**Warm-up Activity**: Working with 2 – 3 students sitting near you, discuss your answers to the “Lesson 2 Flipped Learning Assignment”. Construct a diagram showing the pathway of nutrients moving through a stream ecosystem. Consider movement among trophic levels and upstream and downstream movement. Incorporate the effect of an annual spawning migration by a fish such as a Smallmouth Buffalo or Redhorse. Be prepared to share with the class.

Give students 5 – 10 minutes to produce a diagram. Students should illustrate the movement of nutrients upstream from a larger river by migratory fish such as the smallmouth buffalo. The diagram should include energy and nutrients coming into the stream, mostly by allochthonous inputs such as detritus (e.g., leaves, woody debris) and erosion. Little energy is provided via photosynthesis because of shading of the stream and its small size. Students should demonstrate nutrients being captured by bacteria and being transported to various trophic levels, including the feeding interactions of aquatic insects, fish, and other organisms.

**Research Paper Analysis:**

Redhorses are a distinct genus of fish in the Family Catostomidae. Catostomids are distinguished by an inferior mouth with fleshy lips that are used to suck food from the bottom of streams, rivers, and lakes. Therefore, they are commonly referred to as “suckers”. Similar to salmon and smallmouth buffalo, redhorses make annual upstream migrations from reservoirs and large rivers to headwaters where they spawn. In southern Appalachia, the spawning migrations typically occur in early Spring in March and April. Review the paper by Hudson et al. (2023).

How many species of redhorses occur?

*Photo by J. Davis, Wofford College*

22 species occur of which 7 species are considered imperiled.

What was the research objective of this paper?

Little is known about the ecological role and relevance of redhorse in the streams that they inhabit. The authors wanted to quantify and evaluate the ecological relevance of redhorse based upon the amount of nutrients that they may contribute to a stream.

Where was the study conducted?

The Brasstown Creek watershed, which is located in the Hiwassee River Watershed in southern Appalachia, spanning Georgia and North Carolina.

Consider Figure 2 from the paper shown to the right and answer the following questions.

When did redhorse migration begin in Brasstown Creek and when did the migration reach it peak?

Migration began in late March and peaked around late April and early May.

Based upon Figure 2a, hypothesize as to what triggered the redhorse migration.

It appears that migration began following a spike in discharge, corresponding to a flood, and a temperature near 15°C.

The authors considered the ratio of N inputs (i.e., the estimated contribution of N by redhorses) to N exports (i.e., the amount of nitrogen leaving the stream). What does a value greater than 1.0 in figure 2b represent?

The amount of nitrogen added to the stream exceeds the amount of nitrogen leaving the stream.

Describe the relationship of the amount in nitrogen in the ecosystem to the abundance of redhorses.

The amount of nitrogen is related to the abundance of redhorses. As abundance increase, the amount of nitrogen increases as well.

Research has found that the concentrations of nitrogen in streams is higher during late winter and early summer but relatively low during spring in southeastern U.S. streams. This is likely the result of biological demand by organisms such as algae. In the space below, discuss the ecological relevance of redhorse migrations in the spring.

Typically, the amount of nitrogen that is available in streams is low in the spring. Thus, the lack of nitrogen could be a limiting factor in the overall productivity of the stream. Because the redhorse migration adds an abundance of nitrogen at a time when nitrogen may be limited, this may stimulate or increase stream productivity and support other forms of aquatic life. The results of the study can provide an important reason for increased protection of imperiled redhorses and for activities in the watershed that enhance and preserve sucker migrations.

**Application and Evaluation:**

Consider the histogram below. It shows the stream discharge, a measure of the amount of water flowing through the stream, in 2017 and 2018 in the Valley River, North Carolina. The Valley River is within the same watershed as Brasstown Creek, is assumed to represent flows similar to those experienced by Brasstown Creek, and supports a similar community of redhorses. Using the results from Hudson et al. (2013), indicate the typical start of the redhorse migration and the peak of the spawning migration. This can be done by adding a second y-axis to the right of the graph that is labeled abundance.

