AWESOME AGGREGATIONS

Students study overwintering biology and behavioral ecology with model monarch butterflies

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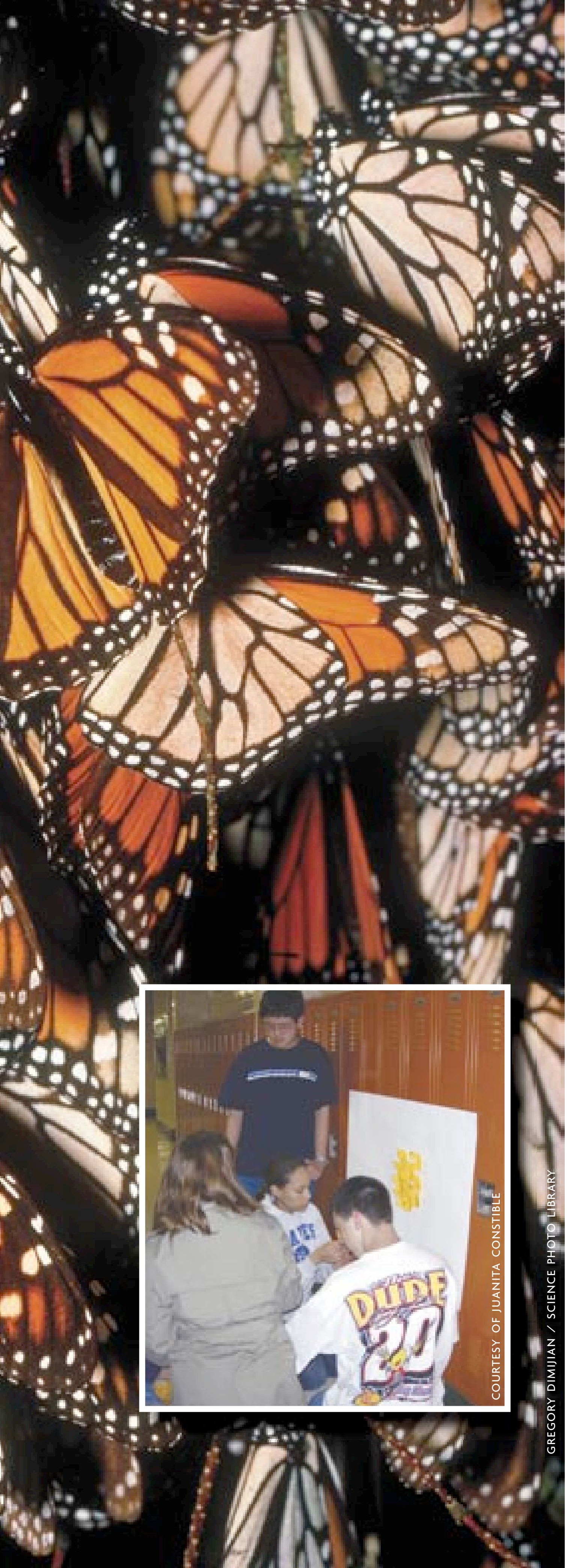
Insects are a natural choice for studying behavioral ecology in the classroom—they are easy to obtain, maintain, and manipulate. Unlike competition and predation, however, the concept of group living does not translate well to small-scale experiments involving only a few individuals. How can we use inquiry to examine why animals live in groups? The answer is to use models, which are more feasible than working with hundreds of test subjects. This article describes a Standards-based directed inquiry into overwintering biology and behavioral ecology titled "Awesome Aggregations" that high school students can carry out with models of monarch butterflies.



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Monarch overwintering

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Every fall, the entire eastern North American population of monarch butterflies *(Danaus plexippus)* escapes harsh winter conditions by migrating up to 4,830 km to central Mexico (Oberhauser and Solensky 2004). The high-elevation fir-pine forests that serve as overwintering sites for monarchs have relatively stable microclimates; even so, freezing temperatures are common and northern winter storms occasionally bring snow and rain.

