? *Double brooding is when the female re-nests while the male continues to feed the young from the first nest. The advantages are that it can greatly increase a pair's reproductive success however it is limited by nest predation and food availability.*

What would be important to tell the class about **Breeding Biology** in a 2-minute presentation?

- *The breeding biology of the black-throated blue warbler affects it reproductive success.*
- *Understanding how long it takes for the eggs to hatch and the nestling to become fledglings is important to determine how many times the adults can re-nest. The breeding biology also explains the roles of the males and females in the process.*

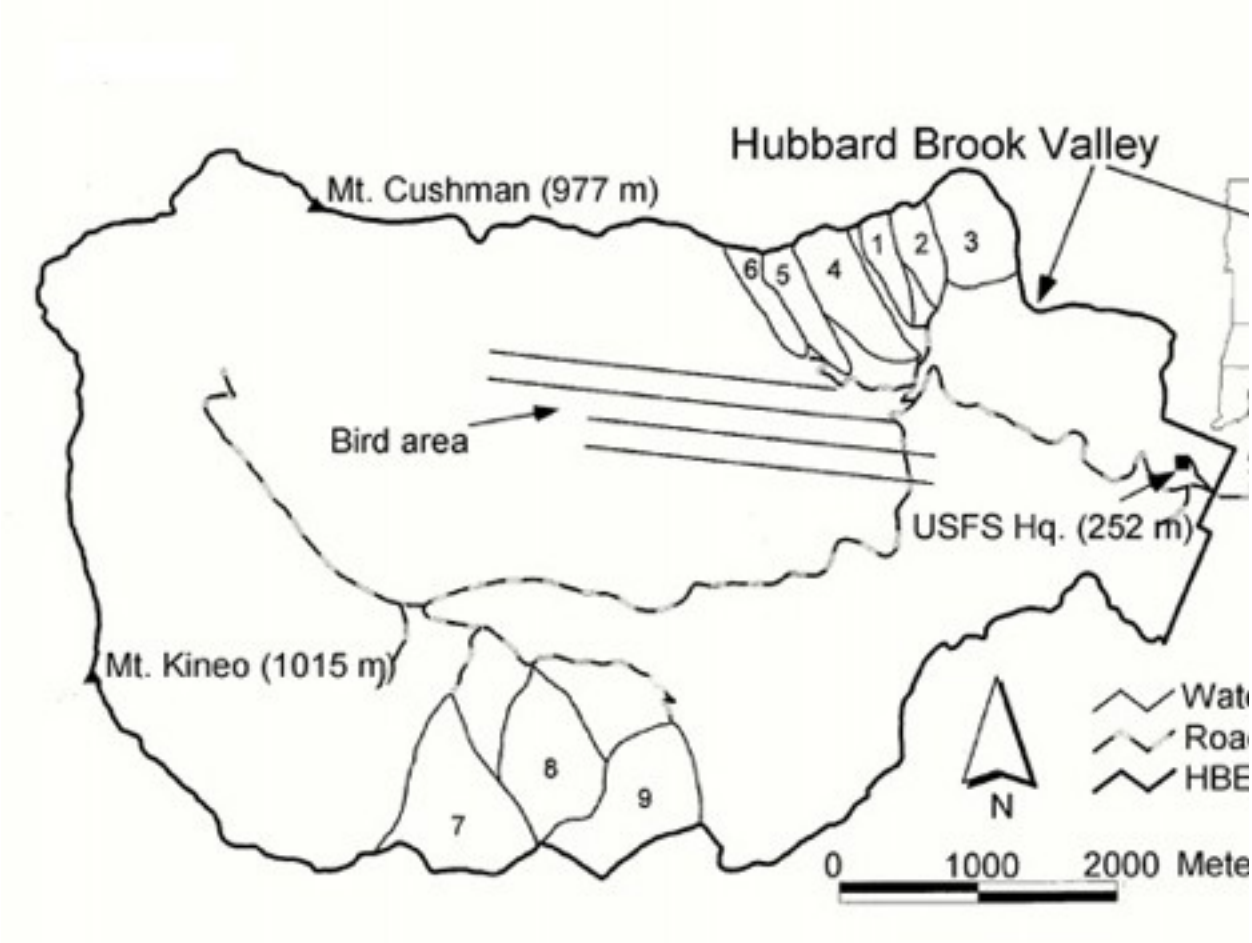
Study Site

Methods essay #1

Hubbard Brook Experimental Forest (photo provided by the Hubbard Brook Research Foundation).

This study was conducted within the Hubbard Brook Experimental Forest, a 3,160 hectare (about 7,800 acres) reserve within the White Mountains of New Hampshire. Hubbard Brook is known throughout the scientific community for being part of a network of LTER (Long-Term Ecological Research) sites, which are funded by the National Science Foundation to conduct research on ecological processes across broad spatial scales and over long periods of time. The collective efforts of hundreds of researchers have generated a tremendous amount of long-term data on the hydrology of the region, the cycling of important nutrients like nitrogen and carbon, the impacts of disturbance events (e.g. ice storms), the causes and consequences of fluctuations in plant and animal populations, and many other facets of the ecosystem at Hubbard Brook. The research that has been conducted on black-throated blue warblers has contributed to, and benefited from, the collective knowledge of ecological processes at the site.

The "bird research area" is just over a mile past Mirror Lake and the building that houses the Hubbard Brook Headquarters (see map below). In 1969, Dr. Richard Holmes of Dartmouth College established a 10 ha (almost as big as 19 football fields) study plot in that area and began monitoring the bird community, going back each year to count all of the birds on the plot. That is, he counted every individual of every species! After getting some information on the community as a whole, he and his colleagues decided to focus more intently on the population ecology of one species - the black-throated blue warbler. The 10 ha study plot was expanded to 64 ha (about the size of 120 football fields), and since 1986 all of the black-throated blue warblers on the plot have been monitored to measure the average number of young each pair produced each year in relation to the environmental factors that affect warbler nesting success (predator abundance, food availability, density).



Map of the Hubbard Brook Experimental Forest, showing its location within New Hampshire (see inset) as well as the location of the "bird area" within the reserve boundaries (note dashed lines; map created by R. Holmes).

Methods essay #1: Study Site

Questions for Group Discussion

Your group is to prepare a **2-minute presentation** of the **Study Site.**
You can work in pairs to prepare your presentation. Each pair could consider one of the topics below:

- What is the Hubbard Brook Experimental Forest, and what scientific work is being done there?
- Give a brief history of the black-throated blue warbler study site.

During the presentation, place the map of the Hubbard Brook Experimental Forest on the document reader or your teacher will have a projector slide of the map.

Reproduction

Methods essay #2

Each year, a team of field workers arrive at Hubbard Brook in early May and await the spring arrival of migratory birds. They survey the study area daily, listening carefully for the characteristic song of the black-throated blue warbler (listen yourself:). Males arrive first, and when they do their territory locations are mapped (see photo). They are then monitored on a daily basis to detect females (males follow around their females to guard them, making it easy to figure out whether a male is paired with a female or not).

One of the many grid flags that are used to map territory boundaries and nest locations within the bird plot at Hubbard Brook (photo by S. Sillett). This particular one is "J-1.5", meaning it is along the J line in between the 1 and 2 lines (lettered lines run perpendicular to numbered ones). Flags occur every 25 m along these lines.

The arrival of females is always an exciting time, because at that point the warblers are monitored even more intently in order to find nests. Females can be sneaky during the nest-building phase, by being quiet or moving through dense vegetation where it is hard to track them. But, over the years researchers at Hubbard Brook have figured out the best nest finding strategies. First, they find the female, either by watching the male, looking for movement in the understory, or by listening for "chip" notes that are produced by the female. Then, they watch to see if she picks up spider webs, birch bark, dead grass or any other material that could be used to build a nest. If she does, then the researcher will try to follow the female back to her nest, all the while being as quiet as possible so as not to disturb her. Of course, sometimes it takes a few tries before the nest is found.

Four nestlings packed into a Black-throated Blue Warbler nest (photo by N. Desnoyers).

Once a nest is located, a flag is placed on a nearby tree and the nest is visited every few days to determine when the female starts to lay eggs, how many eggs she lays, and if the nest gets predated or survives. When the nestlings are 6 days old, they are briefly removed from the nest to place bands on their legs, to measure and weigh them, and to collect a small blood sample. Each band is a small aluminum ring with a unique number that can be used to identify the bird if it gets caught again. A few days after banding, the nests are visited again to determine if the nestlings were successful in leaving the nest - a process called "fledging." This information forms

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the basis of figuring out the birds' reproductive success, which we define here as the average number of young produced (i.e. that "fledge") per warbler pair in a given year.

Methods essay #2: Reproduction

Questions for Group Discussion

Your group is to prepare a **2-minute presentation** on the topic: **Reproduction.**
You can work in pairs to prepare your presentation. Each pair could consider one of the topics below:

- How do researchers determine which birds belong to which nest?
- How is 'reproductive success' defined here? How do the researchers keep track of the fledglings?

During the presentation, place the photo of the nest flagging and nestlings on the document reader or your teacher will have a projector slide of the photo.

Predators

Methods essay #3

While monitoring the reproductive activities of black-throated blue warblers, the researchers also collect data on predator abundance, food availability, and warbler density. For instance, throughout the breeding season predator surveys are conducted in the core area of warbler territories, often near nests. Researchers stand at particular points and spend 5 minutes continuously watching for potential nest predators, noting their location on a data sheet. At Hubbard Brook, the most common nest predators seem to be chipmunks and red squirrels, although there are other predators like jays and hawks that warbler parents also have to contend with. All of these are noted in the surveys, and the data are ultimately used to determine the abundance of different kinds of predators within a warbler's territory, as well as across the study area as a whole.

A Red Squirrel, one of the major predators of Black-throated Blue Warbler nests at Hubbard Brook (photo by S. Lemelin).

Methods essay #3: Predators

Questions for Group Discussion

Your group is to prepare a **2-minute presentation** on the topic: **Predators.**
You can work in pairs to prepare your presentation. Each pair could consider one of the topics below:

- What are the most common nest predators on black-throated blue warblers?
- How are predator surveys conducted?

During the presentation, place the photo of the nestlings on the document reader or your teacher will have a projector slide of the photo.

Food and Density

Methods essay #4

Food

A caterpillar found on vegetation during one of the surveys for warbler food items (photo by S. Sillett).

Researchers also conduct insect surveys to determine the amount of food available to warblers during the breeding season. Black-throated blue warblers primarily forage by gleaning insects off leaves. They have a particular preference for moth and butterfly larvae (also known as caterpillars), energy-rich food items that they eat themselves and also feed to their young. Every two weeks, researchers examine a few hundred leaves on a variety of plant species throughout the study area, carefully looking for and counting the number of caterpillars they see. Those data are then used to determine the relative abundance of caterpillars, both across space and through time.

Density

The final piece of data required for the purposes of this module is warbler density. In order to determine the number of black-throated blue warblers within the study area, the researchers have to mark each individual so that the same one isn't counted twice. A standard protocol in bird studies is to capture birds in mist-nets (see photo) and to place a numbered aluminum and several colored plastic bands on their legs in a unique combination. The bands are of negligible weight and do not impede the birds' movements. They are essential for the purposes of this study because by looking at them through a pair of binoculars and noting what band combination they have - for instance, red-aluminum-white-blue or black-aluminum-blue-black, individual birds can be identified. Usually, males are caught early in the season when they are defending their territories, luring them into a net by playing a recording of another male's song. Females don't respond to playback as readily, so they are usually caught later in the season while they are getting on or off their nest. In the end, the total number of individually-marked birds within the study area is used as a measure of warbler density.

A male Black-throated Blue Warbler caught in a mist-net after responding to a tape recording of another male's song (photo by M. Cline). Shortly thereafter, the bird was safely removed from the net, given leg bands, weighed and measured, and released unharmed.

Methods essay #4: Food and Density

Questions for Group Discussion

Your group is to prepare a **2-minute presentation** on the topics: **Food and Density**
You can work in pairs to prepare your presentation. Each pair could consider one of the topics below:

- How do researchers determine the amount of food available for the birds?
- How are the birds caught and how do researchers tell the difference between birds?

During the presentation, place the photo of the caterpillar and the netted bird on the document reader or your teacher will have a projector slide of the photos.

