CLIMATE CONNECTIONS: CHALLENGES AND SOLUTIONS

OBJECTIVES

Students will be able to interpret and explain charts and graphs of temperature and other environmental measurements through time. They will understand historical and predicted patterns of change in western Montana, and how changes in stream temperatures and flow patterns affect fish and other wildlife as well as humans through impacts to irrigation, flooding, and other water issues.

METHODS

Students working in small groups use the Jigsaw Method to interpret graphs that address various aspects of the topic and then explain what they've discovered to members of the other groups. Much like scientists draw on one another's work to solve a complex problem, the students share information to create a cohesive picture of some cascading effects of climate. They research various ways to mitigate and adapt to climate change effects on streams in western Montana.

Grade level: 7-12

Subject Areas: Biology, Earth Science

Duration: 2 class periods and independent time

Setting: Classroom

MATERIALS

- Student and Figure Pages from this lesson (electronic or printed versions can be used)
- Access to the internet (for creating additional graphs from data and researching science and solutions)
- Climate Connections PowerPoint

BACKGROUND

There is a lot of evidence for how the changing global climate has affected and will continue to affect western Montana, although the tremendous number of variables involved make exact predictions difficult. Patterns of change are not likely to be constant or linear but will vary with local conditions and shorter term climate cycles (such as the El Niño-Southern Oscillation). Projected effects of climate change for our region include the following (see below for sources of this and additional information):

- Warming in western mountains is projected to cause somewhat drier summers and wetter winters, resulting in decreased snowpack, more winter flooding, reduced summer flows, and increased competition for over-allocated water resources in some areas.
- Disturbances from pests, diseases, and fire are projected to have increasing impacts on forests, with an extended period of high fire risk and large increases in area burned.

- More species will be at risk for extinction.
- There will likely be increased damage from floods and storms.
- There may be an increase in some crop productivity at our latitude.

Aquatic systems are expected to show some of the earliest effects of climate change, as stream flows and temperatures respond to changes in snowpack and air temperatures. Changes in stream environments will reflect trends in the climate system, with streams becoming warmer, more variable in flow timing and amount, and subject to more frequent extreme events. Channel structures may also be altered by changes in wildfire regimes, influxes of sediment and woody debris, and from disturbances such as flooding and debris flows.

Although stream changes have already been documented in many areas and are expected to be extensive, changes will not necessarily be consistent across the northern Rockies. Stream systems are changing at different rates and some even show trends opposite to those generally predicted. Monitoring individual streams will not only be important in understanding those particular systems, but will add to the understanding of how characteristics of stream systems may either exacerbate climate change effects or provide some resistance to them.

Coldwater fish species are especially sensitive to changes in water temperature. Many species have a narrow range of temperatures (in some cases just a few degrees) in which they are found. Changes in temperature can also indirectly affect populations by providing more favorable conditions for competitor or predator species. For example, warmer temperatures favor non-native trout species such as brook and brown trout, while native bull and cutthroat trout, especially juveniles, are generally only found in the coldest streams. Predicted increases in stream temperatures indicate greatly reduced habitat available for the native species, particularly for the important and vulnerable juvenile life stages.

For more information on these topics, see the sources listed in the Resource section.

Notes on the structure of this lesson: This lesson uses a version of the Jigsaw Method, in which students in each of 3 groups will interpret graphs to understand an aspect of the effects of climate change in our region on streams and the consequences of those effects. Once all students understand their portion of the puzzle, you'll have them recombine into different groups and explain what they learned to students from the other groups. There are more details on the steps in the Procedure section below. (For general information about use of the Jigsaw Method in teaching science, see http://tiee.ecoed.net/teach/teach_glossary.html#jigsaw.)

Figure Page 1, for Group 1 students**,** has graphs and maps that show how current temperatures compare to historic ones:

- Figure 1A shows that global land and sea surface temperatures in September 2014 were mostly above the average temperatures of 1981-2010.
- Figure 1B shows how annual average global temperatures have varied from the average annual temperature of the 1900's. Global temperatures in the first half of the century were mostly below the average and those in the second half were mostly above it.
- Figure 1C shows that the average annual temperature of the contiguous U.S. has been rising since 1896, although with a lot of short-term variation.
- Figure 1D shows the same results as Graph C for the temperature of western Montana.