Due to their small body size, adult monarch butterflies can remain unfrozen (i.e., supercooled) at temperatures as low as –14°C (Anderson and Brower 1996). Monarchs with water on their bodies freeze at a much higher temperature than dry monarchs; ice crystals on the body of a wet monarch induce freezing within its body fluids by a process called *inoculative freezing* (Larsen and Lee 1994). Unlike some other insects, monarchs cannot survive freezing.

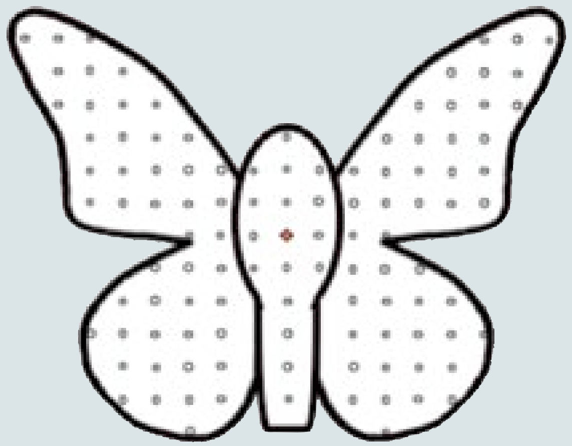
How do monarch butterflies stay dry during winter storms? First, monarchs aggregate in very high numbers: approximately 20 million butterflies may aggregate on less than 1,000 trees! The structure of monarch colonies has evolved, in part, to protect butterflies from wetting (Anderson and Brower 1996). Monarchs on the inside of clusters stay drier than butterflies on the edge. Second, dense tree canopy acts like a blanket and an umbrella for aggregating monarchs (Anderson and Brower 1996). Intact canopy reduces radiational cooling of monarchs (i.e., the energy radiated by monarchs is bounced back to the butterflies by tree canopy rather than lost to the open sky), intercepts precipitation, and reduces dew formation.

Unfortunately, the fir-pine forest required by monarchs for overwintering is restricted to only five mountain peaks and is being rapidly destroyed. Between 1971 and 1999, 44% of the forest within three protected butterfly reserves was thinned or cleared. When the forest is thinned, the protective function of the canopy is reduced and butterflies may be forced to aggregate on the ground or on low bushes. The combination of intense logging and a severe winter storm resulted in an average colony mortality of 75% in January 2002 (Oberhauser and Solensky 2004). Furthermore, climate change models predict that central Mexico will get wetter and less hospitable for overwintering monarchs (Oberhauser and Peterson 2003).

Several monarch butterflies *(Danaus plexippus)* rest together on the trunk of a tree. Monarch butterflies are found throughout North America, and every autumn millions of monarchs head south to spend the winter in hibernation in the warm southern USA and northern Mexico. Photographed in Mexico.
Inset: Students work on the Awesome Aggregations activity.

FIGURE 1

Monarch butterfly template (half size).



Model butterfly construction

To prepare for the Awesome Aggregations activity, teachers should construct model butterflies from goldenrod indicator paper, available at most office product stores, which turns bright red when a basic solution is applied. Teachers should photocopy eight butterfly templates (Figure 1) onto sheets of goldenrod paper and give these templates to students for preparation of the models (Figure 2). Instead of using valuable class time to cut out and fold the butterflies, we recommend that students work on them as a homework assignment or when they have finished in-class work ahead of schedule.

Inquiry activity: Awesome Aggregations

To put this activity in context, teachers can start with a brief slide show describing the life cycle and migration routes of monarch butterflies. Teachers should show several photographs of monarch aggregations (see "On the web" at the end of this article for a list of websites about monarch aggregation) and briefly discuss three possible adaptations for group living in monarchs: (1) locating mates; (2) protection from predators; and (3) staying dry during winter storms. Next, teachers should explain that students will test the following question: "Are monarch aggregations a behavioral adaptation for protection from winter storms?"

Before beginning the activity, teachers should familiarize themselves with the assessment rubric found in Figure 3 and can also share with students how they will be assessed throughout the inquiry. The slide show and the first two parts of the inquiry ("Setup" and "Rainstorm"; Figure 4, p. 48) take approximately 40 minutes. Because there are several parts to this activity, we found it helpful to give at least minimal verbal instructions before each section. For example, after students have completed the second part of the activity ("Rainstorm"; Figure 4), teachers should remind students that the distance from each butterfly to the edge of the cluster should be measured *before* each butterfly is removed from the wall. Likewise, students should understand the importance of carefully recording each butterfly's ID number.