Answer Key

Methods essays

Essay #1, Study Site

Your group is to prepare a 2-minute presentation of the **Study Site.** Consider the topics below:

1. What is the Hubbard Brook Experimental Forest and what scientific work is being done there?

The Hubbard Brook Experimental is a long term ecological research site within the White Mountains of New Hampshire. The collective efforts of hundreds of researchers have generated a tremendous amount of long-term data on the hydrology of the region, the cycling of important nutrients like nitrogen and carbon, the impacts of disturbance events (e.g. ice storms), the causes and consequences of fluctuations in plant and animal populations, and many other facets of the ecosystem at Hubbard Brook

2. Give a brief history of the black-throated blue warbler study site.

The "bird research area" is just over a mile past Mirror Lake). The 10 ha (almost as big as 19 football fields) study plot was first set up in 1969 and all bird species within the area were counted. Researchers decided to focus on black-throated blue warblers. The 10 ha study plot was expanded to 64 ha (about the size of 120 football fields), in 1986 all of the black-throated blue warblers on the plot have been monitored to measure the average number of young each pair produced each year in relation to the environmental factors that affect warbler nesting success (predator abundance, food availability, density).

Essay #2, Reproduction

Your group is to prepare a 2-minute presentation on the topic: **Reproduction.** Consider the topics below:

1. How do researchers determine which birds belong to which nest?

The researches follow the males to help them locate the females and the nest and these are mapped. Six days after the eggs hatch, researchers band the nestling with a unique band.

2. How is 'reproductive success' defined here? How do the researchers keep track of the fledglings?

Reproductive success is the average number of young produced (i.e. that "fledge") per warbler pair in a given year. Because the birds are banded they can be identified.

Essay #3, Predators

Your group is to prepare a 2-minute presentation on the topic: **Predators.** Consider the topics below:

1. What are the most common nest predators on black-throated blue warblers?
The most common nest predators on black-throated blue warblers are chipmunks and red squirrels.

2. How are predator surveys conducted?
Researchers stand at particular points and spend 5 minutes continuously watching for potential nest predators, noting their location on a data sheet

Essay #4, Food and Density

Your group is to prepare a 2-minute presentation on the topics: **Food and Density.** Consider the topics below:

1. How do researchers determine the amount of food available for the birds?
Every two weeks, researchers examine a few hundred leaves on a variety of plant species throughout the study area, carefully looking for and counting the number of caterpillars they see.

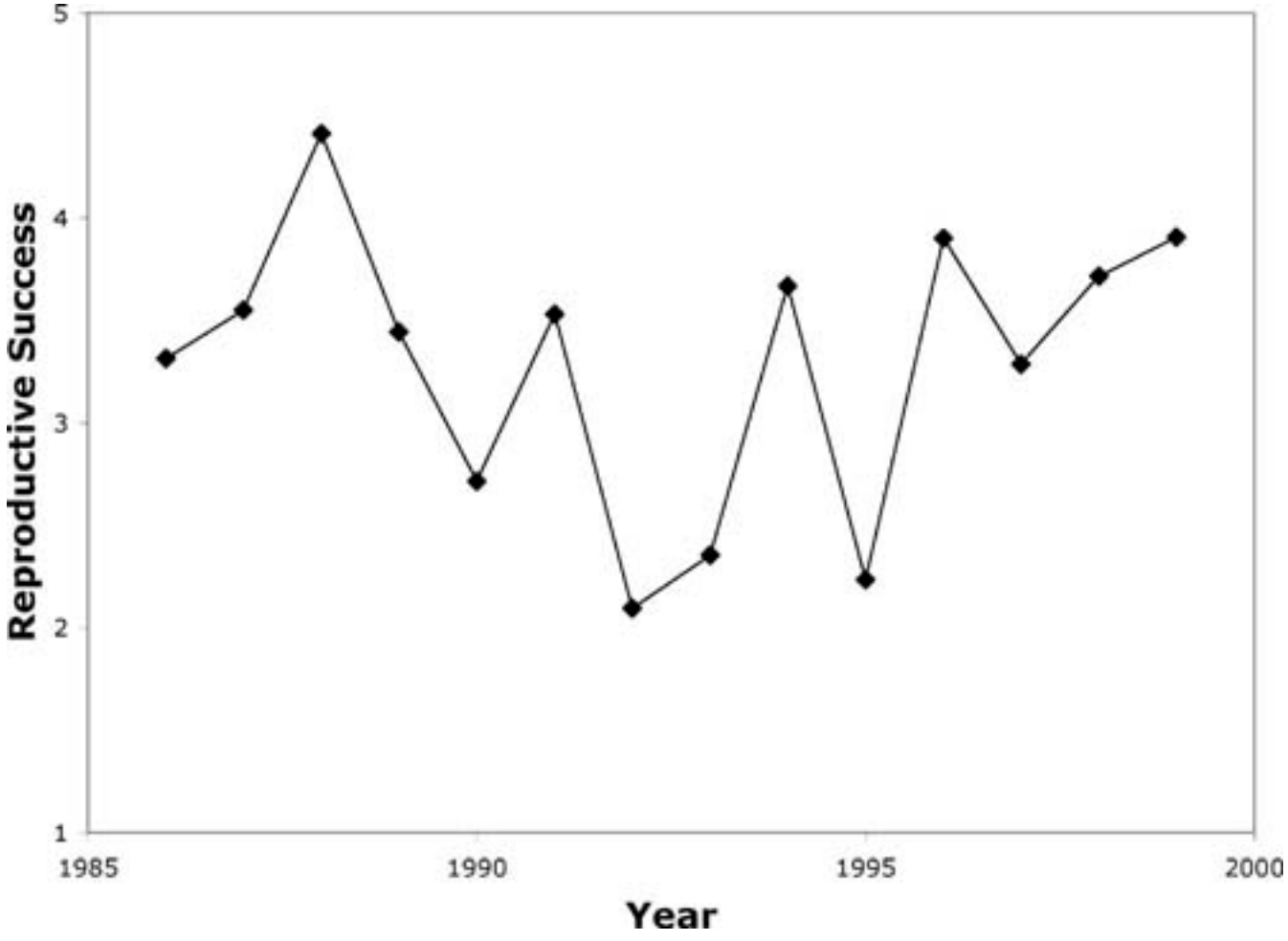
2. How are the birds caught and how do researchers tell the difference between birds?
Birds are caught in mist nets. Each bird has a numbered aluminum and several colored plastic bands on their legs in a unique combination.

Reproductive Success

Results essay #1

So what did the researchers find? Well, first of all they found that the average pair of warblers was able to raise just over 3 offspring over the course of a typical breeding season. The level of reproductive success varied widely between years. In some years more than 4 offspring were produced, and in other years reproductive success was as low as 2 offspring per pair.

Researchers then wanted to know why reproductive success, the number of young raised per pair, varied so much between years. Was it nest predation? Differences in food availability? Was it density? Fortunately, the long-term data that have been collected on all of those variables gave the researchers an opportunity to answer that question. And as it turns out, all three - predation, food, and density - play an important role in limiting the reproductive success of black-throated blue warblers at Hubbard Brook.



Reproductive success (number of young produced per pair per year) on the main study plot at Hubbard Brook from 1986 to 1999 (data from Holmes, Rodenhouse, and Sillett).

Results essay #1: Reproductive Success

Questions for Group Discussion

Use the graph to help you answer the questions below to determine if the reproductive success has changed from 1985 until 2000.

1. What do you think may have caused the reproductive success to be so low in 1992, or so high in 1988?

2. Can we tell what caused the changes or these extremes from this chart? Why or why not?

3. What can you conclude about the reproductive success over the 15-year span of this study?

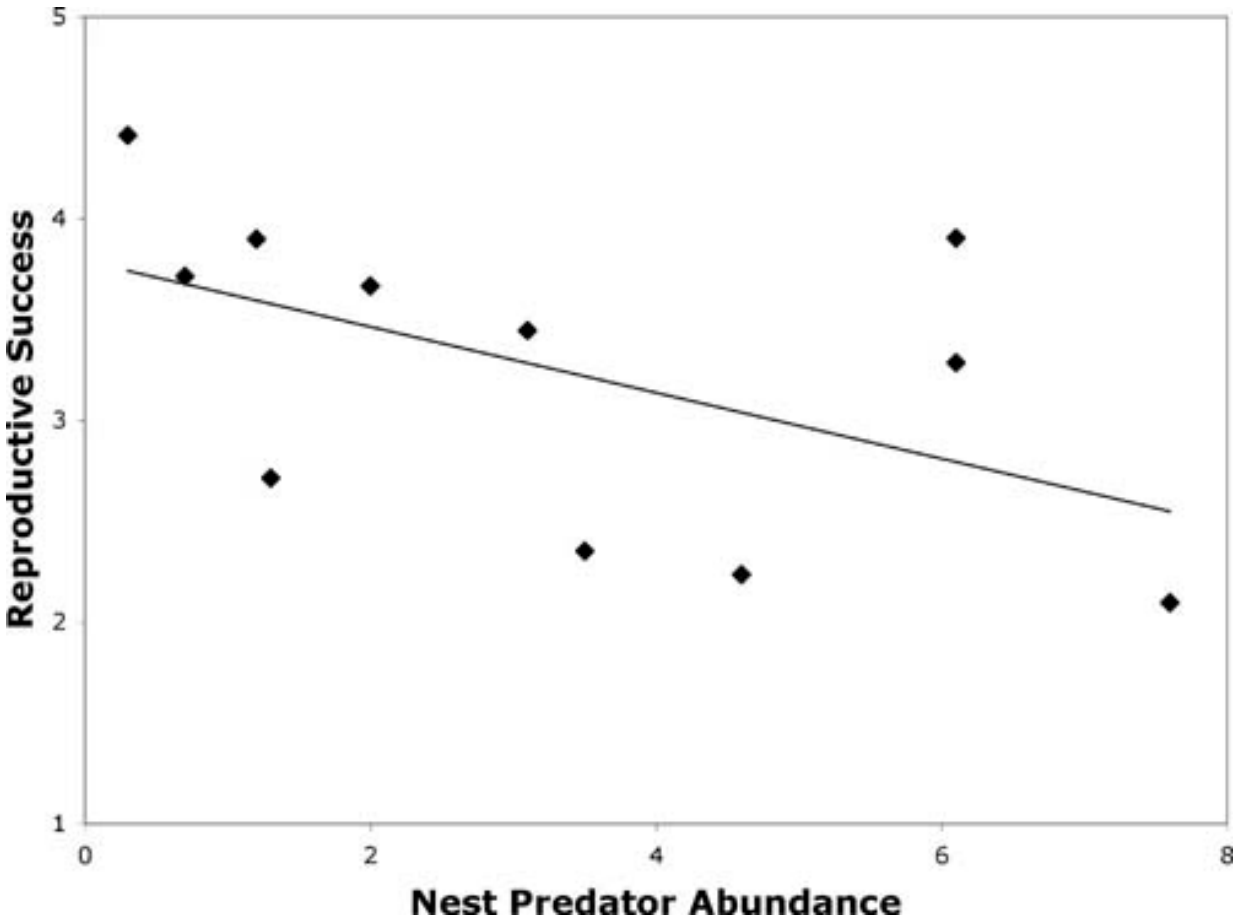
4. Did the reproductive success increase, decrease or stay about the same? Does this mean that the environmental factors of food, predation, and density just about balance out for the black-throated blue warbler in the Study Area?

Present this chart to your classmates (either on the document reader or a projected image from your teacher). Ask your classmates the questions above or similar ones.

Predation

Results essay #2

Squirrels and chipmunks are the major predators of black-throated blue warbler eggs and nestlings. When researchers looked at the relationship between the numbers of these mammals and the warblers' reproductive success in different years, they found that the birds had lower success in years when these predators were more common.
In this figure, each year is plotted as a point, and the line shows the average effect of predator abundance on nest success.



Reproductive success (number of young produced per pair per year) in relation to the abundance of chipmunks and red squirrels (number detected per survey hour) on the main study plot at Hubbard Brook from 1988 to 1999 (predator data were not available for 1986, 1987, and 1991; data from Holmes, Rodenhouse, and Sillett).

Results essay #2: Predation

Questions for Group Discussion

Read about the data researchers gathered that compares the number of predators to the reproductive success of the black-throated warbler in the Study Area. Discuss the graph and see if you can determine the relationship between the number of predators and the reproductive success of the birds.

Can you make a claim about the relationship between predators and reproductive success? (Hint: As the number of predators increases, the _____ .)