Figure Page 2 has maps that show computer model estimates of stream temperatures in the Southwestern Crown of the Continent and a graph of fish species' presence related to temperature (provided by Dan Isaak, U.S. Forest Service, Rocky Mountain Research Station, Boise Aquatic Sciences Laboratory, Boise, Idaho):

- Figure 2A is a map of the average August temperatures of streams in the 1980s.
- Figure 2B shows the predicted average August temperatures in the 2040s for the same streams.
- Figure 2C shows the predicted average August temperatures in the 2080s for the same streams.
- Figure 2D is a graph of the water temperatures in which 2 native and 3 non-native trout species are found in Montana.

Figure Page 3 has maps that show the historic and predicted distributions of native juvenile bull trout in the Southwestern Crown (provided by Dan Isaak, U.S. Forest Service, Rocky Mountain Research Station, Boise Aquatic Sciences Laboratory, Boise Idaho):

- Figure 3A is a map of the likelihood of finding juvenile bull trout in streams in the 1980s, assuming no brook trout were present.
- Figure 3B is a map of the predicted likelihood of finding juvenile bull trout in those streams in the 2040s, assuming no brook trout are present.
- Figure 3C is a map of the predicted likelihood of finding juvenile bull trout in the streams in the 2080s, assuming no brook trout are present.
- Figure 3D is a map of the predicted likelihood of finding juvenile bull trout in streams in the 2080s, assuming brook trout would occur at 50% of the sites within a habitat patch.

Procedure

Part I

1. This lesson starts with a class discussion of the importance of water in your community. Use the following questions and any others you can think of to start the discussion:

   Who depends on water in your community?
   How do they use it?
   How would changes to the amount and timing of the water flowing in local streams affect your community or things they are interested in?
   How might changes in stream temperatures affect those things?

Encourage your students to think about a wide range of direct and indirect uses and users, such as outfitters and other businesses that depend on fisheries, stream recreation, and other tourism-related activities; agriculture, mining, and other industries that use water, etc.

2. Next, explain to your students that they will be exploring some scientific evidence about climate change and its effects right here in western Montana. They will be working in small groups. Each student will be responsible for learning the material in their group well enough to explain it to students from the other groups.

3. Divide students into equally sized groups to form 3 total groups. Assign one group to Figure Page 1, one group to Figure Page 2, and one group to Figure Page 3. In a larger class, you can divide students into 6 groups (two groups to each figure). There are three different parts of the "story" represented by the graphs on the three pages. Students are to interpret the data given in their figures and ensure that each member of their group thoroughly understands and can summarize the information, as they will be required to explain it to someone who has not seen the figures yet. Give students a sufficient amount of time to accomplish this. Make sure all the terms and concepts are understood. **Make sure that students read the figure legends.**

4. Then assign students to new groups, so that each member of each new group has information from a different figure. Therefore the new groups should each contain 3 members, one student having information about Figure Group 1, one from Figure Group 2, and one from Figure Group 3. These students are now to teach each other their "pieces" of information to "piece together the puzzle" with the goal of

understanding the connections between climate change, streams, and fish in the Southwestern Crown in Montana.

5. As a breakdown of the figures, students should be able to conclude that

   (1) Several analyses of temperature data indicate that average global, national, and western Montana temperatures are higher on both a monthly and annual basis than they have been on average in both the past 30 years and the past century or so.

   (2) Average August stream temperatures in the SWCC are predicted to rise over the next 50 years, and be generally higher by 2-4 degrees C by 2080. Native bull trout and cutthroat trout live in the coldest streams, and are found most often in streams below 12° C.

   (3) The probability of finding bull trout in streams in the SWCC decreases from the 1980s to the 2040s, and further declines by the 2080s. In many streams the likelihood decreases from over 90% to less than 10%. The decline is even more dramatic if brook trout (a non-native species which compete with and prey on bull trout) are assumed to be present.