Data from the experiment conducted in our classroom supported the hypothesis that butterflies in the center of a large aggregation are more protected from the elements than butterflies on the edge (Figure 5, p. 50). Class data to the contrary are likely due to coding errors (e.g., wrong position assigned); teachers should ask students to double-check their work if unexpected results are found.

FIGURE 2

Materials and procedures for constructing butterfly models.

Materials:

- Sheets of goldenrod paper with butterfly outlines printed on them
- A pair of scissors
- Double-sided mounting tape

After carefully cutting each butterfly out of the main sheet:

1. Fold each butterfly in half along the A-axis so the printed side is face up.
2. Fold the wings in the opposite direction along the B-axis.
3. Fan the wings out slightly.
4. Attach a small piece of tape to the blank side of the body.

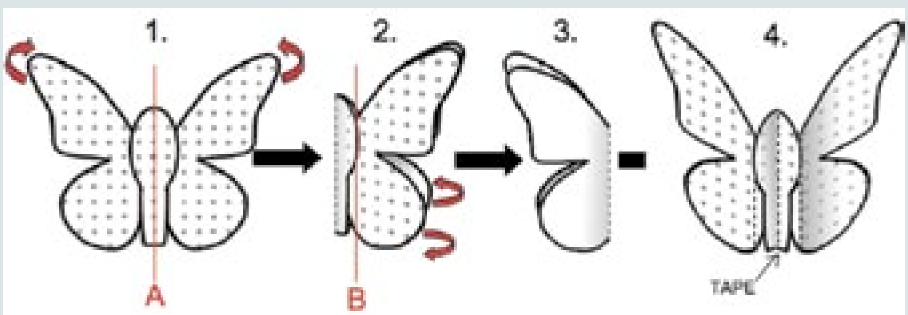


FIGURE 3

Assessment rubrics.

Group assessment rubric.

Criteria (B = Beginning; D = Developing; M = Mastery)	Group A	Group B	Group C	Group D	Comments
Works cooperatively					
Makes good use of time					
Measures/counts accurately					
Completes data sheets correctly					
Chooses appropriate graph					
Includes required elements in graph (e.g., axis labels)					

Individual assessment rubric.

Content	Mastery	Developing	Beginning
Vocabulary	Good understanding of the terms *overwintering, aggregation, migration,* and *adaptation*	Partial understanding of the terms *overwintering, aggregation, migration,* and *adaptation*	Little or no understanding of the terms *overwintering, aggregation, migration,* and *adaptation*
Interpretation	Uses data to accept or reject hypothesis	Uses guesses to accept or reject hypothesis	Cannot accept or reject hypothesis
Natural selection and behavior	Good understanding that some behaviors (e.g., aggregations) have adaptive value	Partial understanding that some behaviors (e.g., aggregations) have adaptive value	Little or no understanding that some behaviors (e.g., aggregations) have adaptive value
Finite resources and population growth	Good understanding that monarch populations are regulated in part by the availability of overwintering habitat	Partial understanding that monarch populations are regulated in part by the availability of overwintering habitat	Little or no understanding that monarch populations are regulated in part by the availability of overwintering habitat

Discussion and extensions

To further assess student knowledge on aggregation, teachers should lead a class discussion once students have completed their graph, based on the following questions:

- Did the class data support the hypothesis (that monarch aggregations are a behavioral adaptation for protection from winter storms)?
- How might our results have differed if we had investigated real butterflies instead of using models?
- How would logging and agriculture (i.e., removal of the forest) change the survival value of large aggregations?