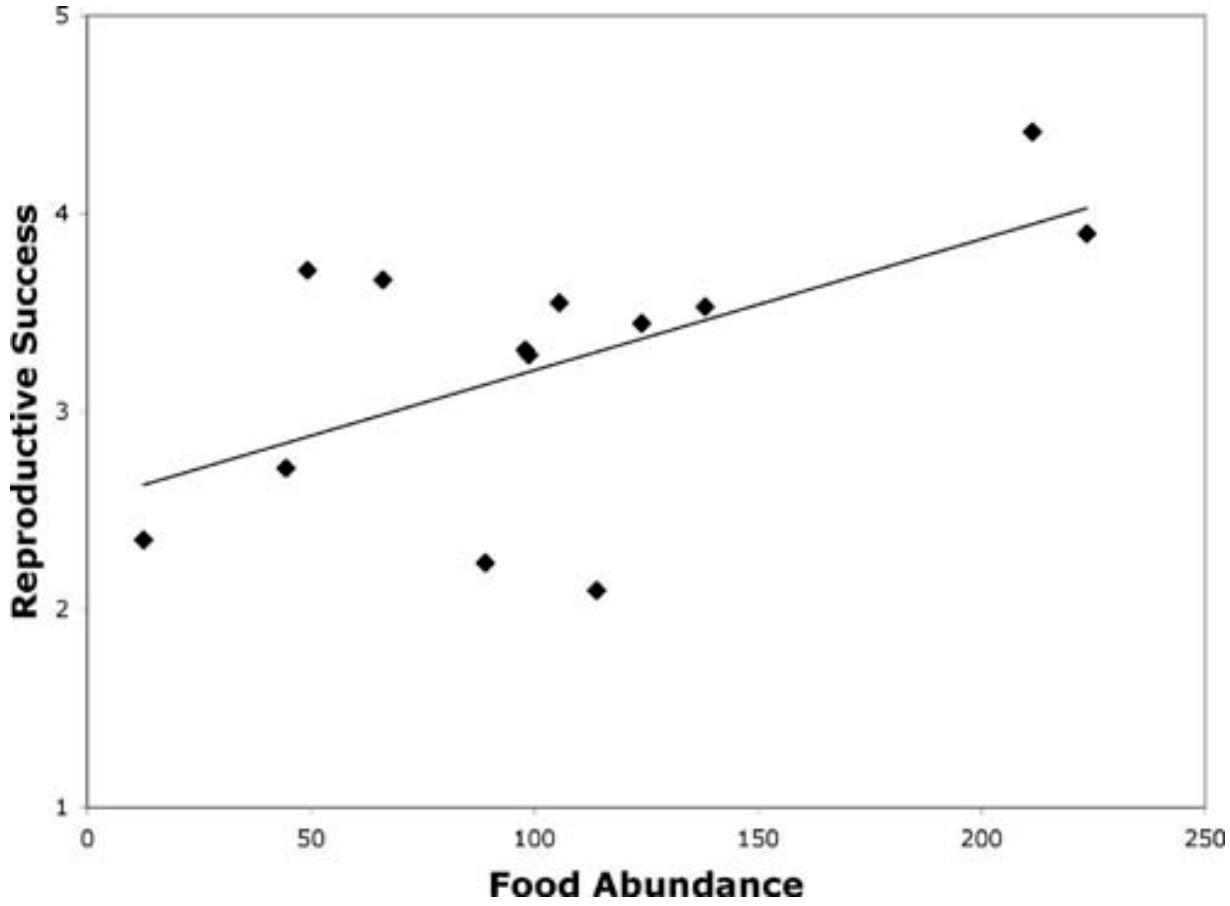
Present this chart to your classmates (either on the document reader or a projected image from your teacher). Ask your classmates to look at the graph and make conclusions like you did in your group.

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Food

Results essay #3

As researchers predicted, in years when caterpillars were more numerous, the birds were able to raise more young. How did this work? It turns out that it's not because nestlings starve in years with fewer caterpillars, but instead birds adjust the number of nests they build to the food availability. In really good years, birds even start over once their nestlings have left the nest! So it's possible to raise two groups of nestlings in a single breeding season, but the number of birds that try to do this is greater when there is more food.



Reproductive success (number of young produced per pair per year) in relation to the availability of caterpillars (mg per 100 leaves) on the main study plot at Hubbard Brook from 1986 to 1998 (food data were not available for 1999; data from Holmes, Rodenhouse, and Sillett).

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Results essay #3: Food

Questions for Group Discussion

Read about the data researchers gathered that compares the amount of food to the reproductive success of the black-throated warbler in the Study Area. Discuss the graph and see if you can determine the relationship between the amount of food and the reproductive success of the birds.

1. Explain why it is not correct to say that in years that food is scarce, there are fewer fledglings that survive because they starve to death. What is a better explanation about the relationship between the abundance of food and reproductive success of the Black-throated Blue Warblers?

2. If you look at the amount of food and how it affects reproductive success can you make a claim about the relationship between food and reproductive success of the birds?
(Hint: As the amount of food increases, the _____ .)

Present this chart to your classmates (either on the document reader or a projected image from your teacher). Ask your classmates to look at the graph and make conclusions like you did in your group.

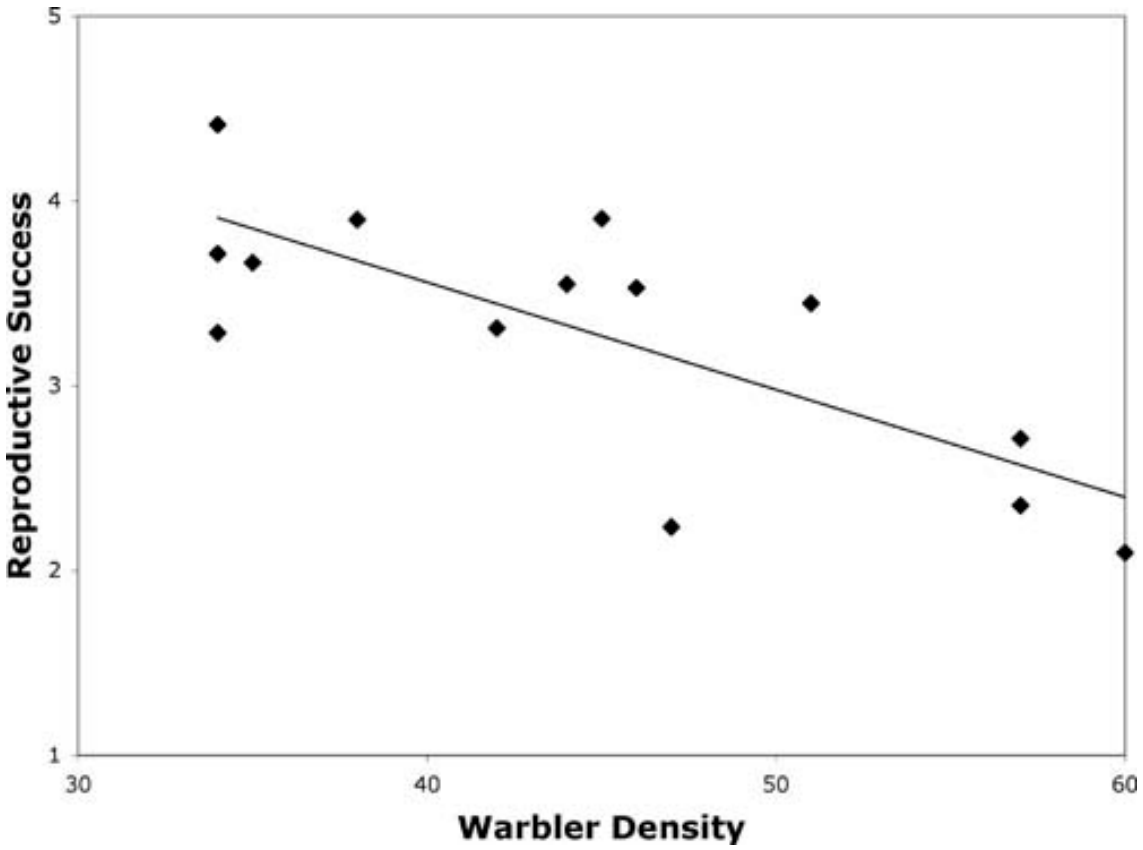
Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Density

Results essay #4

One of the most exciting results to come out of the long-term research on black-throated blue warblers at Hubbard Brook was the strong relationship between density and reproductive success. As the number of birds in the study area increased, the average number of young raised decreased from a high of approximately four to a low of about two, so the average reproductive success was lower at higher densities.

Researchers discovered that high densities of warblers had two effects on the population. First, warblers were packed more tightly into the best habitat, so that territories became smaller and the success of all the birds was lower. Second, when the population was large, birds also set up territories and bred in habitat that they didn't breed in when the population was smaller. This habitat isn't quite as productive, since birds breeding there had even worse success than those packed into the better habitat. Through these two pathways, the reproductive success of the whole population was lower when the population is large.



Reproductive success (number of young produced per pair per year) in relation to the density of Black-throated Blue Warblers (individuals per 64 ha) on the main study plot at Hubbard Brook from 1986 to 1999 (data from Holmes, Rodenhouse, and Sillett).

Results essay #4: Density

Questions for Group Discussion

Read about the data researchers gathered that compares the density of birds to the reproductive success of the black-throated warbler in the Study Area. Discuss the graph and see if you can determine the relationship between density and the reproductive success of the birds.

1. What two effects did a high density of warblers have on the reproductive success of the birds? Explain these effects in your own words.

2. If you look at the density of birds and how it affects reproductive success can you make a claim about the relationship between density and reproductive success of the birds?
(Hint: As the density of birds increases, the _____ .)
_____

Present this chart to your classmates (either on the document reader or a projected image from your teacher). Ask your classmates to look at the graph and make conclusions like you did in your group.

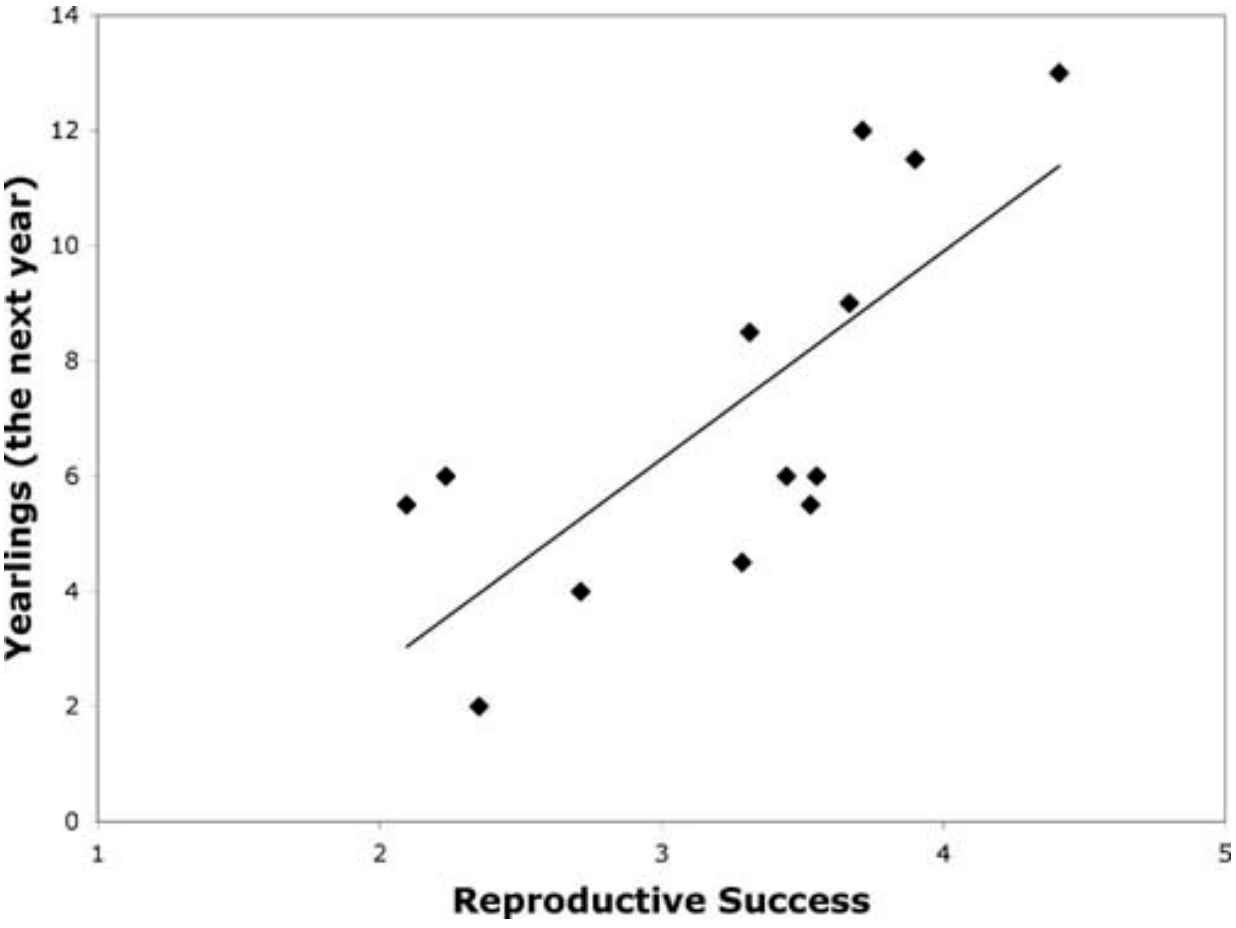
Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Yearling Recruitment

Results essay #5

So far we've shown that predators, food and density are all factors that influence the reproductive success of black-throated blue warblers at Hubbard Brook. But does that really make a difference to the total population size? Researchers testing this question found out that it does. Reproductive success during the breeding season in one year determines the number of yearlings – or first time parents - on the study plot the following year. This indicates that factors during the breeding season, particularly those that lower reproductive success, play an important role in determining the size of the warbler population.