6. After all the final groups have had a chance to share their pieces of the puzzle with one another, discuss the issue with your class as a whole (you can use the Climate Connections PowerPoint so that everyone can see the figures as you discuss them). Ask students to summarize what the scientific data indicate about climate, streams, and native fish in our part of western Montana. Why are bull trout predicted to decline throughout much of their range? Why would the presence of brook trout affect them? Bring the following into your discussion:

   a. What is a scientific prediction? What kinds of factors would go into making predictions about future events like stream temperatures and fish distributions? Do you think such predictions might change over time as scientists gather more data and communicate with one another? If so, how and why?

   b. If air and/or water temperatures are rising, why don't we see a simple straight line as the average temperatures go up through the years? Shorter term and regional trends in climate patterns, such as the El Niño-Southern Oscillation, may be strongly positive, neutral, or even negative and obscure the longer-term patterns for periods of time. See Slide 13 for more details on this explanation.

7. With your students, examine and discuss the slides near the end of the PowerPoint in the Flow section:

    a. Slide 14 shows the extent of the North American and Greenland snow cover in June from 1967-2014. Snow cover is more often above the period average in the first half of the period and below average in the second half. The trendline shows an average loss of 0.41 million km^2 per decade (-7.06%).

    b. Slide 15 shows changes in the timing of spring runoff initiation at flow gages across the western United States from 1948 to 2002. Most gages show runoff beginning at least 5 days earlier than in the beginning of the period.

    c. Slide 16 shows the predicted average snow water equivalent on the first day of each month for the Clearwater River basin in western Montana for the 2020s, 2040s, and 2080s compared to the historical average. The snow water equivalent is generally predicted to be much lower than historic levels. (See slide notes for more details.)

    d. Slide 17 shows the combined monthly average runoff and baseflow for the Clearwater River basin in western Montana for the 2020s, 2040s, and 2080s compared to the historical average. The predictions show generally higher flows earlier in the year and lower flows later than historic levels. (See slide notes for more details.)

How might changes in stream flows (the volume of water moving through streams) affect summer water temperatures? (Smaller volumes of water warm more quickly, creating an inverse correlation between flow and temperature). What kinds of factors might affect stream flows? (precipitation amounts and timing, snowpack persistence, water diversion, …) Besides affecting water temperature, what other issues are related to changes in streamflow amounts and timing? How might those changes affect human water users and local residents? (Timing of water available for irrigation can be critical to crops, streamflows important to recreation industry for floating and fishing, etc.)

8. How does your stream fit in? Have your students compare August temperatures in the stream you monitor to temperatures in which native trout are found. Are bull trout and cutthroat trout likely to be found in your section of the stream? Which fish species are likely to be found there, according to the fish/temperature graph?

PART II

What do your students think can be done to help alleviate some of the problems that may be caused by climate change? Have students research the following topics using the suggested resources in the Resource section or others they find, and report back to the class:

1. Slow anthropogenic (human-caused) climate change
2. Lessen effects and adapt to changes
    a. Protect and enhance habitat for wildlife
    b. More efficient use of water (e.g., through improved irrigation practices)

EXTENSIONS/ASSESSMENT

- Have students create a concept map to depict the relationships between global climate change, changes taking place in western Montana, effects of climate change on streams, and consequences of those changes to fish, wildlife, and humans. Ask them to consider how humans impact the system and what they can do to adapt to the changes. If your students have not worked with concept maps before, briefly describe what they are, perhaps with an example.
- Have students use the resources listed below or others they find to view or create graphs and maps similar to those used in this lesson.
- Students can learn more about some of the scientists right here in Montana who study climate and its potential effects on the environment of western Montana and the people who live here. Have them learn more by checking out the People section of the Resources below and summarizing an aspect of the work of one of the scientists.

RESOURCES

For more information on global climate change as well as regional climate data, go to:

http://www.ncdc.noaa.gov/ (NOAA's National Climatic Data Center)

http://www.wrcc.dri.edu The Western Regional Climate Center has a number of databases that can be used online to produce graphs and maps of national, regional, state, and divisional climate information. To create a graph of temperatures and precipitation in western Montana or any other region within a state, go to http://www.wrcc.dri.edu/spi/divplot1map.html.

http://www.wcc.nrcs.usda.gov/gis/precip.html This NRCS site will allow you to create maps showing SNOTEL data on precipitation and comparisons to averages.

