Hubbard Brook Research Foundation

Migratory Bird Math and Science Lessons

Chestnut Warbler/Robert Royse

Lesson: Energy Expenditures

One of the goals of avian research at the Hubbard Brook Experimental Forest has been to understand what is needed for birds to survive and reproduce. To do so, researchers must first know how much energy birds require to perform vital functions and sustain themselves. To quantify this, researchers at the Hubbard Brook Experimental Forest spent hundreds of hours observing birds during different phases of their breeding season and recorded the amount of time each bird spent flying, hopping, sitting, and incubating eggs. Researchers also conducted laboratory tests to quantify the amount of calories each of these activities burns. Combining the knowledge from the field and the lab allowed researchers to calculate energy budgets for warblers throughout the breeding season.

This lesson aims to share the methods and results of this research with students while providing an interesting and real life example as the context for students to practice solving word problems. The first part of this lesson is aimed at strengthening students' science inquiry skills through guided discussion, focusing on how scientists calculate energy budgets for birds. The second part builds on the first by allowing students to apply math skills to real data in order to quantitatively illustrate the concepts from the first part.

Summary	This lesson shares an actual scientific question posed by researchers and asks students to participate in figuring out how to answer the question. Students perform calculations to compare the daily energy expenditure of male and female warblers during different phases of their breeding season.
Subject areas	Advanced algebra
Skill level	Advanced
Objectives	• Accurately solve problems using multiplication. • Write a formula to translating a problem situation into algebraic expressions. • Use problem-solving strategies to investigate and understand increasingly complex mathematical content. • Recognize connections between mathematics and biology/ecology.
NH Mathematics and Science Framework Standards	M:N&O:10:4, M:F&A:10:3, M:PRP:HS:1, M:CCR:HS:3, S:SPS1:8:4.3
Time	One 45-minute class period, plus homework
Materials	• Student Handout: *Energy Expenditures* Optional: • Breeding Cycle Phases.pdf • Energy Used by Bird Activites.pdf
Assessment	Student Handout with answer key included

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Note to Teachers

Students will perform addition and multiplication to complete a series of six tables, the results of which will enable to answer analysis questions. If desired, these computations can be done in Excel.

1. Introduce lesson to students:

One of the goals of avian research at Hubbard Brook has been to understand what is needed for birds to survive and reproduce. To do so, they must first know how much energy birds require to perform their vital functions. *How much energy does a warbler use daily during the breeding season? Who uses more energy, males or females? Does this change, depending on what phase of the breeding cycle the birds are in? Researchers at Hubbard Brook spent a lot of time trying to answer these questions. How did they go about doing so?*

A. Discuss:

What are some different activities that birds engage in?
Sitting, singing, eating, hopping, flying, sleeping, producing eggs or incubating eggs

Which of these activities do you think requires the greatest number of calories?
Answers will vary.

Which do you think requires the least?
Answers will vary.

B. Brainstorm:

What would you need to know to figure out how much energy a warbler uses daily during the breeding season?
Help students to realize that there are many variables one needs to know to answer the question; they need to know the various activities that birds engage in throughout the day, the amount of time spent in each activity, and the number of calories used per each activity…all of these questions must be considered for each stage of the breeding cycle.

C. How did researchers at the Hubbard Brook Experimental Forest (HBEF) figure out how much time birds spent doing different activities?

The breeding cycle of a warbler is broken up into several phases, some of which can be seen in the slideshow *Breeding Cycle Phases,* included in Support Materials. These phases include: nest building, incubating, nestling care (care for newborn birds), and fledgling care (care for birds just leaving the nest). For more than two summers at the Hubbard Brook Experimental Forest (HBEF) in New Hampshire, scientists Richard Holmes, Craig Black, and Thomas Sherry and their student assistants observed birds during these different phases to quantify the amount of time spent flying, hopping, sitting, etc., during each phase. They used this data to create a *time budget* for each of the phases. You will see this budget on the Student Handout.

D. How did researchers at the HBEF figure out how much energy a warbler uses daily?

Scientists Richard Holmes, Craig Black, and Thomas Sherry[1] worked hard for years to answer this question. First, they had to know how much energy is used by a bird that is resting in an environment that is *thermoneutral* (this is when the outside temperature does not require a bird to expend energy to keep itself warm or cool itself off). This is called the Standard

Metabolic Rate, or **SMR**, and is calculated based on a bird's respiration (a ratio between the carbon dioxide given off and the oxygen taken up). The researchers learned that the SMR of a Black-throated Blue Warbler is 16.8 calories per gram per hour; that is, just being alive uses 16.8 calories per gram of body weight per hour. An average Black-throated Blue Warbler weighs almost 10 grams, which means that its SMR is 168 calories/hour.

Second, researchers needed to know how many calories are used when a bird performs its different activities. So they measured the metabolic rates (the ratio of carbon dioxide liberated to oxygen taken in) of birds in the laboratory, as they flew in wind tunnels, sat in cages, etc.