Of course, environmental factors during the migratory and wintering periods are also important (in fact, they play a huge role in limiting survival of adults). However, this research does emphasize that changes in the environment affect the reproductive success and population size of black-throated blue warblers.



The number of yearlings - or first time breeders - on the 64 ha study plot at Hubbard Brook in relation to the reproductive success of warbler pairs the previous year (yearling data were not available for 1999; data from Holmes, Rodenhouse, and Sillett).

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Results essay #5: Yearling Recruitment

Questions for Group Discussion

Read about the data researchers gathered that compares the reproductive success one year to the number of one-year old black-throated blue warblers (yearlings) the next year in the Study Area. Discuss the graph and see if you can determine the relationship between the reproductive success one year and number of yearlings the next year.

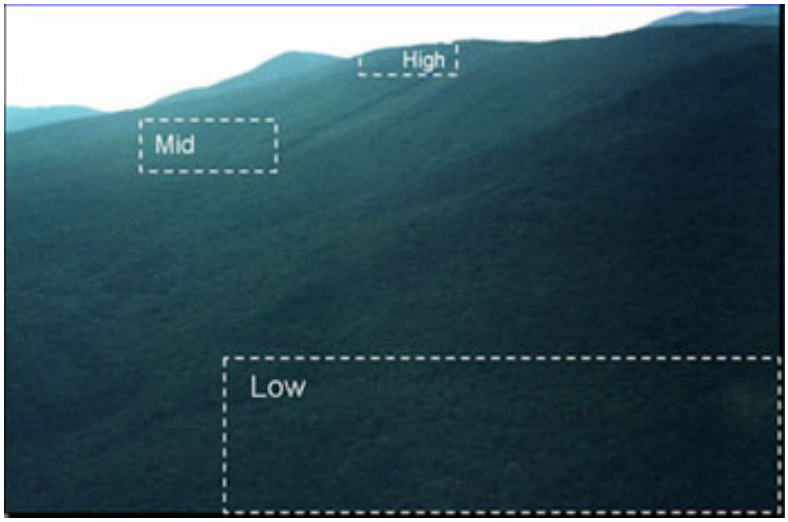
1. Discuss and explain what the graph means in your own words.
2. If you look at the number of yearlings and how it affects reproductive success the next year can you make a claim about the relationship between yearlings and reproductive success of the birds?
(Hint: As the number of yearlings increases one year, the _____ .)
_____

Present this chart to your classmates (either on the document reader or a projected image from your teacher). Ask your classmates to look at the graph and make conclusions like you did in your group.

Conservation Implications

Results essay #6

Collecting data from the same place year after year is clearly useful for figuring out how ecological processes are related to one another - for instance, the number of caterpillars and the reproductive success of warblers. It is also useful for making predictions about how changes in the environment may impact different species.



Representative high, mid and low elevation habitats within the Hubbard Brook Experimental Forest (photo by N. Rodenhouse).

In New Hampshire, scientists are predicting changes in climate that will likely influence the amount, location, and quality of habitat available for black-throated blue warblers. Currently the best habitat is at higher elevations, where food is abundant and the number of nest predators is low. The large number of young produced in those locations is important at a regional level because dispersal to lower elevation sites helps to maintain those populations, some of which don't produce enough young on their own to balance the number of adults that die each year (called "sink habitats").

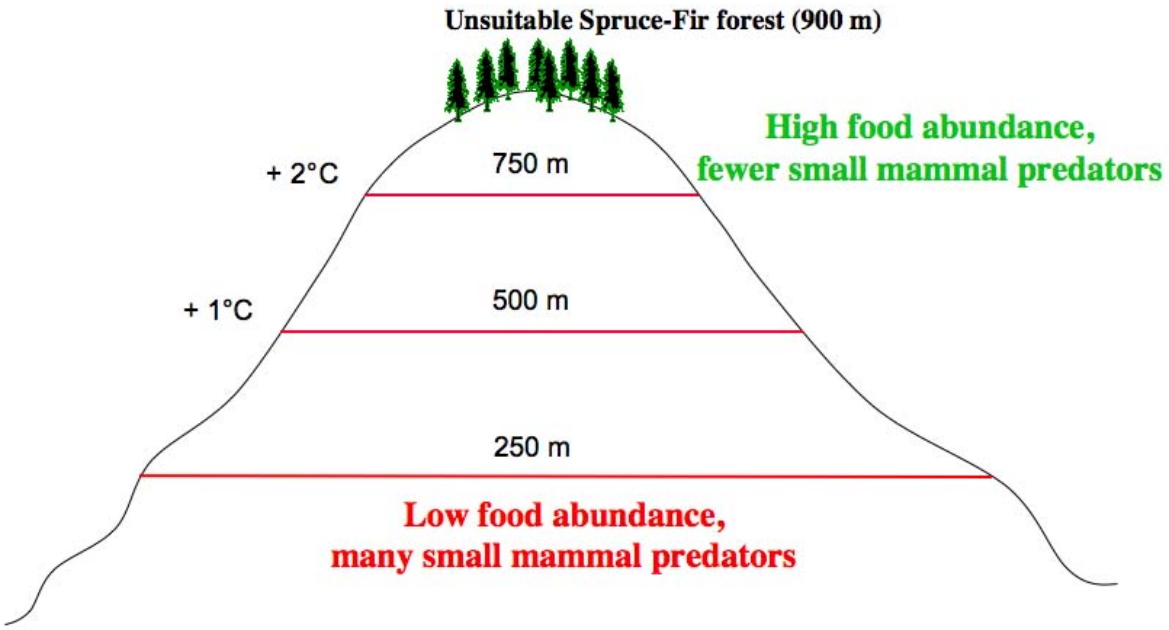
Higher temperatures in the years to come are expected to alter the elevational distribution of the forest community at Hubbard Brook, pushing habitats of lower quality further up the mountains. What this means is that high-elevation habitats, currently the most productive sites for black-throated blue warblers, will essentially disappear because there is no land at even higher elevations for them to expand into. Even the habitats of moderate quality will become less common because the further up the mountains you go, the less land you have to work with.

The key question then becomes:

Can Black-throated Blue Warblers maintain a stable population size over the long-term given these potential changes to their environment?

Current thinking says no, at least not at the current population size. Decreases in habitat quality, and especially the loss of the best habitat, are expected to reduce the reproductive success of black-throated blue warblers and thus the number of young birds that survive to become breeders themselves. That is the prediction, based on our current knowledge of how the environment affects the reproductive success of these birds.

Only time will tell whether this prediction holds true and the black-throated blue warbler population does decline. Fortunately, researchers at Hubbard Brook continue to monitor warblers across a range of elevation zones, and measure key environmental variables like food, predation, and climate, so they should quickly detect any changes that occur. So, the long-term data collected at Hubbard Brook have not only been essential to understanding factors that limit the reproductive success of black-throated blue warblers, but will also serve as a valuable "baseline" when monitoring the potential for future impacts of climate change.



The current distribution of low-quality habitat (low food, high predators) and high-quality habitat (high food, low predators) at different elevation zones within the Hubbard Brook Valley, as well as the projected movement of low-quality habitat (red line) with a 1°C and 2°C increase in annual temperature (image by N. Rodenhouse).

Answer Key

Results essays

Essay #1, Reproductive Success

1. What do you think may have caused the reproductive success to be so low in 1992, or so high in 1988?
Reproductive success may have been affected by food availability or predation.

2. Can we tell what caused the changes or these extremes from this chart? Why or why not?
We can not tell what caused the changes from looking at this chart as it only shows reproductive success over the time span.

3. What can you conclude about the reproductive success over the 15-year span of this study?
We can conclude that there was variability from year to year.

4. Did the reproductive success increase, decrease or stay about the same? Does this mean that the environmental factors of food, predation, and density just about balance out for the black-throated blue warbler in the Study Area?
Reproductive success fluctuated on the study area, some years it was high and the next year it might be low. We can not say anything about why because the information is not presented on the graph.

Essay #2, Predation

Can you make a claim about the relationship between predators and reproductive success?
(Hint: As the number of predators increases, the *reproductive success of the black throated blue warbler decreases.*)

Essay #3, Food Abundance

1. Explain why it is not correct to say that in years that food is scarce, there are fewer fledglings that survive because they starve to death. What is a better explanation about the relationship between the abundance of food and reproductive success of the black-throated blue warblers?
In years when food is less available, the number of eggs laid by the warbler are fewer, which means that even if all hatched birds survive, there will still be fewer fledglings.

2. If you look at the amount of food and how it affects reproductive success can you make a claim about the relationship between food and reproductive success of the birds?
(Hint: As the amount of food increases*, the reproductive success increases.)*

Essay #4, Density

1. What two effects did a high density of warblers have on the reproductive success of the birds? Explain these effects in your own words.

One effect is that there are more warblers in the best habitat and their territories become smaller and so the success of all birds is lower. Secondly, some warblers nest in places where the habitat isn't as good and their reproductive success is also smaller.

2. If you look at the density of birds and how it affects reproductive success can you make a claim about the relationship between density and reproductive success of the birds?

(Hint: As the density of birds increases*, the reproductive success decreases.)*

Essay #5, Yearling Recruitment

1. Discuss and explain what the graph means in your own words*.*

Reproductive success during the breeding season in one year determines the number of yearlings – or first time parents - on the study plot the following year. The greater number of yearlings the greater the reproductive success.

2. If you look at the number of yearlings and how it affects reproductive success the next year can you make a claim about the relationship between yearlings and reproductive success of the birds?

(Hint: As the number of yearlings increases one year*, the reproductive success increases*.)

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

Assignments and Assessments

The following assessments were created to be used with the module *What Limits the Reproductive Success of Migratory Birds?*

High school classes
Short Answer Questions
Answer key for Short Answer Questions
Graphing Long-Term Data
Answer key for Graphing Long-Term Data
Population Simulation Model
Answer key for Population Simulation Model
Multiple Choice & Short Answer Summative Assessment
Answer key for Multiple Choice & Short Answer Summative Assessment
Undergraduate classes
Warbler Data Analysis
Answer key for Warbler Data Analysis

Short Answer Questions

Name _____

1. Give an example of a demographic rate.

2. What can wildlife biologists learn by studying the demography of wild populations?

3. Researchers catch Black-throated Blue Warblers by playing a recording of another male's song and luring them into a mist-net. Why do you think males will fly to the sound of a different male's song in their breeding territory?

4. List some ecological factors that might limit the size of a population of birds.

5. By studying Black-throated Blue Warblers, scientists hope to learn more about how environmental conditions affect the reproductive success of migratory birds.

   a) In your own words, define reproductive success.

   b) In years when the population of squirrels and chipmunks was larger, did birds have higher or lower reproductive success? Why?

   c) How did increasing the number of caterpillars change the reproductive success of these warblers?

   d) Why does population growth slow at higher densities? What is the name for this phenomenon?

6. How might climate change impact Black-throated Blue Warblers in New Hampshire? Will it increase or decrease the amount of high-quality habitat for this species? Why?

Short Answer Questions
Answer Key

1. Give an example of a demographic rate.

   Birth (reproductive success) or death (or survival) rates

2. What can wildlife biologists learn by studying the demography of wild populations?

   Measuring demographic parameters like reproductive success and survival is important for understanding why populations are increasing or decreasing. When environmental variables are also measured, scientists can understand how ecological factors affect demographic rates and predict how a population will respond to environmental changes.

3. Researchers catch Black-throated Blue Warblers by playing a recording of another male's song and luring them into a mist-net. Why do you think males will fly to the sound of a different male's song in their breeding territory?