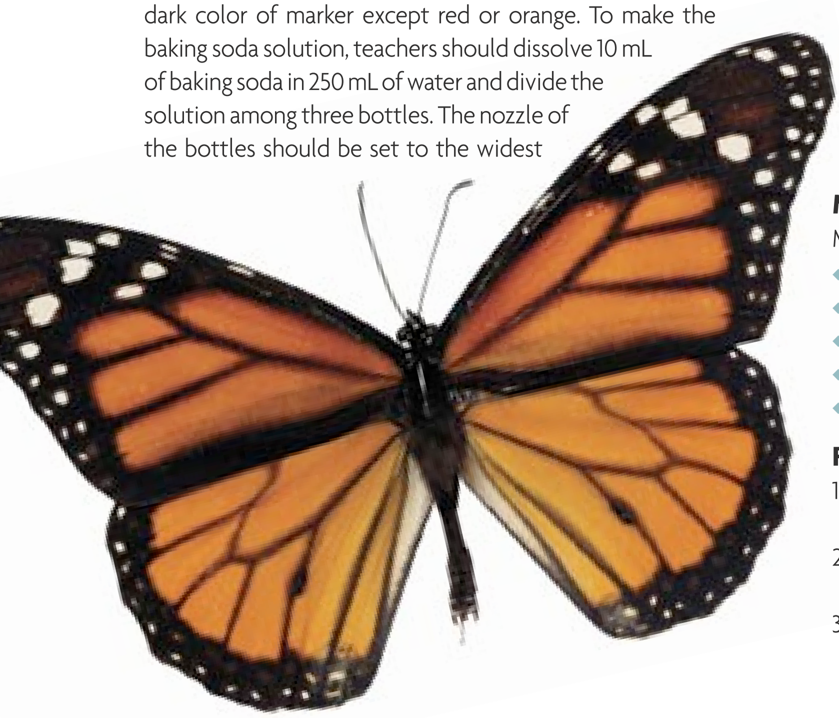
As a further extension to the activity, the following questions can be provided as homework:

1. Recall that other explanations for the evolution of group structure in monarch butterflies include protection from predators and finding mates. Do our results exclude the possibility that those other explanations are true? Explain your reasoning.
2. If there are no trees available, monarchs will cluster on almost any available surface.
   a) How do you think our results would differ if the monarchs were aggregated on the ground?
   b) How would you test this question?

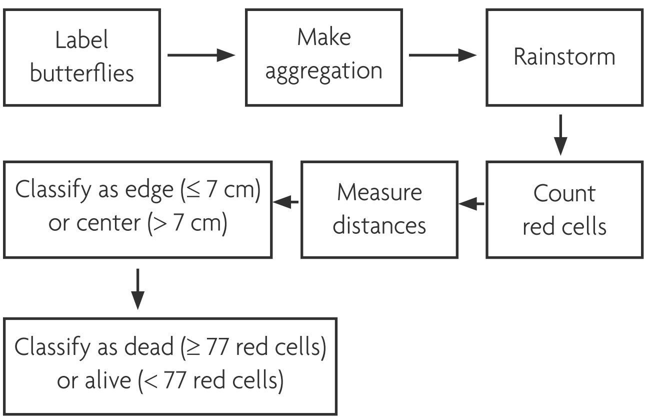
FIGURE 4

Materials and methods for Awesome Aggregations activity.

Teacher tips: To facilitate the activity, teachers should provide any dark color of marker except red or orange. To make the baking soda solution, teachers should dissolve 10 mL of baking soda in 250 mL of water and divide the solution among three bottles. The nozzle of the bottles should be set to the widest "spray" option. The butterflies need to be completely dry before the "Measuring and counting" section. The red color is stable, so butterflies can be analyzed in a later class period. [**Safety note:** All students should wear safety goggles and chemical resistant gloves. Be sure to dispose of all materials properly.] CAUTION



Awesome Aggregations activity.
Summary of procedures:



Materials: Setup

Make sure your group has:

- 50 butterfly models
- 6 waterproof markers, for labeling butterflies
- 1 paper bag, for carrying butterflies

Procedure: Setup

1. Label the back of each butterfly with your Group ID (A, B, C, or D) and a unique number from 1–50 (e.g., A-1, A-2).
2. When your butterflies are numbered, put them in a paper bag labeled with your Group ID (A, B, C, or D).

