

Investigating Aquatic Insect Emergence: A Demonstration of the 5E Learning Cycle

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ABSTRACT

Traditionally, exploration of ecosystems in the context of undergraduate education has been restricted to connections within conventionally defined habitats (i.e., within a stream, within a forest). Further, instruction regarding the aquatic-terrestrial interface has emphasized directional inputs from land to water. However, a relatively new body of research has characterized reciprocal interactions and draws attention to fluxes from water to land, including the emergence of aquatic insects that serve as prey for terrestrial predators. We present a guide to an inquiry-based lesson for undergraduate biology that explores interactions and connections across aquatic and terrestrial habitat boundaries. The focus is on cross-habitat linkages within ecosystems, specifically addressing the question, *What is the role of insect emergence in connecting the web of life linking aquatic and terrestrial habitats and organisms?* Students (1) engage with a documentary film, (2) explore insect emergence and make observations of riparian insectivores, (3) explain the collected data, (4) elaborate on alternative study designs and a measure of ecosystem health, and (5) evaluate their new understanding. This lesson addresses core concepts and competencies for undergraduate biology education, as identified in the *Vision and Change* report.

Key Words: aquatic insects; emergence; inquiry; vision and change; 5e learning cycle.

○ Introduction

Ecologists have long recognized the role of terrestrially derived inputs of plant material and invertebrates to streams; however, more recently the focus has turned to the flux of materials and organisms in the opposite direction, from stream to land (Baxter et al., 2005, Sabo & Hoekman, 2015). The emergence of aquatic insects in an aerial adult form represents an important link between streams and adjacent riparian habitats, facilitating the flow of energy and nutrients from aquatic to terrestrial food webs. Adult aquatic insects are important food subsidies for a range of riparian

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predators, including lizards, birds, bats, and spiders (Baxter et al., 2005). Some estimates indicate that only about 3 percent of emerged aquatic insect biomass returns to the stream to lay eggs because the majority is consumed (Jackson & Fisher, 1986). The focus here is on one specific predator, the spider, because it is relatively easy to observe and identify. Populations of various spiders are known to closely track aquatic insect emergence (Marzcek & Richardson, 2007). The family Tetragnathidae, because of its high mobility, can exploit short periods of emergence in localized areas. In fact, spider counts may be a useful method for assessing stream integrity and habitat quality, and are less labor-intensive than other sampling methods that focus on invertebrates or fish (Benjamin et al., 2011).

We present a guide for an inquiry-based laboratory and field lesson for undergraduate biology courses at any level. Students should have a basic understanding of the scientific method and a high school biology level background, but with more detail added, this lesson can be used to teach students with no preexisting knowledge of the topics covered. The focus is on cross-habitat linkages within ecosystems, specifically addressing the question, *What is the role of insect emergence in connecting aquatic and terrestrial habitats and organisms?* The challenge is to change how students think about the environment we live in: not as an organized puzzle built from discrete pieces with defined boundaries, but rather as a colorful soup, composed of multiple layers of flavor and a taste that becomes more defined the longer you stir it.

○ Objectives

This lesson will teach students several of the core concepts and address competencies for biology education identified in the *Vision and Change* report (AAAS, 2011). The most relevant concepts are: pathways and transformations of energy and matter (i.e., biological systems

grow and change by processes based upon chemical transformation pathways and are governed by the laws of thermodynamics), and systems (i.e., living systems are interconnected and interacting). The most relevant competencies are: the ability to apply the process of science, the ability to use quantitative reasoning, and the ability to understand the relationship between science and society.

○ Description of Lesson

This laboratory and field lesson follows the stages of the 5E Learning Cycle: engage, explore, explain, elaborate, and evaluate.

Engage (~30 minutes)

This lesson will challenge students to answer the question, What is the role of insect emergence in connecting aquatic and terrestrial habitats and organisms? The instructor should lead a discussion to elicit prior knowledge from the students, addressing the following items:

- Name and describe the different organisms in and around a stream or river.
- List examples of specific connections between rivers, streams, and the land.

Have students complete a pre-assessment, drawing on ideas shared during the discussion and their own previous knowledge. Provide an image of a stream and surrounding riparian zone, and ask students to draw a diagram of an aquatic-terrestrial food web (for an example, see Figure 1). Next, have students watch the film *RiverWebs* (Monroe, 2008). This award-winning documentary is a tribute to pioneering stream ecologist Dr. Shigeru Nakano. At heart, it is an inspiring narrative that highlights the web of ecological connections between water and land, the similarly connected community of scientists that extends across cultures, and the connections humans share with environments like streams and forests. Through this story and impressive videography, students learn about the diversity of life in and around streams, as well as new ways of thinking about ecosystems. Revisit the two items discussed at the beginning of the lesson,



Figure 1. Base image of a stream and riparian zone. A sketched food web shows potential pathways of energy and nutrients.

and allow students to add to their aquatic-terrestrial food web using a different colored writing implement.