   Males defend their territories from other males, to prevent intruders from eating the food in their territory, or trying to mate with the female in their territory.

4. List some ecological factors that might limit the size of a population of birds.

   Limiting factors that affect the population size of a certain species of bird could include food availability, habitat availability, size of predator populations, and the degree to which individuals affect the success of their neighbors (the strength of density dependence).

5. By studying Black-throated Blue Warblers, scientists hope to learn more about how environmental conditions affect the reproductive success of migratory birds.

   a) In your own words, define reproductive success.

   Reproductive success is the number of offspring raised by a pair in a certain breeding season. Average reproductive success is the mean number of offspring raised by all pairs in a season.

   b) In years when the population of squirrels and chipmunks was larger, did birds have higher or lower reproductive success? Why?

   When chipmunk or squirrel populations were larger, warbler reproductive success was lower because these rodents eat eggs and young songbirds.

   c) How did increasing the number of caterpillars change the reproductive success of these warblers?

   Increasing the number of caterpillars increased reproductive success, since the caterpillars are an important food source.

   d) Why does population growth slow at higher densities? What is the name for this phenomenon?

   This phenomenon is called density-dependence. Populations can grow quickly when population size is low and conditions are good, but population growth slows once there are so many individuals that there is competition over food and other resources. Competition reduces the amount of resources each individual can get, leading to lower survival and lower reproductive success.

6. How might climate change impact Black-throated Blue Warblers in New Hampshire? Will it increase or decrease the amount of high-quality habitat for this species? Why?

   Climate change is predicted to have a negative impact on songbird populations in New Hampshire. The best habitat for songbirds is at high elevations, where there are few nest predators and high food availability. However, a warmer climate will "push" vegetation upslope, [ie: the climate that was once found at 820 feet (250 meters) might now be found at 1640 feet (500 meters)], and this 'new' climate will not be as favorable to songbirds (more predators and less food). As the climate changes the most favorable habitat will be lost (essentially "pushed" off the top of the mountains) and even the less favorable habitat could become less common because the further up the mountains you go, the less land you have to work with.

Name _____

Graphing Long-Term Data

Access the Excel data file Warbler_data.xls.

1. In the module's study of how food abundance affects reproductive success:

   a) What is the independent variable?

   b) What is the dependent variable?

   c) Should food abundance or reproductive success be graphed on the Y axis?

2. Create a graph of reproductive success vs. food abundance, which includes only data from 1994-1998. (Instructions are provided if needed.) When you are done, there should be five data points on the graph, one for each year. **Do not print out graph**.

What does the graph look like? Is there a clear relationship between the amount of food and the birds' reproductive success in these years?

3. Next, you will make and interpret two more graphs of reproductive success vs. food abundance, similar to the graph in the previous question, but using data from different years. **Place all graphs on same spreadsheet, but do not print out.**

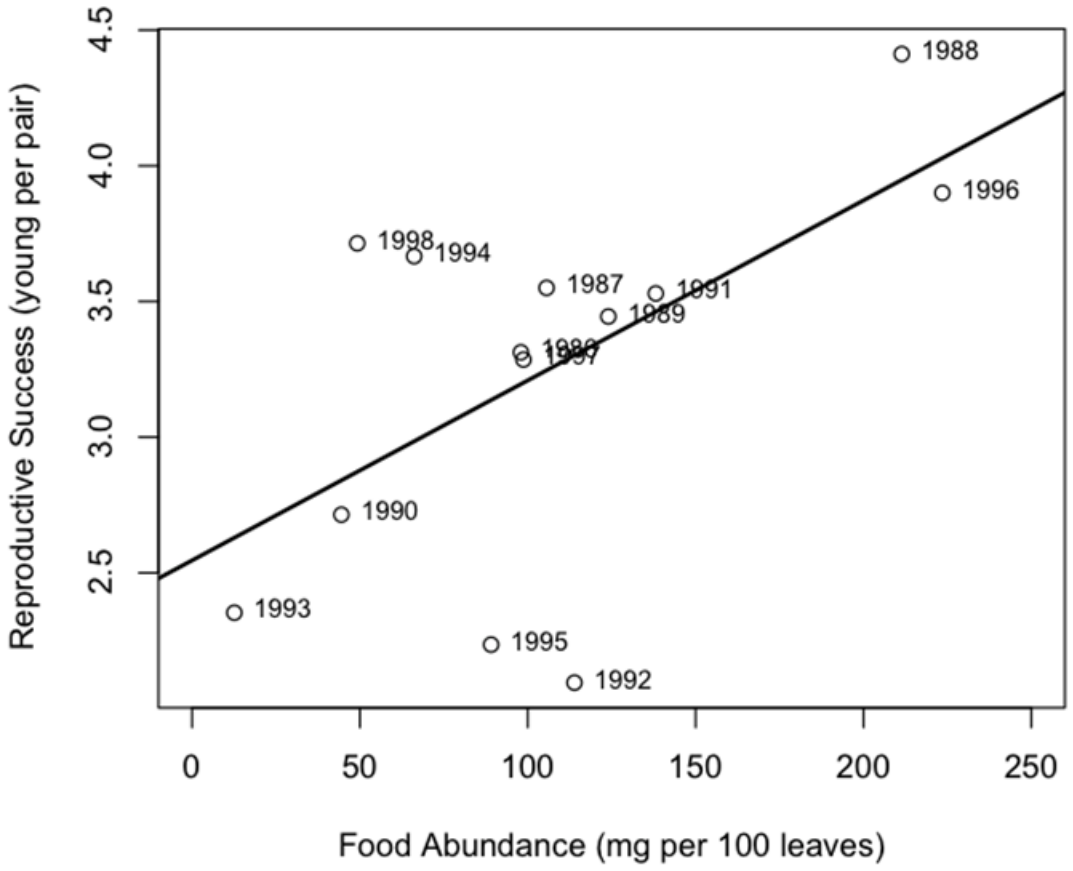
a) Create a graph of reproductive success vs. food abundance using data from 1986-1989.

b) Create a graph of reproductive success vs. food abundance using data from 1990-1993.

c) Do you see any clear relationship between food abundance and reproductive success in each of these graphs?

4. Compare the three graphs you just created to the graph on the website that included all of the data from 1986-1998. If you were a scientist trying to decide if food abundance affected warbler reproductive success, would your opinion depend on how many years you collected data for, or on which years you did your study? Why or why not?

5. Look at the graph below, in which each year is labeled. Overall, higher food abundance led to higher reproductive success. The line on the graph, which is called a regression line, summarizes the effects of food on reproductive success. Most of the points fall close to the line, but in some years the reproductive success was higher or lower than would be expected for the amount of food in that year. For example, in 1992 reproductive success was very low, even though there was an average amount of food. In 1998, reproductive success was higher than expected given the amount of food in that year, so the point falls above the line. The highest reproductive success was in 1988, but this isn't surprising since food availability was also very high in that year. Some of the variation in the data might be due to differences between years in predator abundance or density, since we know that these two factors also affected success.



a) If variation in the nest predator population between years is one of the factors that could cause reproductive success to be different than expected for the amount of food, would you predict that nest predators were more or less common than average in 1992?

b) Would you predict nest predators to be more or less common than average in 1998?

6. Create a graph of predator abundance versus year. Be sure to think about which variable makes more sense on the X axis, and which variable belongs on the Y axis. Place graph on same spreadsheet as other graphs. **Print out one page with all graphs and hand in to your teacher.**

a) Looking at your graph, were your predictions for the abundance of predators in 1992 and 1998 correct?

b) Looking at your graph again, choose one year (not 1991, since predator abundance wasn't measured then), and answer the following questions:

i. Was the number of predators in that year about average, higher than average, or lower than average?

ii. Given this number of nest predators, would you expect reproductive success in that year to be above the line on the graph of reproductive success versus food abundance, below the line, or very close to the line. Think of your answer before you look back at the reproductive success graph!

iii. Were your results what you expected? Can you make a prediction about the density in the year that you looked at?

Graphing Long-Term Data
Answer Key

Access the Excel data file Warbler_data.xls.

1. In the module's study of how food abundance affects reproductive success:

a) What is the independent variable?

Food abundance

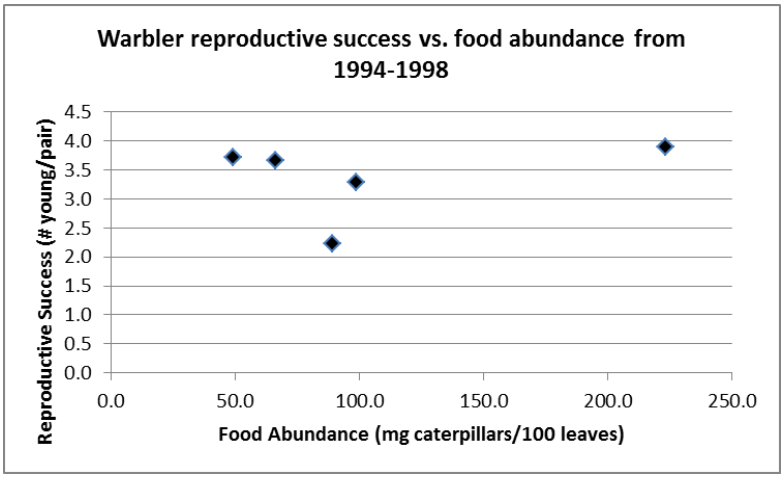
b) What is the dependent variable?

Reproductive success

c) Should food abundance or reproductive success be graphed on the Y axis?

Reproductive success

2. Create a graph of reproductive success vs. food abundance, which includes only data from 1994-1998. When you are done, there should be five data points on the graph, one for each year. (Instructions are included at end of answer key. Student handout has link to same instructions.)

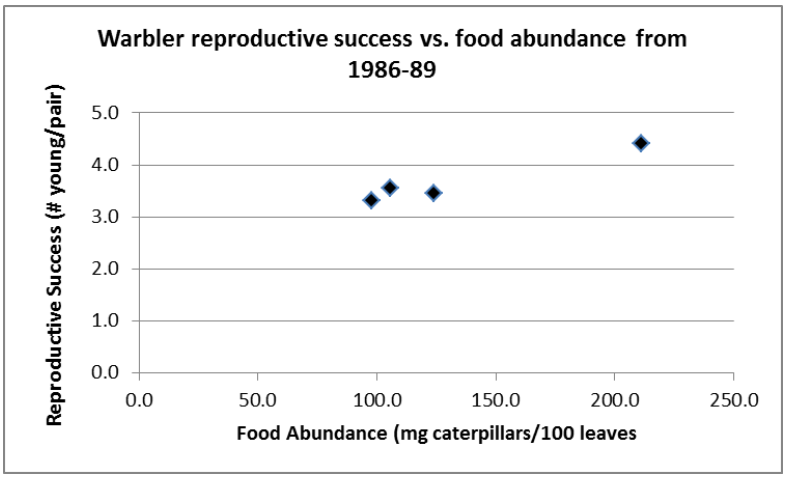


What does the graph look like? Is there a clear relationship between the amount of food and the birds' reproductive success in these years?

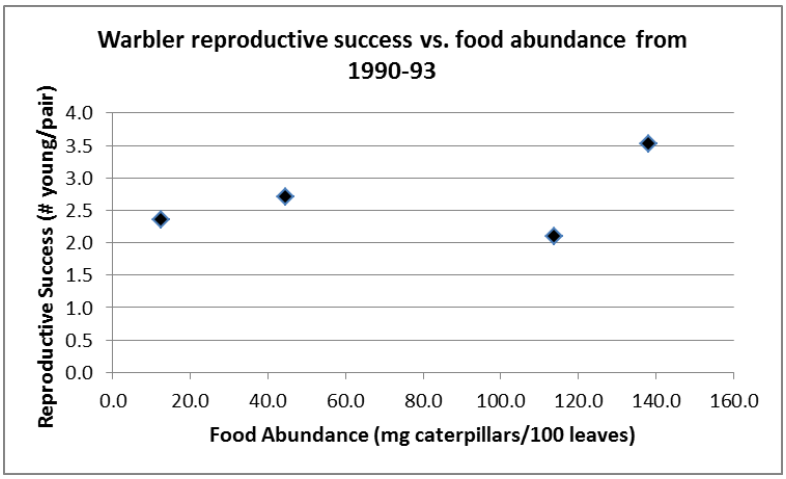
There is no clear pattern between food abundance and reproductive success in these years.