Materials: Rainstorm

Make sure your group has:

- Paper bag containing 50 butterflies
- 1 spray bottle containing baking soda solution
- 1 waterproof marker
- Safety goggles for each student
- Large piece of art paper and double-sided tape

Procedure: Rainstorm

1. Attach the art paper to the wall with tape, placing its center about 1 m from the floor.
2. Make sure your group is at least 2 m from the other groups. Mark a small "X" on the paper, 90 cm from the floor.
3. Use a marker to color in the diamond on the first butterfly. Attach that butterfly to the X on the wall with the double-sided tape on the back of the model. Add butterflies to the cluster in a roughly circular fashion (try to keep an equal number of butterflies on all sides of the central butterfly). Keep the models tightly packed: wings should overlap slightly, but bodies should not. Fan the wings out slightly.
4. Draw a chalk or marker outline around the butterfly cluster. Keep the outline as close as possible to the butterflies (see photo).
5. Select one person from your group to be the rain cloud. The rain cloud should stand directly facing the butterfly cluster, then take one big step to the right and two big steps back. The rain cloud, now about 1 m to the right of the cluster and 1 m back from the wall, should then turn to face the edge of the cluster. After the rain cloud puts on the safety goggles, he or she should spray the butterflies 10 times.

Materials: Measuring and counting

Make sure your group has:

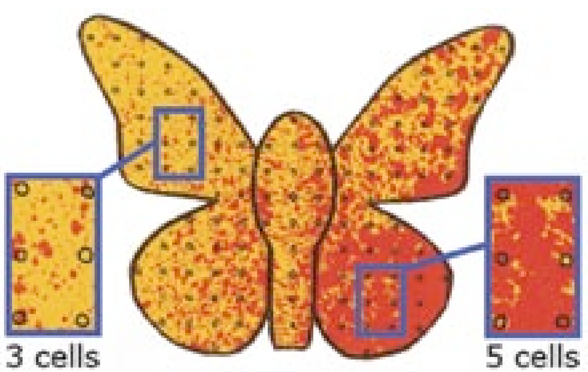
- 2 measuring tapes or rulers
- 2 clip boards
- 5 group data sheets
- 1 summary data sheet
- pencils or pens
- 2 calculators
- 1 sheet of graph paper per student

Procedure: Measuring and counting

1. Decide who gets the following jobs:
   a. One data recorder
   b. Two distance measurers
   c. Cell counters (the rest of your group)
2. Remove the butterflies, starting at the edge of the cluster. Before each model is detached from the tree, measure the distance from the diamond (the fourth cell from the top in the central, vertical line of cells) in the center of each butterfly to the nearest segment of marker marking the outside of the cluster. One person can work on each side of the cluster. Call the numbers out to the data recorder.

Group data sheet (Sheet __ of 5).				
GROUP ID:				
Monarch ID	Distance from edge (cm)	Position in group (edge or center)	Number of red cells	Dead or alive?

3. When the first 10 butterflies have been removed from the wall, give those 10 models and the associated group data sheet to the cell counters. The cell counters should count the number of cells (circles printed on the front of the butterfly) containing any amount of red and enter the number on the group data sheet. For example:



   The counters might want to put a line through each counted cell. There are 110 cells on each butterfly.
4. The measurers and data collector should help the counters when all the butterflies have been removed from the wall.
5. Classify each butterfly as being on the edge (≤ 7 cm from the outside of the aggregation) or in the center (> 7 cm from the outside of the aggregation).
6. Classify each butterfly as dead (≥ 77 red cells) or alive (< 77 red cells).
7. Fill out the summary data sheet.