2. Take a moment to digest this:

Teacher may wish to ask students to predict the amount of energy various activities use in comparison to the SMR, and/or teacher could ask students to rank various activities from highest to lowest energy usage before learning the following, which is included as a short slide show in Support Materials for easy viewing *(Energy Used by Different Bird Activities)*:

What did the researchers find out?

Flying uses 10x more energy than SMR.

Hopping uses 5x more energy than SMR.

Sleeping uses 2.2x more energy than SMR.*

Singing uses 2x more energy than SMR.

Sitting uses 1.5x more energy than SMR.**

Incubation uses 1.3x more energy than SMR.

Digestion uses 0.3x more energy than SMR.

And **egg production?** Well, that depends upon the size of the egg…

*Sleeping does not use the same amount of energy as SMR because birds expend energy to stay warm at night, when temperatures are usually lower than during the day.

**Sitting does not use the same amount of energy as SMR because it's not just 'stationary sitting:' it includes occasional hopping and turning around. Also, birds must expend energy to stay warm even during the day. Most likely, sitting uses less energy than sleeping because daytime temperatures are generally warmer than nighttime temperatures.

Knowing this background information, students can now answer the questions and perform calculations on the Student Handout.

[1] R.T. Holmes, Black, C.P., and Sherry, T.W. 1979. Comparative Population Bioenergetics of Three Insectivorous Passerines in a Deciduous Forest. Condor 81: 9-20.

Student Handout: Energy Expenditures

Name _____

How much energy does a warbler use daily during the breeding season?
Who uses more energy, males or females?
Does this change, depending on what phase of the breeding cycle the birds are in?

1. What variables must you know to answer the above questions?

How much energy is expended during different bird activities?

2. Based on the discussion led by your teacher, describe, in your own words, the meaning of Standard Metabolic Rate (SMR).

3. Given the information in the table below, calculate the calories used per hour during each of the following activities:

Given: SMR of Black-throated Blue Warbler = 16.8 cal/g/hr		
Activity	**Energy used by activity in comparison to SMR**	**Calories used by activity, per gram per hour**
Flying	10 x SMR	
Hopping	5 x SMR	
Sitting	1.5 x SMR	
Incubating	1.3x SMR	

What is the daily energy expenditure of a warbler?
(How many calories does a warbler use daily, and does the amount change according to gender and phases of breeding cycle?)

4. Each table below provides the number of calories spent per hour on each activity AND the amount of time spent on each activity. With this information, you can calculate the total amount of energy expended daily by male and female birds. **How will you do this? Describe.**

Complete the tables below. Your teacher may wish for you to show your work on a separate piece of paper.

5.

Female warbler during NEST BUILDING phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.96		
Hopping	84	0.88		
Sitting	25.2	0.00		
Incubation	21.8	13.78		
TOTAL	----	----		

6.

Male warbler during NEST BUILDING phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.79		
Hopping	84	0.57		
Sitting	25.2	0.00		
Incubation	21.8	14.14		
TOTAL	----	----	——	

7.

Female warbler during INCUBATION phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.54		
Hopping	84	1.29		
Sitting	25.2	11.70		
Incubation	21.8	1.92		
TOTAL	----	----	___	

8.

Male warbler during INCUBATION phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	1.10		
Hopping	84	0.65		
Sitting	25.2	0.00		
Incubation	21.8	13.75		
TOTAL	----	----	___	

9.

Female warbler during NESTLING CARE phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.96		
Hopping	84	0.88		
Sitting	25.2	0.00		
Incubation	21.8	13.78		
TOTAL	----	----	___	

10.

Male warbler during NESTLING CARE phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	1.12		
Hopping	84	1.01		
Sitting	25.2	13.58		
Incubation	21.8	0		
TOTAL	----	----	___	

11. Write your calculations from Questions 5–10 into the table below to make comparison easier. Then answer the questions that follow.

Daily energy expenditure (calories) of warblers during different phases of breeding cycle		
	Female	**Male**
Nest building		
Incubation		
Nestling		

Data Analysis

12. Based on your calculations, infer which gender builds the nest: males, females, or both? Explain your answer.

13. Why do you think that the male's Daily Energy Expenditure (DEE) is higher than the female's, during the incubation phase?

14. The male flies more during the incubation phase than during the nest building phase. What do you think he might be doing?

15. Who do you think feeds the nestlings (baby birds that have not yet left the nest)? Explain your answer.

16. What types of information might be missing from the tables above that could affect the calculation of total daily energy expenditure for these birds?

17. Write a formula that more accurately expresses the Daily Energy Expenditure (DEE) of a bird. Do so by assigning variables to various activities as well as to the amount of time spent in each activity. Use correct mathematical notation. Example: let F_t = flying time, let F_c = flying cost (calories used in flying)

Answer Key: Energy Expenditures

1. What variables must you know to answer the above questions?
Answers will vary, but with teacher-led discussion, students should realize that they need to know: the different activities birds do, the amount of calories each activity uses, the amount of time a bird spends doing each activity, and whether this changes during the different phases of the breeding cycle.