3. Next, you will make and interpret two more graphs of reproductive success vs. food abundance, similar to the graph in the previous question, but using data from different years.

a) Create a graph of reproductive success vs. food abundance using data from 1986-1989.



b) Create a graph of reproductive success vs. food abundance using data from 1990-1993.



c) Do you see any clear relationship between food abundance and reproductive success in each of these graphs?

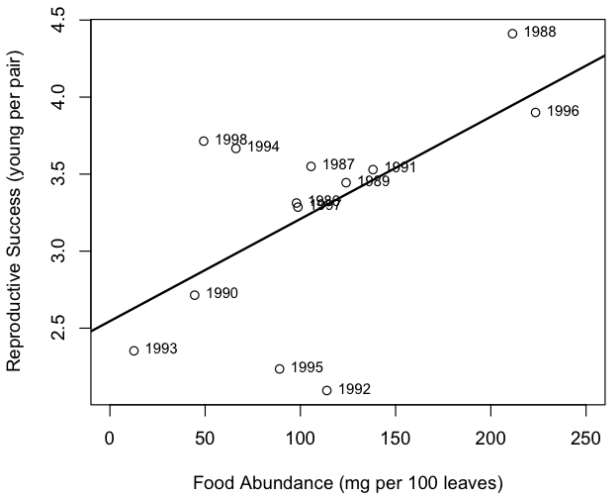
It is hard to see a clear pattern in either graph. The data from 1986-1989 hint at a possible pattern, but that pattern is just due to one point with high food abundance and high reproductive success.

4. Compare the three graphs you created to the graph on the website that included all of the data from 1986-1998. If you were a scientist trying to decide if food abundance affected warbler reproductive success, would your opinion depend on how many years you collected data for, or on which years you did your study? Why or why not?

The graph showing data from all the years shows a strong pattern, which is not clear in the graphs of data from just a few years. Scientists that collected data from more years would be able to reach a stronger conclusion about the effect of food on reproductive success. Some of the graphs from just a few

years showed a hinted at a pattern, while others didn't, so conclusions could also depend in which years the study was conducted.

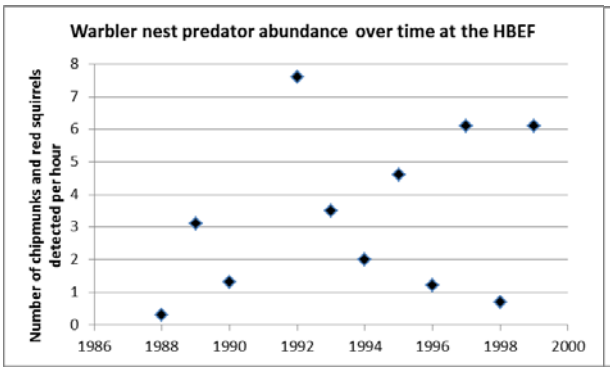
5. Look at this graph, in which each year is labeled. Overall, higher food abundance led to higher reproductive success. The line on the graph, which is called a regression line, summarizes the effects of food on reproductive success. Most of the points fall close to the line, but in some years the reproductive success was higher or lower than would be expected for the amount of food in that year. For example, in 1992 reproductive success was very low, even though there was an average amount of food. In 1998, reproductive success was higher than expected given the amount of food in that year, so the point falls above the line. The highest reproductive success was in 1988, but this isn't surprising since food availability was also very high in that year. Some of the variation in the data might be due to differences between years in predator abundance or density, since we know that these two factors also affected success.

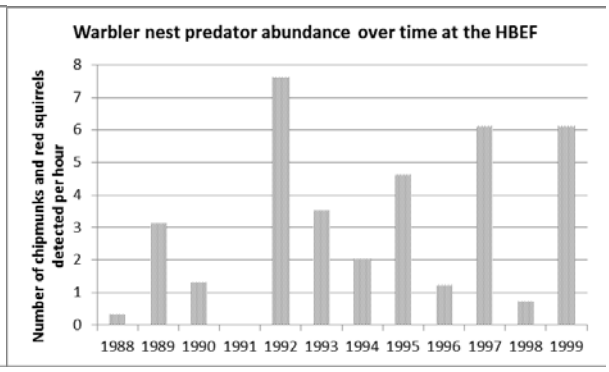


a) If variation in the nest predator population between years is one of the factors that could cause reproductive success to be different than expected for the amount of food, would you predict that nest predators were more or less common than average in 1992?
More common

b) Would you predict nest predators to be more or less common than average in 1998?
Less common

6. Create a graph of predator abundance versus year. Be sure to think about which variable makes more sense on the X axis, and which variable belongs on the Y axis.





Note: Students may choose to represent data in scatterplot of bar graph.

a) Looking at your graph, were your predictions for the abundance of predators in 1992 and 1998 correct?
Yes, 1992 was the year with the most predators, and predators were rare in 1998.

b) Looking at your graph again, choose one year (not 1991, since predator abundance wasn't measured then), and answer the following questions:

i. Was the number of predators in that year about average, higher than average, or lower than average?
Answers to this question will depend on what year the student selects. Students will look at the graph of predator abundance vs. year and choose one year. Years with high predator populations were 1992, 1997, and 1999. Years with average predator populations were 1989, 1993, and 1995. Predator populations were low in 1988, 1990, 1994 (which could be considered average), 1996, and 1998. In 1991, no data were collected.

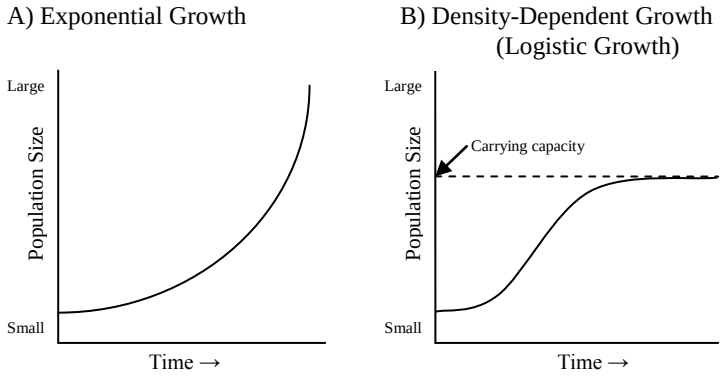
ii. Given this number of nest predators, would you expect reproductive success in that year to be above the line on the graph of reproductive success versus food abundance, below the line, or very close to the line. Think of your answer before you look back at the reproductive success graph!
Answers to this question will depend on what year the student selects. For years with high predator abundance, the point for that year should fall below the line on the reproductive success vs. food abundance graph. Years with few predators should fall above the line, and average years should be near the line.

iii. Were your results what you expected? Can you make a prediction about the density in the year that you looked at?
Answers to this question will depend on what year the student selects. High densities could lead to lower reproductive success than expected for the food abundance and predator population in a certain year. Conversely, low densities could lead to higher reproductive success than expected.

Population Simulation Model

Name _____

Biologists studying a natural population can test whether or not the population growth rate depends on the number of individuals in the population. If the population grows more slowly when there are a lot of individuals, then the population growth is *density-dependent*. This happens because of competition between individuals, which lowers the amount of food or other resources that each individual gets. In contrast, if a population's growth rate doesn't depend on the number of individuals in that population, then the population can undergo *exponential growth*. A population experiencing exponential growth would keep increasing in size, and would grow more quickly each year (see Figure A). This can only happen when resources aren't limiting—and so it is extremely rare in nature. Instead, populations are often fairly stable around an average population size, although all populations go up or down at least a little each year.



The amount of resources in an area, for example the abundance of food, will determine the total number of individuals that can survive and reproduce in that area. This population size is called the *carrying capacity* (see Figure B). For example, warblers eat insects, and when there aren't enough insects, some of the birds starve or don't reproduce, leading to a smaller population the next year. This bird population would keep declining until the number of birds could be supported by the food supply. But, if there are more insects than the birds need to eat and feed their young, many birds will survive and they will raise lots of offspring, leading to a larger population the following year. In this example, the average food supply sets the population size that can be stable over many years in a given location, the carrying capacity.

Understanding what resources or environmental conditions affect the carrying capacity of a population is a powerful tool for wildlife managers. For example, if scientists know what limits the number of birds in an area, they might be able to increase the population or predict how the population size will change with time. Researchers have found that the carrying capacity is often set by food availability, but in some species there are other resources that are limiting, such as good places to put a nest or a den. If predators are very common, they can also lower the carrying capacity of an environment. Finally, the strength of density-dependence also sets the carrying capacity. The strength of density dependence is measured as how much one additional bird in the population affects the demography of the other birds. If high densities lower reproductive success, then the strength of density dependence is measured as how many fewer young the average bird has when the population size is larger.

This simulation explores how density-dependence can keep a population fairly stable through time, and how factors like food availability and the strength of density dependence affect the stable population size (the carrying capacity).

Here are the default parameters for you to refer back to, if needed:

Initial warblers = 45

Density-dependence = 0.037 reproductive decline/warbler (This means that as population size increases, the average bird will have 0.037 fewer young. Of course, young come in whole numbers, but the average decline doesn't have to be a whole number.)

Predators = 3.3 detections/hour

Food = 105 mg/100 leaves

Each time you move the position of a slider, press 'setup', then press 'go' to run the model.

1. Run the model with the default parameters (before changing the position of the sliders under the graph—you can refresh the window to get back to these positions).
   a) What pattern do you see in the graph? What does it tell you about the population size?

   b) What is the final number of warblers?

   c) What type of population growth, density-dependent or exponential, could give the pattern that you see? Explain your answer.

2. Answer this question before running the simulation again. When the population is stable at a given size, this size is the carrying capacity, or the number of birds the environment can support. In a full sentence that includes your reasoning, write a hypothesis to predict what will happen if you:
   a) Decrease the population size below the carrying capacity.

   b) Increase the number of birds above the carrying capacity.

3. Now increase the initial number of warblers in the population. Set the Initial-Warblers slider to 80. Press 'Setup' and then 'Go' to run the model (you must press setup and go to re-run it after each change).

a) What results did you get?

b) What was the final number of warblers?

c) How does this compare to your hypothesis in Question 2a?

4. Now set the Initial-Warblers to 20, and run the model.

a) What is the final number of birds?

b) How does this compare to your hypothesis in Question 2b?

c) How does the strength of competition vary with population size? How can competition lead to a stable population size?

5. Reset the initial number of warblers to 45 (you can do this by moving the slider or refreshing the web page), then increase the strength of density dependence by moving the density-dependence bar to about 0.070, and run the model.

a) What pattern do you see in the graph?

b) What is the final number of warblers, and how does this compare to the number in Question 1?

6. Now decrease the strength of density-dependence all the way to zero, and then run the model.

a) What pattern do you see in the graph?

b) What is the final number of warblers?

c) What type of population growth, density-dependent or exponential, could give the pattern that you see?

7. Reset the strength of density-dependence to 0.037, the starting value. Next increase the food availability all the way to 200 mg (the furthest to the right).

a) What is the final number of warblers, and how does that compare to Question 1?

b) Hypothesize what will happen if you decrease the food availability all the way to 20mg.

c) Reduce the food and give the final warbler population size. Was your hypothesis supported or refuted?

8. Choose one more change or combination of changes to make, and answer the following questions. You may want to reset the food to an average level before starting

a) Which factors will you change, and how do you expect it to affect the warbler population?

b) Describe the results. Were they what you expected?

Population Simulation Model
Answer Key

1. a) What pattern do you see in the graph? What does it tell you about the population size?
   The slope is a flat line. It tells you the population size is stable.
   b) What is the final number of warblers?
   The final number is 45 warblers.
   c) What type of population growth, density-dependent or exponential, could create the pattern that you see? Explain your answer.
   Density-dependent. A graph showing an exponential type of population growth would show a curve that keeps increasing, and is never flat. This graph shows a stable population size; density dependence is keeping the population stable at its carrying capacity.

2. In a full sentence that includes your reasoning , write a hypothesis to predict what will happen if you:
   a) Decrease the population size below the carrying capacity.
   The population should increase back up to the carrying capacity. The population increases because at population sizes below the carrying capacity, there are enough resources for individuals to have high survival and reproductive rates.
   b) Increase the number of birds above the carrying capacity.
   The population should decrease back to the carrying capacity. At population sizes bigger than the carrying capacity, there is strong competition for resources, so individuals have low survival and reproductive rates.

3. a) What results did you get?
   The population size decreased and then stabilized at the carrying capacity.
   b) What was the final number of warblers?
   The final size was 45 warblers, the same as the original number.
   c) How does this compare to your hypothesis in Question 2a?
   Results were as predicted.