The *RiverWebs* DVD can be ordered through the non-profit organization Freshwaters Illustrated. However, if instructors are unable to purchase this DVD, we recommend supplementing with YouTube video clips. The video clips lack the human element of the *RiverWebs* film, but can still add to the discussion. Links to relevant content are provided below:

1. *RiverWebs* film trailer, 2:49 in length: <https://www.youtube.com/watch?v=fs1AZrhhXtw>
2. About NABS (North American Benthological Society), 5:04 in length: https://www.youtube.com/watch?v=dChyTqgP_cU
3. Educational segments from the *RiverWebs* film, 3:42 in length: <https://www.youtube.com/watch?v=hETqalpejiU>
4. Dragonfly emergence segment from the BBC documentary, *Life in the Undergrowth*, 2:02 in length: <https://www.youtube.com/watch?v=CyIF7eX6qmo>

Lastly, because an understanding of the ecological linkages being explored requires recognition of how the life cycles of insects connect land and water, challenge students to build a concept map (Angelo & Cross, 1993) of insects in different stages of their life cycles using photos (see the Penobscot County SWCD, 1994, identification guide for a selection of images). It is important to distribute the photos in a random stack, allowing students to create the connections and groupings themselves. Ask students to share and compare their concept maps (for an example, see Figure 2). Discuss the process of metamorphosis, and describe the complex life cycles of aquatic insects. Hemimetabolous insects (from orders such as



Figure 2. A sample student concept map. This student does not recognize the larval and adult forms of the focal insect life cycles. A comprehensive map will have the larval stages matched with the adult stages while also distinguishing the aquatic and terrestrial stages. Common misconceptions encountered during this exercise: insects have only one life stage, insects without wings will be wingless adults, adults with wings are never aquatic, and insects do not transition from the aquatic to terrestrial environment.

Ephemeroptera, Odonata, and Plecoptera) undergo incomplete metamorphosis. The wings develop externally, and the immature individuals (called instars) have legs. Holometabolous insects (from orders such as Coleoptera, Trichoptera, and Diptera) undergo complete metamorphosis. The wings develop internally, and the immature individuals (called larvae) resemble worms. This concept mapping activity is intended to be a discovery experience. It is unlikely that students will recognize the images of immature and adult forms as the same organism; the surprise will generate interest, and prompt students to revisit and modify their concept maps.

Explore (~120 minutes)

For students, the *explore* stage is an opportunity to foster a sense of discovery and act the part of a scientist. For instructors, it is a time to guide and facilitate, providing background information and resources, but challenging students to develop a hypothesis and study design themselves. The question to be addressed is, What is the role of insect emergence in connecting aquatic and terrestrial habitats and organisms within an ecosystem? Field investigations will require access to a local river or stream; they may be carried out as a class, in small groups, or individually. The following information is intended for the instructor, but may be disclosed to students as well.

Emerging aquatic insects can be sampled using floating emergence traps adapted from Malison and colleagues (2010) or sticky traps (Smith et al., 2014). The floating traps are constructed from

a frame of PVC pipe, with swimming pool noodles wrapped around the base, and a fine mesh tent to capture insects (Figure 3). Floating traps need to be secured to a post or rebar when set out in the water. Insects can be collected in the bottom of the bottle trap (if used), which can be detached and brought back to the laboratory. However, we recommend that students collect the adult insects from the traps using an aspirator (Carolina Biological Supply, Burlington, NC, USA). The sticky traps are constructed from petri dishes coated with adhesive, and attached to a PVC pole with Velcro (Figure 4). Traps can be spaced along the bank, and in the water of a shallow stream or river, with the base of the pole driven securely into the ground. Insects should collect in the sticky petri dishes, which can be detached, covered with lids, and brought back to the laboratory. Both trap types are established, scientific methods for sampling emergence (Malison et al., 2010; Smith et al., 2014; Baxter et al., in press).

Students must provide a justification for their proposed study design, showing evidence of background research and planning, and explain the reasoning behind the following decisions:

1. What type of emergence trap will you use?

The advantage of the floating traps is the ability to observe live insects and collect good, whole specimens. Floating traps can be deployed in the river or stream, and partly onto the bank. Sticky traps can be set up on the bank or in shallow water, and are relatively easier to build and transport.