2. Based on the discussion led by your teacher, describe, in your own words, the meaning of Standard Metabolic Rate (SMR).
Answers will vary, but should indicate that the SMR is a measure of the amount of energy a bird uses when it is at rest in a thermoneutral environment. (Teacher has led discussion to explain what is meant by thermoneutral.)

3. Given the information in the table below, calculate the calories used per hour during each of the following activities:

Given: SMR of Black-throated Blue Warbler = 16.8 cal/g/hr		
Activity	**Energy used by activity in comparison to SMR**	**Calories used by activity, per gram per hour**
Flying	10 x SMR	168 cal/g/hr
Hopping	5 x SMR	84 cal/g/hr
Sitting	1.5 x SMR	25.2 cal/g/hr
Incubating	1.3x SMR	21.8 cal/g/hr

4. Each table below provides the number of calories spent per hour on each activity AND the amount of time spent on each activity. With this information, you can calculate the total amount of energy expended daily by male and female birds. How will you do this? Describe.
Answers will vary.

5.

Female warbler during NEST BUILDING phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.96	161.28	1612.80
Hopping	84	0.88	73.92	739.20
Sitting	25.2	0.00	347.26	3472.56
Incubation	21.8	13.78	0.00	0.00
TOTAL	----	----	——	5824.56

6.

Male warbler during NEST BUILDING phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.79	132.72	1327.2
Hopping	84	0.57	47.88	478.8
Sitting	25.2	0.00	356.33	3563.28
Incubation	21.8	14.14	0	0
TOTAL	----	----	——	5369.28

7.

Female warbler during INCUBATION phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	0.54	90.72	907.2
Hopping	84	1.29	108.36	1083.6
Sitting	25.2	11.70	48.38	483.84
Incubation	21.8	1.92	255.06	2550.6
TOTAL	----	----	——	5025.24

8.

Male warbler during INCUBATION phase				
	hourly energy expenditure (cal/g/hr)	**hours spent doing activity**	**daily energy expended (cal/g)**	**daily energy expended for a 10 g warbler**
Flying	168	1.10	184.8	1848
Hopping	84	0.65	54.6	546
Sitting	25.2	0.00	346.5	3465
Incubation	21.8	13.75	0	0
TOTAL	----	----	——	5859

9.

Female warbler during NESTLING CARE phase				
	hourly energy expenditure (cal/g/hr)	hours spent doing activity	daily energy expended (cal/g)	daily energy expended for a 10 g warbler
Flying	168	0.96	252	2520
Hopping	84	0.88	96.6	966
Sitting	25.2	0.00	327.348	3273.48
Incubation	21.8	13.78	0	0
TOTAL	----	----	——	6759.48

10.

Male warbler during NESTLING CARE phase				
	hourly energy expenditure (cal/g/hr)	hours spent doing activity	daily energy expended (cal/g)	daily energy expended for a 10 g warbler
Flying	168	1.12	188.16	1881.6
Hopping	84	1.01	84.84	848.4
Sitting	25.2	13.58	342.216	3422.16
Incubation	21.8	0	0	0
TOTAL	----	----	——	6152.16

11. Write your calculations from above into the table below to make comparison easier. Then answer the questions that follow.

Daily energy expenditure (calories) of warblers during different phases of breeding cycle		
	Female	Male
Nest building	5825	5369
Incubation	5025	5859
Nestling	6759	6152

Data Analysis

12. Based on your calculations, can you infer which gender builds the nest: males, females, or both? Explain your answer.

The female builds the nest. This is reflected in the DEE for the nest building phase: she spends more energy (456 cal per day) than the male, in building the nest.

13. Why do you think that the male's DEE is higher than the female's, during the incubation phase?

The female is sitting on the eggs and not using as much energy flying around.

14. The male flies more during the incubation phase than during the nest building phase. What do you think he might be doing?

He is likely defending the nest from predators as well as defending his territory.

15. Who do you think feeds the nestlings (baby birds that have not yet left the nest)? Explain your answer.

At first, it might seem like the female is the only one to feed nestlings, since her DEE is higher than the male's. However, both the male's and female's DEE are higher during this phase than during the other phases. This suggests that both genders are feeding the nestlings.

16. What types of information might be missing from the tables above that could affect the calculation of total daily energy expenditure for these birds?

Not all bird activities are included in the tables: egg production, singing, digestion, sleeping, etc.

17. Write a formula that more accurately expresses the Daily Energy Expenditure (DEE) of a bird. Do so by assigning variables to various activities as well as to the amount of time spent in each activity. Use correct mathematical notation. Example: let F_t = flying time, let F_c = flying cost (calories used in flying)

Answers will vary, but should include more activities than those listed in the tables above.
Possible answer:

let F_t = flying time	L = sleeping
let F_c = flying cost	I = incubating
H = hopping	P = egg production
S = singing	D = digestion
T = sitting	

$$DEE = F_tF_c + H_tH_c + S_tS_c + T_tT_c + L_tL_c + I_tI_c + P_tP_c + D_tD_c$$