4. a) What is the final number of birds?
   45
   b) How does this compare to your hypothesis in Question 2b?
   Results were as predicted.
   c) How does the strength of competition vary with population size? How can competition lead to a stable population size?
   Competition is weak at population sizes far below the carrying capacity, and very strong at population sizes above the carrying capacity. The strength of competition determines the amount of resources each individual will have for survival and reproduction. At the carrying capacity, competition is strong enough that on average, each individual has enough resources to have one offspring that survives to reproduce. The population size is stable, since each individual replaces themselves in the population.

5. a) What pattern do you see in the graph?
   The graph shows a rapid decline in population and then it stabilizes.
   b) What is the final number of warblers, and how does this compare to the number in Question 1?
   The final number is 24 warblers, which is much lower than 45, the final number in Question 1.

6. a) What pattern do you see in the graph?
   The slope is fairly flat and then starts to increase more and more quickly (exponentially).
   b) What is the final number of warblers?
   4,414,310,551,173
   c) What type of population growth, density-dependent or exponential, could give the pattern that you see?
   Exponential growth would lead to this pattern, since the population keeps growing, and the rate of population growth also keeps increasing.

7. a) What is the final number of warblers, and how does that compare to Question 1?
   The final number is 54 warblers, more than in Question 1.
   b) Hypothesize what will happen if you decrease the food availability all the way to 20mg?
   If food availability is decreased to 20 mg, then the population size should first decrease and then become stable at a lower number of warblers.
   c) Try it and report on final warbler numbers. Was your hypothesis supported or refuted?
   The final number of warblers is 37, so the results support my hypothesis. The carrying capacity is lower when food is less abundant.

8. a) Which factors did you change, and how did you expect it to affect the warbler population?
   Answers will vary.
   b) Describe the results. Were they what you expected?
   Answers will vary.

Multiple Choice and Short Answer
Summative Assessment

Name _____

1. Which of the following factors must be present for a population of warblers to thrive in a certain location from year to year?
   a. Birds are visible in a designated location for at least two consecutive years.
   b. Birds outnumber predators.
   c. Birth rate is greater than the death rate.
   d. Death rate is greater than the birth rate.

2. Male Black-throated Blue Warblers defend their territories. Defense of their territory has many advantages. Which statement below is not one of the advantages?
   a. maintaining a nesting site
   b. sharing nest building materials with other bird pairs
   c. mating with the female
   d. finding food for chicks

3. Which of the following statements is the definition of reproductive success used in this scientific study of the Black-throated Blue Warbler?
   a. the number of yearlings produced
   b. the number of eggs hatched
   c. the number of young raised per pair in a given year
   d. the number of females returning from their wintering location

4. Define reproductive success in your own words.

5. Which of the following factors limits the density of populations of Black-throated Blue Warblers?
   a. the competition for nutrients
   b. the buildup of toxic waste
   c. predation
   d. all of the above

6. What does density of population mean?

7. When comparing reproductive success to warbler density, reproductive success is considered to be the dependent variable because:
   a. Reproductive success is the outcome of variations in warbler density.
   b. Warbler density depends on reproductive success.
   c. Warbler density is controlling reproductive success.
   d. Reproductive success is related to warbler density.

8. Explain the difference between dependent and independent variables.

9. Using the graph of the Black-throated Blue Warbler study, determine in which year the reproductive success of the birds was the greatest?

a. 1988
b. 1989
c. 1994
d. 1996

10. Using the graph of the Black-throated Blue Warbler study, in 1992 the reproductive success of the birds was only about 2 young per pair and was below the average of 3 young per pair per year for the study period. Which of the following statements best explains the small number of young produced that year?

a. The abundance of food and predators were relatively low.
b. The abundance of food and predators were relatively high.
c. The abundance of food was about average but the abundance of predators was high.
d. No reasonable explanation can be given from the data in the graph.

11. Explain the reasoning behind your answer for question 10.

12. The graph compares reproductive success of the Black-throated Blue Warbler to the abundance of food and predators. There are other factors that influence the reproductive success of the birds. Which factor listed below is <u>not</u> likely to influence reproductive success.

a. density of the nests
b. number of birds caught in mist nets
c. parasite mites
d. climate change

13. Explain the reasoning behind your answer for question 12.

14. A yearling bird:

a. is not yet one year old
b. is a parent for the first time
c. is a female that produces young every year
d. is wintering for the first time

15. Climate change may affect reproductive success of the Black-throated Blue Warbler because:

a. The expected changes will favor the continued reproductive success of the Warblers.
b. There will be fewer predators in the densest area of the Warbler territory.
c. The population of Warblers will not be able to adapt to sudden temperature changes.
d. Warblers will be squeezed into smaller areas of higher density as they seek habitats in higher elevations (where food is more abundant and numbers of nest predators are lower).

16. Explain the reasoning behind your answer for question 15.

Multiple-Choice Assessment Questions for *What Limits the Reproductive Success of Migratory Birds?*

Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

No.	Item	DOK*	Module Reference	Ans.
1	Which of the following factors must be present for a population of warblers to thrive in a certain location from year to year? a. Birds are visible in a designated location for at least two consecutive years. d. Birds outnumber predators. c. Birth rate is greater than the death rate. d. Death rate is greater than the birth rate.	2	Background, Introduction Short Answer Questions, question 2	c
2	Male Black-throated Blue Warblers defend their territories. Defense of their territory has many advantages. Which statement below is <u>not</u> one of the advantages? a. maintaining a nesting site b. sharing nest building materials with other bird pairs c. mating with the female d. finding food for chicks	2	Methods, Density Short Answer Questions, question 3	b
3	Which of the following statements is the definition of reproductive success used in this scientific study of the Black-throated Blue Warbler? a. the number of yearlings produced b. the number of eggs hatched c. the number of young raised per pair in a given year d. the number of females returning from their wintering location Define reproductive success in your own words _____ _____ _____	1	Methods, Reproduction Results, Reproductive Success	c
4	Which of the following factors limits the density of populations of Black-throated Blue Warblers? a. the competition for nutrients b. the buildup of toxic waste c. predation	2	Results, Density Short Answer Questions, question 5d	d

* Depth of Knowledge designated by four levels: Level 1 = recall, Level 2 = skill/concept, Level 3 = strategic thinking, Level 4 = extended thinking

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No.	Item	DOK*	Module Reference	Ans.
	d. all of the above What does density of population mean? _____ _____ _____			
5	When comparing reproductive success to warbler density, reproductive success is considered to be the dependent variable because: a. Reproductive success is the outcome of variations in warbler density. b. Warbler density depends on reproductive success. c. Warbler density is controlling reproductive success. d. Reproductive success is related to Warbler density. Explain the difference between dependent and independent variables _____ _____ _____	1	Graphing Long-Term Data, Results, Density	a

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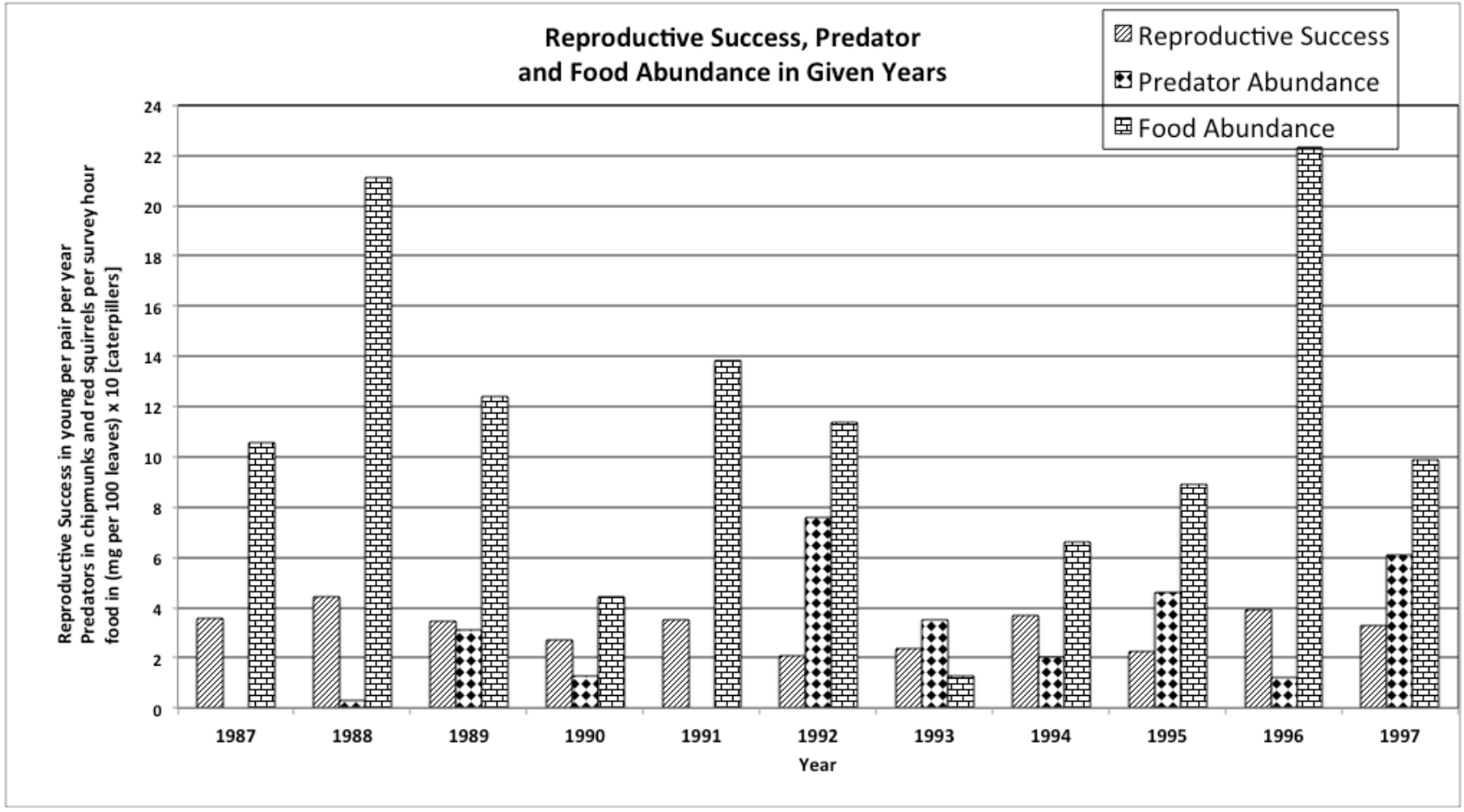
No.	Item	DOK*	Module Reference	Ans.
				
Data From the Hubbard Brook Research Foundation Study of the Black-throated Blue Warbler				
6	Using the graph of the Black-throated Blue Warbler study, determine in which year the reproductive success of the birds was the greatest? a. 1988 b. 1989	1	Results, Reproductive Success, Food Abundance, Predator Abundance Graphing Long-Term Data	a

* Depth of Knowledge designated by four levels: Level 1 = recall, Level 2 = skill/concept, Level 3 = strategic thinking, Level 4 = extended thinking

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No.	Item	DOK*	Module Reference	Ans.
	c. 1994 d. 1996			
7.	Using the graph of the Black-throated Blue Warbler study, in 1992 the reproductive success of the birds was only about 2 young per pair and was below the average of 3 young per pair per year for the study period. Which of the following statements best explains the small number of young produced that year? a. The abundance of food and predators were relatively low. b. The abundance of food and predators were relatively high. c. The abundance of food was about average but the abundance of predators was high. d. No reasonable explanation can be given from the data in the graph. Explain the reasoning behind your answer _____ _____ _____	2	Results, Reproductive Success, Food Abundance, Predator Abundance Graphing Long-Term Data	c
8.	The graph compares reproductive success of the Black-throated Blue Warbler to the abundance of food and predators. There are other factors that influence the reproductive success of the birds. Which factor listed below is <u>not</u> likely to influence reproductive success. a. density of the nests b. number of birds caught in mist nets c. parasite mites d. climate change Explain the reasoning behind your answer _____ _____ _____	3	Graphing Long-Term Data	b
9.	A yearling bird:	1	Results, Yearling Recruitment	b

* Depth of Knowledge designated by four levels: Level 1 = recall, Level 2 = skill/concept, Level 3 = strategic thinking, Level 4 = extended thinking

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Learning module developed by K. Langin, H. Sofaer and S. Sillett for Hubbard Brook Research Foundation (2009) and adapted by David Kukla, Associates in Learning and Leadership, Science Education Coach/Consultant (2013).