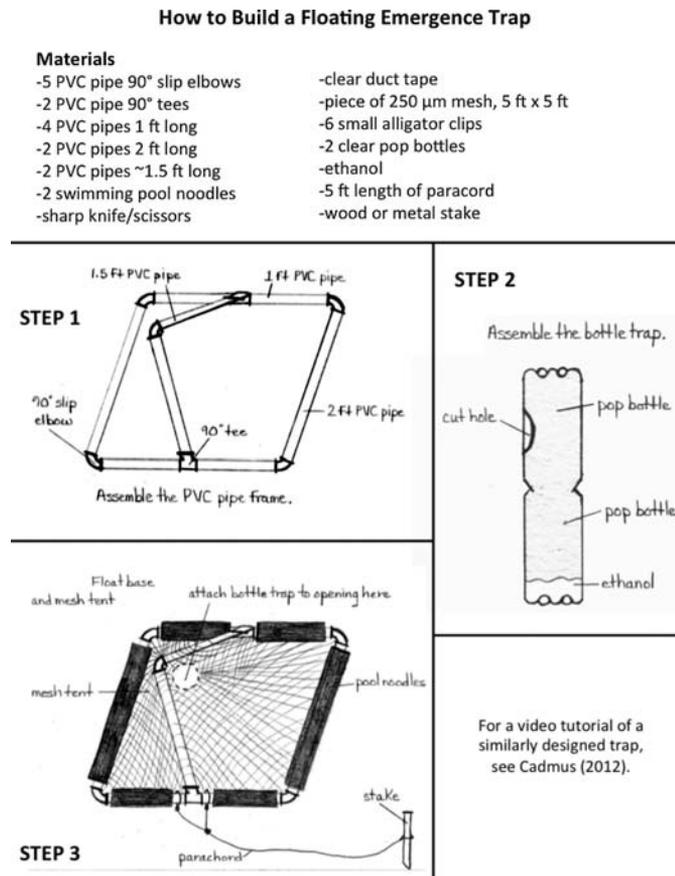


Figure 3. Guide to how to build a floating insect emergence trap.

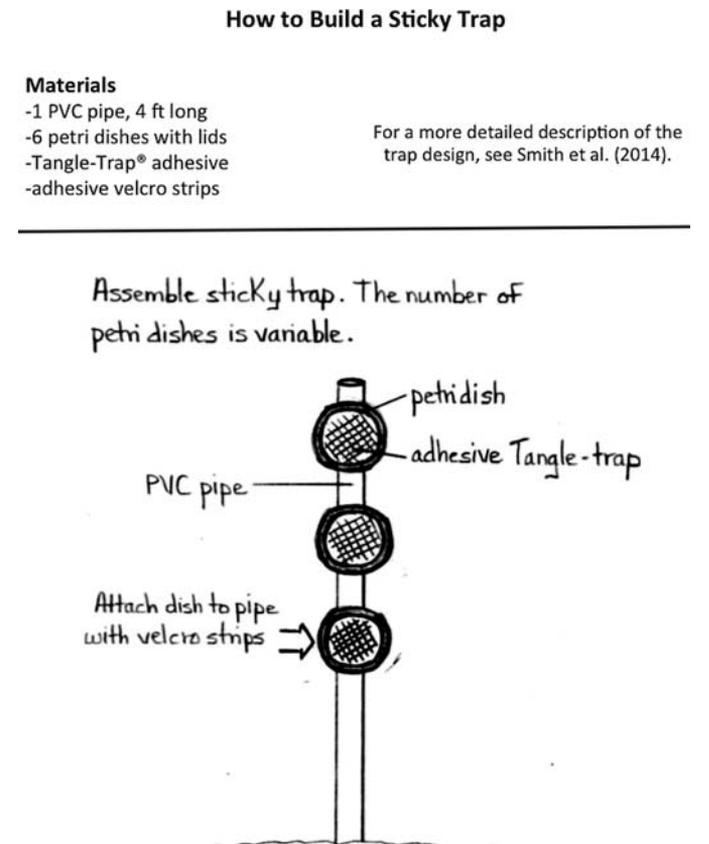


Figure 4. Guide to how to build a sticky trap for insects.

2. Where will you set the emergence traps, and how many will you use?

Trap placement is important, as emergence varies with distance from stream edge and between pool and riffle habitats (Malison et al., 2010). Floating traps set mid-channel collect proportionately more insects of the orders Trichoptera, Ephemeroptera, and Diptera, whereas traps set against the bank collect proportionately more Plecoptera (Malison et al., 2010). Emergence can be greater from pool versus riffle habitats (Iwata, 2007), but can also be high from habitats like floating mats of algae or aquatic vegetation (Power et al., 2004), and certain taxa may prefer one habitat type to the other (Malison et al., 2010). There are many spatial aspects of emergence that students can explore, not only between stream reaches but also within a single reach.

3. When will you sample, and how long will the emergence traps remain set?

In many temperate watersheds, the best time of year to sample is the spring, when emergence rates are high (Nakano & Murakami, 2001) and there is a strong chance of trap success. However, emergence is a year-round phenomenon, and some insects (e.g., winter stoneflies from the family Capniidae) only emerge in the middle of winter and may provide a crucial, seasonal food resource to streamside predators such as resident birds (Nakano & Murakami, 2001). Depending on time constraints set by the instructor, there are numerous temporal aspects of emergence that students can investigate. To obtain a representative sample from the emergence traps though, we recommend setting them for a period of 1–3 days. For further, detailed discussion regarding trap types, placement, replication, and timing, see Baxter et al. (in press).