Summary data sheet.			
GROUP ID:			
Position in group	Total number of butterflies	# Dead butterflies	% Dead butterflies
Center (> 7 cm from edge of cluster)			
Edge (≤ 7 cm from edge of cluster)			
	TOTAL = 50		

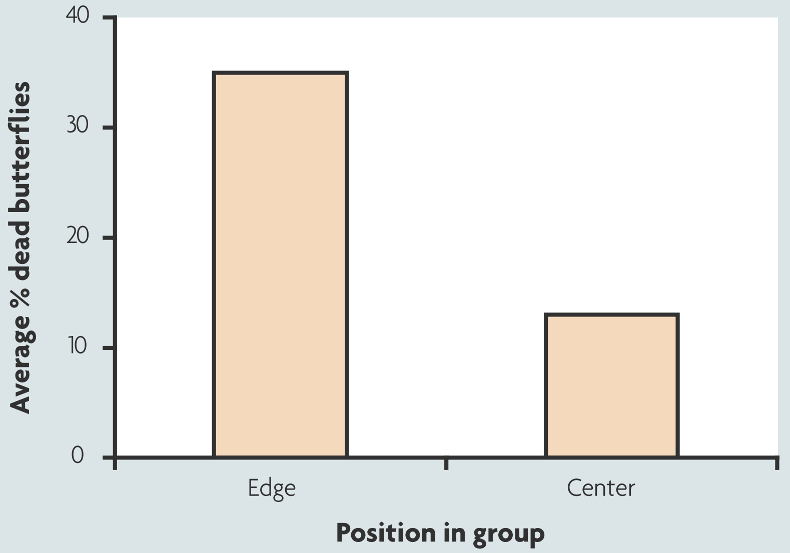
Procedure: Counting and reporting

1. Enter your summary data in the master data sheet on the overhead projector.
2. If the other groups are still counting, go to their table and help them count.
3. Summarize the data in the master data sheet with an appropriate graph on graph paper. You can work together as a group, but each person needs to make his or her own graph.

Master data sheet.		
	% Dead butterflies	
Group ID	Edge	Center
A		
B		
C		
D		
Average		

FIGURE 5

Sample graph based on data from master data sheet.



In our class, some responses to homework question 2 were: "If monarchs rested on the ground, a larger surface area would be exposed to the rain. To test this, we would spray our models more directly rather than from an angle." "The results would differ because butterflies would be a little more spread out on the ground…You can test this question by collecting data when the butterflies are clustered on the trees, then collect data when butterflies are clustered on the ground." "People would step on them because they have no protection...We can put butterflies in random walking areas." If time permits, the logical extension of this lesson would be to allow students to test the experimental designs they suggest in response to the homework question.

The most familiar examples of group living in insects are the cooperative associations of social insects such as bees and ants. Although monarch butterflies are one of the most beautiful and well-known insects in North America, most students think of monarchs as strictly solitary and are unaware of the significant threats to monarch overwintering habitat. This inquiry reinforces the amazing diversity of the animal kingdom, provides a concrete illustration of the importance of evolutionary biology to wildlife conservation efforts, and serves as an example of the type of basic research done by real-life biologists all over the world. Perhaps most importantly, students will be amazed to learn that an animal living right in their backyard has such an exotic lifestyle! ■

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References

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Larsen, K.J., and R.E. Lee, Jr. 1994. Cold tolerance including rapid cold-hardening and inoculative freezing of fall migrant monarch butterflies in Ohio. *Journal of Insect Physiology* 40: 859–864.

National Research Council (NRC). 1996. *National science education standards*. Washington, DC: National Academy Press.

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Oberhauser, K.S., and M.J. Solensky, eds. 2004. *The Monarch butterfly: Biology and conservation*. Ithaca, NY: Cornell University Press.

On the web

Pictures of aggregations and of fragmented forest: *http://wildlife.wisc.edu/courses/375c/Mexico/Pages/Photo%20Album/photoalbumsidetrips.htm*

Life cycle, global distribution, and overwintering aggregations: *www.monarchlab.org/biology/adult_overwintering.htm*

Fall and spring migration maps: *www.monarchwatch.org/tagmig/index.htm*

National Science Education Standards (NRC 1996) addressed by this inquiry.

Content Standard A: Science as Inquiry (pp. 175–176)

Content Standard C: Life Science
- Biological evolution (p. 185)
- Interdependence of organisms (p. 186)
- Behavior of organisms (p. 187)

Content Standard G: History and Nature of Science
- Science as a human endeavor (pp. 200–201)

Program Standard C: Integration of Science and Mathematics (pp. 214 and 218)