Students should draw a line that indicates migration beginning in late March and peaking in early-mid May and subsequently declining by late May.

Compare the pattern of discharge between 2017 and 2018. How do they differ?

2017 maintains low flows (baseflow) through much of the season with a small increase in discharge at the start of the migration and a moderate increase in flows in late April prior to the start of peak migration. Flow is low during the entire spawning season (late April to late May). In 2018, discharge is near baseflow from March to late May. There is a significant flood event that occurs in late May.

Speculate as to how the differences in discharge could impact spawning success and nitrogen availability in the stream. Review the discussion in Hudson et al. (2023) to guide you.

If most spawning occurs in May, the low flows for both years could result in successful spawning, resulting in an abundance of nitrogen being added to the stream. Hudson et al. states that “nutrient subsidies from migratory fishes such as redhorses are most likely to be ecologically meaningful during baseflow periods”. However, the strong flood in 2018 could have flushed much of the nitrogen out of the stream before it could be assimilated and used. The article suggests that export of nitrogen was low because of baseflow conditions during the study and that it takes time for introduced nitrogen to become available. Because the majority of nitrogen was introduced in May, it may be likely that much of the nitrogen was lost during the late May flood.

**Critical Thinking and Analysis:** Research suggests that redhorse migration may be triggered by a high flow event in early spring. Peak redhorse migration also occurs when stream temperature nears 15°C. In addition, the timing of spring flows may affect how much of the nitrogen imported by redhorses is actually used in the headwater stream. Consider the figures below showing the observed changes in temperature and precipitation in the southeastern US. Summarize each figure.



![[object Object]]()

Hypothesize how climate change may impact the redhorse migration, nitrogen availability, and headwater streams.

If redhorses migrate based upon temperature cues, then redhorse migration may shift to occur earlier. If redhorse migration is triggered by high flow events, the timing of migration may also be affected. Because migration to headwaters may occur to seek refuge from high spring flows to spawn, spawning success could be impacted. This could decrease the amount of nitrogen that is imported to streams. Lastly, high flow events during or immediately after the spawning season could increase the amount of nitrogen exported or flushed downstream, reducing the amount of nitrogen available to headwater stream ecosystems at a time when organisms are actively acquiring and utilizing nitrogen. The magnitude and timing of nutrient subsidies from redhorses may have important nutrient dynamics implications.

**Modifications and Extensions:**

This activity can be extended by incorporating the findings of White et al. (2023). The paper is similar in its approach but focuses on Smallmouth Buffalo. Students can compare the findings of this paper to Hudson et al. (2023). Because this activity focused on nitrogen, students can investigate if similar effects are found for phosphorus. A similar handout can be created asking students to describe the research hypothesis and experimental approach, interpret figures and data, and draw conclusions from the study.

There are four similar papers on the effect of suckers on nutrient delivery. They are:

Hudson, R.R., K. Wheeler, M. White, and J.N. Murdock. 2023. Migratory redhorse suckers provide subsidies of nitrogen but not phosphorus to a spawning stream. Ecology of Freshwater Fish 33(2):1-12.

White, M., K. Wheeler, R.R. Hudson, and J.N. Murdock. 2023. Salmon of the southeastern U.S.: Sucker migrations deliver resource subsidies to oligotrophic stream. Ecology of Freshwater Fish 32(1):181-194.

Childress, E.S. and P.B. McIntyre. 2015. Multiple nutrient subsidy pathways from a spawning migration of iteroparous fish. Freshwater Biology 60:490-499.

Jones, N.E. and R.W. Mackereth. 2016. Resource subsidies from adfluvial fishes increase stream productivity. Freshwater Biology 61:991-1005.

The pre-class assignment can divide a class into groups and assign groups one of the papers to read and summarize. In class, a jigsaw activity can be conducted, creating groups containing students that each read a different paper. Students can then share findings from the paper and draw connections between the four studies.