To answer the question, What is the role of insect emergence in connecting aquatic and terrestrial habitats and organisms?, students need to go beyond collecting aquatic insects and quantitatively

measure the connection from the terrestrial side. We recommend counts of spiders. A procedure is described here, but students can also search the literature and review other methods; for example, the study by Benjamin and colleagues (2011), who measured the effects of nonnative trout on riparian spiders via reduced insect emergence, provides a good example. In either case, instructor supervision may be required as spider surveys are best conducted after sunset. Students will need a 10-meter length of string or a measuring tape, a good flashlight or headlamp, a classification key (see Figure 5 for an example), and a data sheet (see Figure 6 for an example).

A transect (i.e., a straight line path that can be walked along) should be established 10 m upstream and 10 m downstream from an insect trap. Students need to walk the transect line and scrutinize the area 2 m on either side of the line, looking for spiders and webs. Students do not need to handle or disturb the spiders, which should help avoid possible issues associated with arachnophobia, though the exercise may also present an opportunity to educate students about dangerous spiders. Nevertheless, the dominant groups they will encounter during such surveys are innocuous. Several dominant families of web-weaving spiders can be identified to the family level with relative ease, based upon body form and web characteristics (Figure 5; see also DMNS, n.d., and Ubick et al., 2005).

Searching for spiders during the daytime may be more challenging, but to overcome this difficulty, students can “beat” riparian vegetation with a net (this may also reveal adult insects on the vegetation). Students can also quickly and effectively search for webs in the vegetation, and webs will commonly have adult aquatic insects ensnared in them. Recognition of how dense spider webs are along and over streams can be a good representation of their abundance. Again, we promote the use of spiders because they are relatively easy to observe and identify, but students may encounter other riparian predators, like insectivorous birds, that they may want to document. With slight modification to the data

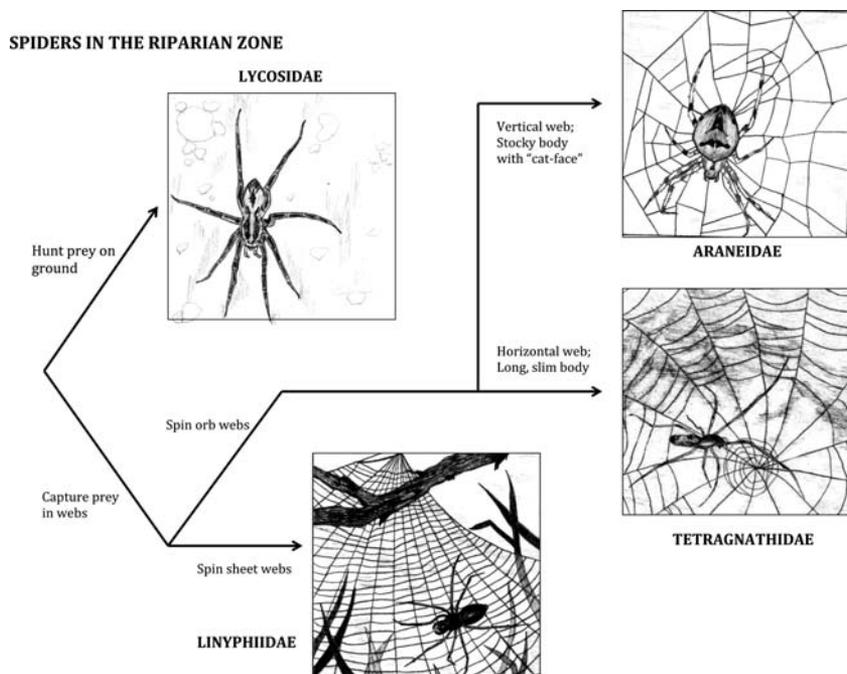


Figure 5. Identification key for the common families of riparian spiders found along streams in temperate zones. Also see DMNS (n.d.) and Ubick et al. (2005).

Field Datasheet

Stream/River name: _____ Date: _____
 Personnel: _____ Start time: _____ End time: _____

Temperature: _____ °F or °C (circle one) Cloud cover: _____ %

Wind speed (circle one):
 Calm - *no wind*
 Light breeze - *leaves rustle, wind felt on face*
 Gentle breeze - *leaves and twigs in motion*
 Moderate breeze - *wind raises dust and loose paper*
 Strong breeze - *trees sway, wavelets form on water*

Insect emergence

Tally the number of individuals and write the total after the name of the order Total number counted: _____

Ephemeroptera:	Plecoptera:	Trichoptera:	Diptera:	Odonata:		Other/Unknown:
				<i>Anisoptera</i>	<i>Zygoptera</i>	

Riparian spiders

Tally the number of individuals and write the total after the name of the order Total number counted: _____

Tetragnathidae:	Araneidae:	Lycosidae:	Linyphiidae:	Other/Unknown:

Additional notes/observations: _____

Figure 6. Field data sheet for insect emergence and riparian spider counts.

sheet, bird counts can be incorporated, and may even replace spider counts (see Ralph et al., 1995, for bird count methods).