For aquatic climate change effects in our region:

http://greatnorthernlcc.org/features/climate-change-aquatic-ecosystems (Great Northern Landscape Conservation Cooperative)

http://www.nrmsc.usgs.gov/research/climate_fish (USGS Northern Rocky Mountain Science Center)

http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html U.S. Forest Service Rocky Mountain Research Station's stream temperature modelling site has maps that show historic and predicted stream temperatures for the northwest.

http://warm.atmos.washington.edu/2860/products/sites/ (University of Washington Pacific Northwest Climate Change Scenarios) This site has hydrologic scenarios for northwestern streams accessible to anyone for support of climate change adaptation and long-range planning. Click on Montana under Site Maps to select and view data for individual streams in our state.

For information primarily specific to Montana:

http://deq.mt.gov/ClimateChange/default.mcpx (Montana Department of Environmental Quality Climate Change Homepage)

http://climatechangemt.org/ (Northern Rockies office of The Wilderness Society) This site provides information about climate change in Montana and links to local resources.

For information about plans and innovations to adapt to climate change in Montana:

http://blackfootchallenge.org/Articles/?p=942 Blackfoot Challenge Drought Response Plan http://crownmanagers.org/adaptative-management/ Taking Action on Climate Change Adaptation: Piloting Adaptation Strategies to reduce Vulnerability and Increase Resilience for Native Salmonids in the Crown of the Continent Ecosystem

http://fwp.mt.gov/fishAndWildlife/management/fisheries/statewidePlan/default.html Montana Fish, Wildlife and Parks fisheries management plan

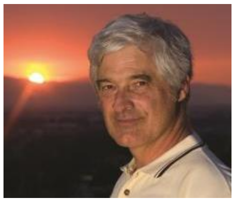
http://www.fs.fed.us/rm/pubs/rmrs_gtr250.pdf? Climate Change, Aquatic Ecosystems, and Fishes in the Rocky Mountain West: Implications and Alternatives for Management

http://store.msuextension.org/publications/YardandGarden/MT198915AG.pdf Montana State University's Yard and Garden Water Management Plan

http://clarkfork.org/ The Clark Fork Coalition's projects include re-watering and reconnecting tributaries to main-stem rivers by brokering voluntary water transactions that have returned 25 billion gallons of water to thirsty streams since 2003. They work to improve water quality, remove fish barriers, improve irrigation efficiency, and enhance fish and wildlife habitat by working with private and public landowners to restore streams in the Bitterroot, Blackfoot, Nine Mile and Upper Clark Fork. Check out their climate change page at http://clarkfork.org/learn/watershed-history-challenges-need/climate-change/.

www.climatechangemt.org/learn/montanans-address-climate-change/ Additional links and examples of climate change adaptation in Montana

Montana Scientists Studying Climate, Aquatics, and Solutions
Visit their websites to learn more about them and the work they do!



Steve Running is a Regents Professor at the University of Montana and a Nobel Laureate who studies global climate patterns through remote sensing and computer modelling. www.ntsg.umt.edu/user/9

Cathy Whitlock is a professor of Earth Sciences and Director of the Institute on Ecosystems at Montana State University. She studies paleoecology (ecological history), climate, and fire. www.montana.edu/wwwes/facstaff/whitlock.htm

Clint Muhlfeld is an aquatic biologist in Glacier National Park who studies threats of invasive species, habitat destruction, and climate change to native species in the Crown of the Continent in the northern Rocky Mountains. www.nrmsc.usgs.gov/staff/muhlfeld

Diana Six is a professor of forest entomology at the University of Montana. She studies the ways that climate change is affecting pine beetles in the forests of North America. www.cfc.umt.edu/sixlab/Six.html

Greg Pederson is an ecologist with the U.S. Geological Survey in Bozeman who studies how the West's climate is changing by studying glaciers and snowpack-- much of it in Montana's Crown of the Continent. www.nrmsc.usgs.gov/staff/gpederson