No.	Item	DOK*	Module Reference	Ans.
	a. is not yet one year old b. is a parent for the first time c. is a female that produces young every year d. is wintering for the first time			
10.	Climate change may affect reproductive success of the Black-throated Blue Warbler because: a. The expected changes will favor the continued reproductive success of the Warblers. b. There will be fewer predators in the densest area of the warbler territory. c. The population of warblers will not be able to adapt to sudden temperature changes. d. Warblers will be squeezed into smaller areas of higher density as they seek habitats in higher elevations (where food is more abundant and numbers of nest predators are lower). Explain the reasoning behind your answer _____ _____ _____	2	Results, Conservation Implications	d

* Depth of Knowledge designated by four levels: Level 1 = recall, Level 2 = skill/concept, Level 3 = strategic thinking, Level 4 = extended thinking

* Depth of Knowledge designated by four levels: Level 1 = recall, Level 2 = skill/concept, Level 3 = strategic thinking, Level 4 = extended thinking

What Limits the Reproductive Success of Migratory Birds?
Warbler Data Analysis (50 pts.)

This assignment is based on background information on the following website:
http://btbw.hubbardbrookfoundation.org/.

To do this assignment, you will need to use the Data Analysis Add-in for Excel.
(http://office.microsoft.com/en-us/excel-help/load-the-analysis-toolpak-HP001127724.aspx)

Download Warbler Data.xls. The dataset contains the following data:

- *Predator Abundance* refers to the number of chipmunks and red squirrels detected per hour, on average, during predator observations. Predator abundance data were not collected in 1986, 1987, or 1991.
- *Food Abundance* refers to the biomass of caterpillars (in milligrams per 100 leaves) on the study plot during the breeding season. Food abundance data were not collected in 1999.
- *Reproductive Success* refers to the average number of young that left nests ("fledged") per territory in each year. This is a good measure of fecundity in passerine birds.

1. Researchers quantified how food abundance affected warbler reproductive success:
    a) What is the independent variable in this analysis? (2 pts.)

    b) What is the dependent variable? (2 pts.)

2. Create a graph of food abundance versus reproductive success. Be sure to label your axes! Add a trendline to your graph. (4 pts.)
    a) What is the relationship between food abundance and reproductive success? (2 pts.)

3. Test if the relationship you just graphed is statistically significant. To do so, do a regression analysis, using the data analysis add-in. Check the box to save the residuals from this analysis.
    a) Are the results of your regression statistically significant? What output did you use to make this determination? (3 pts.)

    b) Part of your output is an R^2 value. Report the result for this value, and how this result should be interpreted. (3 pts.)

    c) You saved the residuals from your analysis. What is a residual? Include in your answer how to interpret the sign (positive or negative) of each residual. (4 pts.)

4. Ecologists have found that nest predator abundance can also affect warbler reproductive success. In this question you'll test if differences in nest predator abundance between years might account for the deviations we saw from the relationship between food abundance and reproductive success. First, you'll need to paste the residuals you saved (which probably got output into a separate worksheet) in a column beside the original dataset. Be absolutely sure you line up the rows right! Next, because Excel cannot deal with missing values, you'll need to delete any rows with missing values in either the nest predator or residual columns. (It's smart to copy the whole dataset into a new worksheet, and then delete.)

a) Here we will test if variation between years in nest predator abundance can explain higher or lower warbler fecundity than expected for the food abundance in a given year. In this analysis, what is your independent variable, and what data will you use for your dependent variable? (2 pts.)

b) Make a graph of nest predator abundance versus the residuals you saved from the analysis of the effects of food on reproductive success. Use your answer from part a to decide which axis each variable should go on. Again, label your axes and add a trendline to the graph. (6 pts.)

5. Next, we'll do another regression analysis to test if the relationship we graphed in question 4 is statistically significant. This time, you don't need to save the residuals.

a) Are your results statistically significant? What output did you use to make this determination? (3 pts.)

b) Report the R^2 value, and how this result should be interpreted. (3 pts.)

6. Summarize the biological interpretation of your results, and the effects of food and nest predator abundance on warbler fecundity. (6 pts.)

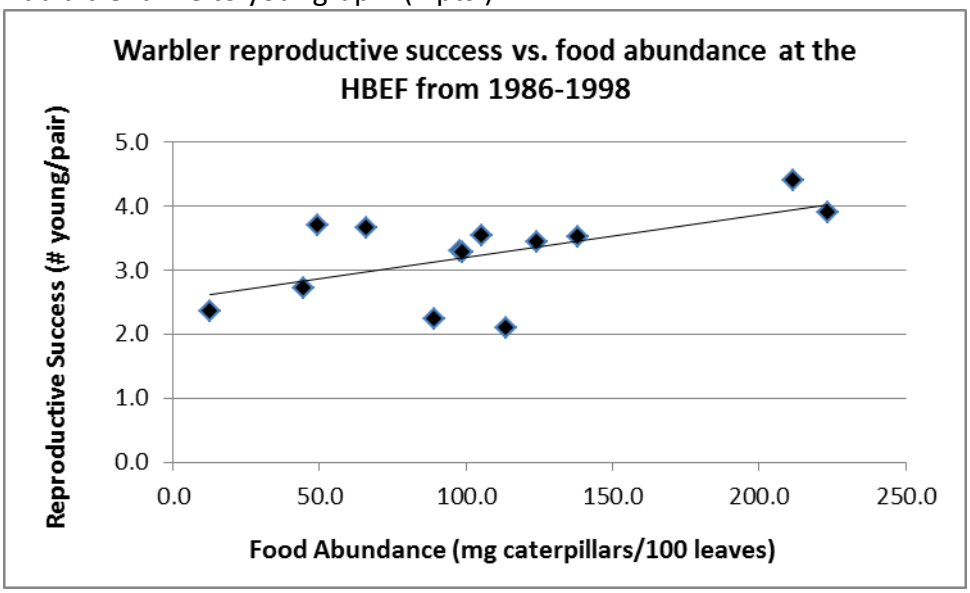
7. Based on the background information on the effects of density on warbler fecundity, look at the point for 1995 in both graphs, and predict whether the density in that year was above average, below average, or approximately average. Be clear about why you made the prediction you did. (5 pts.)

8. Can we say that variation in food and predators *causes* variation in warbler fecundity? If so, why? If not, what would need to be done to establish causation? (5 pts.)

What Limits the Reproductive Success of Migratory Birds?
ANSWER KEY
Warbler Data Analysis (50 pts.)

1. Researchers quantified how food abundance affected warbler reproductive success:
   a) What is the independent variable in this analysis? (2 pts.)
   Food abundance
   b) What is the dependent variable? (2 pts.)
   Reproductive success

2. Create a graph of food abundance versus reproductive success. Be sure to label your axes! Add a trendline to your graph. (4 pts.)



   a) What is the relationship between food abundance and reproductive success? (2 pts.)
   Reproductive success was higher in years with more food.

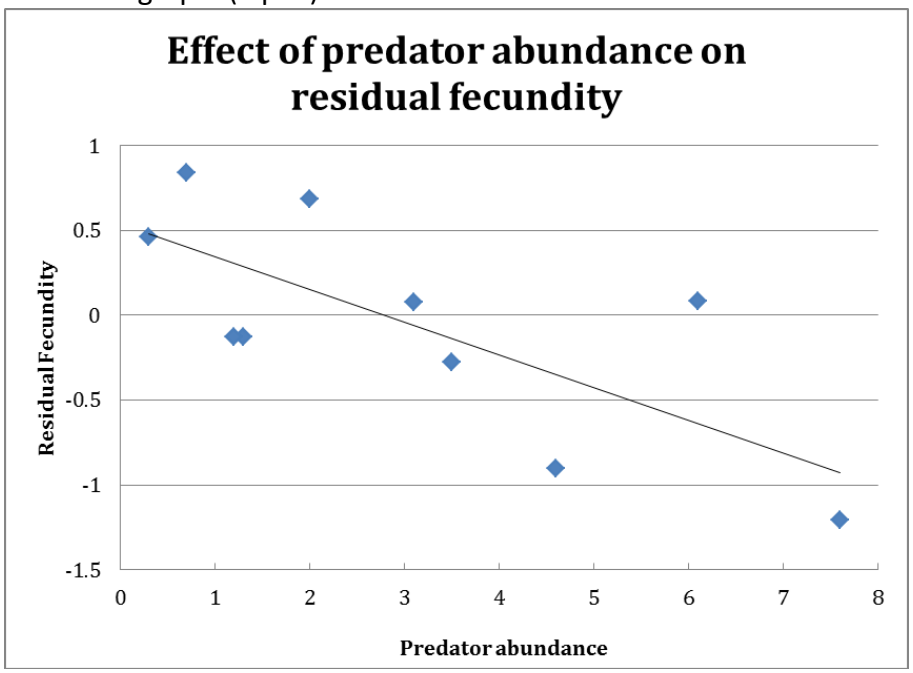
3. Test if the relationship you just graphed is statistically significant. To do so, do a regression analysis, using the data analysis add-in. Check the box to save the residuals from this analysis.
   a) Are the results of your regression statistically significant? What output did you use to make this determination? (3 pts.)
   Yes, because the p-value is less than 0.05; in this analysis *P* = 0.0391
   b) Part of your output is an R^2 value. Report the result for this value, and how this result should be interpreted. (3 pts.)
   The R^2 value is 0.33; this means that 33% of the variation in reproductive success is explained by variation in food abundance.

c) You saved the residuals from your analysis. What is a residual? Include in your answer how to interpret the sign (positive or negative) of each residual. (4 pts.)
Each residual measures how far a given point is from the expected relationship; it gives the distance from the regression line. Positive values indicate the Y-value is larger than expected, so the point is above the line.

4. Ecologists have found that nest predator abundance can also affect warbler reproductive success. In this question you'll test if differences in nest predator abundance between years might account for the deviations we saw from the relationship between food abundance and reproductive success. First, you'll need to paste the residuals you saved (which probably got output into a separate worksheet) in a column beside the original dataset. Be absolutely sure you line up the rows right! Next, because excel cannot deal with missing values, you'll need to delete any rows with missing values in either the nest predator or residual columns. (It's smart to copy the whole dataset into a new worksheet, and then delete.)

a) Here we will test if variation between years in nest predator abundance can explain higher or lower warbler fecundity than expected for the food abundance in a given year. In this analysis, what is your independent variable, and what data will you use for your dependent variable? (2 pts.)
Independent variable: Predator abundance
Dependent variable: residual fecundity

b) Make a graph of nest predator abundance versus the residuals you saved from the analysis of the effects of food on reproductive success. Use your answer from part a to decide which axis each variable should go on. Again, label your axes and add a trendline to the graph. (6 pts.)



5. Next, we'll do another regression analysis to test if the relationship we graphed in question 4 is statistically significant. This time, you don't need to save the residuals.

a) Are your results statistically significant? What output did you use to make this determination? (3 pts.)
Yes, *P* = 0.0175

b) Report the R^2 value, and how this result should be interpreted. (3 pts.)
R2 = 0.526, indicating that nest predator abundance explained 53% of the variation in residual fecundity

6. Summarize the biological interpretation of your results, and the effects of food and nest predator abundance on warbler fecundity. (6 pts.)
Both food abundance and nest predator abundance affected average warbler reproductive success in each year. In our analyses, we showed that variation in food accounted for approximately 1/3 of the variation in fecundity between years. Fecundity was higher in years with more food. When we analyzed the residuals from that regression, we found that deviations from expected fecundity were explained by variation in nest predator abundance between years. Specifically, nest predator abundance explained half of the variation in reproductive success that was not explained by food abundance. As the abundance of nest predators increased, reproductive success declined. This can be seen on the second figure where high nest predator abundance is associated with negative values of residual fecundity. This means that in years with many predators, fecundity was lower than would be expected just based on the amount of food.

7. Based on the background information on the effects of density on warbler fecundity, look at the point for 1995 in both graphs, and predict whether the density in that year was above average, below average, or approximately average. Be clear about why you made the prediction you did. (5 pts.)
In 1995, residual fecundity was approximately -1, so that year's fecundity was lower than expected given the food abundance. The abundance of nest predators in that year was relatively high, but the point still falls below the expected relationship between nest predator abundance and residual fecundity. High densities are expected to reduce fecundity. I would therefore predict that density in that year was higher than average, since fecundity was lower than expected given both food and nest predator abundance.

8. Can we say that variation in food and predators *causes* variation in warbler fecundity? If so, why? If not, what would need to be done to establish causation? (5 pts.)
No, we cannot say that variation in these ecological factors caused variation in warbler fecundity. Experimental manipulations are required to establish causation, whereas these data only show a correlation, although a very convincing one.