Explain (~50 minutes)

At this stage, students must organize, process, and make sense of information gathered in the field. Collected insects should be identified to the order level with a classification key (Stroud Water Research Center, 2015; and see Figure 7), and the information recorded. Instructors can ask students to develop their own data sheet or supply a template (Figure 6). Students need to analyze, summarize, and present the data comparing the insect and spider assemblages. There are different methods for completing these tasks (see Figure 8 for one example), and students should defend their choice with a list of advantages and disadvantages.

Elaborate (~20 minutes)

Ask students to propose a new study design to answer these additional questions:

1. How different is the insect assemblage between streams and rivers within the same watershed?

2. When does the highest rate of insect emergence occur, and how does this affect riparian predators?
3. How far do emergent adult insects disperse away from a stream?

Using the combined data of the whole class, reanalyze the collected data with a focus on members of the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), which are widely regarded as indicators of healthy aquatic habitats (Barbour et al., 1999). Additionally, explain that other taxa (e.g., Chironomid midges and the order Diptera) are pollution-tolerant species. Given this new information, have students evaluate the health of the stream or river being investigated.

Evaluate (~20 minutes)

Challenge students to critique the study design, identifying areas of weakness, suggesting improvements, and determining the validity of their results. Further, have students propose a new study to collect additional evidence that would support or challenge their conclusions. As a post-assessment, have students draw a second diagram of an aquatic-terrestrial food web and compare it to their initial depiction. Present the image of the food web featured in the RiverWebs film (Figure 9), and revisit the question: “What is the role of insect emergence in connecting aquatic and terrestrial habitats and organisms?”