Chris Brick is the Science Director at the Clark Fork Coalition. She applies hydrogeological science expertise to improving water quality in streams in western Montana. www.clarkfork.org

Dan Fagre is a Research Ecologist and Climatel Change Research Coordinator for the Northern Rocky Mountain Science Center of the U. S. Geological Survey in Glacier National Park. His research focuses on how climate changes affect mountain ecosystems in diverse ways. www.nrmsc.usgs.gov/staff/fagre.html

Student Group 1

Read through this page of directions and information thoroughly before examining the accompanying figures on the next page!

Individually examine the figures on the following page and make sure you understand what kind of information is being provided. In the graphs, what do the axes and data points mean? What information do the graphs provide? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly*!

Share with your group any questions or difficulty you may have had with the figures so everyone will be ready to explain them to others. Practice teaching it to each other within your group. For example, ask your fellow students: what does *anomaly* mean? What do data above the horizontal line at 0.0 signify in Figure B? What about data below the line? After your group has discussed it, if there are terms or ideas that no one understands, look them up or ask your teacher for help.

Figures A and B are from the National Climatic Data Center (NCDC) at the National Oceanic and Atmospheric Administration, a government agency at the U.S. Department of Commerce. The NCDC "is responsible for preserving, monitoring, assessing, and providing public access to the Nation's treasure of climate and historical weather data and information". **Figures C and D** are graphs generated at the Western Regional Climate Center, a program is administered by the National Oceanic and Atmospheric Administration. The maps and graphs generated from their data are important pieces in the ecological puzzle you will be putting together to understand the connections between global climate and western Montana waters.

Now, check out your piece of the puzzle!

Student Group 2

Read through this page of directions and information thoroughly before examining the accompanying figures on the next page!

Individually examine the figures on the following page and make sure you understand what kind of information is being provided. In the graphs, what do the axes and data points mean? What information do the graphs provide? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly*!

Share with your group any questions or difficulty you may have had with the figures so everyone will be ready to explain them to others. Practice teaching it to each other within your group. For example, ask your fellow students: what are the general patterns of change in temperatures? Approximately how much do stream temperatures differ from the 1980s to the 2080s? It may help to pick a few streams to compare individually from map to map. In figure D, which trout species are found in the coldest streams? What temperatures are they mostly found in? After your group has discussed them, if there are terms or ideas that no one understands, look them up or ask your teacher for help.

Figures A, B, and C are from the U.S. Forest Service Northern Rocky Mountain Science Center's NorWeST Stream Temperature Project. **Figure D** is from Dan Isaak at the U.S. Forest Service Northern Rocky Mountain Science Center's Boise Aquatic Sciences Laboratory, Boise Idaho. These maps and graphs are important pieces in the ecological puzzle you will be putting together to understand the connections between global climate and western Montana waters.

Now, check out your piece of the puzzle!

Student Group 3

Read through this page of directions and information thoroughly before examining the accompanying figures on the next page!

Individually examine the figures on the following page and make sure you understand what kind of information is being provided. In the graphs, what do the axes and data points mean? What information do the graphs provide? After everyone has completed this, discuss the figure with the other members of your group and decide what the authors wanted to convey with the data presented in the graphs. *You will need to understand the information thoroughly as you will be teaching others about it shortly*!

Share with your group any questions or difficulty you may have had with the figures so everyone will be ready to explain them to others. Practice teaching it to each other within your group. For example, ask your fellow students: what is represented by the different colors of the streams? What is the difference between dark blue streams and yellow streams, in your own words? What are the general patterns of change in bull trout occurrences? What is the difference between Figure C and Figure D? After your group has discussed them, if there are terms or ideas that no one understands, look them up or ask your teacher for help.

Figures A, B, C and D are from Dan Isaak at the U.S. Forest Service Northern Rocky Mountain Science Center's Boise Aquatic Sciences Laboratory, Boise Idaho. These maps are important pieces in the ecological puzzle you will be putting together to understand the connections between global climate and western Montana waters.

Now, check out your piece of the puzzle!