AQUATIC INSECT ORDERS

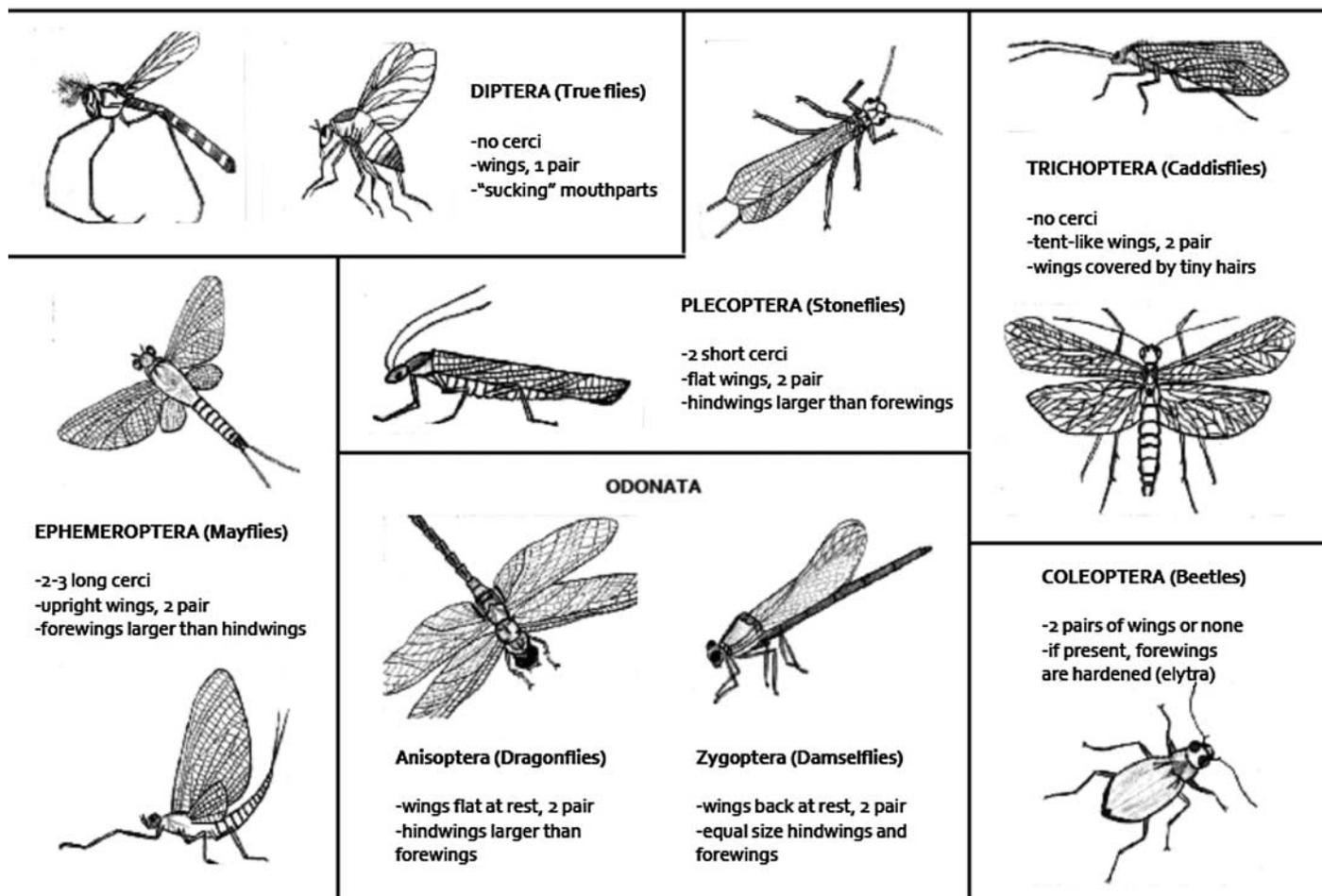


Figure 7. Identification key for the adult forms of common aquatic insect orders.

○ Conclusion

The interface between aquatic and terrestrial habitats is bridged by flows of many materials and organisms; this complex web continues to be untangled by scientists, and presents an engaging mystery for students to investigate. Through this lesson, students not only act and think as scientists do, but learn a set of concepts and competencies fundamental to biology education (AAAS, 2011; Brownell et al., 2014). These are:

1. Pathways and transformations of energy and matter: Students learn this concept by drawing food webs to show the movement of resources between organisms and trophic levels.
2. Systems: Students learn this concept by measuring the spider and insect assemblage of a stream reach to demonstrate that within an ecosystem, interactions among individuals form dynamic networks.
3. The ability to apply the process of science: Students build competency in this area by designing and carrying out an investigation to answer a scientific question.

4. The ability to use quantitative reasoning: Students build competency in this area by analyzing collected data, and using statistics or other tools to answer a scientific question.
5. The ability to understand the relationship between science and society: Students build competency in this area by using the EPT taxa and riparian spiders as indices to assess habitat quality and overall health of a stream or river.

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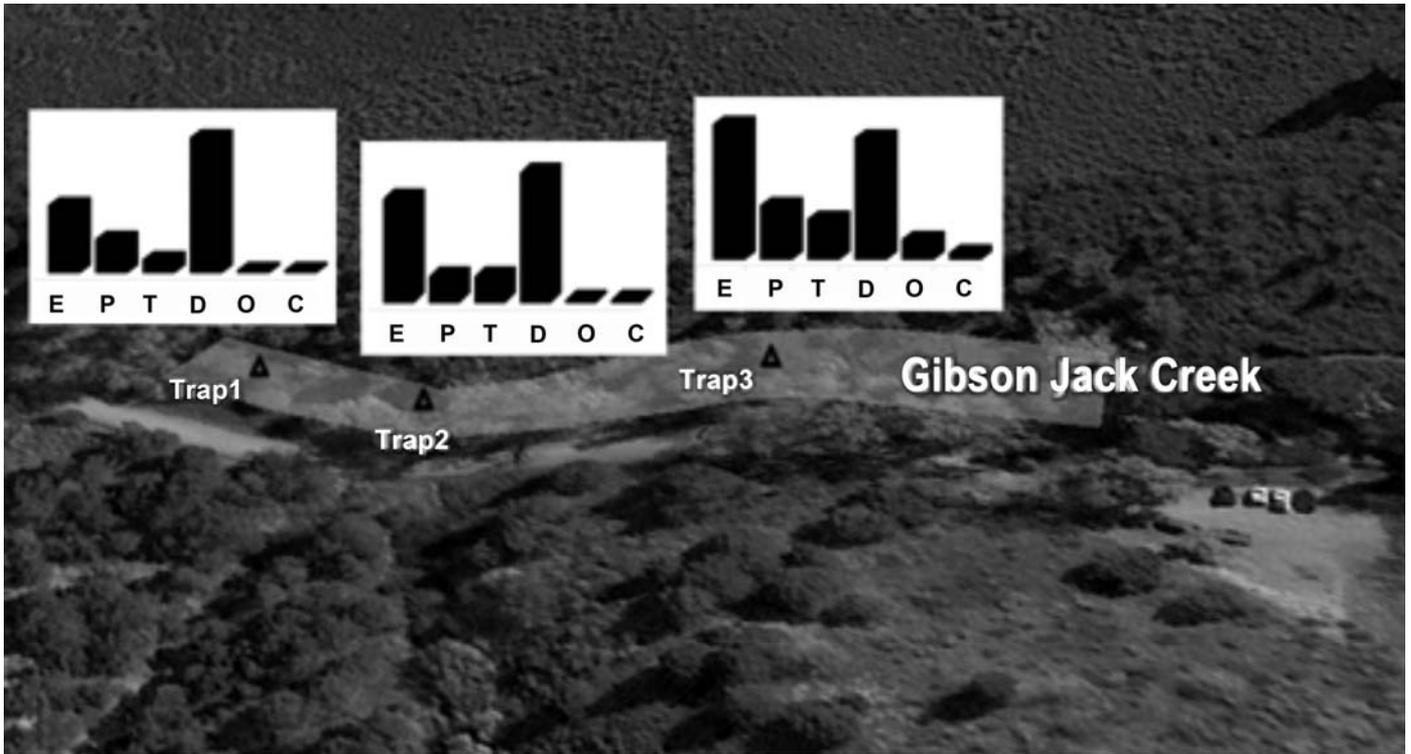


Figure 8. Georeferenced data on the insect assemblage of Gibson Jack Creek, Pocatello, Idaho. The bar graphs show the number of aquatic insects collected. From left to right, the bars represent the orders Ephemeroptera, Plecoptera, Trichoptera, Diptera, Odonata, and Coleoptera. Students may also include data from their spider counts as abundance and/or diversity may vary.

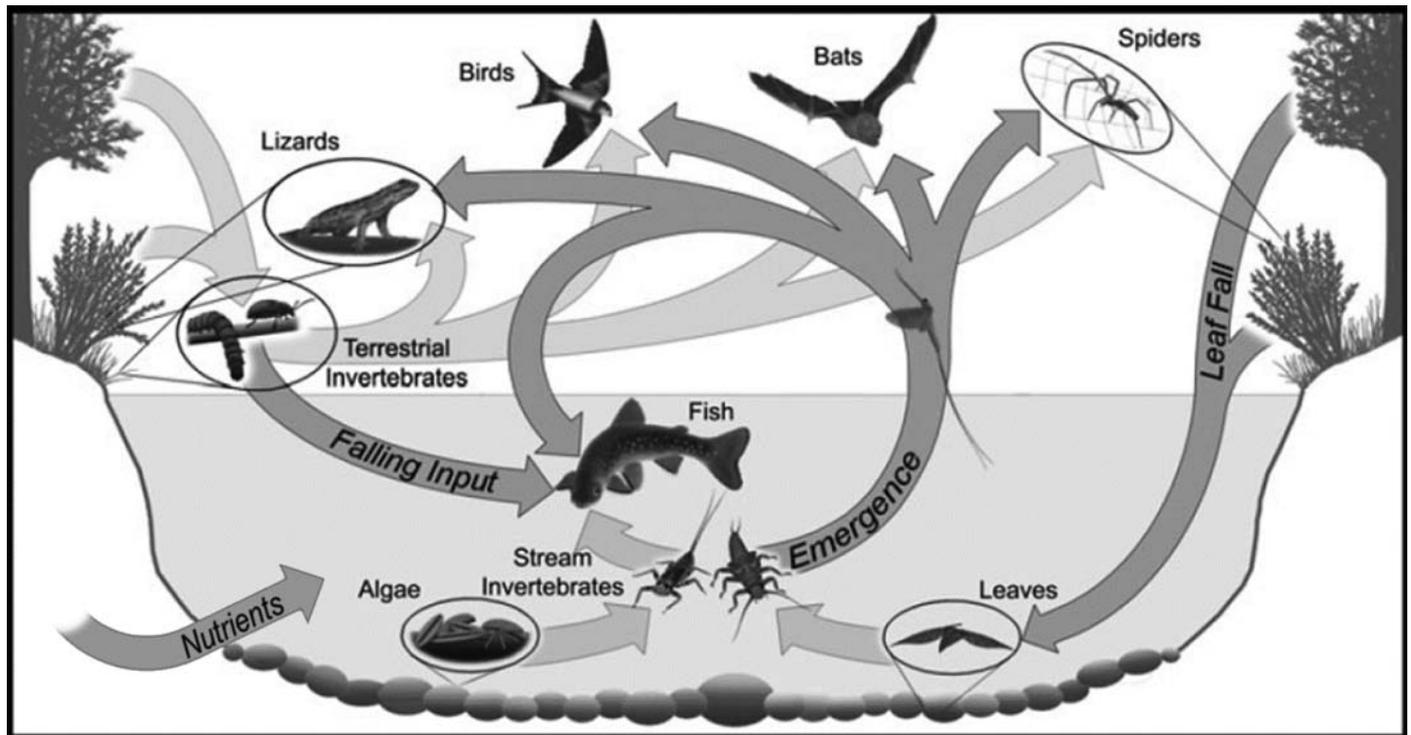


Figure 9. Diagram of an aquatic-terrestrial linked food web. Figure modified from Baxter et al. (2005), with graphics by Jeremy Monroe, Freshwaters Illustrated.

References

- AAAS (American Association for the Advancement of Science). (2011). *Vision and change in undergraduate biology education: A call to action—Final Report*. C. A. Brewer and D. Smith, Eds. Retrieved from <http://visionandchange.org/finalreport/>, “Final Report.”
- Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers*. San Francisco: Jossey-Bass.
- Barbour, M. T., Gerritsen, J., Snyder, B. D., & Stribling, J. B. (1999). *Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish* (2nd ed.). EPA 841-B-99-002. Washington, DC: U.S. Environmental Protection Agency, Office of Water.
- Baxter, C. V., Fausch, K. D., & Saunders, W. C. (2005). Tangled webs: Reciprocal flows of invertebrate prey link streams and riparian zones. *Freshwater Biology*, 50, 201–220.
- Baxter, C. V., Kennedy, T. A., Miller, S. W., Muehlbauer, J. D., & Smock, L. A. (in press). Macroinvertebrate drift, adult insect emergence, and oviposition. In R. Hauer & G. A. Lamberti (Eds.), *Methods in stream ecology* (3rd ed.). San Diego: Academic Press.
- Benjamin, J. R., Fausch, K. D., & Baxter, C. V. (2011). Species replacement by a nonnative salmonid alters ecosystem function by reducing prey subsidies that support riparian spiders. *Oecologia*, 167, 503–512.
- Brownell, S. E., Freeman, S., Wenderoth, M. P., & Crowe, A. J. (2014). BioCore guide: A tool for interpreting the core concepts of vision and change for biology majors. *CBE—Life Science Education*, 13, 200–211.
- Cadmus, P. (2012). DIY aquatic insect floating emergence net with bottle trap. Available from https://www.youtube.com/watch?v=Fu-L5W_NPI4
- DMNS (Denver Museum of Natural Science). (n.d.). *Spider ID*. Available from <http://www.dmns.org/colorado-spider-survey/spider-id/>
- Iwata, T. (2007). Linking stream habitats and spider distribution: Spatial variations in trophic transfer across a forest–stream boundary. *Ecological Research*, 22, 619–628.
- Jackson, J. K., & Fisher, S. G. (1986). Secondary production, emergence, and export of aquatic insect of a Sonoran desert stream. *Ecology*, 67, 629–638.
- Malison, R. L., Benjamin, J. R., & Baxter, C. V. (2010). Measuring adult insect emergence from streams: The influence of trap placement and a comparison with benthic sampling. *Journal of the North American Benthological Society*, 29, 647–656.
- Marczak, L. B., & Richardson, J. S. (2007). Spiders and subsidies: Results from the riparian zone of a coastal temperate rainforest. *Journal of Animal Ecology*, 76, 687–694.
- Monroe, J. (2007). *RiverWebs* [Motion picture]. United States: Freshwaters Illustrated. Available from <http://freshwatersillustrated.org/link/RiverWebs>
- Nakano, S., & Murakami, M. (2001). Reciprocal subsidies: Dynamic interdependence between terrestrial and aquatic food webs. *Proceedings of the National Academy of Sciences*, 98, 166–170.
- Penobscot County Soil & Water Conservation District (SWCD). (1994). Identifying aquatic insects from your pond. Bangor, ME: United States Department of Agriculture, Natural Resources Conservation Service. Retrieved from <http://docplayer.net/21418246-Identifying-aquatic-insects-from-your-pond.html>
- Power, M. E., Rainey, W. E., Parker, M. S., Sabo, J. L., Smyth, A., Khandwala, S., . . . , & Anderson, C. (2004). River to watershed subsidies in an old-growth conifer forest. In G. A. Polis, M. E. Power, & G. R. Huxel (Eds.), *Food Webs at the Landscape Level* (pp. 217–240). Chicago: University of Chicago Press.
- Ralph, C. J., Sauer, J. R., & Droege, S. (Eds.) (1995). Monitoring bird populations by point counts. U.S. Forest Service, General Technical Report PSW-GTR-140.
- Sabo, J. L., & Hoekman, D. (2015). Dynamic systems of exchange link trophic dynamics in freshwater and terrestrial food webs. In T. C. Hanley & K. J. La Pierre (Eds.), *Trophic Ecology: Bottom-up and Top-down Interactions across Aquatic and Terrestrial Systems* (pp. 134–156). Cambridge: Cambridge University Press.
- Smith, J. T., Kennedy, T. A., & Muehlbauer, J. D. (2014). Building a better sticky trap: description of an easy-to-use trap and pole mount for quantifying the abundance of adult aquatic insects. *Freshwater Science*, 33, 972–977.
- Stroud Water Research Center. (2015). Identification guide to freshwater macroinvertebrates. Avondale, PA. Retrieved from http://www.stroudcenter.org/education/MacroKey_Complete.pdf
- Ubick, D. P., Paquin, P., Cushing, P. E., Roth, V., & Dupérré, N. (2005). *Spiders of North America: An identification manual* (No. C/595.44097 S7). Columbia, MO: American Arachnological Society.

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